# A STUDY OF THE EFFECT OF OPERATING PRESSURE AND ROTATION SPEEDS ON DISTRIBUTION OF WATER FROM A MEDIUM PRESSURE ROTARY IRRIGATION SPRINKLER

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# ABSTRACT

## A STUDY OF THE EFFECT OF OPERATING PRESSURE AND ROTATION SPEEDS ON DISTRIBUTION OF WATER FROM A MEDIUM PRESSURE ROTARY IRRIGATION SPRINKLER

by Namik Kemal Kiliç

The distribution of water from a rotary irrigation sprinkler is a function of the operating pressure, rotation speeds, nozzle size, angle of inclination, wind, and spacing. The objective of this study was to investigate the effect of operating pressure and rotation speeds on the rate of application, range, and size of water drops from a rotary irrigation sprinkler.

This study was conducted indoors to eliminate weather variables. The distribution of water and drop characteristics were investigated under three operating pressures (30, 45, and 60 psi), and three rotation speeds (with oscillating arm, 2.3 and 6 rpm by rotating mechanism). Other factors were held constant throughout the experiment.

Experimental data show that an increase in operating pressure resulted in: (a) a more even distribution of water, (b) a general decrease in the diameter of drops, and (c) a limited increase in the range of sprinkler.

Namik Kemal Kiliç

An increase of rotation speeds resulted in: (a) decreasing uniformity of water application, (b) increasing the size of water drops, and (c) a general decrease in the range of sprinkler.

Approved E. H. Kidder cw.
Major Professor

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Department Chairman

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By

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# INTRODUCTION

To have a successful practice in high producing agriculture, it is essential that the sprinkler irrigation system be planned to fit the requirement of soil, crops, water supplies and farming operations found on each individual farm. Many factors influence the efficiency and economy of sprinkler irrigation. One of the more important factors is uniformity of water distribution. Numerous experiments have been conducted to determine the uniformity of water distribution and various aspects of sprinkler operation as affected by operating pressure, rotation speed of the sprinkler, nozzle size, wind and spacing. Other important factors are the size, velocity and energy of water drops that strike the ground from a sprinkler. The compaction of soil by falling water drops is in part a function of the characteristics of water drops. A careful study, however, indicates that an approximately uniform application is possible when:

1. the type of pattern produced is correct for the arrangement of sprinklers
2. the sprinklers are correctly spaced
3. the sprinklers rotate at a uniform rate

4. the operating pressure is constant

5. there is no appreciable wind

The objective of this study was to investigate the characteristics of water drops and the uniformity of application from an irrigation sprinkler under different pressures and rotation speeds.

# REVIEW OF LITERATURE

## I. Drop formation from a sprinkler nozzle

The formation of water drops from a sprinkler nozzle is quite complicated and extremely difficult to analyze. Baron (1947) studied the atomization of liquid jets and droplets. He concluded that deformation of a moving drop is forced by vibration of viscous damping. This force drives the liquid toward the periphery producing small water particles of different sizes. Further break-up is a function of the surface tension of the water and the resistance of the air. Green (1952) observed that the surface tension tended to hold the drops intact in a sphere, while air resistance tended to cause oblation by flattening the leading side of the drops. When the surface tension was overcome, the drop broke up into smaller drops.

Levine (1952) determined that the diameter of individual drops was fairly small at distances of from 25 to 30 feet from the sprinkler; whereas, the drops were larger in diameter from 30 to 50 feet out from the sprinkler.

Bilanski and Kidder (1958) concluded that turbulence, distribution of velocities and the amount of secondary motion in the jet of water as it emerged from the sprinkler, caused the formation of droplets. Actual velocities of a water jet emerging from an orifice varied from near zero at the perimeter to a maximum at the center of the stream. The variation in stream velocity and the mechanical dispersion caused by the sprinkler rotation initiated drop formation. The surface tension tended to hold the drops intact in a sphere, while air resistance tended to cause oblation by flattening the leading side of the drops. When oblation occurred to such a degree that the surface tension was overcome, drops broke up into two or more drops.

Even after drops formed, their characteristics were dynamic. Green (1952) proposed a mathematical analysis of the distance of travel and the velocity of drops from an orifice which resulted in the following relationship:

$$r = v(m/k)(1-e^{-(k/m)t}) - g(m/k)^2 (e^{-(k/m)t}-1) - g(m/k)t \quad (1)$$

Where $r$ = distance from the orifice

$v$ = initial velocity

$m$ = mass of the drop

$k$ = constant

$t$ = time

$g$ = gravitational acceleration

In the limiting case, as the value of m/k approached zero, the value of "r" also approached zero. Consequently, small drops traveled only negligible distances. Actual measurements of drops from an irrigation sprinkler showed a rapid increase in the diameter of the drop as the distance from the sprinkler increased.

Investigators of raindrop simulator [Laws (1941), Mutchler (1965), and Gunn and Kinzer (1949)] present results which differ widely from one another. But most of them agree on the effects of pressure, aperture size and angular velocity on the values of the median drop diameter. The size of the nozzle also seems to have a significant effect, since the nozzle with larger diameter gives better distribution at any given operating pressure. It is not yet clearly known whether the drops separated from the main water jet approach their terminal velocity within the height of their fall. The effect of the rotation speed of nozzle on the energy of the simulated rain is quite pronounced because the effect is more on the drop velocity than on the drop size.

Most investigators have considered the following factors in jet break-up: change in potential energy due to surface tension, change in kinetic energy due to liquid motion, turbulence, nozzle dimensions, liquid viscosity and density, jet velocity, air viscosity, density and drag force.

## II. Effect of water drops on soil

The deleterious effect of raindrop impact on bare soil was noted as early as 1877. Neal and Baver (1937) stated that experimental results show that the falling raindrop breaks down soil aggregates, displaces and transports the soil particles. The continued impact of the raindrops compacts and seals the immediate soil surface.

Cook (1936) concluded that water drop velocity was one of the variables in the water erosion process. Laws (1941) spent considerable time in studying the distribution and the intensity of raindrops in relation to the kinetic energy developed in a rainstorm. They observed that infiltration decreased about 70 percent and runoff increased 1200 percent as the drop size in artificial rain was stepped from 1mm to 5mm in diameter. Ellison (1945) showed conclusively that a variation in either drop size or drop velocity will cause a change in the infiltration capacity of the soil. This was substantiated by Free's (1952) finding that soil crusts resulting from water drop impact had a volume weight of about 30 percent more than the soil immediately below the crusts. Duley (1939) observed that the rapid reduction in the rates of intake of water by bare soils as rain falls on the surface was accompanied by the formation of a thin compact layer at the surface. This layer was due in part to the beating action of raindrops and in part to the sorting action as water flowing over the surface placed fine particles into the voids around the larger ones. Levine (1952) reported that infiltration was decreased by the use of large drops from an irrigation sprinkler. Thus, at present a detailed study of both drop spectrum and velocity distribution must remain the goal of sprinkler designers.

III. Measurement of drop energy

Several methods have been used for determining drop sizes. Most of them assumed terminal velocities for purposes of calculating drop energy. Neal and Baver (1937) developed a method to measure drop energy. Their equipment consisted of a beam balance connected to a recording pen and chart. Drops were allowed to fell on a plate at one end of the beam. The pen at the other end recorded the deflection.

Many investigators have used photography as a means of studying the moving water drop. Wortington (1894) used a high speed camera to study turbulence created by drop impacts. Green (1952) worked with a similar technique and strobe light to measure drop sizes and velocities. Edgerton (1937) and Davis (1966) used photographic methods for recording size of spray drops and drop formation.

Schleusener (1960) used a styrofoam target mounted on a cantilever beam to measure the energies of drop impacts. Strain gauges on the beam detected deflection which was recorded on an oscillograph. However, Brazee's (1963) "Theoretical aspects of droplet impact measurements" by damped oscillating tranducer as a method of measuring random impact energies opened questions as to the validity of such procedures.

Before the impact of a falling drop of water can be evaluated, it is necessary to know the size of drops and velocity of the fall. Most of the experimental study of the intensity of the drops from varying heights showed that their acceleration varied approximately inversely as the square root of time, even if the effects of the wind and temperature are not considered. Therefore, it would be more accurate to measure the impact of water drops per unit area at a given time.

## DESIGN OF EXPERIMENT

### I. Analysis of the problem

In order to improve the rotary irrigation sprinkler, we should know the factors that affect: (1) drop formation from a nozzle and (2) distribution of water over the ground. The formation of drops from a nozzle is quite complicated and extremely difficult to analyze. We assume that the drops are spherical in shape and that break-up is homogeneous. The effect of the curved pipes in the sprinkler head and the nozzle shape with its boundary condition are not taken into consideration. The sprinkler is rotated by means of a sprinkler rotating mechanism.

The distribution of water from a mechanically rotated irrigation sprinkler is function of the following factors:

$$f(P, D, V, w, \theta, g, \mu_a, \rho_a, \mu_w, \rho_w, \sigma, r) = 0 \qquad (2)$$

where
- $P$ = operating pressure
- $D$ = diameter of nozzle
- $V$ = velocity of water jet from nozzle
- $w$ = rate of rotation of sprinkler head
- $\theta$ = angle of inclination
- $g$ = acceleration of gravity

$\mu_a, \rho_a$ = dynamic viscosity and mass density of air

$\mu_w, \rho_w$ = dynamic viscosity and mass density of water

$\sigma$ = surface tension

r = hydraulic radius of the nozzle (as a shape factor)

The hydraulic radius of the nozzle is included to consider the effect of nozzle shape on the formation of droplets.

Some work has been done on the velocity and the range of water drops from sprinklers. Green (1952) analyzed it mathematically by assuming friction in the air to be proportional to the velocity of drops. By using Laws' (1941) data, he found the relationship between friction and size of drops to be in the form:

$$k = .000251\ d \tag{3}$$

This conclusion was used by Bilanski (1958) to determine the equation of a single drop trajectory.

The main considerations in the foregoing discussion were to find out the effects of pressure and rotation speed on the distribution of water from an irrigation sprinkler and to arrive at a compromise value between variable pressure and rotation to get a uniform distribution without changing the other factors.

A) Range was defined empirically in the form of

$$R = \theta P^{n} \tag{4}$$

in which R = range (radius)

θ = angle of inclination

P = pressure

n = constant

Theoretically, maximum range may be obtained when θ = 45°. Under actual condition maximum range may be obtained when θ = 23° and may be reached at a limiting pressure beyond which no further increase in the range is observed. Range is therefore not a function of angle of inclination and pressure only. We should take into consideration the other factors such as the friction exerted by the air on the smaller drops that are produced at higher pressures. Consequently, the range may be indicated by the equation,

$$f(R, P, D, V, w, \theta, g, \rho_a, \mu_a, \rho_w, \sigma) = 0$$

Dimensional analysis of the equation yields,

$$f\left(\frac{R}{D}, \frac{VD\rho_w}{\mu_w}, \frac{P}{\mu_w gD}, \frac{V^2}{gD}, \frac{\rho_w V^2 D}{\sigma}, w\sqrt{\frac{D}{g}}, \theta, \frac{\rho_a}{\rho_w}\right) = 0 \qquad (5)$$

where $\frac{VD\rho_w}{\mu_w}$ = Reynolds number

$\frac{V^2}{gD}$ = Froude number

$\frac{\rho_w V^2 D}{\sigma}$ = Webers number

in the fluid mechanics. The last term $\frac{\rho_a}{\rho_w}$ may be discarded, since it has a negligible influence on the phenomenon.

If we keep all the variables except rotation, we will have

$$R = D\ f\ (w\sqrt{\frac{D}{g}}\ ,\ k_1) \qquad (6)$$

where f is an unspecified function. Data may be plotted ($\frac{R}{D}$ as abscissa, $w\sqrt{\frac{D}{g}}$ as ordinate) as a function off the dimensionless variable.

Since the range is proportional to the pressure, equation (5) must take a special form, for variable pressure. By eliminating velocity (V), since it depends on pressure and diameter of nozzle, some terms of equation (5) would be transformed into another dimensionless product,

$$R = D\ f\left(\frac{P\nu_a}{V\sigma},\ k_2\right) \qquad (7)$$

By substituting pressure P, in terms of head, and eliminating we get,

$$R = D\ f\left(\frac{V_a\rho_w}{\sigma}\sqrt{\frac{Hg}{2}}\ ,\ k_2\right) \qquad (8)$$

Equation (8) yields the principle: when a rotational sprinkler operates at a constant angle of inclination and speed of rotation, the range is proportional to the square root of head and the kinematic viscosity of air. By plotting the data $\frac{R}{D}$ as abscissa, $\frac{V_a\rho_w}{\sigma}\sqrt{\frac{Hg}{2}}$ as ordinate, we see the relationship in terms of unity.

B) The intensity of irrigation sprinkler is defined as

$$\int Q\, dt = AI = \pi R^2 I \tag{9}$$

where Q = discharge from nozzle in (t) time

R = range

The discharge is proportional to the square root of pressure and the range is also proportional to pressure as well as the rate of rotation. Therefore, there must be a uniform distribution of water at sufficiently high pressure heads with a sufficient rotation.

Assuming the evaporation loss and wind effect is not taken into consideration. The intensity (I) is expressed as "cm. of water/per unit time." Then the most important variables that influence the distribution of water may be written in the form of,

$$f(I, R, Q, t, w, D, \theta, r, \nu_w, \rho_w, g) = 0 \tag{10}$$

It is impossible to form a dimensionless product that contains $\rho_w$, since $\rho_w$ is the only variable that contains the dimension of mass. Therefore, $\rho_w$ actually does not enter the problem. The dimensional analysis of the above equation yields,

$$I = R\ f\left(\frac{Qt}{D^3},\ w\sqrt{\frac{D}{g}},\ \frac{\nu_w r}{g},\ \theta\right) \tag{11}$$

for constant $\theta$, the equation becomes,

$$\frac{I}{R} = f(x, y, k_3) \tag{12}$$

where $x = \frac{Qt}{D^3}$

$$y = w\sqrt{\frac{D}{g}}$$

Consequently, if a curve is plotted with ordinate $\frac{I}{R}$ and abscissa x or y, the curve will give the performance of the sprinkler for variations of the rate of rotation or operating pressure.

We are, in fact, most interested in having a uniform distribution. In case of the uniform distribution, by plotting $\frac{I}{R_x}$ as the abscissa, $\frac{R_x}{R}$ as the ordinate, theoretically we get a line as in Figure 1.

We can set up a relationship between mean drop diameter and intensity by writing the discharge of nozzle in terms of drop diameter in equation (9), then we get,

$$I = \frac{Qt}{\pi R^2} = \frac{t\ \pi/6 \sum_{i=1}^{n_i} n\ \bar{d}_i^3}{\pi R^2}$$

$$= \frac{t}{6}\ \frac{\sum_{i=1}^{n_i} n\bar{d}_i^3}{R^2}$$

where $\bar{d}$ = mean diameter of drops

n = number of drops (assume countable)

R = range

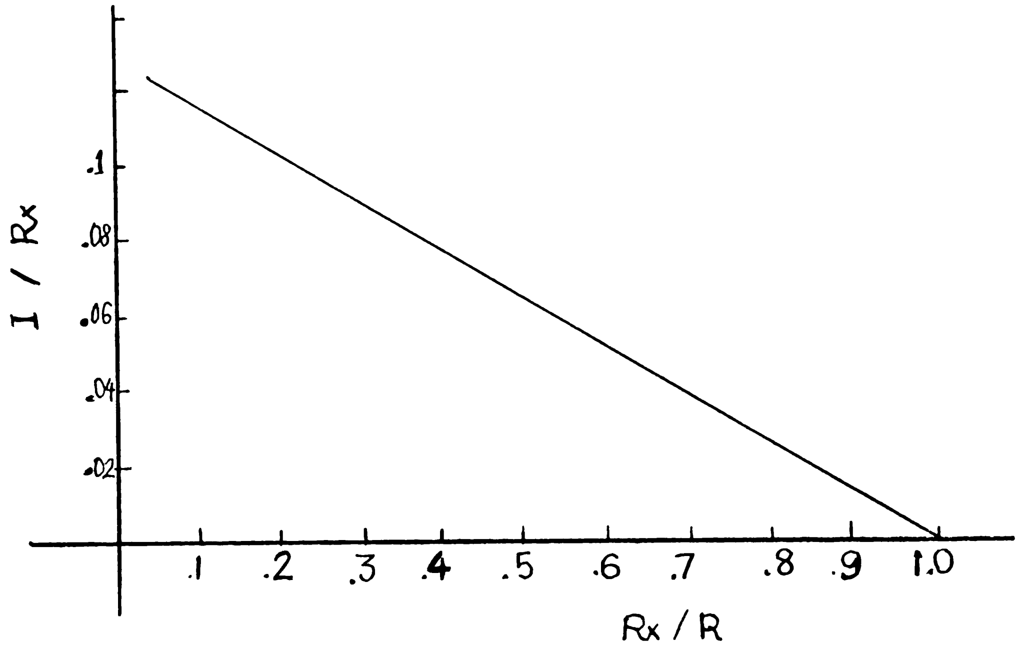


Figure 1. Theoretical relationship between intensity and range of a rotating sprinkler.

From this equation, we can estimate the number of drops falling at certain distance from the sprinkler nozzle.

A second objective of this study was to investigate those relationships experimentally, and find out through what combination of pressure and rotation may produce uniform distribution.

## II. Methodology for measurement

The measurement of rainfall drop size and distribution has been carried out through the centureis and little attempt was made to improve on them. Bentley (1904) developed a simple method of measuring the size of a raindrop. He used pans of fine uncompacted flour, and let the rain fall for a few seconds into the pans so that each drop produced a dough pellet. After drying the pellets, he measured their diameter. He determined the relationship between the diameter of pellets and raindrop by calibration. Laws (1941) utilized Bentley's flour technique and obtained more measurements.

Wischmeier (1958) developed another technique to measure the size of raindrops by use of absorbent paper. This procedure is in common use today. Photographic techniques have been used to determine drop sizes as well as drop velocities.

Frozen drops, card stain and rupe cell methods have been used in measurement of droplet size from spray nozzle. Buchele and associates (1967) used an automatic particle counting equipment such as the cathode ray tube raster to measure size and distribution of droplets from spray nozzle.

Blanchard (1949) used screens to measure the size of raindrops. When the raindrops passed through a screen, they left an indication of their size by removing a circular spot of soot and carrying it along with them. He referred to Howell and his co-workers who improved the screen method by substituting (60 gauge) nylon stockings for wire screen, and confectioner's sugar for the black soot.

The relationship between the diameter of the raindrop and the diameter of its indentation on a sugared nylon screen is shown in Figure 2.

The use of nylon stockings screen coated with confectioner's sugar appears to offer a most reliable method of determining drop sizes.

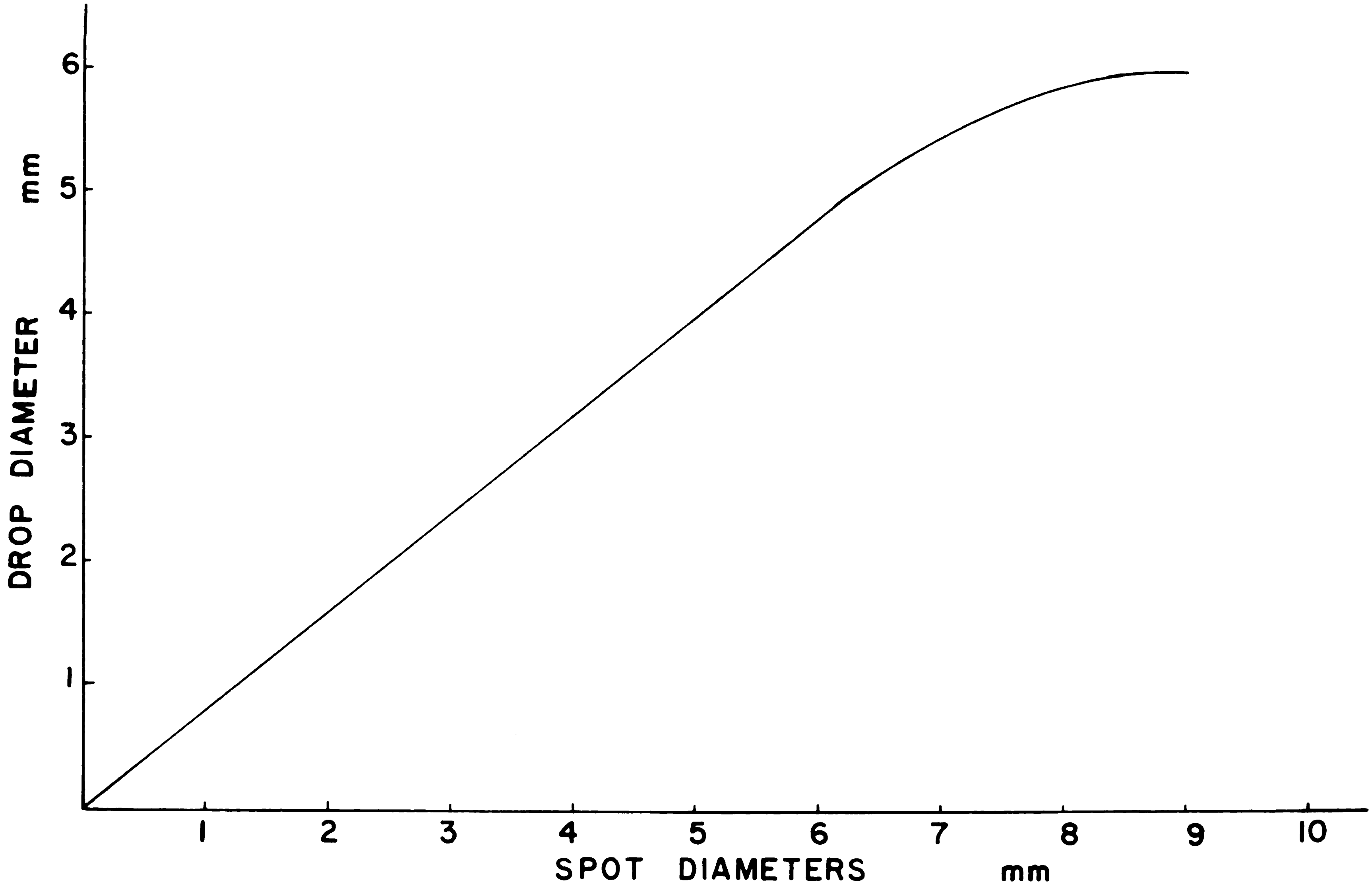


Figure 2. The relationship between the diameter of the water drops and its indentation on a sugared nylon screen.*

*Blanchard, D. C. (1949) "The use of sooted screens for determining raindrops size and distribution." General Electric Company, Occasional Report, No. 16.

## APPARATUS AND EXPERIMENTAL PROCEDURE

This study was conducted in the land development laboratory located in the basement of the Agricultural Engineering Building of Michigan State University in East Lansing, Michigan. Water was obtained from the university water system and pressurized with a horizontal centrifugal pump. The pump was driven by a five horse-power electric motor shown in Figure 3.

A "Rainbird" model (14 V) irrigation sprinkler was used throughout the experiment. The sprinkler was mounted in a barrel with an adjustable width slot cut in the side. The slot allowed the stream of water from the sprinkler to emerge in one direction for sampling purposes. The test for the measurement of drop size was carried out with the same nozzle of 3/32 in. under pressures of 30, 45 and 60 psi. The rotation of sprinkler was maintained by a rotating mechanism as shown in Figure 4. This mechanism consisted of a motor of variable speed and a speed reduction box, which allowed the sprinkler rotation rate to vary between 2.3 rpm and several hundred rpm.

The pressure was observed on two gauges having a scale range from zero to one hundred psi. One gauge was placed on the pressure tank and the other in the delivery

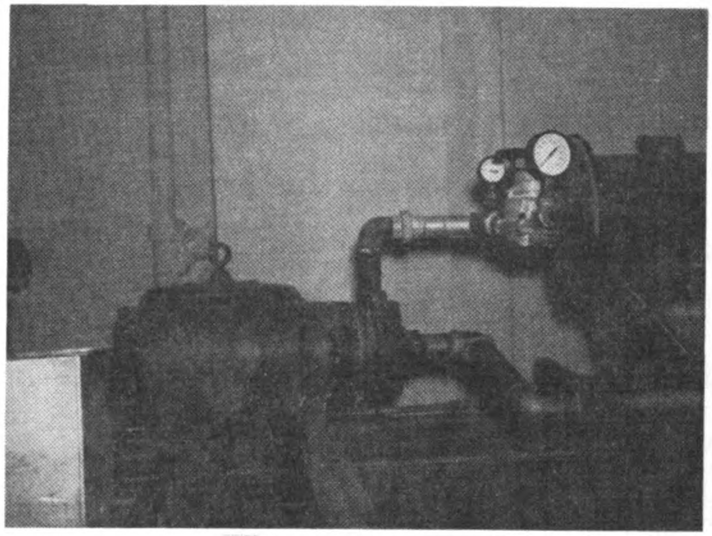

Figure 3. Pump unit and pressure tank.

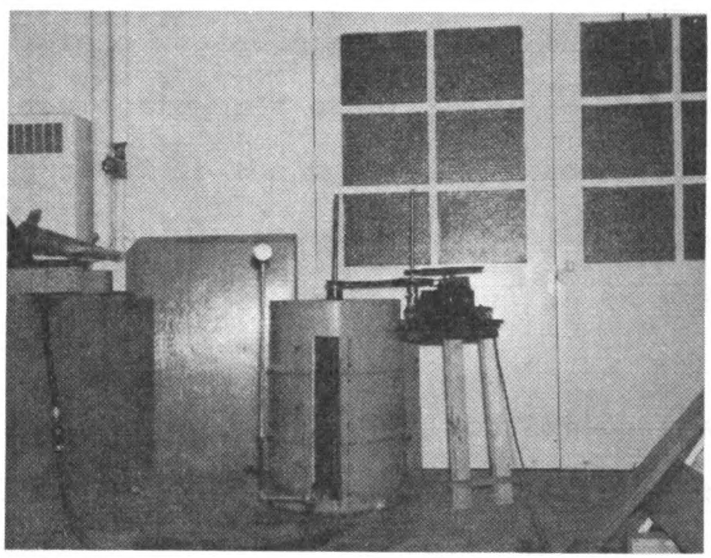

Figure 4. Slotted barrel shield and rotating mechanism.

line at a distance of one foot from the sprinkler. The gauges were checked for accuracy with a dead-weight gauge tester.

Wire window screening was used to minimize the splashover of drops from the concrete floor into the cans. Sampling cans were placed along the screened strip at 1.5 meter intervals as shown in Figure 5. Each test for measurement of water distribution was run for two hours. The water in each can was weighed in grams after each test. The intensity of water distribution was calculated for each point on the radius in terms of cm./hr.

The diameter of water drops from the sprinkler was measured by the screen method. The hoops were designed in a rectangular shape with a size of 50 x 20 cm. The 60 gauge nylon screen was mounted tightly on the hoops and coated with confectioner's sugar. It was observed that the sugar did not stick to the new nylon screen. Therefore, it was placed in a solution of vaseline in benzene, which left a thin but sticky layer of vaseline on the nylon fibers.

Nylon screens coated with confectioner's sugar were then placed at 1.5 meter intervals and were exposed to water droplets for one rotation of the sprinkler as shown in Figure 6. The relationship between the diameter of the raindrops and the diameter of the indentations that they make on the nylon screen was originally plotted by

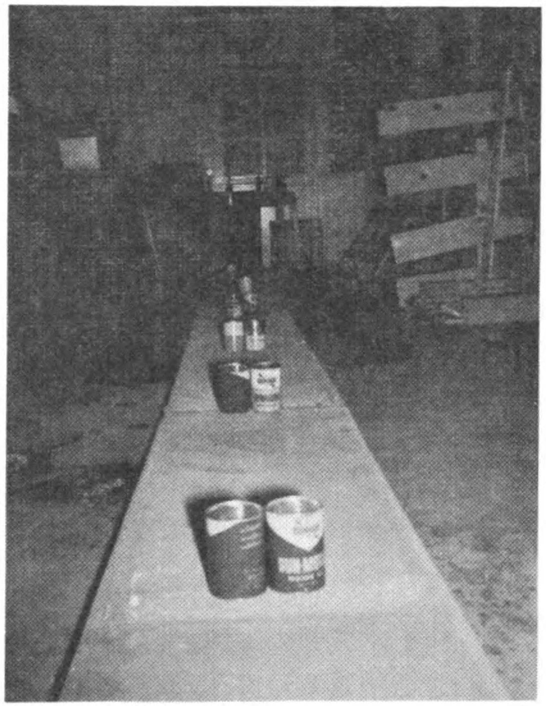

Figure 5. Laboratory where tests were conducted. Sprinkler barrel in background with distribution test equipment in place.

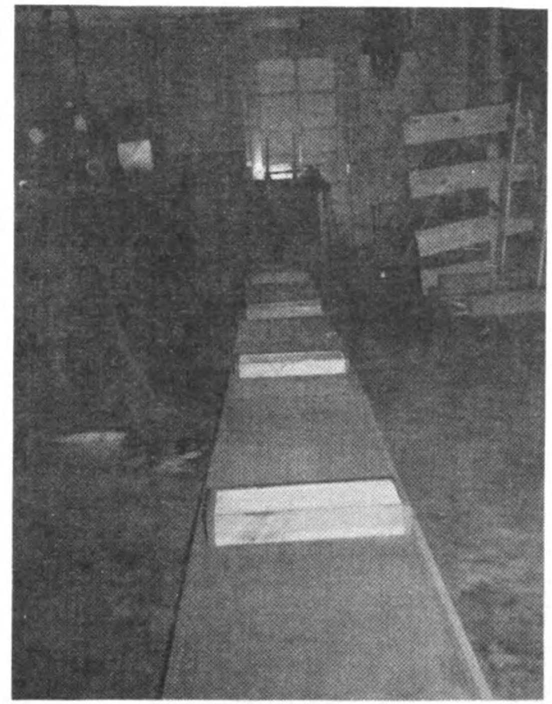

Figure 6. The nylon screen placed at 1.5 meter intervals along a radius emanating from the sprinkler.

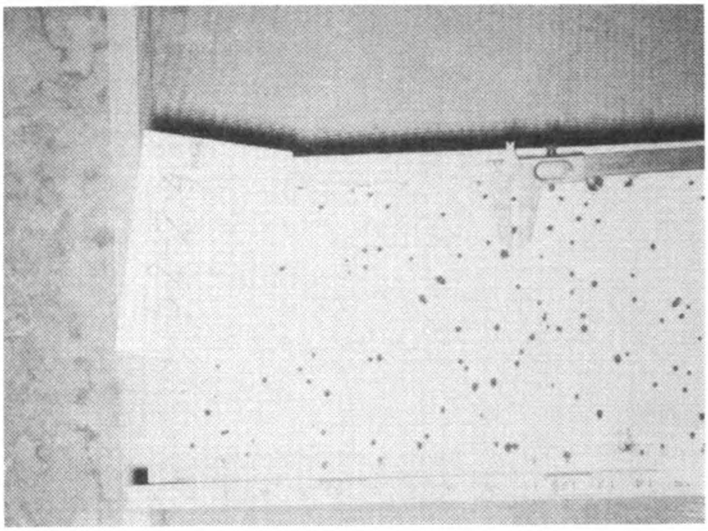

Figure 7. (a) Sugar-coated nylon screen on hoop shows the spots of water drop at 9 meter distance from the sprinkler with oscillating arm, a) at 30 psi, b) at 45 psi, c) at 60 psi operating pressures.

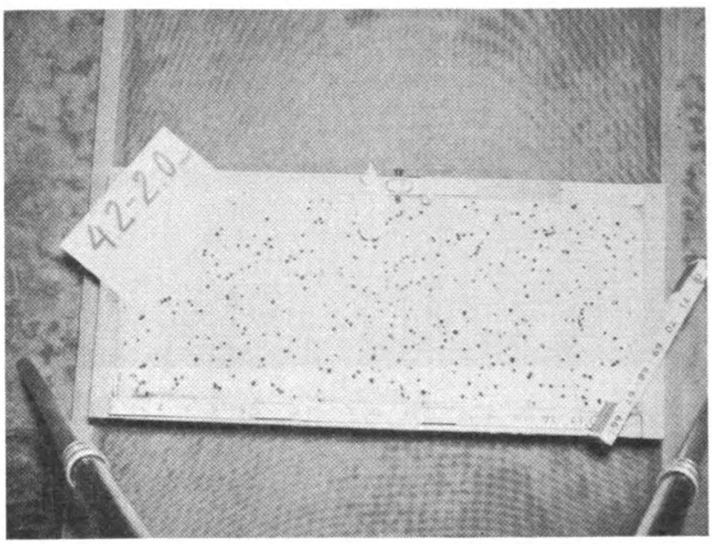

Figure 7. (b)

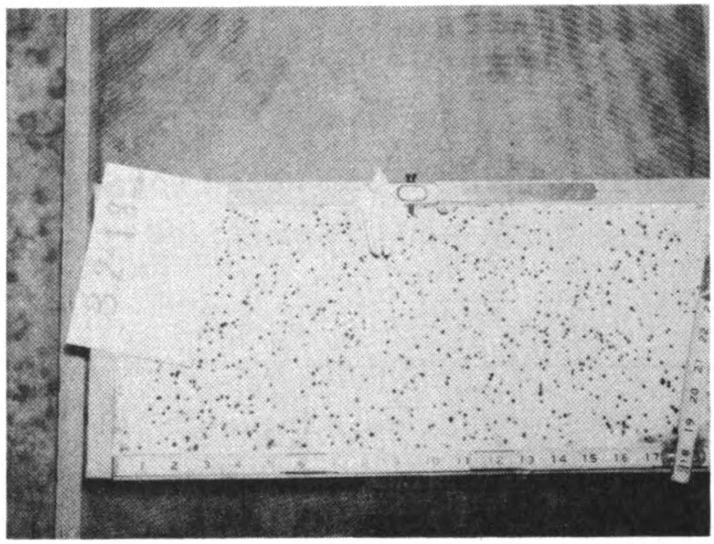

Figure 7. (c)

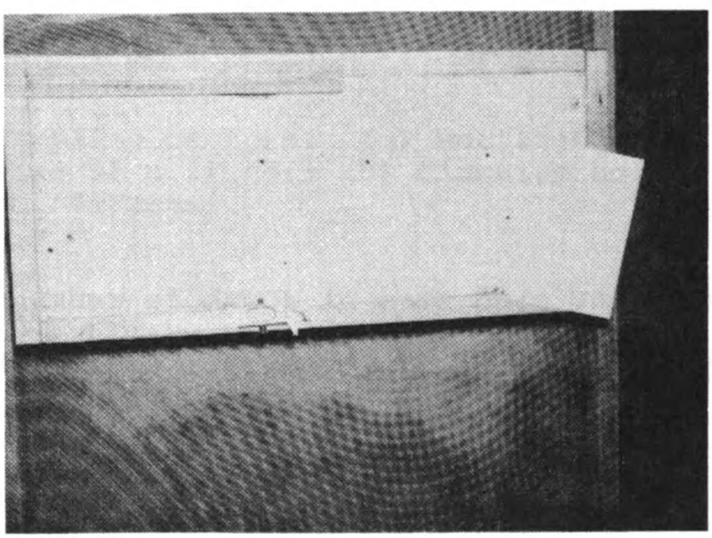

Figure 8. The spots of water drops on nylon screen at 9 meter distance from sprinkler with a rotating mechanism (6 rpm) at 60 psi.

Blanchard (1949). This calibration curve was used in the determination of the true drop diameters.

As the tests were run, it was impossible to measure all the indentation diameters on the nylon screen. Sampling cartons were designed which had 5 holes in them, Figure 9.

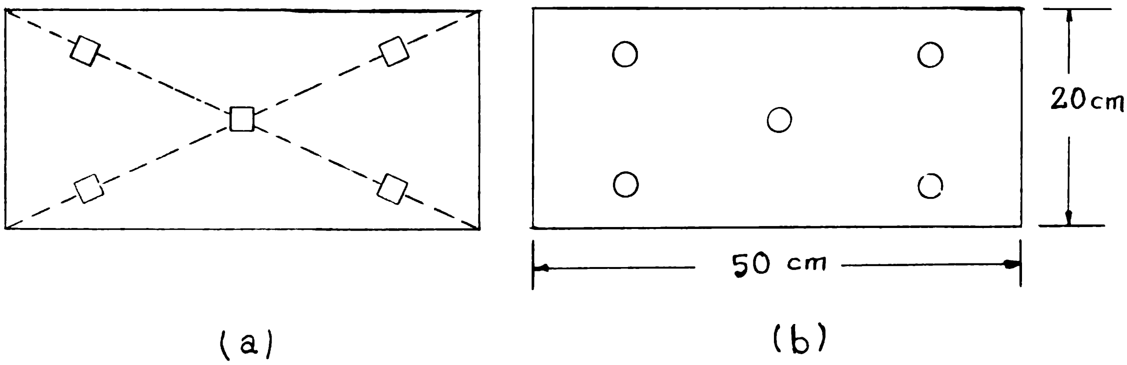


Figure 9. Sampling cartons: (a) Rectangular holes with size (5 x 2) cm.; (b) Circular holes with (3) cm. diameter.

The number of drops in each hole were counted and their diameters were measured with a caliper in terms of mm. Their median diameter was calculated in the usual way after finding their true values from the calibration curve. This procedure was repeated for each rotation and pressure setting until all the tests were completed.

## DISCUSSION OF RESULT

I. The rate of water application

The rate of water application was determined for a sprinkler by using catchment cans and the true rate of water application was obtained by averaging the total fall-out of water over a particular target area during a defined time interval. The numberical values are given in the Appendix, Table I.

The rate of water application from the sprinkler with an oscillating arm approaches the ideal uniform distribution as shown in Figure 10(a). The action of the oscillating drive arm causes the sprinkler to rotate. It is actuated by the jet issuing from a nozzle. It frequently diverts the jet from its normal path. This leads to an excess concentration of water near the sprinkler, which decreases as the distance from the sprinkler increases. It reaches an end point at about one-half the trajectory, when the operating pressures are 30 and 45 psi, but only one-fourth of the total trajectory when the operating pressure is 60 psi. The rate of water application starts to increase beyond this minimum point and reaches a maximum at a distance of approximately three-fourths of the trajectory when the operating pressures are 30 and 45 psi.

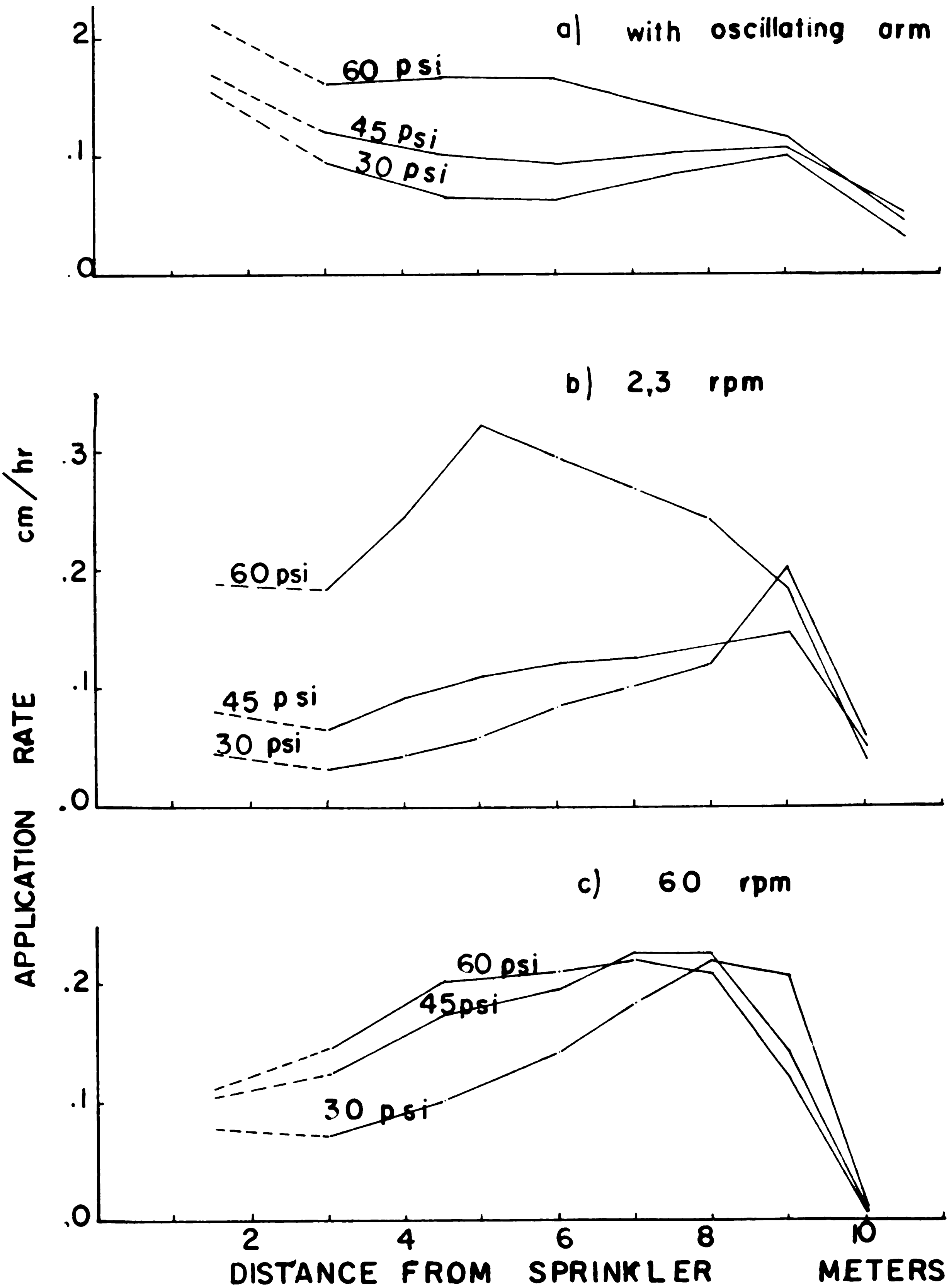


Figure 10. Application rate versus distance from sprinkler with 3/32 inch nozzle for the speed of rotation and pressure tested.

This point of maximum water application spreads out considerably along the trajectory of the sprinkler at the operating pressure of 60 psi (Figure 11).

The pattern of water distribution, when the sprinkler was rotated by a rotating mechanism instead of the oscillating arm, was such that the maximum point was reached at a distance of four-fifths of the trajectory, when operated at a pressure of 30 psi. This maximum point shifts from far out to the mid-trajectory distance when the pressure was increased from 30 to 60 psi.

A higher concentration of water occurred between the distance of 3 and 9 meters at operating pressures of 30 psi and 45 psi when the rate of rotation was increased from 2.3 rpm to 6 rpm. However, the effect of increased rate of rotation to 6 rpm at 60 psi was a pronounced decrease in the rate of water application all along the trajectory as shown in Figure 11. This can be explained by an excess tangential velocity effect on the distribution of water droplets as the discharge from the sprinkler nozzle remain constant throughout both the rate of rotations. The tangential velocity effect was such that the jet of water from the nozzle through the slot of the barrel at 6 rpm and 60 psi covers more area than the 2.3 rpm and 60 psi. Thus, it was concluded that this was an experimental error rather than a physical phenomenon.

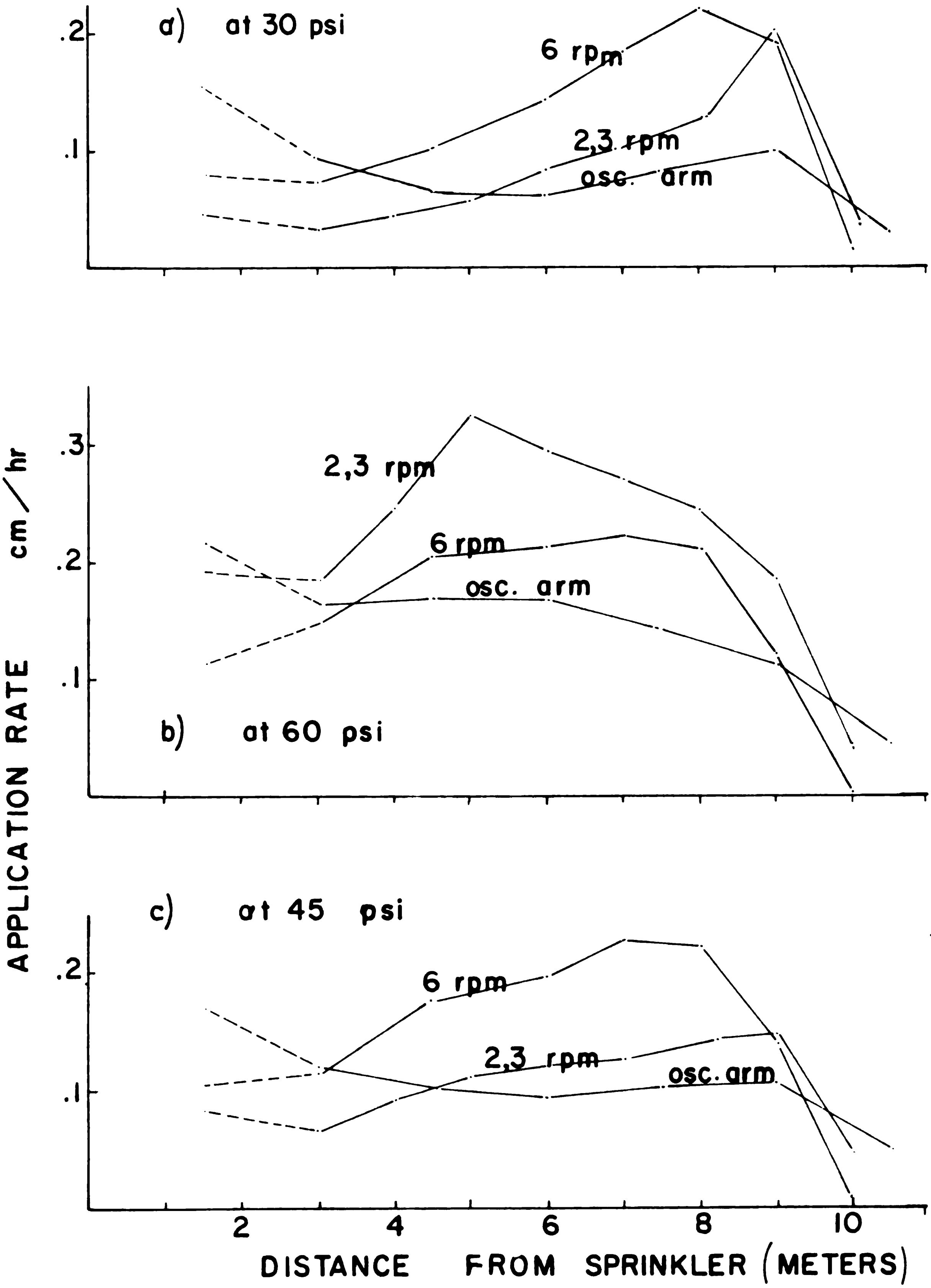


Figure 11. Application rate versus distance from sprinkler with 3/32 inch nozzle for the speeds of rotation and pressure tested.

In the analysis of the problem we defined the ideal uniformity of water application as a straight line with $\frac{I}{R_x}$ as abscissa and $\frac{R_x}{R}$ as ordinate. But this theoretical approach does not hold in describing the distribution of water from the sprinkler in the experiment, except when the rotation was maintained by the oscillating arm as shown in Figure 12(a), (b) and (c).

II. Range of the sprinkler

The variation of the pressure does not effect the range of the sprinkler as expected in the analysis of the problem as shown in Figure 11. High pressure causes a greater dispersion and break-up of the water jet, resulting in smaller drops. Since the distance of travel of a water drop is proportional to its size, the effect of operating pressure change is limited.

On the other hand, an increase in the rate of rotation of the sprinkler shortens the range as shown in Figure 13. The effect of rotation on the range was negligible when the rate of rotation was 6 rpm.

III. Size of drops

The size of drops was determined by using the data measured from the nylon screen coated with confectioner's sugar. Mean diameter of drops was calculated from catchment samples and plotted against the distance from the

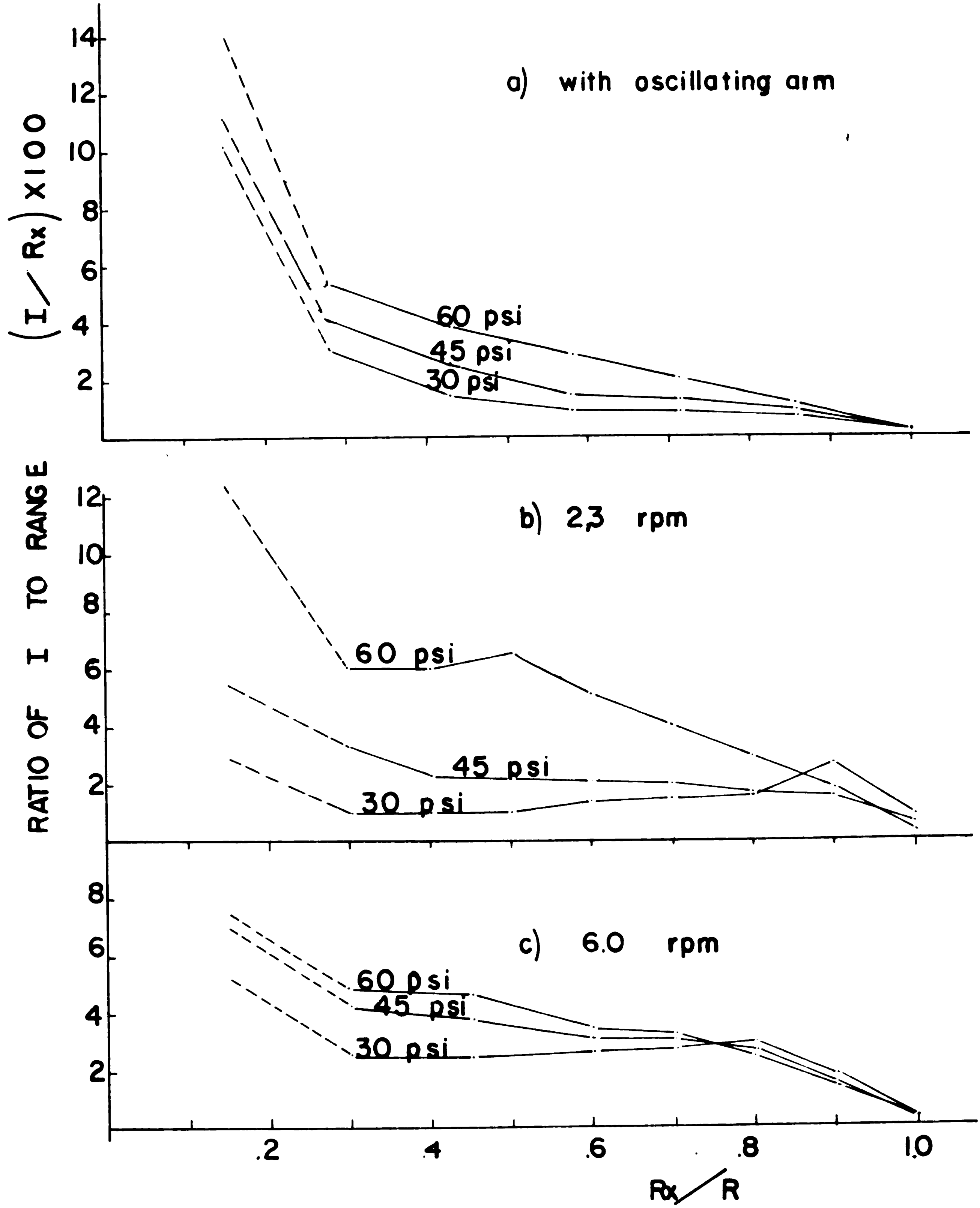


Figure 12. The relationship between the rate of application and range of a rotational sprinkler with 3/32 inch nozzle for the rotation and pressure tested.

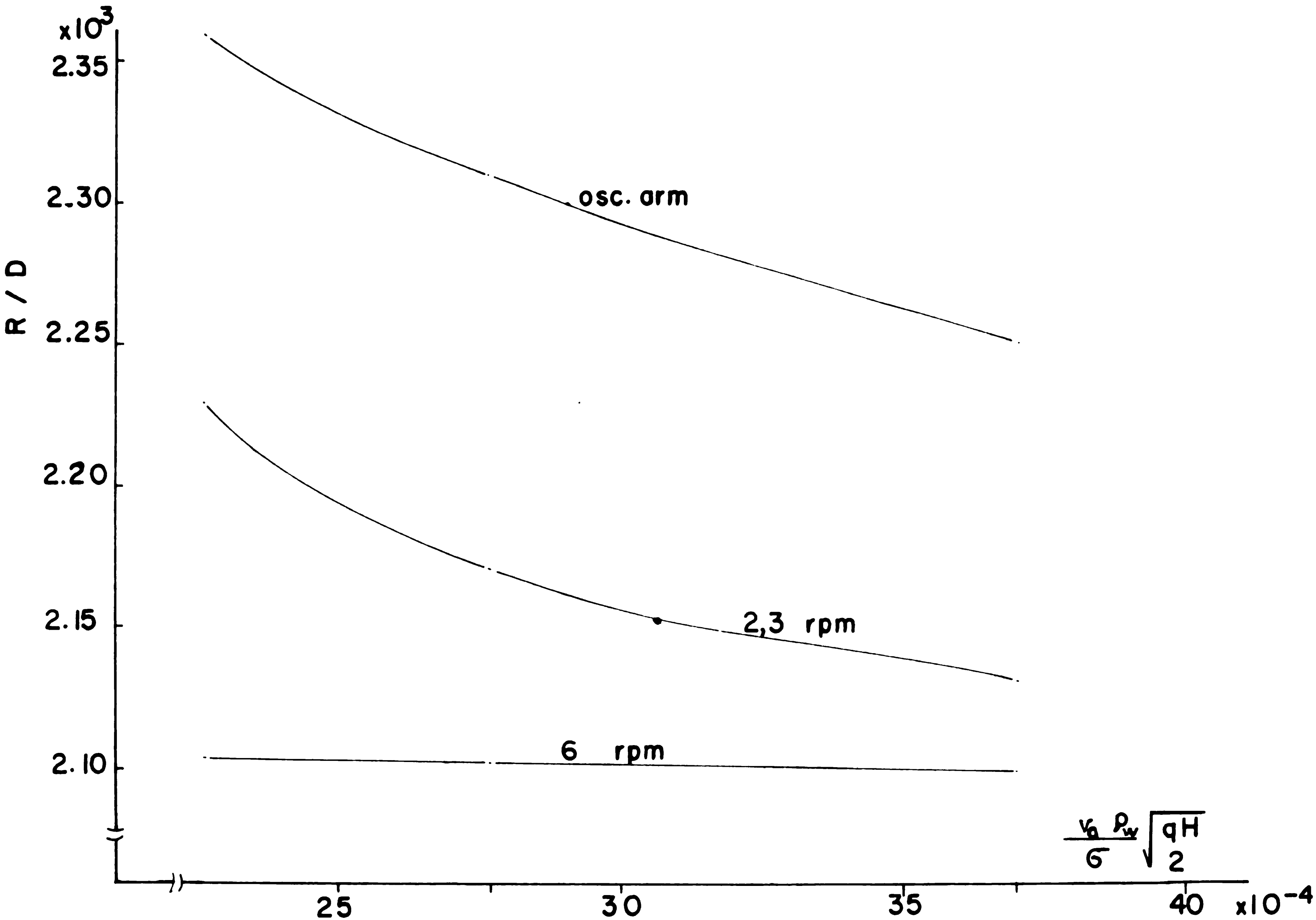


Figure 13. Dimensionless relationship between operating pressure and range for the sprinkler tested.

sprinkler as shown in Figure 14(a), (b) and (c). Drop sizes increase as the distance from nozzle increases. The diameter of drops ranges from 518 to 5078 microns.

When a sprinkler rotates with the oscillating arm, an increase in pressure causes smaller drops, and a reduction in size becomes greater as the distance from the nozzle increases. At distances greater than 7 meters from the nozzle, drop sizes are significantly great at different operating pressures as shown in Figure 14(a). This result can be explained by pointing out the effect of pressure increase in breaking up the jet of water. The diameter of drops versus the distance from the sprinkler approximately gives a linear relationship at 45 psi when the rotation was obtained by oscillating arm.

On the sprinkler with a rotating mechanism, as operating pressure increases from 30 to 45 psi it produces a relationship similar to that we had with the oscillating arm as shown in Figure 14(b). However, the change of operating pressure from 45 to 60 psi does not effect the size of drops, within 8 meters of the nozzle, when the rate of rotation was 6 rpm as shown in Figure 14(c). Hence it was thought that tangential velocity was another important factor in breaking-up of the jet of water.

The rate of rotations for a sprinkler with oscillating arm are 1.667, 1.715 and 1.765 rpm at operating pressures of 30, 45 and 60 psi respectively. Therefore, the

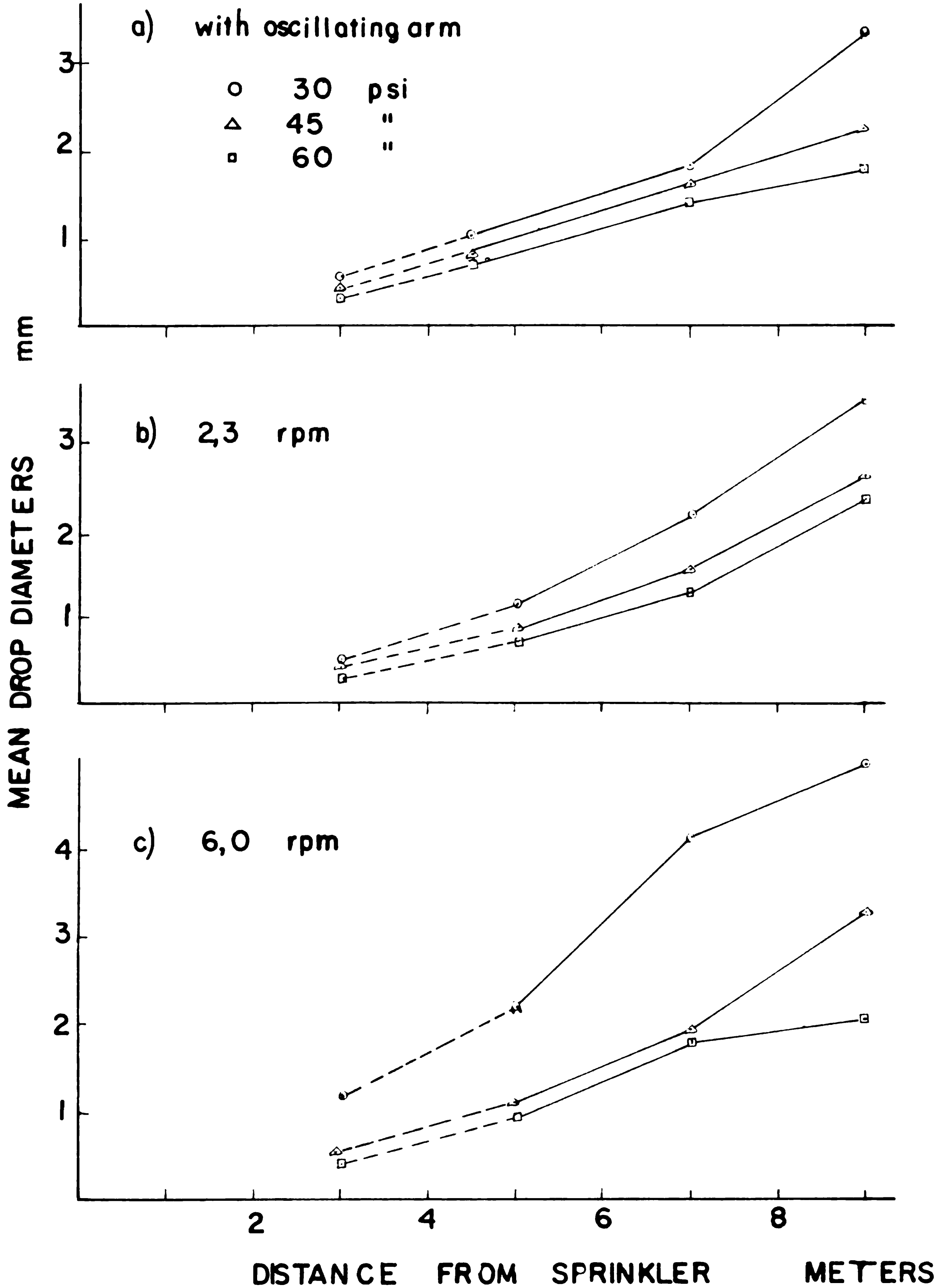


Figure 14. Mean drop diameter versus distance from sprinkler with 3/32 inch nozzle for the rotation and pressure tested.

effect of rotation on the sprinkler with the oscillating arm was negligible. When the rate of sprinkler rotation was maintained by a rotating mechanism, the effect of rotation in the diameter of drops was important as shown in Figure 15. An increase in the rate of rotation from 2.3 to 6 rpm, produces significantly larger drops in the area farther than 5 meters from the nozzle, when the operating pressures are 30 and 45 psi. In the area within 5 meters of the nozzle, the effect of rotation was negligible. But when the operating pressure was 60 psi, an increase in the rate of rotation from 2.3 to 6 rpm causes smaller drops. This result may be explained by taking into consideration the effect of pressure, as shown in Figure 14. The effect of pressure on the size of drops was very clear.

IV. Limitation of Testing Method

The diameter of drops cannot be measured within 4 meters of the sprinkler with a 3/32 inch nozzle because a high number of drops fall on the same target and overlap each other on the nylon screen as shown in Figure 16(a) and (b).

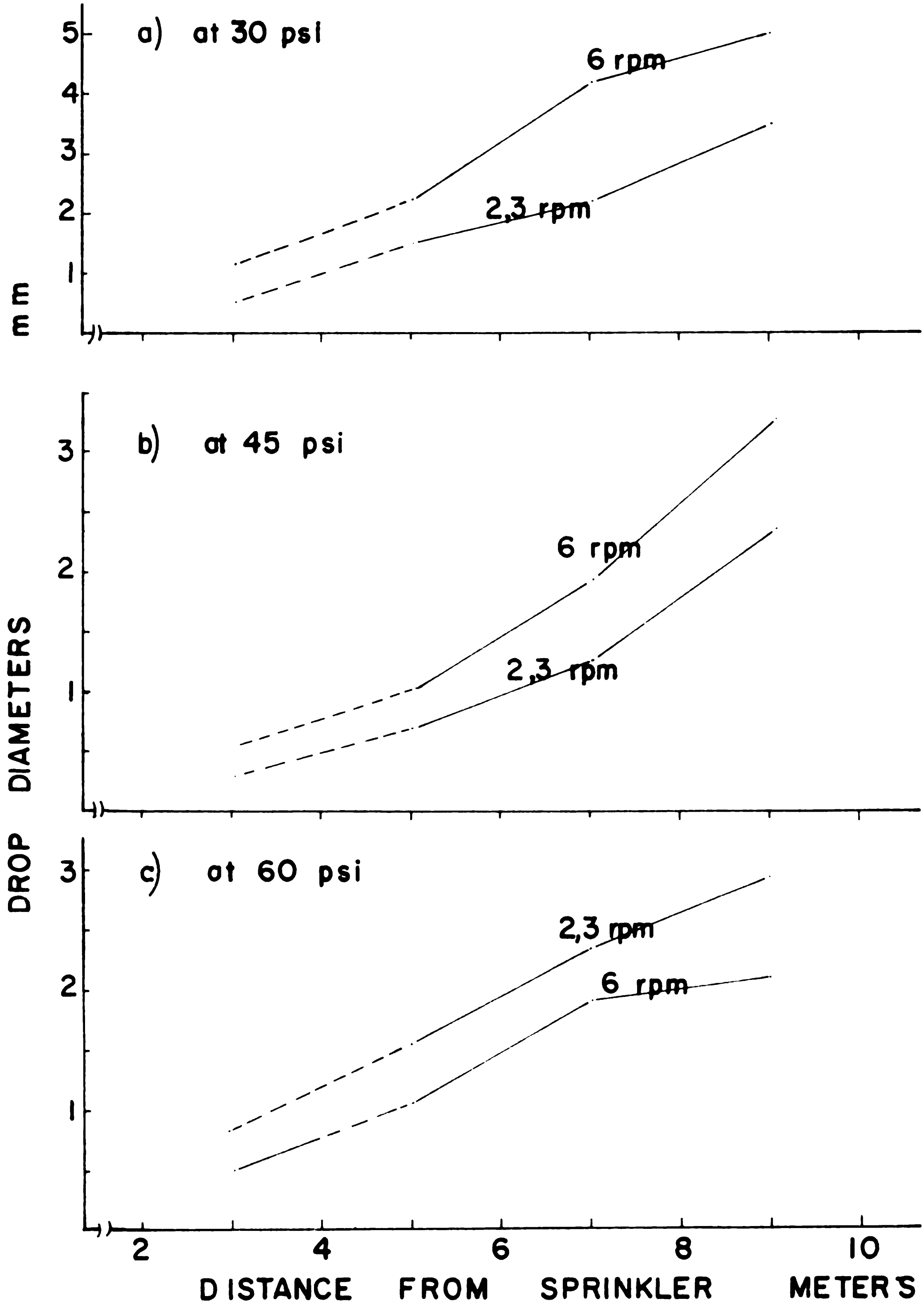


Figure 15. Mean drop diameter versus distance from sprinkler with rotating mechanism for rotation and pressure tested.

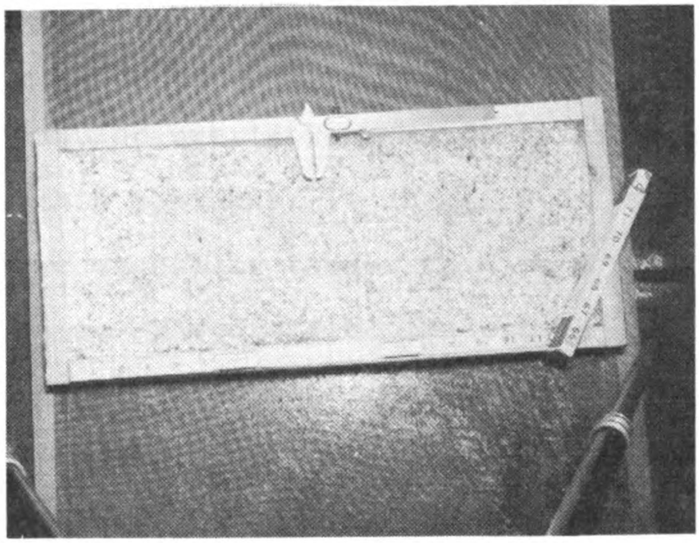

Figure 16. (a) Sugar-coated nylon screen on hoop shows the spots of waterdrop overlapping each other, (a) at 3 meters from the sprinkler with the oscillating arm, (b) at 4 meters from the sprinkler with a rate of rotation 6 rpm.

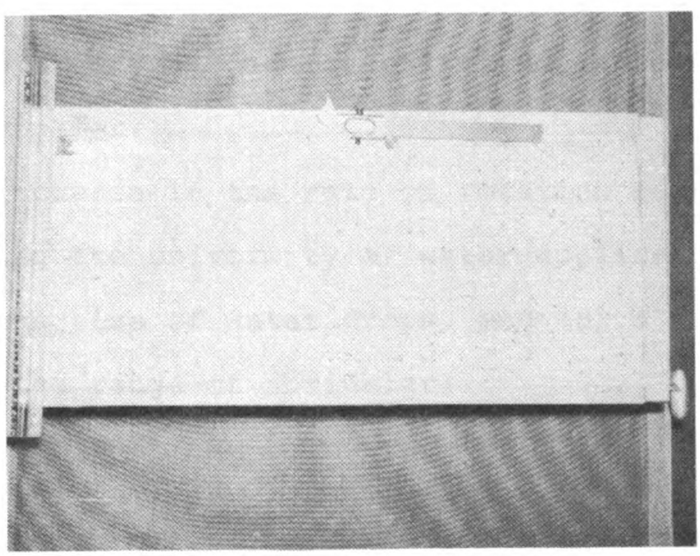

Figure 16. (b)

## CONCLUSION

1. The manufacturer's recommended minimum operating pressure for this sprinkler is 45 psi. It was found that higher pressure generally tended to give a more uniform application rate. The distribution curves show that the most uniform application rate resulted when the sprinkler with oscillating arm operated at 60 psi.

2. The use of nylon screen method for drop size investigation is feasible. The reliability of these measurements was dependent on the distance from the sprinkler that the observation was made.

3. An increase of operating pressure resulted in: (a) a more even distribution of water, (b) a general decrease in the diameter drops, and (c) a limited increase in the range of sprinkler.

4. An increase in the rate of rotation resulted in: (a) decreasing the univormity of water application, (b) increasing the size of water drops, and (c) a general decrease in the range of sprinkler.

## RECOMMENDATIONS FOR FUTURE WORK

1. Further studies of irrigation sprinkler should be continued to determine what combination of operating pressure and rotation may produce uniform distribution.

2. Future work should be directed to study turbulence, distribution of velocities, and amount of secondary motion effect on the dispersion of the water jet as it emerges from the sprinkler nozzle.

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## REFERENCES


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# APPENDIX

Table A-1. Sprinkler distribution data.

| rotation speeds rpm | | sample distance meters | application rate in cm/hr. at 30 psi | at 45 psi | at 60 psi |
|---|---|---|---|---|---|
| with oscillating arm | 1,667, 1715 and 1,765 respectively | 1.5 | .155 | .170 | .214 |
| | | 3.0 | .095 | .120 | .164 |
| | | 4.5 | .067 | .107 | .169 |
| | | 6.0 | .064 | .095 | .167 |
| | | 7.5 | .840 | .103 | .143 |
| | | 9.0 | .102 | .108 | .117 |
| | | 10.5 | .034 | .051 | .041 |
| with rotating mechanism | 2.3 rmp. | 1.5 | .047 | .082 | .190 |
| | | 3.0 | .034 | .066 | .187 |
| | | 4.0 | .044 | .093 | .245 |
| | | 5.0 | .057 | .111 | .326 |
| | | 6.0 | .086 | .121 | .296 |
| | | 7.0 | .101 | .127 | .271 |
| | | 8.0 | .133 | .140 | .246 |
| | | 9.0 | .206 | .149 | .182 |
| | | 10.0 | .056 | .048 | .045 |
| with rotating mechanism | 6.0 rpm. | 1.5 | .079 | .105 | .111 |
| | | 3.0 | .073 | .124 | .146 |
| | | 4.5 | .102 | .175 | .204 |
| | | 6.0 | .143 | .197 | .213 |
| | | 7.0 | .183 | .229 | .226 |
| | | 8.0 | .220 | .219 | .213 |
| | | 9.0 | .207 | .140 | .124 |
| | | 10.0 | .006 | .006 | .007 |

Table A-2. Diameter of drops for 3/32 inch nozzle.

| rotation speeds rpm | sample distance meters | mean drop diameter in mm at 30 psi | at 45 psi | at 60 psi |
|---|---|---|---|---|
| with oscillating arm | 3.0 | .571 | .425* | .400* |
| | 5.0 | 1.126 | .826 | .673 |
| | 7.0 | 1.740 | 1.607 | 1.425 |
| | 9.0 | 3.360 | 2.296 | 1.808 |
| with rotating mechanism 2.3 rpm | 3.0 | .497 | -* | .302* |
| | 5.0 | 1.148 | .846 | .704 |
| | 7.0 | 2.155 | 1.556 | 1.241 |
| | 9.0 | 3.490 | 2.320** | 2.358 |
| with rotating mechanism 6.0 rpm | 3.0 | 1.184 | .558 | .518 |
| | 5.0 | 2.260 | 1.068 | 1.063 |
| | 7.0 | 4.226 | 1.929 | 1.916 |
| | 9.0 | 5.078 | 3.275 | 2.108 |

*At those points, the diameter of drops could not be measured.

**This value was measured at 8.5 meters from sprinkler.