DROP SIZE DISTRIBUTION AND ENERGY OF
FALLING DROPS FROM A MEDIUM PRESSURE IRRIGATION SPRINKLER

AN ABSTRACT

Water drops from an irrigation sprinkler had the same deleterious effects on soil as did raindrops. The impact of falling water drops altered the open structure of the top fraction of an inch of the soil, reduced the effective pore size and formed a more dense layer of soil which hindered the infiltration of water. Large drops from an irrigation sprinkler reduced the infiltration capacity of the soil by as much as 90 per cent. A reduced infiltration capacity was accompanied by an increased erosion loss.

Insufficient data are available to permit accurate design of sprinkler irrigation systems which minimize detrimental structural changes in the soil. Research is necessary to determine the effect of nozzle shape, nozzle size, and pressure at the nozzle upon the size of drops striking the soil surface and upon the energy imparted by the drops to the soil.

The purpose of this study was (1) to measure the size of drops from an irrigation sprinkler, (2) to develop a technique for measuring, and (3) to determine the energy imparted by drops from a sprinkler striking a target near the soil surface.

A Rainbird Model 20 irrigation sprinkler was used for all tests in this study. Two nozzle sizes at two pressures

approved by E H Kidder

were tested. A 5/32-inch diameter nozzle was tested at thirty and thirty-five pounds per square inch and a 3/16-inch diameter nozzle was tested at thirty-five and forty pounds per square inch pressure. For both nozzle sizes the pressures selected were below and above the dividing line recommended by the manufacturer as the minimum pressure for operation on bare soils. All tests were conducted in a laboratory to remove the variable factors of weather.

The sprinkler was placed into a 55-gallon barrel open at the bottom. A vertical slit was cut into the barrel permitting the jet of water from the nozzle to emerge unmolested.

A general purpose flour or dental plaster (plaster of Paris) was used as the medium for collecting the water drops. Samples of drops were taken at five-foot intervals along a radius emanating from the sprinkler. Drops falling into the medium formed pellets. The mixture of medium and pellets was separated into size classes of pellets by means of a set of standard sieves.

The spectrum of pellet sizes received at each location was converted to the equivalent spectrum of water drops. A single number, called "median drop mass," representing the particular spectrum of drops at each location was calculated.

A transducer was constructed whereby the physical displacement of an elastic member was changed into an electrical signal by the use of strain gages. The elastic member with an attached target was placed near the ground level along a radius emanating from the sprinkler. The water drops from the sprinkler struck the target causing a deflection and oscillation of the elastic member. The resulting deflections were recorded by an oscillograph.

The energy added to the elastic member and target by the drops striking the target was calculated. The total energy received by the system during the time drops were striking the target was also calculated.

The following results were obtained:

(1) The logarithm of the median drop mass varied linearly with distance from the nozzle, increasing rapidly with greater distance from the nozzle. An increase in pressure of five pounds per square inch had little effect on the size of drops falling within approximately twenty feet of the nozzle. Changes in drop size caused by a change in nozzle pressure increased with distance from the nozzle.

(2) The logarithm of the energy imparted by drops from a sprinkler striking a target near the ground level varied linearly with distance from the nozzle, increasing rapidly with greater distance from the nozzle. Greatest amounts of energy were received from the drop spectrum from a 5/32-inch diameter nozzle operating at thirty pounds per square inch. Less energy was imparted by the drop spectrums from the remaining three combinations of nozzle size and pressure tested.

(3) True water application rates based upon the actual time of water application were as high as 7.5 inches per hour ranging from thirty to ninety times as great as the application rates based upon total elapsed time. The increment of pressure increase recommended by the sprinkler manufacturer as the difference between undesirable and desirable operation on bare soils was effective in reducing the highest application rates occurring in the area farther than thirty feet from the sprinkler.

DROP SIZE DISTRIBUTION AND ENERGY OF FALLING DROPS FROM A MEDIUM PRESSURE IRRIGATION SPRINKLER

By

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INTRODUCTION

Effect of Water Drops on Soil

The deleterious effect of raindrop impact on bare soil was noted as early as 1874. Baver (3) stated that Wollny (73) found "The loose granular structure of the unprotected soils was not only broken down to cause a compaction of the soil but the non-capillary porosity was also decreased as a result of the percolation of turbid water into the large pores and the subsequent clogging up of these pores with fine particles." Wollny's results have been confirmed by Lowdermilk (48) who reported that suspended particles in runoff water were filtered out at the surface of bare soils and sealed the seepage openings. Laboratory experiments (37) in which silt and clay were incorporated in rainfall resulted in the fine material being deposited in the top one sixteenth to one fourth of an inch. Effective downward translocation of the clogging surface layers did not occur although as much as twenty-seven inches of rainfall were applied. Clay applied in suspension blanketed the surface of a field plot, checked normal infiltration, and induced runoff very quickly.

The reduction of infiltration rates on cultivated land appeared to be caused by the development of a compact layer (22) only a few millimeters thick on the surface of the soil which did not permit rapid penetration of water. The compact layer was formed through alteration of the structure at the surface by the impact of rain drops and by further assortment of particles and wedging and fitting of these into close formation by running water, all of which slowed down the entrance of water through the immediate surface. The results indicated that the development of the compacted layer on the surface of a cultivated bare soil had a greater effect on intake of water than the combined effect of differences in soil type, degree of slope, previous moisture content of the soil, or rate of rainfall.

The amount of crust formed by applying rain artificially (12) varied with the amount of rainfall. Microscopic studies of the changes occurring in soil structure during compression (19) (at the lower plastic limit) showed a progressive closing of the interaggregate spaces as the pressure was increased. Crusts and thin surface seals were formed in artificially prepared soils (32) which had volume weights of about 1.4 compared to 1.1 or less for the "soil" below the crusts.

The impact of raindrops altered the open structure of the top fraction of an inch of the soil, reduced the effective pore size (57), and formed a more dense layer which hindered

the infiltration of water (55). Laws (43) determined that the infiltration rate decreased by as much as 70 per cent as drop size increased. The erosion losses resulting from the reduced infiltration rates increased by as much as 1200 per cent. Ellison's data (28) showed conclusively that a variation in either drop size or drop velocity will cause a change in infiltration capacity of the soil. Changes in drop velocity had greatest effect, changes in drop size were second, and changes in rainfall intensity were least effective. A small amount of surface sealing occurred on the soils tested without raindrop impact (30). Sealing was associated with the effects of wetting, slacking, and with adjustments of soil surface particles under the influence of surface water. The rates of such sealing were shown to be very slow and fairly uniform throughout a long time interval. Decreases in infiltration were also reported from the use of large drops from an irrigation sprinkler (47).

Increased surface runoff of water accompanied a reduction in infiltration (53) thereby requiring more protection against erosion. Erosion at La Crosse, Wisconsin (54) was proportional to the maximum amount of rainfall occurring in any given thirty-minute period. The same relationship was found to be approximately true at stations in Texas, Oklahoma, South Carolina, and New Jersey. The amount of a standard sand transported by water drop impact (27) was found to be directly proportional to the intensity of precipitation. The erosive capacity of a falling mass of water depends on the energy per unit area of the individual drop. The kinetic energy of the falling drop determined the force of the blow that must be absorbed at each impact, while the horizontal area of the drop determined the amount of soil that must sustain that blow.(26)

Protective Measures

Vegetative protection of the soil from the impact of raindrops was observed by Wollny (74). Vegetation protected the soil from the impact of raindrops to such an extent that the non-capillary porosity was 34 to 53 per cent higher than in unprotected soils. The decrease in volume of a cultivated soil was related to the density of the vegetation and the rapidity with which a vegetative canopy was established. Wollny concluded that the major effect of vegetation upon the properties of the soil was due to the protective influences of the canopy against the impact of raindrops.

The striking force of rain in the open bore a positive relation to rainfall intensity, whereas the striking force under a pine canopy apparently remained unchanged as the rate of precipitation increased (13). Under such a canopy (twenty-eight feet above the soil surface) the kinetic energy of rainfall for each inch of rain per square foot of soil surface was greater than in the open.

Intake rates were reduced much more gradually on plots artificially covered with a straw mulch than on bare plots (21,23).

The basic intake rate was higher on the covered plots. The mulch appeared to have a retarding effect on the formation of the compact layer on the surface.

Need for Research on Water Distribution Pattern from Sprinklers

Water drops from irrigation sprinklers had the same "puddling" effect on soil as did raindrops (11). Christiansen (14) pointed out that the largest drops from a sprinkler were carried to the outside of the area covered, while the smallest drops fell near the sprinkler. As the pressure was increased, more of the water fell near the sprinkler, and the average size of the drops became smaller. More detailed research (47) verified Christiansen's observations and also showed as much as a 90 per cent decrease in infiltration capacity when large water drops from an irrigation sprinkler were applied to a soil. Sprinkler manufacturers (33, 67) recognized the deleterious effect of large water drops on soil by recommending minimum pressures for various nozzle sizes.

Unfortunately, insufficient data are available to permit accurate design of sprinkler irrigation systems to minimize structural changes in the soil. Research is necessary to develop a technique for measuring the energy imparted by water drops from a sprinkler. Trials should then be made to determine the physical changes occurring in a soil when a known precipitation and resulting energy are applied to the soil.

Such information would permit sprinkler manufacturers to make necessary changes in nozzle design to meet the requirements of the soil; irrigation system designers would be more readily able to select proper nozzle size and operating pressure to minimize deleterious structural changes in the soil caused by excessive application rates; and the irrigator would be able to use the equipment without severe damage to soil structure.

Purpose of the Study

The purpose of this study was (1) to measure the size of drops from an irrigation sprinkler, (2) to develop a technique for measuring, and (3) to determine the energy imparted by drops from a sprinkler striking a target near the ground.

APPARATUS AND METHODOLOGY

Irrigation Equipment Used

A Rainbird Model 20 irrigation sprinkler was used for all tests in this study. This sprinkler was a medium pressure sprinkler adapted for use in agriculture and had a sufficiently low trajectory to be used inside a laboratory. All tests were conducted indoors to remove the variable factors of weather.

Two nozzle sizes at two pressures were tested. The nozzle sizes were 5/32-inch and 3/16-inch diameter. The 5/32-inch diameter nozzle was tested at thirty and thirty-five pounds per square inch pressure and the 3/16-inch diameter nozzle was tested at thirty-five and forty pounds per square inch pressure. In both cases the pressures selected were below and above the dividing line recommended by the manufacturer as the minimum pressure for operation on bare soils (33).

Apparatus for Determining Drop Size

The physical characteristics of water drops have been reported as early as 1894. Worthington (75) made sketches of drop action when drops strike another surface. Photographs taken just prior to the presentation of his paper verified the sketches. Studies on the measurement of the frequency distribution of various sizes of drops, fall velocity, electrostatic charge, number and form of falling drops, chemical composition, pH, temperature of rain and the intensity of rain are reported in German literature (58). Drop size determinations were made by Bentley (5), Defant (20), and Landsberg (42) (who measured the size of sleet drops). In 1919 Harkins made a detailed study of the surface tension of water drops (36). Edgerton used a high speed motion camera to analyze the stresses in a pendant drop (24). Modern electronic equipment was used by Gunn and Kinzer to obtain terminal velocities of drops (35).

Sizes of water drops have been determined by various methods. Bentley (5) allowed raindrops to fall into a layer of fine, uncompacted flour. The drops were allowed to remain in the flour until the dough pellet that each drop always produced at the bottom of the cavity was dry and hard. An investigator in Germany (72) used absorbent paper for determining drop sizes. Niederdorfer (59) estimated the average error in using the absorbent paper method to range from fourteen per cent of the drop weight at 0.037 milligram to six per cent for a drop weight of 37 milligrams. Measurement of the size of drops by freezing them artifically was attempted (58, 68). Controlled droplet sizes were obtained from a rotating disk (76) and from a vibratory apparatus (18). Screens of various materials coated with soot (8) or nylon hosiery mesh treated chemically and dusted with sugar (10) were successfully used to measure drop sizes. An optical instrument (16) in which a beam of light was interrupted by a drop measured the resulting shadow area by the output level of a photomultiplier tube. An impact type of unit permitted drops to strike a membrane (16). The resulting oscillations were picked up by an oscillograph and photographed. The force of impact was used as a measure of drop size in Australia (15). Each drop produced a transient modulation in an air-borne transmitter carrier to an extent which depended on drop size. A receiver on the ground demodulated the transmission and reproduced impulses which were a measure of drop size. Auxiliary circuits sorted the pulses into a number of amplitude groups and the total count was registered on electric counters. The change in capacity of a parallel plate condenser caused by a drop falling between the plates was used as a measure of drop size at Cambridge, England (62, 63). Spray deposits were obtained on slides coated with magnesium oxide (39). Photographic techniques have been used to determine drop sizes as well as drop velocities (17, 34, 44, 55). Schmidt (61) measured the velocity of raindrops by using two disks mounted on an axle and rotated at a known rate. A drop, which by chance fell through a small sector cut in the upper disk, fell upon a piece of absorbent paper fastened to and rotating with the lower disk. The location of the spot relative to the projection of the sector on the paper gave a measure of the velocity, while the diameter of the spot gave a measure of the drop size.

The use of flour or dental plaster appeared to offer the most reliable method of determining drop sizes without requiring detailed and lengthy photographic analyses. Bentley (5) stated that the dough pellets corresponded very closely in size with the raindrops that made them.

Apparatus for Determining Energy Imparted by Falling Drops

Energy of falling water drops. The energy of falling drops from either rainfall or irrigation sprinklers must be converted to other forms of energy such as heat or must do work. Falling drops may do work in overcoming the surface tension of the drops when the parent drop is shattered and smaller ones formed; soil aggregates may be torn apart (49, 50); soil particles may be moved horizontally and vertically (26, 27, 29, 32, 34, 51, 52); shattered drops may be imparted with a horizontal and vertical velocity (4); turbulence may be introduced into surface runoff waters (29). The task of research is similar to that expressed for natural rainfall (28). First, the total energy of the falling drops must be determined--the energy which is available for damaging the surface soils, moving soil particles and reducing infiltration rates. Second, the amount of total energy used in deleterious effects on the soil must be determined.

Applicability of stress analysis techniques. The energy of moving water drops can be measured directly (41, 56). A device, called a transducer (60), can be constructed whereby

the physical displacement of an elastic member is changed into an electrical signal by the use of strain gages. Proper instrumentation is needed to pick up and magnify such a signal for recording and study (Figure 1).

A steel cantilever beam was selected for the elastic member. A target of Styrofoam* was attached to the free end of the cantilever beam. The energy imparted by the water drops striking the target area caused the beam to deflect resulting in a strain in the elastic member. Since maximum strain occurs at the fixed point of a cantilever beam, strain gages were attached near that point. The transducer constructed for measuring the energy imparted by the falling drops is shown in Figures 2 and 3.

Methodology for Determining Drop Size Distribution

Complex nature of drop formation from a sprinkler. The formation of water drops from a sprinkler nozzle is quite complicated and extremely difficult to analyze. Actual velocities of a water jet emerging from an orifice vary from near zero at the perimeter to a maximum at the center of the stream. The relationship between the average velocity, which can be readily measured, and the maximum velocity is a function of Reynold's number (66).

*Styrofoam has low density, thereby keeping the inertia of the system to a minimum. It is also resistant to water penetration.

Figure 1. Transducer and instrumentation for pickup, magnification, and recording of the signal from the transducer. The amplifier (center) is a Universal Amplifier Model BL-520 manufactured by Brush Electronics Company. The recorder (right) is a Model BL-202 Double-Channel Oscillograph manufactured by Brush Electronics Company.

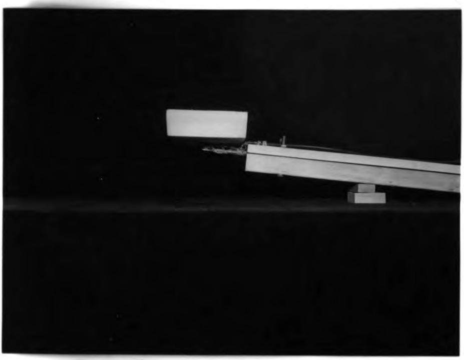


Figure 2. The cantilever beam was a steel strap 1 7/8" x 3/64". The beam had an overhang of 4 inches. The Styrofoam target was mounted on a stove bolt secured to the end of the cantilever beam. Two strain gages (SR4 Type A-12) were fastened to the top of the beam and two on the underside of the beam. Gages and electrical connections were carefully waterproofed.

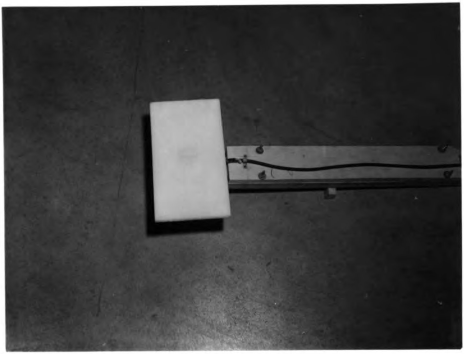


Figure 3. The Styrofoam target was 16.5 centimeters by 30.3 centimeters with the greater dimension placed along a radius emanating from the sprinkler nozzle.

Initial breakup of the stream into variously sized drops occurred after the stream passed the vena contracta. The variation in stream velocity and the mechanical dispersion caused by the sprinkler rotation initiated drop formation. Further breakup was a function of the surface tension of the water and the resistance of the air to the passage of water drops. 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 (34).

Drops may collide and coalesce with other drops (69). Drops suspended in a vertical air stream which came into a region within six centimeters above another drop usually began to fall in an ever tightening spiral until collision took place (9). Bombardment of large drops with a spray of small droplets showed that not all the small droplets coalesced with the large drops. Some of the smaller drops rolled across the under surface of the large drop exhibiting a "bounce-off" effect.

Even after the drops formed, their characteristics were not constant, but dynamic. Two types of deformation occurred (7). When the drop was deformed to an ellipsoidal shape a rotational deformation occurred. Drops artificially developed and placed into an air stream for observation rotated on their minor axis with the minor axis vertical. The second mode of deformation was free of rotational effects, but consisted of an oscillation. Such oscillation caused the drop to oscillate between ellipsoidal shapes ninety degrees apart in the horizontal plane. Surface tension began to draw the drop together. But since the vertical dimension was unchanged, the horizontal axis perpendicular to the plane of the paper increased. Thus, like a pendulum, too much contraction of the major axis occurred and the minor axis was transformed into the major axis and the process repeated. Theoretical determinations of the ratio of vertical and horizontal axes of ellipsoidal drops and the ratio of the horizontal cross sections of spherical and ellipsoidal drops were made by Spilhaus (65).

A mathematical analysis (34) of the distance of travel and the velocity of drops from an orifice resulted in the following relationship:

$$r = V_o(m/k)(1 - e^{-(k/m)t}) - g(m/k)^2(e^{-(k/m)t} - 1) - g(m/k)t,$$

where

r = distance from the orifice;

V_o = initial velocity;

m = mass of the drop;

k = a constant;

e = 2.718 . . .;(38)

t = time;

g = gravitational acceleration.

As the value of m/k approached zero as its limit the value of "r" also approached zero. Consequently, small drops traveled only negligible distances (34). 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 (47).

Simplifying assumptions. To avoid the difficulties encountered in attempting to analyze a dynamic, shifting stream of colliding and oscillating drops, this study was based upon samples taken at the ground level. The following assumptions were made to permit analysis of the data:

1. The break up of the stream into drop sizes was considered equivalent to the action in which some homogeneous substance was broken into fine particles by some random process. Drop formation, then, was subject to the laws of probability and the number of drops in the size classes followed a normal distribution.
2. The drops were spherical in shape. Ekern (26) reported Spilhaus' calculated ratios of the horizontal cross sections of spherical and ellipsoidal drops (65). For a 2.74 millimeter drop the ratio was ninety-three one hundredths and for a 6.52 millimeter drop the ratio was seventy-nine one hundredths. If all the drops were ellipsoidal in shape when they entered the pellet forming medium, the error would be less than 20 per cent. It is not probable that such a situation would occur.

3. Evaporation from the time the drops struck the pan until the pellets were formed was negligible (44).
4. Four samples, taken from successive rotations of the sprinkler, adequately represented the drop population.

Pellet and drop size distribution. The frequency distribution of raindrop sizes was initially reported by Lenard (46). In 1904 he published tables showing the frequency of occurrence of drops of different sizes in several rains. Size distribution analyses were made more frequently in later years indicating that the procedure formed a powerful tool for the quantitative determination of thunderstorm dimensions and characteristics in rain-intensity distribution (40, 45) and should be equally valuable in the study of water distribution from an irrigation sprinkler. A consideration of the theory of probability seemed to lead to a rational equation representing the distribution curves of dispersed materials (1). Samples of solid materials (quartz, hornblende and orthoclase feldspar) were ground up and analyses made. The data followed the calculated curve closely (31). It was concluded that the physical processes that break down soil minerals of various kinds involve primarily the theory of probability. Similarly, the processes that break up a stream of water from an irrigation sprinkler and dispersal into various drop sizes may also be considered to involve the theory of probability.

Pellet calibration. Actual drop dimensions could not be found from the dimensions of the sieve openings. The drop

undergoes a certain amount of flattening in becoming a pellet (40). The mass of the average pellet retained on a given sieve was used to define that size class. The average pellet mass was obtained by dividing the mass of the total drops retained on a sieve by the number of pellets retained. To convert the mass of the average pellet into the mass of the average drop required the use of a "mass-ratio"--that is, the ratio of the mass of the drop to the mass of the pellet. The mass-ratio for flour was reported by Laws in 1941 (44) and in 1943 (45). Use of Laws' data in a linear regression analysis (Table I) resulted in the following equation plotted in Figure 4:

$$R = 1.008{,}3\ M^{0.031{,}582}, \text{ where}$$

$R =$ the mass-ratio $= \dfrac{\text{mass of drop}}{\text{mass of pellet}}$;

$M =$ the mass of the pellet in milligrams.

Drop sizes larger than those occuring in natural rain (two milligrams) were not anticipated from the sprinkler. Early analyses of drops from a sprinkler indicated that pellet masses as low as one tenth of a milligram would be obtained. Drops smaller than 0.877 milligram were not obtained by Laws by using tubes of different diameters. Hair-like capillaries coated with paraffin were used and pressure was introduced to hasten dripping. Nevertheless, the small drops were not obtained.

Extension of the mass-ratio calibration to the drops between one tenth and one milligram (five hundred to twelve hundred microns in diameter) was desirable to avoid the neces-

TABLE I

CALCULATION OF LINEAR REGRESSION

	Log of Pellet Mass	Log of Mass-Ratio	Deviations from Mean		Squares of Deviations	Products of Deviations
	X	Y	x	y	x^2	xy
	0.176,09	0.010,72	-0.888,28	-0.026,49	0.789,041	0.023,531
	0.380,21	0.013,84	-0.684,16	-0.024,37	0.468,075	0.016,673
	0.698,97	0.017,03	-0.365,40	-0.020,18	0.133,517	0.007,374
	0.977,72	0.033,42	-0.086,65	-0.003,79	0.007,508	0.000,328
	1.079,18	0.049,22	0.014,81	0.012,01	0.000,219	0.000,178
	1.462,40	0.053,08	0.398,03	0.015,87	0.158,428	0.006,317
	1.740,36	0.064,46	0.675,99	0.037,25	0.456,962	0.018,421
	2.000,00	0.056,90	0.935,63	0.019,69	0.875,403	0.018,423
Sum	8.514,93	0.297,67	-0.000,03	-0.000,01	2.889,153	0.091,245
Mean	1.064,37	0.037,21				

$$\hat{Y} = \bar{y} + \frac{Sxy}{Sx^2}(X - \bar{x})$$

$$= 0.037,21 + \frac{0.091,245}{2.889,153}(X - 1.064,37)$$

$$= 0.037,21 + 0.031,582\,X - 0.033,615$$

$$\hat{Y} = 0.003,595 + 0.031,582\,X$$

Antilog 0.003,595 = 1.008,3

$$R = 1.008,3\,M^{0.031,582}$$

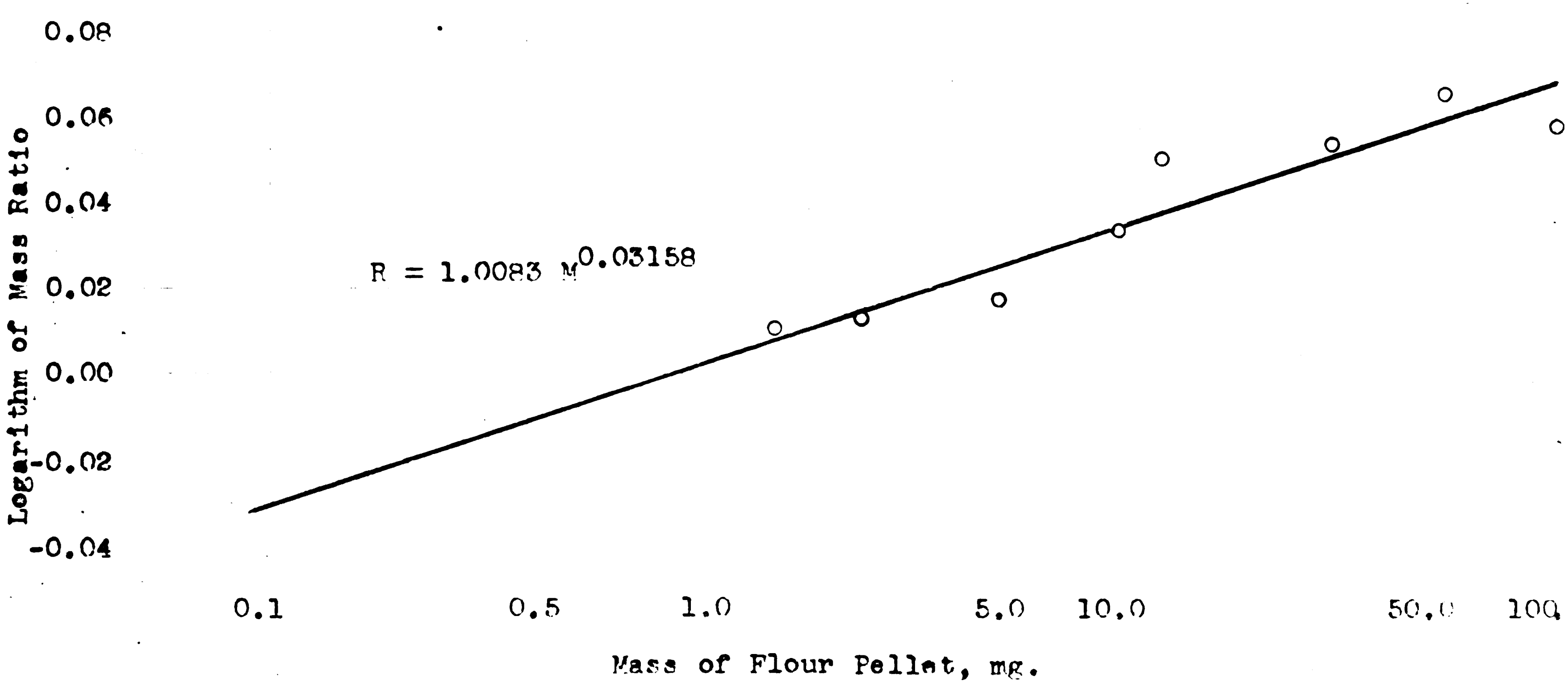
$$R = \text{mass-ratio} = \frac{\text{mass of drop}}{\text{mass of pellet}}$$

M = mass of pellet in milligrams

FIGURE 4

CALIBRATION OF FLOUR PELLETS*

$$\text{Mass Ratio} = \frac{\text{Mass of Drop}}{\text{Mass of Pellet}}$$



*Laws, J. Otis & Donald A. Parsons, "Relation of Raindrop-Size to Intensity." Trans. Amer. Geophys. Union, vol.24, p. 455, 1943.

sity of extrapolation. Oil drops of uniform size between six and one hundred forty microns were produced from a vibratory apparatus (18). Such small drops were not required for the sprinkler analysis. Controlled drop sizes were also obtained from a rotating disk (76). Drops with diameters from fifty to six hundred microns were obtained by changing the peripheral velocity of the rotating disk or by changing the rate of flow of water upon the disk. The rotating disk method appeared feasible for extending the mass-ratio calibration.

Method employed for obtaining drop size. The sprinkler was placed into a fifty-five gallon barrel open at the bottom, thereby preventing water from spraying over the entire laboratory. To permit a stream of water to emerge for testing purposes, a vertical slit was cut into the barrel permitting the jet of water from the nozzle to emerge unmolested.

A general purpose flour or a dental plaster (plaster of Paris) was used as the medium for collecting the drops from the sprinkler. In order to be certain that the medium was free from all lumps and was fluffy and loose for receiving the drops, the samples were prepared by passing all of the material through a forty-mesh sieve. The initial sieving was always done on the same day that the samples were taken. The sieved material was then placed into aluminum pie pans nine inches in diameter (Figure 5).

The test run was started by adjusting the rate of flow of water into the sprinkler until the desired pressure was

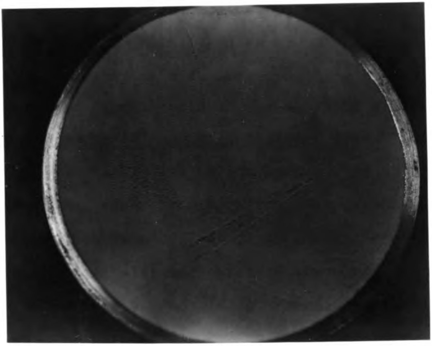


Figure 5. Pan of flour prepared for receiving water drops.

obtained. The pressure gauge had been previously calibrated. A calibrated water meter was placed into the line permitting the rate of flow of water to be measured accurately.

Samples of drops were taken at five-foot intervals along a radius emanating from the sprinkler. Four replicates were taken at every point. Pans containing the medium were placed along the radius so that the stream from the sprinkler made an unmolested sweep across the pan. Drops falling into the medium formed pellets (Figures 6 and 7). At least once after each replicate the pressure was checked to be certain that it maintained a constant value.

The mixture of medium and pellets was separated into size classes of pellets by means of a set of standard sieves. The material retained on each sieve was placed into a can and later weighed. Weighing was done on a balance permitting readings to one thousandth of a gram.

Pellet mass retained on each of the sieves was reduced to drop mass by using the mass-ratio. The average weight of a single pellet retained on each of the eleven sieves was obtained (Appendixes A and B). The weight of the pellets retained on each sieve divided by the weight per pellet resulted in the number of pellets or drops in each size class for each location. The number of pellets in each size class for the 5/32-inch nozzle operating at thirty pounds per square inch is shown in Table II.

Procedure for calculation of median drop mass. The

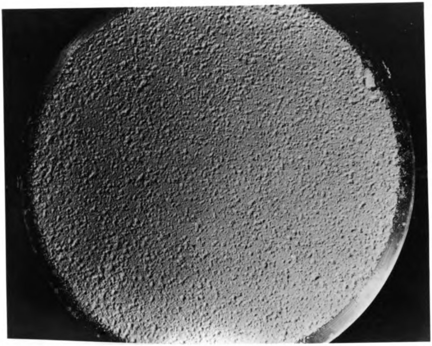


Figure 6. Pan of flour after receiving water drops at a point near the sprinkler.

Figure 7. Pan of flour after receiving water drops at the farthest point from the sprinkler nozzle.

TABLE II

DISTRIBUTION OF PELLET SIZES FIFTEEN FEET FROM A 5/32-INCH NOZZLE OPERATING AT THIRTY POUNDS PER SQUARE INCH PRESSURE

Sieve Opening, microns	Weight of Pellets Retained on Screen, gms				Calculated Number of Pellets or Drops				
	Replicate No.				Replicate No.				
	1	2	3	4	1	2	3	4	Ave.
420	.157	.142	.106	.142	1495	1352	1010	1352	1302
589	.240	.243	.250	.286	1263	1279	1316	1505	1341
840	.590	.562	.569	.637	1157	1102	1116	1249	1156
1168	.214	.186	.198	.227	171	149	158	182	165
1397	.280	.273	.348	.287	135	131	168	138	143
1900	.030	.032	.019	.014	5	5	3	2	4

droplet spectrum expressed as a single figure was more convenient to use than a tabulation of the complete spectrum (70). Neither the arithmetic mean of the range of sizes nor the median diameter by number was wholly satisfactory as each tended to mask the effect of the largest drops in the spectrum. In the analysis of sprays for weed control the best single figure was a mass median diameter which had half of the mass in droplets smaller than it, and half of the mass in droplets larger than it (25). The value of the mass median diameter was determined by computing the volume in each of the size classes and by plotting the cumulative figure on logarithm-probability paper (2).

The method used in this investigation follows:

1. The per cent of the total mass of drops at each location contributed by each size class was calculated, from which the cumulative percentages were determined (Table III).
2. The logarithm of the mass of a single drop of each size class was plotted against the cumulative percentages on a probability scale (Figure 8).
3. The same points were plotted on rectangular coordinate paper (Figure 9) from which the best fitting straight line was calculated by the method of least squares (Table IV).
4. The line calculated in step 3 was imposed upon the data plotted on the probability scale and the loga-

TABLE III

CALCULATION OF CUMULATIVE PERCENTAGES OF MASS OF WATER STRIKING GROUND

(Fifteen feet from a 5/32-inch nozzle operating at 30 psi)

Mass of Single Drop, mg.	No. of Drops	Total Mass for Size Class, gm.	Cumulative per cent
0.098,6	1,302	0.128	8.5
0.181,8	1,341	0.244	24.6
0.513,4	1,156	0.593	63.9
1.269	165	0.209	77.8
2.145	143	0.307	98.1
7.128	4	0.029	100.0
		1.512	

Sample calculation for 0.513,4 mg class:

Total mass for size class, M = mN, where

m = mass of drops in grams;

N = number of drops of mass m.

$$M = \frac{0.513{,}4 \text{ mg} \times 1 \text{ gm} \times 1{,}156}{1000 \text{ mg}} = 0.593 \text{ grams}$$

FIGURE 8

DETERMINATION OF MEDIAN DROP MASS

Fifteen feet from a 5/32-inch nozzle
operating at 30 psi

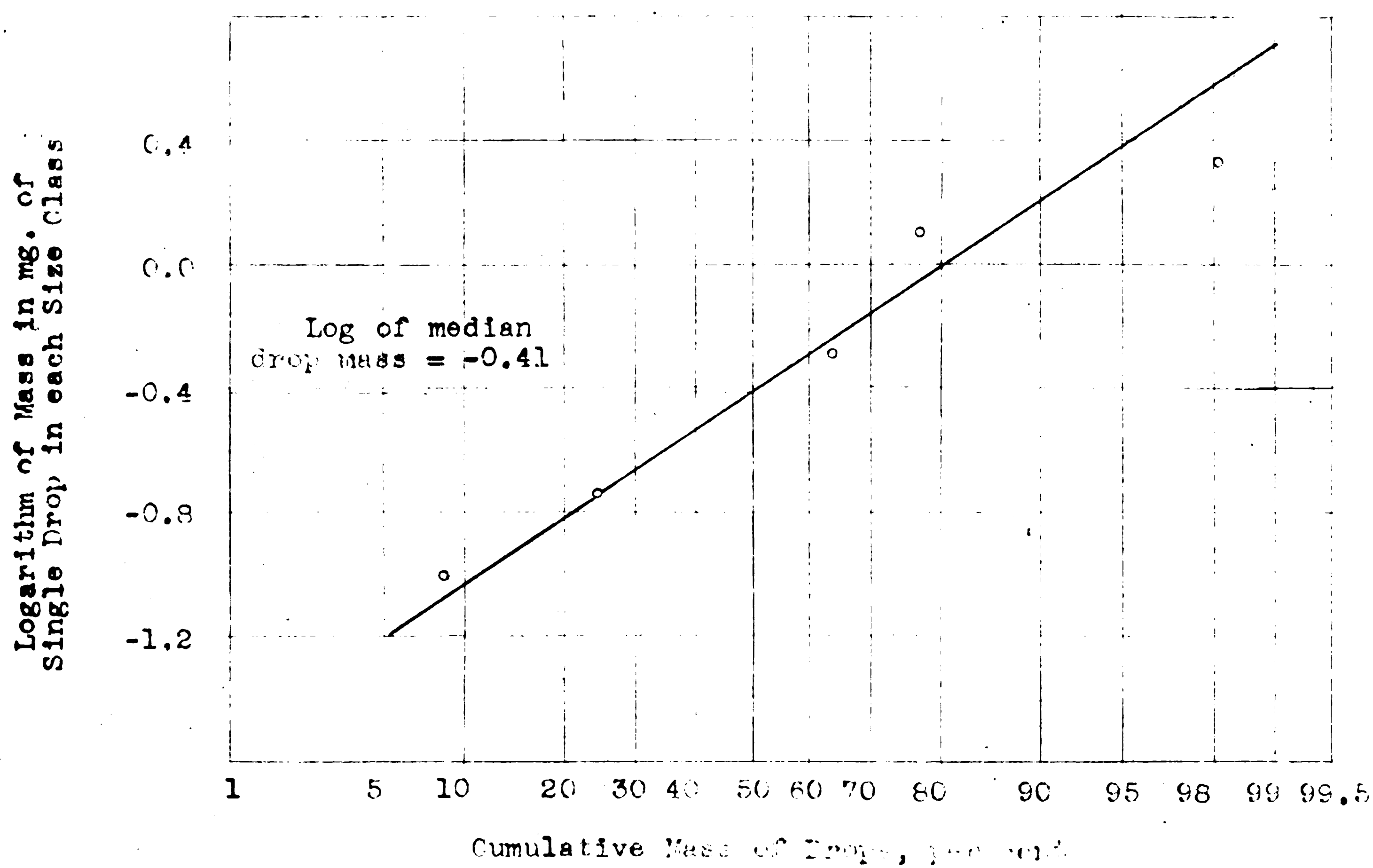


FIGURE 9

ASSIGNMENT OF RECTANGULAR COORDINATES

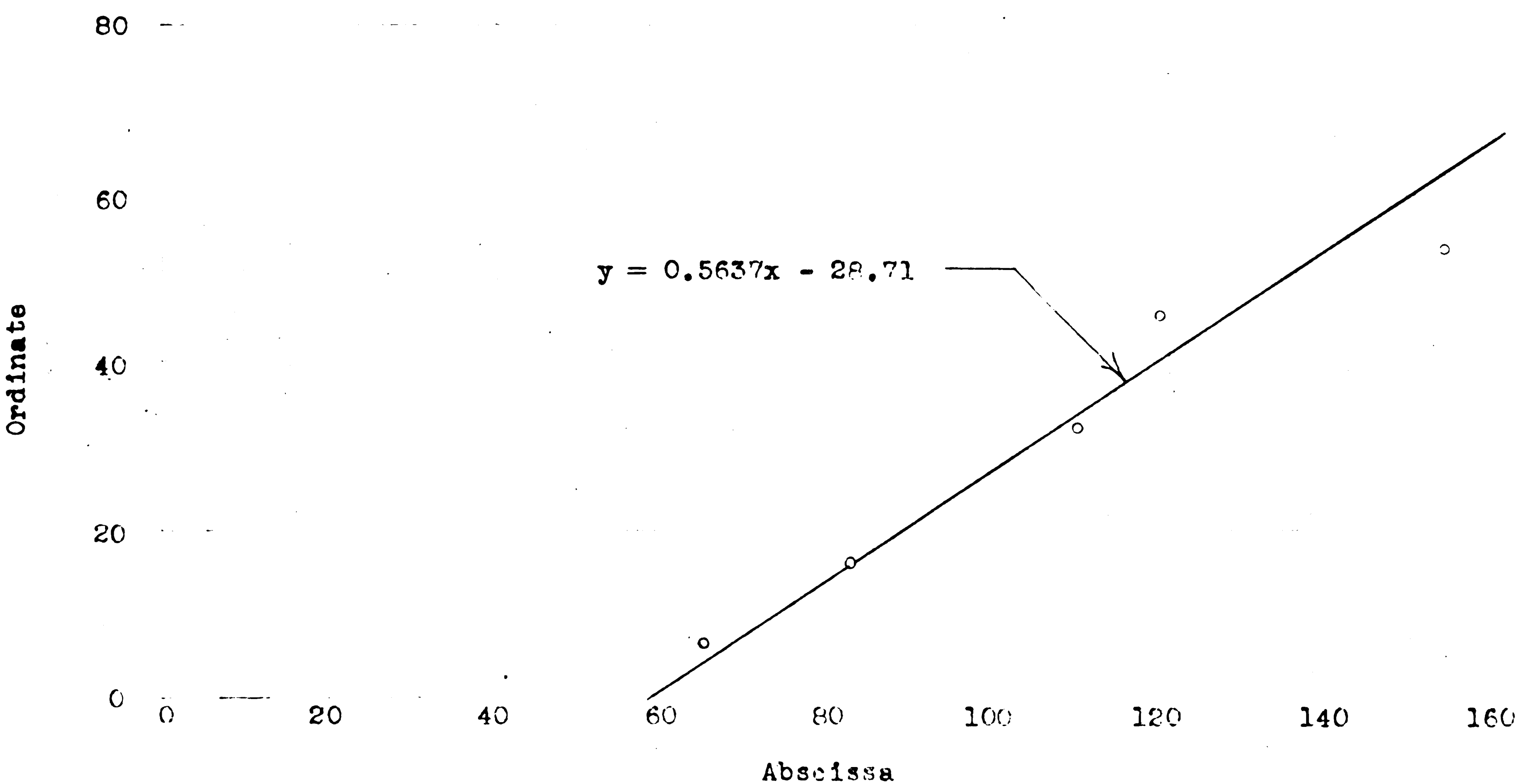


TABLE IV

FITTING A STRAIGHT LINE TO DATA BY THE METHOD OF LEAST SQUARES

(For spectrum of drop sizes falling fifteen feet from a 5/32-inch nozzle operating at 30 psi)

Coordinates	x	64.5	82.0	109.0	119.0	152.5
for points	y	6.5	16.0	32.0	45.5	53.5

$$\Sigma y = 153.5$$

$$\Sigma x = 527.0$$

$$\Sigma xy = 18{,}792.50$$

$$\Sigma x^2 = 60{,}182.50$$

$$N = 5$$

$$y = a + bx$$

$$a = \frac{(\Sigma y)\ (\Sigma x^2) - (\Sigma xy)(\Sigma x)}{N\ (\Sigma x^2 - (\Sigma x)\ (\Sigma x)}$$

$$= \frac{(153.5)(60{,}182.50) - (18{,}792.50)\ (527.0)}{(5)(60{,}182.50) - (527)(527)}$$

$$= -28.71$$

$$b = \frac{N\ (\Sigma xy) - (\Sigma x)(\Sigma y)}{N\ (\Sigma x^2) - (\Sigma x)(\Sigma x)}$$

$$= \frac{5(18{,}792.50) - (527.0)(153.5)}{5(60{,}182.50) - (527)(527)}$$

$$= 0.563{,}7$$

$$y = 0.563{,}7\ x - 28.71$$

Logarithm of mass of equivalent drop = -0.41 = 9.59 -10

Mass of equivalent drop = 0.389 mg.

rithm of the "median drop mass" was obtained from the intersection of the straight line and the 50 per cent probability line.

Methodology for Determining Energy of Drops Striking the Target

An example of the type of record made by the oscillograph when the target was subjected to the falling drops is shown in Appendix C. The record consists of a series of oscillations across a moving center line. The center line changed as the total inertia load of the target and beam changed. Changes in the inertia of the system occurred as water was added from the falling drops and as excess water drops fell off the system.

Energy imparted to the target and beam was dissipated through the natural damping of the oscillations of the beam. The amount of energy in the system was calculated for different points of the damping cycle.

$E = \frac{1}{2}kA^2$, where

E = energy available in the system, ergs;

k = spring constant of the beam, (gm cm)/(cm sec^2);

A = deflection of the beam, cm.

The energy per cycle lost in damping was calculated and plotted for expected values of A.

At time t_1, $e_1 = 1/2kB_1^2$.

At time t_2, $e_2 = 1/2kB_2^2$, $B_2 < B_1$ during damping.

Energy loss, $\Delta E = e_1 - e_2$

$$= 1/2\ k\ B_1^2 - 1/2\ k\ B_2^2$$

$$\Delta E/E = \frac{1/2\ k\ B_1^2 - 1/2\ k\ B_2^2}{1/2\ k\ B_1^2}$$

$$= \frac{B_1^2 - B_2^2}{B_1^2}$$

$$B_2^2 = B_1^2\ (1 - \Delta E/E)$$

Values of $\Delta E/E$ for expected values of B (expressed as lines on the oscillograph) were calculated. The relationship was expressed as $\Delta E/E = 0.722 - 0.009{,}7\ B$. Values are given in Appendix D.

The energy added to the system by the drops striking the target was calculated. At time t_1, $E_1 = 1/2\ k\ A_1^2$ and at time t_2, $E_2 = 1/2\ k\ A_2^2$. For the time interval t_1 to t_2, $B_1 = A_1$, $e_1 = E_1$, and $A_2 > B_2$. Then the energy added to the system was $E_2 - e_2$.

$$E_2 - e_2 = 1/2kA_2^2 - 1/2kB_2^2$$

$$= 1/2kA_2^2 - 1/2kB_1^2\ (1 - \Delta E/E)$$

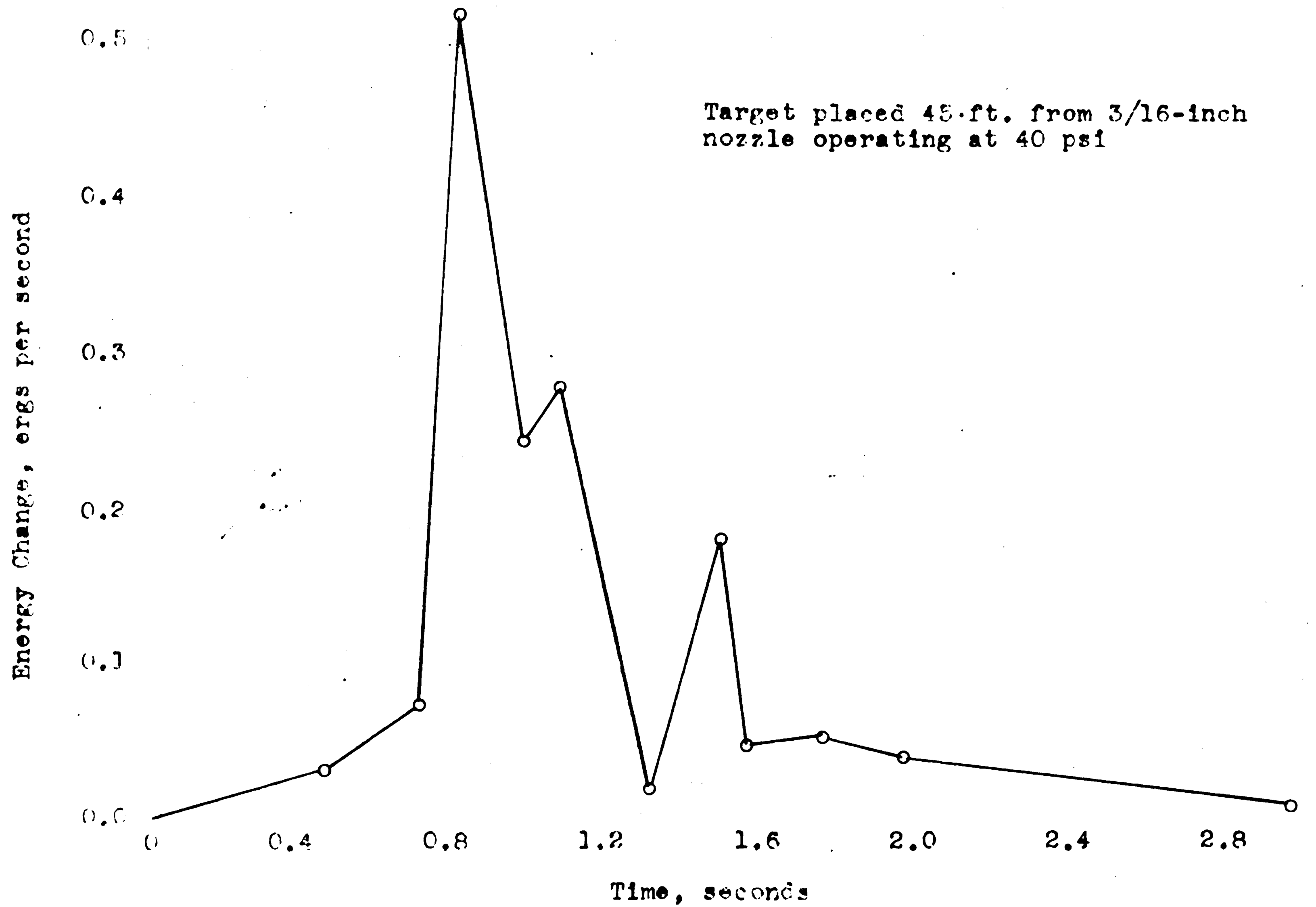
$$= 1/2kA_2^2 - 1/2kB_1^2 + 1/2kB_1^2 \left[\frac{1/2kB_1^2 - 1/2kB_2^2}{1/2kB_1^2}\right]$$

$$= E_2 - E_1 + \Delta E$$

The total energy received by the system during the time drops were striking the target was determined. The oscillograph record was divided into intervals of time convenient for analyzing the energy change of the system. The energy change per unit of time was plotted against time and the total energy was determined by measuring the area under the resulting curve (Figure 10).

FIGURE 10

RATE OF CHANGE OF ENERGY



PRESENTATION AND ANALYSIS OF DATA

Pellet Calibration

Drops of a uniform diameter were thrown from a polished brass disk two and one half inches in diameter attached to a variable speed motor. The drops were caught on the dental plaster and permitted to harden. The resultant pellets were run through a set of standard sieves. The relationship between the drop diameter and the pellet diameter was then calculated.

The equation relating disk diameter, rate of water flow, speed of rotation of the disk, and the drop diameter was (76):

$$d = \frac{870{,}000}{(D\,w^2)^{0.462}} + 7{,}560\ \frac{Q}{D^{1.462}w^{0.924}}\ ;\ \text{where}$$

d = drop diameter in microns;

D = disk diameter in inches (in this case 2.5 inches);

w = rate of rotation of disk in revolutions per minute;

Q = rate of flow onto the center of the disk in cubic centimeters per minute.

Calibration of pellets for drops smaller than 0.877 milligram was also attempted. Undesirable disk vibration introduced too many smaller "satellite" drops to permit evaluation of the data for small drops.

The ratios of the diameters of the drop and the plaster pellet were compared (Table V). The average diameter

TABLE V

PLASTER PELLET CALIBRATION

Drop Diameter, microns	Sieve Opening on which Pellet was Retained, microns	Diameter Ratio, $\frac{\text{drop}}{\text{pellet}}$
801	833	0.962
982	833	1.179
1,119	1,168	0.958
1,566	1,651	0.959
2,329	1,981	1.176
2,856	2,830	1.009
2,995	2,362	1.269
5,703	4,699	1.214

Average 1.09

ratio of 1.09 and the diameter ratio of Laws' flour calibration (Table VI) of 1.08 compared favorably. The pellet-making characteristics of the flour and the plaster were very similar. Consequently, the flour calibration was used for the plaster pellets by making a correction for the difference in density of the pellets from the two materials.

Density of flour pellets and plaster pellets was obtained by weighing a container of known volume carefully filled with the pellets. Weighings were replicated eight times. The ratio of the flour to the plaster pellets was 0.96.

The calculation of the mass of the drop from the flour and plaster pellets is shown in Table VII.

Median Drop Mass

The median drop mass at each location was obtained by plotting the logarithm of the mass of a single drop in each size class against cumulative percentage of total mass on probability paper as shown in Figures 8 and 9. Values of the median drop mass are shown in Table VIII. Equations from which each median drop mass was calculated are shown in Appendix E. Statistical tests for linearity were made for each location. The hypothesis was that the relationship between the logarithm of the mass of a single drop in each size class and the cumulative percentage plotted on a probability scale was not linear. The hypothesis was rejected at the 99 per cent probability level (64) except at two points. For

TABLE VI

FLOUR PELLET CALIBRATION*

Drop Diameter, microns	Sieve Opening on which Pellet was Retained, microns	Diameter Ratio, $\frac{\text{drop}}{\text{pellet}}$
1,433	1,397	1.026
1,677	1,651	1.016
2,150	1,981	1.085
2,696	2,362	1.141
2,950	2,794	1.056
3,970	3,327	1.193
4,958	4,699	1.055
6,016	5,613	1.072
		Average 1.08

*Adapted from Laws, J. Otis, and Donald A. Parsons, "The Relation of Raindrop-Size to Intensity," Transactions American Geophysical Union, 24:452-460, 1943.

TABLE VII

CALCULATION OF MASS OF DROP

Flour
Mass of drop = (mass-ratio)(mass of pellet)

Sieve Opening, microns	Mass of Pellet, mg.	Mass-Ratio	Mass of Drop, mg.	Diameter of Drop, microns
420	0.105,00	0.939	0.098,60	573
589	0.190,00	0.957	0.181,83	703
840	0.519,58	0.988	0.513,35	993
1,168	1.250,3	1.015	1.269,1	1,340
1,397	2.080,5	1.031	2.145,0	1,600
1,900	6.655,4	1.071	7.127,9	2,390
2,362	13.708	1.095	15.010	3,060
2,830	19.784	1.108	21.921	3,470
3,360	34.675	1.128	39.113	4,210
4,000	58.238	1.146	66.741	5,030
4,699	94.174	1.164	109.62	5,940

Dental Plaster
Mass of drop = (mass-ratio)(mass of plaster pellet)(0.96)

Sieve Opening, microns	Mass of Plaster Pellet, mg.	Corrected Mass of Plaster Pellet, mg.	Mass-Ratio	Mass of Drop	Diameter of Drop, microns
420	0.088,30	0.084,87	0.933	0.079,18	533
589	0.327,20	0.314,48	0.972	0.305,67	836
833	0.744,06	0.715,11	0.998	0.713,68	1,110
1,168	2.076,0	1.995,2	1.030	2.055,1	1,580
1,651	4.151,3	3.989,8	1.054	4.205,2	2,000
1,981	7.844,5	7.539,4	1.075	8.104,9	2,490
2,362	12.296	11.817	1.090	12.881	2,910
2,830	21.579	20.740	1.109	23.001	3,530
3,360	27.265	26.205	1.118	29.297	3,820
4,000	48.750	46.854	1.138	53.320	4,670
4,699	94.453	90.779	1.163	105.58	5,860

TABLE VIII

MEDIAN DROP MASS
(Milligrams)

Distance from Nozzle, ft.	5/32-inch Nozzle		3/16-inch Nozzle	
	30 psi	35 psi	35 psi	40 psi
5	0.129	0.219	0.794	0.741
10	0.234	0.257	0.417	0.316
15	0.389	0.331	0.617	0.589
20	0.550	0.550	0.776	0.891
25	1.445	0.832	1.445	3.162
30	2.951	1.660	3.020	7.244
35	6.761	4.786	3.631	5.888
40	12.882	9.333	4.898	17.378
45				19.953

those two points the hypothesis was rejected at the 95 per cent probability level (64).

The relationship between the logarithm of the mass of the median drop falling at each point along the radius and the distance from the sprinkler is approximately linear (Figures 11, 12, and 13). The drop size increased rapidly as the distance from the nozzle increased. The measured drops ranged in size from 0.079 milligram to 109.62 milligrams corresponding to drop diameters of 533 microns and 5,940 microns.

An increase in pressure of five pounds per square inch had little effect on the drop sizes falling within approximately twenty feet of the nozzle. The effect of the oscillating arm on the break-up of the stream was limited to a similar area.

At distances greater than twenty feet from the nozzle, drop sizes were significantly different at the different pressures. For the 5/32-inch nozzle (Figure 11), a pressure increase from thirty to thirty-five pounds per square inch caused a reduction in drop size. Drop size reduction was greater as the distance from the nozzle increased. For the 3/16-inch nozzle (Figure 12), a pressure increase from thirty-five to forty pounds per square inch caused an increase in drop size. The difference in drop sizes was greatest at the points farthest from the sprinkler.

The change in drop size caused by an increase in nozzle size from 5/32- to 3/16-inch diameter at thirty-five pounds per square inch is shown in Figure 13. The larger

FIGURE 11

EFFECT OF PRESSURE ON MEDIAN DROP MASS
5/32-inch diameter nozzle

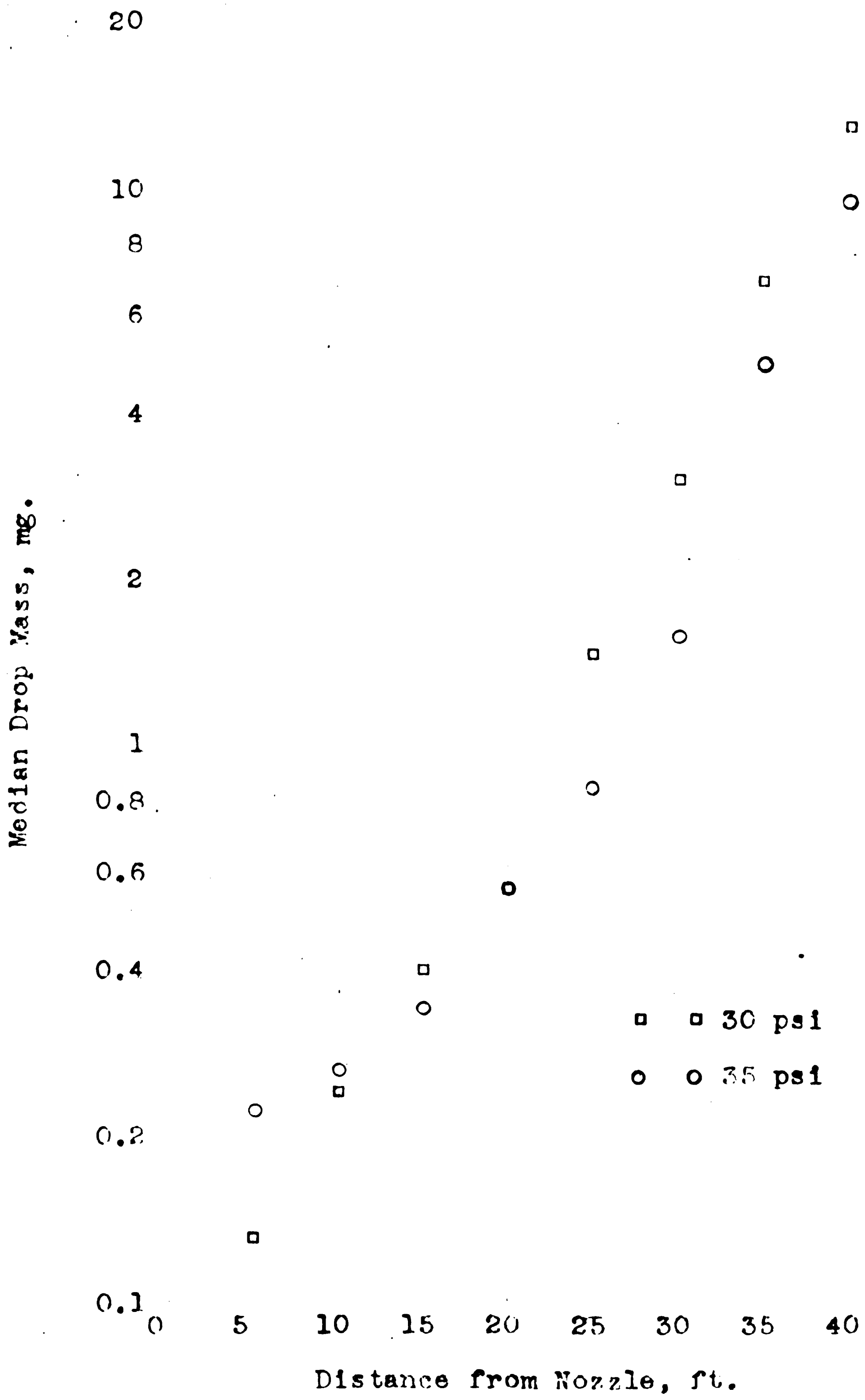


FIGURE 12

EFFECT OF PRESSURE ON MEDIAN DROP MASS
3/16-inch diameter nozzle

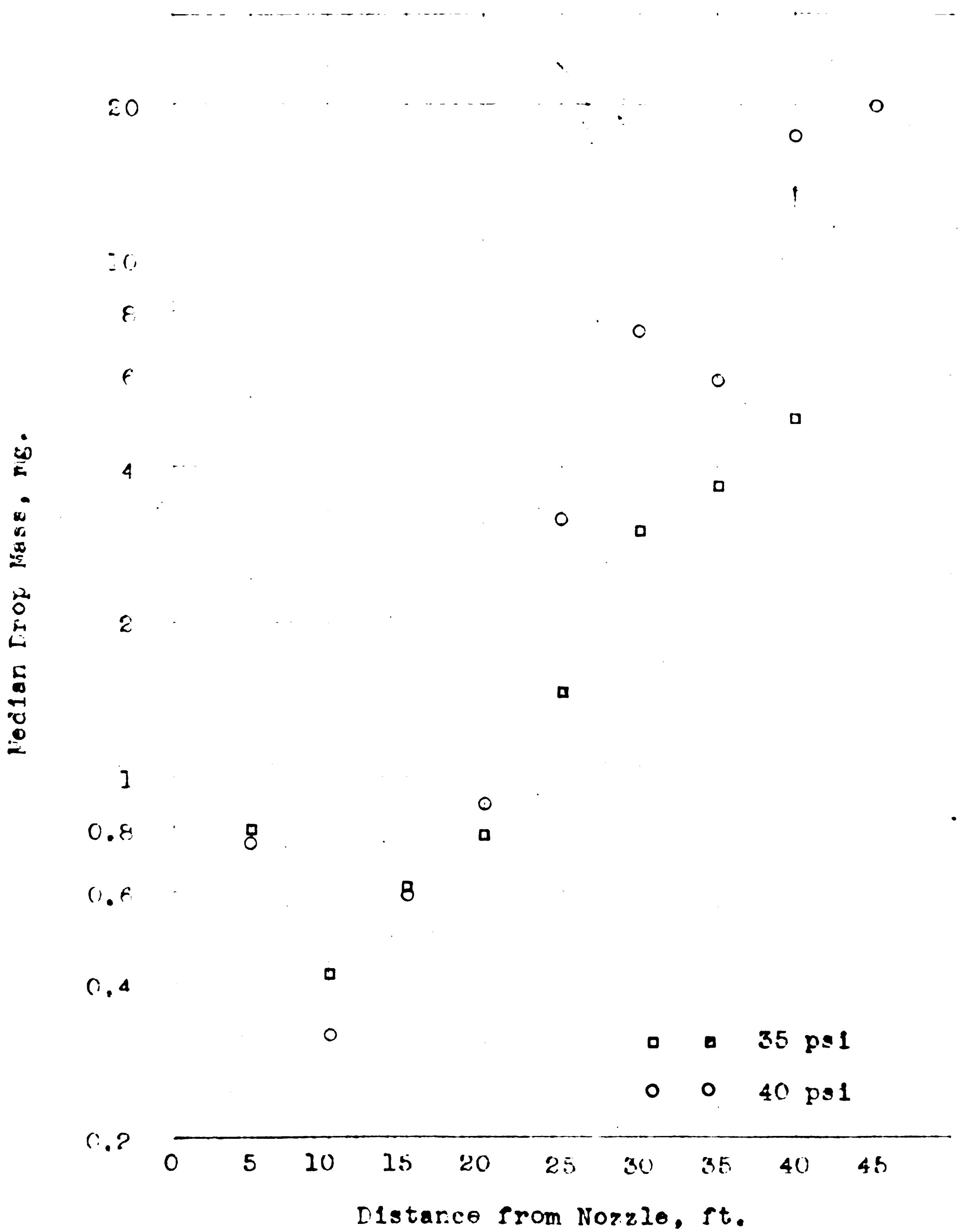
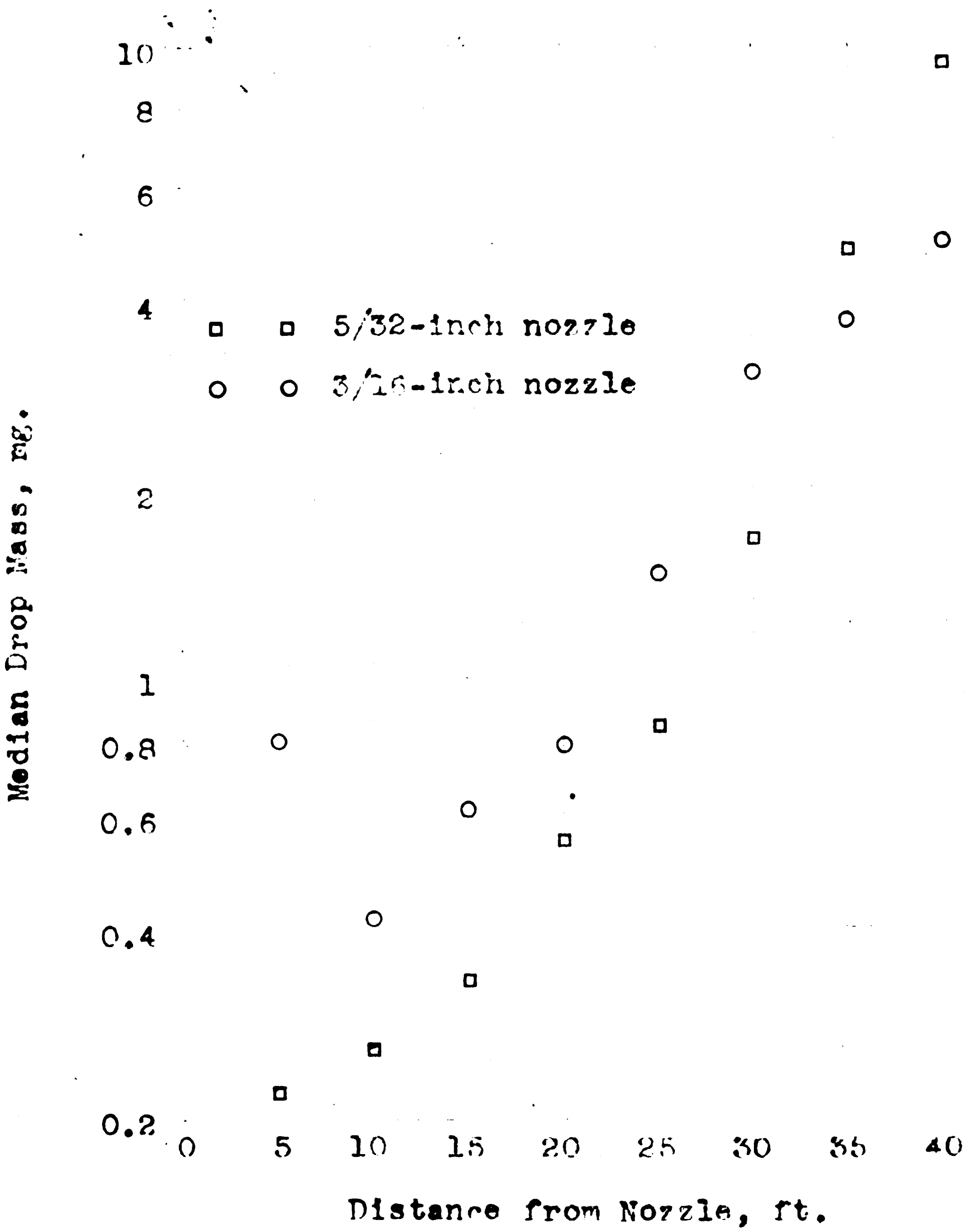


FIGURE 13

EFFECT OF NOZZLE SIZE
ON MEDIAN DROP MASS
35 psi



nozzle produced larger drops in the area within approximately thirty feet of the nozzle. In the area farther than thirty-five feet from the nozzle, larger drop sizes were obtained from the smaller nozzle.

Energy of Drops Striking Target

The relationship between the logarithm of the energy received at the target and the distance from the nozzle is approximately linear (Figures 14, 15, and 16). The amount of energy received increased rapidly as the distance from the nozzle increased.

The energy at points within twenty-five feet of the nozzle could not be obtained with the transducer used in this experiment. The sensitivity was not great enough to permit analysis of the oscillograph records for those points.

The largest amounts of energy received by the target were imparted by drops from the 5/32-inch nozzle operating at thirty pounds per square inch (Figure 14). A reduction in energy received at pounts farther than twenty-five feet from the sprinkler was obtained by increasing the pressure to thirty-five pounds per square inch.

A further reduction in energy occurred at thirty-five pounds per square inch by increasing the nozzle size from 5/32-inch to 3/16-inch diameter (Figure 15). Such reductions became negligible at forty feet from the sprinkler. At points greater than thirty feet from the sprinkler greater

FIGURE 14

EFFECT OF NOZZLE PRESSURE
ON ENERGY OF DROPS
5/32-inch diameter nozzle

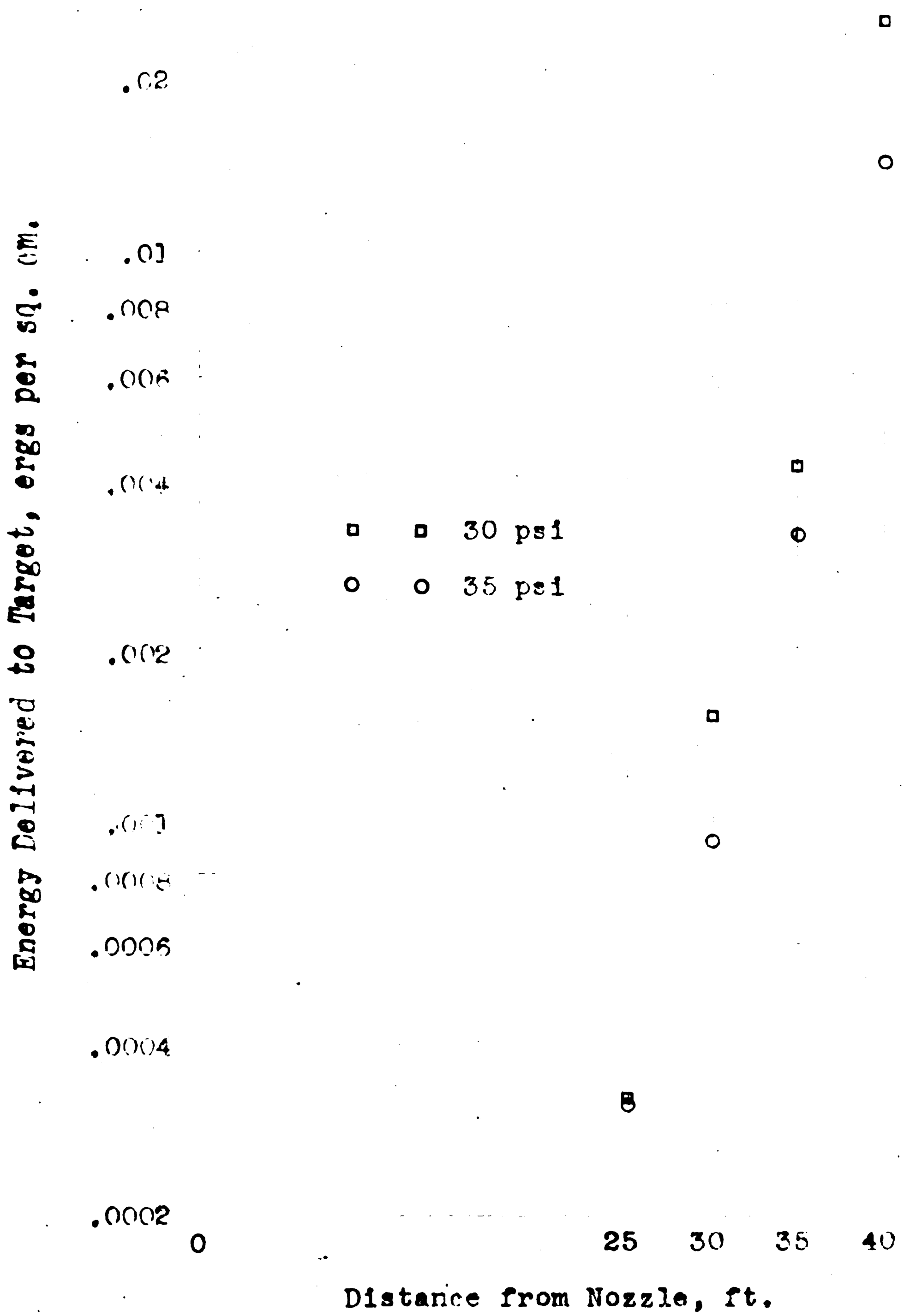


FIGURE 15

EFFECT OF NOZZLE SIZE ON
ENERGY OF DROPS
35 psi

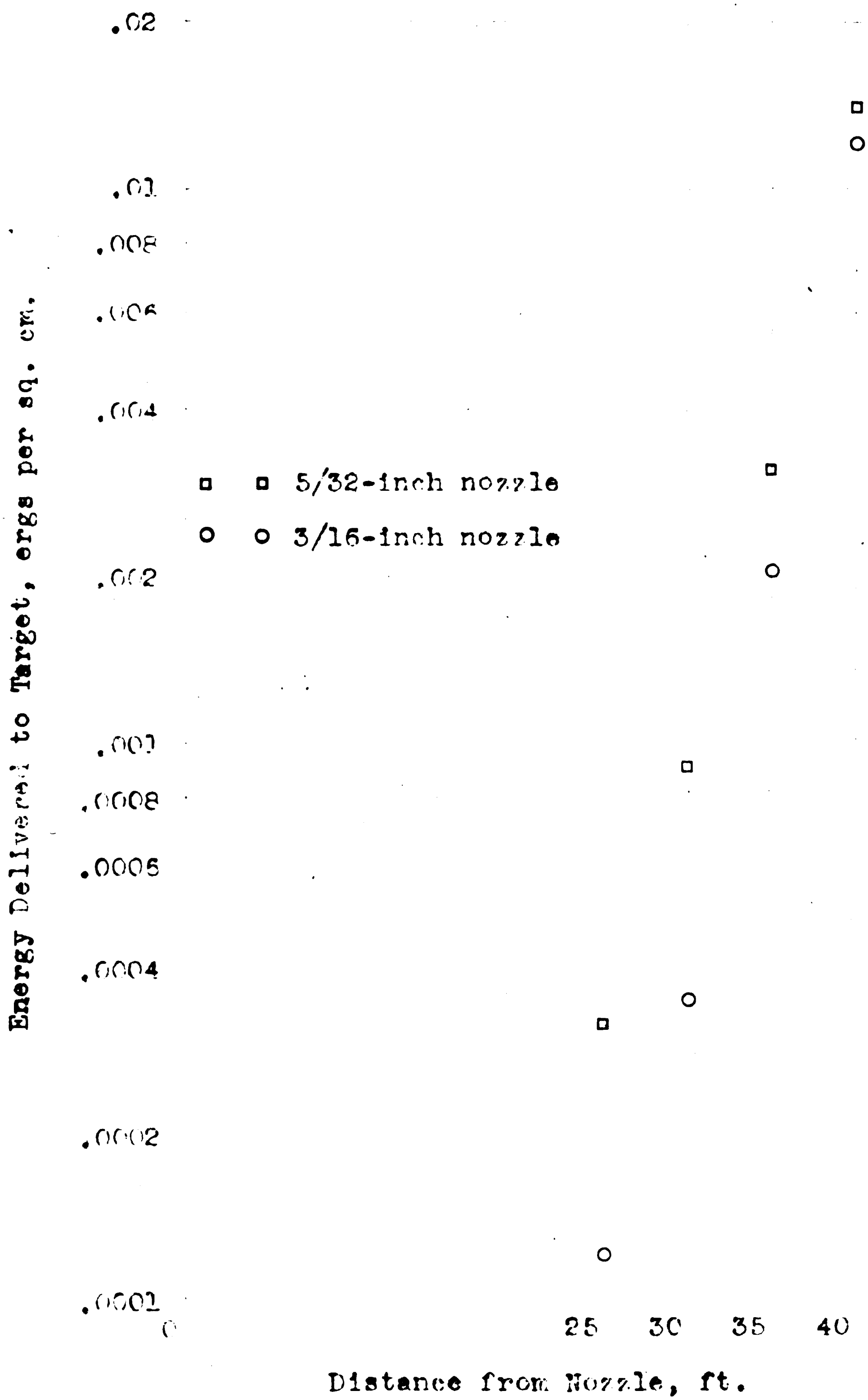
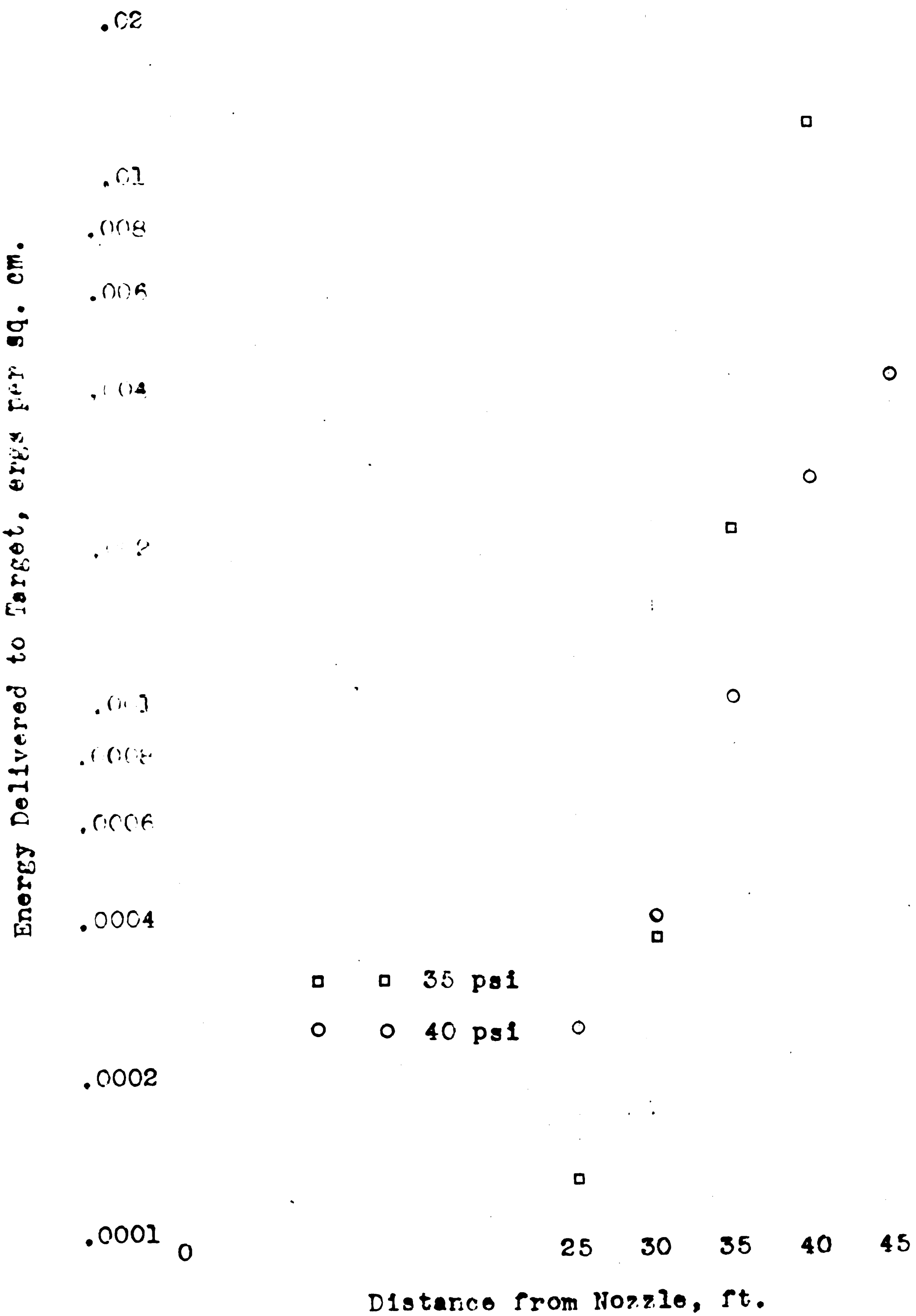


FIGURE 16

EFFECT OF NOZZLE PRESSURE
ON ENERGY OF DROPS
3/16-inch diameter nozzle



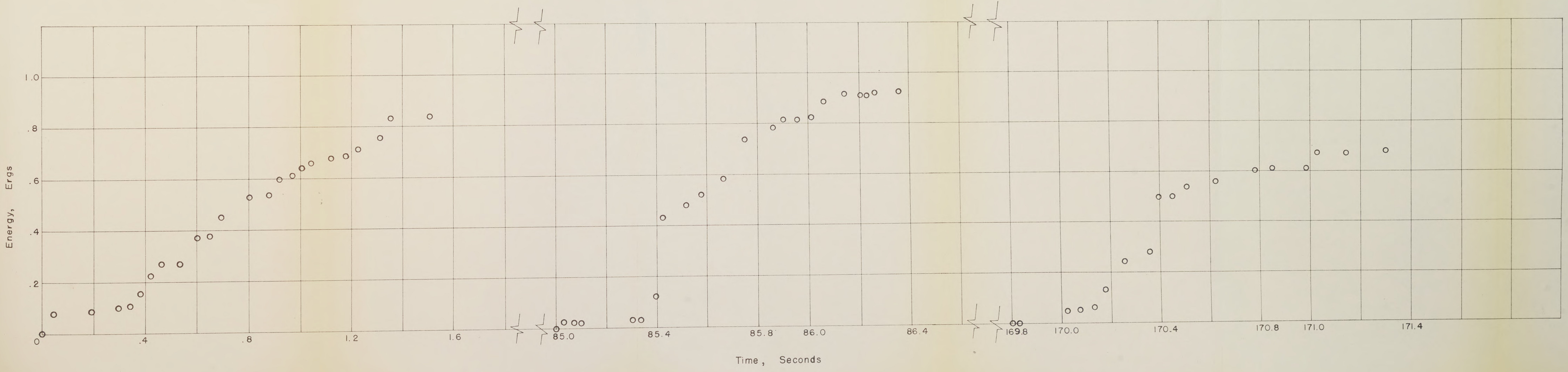
energy reductions were obtained by increasing the nozzle size to 3/16-inch and by increasing the pressure to forty pounds per square inch (Figure 16).

Consequently, the least destructive action to the soil would occur by the use of a 3/16-inch diameter nozzle operating at forty pounds per square inch. The use of the other three combinations of nozzle size and pressure resulted in greater energy imparted to the target.

The amount of energy measured at forty-five feet from the 3/16-inch nozzle operating at forty pounds per square inch did not follow the relationship exhibited by the other points. The character of the water distribution at this point was extremely irregular. Sometimes very few drops reached that distance and at other times a sizeable quantity of water struck the target. When the single trial resulting in the largest amount of energy measured (Appendix F) was plotted, the linear relationship was maintained.

Cumulative energy is plotted against time in Figure 17. Energy was delivered to the target during one to three and one half per cent of the total time. The changing slope of the curves indicates that the delivery of energy to the target was not uniform during the short interval the drops struck the target. Portions of the curves have a flat slope showing that during some time intervals, little or no energy was imparted to the target. During other time intervals the curves have a greater slope, indicating a rapid delivery of

FIGURE 17
MASSED ENERGY CURVE
35 ft. from 3/16 - inch nozzle
operating at 35 psi



energy. The maximum rate of change of energy observed in this investigation was forty-seven ergs per second. This extreme value was measured forty feet from the 5/32-inch nozzle operating at thirty pounds per square inch.

Energy Imparted by Drops Compared with the Energy Required to Move Sand from a Target

The energy imparted to the target under the conditions reported herein was much less than the energy required to move sand from a target area. An initial energy unit of five thousand ergs per square centimeter was required to move fine sand. (26) However, only about 2 per cent of the total energy possessed by the drops was imparted to splashed sand (27). An initial energy unit of one hundred ergs per square centimeter must be imparted to the sand for it to be moved from the target. Drops from the 5/32-inch nozzle operating at thirty pounds per square inch imparted about one fortieth of an erg of energy per square centimeter to the target placed forty feet from the nozzle. Assuming that all the energy imparted to the target would be exerted to splash sand from the target area, four thousand revolutions of the sprinkler would be necessary to provide the initial energy unit of one hundred ergs. With the sprinkler requiring about seven minutes to complete one revolution, it is not likely that sufficient energy would be received at the target area to move fine sand during an irrigation.

Water Application Rates

Water application rates have been determined for sprinklers by using catchment cans and by averaging the total fall out of water over the total period of time the sprinkler was operated (6, 14, 71). Similar calculations were used to obtain the data in columns three and five in Table IX.

The true water application rate is shown in the even-numbered columns of Table IX. True application rates were obtained by averaging the total fall out of water over the time interval during which it fell on a particular target area. The true application rates were thirty to ninety times greater than the conventionally calculated application rates.

An increase of operating pressure from thirty to thirty-five pounds per square inch on the 5/32-inch nozzle caused lower application rates at points beyond thirty feet from the nozzle. At thirty-five pounds per square inch an increase in nozzle size from 5/32- to 3/16-inch diameter caused an increase in the application rates at the points tested. An increase of operating pressure from thirty-five to forty pounds per square inch on the 3/16-inch nozzle caused a reduction in application rates at points greater than twenty-five feet from the sprinkler.

The increment of pressure increase recommended by the manufacturer (33) as the difference between undesirable and desirable operation on bare soils was effective in reducing

TABLE IX

WATER APPLICATION RATES
(Inches per hour)

5/32-inch diameter nozzle

Distance from Nozzle, ft.	Averaged over Application Time	Averaged over Total Time	Averaged over Application Time	Averaged over Total Time
	30 psi		35 psi	
25	0.5	0.01	1.9	0.04
30	1.9	0.05	2.4	0.05
35	4.0	0.06	2.2	0.05
40	5.4	0.11	4.6	0.07

3/16-inch diameter nozzle

	35 psi		40 psi	
25	2.1	0.04	3.4	0.10
30	3.6	0.05	3.5	0.12
35	4.8	0.06	3.7	0.11
40	7.5	0.08	6.8	0.13
45			0.86	0.08

the highest application rates occurring in the area farther than thirty feet from the nozzle. Such reductions tended to make the application rates more uniform along a radius emanating from the sprinkler.

The calculation of true application rates included a possible error of as much as 30 per cent. Nevertheless, a clearer understanding of the phenomena of water application by rotating sprinklers and their effect upon the soil may be obtained by calculating water application rates on the basis of actual time of application.

CONCLUSIONS

The following conclusions may be drawn from the data reported herein:

1. The spectrum of drop sizes received at points spaced along a radius emanating from a small irrigation sprinkler may be expressed as a single number that represents that particular spectrum. Such a number was called "median drop mass."

2. The logarithm of the median drop mass varied linearly with distance from the nozzle. Median drop mass increased rapidly with greater distance from the nozzle. An increase in pressure of five pounds per square inch had little effect on the size of drops falling within approximately twenty feet of the nozzle. Changes in drop size caused by a change in nozzle pressure increased with distance from the nozzle.

3. The logarithm of the energy imparted by drops from a sprinkler striking a target near the ground varied linearly with distance from the nozzle. The energy increased rapidly with greater distance from the nozzle. Greatest amounts of energy were received from the drop spectrum from a 5/32-inch diameter nozzle operating at thirty pounds per square inch. Some reduction in energy was obtained by increasing the pressure to thirty-five pounds per square inch. A reduction in energy occurred at thirty-five pounds per square inch by increasing the nozzle size from 5/32-inch to 3/16-inch diameter.

Additional reduction in energy was obtained by increasing the pressure at the 3/16-inch nozzle to forty pounds per square inch.

4. Energy was delivered to the target during one to three and one half per cent of the total time.

5. Assuming that all of the energy imparted to the target was exerted to splash sand from the target area, fine sand (26) would not be splashed from the target area during an irrigation.

6. True application rates based upon the actual time of water application were as high as 7.5 inches per hour and ranged from thirty to ninety times as great as the application rates based upon total elapsed time. The increment of pressure increase recommended by the manufacturer as the difference between undesirable and desirable operation on bare soils was effective in reducing the highest application rates occurring in the area farther than thirty feet from the nozzle.

RECOMMENDATIONS

1. Detailed studies of the energy imparted by drops from irrigation sprinklers should be continued. The transducer used to obtain the data reported herein was capable of sensing eighty milligrams per line on the oscillograph (2.31 x 10^{-5} centimeters of deflection of the beam per line on the oscillograph and 350 milligrams required for one micron of beam deflection). Further studies of medium pressure sprinklers will require an element capable of sensing two milligrams per line on the oscillograph. The system should include automatic adjustments for changes in inertia load on the target.

2. Similar equipment should be used to determine true water application rates of irrigation sprinklers.

3. Energy patterns similar to those reported herein should be applied to typical irrigated soils to measure changes in soil condition caused by that application of energy. Evaluation of the changes caused by the energy application will:

a. Assist the sprinkler manufacturer to make necessary changes in nozzle design to meet prevailing soil conditions;

b. Permit irrigation system designers to be more readily able to select the proper combination of nozzle size and operating pressure to minimize harmful structural changes in the soil caused by excessive quantities of energy applied to the soil; and

c. Permit irrigators to use properly designed and selected equipment without severe damage to soil physical characteristics.

B I B L I O G R A P H Y

LITERATURE CITED

(1) Affleck, C., "Application of the Theory of Probability to the Size Distribution of Soil Aggregates," Soil Science, 38:113-119, 1934.

(2) Anderson, Lloyd J., "Drop-Size Distribution Measurements in Orographic Rain," Bulletin American Meteorological Society, 29:362-366, 1948.

(3) Baver, L. D., "Ewald Wollny, a Pioneer in Soil and Water Conservation Research," Soil Science Society of America Proceedings, 3:330-333, 1939.

(4) Bennett, H. H., Forrest G. Bell, and Bert D. Robinson, Raindrops and Erosion. United States Department of Agriculture Circular No. 895, 1951. 23 pp.

(5) Bentley, W. A., "Studies in Raindrops and Raindrop Phenomena," Monthly Weather Review, 32:450-456, October, 1904.

(6) Bilanski, Walter K., "Factors that Affect Distribution of Water from a Medium Pressure Rotary Irrigation Sprinkler." Unpublished Doctor's dissertation, Michigan State University, East Lansing, 1956.

(7) Blanchard, D. C., "Observations on the Behavior of Water Drops," General Electric Research Lab Report No. 7 Project Cirrus, 1948.

(8) Blanchard, D. C., "The Use of Sooted Screens for Determining Raindrop Size and Distribution," General Electric Company Occasional Report No. 16 Project Cirrus, 1949. 11 pp. Cited by Boucher, Roland J., "Results of Measurements of Raindrop Size," Illinois State Water Survey Bulletin 41, Conference on Water Resources, pp. 293-297, 1951.

(9) Blanchard, Duncan C., "The Behavior of Water Drops at Terminal Velocity in Air," Transactions American Geophysical Union, 31:836-842, December 1950.

(10) Boucher, Roland J., "Results of Measurements of Raindrop Size," Illinois State Water Survey Bulletin 41, Conference on Water Resources, pp. 293-297, 1951.

(11) Bureau of Reclamation, Sprinkler Irrigation. United States Department of the Interior, Washington, Revised December 1949, 61 pp.

(12) Carnes, A., "Soil Crusts," Agricultural Engineering, 15:167, 1934.

(13) Chapman, Gordon, "Size of Raindrops and Their Striking Force at the Soil Surface in a Red Pine Plantation," Transactions American Geophysical Union, 29:664, October 1948.

(14) Christiansen, J. E., Irrigation by Sprinkling. University of California Agricultural Experiment Station, Berkeley, Bulletin 670, October 1942. 124 pp.

(15) Cooper, B. F., "A Balloon-Borne Instrument for Telemetering Raindrop-Size Distribution and Rainwater Content of Cloud," Australian Journal of Applied Science, 2:43-55, 1951.

(16) Cunningham, Robert M., "Airborne Raindrop Size Measurement and Instrumental Techniques," Illinois State Water Survey Bulletin 41, Conference on Water Resources, pp. 285-291, 1951.

(17) Davis, J. M., A Photographic Method for Recording Size of Spray Drops. United States Department of Agriculture, Agricultural Research Administration, Bureau of Entomology and Plant Quarantine, Washington, ET-272, July, 1949. 7 pp.

(18) Davis, J. M., A Vibratory Apparatus for Producing Drops of Uniform Size. United States Department of Agriculture, Agricultural Research Administration, Bureau of Entomology and Plant Quarantine, Washington, ET-295, April, 1951. 3 pp.

(19) Day, P. R., and G. G. Holmgren, "Microscopic Changes in Soil Structure During Compression," Soil Science Society of America Proceedings, 16:73-77, 1952.

(20) Defant, Albert, "Gesetzmaessigkeiten in der Verteilung der verschiedenen Tropfengroessen bei Regenfaellen," Sitzungsberichte der Mathematisch-Naturwissenschaftlichen Klasse der Kaiserlichen Akademie der Wissenschaften, CXIV Band, Abteilung IIa, 585-646, February 16, 1905, cited by Laws and Parsons, "Relation of Raindrop Size to Intensity," Transactions American Geophysical Union, 24:452-460, 1943.

(21) Duley, F. L., "Surface Factors Affecting the Rate of Intake of Water by Soils," Soil Science Society of America Proceedings, 4:60, 1940.

(22) Duley, F. L., and L. L. Kelly, Effect of Soil Type, Slope and Surface Conditions on Intake of Water. University of Nebraska Agricultural Experiment Station, Lincoln, Nebraska, Research Bulletin 112, May 1939. 16 pp.

(23) Duley, F. L., and L. L. Kelly, Surface Condition of Soil and Time of Application as Related to Intake of Water. United States Department of Agriculture Circular No. 608, 1941. 30 pp.

(24) Edgerton, H. E., F. A. Hauser, and W. B. Tucker, "Studies in Drop Formation as Revealed by High Speed Motion Camera," Journal of Physical Chemistry, 41:1017, 1937.

(25) Edwards, C. J. and W. E. Ripper, Droplet Size Rates of Application and the Avoidance of Spray Drift. Reprinted from the Proceedings of the British Weed Control Conference, 1953.

(26) Ekern, Paul C., "Raindrop Impact as the Force Initiating Soil Erosion," Soil Science Society of America Proceedings, 15:7-10, 1951.

(27) Ekern, Paul C., and R. j. Muckenhirn, "Water Drop Impact as a Force in Transporting Sand," Soil Science Society of America Proceedings, 12:441-444, 1948.

(28) Ellison, W. D., "Some Effects of Rain Drops and Surface-Surface-Flow on Soil Erosion and Indiltration," Transactions American Geophysical Union, 26:415, 1945.

(29) Ellison, W. D., "Soil Erosion Studies Parts I-VII," Agricultural Engineering, 28:145, 197, 245 297, 349, 402, 442, 1947.

(30) Ellison, W. D., and C. S. Slater, "Factors that Affect Surface Sealing and Infiltration of Exposed Soil Surfaces," Agricultural Engineering, 26:156-162, 1945.

(31) Evans, P. W., "Theory of Probability and Size Distribution of Soil Aggregates," Soil Science, 72:245, 1951.

(32) Free, George R., "Soil Movement by Raindrops," Agricultural Engineering, 33:491, 1952.

(33) Gray, Alfred S., Sprinkler Irrigation Handbook. Edited by Crawford Reid. Fifth Edition; Glendora California: Rain Bird Sprinkler Manufacturing Corporation, 1952. 40 pp.

(34) Green, Robert L., "A Photographic Technique for Measuring the Sizes and Velocities of Water Drops from Irrigation Sprinklers," Agricultural Engineering, 33:563, 1952.

(35) Gunn, Ross, and Gilbert D. Kinzer "The Terminal Velocity of Fall for Water Droplets in Stagnant Air," Journal of Meteorology, 6:243-248, 1949.

(36) Harkins, W. D., and F. E. Brown, "Determination of Surface Tension (Free Surface Energy) and the Weight of Falling Drops," Journal of the American Chemical Society, 41:499-524, 1919.

(37) Hendrickson, B. H., "The Choking of Pore Space in the Soil and Its Relation to Runoff and Erosion," Transactions American Geophysical Union, 15:500-505, 1934.

(38) Hodgman, Charles D., editor in chief, Handbook of Chemistry and Physics. Thirty-fourth edition; Cleveland, Ohio: Chemical Rubber Publishing Company, 1952. 2950 pp.

(39) Hogan, T. W., "The Ground Recovery and Drop Spectra of Sprays Dispersed from Two Types of Aircraft," Australian Journal of Agricultural Research, 2:302-321, 1951.

(40) Horton, R. E., "Statistical Distribution of Drop Sizes and the Occurrence of Dominant Drop Sizes in Rain," Transactions American Geophysical Union, 29:624-630, 1948.

(41) Katz, Isadore, "A Momentum Disdrometer for Measuring Raindrop Size from Aircraft," Bulletin American Meteorological Society, 33:365-368, 1952.

(42) Landsberg, H., and H. Neuberger, "On the Frequency Distribution of Drop Sizes in a Sleet Storm," Bulletin American Meteorological Society, 19:354-366, 1938.

(43) Laws, J. O., "Recent Studies in Raindrops and Erosion," Agricultural Engineering, 21:431, 1940.

(44) Laws, J. Otis, Measurements of the Fall-Velocities of Water-Drops and Raindrops. United States Department of Agriculture, Soil Conservation Service, Washington, SCS-TP-45, November, 1941. 33 pp. Also appears in Transactions American Geophysical Union, 22:709-721, 1941.

(45) Laws, J. Otis, and Donald A. Parsons, "The Relation of Raindrop-Size to Intensity," Transactions American Geophysical Union, 24:452-460, 1943.

(46) Lenard, P., "Ueber Regen," Meteorologische Zeitschrift, 21:248-262, June 1904.

(47) Levine, Gilbert, "Effects of Irrigation Droplet Size in Infiltration and Aggregate Breakdown," Agricultural Engineering, 33:559, 1952.

(48) Lowdermilk, W. C., "Influences of Forest Litter on Runoff, Percolation and Erosion," Journal of Forestry, 28:474, 1930.

(49) McCalla, T. M., "Influence of Biological Products on Soil Structure and Infiltration," Soil Science Society of America Proceedings, 7:209-214, 1942.

(50) McCalla, T. M., "Water-Drop Method of Determining Stability of Soil Structure," Soil Science, 58:117-121, 1944.

(51) Mech, S. J., and G. R. Free, "Movement of Soil During Tillage Operations," Agricultural Engineering, 23:379, 1942.

(52) "Mighty Raindrop," Farm Quarterly, 4 No. 4:72, 1950.

(53) Musgrave, G. W., "The Infiltration Capacity of Soils in Relation to the Control of Surface Run-off and Erosion," Journal of American Society of Agronomy, 27:336, 1935.

(54) Musgrave, G. W., "The Quantitative Evaluation of Factors in Water Erosion -- a First Approximation," Journal of Soil and Water Conservation, 2:133, 1947.

(55) Neal, J. H., The Effect of the Degree of Slope and Rainfall Characteristics on Run-off and Soil Erosion. University of Missouri Agricultural Experiment Station, Columbia, Missouri, Research Bulletin 280, 1938.

(56) Neal, J. H., and L. D. Baver, "Measuring the Impact of Raindrops," Journal of American Society of Agronomy, 29:708, 1937.

(57) Nelson, W. R., and L. D. Baver, "Movement of Water through Soils in Relation to the Nature of the Pores," Soil Science Society of America Proceedings, 5:69, 1940.

(58) Neuberger, Hans, "Notes on Measurement of Raindrop Sizes," Bulletin American Meteorological Society, 23:274, 1942.

(59) Niederdorfer, E., "Messungen der Groesse der Regentropfen," Meteorologische Zeitschrift, 49:1-14, 1932, cited by Laws and Parsons, "The Relation of Raindrop-Size to Intensity," Transactions American Geophysical Union, 24:452-460, 1943.

(60) Perry, C. C., and H. R. Lissner, The Strain Gage Primer. New York: McGraw-Hill Book Company, Inc., 1955. 281 pp.

(61) Schmidt, W., "Eine unmittelbare Bestimmung der Fallgeschwindigkeit von Regentropfen," Sitzungsberichte der Mathematisch-Naturwissenschaftlichen Klasse der Kaiserlichen Akademie der Wissenschaften, CXVIII Band Abteilung IIa, Wien,

1909, cited by Laws, J. Otis, Measurements of the Fall-Velocities of Water-Drops and Raindrops. United States Department of Agriculture, Soil Conservation Service, Washington, SCS-TP-45, November, 1941.

(62) Smith, L. G., "New Method to Measure Raindrop Size," Illinois State Water Survey Bulletin 41, Conference on Water Resources, p. 299, 1951.

(63) Smith, L. G., "The Electric Charge of Raindrops," Quarterly Journal of the Royal Meteorological Society, 81:23-47, 1955.

(64) Snedecor, George W., Statistical Methods Applied to Experiments in Agriculture and Biology. Fifth Edition; Ames, Iowa: Iowa State College Press, 1956. 534pp.

(65) Spilhaus, A. F., "Raindrop Size, Shape and Falling Speed," Journal of Meteorology, 5:109, 1948.

(66) Stanton, T. E., and J. R. Pannell, "Similarity of Motion in Relation to the Surface Friction of Fluids," Transactions Royal Society (London), A214, 1914.

(67) Strong, Winston C., Agricultural Sprinkler Irrigation Manual. John B. Gill, editor; First edition; Fresno, California: Buckner Manufacturing Company, Inc., 1955. 31 pp.

(68) Taylor, E. H. and D. B. Harmon, Jr., "Measuring Drop Sizes in Sprays," Industrial and Engineering Chemistry, 46:1455-1457, July, 1954.

(69) Telford, J. W., N. S. Thorndike, and E. G. Bowen, "The Coalescence Between Small Water Drops," Quarterly Journal of the Royal Meteorological Society, 51:241-250, 1955.

(70) Van Bavel, C. H. M., "Mean Weight-Diameter of a Soil Aggregate as a Statistical Index of Aggregation," Soil Science Society of America Proceedings, 14:20, 1949.

(71) Wiersma, John L., Effect of Wind Variation on Water Distribution from Rotating Sprinklers. South Dakota State College Agricultural Experiment Station, Brookings, Technical Bulletin No. 16, May 1955. 18 pp.

(72) Wiesner, J., "Bietraege zur Kenntniss des tropischen Regens," Sitzungsberichte der Mathematisch-Naturwissenschaftlichen Klasse der Kaiserlichen Akademie der Wissenschaften, 104: 1397-1434, 1895.

(73) Wollny, E., "Untersuchungen uber den Einfluss der Pflanzendecke und der Beschattung auf die physikalischen Eigenschaften des Bodens," Forsch. Geb. Agri-Phys., 10:261-344, 1887,

cited by Baver, "Ewald Wollny, A Pioneer in Soil and Water Conservation Research," Soil Science Society of America Proceedings, 3:330-333, 1939.

(74) Wollny, E., "Untersuchungen uber den Einfluss der Pflanzendecke und der Beschattung auf die physikalischen Eigenschaften des Bodens," Forsch. Geb. Agri-Phys., 12:1-75, 1889, cited by Baver, "Ewald Wollny, A Pioneer in Soil and Water Conservation Research," Soil Science Society of America Proceedings, 3:330-333, 1939.

(75) Worthington, A. M., "The Splash of a Drop and Allied Phenomena," Annual Report of Board of Regents of Smithsonian Institute, 197, 1894.

(76) Yates, Wesley E., "An Analysis of Atomization by the Rotating Disk for Controlled Droplet Size." Unpublished Master's thesis, The University of California, Davis, 1951.

ADDITIONAL REFERENCES

Atlas, David, and Shepard Bartnoff, "Cloud Visibility, Radar Reflectivity, and Drop-Size Distribution," Journal of Meteorology, 10:143-148, 1953.

Atlas, David, and Vernon G. Plank, "Drop-Size History During a Shower," Journal of Meteorology, 10:291-295, 1953.

Best, A. C., "The Size Distribution of Raindrops," Quarterly Journal of the Royal Meteorological Society, 76:16, 1950.

Best, A. C., "Emperical Formulae for the Terminal Velocity of Waterdrops Falling Through the Atmosphere," Quarterly Journal of the Royal Meterological Society, 76:302, 1950.

Blanchard, D. C., "A Simple Recording Technique for Determining Raindrop Size and Time of Occurrence of Rain Shows," Transactions American Geophysical Union, 34:534, 538, 1953.

Bodman, G. B., and J. Rubin, "Soil Puddling," Soil Science Society of America Proceedings, 13:27, 1949.

Bowen, E. C., and K. A. Davidson, "A Raindrop Spectograph," Quarterly Journal of the Royal Meteorological Society, 77:445, 1951.

Gumbel, E. J., "On the Frequency Distribution of Extreme Values in Meteorological Data," Bulletin American Meteorological Society, 23:95-105, 1942.

Gunn, Ross, and Charles Devin, Jr., "Raindrop Charge and Electric Field in Active Thunderstorms," Journal of Meteorology, 10:279-284, 1953.

McDonald, James E., "The Shape and Aerodynamics of Large Raindrops," Journal of Meteorology, 11:478-494, 1954.

Magono, Choji, "On the Shape of Water Drops Falling in Stagnant Air," Journal of Meteorology, 11:77-79, 1954.

Marshall, J. S., and W. McK. Palmer, "The Distribution of Raindrops with Size," Journal of Meteorology, 5:165-166, 1948.

Osborn, Ben, "Soil Splash by Raindrop Impact on Bare Soils," Journal of Soil and Water Conservation, 9:33-38, 43, 49, January 1954.

Osborn, Ben, "Effectiveness of Cover in Reducing Soil Splash by Raindrop Impact," Journal of Soil and Water Conservation, 9:70-76, March 1954.

Russell, E. W., and R. V. Tamhane, "The Determination of the Size Distribution of Soil Clods and Crumbs," Journal of Agricultural Science, 30:210-234, 1940.

Shanks, G. L., and J. J. Paterson, "Technique for Spray Nozzle Testing," Agricultural Engineering, 29:539, 1948.

Spilhaus, Athelstan F., "Drop Size, Intensity, and Radar Echo of Rain," Journal of Meteorology, 5:161-164, 1948.

Wilcox, J. C., and J. M. McDougald, "Water Distribution Patterns from Rotary Sprinklers," Canadian Journal of Science, 35:217-228, 1955.

A P P E N D I X E S

APPENDIX A

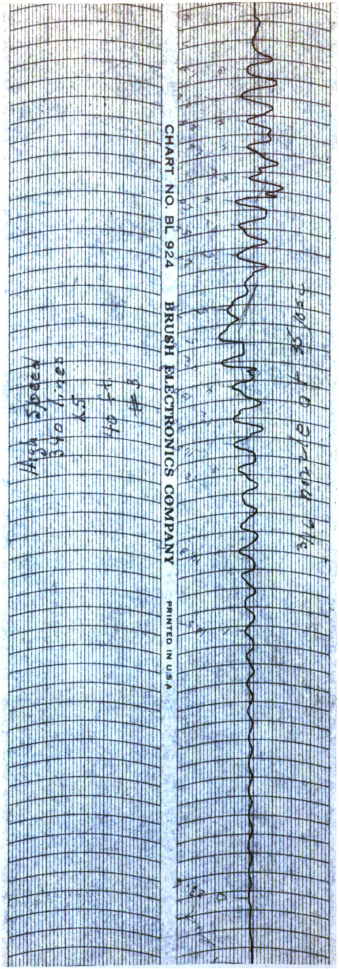
WEIGHT PER PELLET FOR DENTAL PLASTER
(For 3/16-inch nozzle at 35 and 40 psi)

Screen Opening, microns	Total Wt. of Pellets Retained, gm.	Total No. Pellets Retained	Weight per Pellet Retained, mg.
420	13.480	152,655	0.088,304
589	15.500	47,371	0.327,204
833	29.600	39.782	0.744,055
1,168	29.020	13,979	2.075,971
1,651	22.720	5,473	4.151,288
1,981	13.775	1,756	7.844,533
2,362	17.755	1,444	12.295,706
2,830	14.760	684	21.578,947
3,360	10.170	373	27.265,416
4,000	9.555	196	48.750,000
4,699	6.045	64	94.453,125

APPENDIX B

WEIGHT PER PELLET FOR FLOUR
(For 5/32-inch nozzle at 30 and 35 psi)

Screen Opening, microns	Total Wt. of Pellets Retained, gm.	Total No. Pellets Retained	Weight per Pellet Retained, mg.
420	16.836	160,344	0.104,999
589	26.365	138,764	0.189,999
840	44.245	85,155	0.519,582
1,168	9.934	7,945	1.250,346
1,397	26.757	12,861	2.080,476
1,900	19.081	2,867	6.655,389
2,362	12.899	941	12.707,758
2,830	14.838	750	19.784,000
3,360	11.408	329	34.674,772
4,000	6.115	105	58.238,095
4,699	4.332	46	94.173,913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APPENDIX D

ENERGY LOSS PER CYCLE DURING DAMPING

$$\Delta E/E = 0.722 - 0.009{,}7\ B \pm 0.030$$

B	$\Delta E/E$	B	$\Delta E/E$
$\frac{1}{2}$	0.717	$10\frac{1}{2}$	0.620
1	0.712	11	0.615
$1\frac{1}{2}$	0.707	$11\frac{1}{2}$	0.610
2	0.703	12	0.606
$2\frac{1}{2}$	0.698	$12\frac{1}{2}$	0.601
3	0.693	13	0.596
$3\frac{1}{2}$	0.688	$13\frac{1}{2}$	0.591
4	0.683	14	0.586
$4\frac{1}{2}$	0.678	$14\frac{1}{2}$	0.581
5	0.674	15	0.576
$5\frac{1}{2}$	0.669	$15\frac{1}{2}$	0.572
6	0.664	16	0.567
$6\frac{1}{2}$	0.659	$16\frac{1}{2}$	0.562
7	0.654	17	0.557
$7\frac{1}{2}$	0.649	$17\frac{1}{2}$	0.552
8	0.644	18	0.547
$8\frac{1}{2}$	0.640	$18\frac{1}{2}$	0.543
9	0.635	19	0.538
$9\frac{1}{2}$	0.630	$19\frac{1}{2}$	0.533
10	0.625	20	0.528

APPENDIX E

EQUATIONS FOR CALCULATING MEDIAN DROP MASS

Distance from Nozzle, ft.	5/32-inch nozzle 30 psi	5/32-inch nozzle 35 psi
5	$y = 0.5096x - 40.23 \pm 5.65$	$y = 0.4404x - 25.10 \pm 4.61$
10	$y = 0.5265x - 32.59 \pm 4.82$	$y = 0.5341x - 32.08 \pm 3.44$
15	$y = 0.5637x - 28.71 \pm 4.80$	$y = 0.4791x - 22.53 \pm 5.12$
20	$y = 0.6378x - 30.91 \pm 4.71$	$y = 0.5728x - 24.63 \pm 5.31$
25	$y = 0.7127x - 23.71 \pm 5.72$	$y = 0.5686x - 17.70 \pm 5.02$
30	$y = 0.7546x - 17.02 \pm 6.97$	$y = 0.6752x - 17.64 \pm 4.77$
35	$y = 1.2433x - 52.95 \pm 8.97$	$y = 0.9158x - 25.76 \pm 8.23$
40	$y = 1.5006x - 69.43 \pm 14.81$	$y = 1.0192x - 25.92 \pm 12.23$

Distance from Nozzle, ft.	3/16-inch nozzle 35 psi	3/16-inch nozzle 40 psi
5	$y = 1.2343x - 82.44 \pm 3.10$	$y = 1.2367x - 84.03 \pm 2.11$
10	$y = 0.7154x - 40.87 \pm 3.32$	$y = 0.8116x - 55.10 \pm 4.75$
15	$y = 0.6912x - 32.41 \pm 5.01$	$y = 0.6883x - 32.78 \pm 4.31$
20	$y = 0.8967x - 48.85 \pm 4.30$	$y = 0.7552x - 32.66 \pm 5.38$
25	$y = 0.9061x - 40.08 \pm 5.76$	$y = 0.9460x - 31.65 \pm 6.70$
30	$y = 1.0043x - 38.09 \pm 8.19$	$y = 1.0849x - 32.17 \pm 9.97$
35	$y = 1.1962x - 54.42 \pm 10.30$	$y = 1.0456x - 31.55 \pm 11.54$
40	$y = 1.6024x - 90.03 \pm 8.00$	$y = 1.5608x - 65.93 \pm 11.56$
45		$y = 2.1078x - 118.00 \pm 8.47$

APPENDIX F

ENERGY OF FALLING DROPS
(Ergs on target area of 500 sq. cm.)

Distance from Nozzle, ft.		5/32-inch nozzle 30 psi	5/32-inch nozzle 35 psi	3/16-inch nozzle 35 psi	3/16-inch nozzle 40 psi
25				0.068,4	0.091,6
		0.140,8	0.189	0.031,2	0.133,6
		0.175,2	0.124	0.082,0	0.120,8
	Ave.	0.158,0	0.156,5	0.060,5	0.115,3
30		0.554,8		0.325,6	0.140,0
		1.004,8	0.502	0.128,4	0.356,4
		0.686,8	0.413	0.060,4	0.073,6
	Ave.	0.748,8	0.457,5	0.171,5	0.190,0
35		1.844		1.124	0.751,2
		2.244	1.445	1.058	0.313,6
		2.092	1.697	0.908	0.409,6
	Ave.	2.060	1.571	1.030	0.491,5
40		8.72	6.312	3.612	2.004
		18.38	6.788	6.716	0.552
		10.640	8.200	7.864	1.300
	Ave.	12.58	7.100	6.064	1.285
45					1.996
					0.236,4
					0.222,8
	Ave.				0.818,4

APPENDIX F (CONTINUED)

ENERGY OF FALLING DROPS
(Ergs per sq. cm. on target area of 500 sq. cm.)

Distance from Nozzle, ft.	5/32-inch nozzle 30 psi	5/32-inch nozzle 35 psi	3/16-inch nozzle 35 psi	3/16-inch nozzle 40 psi
25	0.000,316	0.000,313	0.000,121	0.000,231
30	0.001,50	0.000,915	0.000,343	0.000,380
35	0.004,12	0.003,14	0.002,06	0.000,983
40	0.025,2	0.014,2	0.012,1	0.002,57
45				0.001,64
		(Max. single observation 0.003,99)		