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EFFECT OF GRANULE SIZE ON APPLICATION

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by

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Sixty-two percent (29 million tons) of the fertilizer applied in the U.S. in 1982 was in the form of dry fertilizer (1). Most of this fertilizer was applied with spinner spreaders. Though most spinner spreaders have the disadvantage of producing uneven distribution, their high capacity, simplicity, and low maintenance have made them the most popular machine for broadcasting dry fertilizer. More than 20 years ago particle size was recognized as the most important factor for maintaining uniform swaths among raw materials in a blend (2). Small particles travel a shorter distance from the spinning discs than do large particles. This has discouraged the use of materials smaller than conventional granular products. Advantages of broadcasting larger-than-conventional materials has, up to this time, not been explored. Work described in this paper was aimed at determining the advantages of broadcasting materials larger than the typical minus 6- plus 16-mesh materials.

Literature Review

Hoffmeister conducted a series of tests to determine the extent to which particle shape, density, and size affected segregation of raw materials in blends (2). The overall conclusion was that particle size was by far the most important property that had to be matched to prevent segregation from ballistic action.

Mennel and Reece investigated particle trajectories from spinning discs and were able to predict the distance that spherical particles travel (3). Their equations predicted that a 1/8-inch-diameter particle (6-mesh) would travel roughly twice as far from a spinner 3 feet above ground than would a 1/64-inch-diameter (35-mesh) particle. Irregular shaped crystals did not travel as far as spherical particles.

Reints and Yoerger suggested that if granular fertilizer particles had a wide size range they would be better distributed laterally from the spreader (4). Cunningham and Chao chose to use discs having blades pitched at different angles to produce more divergence among particles leaving the spinners, thus improving broadcast uniformity (5). Mennel and Reece had already shown that the irregularity of fertilizer particles produces trajectories at large angles to the plane of the disc, thus causing large variation in the distance that particles travel (3).

More recent work by Pitt, et al has shown that variability in particle size has little effect on spread pattern (6). Median particle size is important; however, size variability merely tends to smooth out edges of the distribution pattern.

Facts that can be deduced from previous work is that mathematical modeling of fertilizer spread patterns is made difficult by particle irregularity. Large particles travel farther because their mass increases with the cube of the diameter while the frontal area on which drag forces act increases with the square of the diameter. Spherical particles travel farther than irregular shaped particles because they have smaller drag coefficients.

Equipment and Procedure

Field spreading tests provided the data for this study. A double-spinner spreader was used for all but two tests. A sketch showing the relative position of the fertilizer delivery system and spinners is shown in figure 1. The delivery chute had three adjustments to control the placement of fertilizer on the two spinners. The entire chute could be moved forward or backward. Depth of the two openings in the bottom of the chute could be varied by moving the rear plate. Width of the two chute openings could be varied by adjusting the width of the inverted vee. Widening the inverted vee placed fertilizer nearer the center of the spinners and decreased the width of the two openings.

The spinner discs were 24 inches in diameter and their axes were tilted 5 degrees from vertical. The outer edges of the discs were, therefore, 2 inches higher above ground than the inner edges. Height of the spinners above ground was about 35 inches.

The other spreader was a high flotation applicator with a single spinner about 36 inches above ground.

Three different sizes of urea were used in the tests. The sieve analyses of the three materials are shown in figure 2. The large sizes were curtain-granulated urea from TVA's pilot plant. The prilled urea was produced commercially. The materials were denoted forestry grades 1 and 2 and prilled urea. Forestry grade 2 was the largest and was nominally minus 2- plus 4-mesh (U.S. Sieve Series). Forestry grade 1 was minus 3- plus 5-mesh. Median particle sizes of the three materials were, respectively, 4.7, 3.94, and 1.71 mm. These materials were chosen because their density, shape, and surface roughness were similar. Variations in spread patterns could, therefore, be attributed to differences in granule size.

Spreading tests were conducted in a level field with wind speeds below 5 mph and relative humidity below 70 percent. Ambient temperatures ranged from 80 to 95^{o}F.

The test pans were rectangular, 17-1/2 by 14 inches, and 4 inches deep. Compartments for preventing fertilizer ricocheting were square, 3-1/2 inches on a side, and the same depth as the trays. Pans were spaced five feet between centers with their long dimension parallel to the applicator path. Twenty-one pans were used and the spreader was driven astride the center pan. A spreader speed of 5 mph was maintained during tests and the pan samples were weighed to the nearest 0.1 gram.

To compare spread patterns of different size particles, urea granules were spread with several spreader adjustments. This was necessary since some adjustments could favor one size particle. Figure 1 shows a sketch of the applicator with normal settings. Two spinner rotational speeds were used, 600 and 800 rpm.

The chute location shown in figure 1 was denoted the central position and was based on the spreader manufacturer's recommendation. Three other chute locations were used; 9/16 inches forward of the central position and 9/16 inches rearward and 1 inch rearward of the central position. These chute locations were, respectively, denoted forward, rearward, and rearward-plus.

The rear plate was always adjusted so that the depth of the chute opening was double the height of the gate opening. Gate openings of 1 and 2 inches were used.

Two settings of the inverted vee divider were used. The vee was widened from that shown in figure 1. The wider setting increased the width of the vee from 8 inches to 9 and 1/2 inches.

Results

Spread patterns were analyzed using a computer program. The program superpositions a spread pattern upon itself and the overlapped segments are summed to simulate field application. The driving interval (swath width) must be a multiple of the pan spacing. The optimum swath width is determined iteratively by selecting the driving interval which yields the lowest coefficient of variation. The coefficient of variation is defined as the standard deviation of the sample weights divided by the mean and multiplied by 100. More specifically:

$$C.V.\ (\%) = 100\ ((\sqrt{(\Sigma(x_i-\bar{x})^2)/n-1})/\bar{x})$$

Where $\bar{x}$ = mean of samples

x_i = individual sample weights

n = total number of samples

A single test consisted of three passes of the applicator over the test pans. Three passes were necessary to produce samples large enough to measure. Tests were originally replicated three times but since results were very reproducible the replications were later omitted. Figure 3 shows the reproducibility of a pattern produced with prilled urea. Each curve is the sum of three passes.

Ballistic segregation of urea granules was observed by accumulating the samples from spread tests of the prilled and forestry grade 1 urea. Accumulated samples from each pan were sieve analyzed and the median particle size plotted against pan location in figure 4. The median particle size is smallest near the spreader and largest at the outer edges. This shows that small and broken granules remain near the spreader while the larger granules travel farther from the spreader.

Size variation was greater for the prill than for the forestry grade 1. Median size of the forestry sample containing the largest granules was 15 percent larger than the median size of the sample containing the smallest granules (4.02 versus 3.49 mm). For prilled urea the largest median particle size was 49 percent larger than the smallest (2.04 versus 1.37 mm). This size variation is also reflected in the sieve analyses of the two materials (figure 2). Though the slopes of the curves are similar the prilled urea had a greater size variation. The size range between the 10 and 90 percent retained fractions was 1 mm (2.28 to 1.28 mm). The ratio of this range and the median particle size (1.71 mm) was 0.58:1. The forestry grade 1 had a size range of 1.28 mm but its median size was 3.94 mm. Thus the ratio of the range to median particle size was only 0.31:1. Some researchers believe that size variation is necessary for uniform broadcast application (5).

Comparisons of forestry grade and prilled urea spread patterns are shown in figures 5 through 14. The chute and spinner adjustments of the 10 tests are listed in table 1. Forestry grade 1 urea was used in tests 1 through 7 (figures 5-11). Swath widths which yielded the lowest coefficient of variation for each material in each test are listed in table 2.

The effect of increasing spinner speed is shown in figures 5 and 6. The higher spinner speed (figure 6) caused the fertilizer to leave the spinner sooner thus increasing the application behind the spreader. Increasing spinner speed had the same effect on the spread pattern as did moving the chute forward (figure 7).

In nearly every comparison, there was more forestry-size urea at the outer edges of the pattern than prilled urea. There was often, however, a more severe accumulation of forestry material in the center of the swath which reduced the swath width. In test 4 (figure 8) the forestry grade 1 urea yielded a swath of 60 feet. The widest swath obtained with prilled urea was 50 feet. Prilled urea spread better with the chute in the rearward plus position (figure 9). The forestry material yielded a more uniform pattern with the chute in the rear position.

In tests 6 and 7 (figures 10 and 11) the gate height was raised to 2 inches. Some manufacturers of double-spinner spreaders recommend that the chute be moved forward for higher gate openings. The benefit of this adjustment is shown in figure 11. Movement of the chute from the rear position to the center position helped eliminate the W-shaped pattern.

The rates of application of prilled urea in the first seven tests were higher than those for the forestry grade urea. Whether or not this was caused by imprecise gate adjustment, unmatched applicator speed, or flow characteristics of the two materials is not certain. Some custom applicators say that prilled urea tends to meter at higher rates than other materials. This phenomenon may be common of all spherical particles. The effect of granule size and shape on volumetric metering needs to be further studied.

Figures 12 through 14 are patterns produced with the widened vee. This adjustment eliminated the W-shaped pattern which was prevalent among the previous forestry grade patterns. Forestry grade 2 urea was used in these tests. A 65-foot swath width was obtained with the forestry grade urea using the wider inverted vee and the higher spinner speed. These results suggest that larger granules can be broadcast better if placed nearer the centers of double spinners.

Combinations of chute adjustments other than those listed in table 1 were used but the resulting patterns were unacceptable and were thus omitted.

Observations of the departure of fertilizer from the double-spinner spreader revealed some problems that might be eliminated by altering the fertilizer delivery system or spinner design. A considerable amount of fertilizer is deflected upward during application. This is verified by the abrasive damage sustained by the lower part of the rear plate and the chute adjustment crank. Fertilizer distribution can be better controlled if the path of fertilizer departing the spinner is not obstructed. Raising the discs would help solve this problem. The 17-inch drop from the apron to the discs (figure 1) enables granules to attain an appreciable vertical velocity. Inns and Reece showed that vertical velocity of granules is not lost during impact with the spinners, thus, particles move up or down on the blade surface until they leave the spinner (7).

Tilt of the discs causes granules which bounce upward from the discs to bounce toward the inner edges. The granules then depart from the spinner blades in the rearward direction. Granules bouncing from horizontal discs are not displaced inward and thus are not directed toward the rear of the applicator.

Bolts which hold down the blades are on the side of the blades where they will block the path of sliding granules (figure 1). This adds more randomness to the trajectories of granules and obstructs the path of granules leaving the spinners.

Two pattern tests were made with a single-spinner spreader. A granular urea and forestry-size sulfur-coated urea were used in these tests. Sieve analyses of the two materials are plotted in figure 15. Bulk density of the sulfur-coated material was slightly higher than that of the granular urea (54 versus 49 pounds per cubic foot). The difference was not considered significant enough to influence spreading characteristics.

The applicator was driven at a speed of 12 mph and spinner speed was measured at 800 rpm. An application rate of 200 pounds per acre was chosen. Wind speeds varied with gusts approaching 20 mph. The applicator was driven parallel to the wind direction to minimize the effect of wind on the lateral distribution of fertilizer.

In these tests forestry-size sulfur-coated urea yielded a swath width of 65 feet with a coefficient of variation of 14.3 percent. Granular urea yielded a 35-foot swath width with a coefficient of variation of 20.7 percent. Spread patterns from the two materials are shown in figure 16.

Conclusions

Granular fertilizer with large particles can be applied in wider swaths than can conventionally sized (minus 6- plus 16-mesh) fertilizer. Spread pattern tests yielded increases in swath width of up to 30 feet. Adjustment in drop location on some double spinners is required. Spreading tests indicated that the large material yielded a wider and more uniform pattern if dropped nearer the centers of double spinners. The adjustments required to obtain the optimum pattern with large granules may vary for different spinner designs. A single-spinner spreader tested under normal use by a dealer produced a swath 65 feet wide with large granules and only 35 feet wide with prilled urea.

Larger granules produced significantly less dust when broadcast than did the prilled urea and thus would be less likely to drift. Problems associated with the buildup of urea dust on the chute in humid weather also would be reduced with the larger granules.

More work is required to determine if any differences in metering rates will occur with larger materials. If blended with conventionally sized granules, forestry-size granules will segregate; using such materials in blends is not recommended. The advantage of the large granules can be realized in direct application. The wider swaths attainable with large granules will reduce application costs and shorten the time required to broadcast direct applied fertilizer.

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Table 1

Spinner and Chute Adjustments for Spread Pattern Tests[a]

Test Number	Spinner Speed (RPM)	Chute Location[b]	Inverted Vee[c]	Gate Opening (inches)
1	600	Center	Narrow	1
2	800	Center	Narrow	1
3	600	Forward	Narrow	1
4	600	Rearward	Narrow	1
5	600	Rear Plus	Narrow	1
6	600	Rearward	Narrow	2
7	600	Center	Narrow	2
8	600	Center	Wide	1
9	600	Rearward	Wide	1
10	800	Rearward	Wide	1

a. Applicator speed was 5 mph in all tests. Application rates were 200 and 400 pounds per acre.

b. Center chute location is shown in figure 1. Forward and rearward locations were 9/16 inch to the front and rear of center. Rear plus was 1 inch rearward of the center position.

c. The narrow vee position is shown in figure 1. The wide vee was 9-1/2 inches wide instead of 8.

Table 2

Swath Widths[a] and Coefficients of Variation[b] of the Spread Patterns

Test Number	Prilled Urea		Forestry Urea	
	Swath (ft)	C.V. (%)	Swath (ft)	C.V. (%)
1	40	12.4	35	20.6
2	35	13.6	35	13.6
3	35	13.8	35	33.7
4	45	14.6	60	18.9
5	50	15.0	60	22.6
6	30	18.4	35	20.2
7	45	17.3	35	23.0
8	35	22.0	55	31.6
9	45	22.8	35	34.8
10	35	22.6	65	19

a. Swath widths are a multiple of the pan spacing (5 feet). A width of 35 feet was the narrowest spacing for which a coefficient of variation could be calculated.

b. Coefficient of variation is the standard deviation of the sample weights divided by the mean and multiplied by 100. Coefficient of variation is used because of the wide variations in the mean.

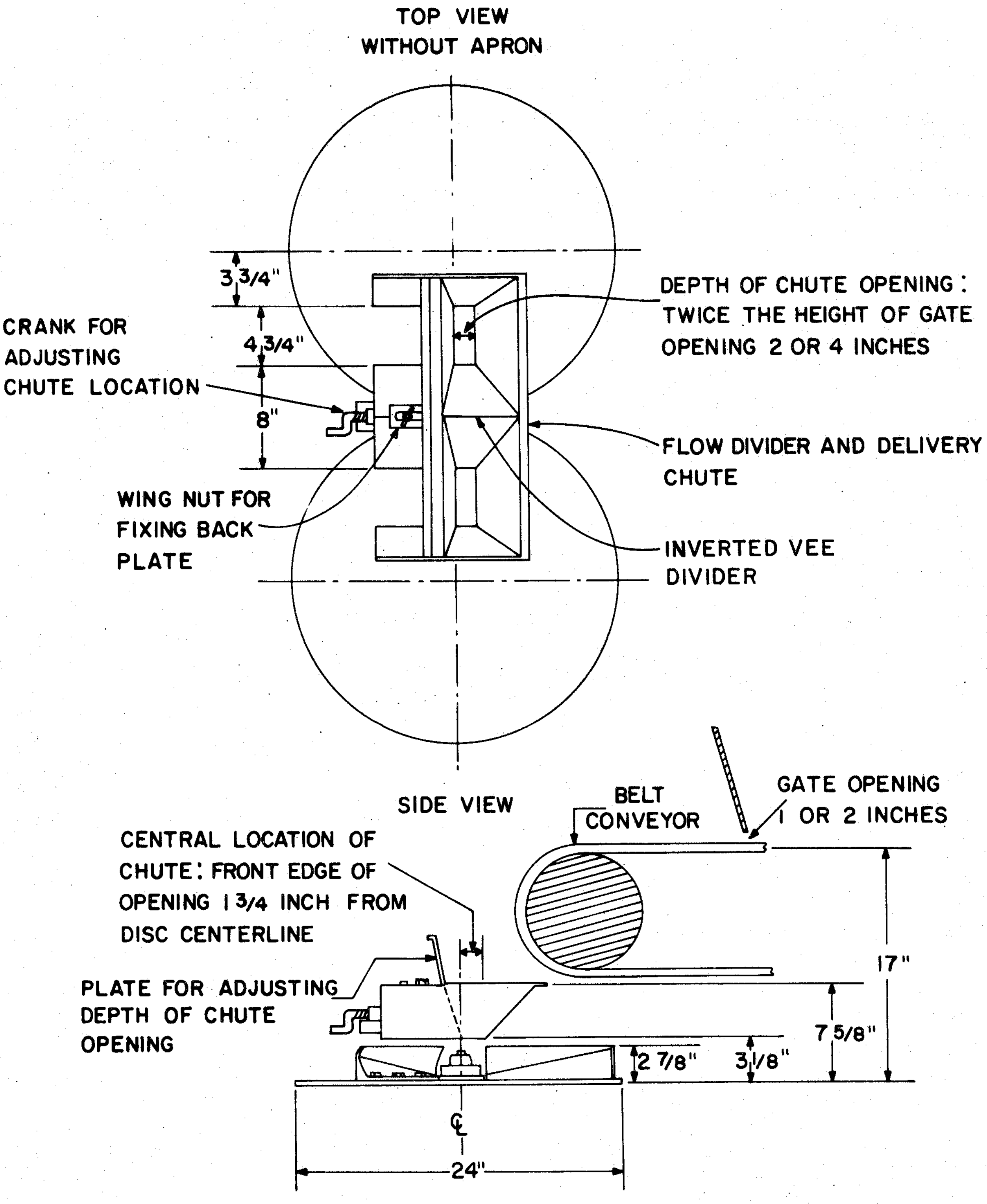

FIGURE 1. DOUBLE SPINNER FERTILIZER DELIVERY SYSTEM

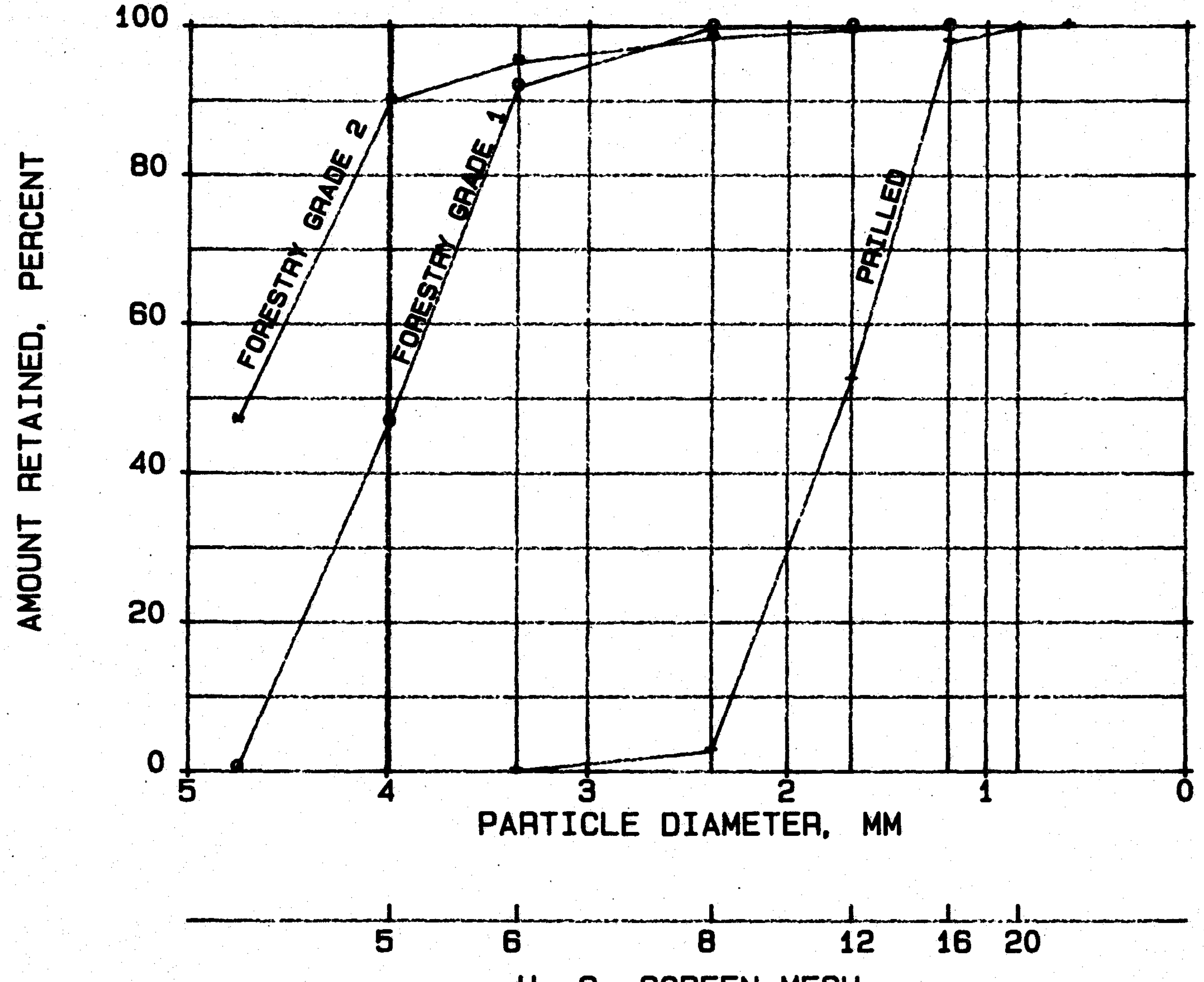

FIGURE 2

SIEVE ANALYSES OF UREA

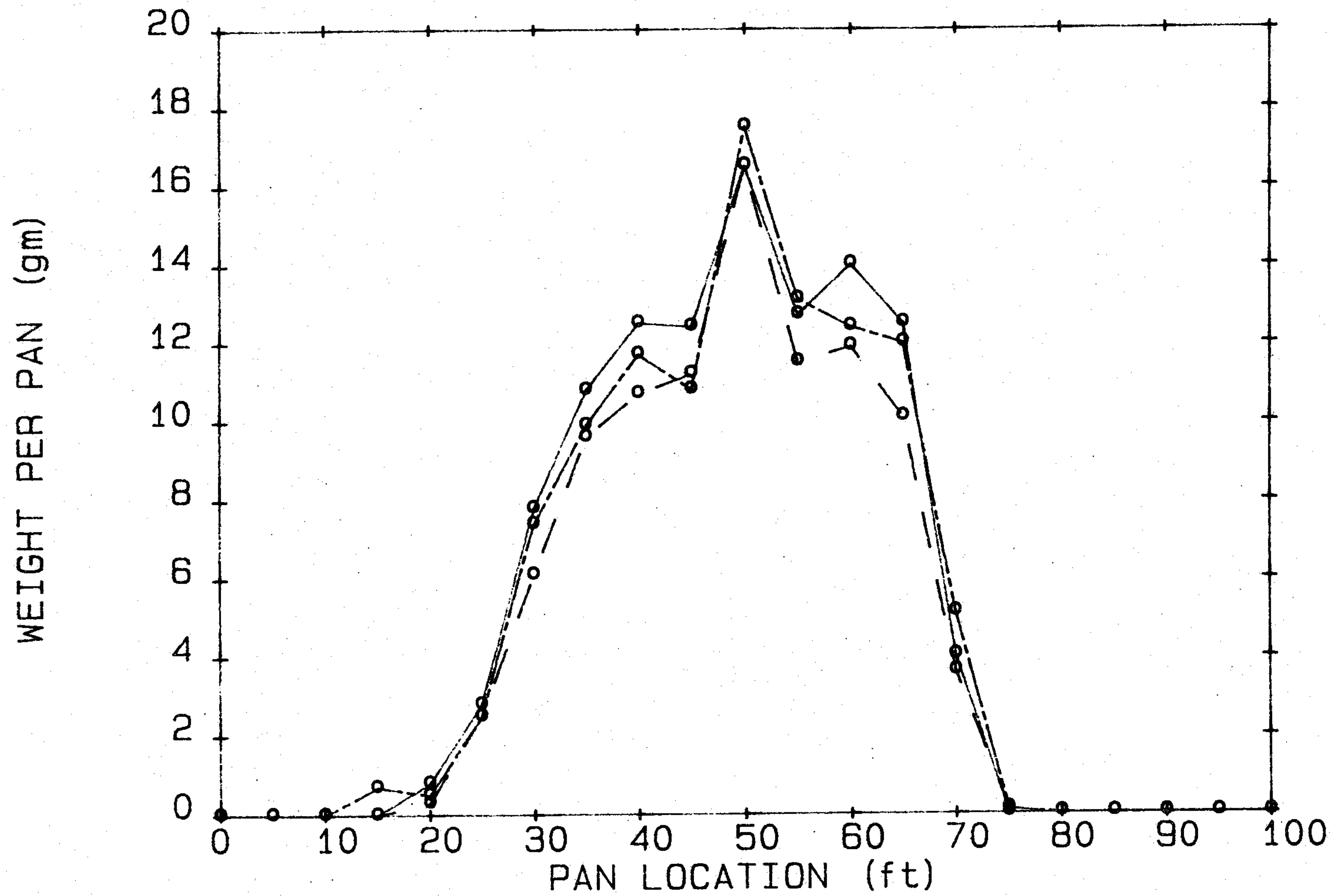

FIGURE 3

REPLICATIONS OF SPREAD PATTERN PRILLED UREA

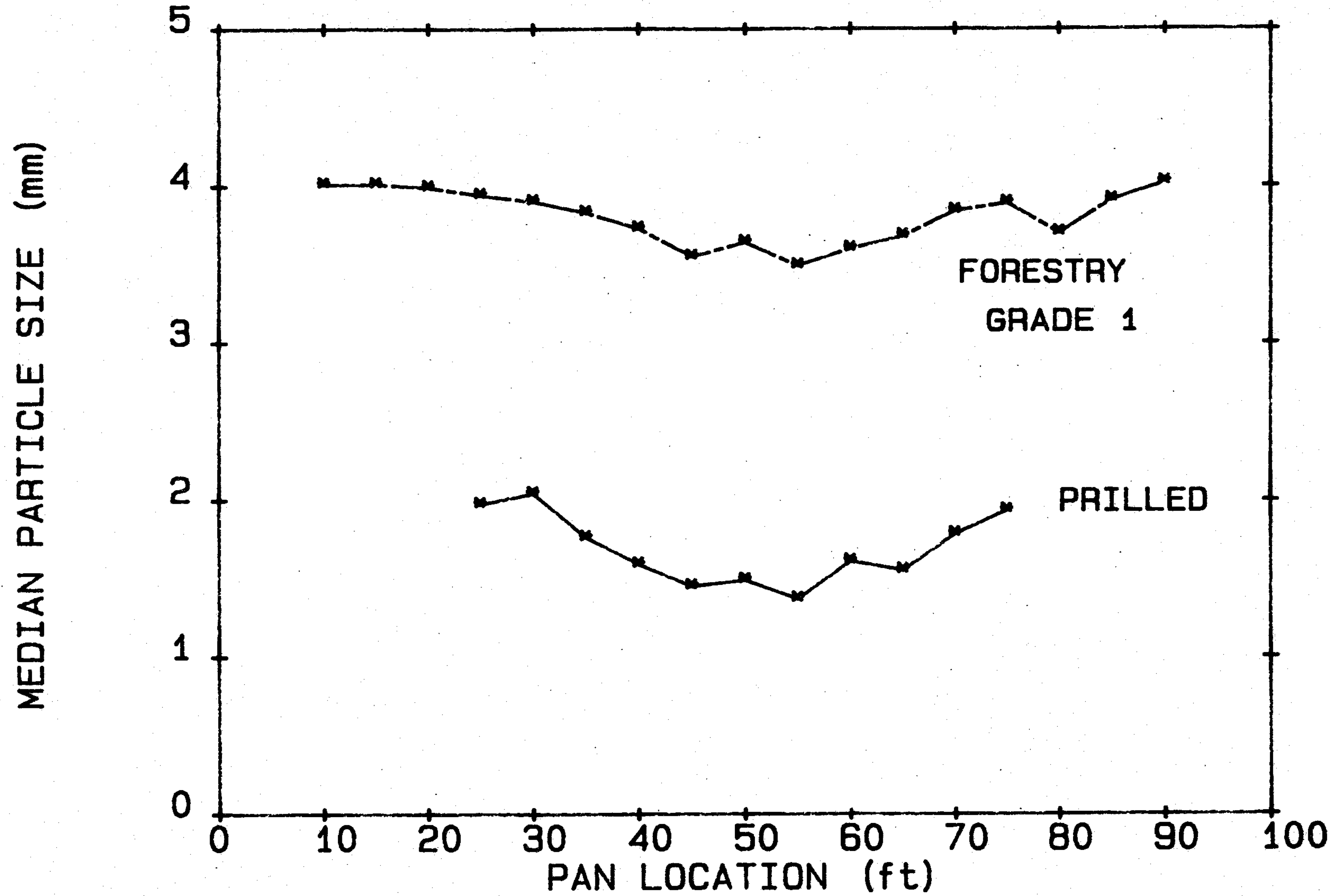

FIGURE 4
BALLISTIC SEGREGATION DUE TO SIZE

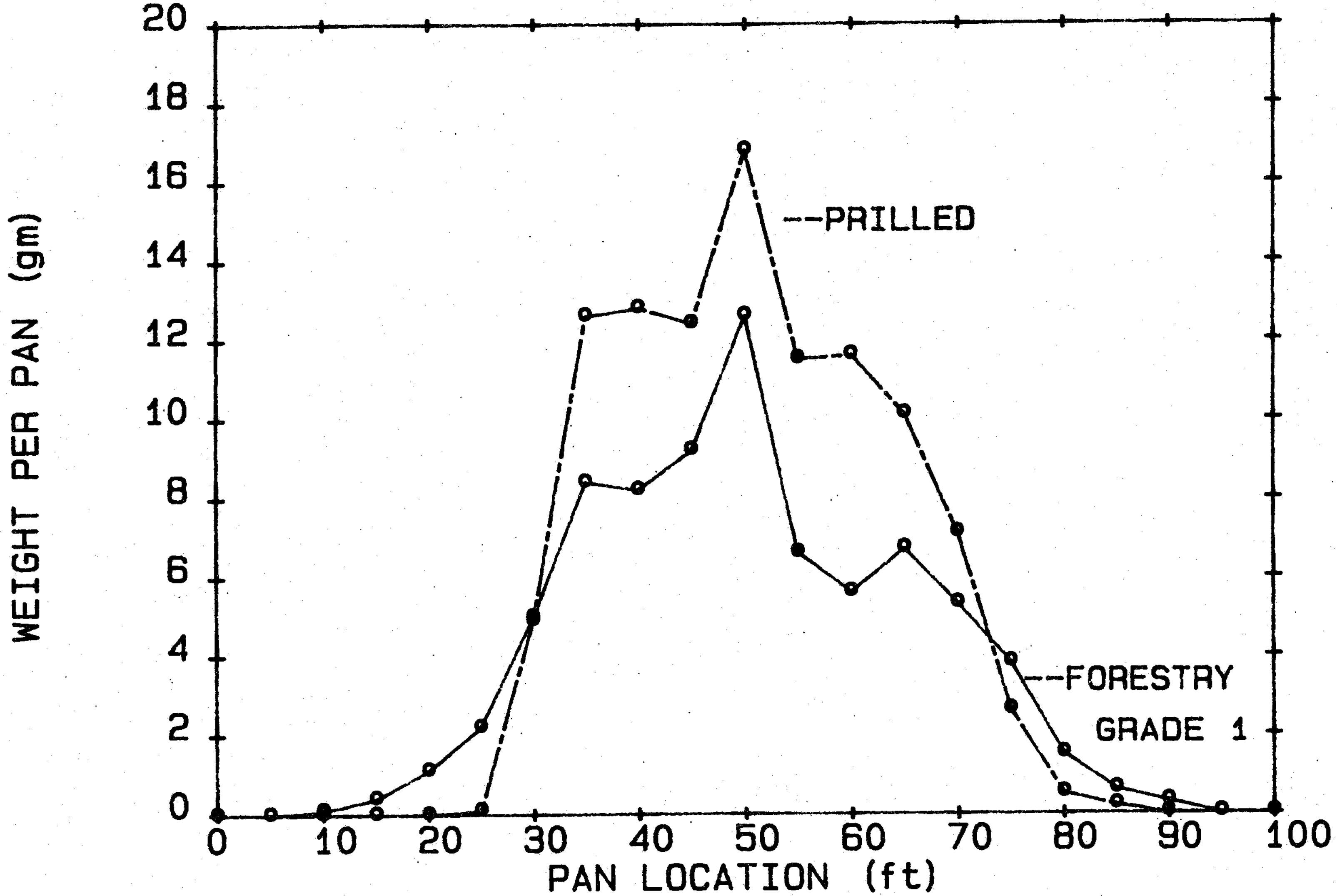

FIGURE 5 SPREAD PATTERN TEST 1

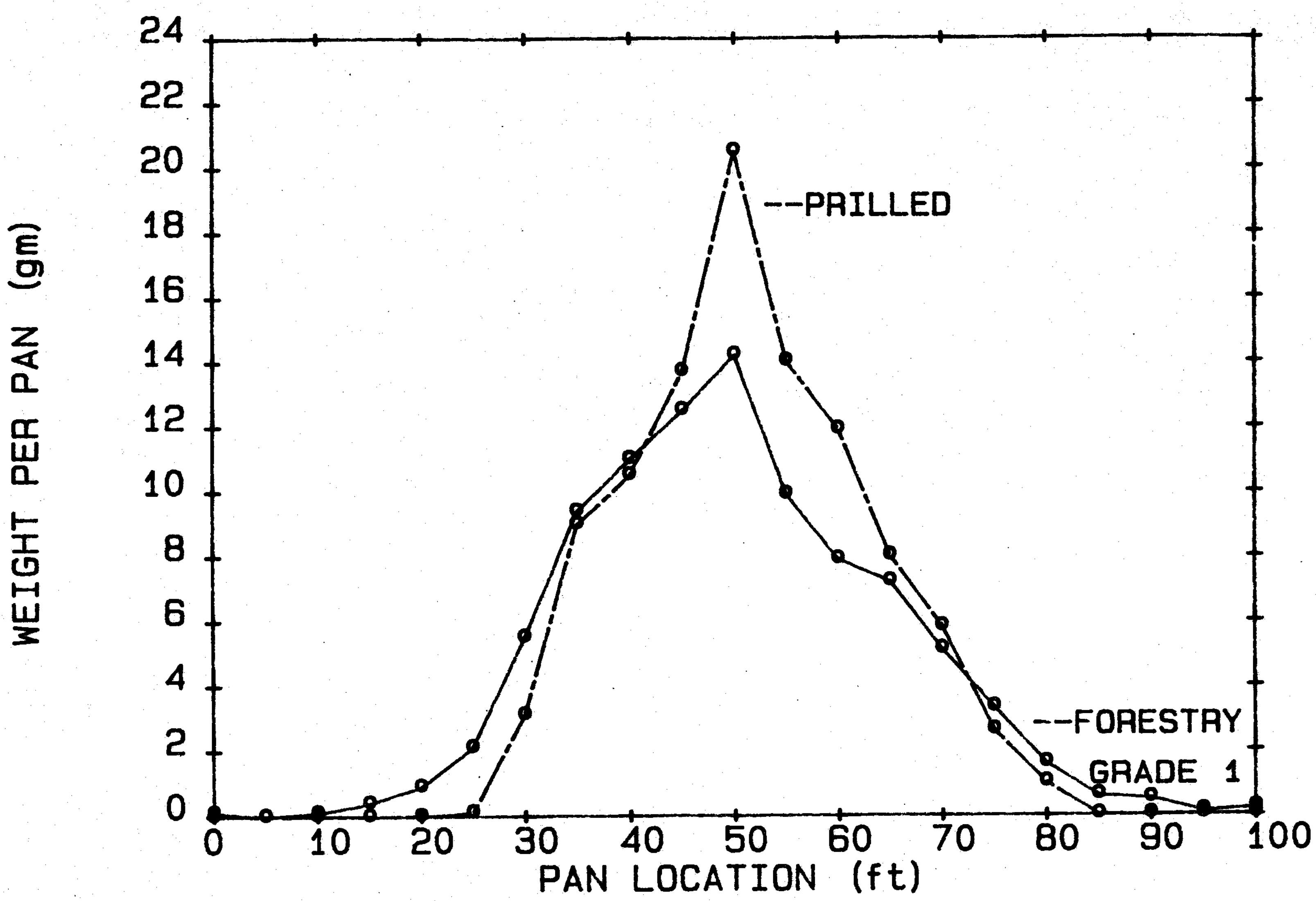

FIGURE 6 SPREAD PATTERN TEST 2

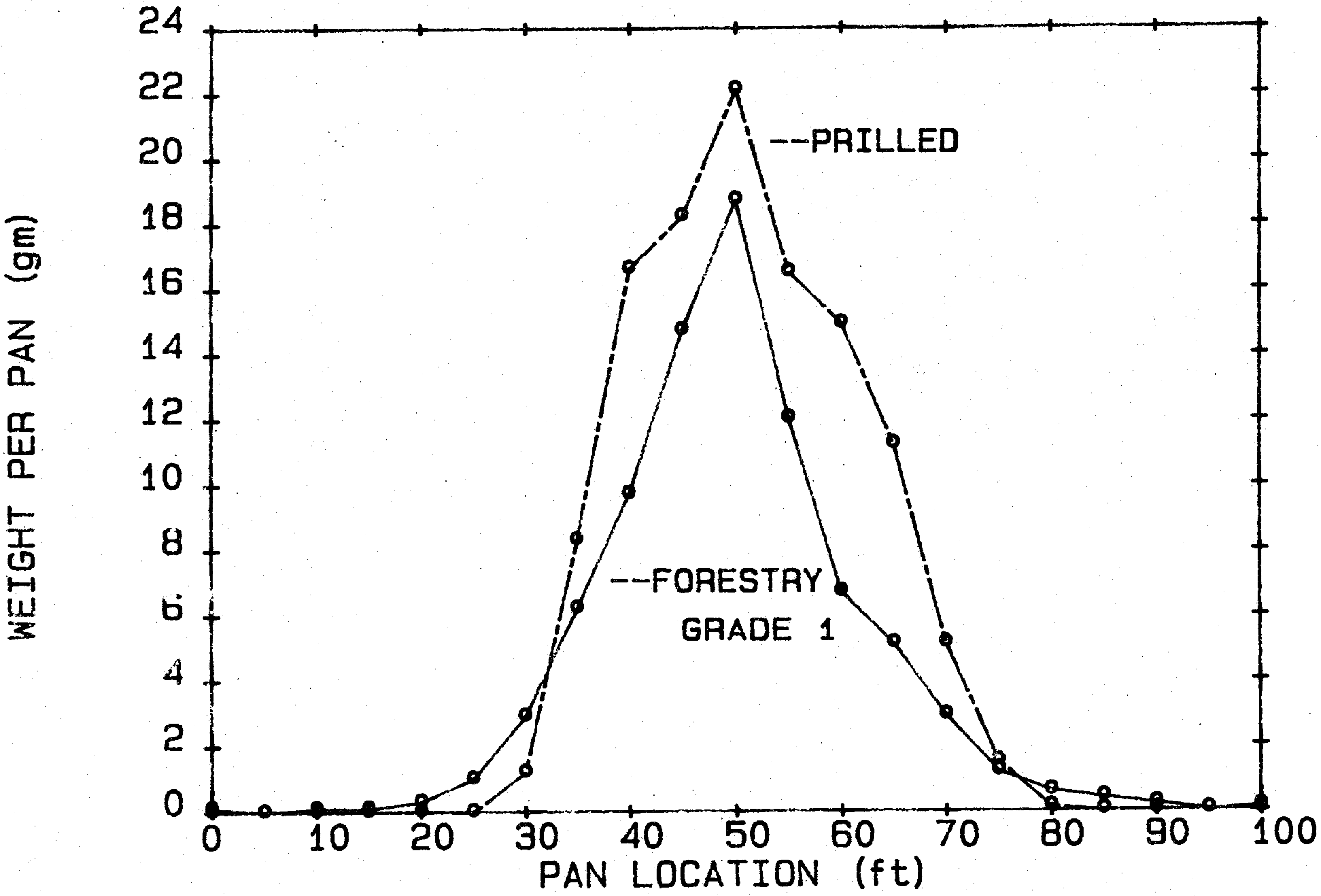

FIGURE 7 SPREAD PATTERN TEST 3

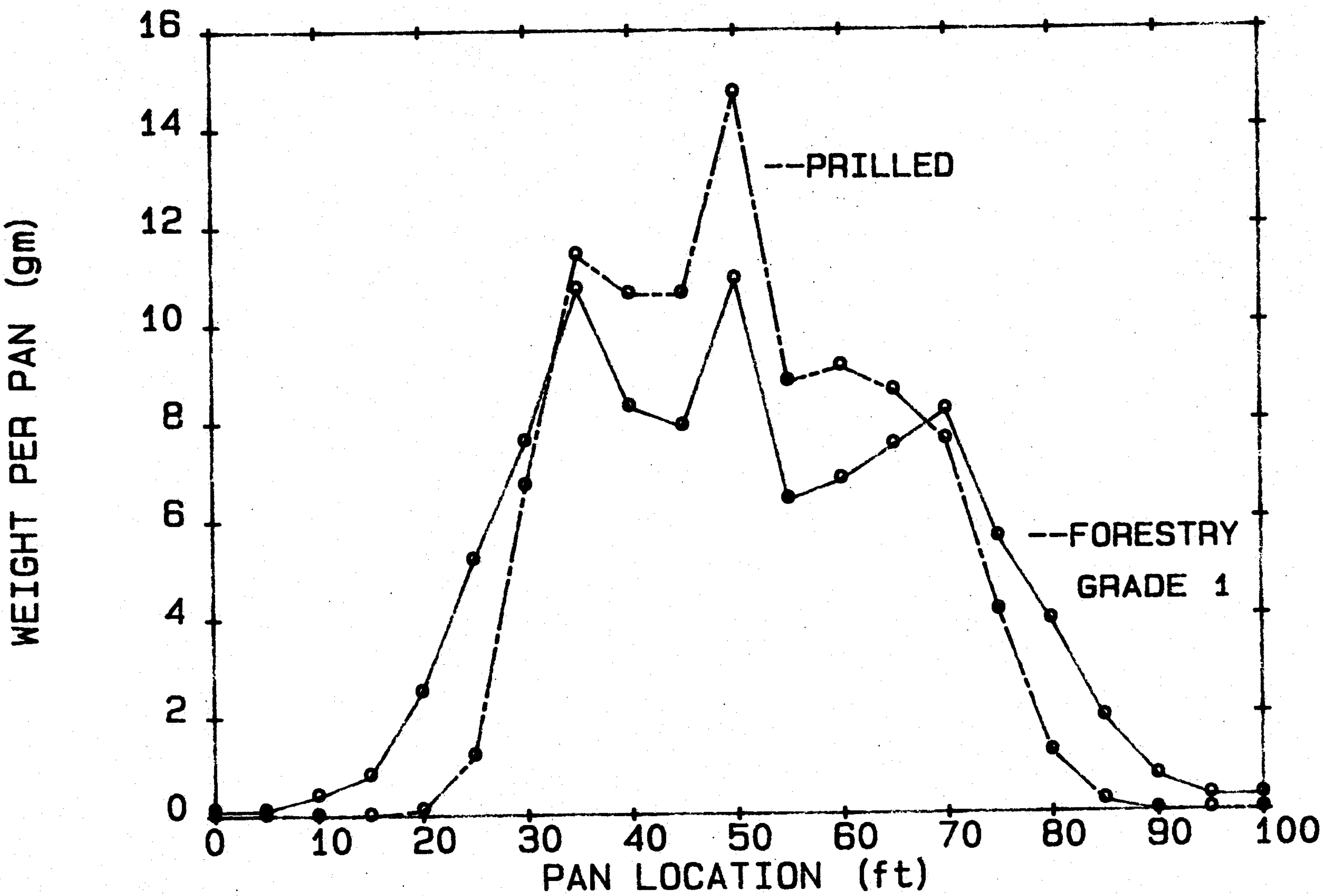

FIGURE 8 SPREAD PATTERN TEST 4

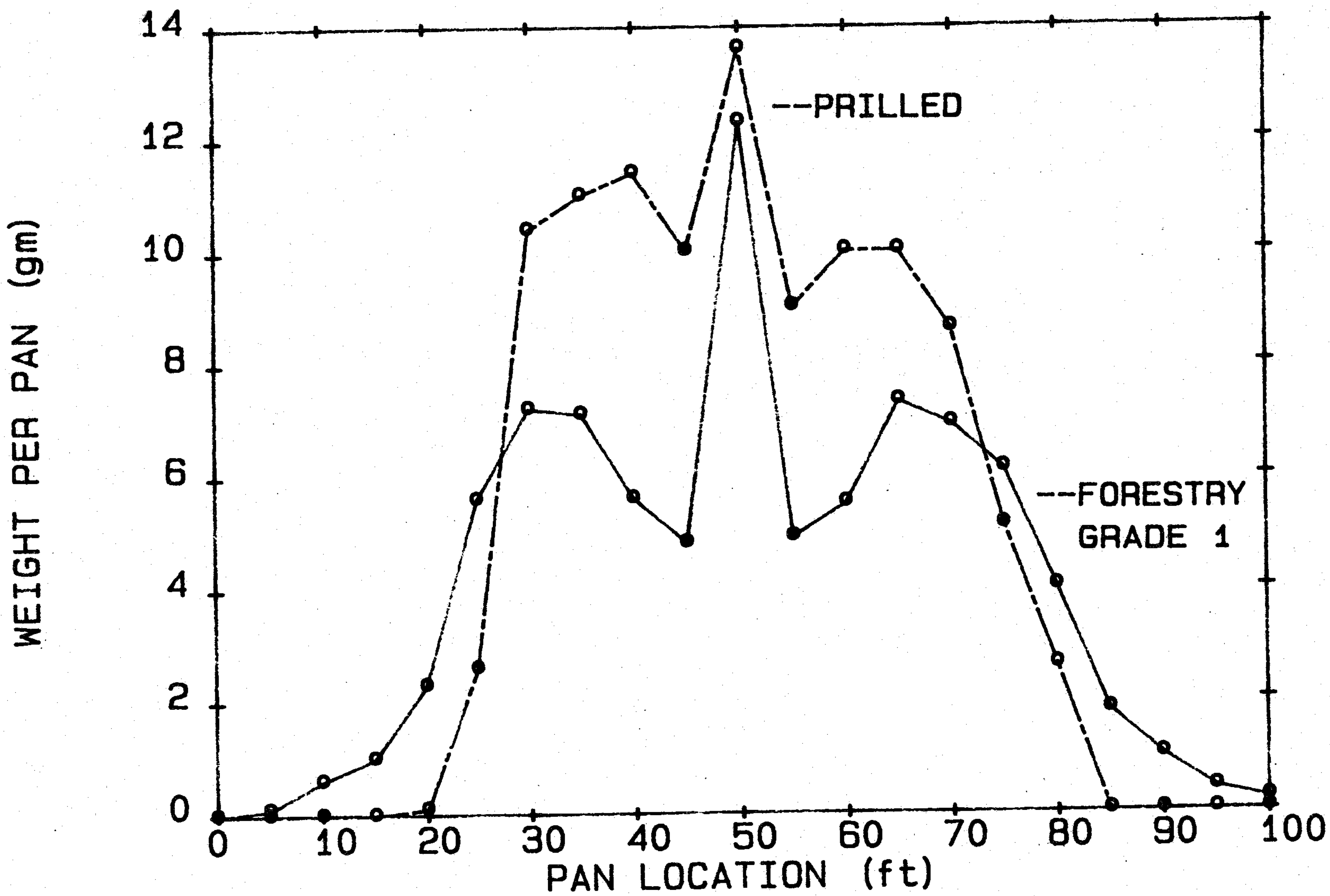

FIGURE 9 SPREAD PATTERN TEST 5

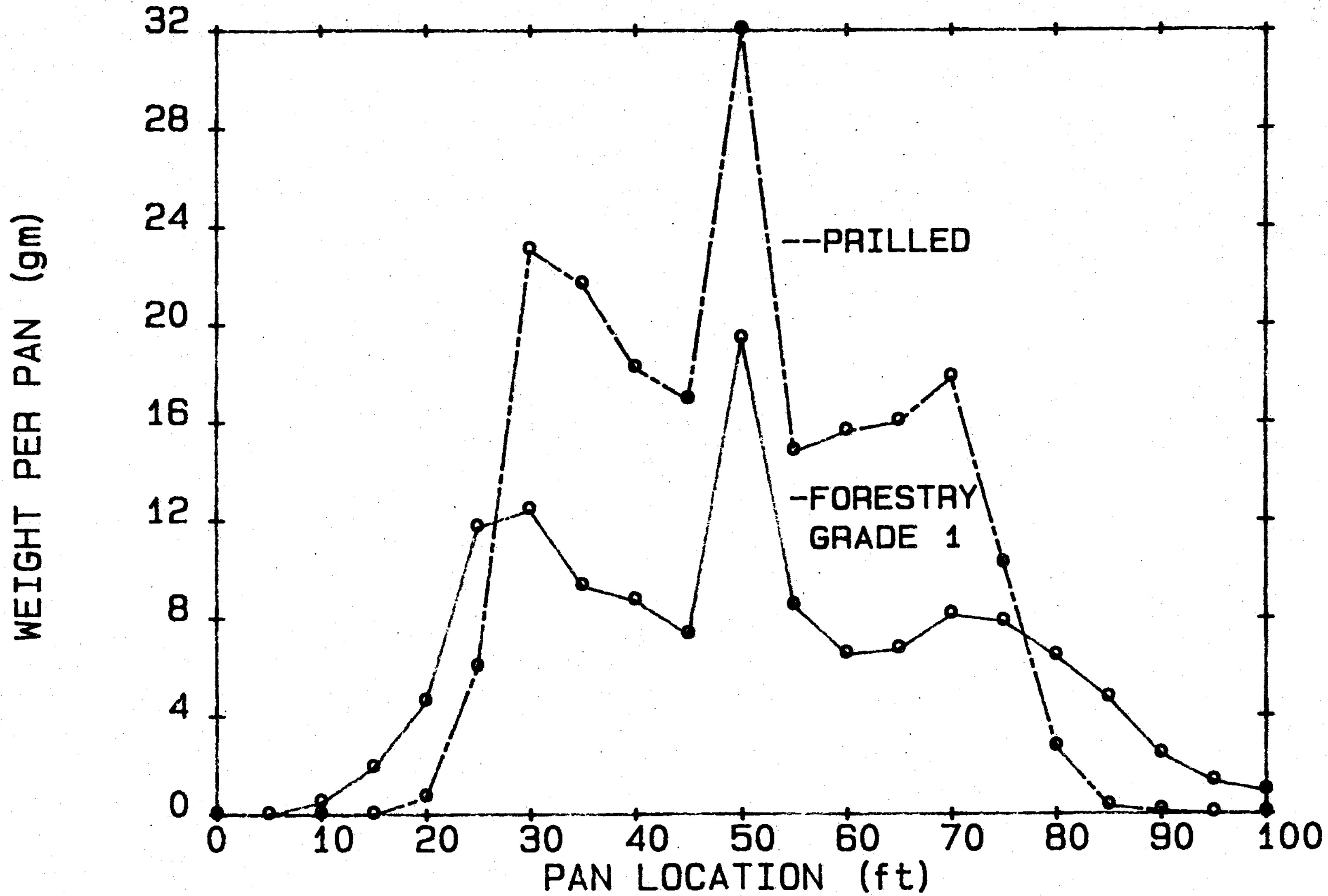

FIGURE 10 SPREAD PATTERN TEST 6

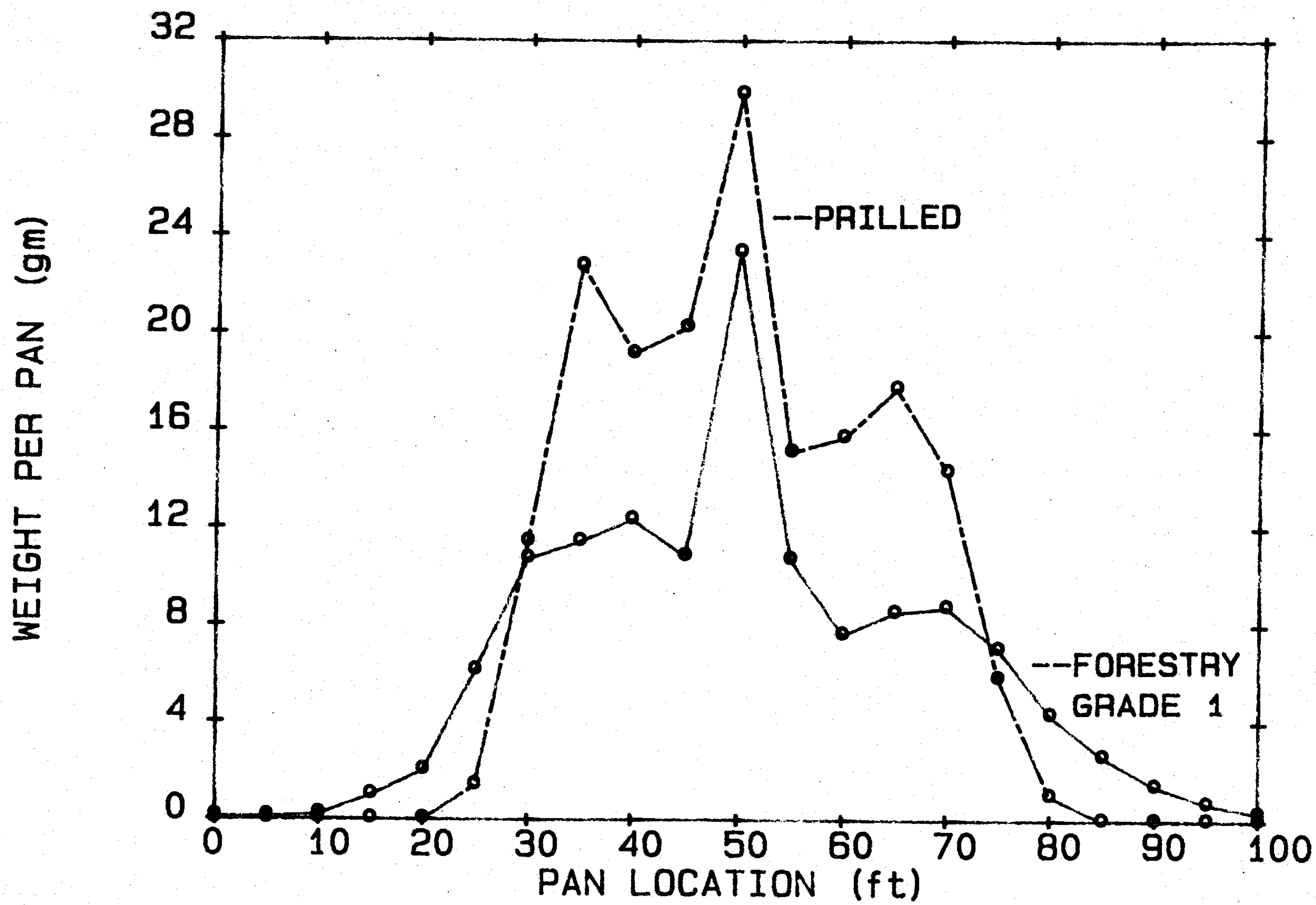

FIGURE 11 SPREAD PATTERN TEST 7

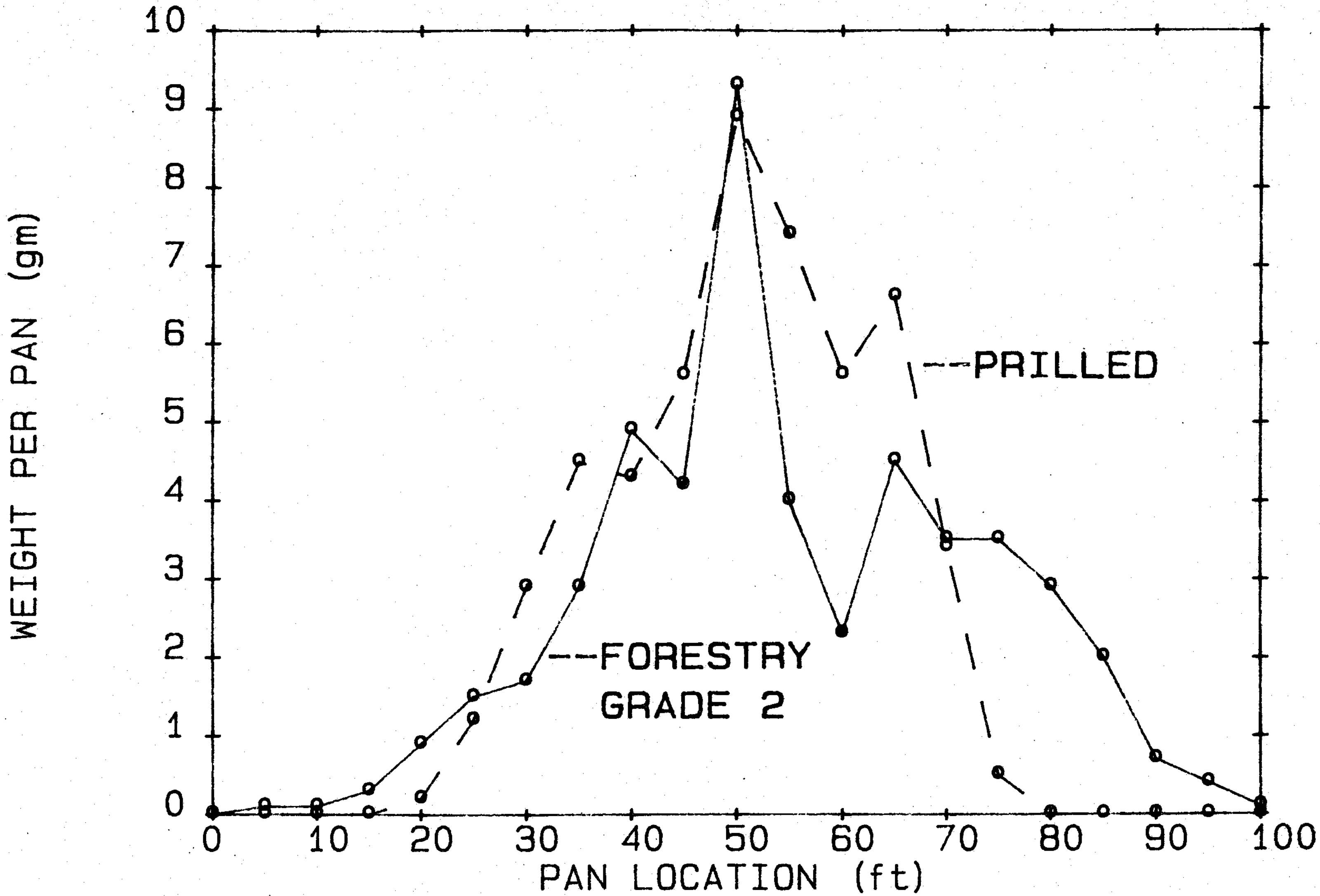

FIGURE 12 SPREAD PATTERN TEST 8

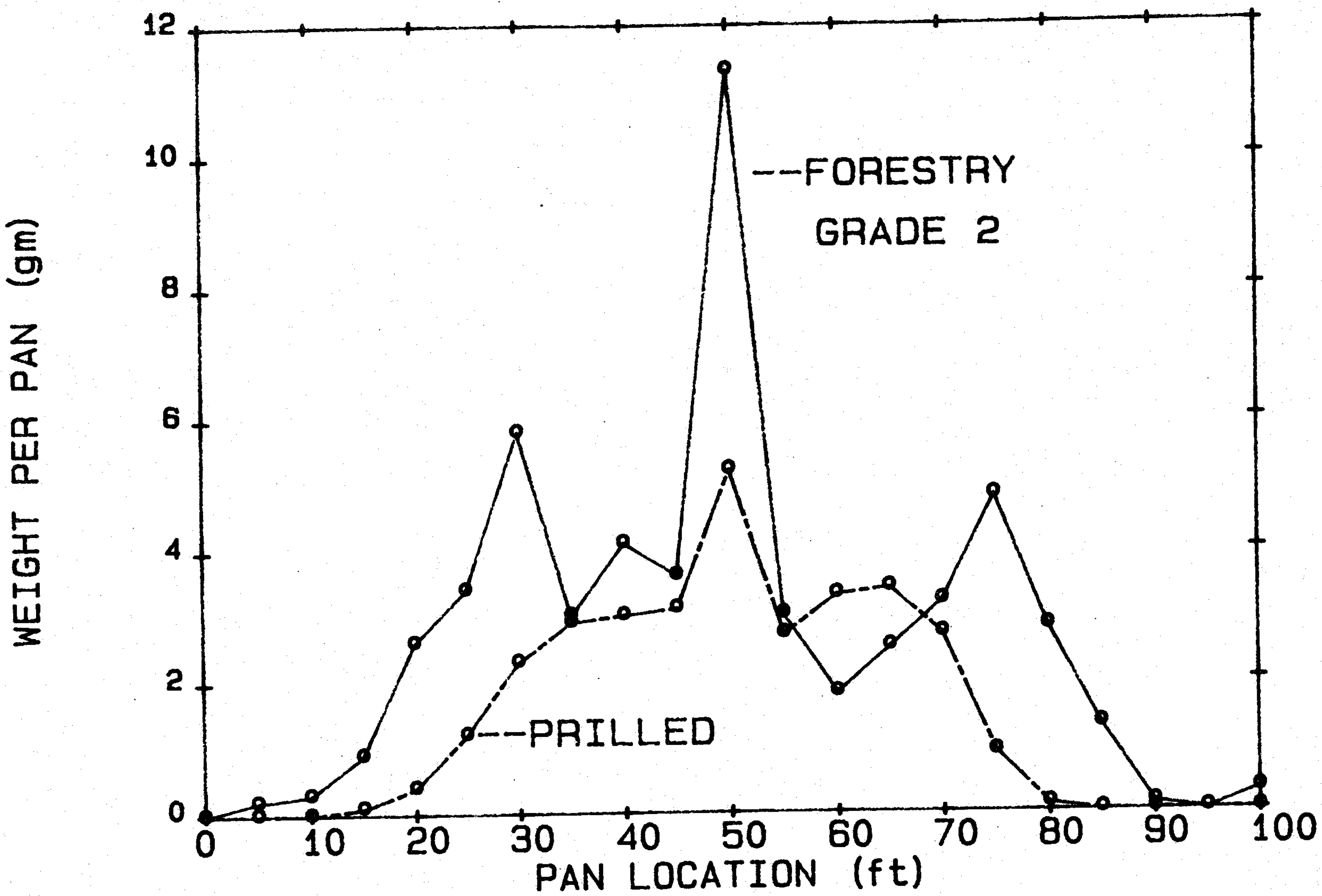

FIGURE 13 SPREAD PATTERN TEST 9

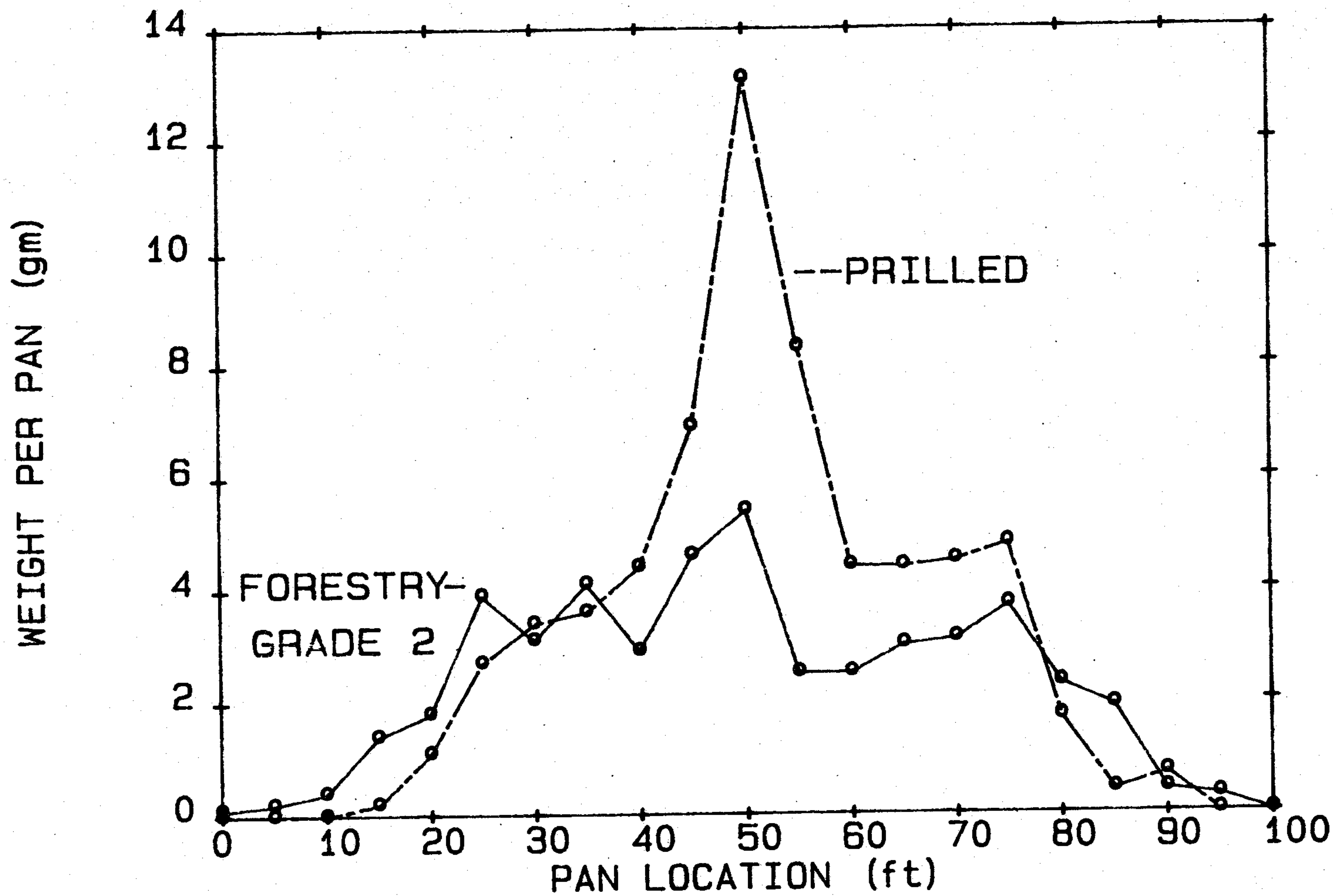

FIGURE 14 SPREAD PATTERN TEST 10

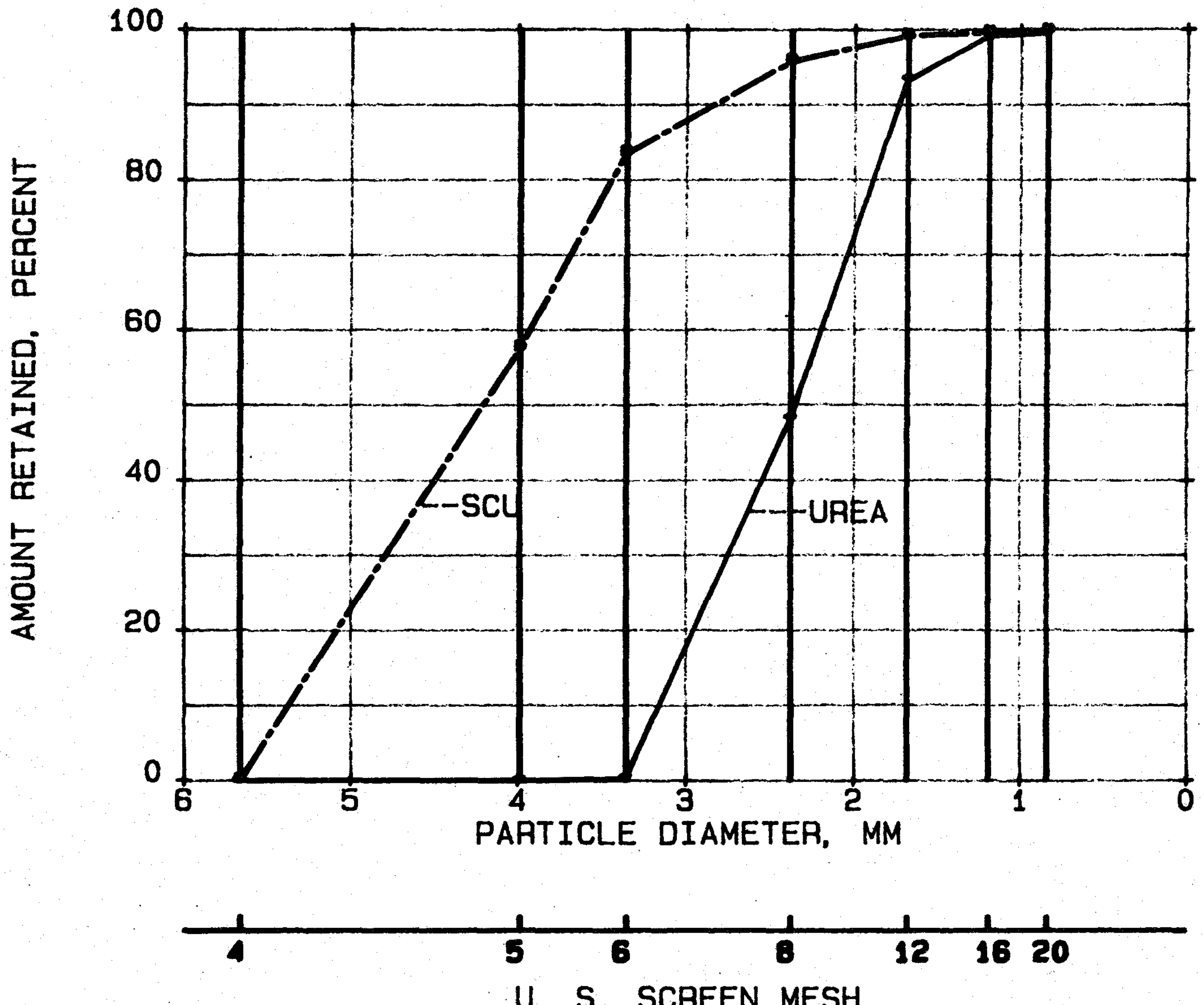

FIGURE 15

SIEVE ANALYSIS OF SCU

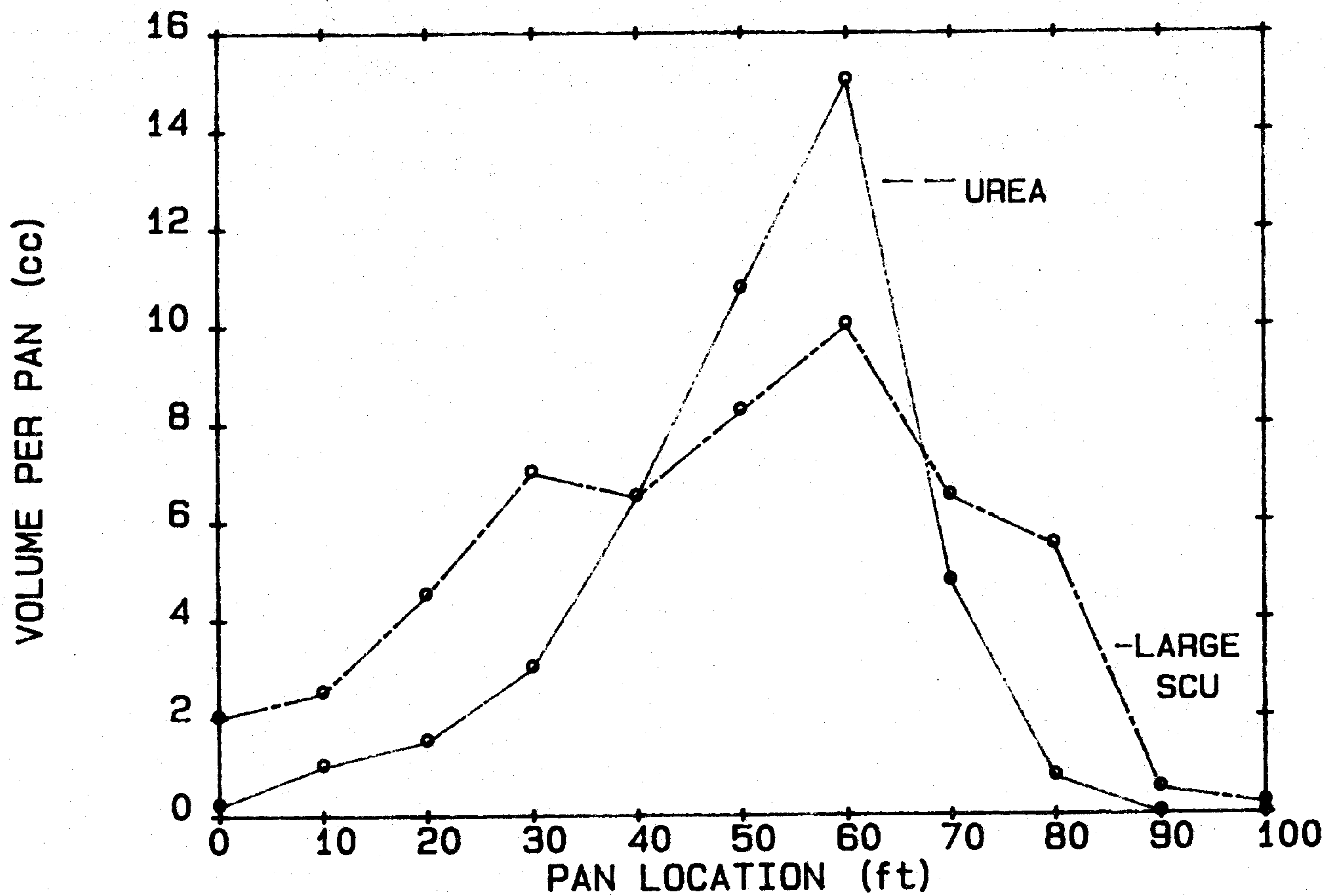

FIGURE 16
SPREAD PATTERNS SINGLE SPINNER