# DEVELOPMENT OF A CENTRIFUGAL DISTRIBUTOR HAVING VERTICAL DISPROPORTIONATE BLADES FOR GRANULAR PARTICLES

By

KAMALEDDIN JAZAYERI

Bachelor Degree

Jundi Shapur University

Ahvaz, Iran

1975

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1978

DEVELOPMENT OF A CENTRIFUGAL DISTRIBUTOR HAVING
VERTICAL DISPROPORTIONATE BLADES FOR
GRANULAR PARTICLES

Thesis Approved:

Richard W. Whitney
Thesis Adviser

James E. Garton

Lawrence O. Roth

Norman N Durham
Dean of Graduate College

## PREFACE

The research reported in this thesis was financed by the Oklahoma Agricultural Experiment Station under Project S-1614. The pellets used for the test in this experiment were furnished by Elanco Company, Dallas, Texas. This support is sincerely appreciated.

The author is especially grateful to his major adviser, Dr. Richard W. Whitney, for his advice, criticism, and inspiration throughout this study. Appreciation is extended to other members of advisory committee, Professor Larry O. Roth, and Professor James E. Garton for the constructive suggestions that each provided. To Dr. L. R. Ebbesen, mechanical engineering department, for his suggestion on the theory part of the experiment, to all of my fellow graduate students who have so generously endured my moments of despair, and to all of the undergraduate students who helped to build the machine and conduct the test, I am sincerely grateful.

In addition, the author wishes to thank the laboratory personnel, Clyde Skoch and Norvil Cole, for their assistance. Thanks is also given to Mr. Jack Fryrear for his effort in the preparation of illustrative material. A note of thanks is given to Mrs. Paula Lehman of the Statistics Department and Mrs. Pam Haught of the Computing & Information Sciences Department for excellence of the draft and final copy and their valuable suggestions concerning form.

Appreciation is expressed to Dr. Abbas Jamaee, the President of Jundi Shapur University, for assigning me a scholarship which made my study in the United States possible.

Last, but certainly not least, are my parents, Mr. and Mrs. Jazayeri, for their thoughtfulness, encouragement, and many sacrifices.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

| Figure | | Page |
| --- | --- | --- |

## LIST OF SYMBOLS

| | | |
|---|---|---|
| $r$ | - Distance of the particle from the center of the disc, | m |
| $dr/dt$ | - Radial velocity of the particle, | m/sec |
| $d^2r/dt^2$ | - Radial acceleration of the particle, | $m/sec^2$ |
| $R$ | - Maximum value of r or blade's radius, | m |
| $\omega$ | - Distributor angular speed, | rad/sec |
| $\mu$ | - Coefficient of friction between particle, wheel and blade | |
| $\beta$ | - The angle between the blade's curve and distributor radius | degree |
| $\theta$ | - The angle of rotation of the wheel beyond the point of initial contact, r=0 | degree |
| $\phi$ | - Projection angle | degree |
| $g$ | - Gravity acceleration | $m/sec^2$ |
| $X_m$ | - The maximum trajectory distance from the center of the wheel | m |
| $t$ | - The time for a single particle to pass the length of the blade | sec |
| $M$ | - Mass of the particle | kg |
| $k$ | - Coefficient of air resistance, 0.03 for spherical shape | |
| $S$ | - The cross sectional area of the particles | $m^2$ |
| $n$ | - The velocity exponent in rotation with air resistance | |

| | | |
|---|---|---|
| $r''$ | - The length of blade curvature | m |
| $V_o$ | - The outlet velocity of the single pellet from the blades | m/sec |
| C | - Capacity of auger | $m^3/sec$ |
| D | - Screw diameter | m |
| d | - Shaft diameter | m |
| P | - Pitch of screw flighting | m |
| N | - RPM | RPM |
| E | - Conveyer efficiency | % |
| $V_i$ | - The pellet initial velocity | m/sec |
| $X_{i_o}$ | - The auger's pipe radius | m |

# CHAPTER I

## INTRODUCTION

The centrifugal fertilizer or granular distributor has become increasingly popular among farmers in spite of the disadvantage, present in all current distributors, of nonuniformity of distribution. This popularity comes from the four following advantages:

1. Low cost
2. Simplicity of operation
3. Ease of cleaning
4. Relatively small size for a given width of spread

During the period of May 1977 through September 1977 a distributor was used for distribution of solid $CO_2$ at the Agricultural Engineering Department of Oklahoma State University under the project title of "A $CO_2$ Pesticide Distribution System for Tick Control." The material used in this experiment was solid $CO_2$ pellets (1.6 cm diameter and 1 to 3 cm long). The distribution of solid $CO_2$ by this equipment was reported adequate.

The probability of obtaining a uniform distribution by a centrifugal distributor is a function of air resistance, shape, size, etc. of the granular material with the distribution of relatively small particles being most affected by these parameters (12). Since many of the granular agricultural chemicals are relatively small in size, development of spreader or design of a new distributor for uniform distribution seems to be necessary.

## Description of the Distributor

A schematic diagram of the vertical wheel distributor designed for clay pellet distribution is presented in Figure 1. As shown by the diagram, the pellets were conveyed into a central auger, designed near the center of the slinger wheel, through a chute from a hopper - bottom auger. The hopper - bottom auger was driven by a ground traction wheel which kept the pellet's application proportional to ground travel. The distributor wheel was made of two 0.32 cm thickness hot rolled steel plates and 7.6 cm spaced.

A 14.2 cm diameter hole was drilled in the center of one of the plates to allow feeding the wheel by the central auger. Six unequal length curve blades, 7.6 cm wide, were mounted between the two plates.

## Statement of the Problem

It was the purpose of this study to establish the relation uniformity of distribution of small particles by a vertical wheel distributor.

## Objectives

1. To develop a prediction equation for vertical wheel distributor based on centrifugal, tangential, and ballistic forces affecting the granular material to be distributed;
2. To use the equation to design a vertical wheel distributor with six unequal length blades to obtain a uniform distribution;

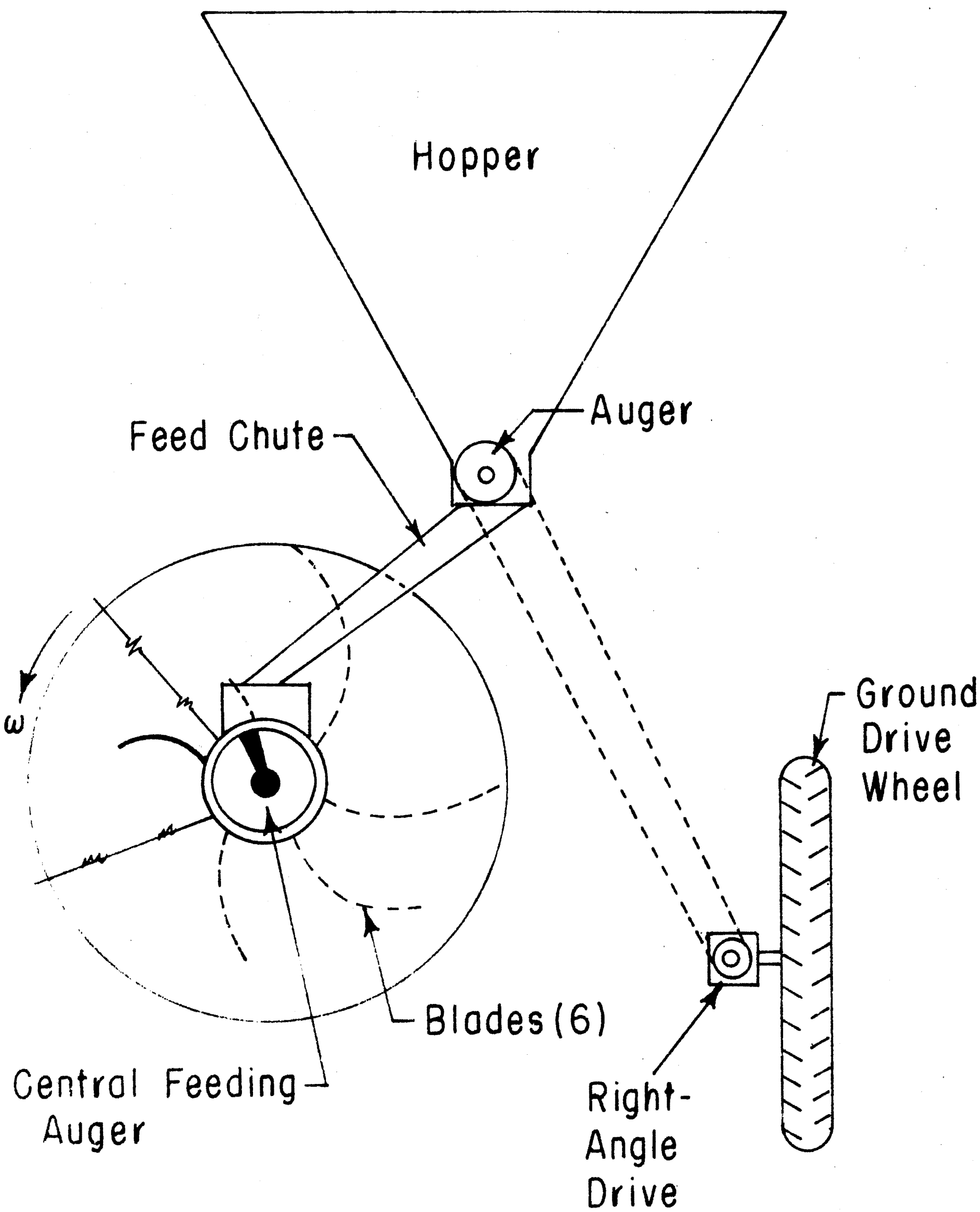



Figure 1. Schematic Diagram of Vertical Slinger Wheel

3. To determine the uniformity of distribution across the swath width resulting from material application with the designed distributor.


Figure 2. Side View of Vertical Distributor Connected to the Tractor

## CHAPTER II

## REVIEW OF LITERATURE

Use of centrifugal distributors is one of the oldest ideas used in agricultural machinery. West (14) showed that one of the best methods for the distribution of particles (fertilizers) is the horizontal centrifugal distributor. However, variation in application rate with the centrifugal distribution may reduce the yield.

One of the biggest problems involved in study of distributors using the centrifugal slinging principle is their inability to produce an even distribution pattern. Hepherd and Pascal (6) used five different materials: a granular compound fertilizer; granular triple super phosphate, sulphate of ammonia, basic slag and ground chalk to investigate the distribution of fertilizer by a conventional type of distributor. Although they obtained some useful information on the effect of wind on the transverse distribution, they concluded that under identical conditions, the transverse distribution generated by their machine was more uneven than that of other types.

Also, Crowther (2) studied the idea of centrally feeding a horizontal spinning disc. Crowther concluded that the segregation of particles of different sizes increases with disc speed, but is not likely to reduce the efficiency of a disc spreader at the speed, 200 rpm to 500 rpm, used in his experiments. Also, as a result, Crowther discovered that he could not obtain even distribution by a centrally-fed distributor.

Inns and Reece (7) reported the impossibility of predicting the direction and velocity of a single irregular surfaced particle. They concluded that it is possible, however, to predict direction and average velocity of particles by assuming the particles as spherical.

In a study of ballistic behavior of the particles, Cunningham (4) investigated the performance characteristics of bulk spreaders for granular fertilizer. In this study, air resistance, particle size, density and shape factors were noted. He obtained three different curves representing the ballistic behavior of his samples.

Study of motion, sliding and rolling, by Patterson and Reece (11) was done using a horizontal distributor. They found that spherical particles which can roll can be assumed to leave the disc with the maximum velocity. A particle which slides all the way along the disc will leave with the minimum velocity.

Mennel and Reece (10), completed a comprehensive study of horizontal centrifugal distribution and summarized their conclusions in six points:

1. Air resistance can not be neglected in the computation of the trajectory of even the largest fertilizer particles.
2. The air flow around the granular and crystalline fertilizer most commonly spread centrifugally on the farm is turbulent.
3. Separation of particles due to size differences may be considerable for fragile crystalline fertilizers, but can be very small for homogeneous granular material.
4. Unless the blades are specially shaped, a centrifugal

distributor will project material at quite large angles to the plane of the disc. This will result in large variation of range.

5. The range of a normal distributor with a low disc and flat trajectories is much affected by pitching and rolling as the machine moves over rough ground.
6. A distributor with low projection velocities will have a particular range that is less affected by particle size, initial projection direction and machine movement, than one with high velocities.

Previous to 1973 aerodynamic resistance coefficients [k] had been determined and were used in calculating the trajectory of a particle through a fluid. At this time Law and Collier (9) derived k factors for common agricultural products. These coefficients are necessary in the equation of motions for these particles.

With the aid of these k factors, Davis and Rice (5) designed a computer program to predict the theoretical distribution of the particles. They found their results closely resembled the data recorded from experimental field use. The accuracy of the computed results proved them to be of great help in later theorical studies of particle motion. They showed a cone installed in the center of a horizontal disc distributor would give more accurate placement of material on the disc. The accuracy of the placement caused the application rate near the center of the swath to be reduced and the effective swath width increased.

The blades on horizontal discs have the most influence on distribution. Alizadeh (1) used an electronic analog computer to solve a theorical equation developed by Cunningham. Cunningham and Chao (3) studied the relationship of blade design and the effect on particle distribution. The distributor disc was made of a disc with 14.5 degree straight forward and 4.7 degree straight backward blades. They indicated that the use of two different pitch blade angles should provide a positive means of imparting divergent velocities to particles.

Whitney and Roth (15), in studying the behavior of ticks at the presence of solid $CO_2$ pellets (1 to 6 cm diameter and 1 to 3 cm long), used a vertical wheel distributor system with two blades for $CO_2$ distribution. The resulting distribution tick control was reported satisfactory (Figure 3). Regarding the importance of the blades, Patterson and Reecé (11) found the principle factor controlling the motion of a particle to be the coefficient of friction relative to the blade and the shape, which decided whether or not it has any possibility of rolling along the blades instead of merely sliding.

The results of these studies indicate that the centrifugal-type distributor would be more economical and useable if the equipment design, specially the blades and feeding system, are proper.

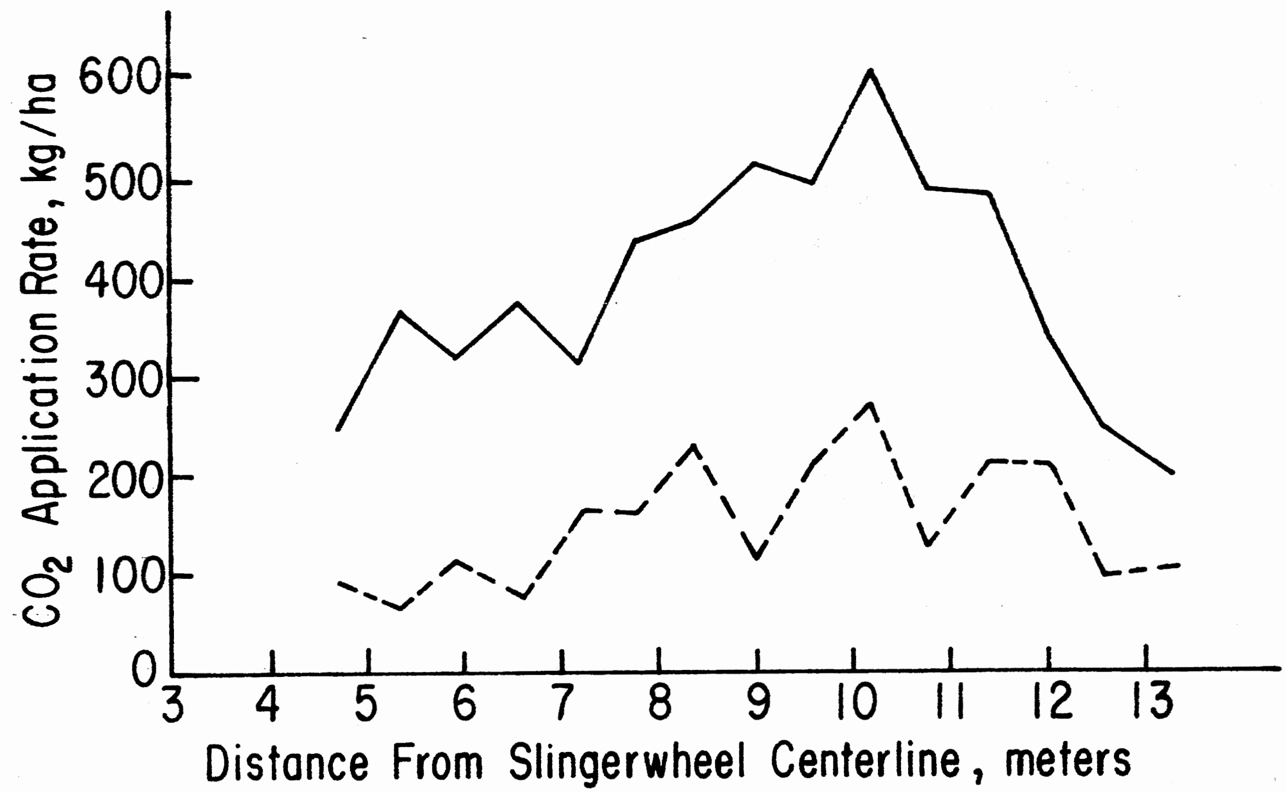



Figure 3. Distribution of Solid $CO_2$ Pellets from Vertical Distributor (15)

# CHAPTER III

## THEORY

A pellet trajectory through the spreader is constrained to follow the rotation of the wheel and the curvature of the blades during the time it is in contact with the blade. When the pellet is not contacting the blades, it's motion is that of a projectile under the influence of gravity.

### Motion Along a Smooth Blade

Consider a single particle in contact with a blade at a point distance r from the wheel center. When the particle drops on the blade at $\theta = 0$ (Figure 4) the following components of motion are known:

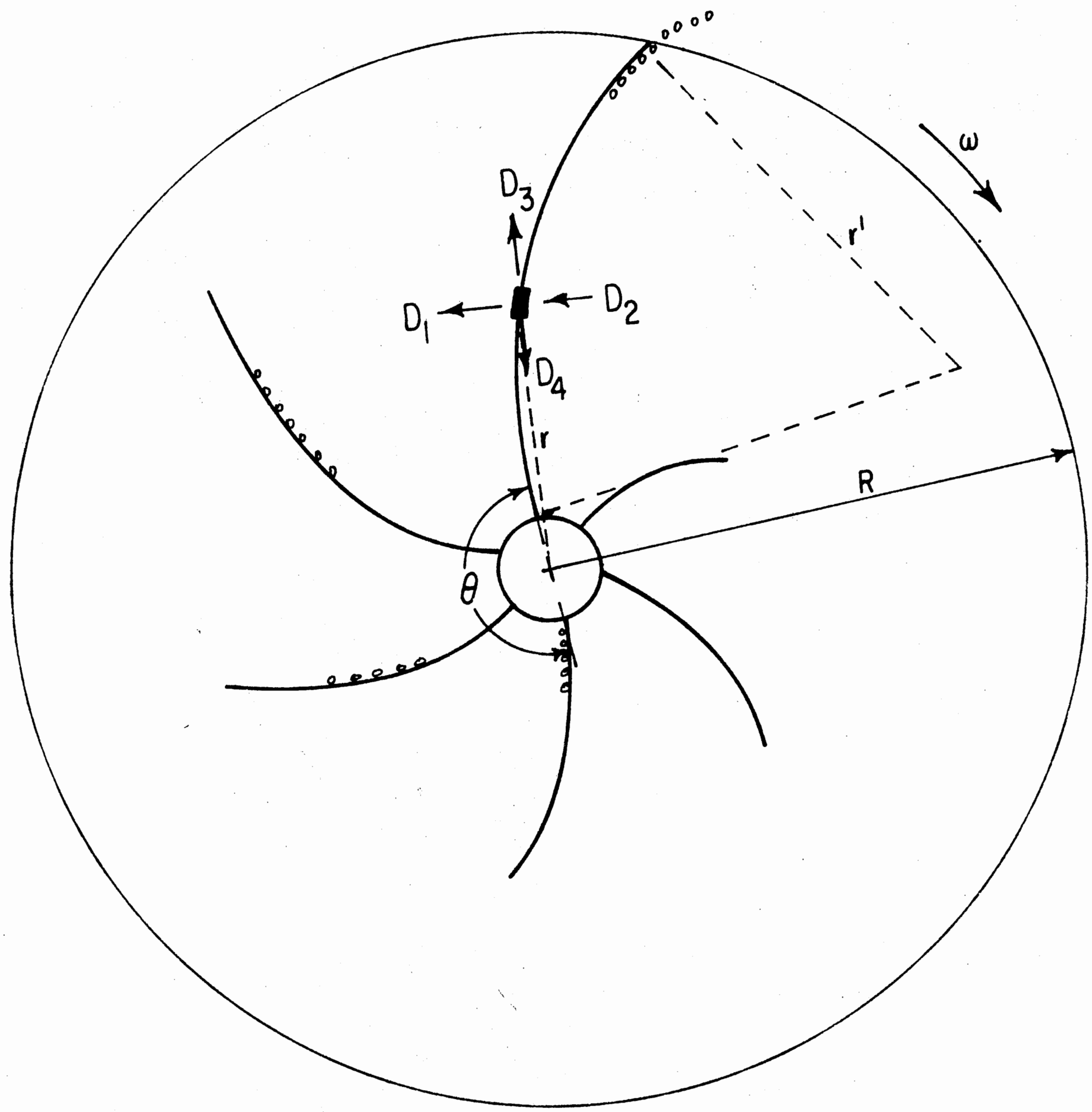
$\frac{1}{r} \, d^2r/dt^2$ = The component created by the shape of the blade.

$2\omega \; dr/dt$ = Coriolis acceleration, which is twice the vector product of the particle velocity, and angular velocity ($\omega$), acting toward the center of the wheel.

$\omega^2 r \, \text{Sin } \beta$ = An acceleration of the particles acting away from the center of rotation.

$d^2r/dt^2_{\text{gravity}} = g \text{ Cos } \theta$

= The radial acceleration due to the




$D_1$ = The acceleration created by the shape of the blade

$D_2$ = Corilios acceleration

$D_3$ = Centrifugal acceleration

$D_4$ = Gravity acceleration

Figure 4. Side View of Vertical Wheel Showing Pellet Acceleration Diagram

gravity toward the center of the wheel.

$d^2r/dt^2_{friction} = -\mu g \, Sin\theta$

The radial acceleration due to the friction.

The resultant summation of the last two components is: $g(Cos\theta - \mu Sin\theta)$, and the total acceleration causing the motion of the particle along the smooth blades is:

$$(1 - \frac{\mu}{r}) \frac{d^2r}{dt^2} = 2\omega\mu \, dr/dt + \omega^2 r \, Sin\beta + g(Cos\theta - \mu Sin\theta) \qquad (3.01)$$

In order to simplify the above equation, the following assumptions were made:

1. The effect of air resistance within the blades is negligible.
2. Bouncing does not occur since the particles are fed on the wheel with minimum initial velocity and minimum impact.
3. The particles are assumed as a single particle moving along the blade.
4. The blades are assumed to be radially straight.
5. The rotation angle (θ) is assumed to be 180°, that is, when the particle goes out of the wheel at the top portion (point 0 in Figure 5).

The above assumptions, result in equation (3.01) being reduced to a relationship for the granular particle motion along a vertical, radial blade, wheel. This equation (3.02) is similar to the one, stated by Patterson and Reece (11):

$$\frac{d^2r}{dt^2} = \omega^2 r - 2\mu\omega \, dr/dt - g \qquad (3.02)$$

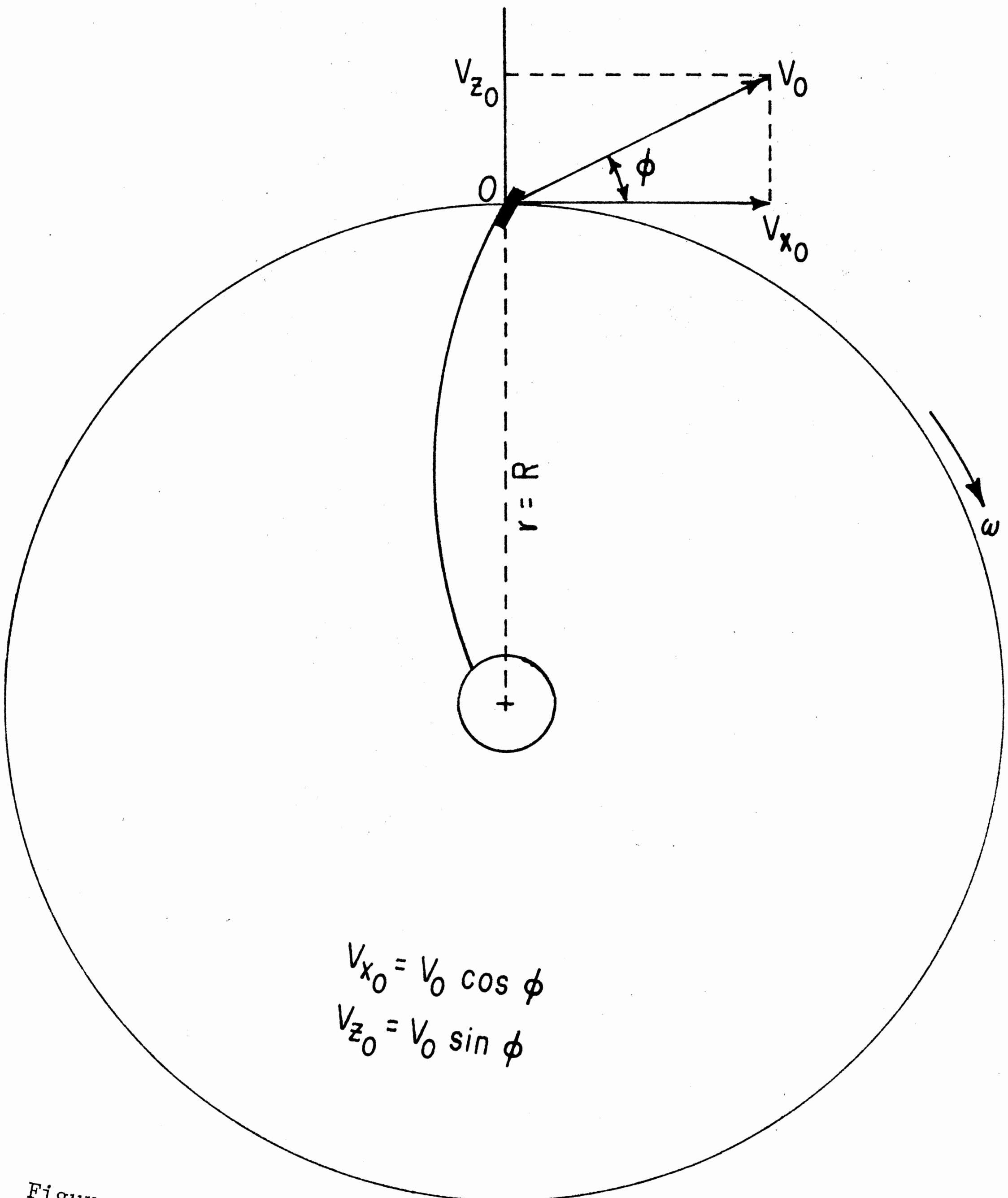



Figure 5. Side View of Outlet Velocity (Theoretical)

A significant factor that affects the distributor performance and validity of the above equation for the vertical wheel distributor is the location at which the pellets are introduced to the blades with the minimum initial velocity.

The simplified equation 3.02 was used to predict the velocity of particles at the point where they leave the wheel. For the vertical wheel the departure point was assumed to be at the position of 0 (Figure 6) and the motion was assumed to occur only in the XZ plane. The resultant velocity of the particles at point 0, which is Vo (the diagonal of XZ plane), is shown in Figure 6. From this figure, the two following trigonometric relationships were obtained:

$$V_{Xo} = Vo \text{ Cos } \phi \qquad (3.03)$$

$$V_{Zo} = Vo \text{ Sin } \phi \qquad (3.04)$$

## Projectiles

Consider the motion of a projectile, regarding the problem to be that of a particle moving in two dimensions in a uniform gravitational field. The factors affecting this motion were the influence of air resistance, shape of the particles, and angle of outlet. Assuming that the projectile starts from point 0 (Figure 6), as an origin (0,0,0) and motion happens in plane XZ which $V_y = 0$ (13):

$$X = V_{X_o} \, t \qquad (3.05)$$

$$Y = 0 \qquad (3.06)$$

$$Z = V_{Z_o} \, t - \frac{1}{2} g t^2 \qquad (3.07)$$

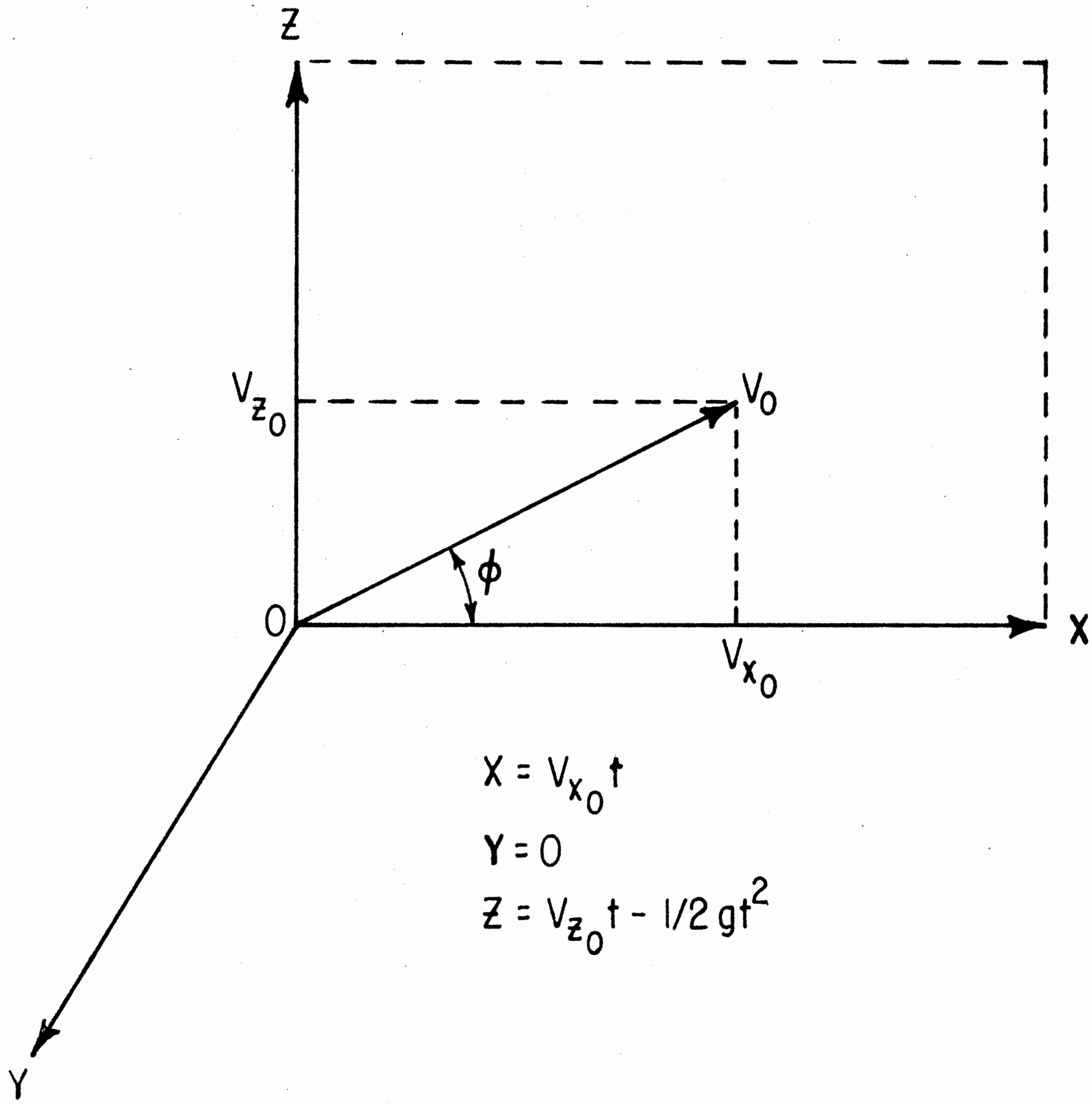



Figure 6. Resultant Velocity Component

and

$$X_m = \frac{2V_{x_o} V_{y_o}}{g} \tag{3.08}$$

When there is no air resistance, the equation (3.08) is useful. The problem of the motion of a particle in a viscous medium, such as air for a wide range of velocities is a complicated one. It is usually assumed that the air resistance is proportional to a power of n of the velocity:

$$R = KSV^n = KS\left(\frac{d^nX}{dt^n}\right) \tag{3.09}$$

Maximum Distance Equation

The velocity of the particle at the leaving point (0) on the vertical wheel was used as the initial velocity for the projectile equation. Equation (3.02) is a second degree differential equation inform of:

$$\ddot{r} + A\dot{r} + Br = C \tag{3.10}$$

The solution of this equation, when the initial conditions are $t = 0$, $r = 0$ and $V_{i_o} = 0.8$, is:

$$V_{i_o} = \sqrt{2gX_{i_o}} = 0.8 \text{ m/sec} \tag{3.11}$$

r = particular solution ($r_p$) + solution of homogenous equation ($r_c$).

$$r = r_p + r_c \text{ hence } r_p = \frac{g}{\omega^2} \text{ and } r_c = C_1 e^{\lambda_1 t} + C_2 e^{\lambda_2 t} \tag{3.12}$$

from the polynomial equation:

$$\lambda^2 + 2\mu\omega\lambda - \omega^2 = 0 \quad \text{implies} \quad \begin{aligned} \lambda_1 &= -\mu\omega + \omega\sqrt{\mu^2 + 1} \\ \lambda_2 &= -\mu\omega - \omega\sqrt{\mu^2 + 1} \end{aligned}$$

where using initial condition $t = 0 \begin{array}{l} r = 0 \\ V_{i_o} = 0.8 \end{array}$ and following parameters:

| | | |
|---|---|---|
| $\mu = 0.4$ | | was measured |
| $\omega = 750$ RPM $= 78.3$ | | rad/sec |
| $k = 0.03$ | assumed the particle were spherical | |
| $S = 9.6 \times 10^{-6}$ | (average particle radius = 3.5 mm) | $m^2$ |
| $g = 9.81$ | | $m/sec^2$ |
| $\phi = 55°$ | | degree |

resulted the solution for equation (3.02):

$$C_1 = 2.77 \times 10^{-3} \quad \text{and} \quad C_2 = -3.41 \times 10^{-3}$$

therefore,

$$r = 2.77 \times 10^{-3}\, e^{53.01t} - 3.41 \times 10^{-3}\, e^{-115.65t} + 1.6 \times 10^{-3} \quad (3.13)$$

and

$$\frac{dr}{dt} = V_o = 1.47 \times 10^{-1}\, e^{53.01t} + 3.95 \times 10^{-1}\, e^{-115.65t} \quad (3.14)$$

Since the relationship (3.09) is assumed to be linear, considering equation (3.08), the resultant equation after simplifying, was obtained:

$$X_m = \frac{2V_{X_o} V_{Z_o}}{g} - 8/3\, \frac{KSV_{Z_o}^2 V_{X_o} V_o}{Mg^2} \quad (3.15)$$

where the equation (3.03) and (3.04) exist, the equation (3.15) is reduced to:

$$X_m = \frac{V_o^2 \mathrm{Sin}2\phi}{g} - 8/6 \frac{KSV_o^4 \mathrm{Sin}\phi \ \mathrm{Sin}2\phi}{Mg^2} \tag{3.16}$$

or

$$X_m = 0.096\ V_o^2 - 3 \times 10^{-9}\ V_o^4/M \tag{3.17}$$

The $V_o$ for each blade was found by equation (3.17).

## CHAPTER IV

## DESIGN AND INSTRUMENTATION

The slinger wheel was assembled in the Agricultural Engineering Laboratory. Figure 7 is a picture of the over all slinger driving system. It was deemed necessary to discuss only those parts of the distributor which relate to dispersal of the clay particles which are:

### Blade Shape Design

The first step in design procedure was the choice of blade shape. The primary objective in mind was to use the combination of several different blade shapes between the two plates to achieve a wide range of particle trajectories. Four alternative type of blade shapes were considered.

1. A combination of six arc circular blades with equal length and unequal discharge angles.
2. A combination of six arc circular blades with unequal length and equal discharge angles, Figure 10.
3. A combination of two radial, two forward pitch, and two arc circular blades with equal length and discharge angles, Figure 8.
4. Case number three, with unequal blade lengths.

Studies by Jorgensen (8) showed that the curved tipped blade provided the maximum head energy for given a rotor size. Also it showed,

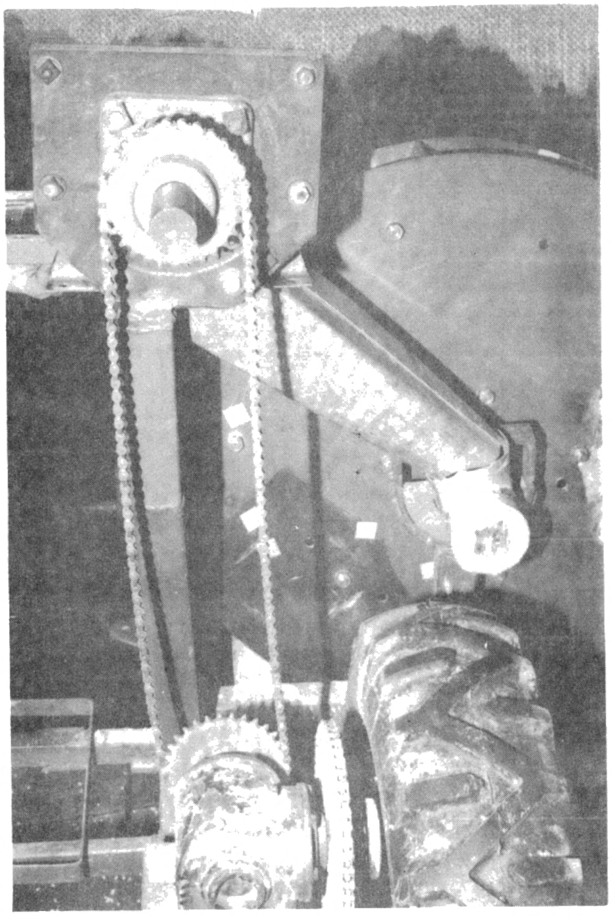


Figure 7. The Slinger Driving System

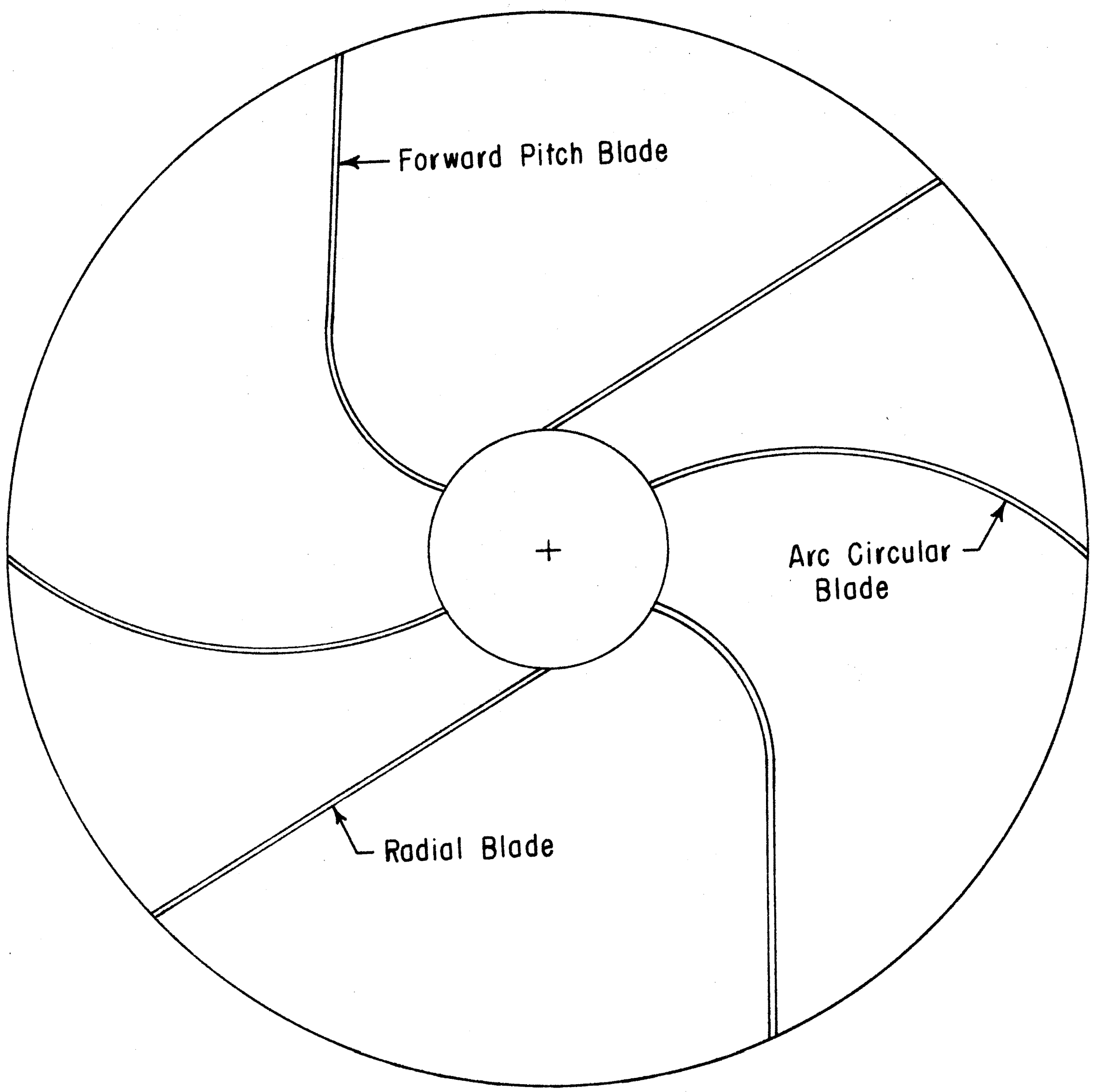



Figure 8. Side View of Radial, Forward Pitch, and Arc Circular Blade's Wheel

the arc circular shape blade not only minimized the amount of impact on pellets, but also permitted the use of arbitrary entry and discharge angles. Therefore, the decision was made to construct case two, six arc circular curved blades.

Table I presents the specifications for the blade's construction. The parameters shown in this table are:

$r'$ is the radius of blade curvature which was found for each individual blade based on the fan formulation laws.

c Figure 9, is the distance of first blade connection to the wheel, from the feeding orifice. An attempt was made to construct the distance c equal for all the blades.

b is the distance of the second blade connection from the blade tip.

The value of $9.65 \text{ mm} \leq f \leq 47 \text{ mm}$, shown in Figure 10, was chosen for the six blades. The blades were identified by number, number one through six, number one refers to the longest blade and number six refers to the smallest.

## Length of the Blades

The following explanation will demonstrate the calculations necessary to determine the lengths of the curved blades for the slinger wheel.

The pellets were distributed by the six unequal length blades, as was mentioned before. To calculate the blade's length it was desired to consider the mass of a single pellet, the effect of air resistance, impact, wheel RPM, and discharge angle. These conditions were satisfied by the equation 3.17. According to this equation, the optimum trajectory distance coverage was decided to be 21.8 m. Since there were six

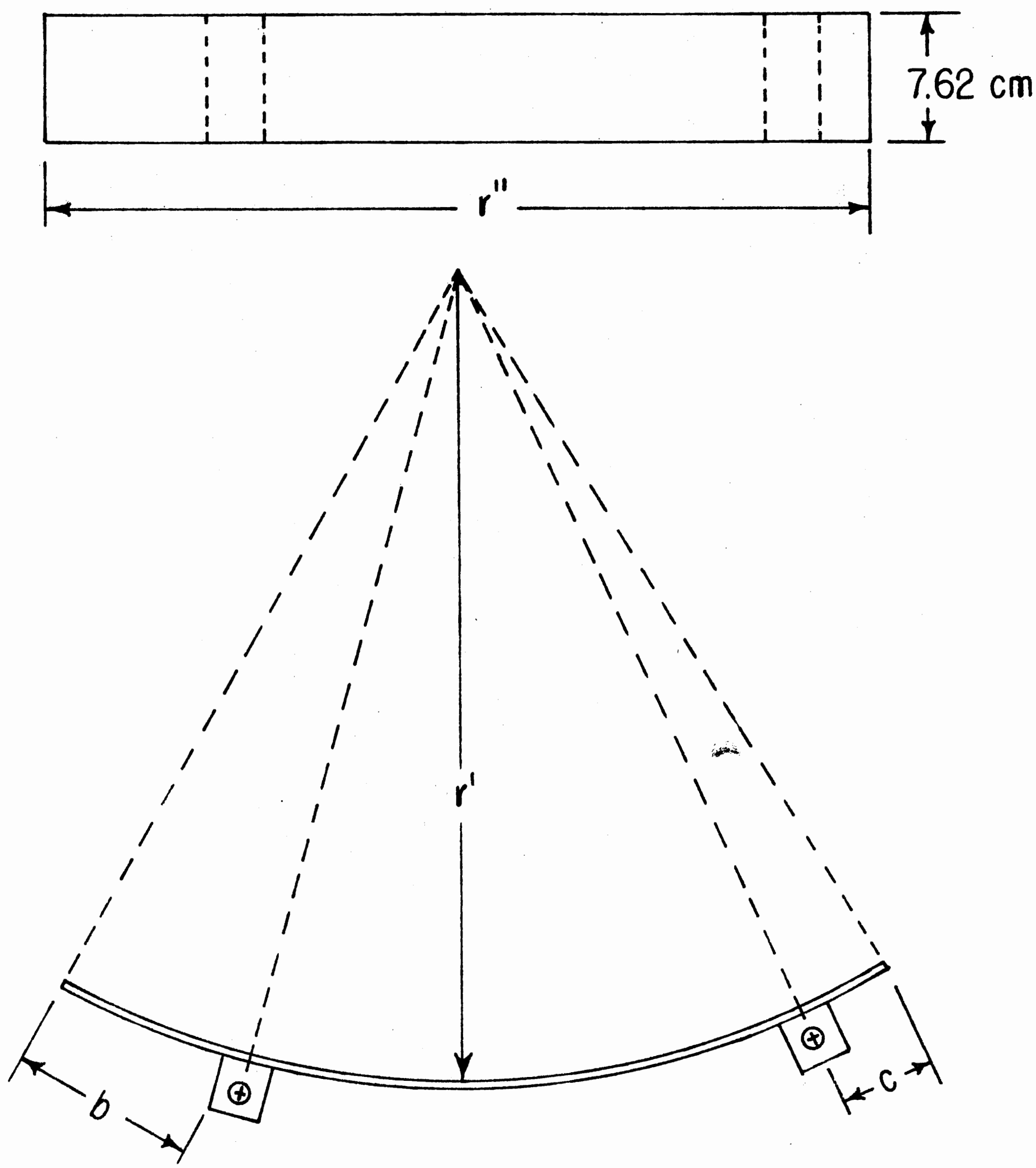



Figure 9. Arc Cicular Curve Blade Diagram

TABLE I

ARC CIRCULAR CURVED BLADES
SPECIFICATION

| Blade Number | c<br>m | b<br>m | r´<br>m |
|---|---|---|---|
| 1 | 0.038 | 0.083 | 0.338 |
| 2 | 0.038 | 0.064 | 0.292 |
| 3 | 0.038 | 0.074 | 0.248 |
| 4 | 0.038 | 0.067 | 0.201 |
| 5 | 0.038 | 0.035 | 0.152 |
| 6 | 0.047 | -- | 0.067 |

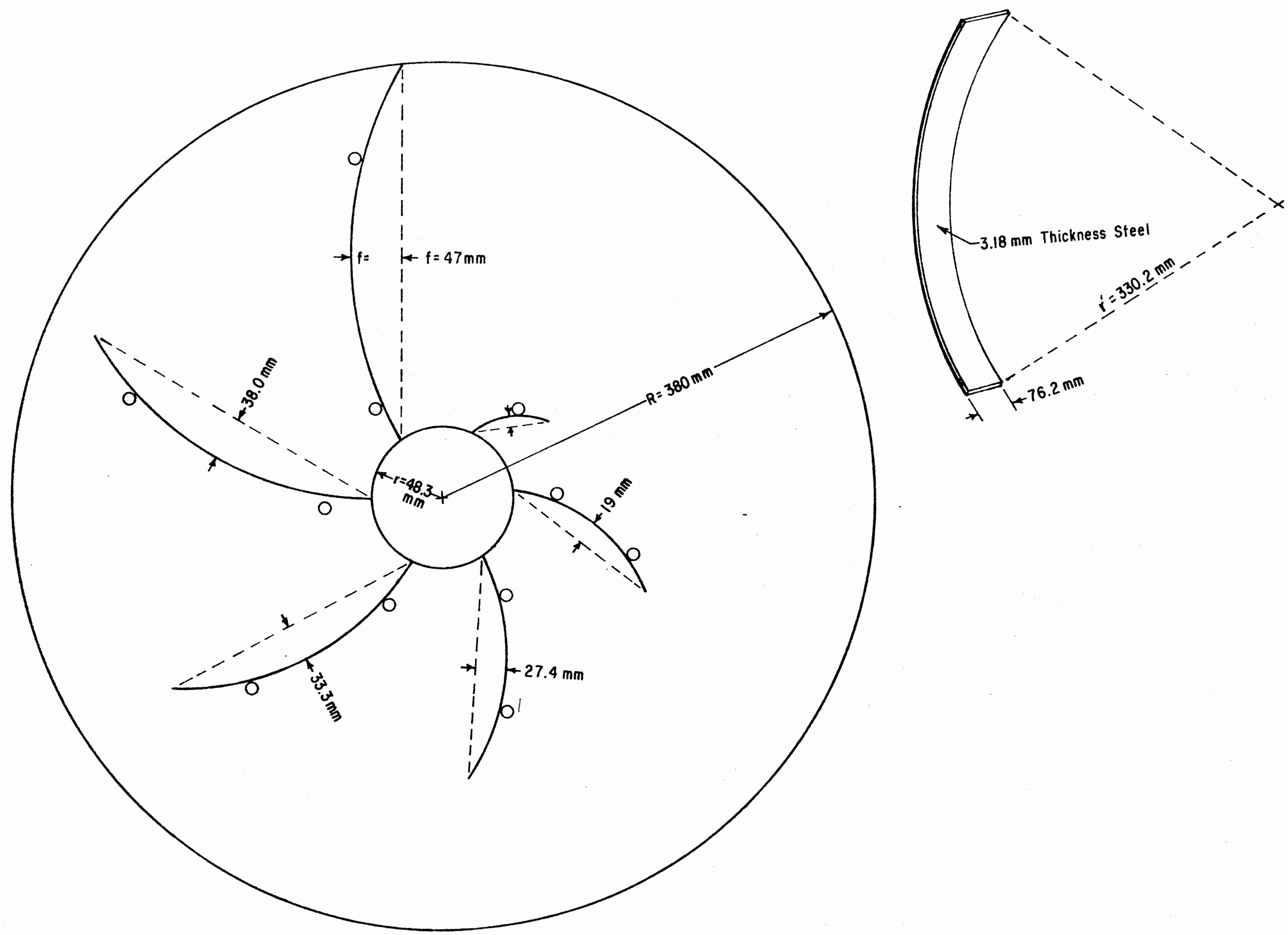



Figure 10. Side View of Blade's Specification

blades, each blade had to cover 3.7 m length to obtain a uniform distribution.

The parameters presented in Table II are, calculated from equations 3.17, 3.14, and 3.13, and it should be recognized that because of the variation in pellet size and mass, the single pellet mass used in all above calculations was chosen from sieve number seven.

## Blade Arrangement

A flow of air into the wheel, causing pellet interaction, was expected to be more significant for clockwise blade arrangement than counterclockwise. To investigate this portion of the design, a qualitative test was conducted to evaluate the effect of the air flow pumping into the wheel caused by rotation and the resulting interaction of the pellets. The expected situation occured resulting in severe interaction of the particles. This is shown by Figure 11, the pattern of particle interaction on the wheel plate in clockwise arrangement, and Figure 12, the interaction pattern in counterclockwise. The test showed that interaction for clockwise blade arrangement was greater than for counterclockwise. It was realized that the air flow into the wheel was only one cause of pellet interaction. The method of feeding pellets into the wheel was also significant.

The most critical aspect of the blade design was the blade angle. The angles used in the initial design was 55 degrees for all the blades, but in order to reduce the interaction between the pellets in the outlet, the discharge angle for blade number one (the longest blade) and number six (the shortest blade), were chosen to be 60 degrees and 45 degrees respectively. The rest of the blade discharge angles were

TABLE II

BLADE LENGTH SPECIFICATION

| Blades Number | $X_m$ Meters (m) | V m/sec | t sec | r" m | R m |
|---|---|---|---|---|---|
| 1 | 21.8 | 17.7 | 0.0904 | 0.330 | 0.381 |
| 2 | 18.3 | 15.6 | 0.0880 | 0.295 | 0.343 |
| 3 | 14.6 | 13.5 | 0.0853 | 0.256 | 0.305 |
| 4 | 11.0 | 11.4 | 0.0819 | 0.214 | 0.263 |
| 5 | 7.3 | 9.1 | 0.0778 | 0.173 | 0.221 |
| 6 | 3.7 | 6.3 | 0.0708 | 0.120 | 0.168 |

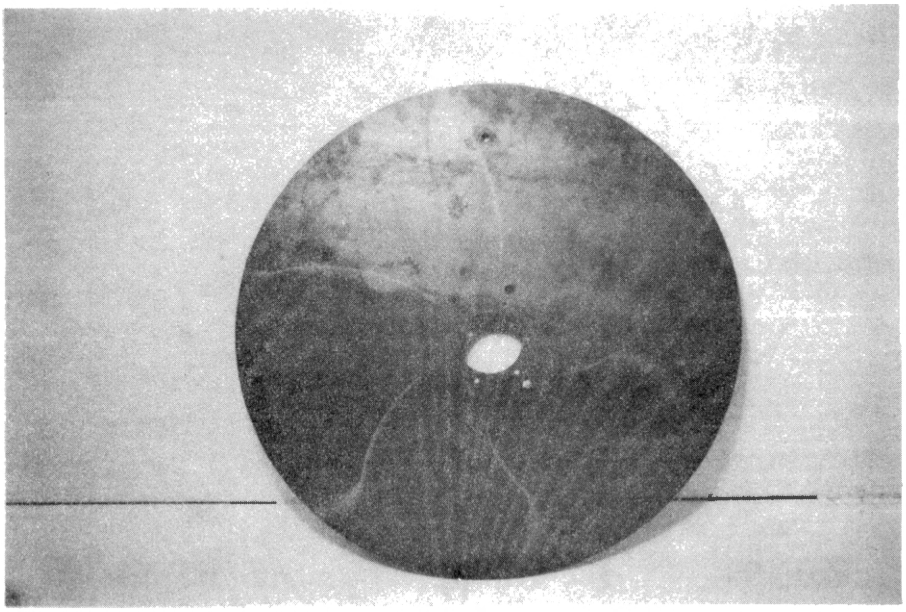


Figure 11. Pellet's Interaction Patterns on Wheel, in Clockwise Arrangement

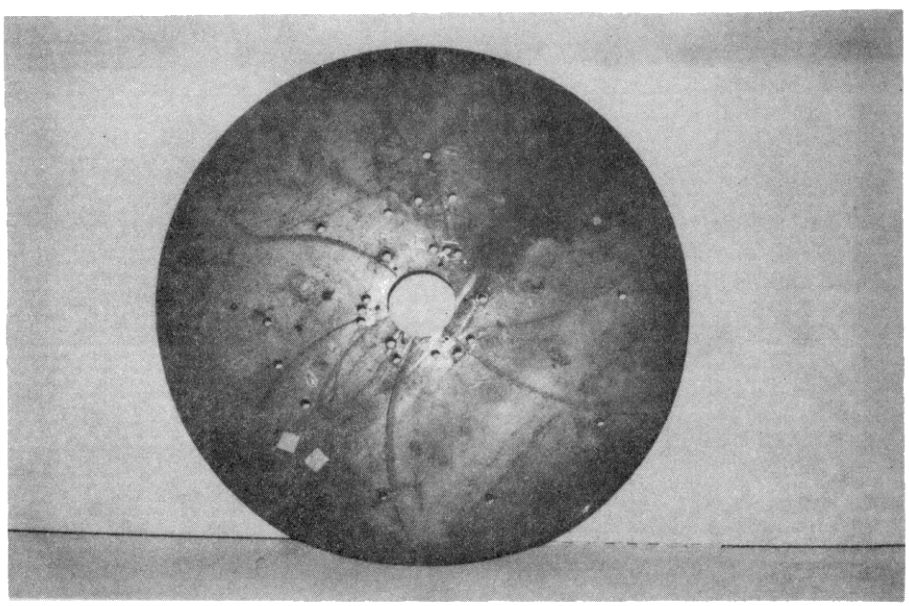


Figure 12. Pellet's Interaction Patterns on Wheel, in Counterclockwise Arrangement

kept at 55 degrees. More detail on the discharge angle combination is presented in the test procedure of Chapter V.

## Wheel Plate Design

The wheel plates were made of hot roll steel 0.0032 m thickness with radius of 0.38 m. A feeding orifice was designed with the radius 0.048 m at the center of the cover plate to provide an inlet area for the pellets. On each plate and for each blade attachment, two holes were drilled. Adjustment holes were provided for changing the blade discharge angles.

## Balancing the Wheel

One of the requirements of the vertical slinger wheel operation was the uniformity of mass in all point of the wheel. Identifying the mass concentration point on the wheel, by the graphical centroid method, permitted in balancing the wheel with a 0.65 kg weight at point G', 26.7 cm from the wheel center, Figure 13.

## Shielding

As Figure 14 shows, a steel safety shield was installed. This shield served as a safety device to prevent randomly dispersed pellets from striking the tractor driver. Another function for the shield was to correct the direction of the random spread pellets.

## Central Feeding Auger

The entry point of the particles was recognized to be one of the most important variables affecting the performance of vertical slinger

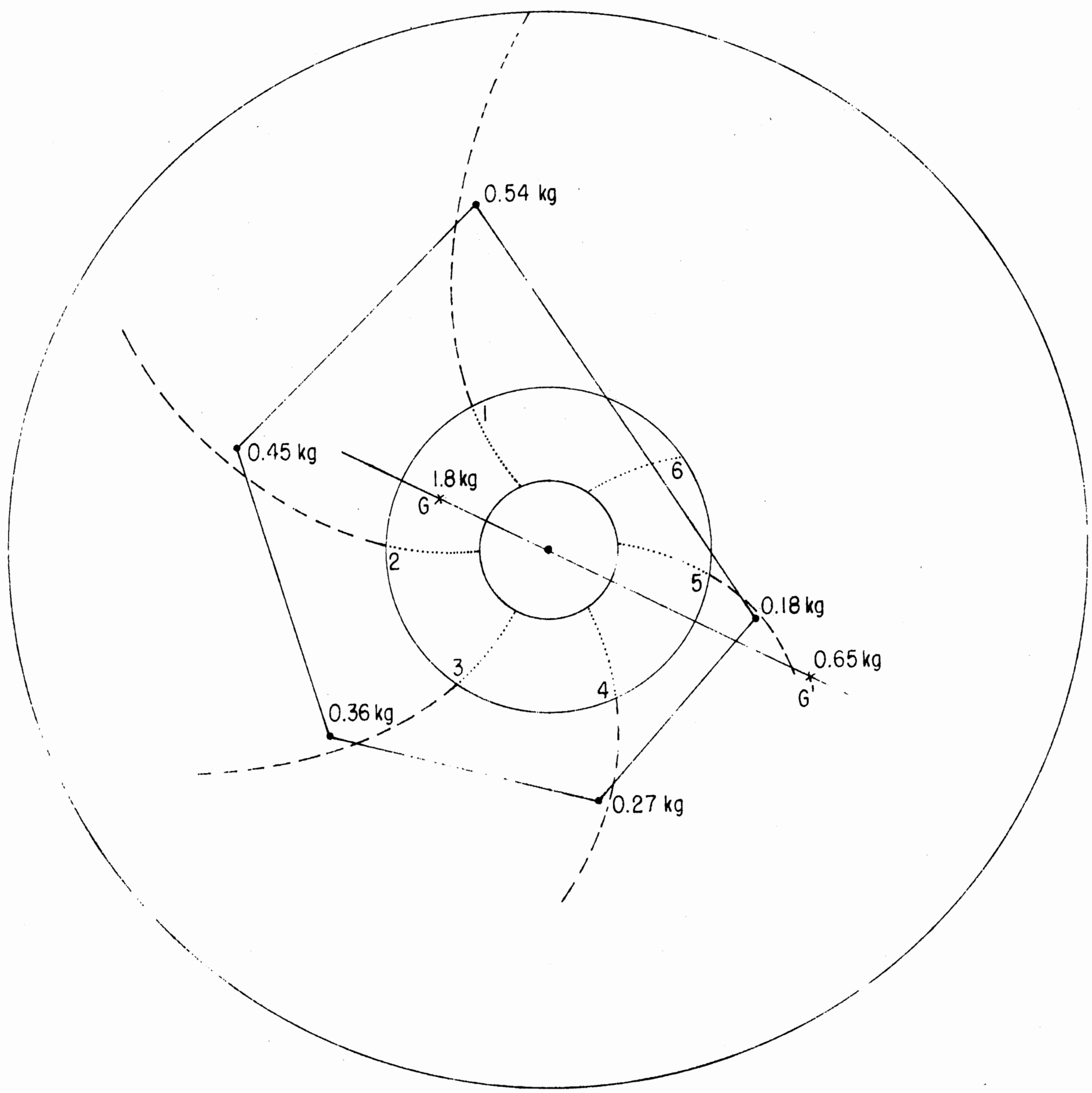



Figure 13. Vertical Slinger Wheel Centroid, Balancing the Wheel

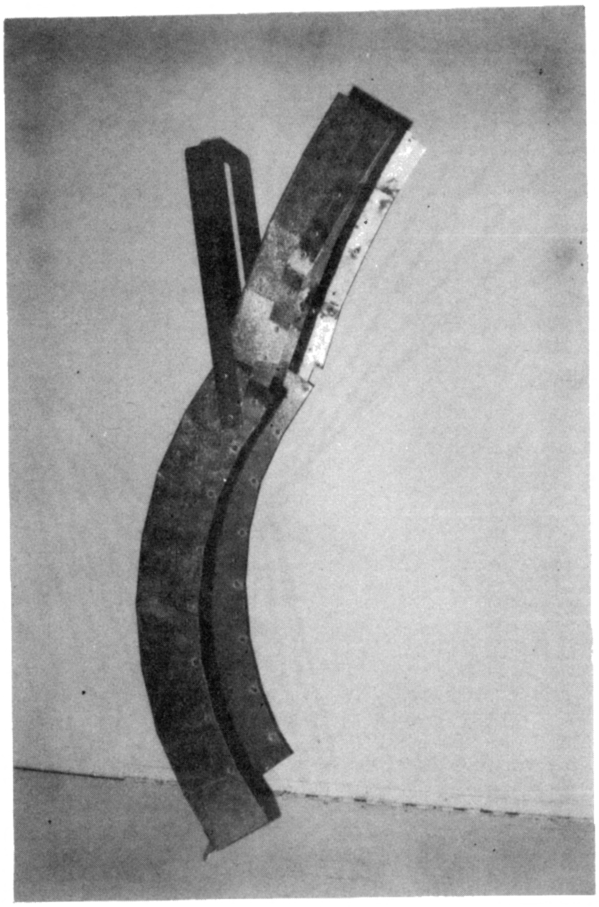


Figure 14. Safety Metal Shield

wheel. To reduce the perturbing effect of radial entry velocity of the pellets and to reduce pumping of the air through the wheel caused by rotation of the wheel, a feeding screw — type conveyer was used instead of a gravity feeding system, as they are shown in Figures 15 and 16.

The auger conveyer (screw conveyer) was designed based on the following formula:

$$C = \frac{(D^2 - d^2)\ PNE}{75 \times 100}$$

As the Figure 17 shows, a helix was fabricated within a cylindrical pipe in horizontal position. The helix shaft was connected to the center of the slinger wheel and was thus driven at the same RPM as the wheel. The pipe was free from the wheel supported from the distributor frame. Along the bottom of the pipe inside the wheel, a 2.5 by 7.6 cm rectangular orifice, Figure 18, was provided to allow the particles to drop vertically into the slinger wheel on the blades. At the entry end of the pipe, the pellets were fed in from the hopper.

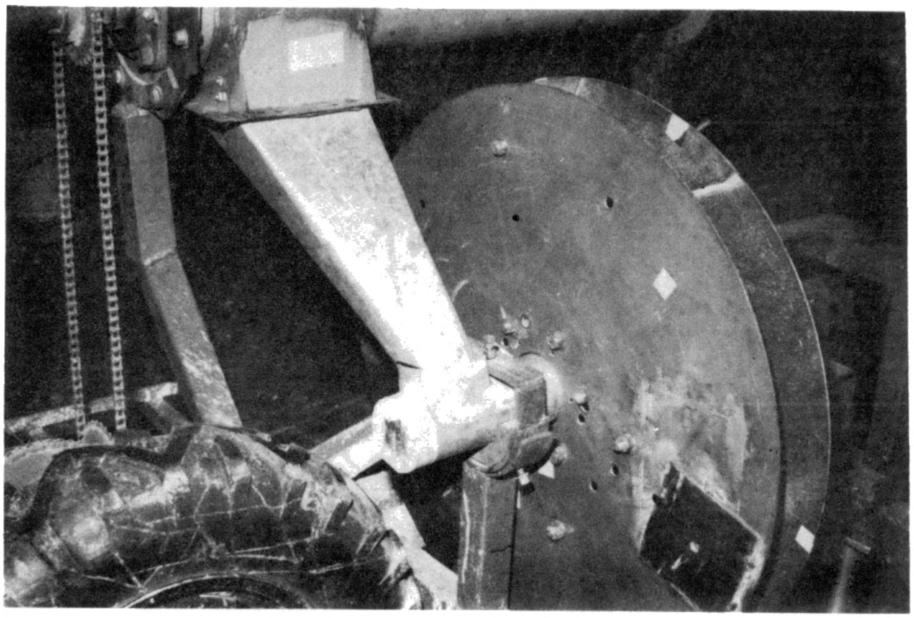


Figure 15. Central Feeding Auger System

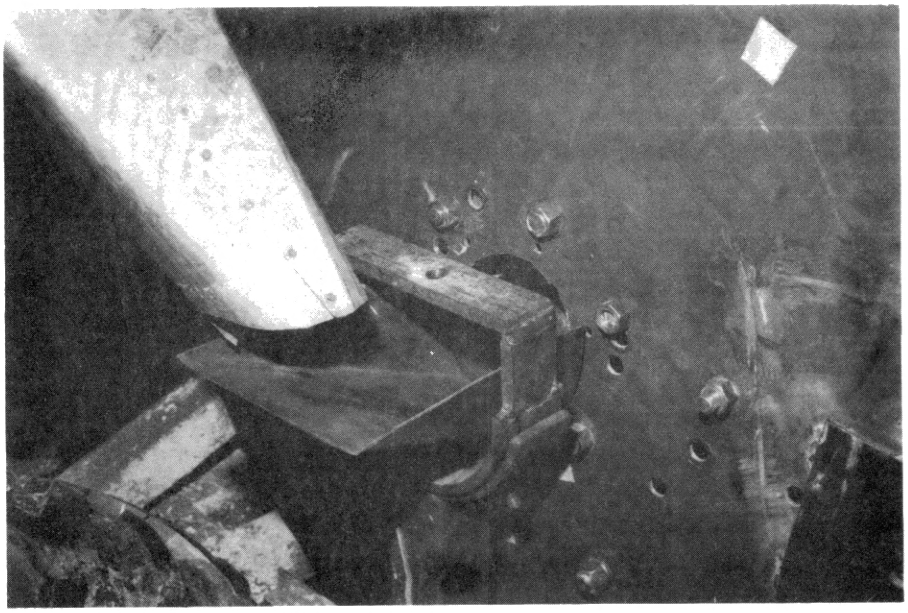


Figure 16. Gravity Feeding System

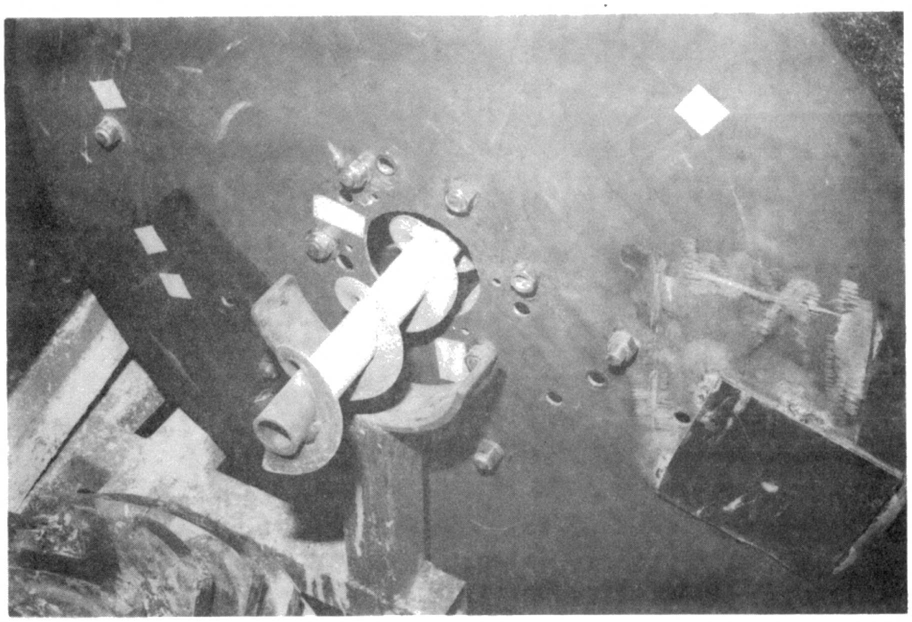


Figure 17. Auger Helix Connection to the Center of the Slinger Wheel

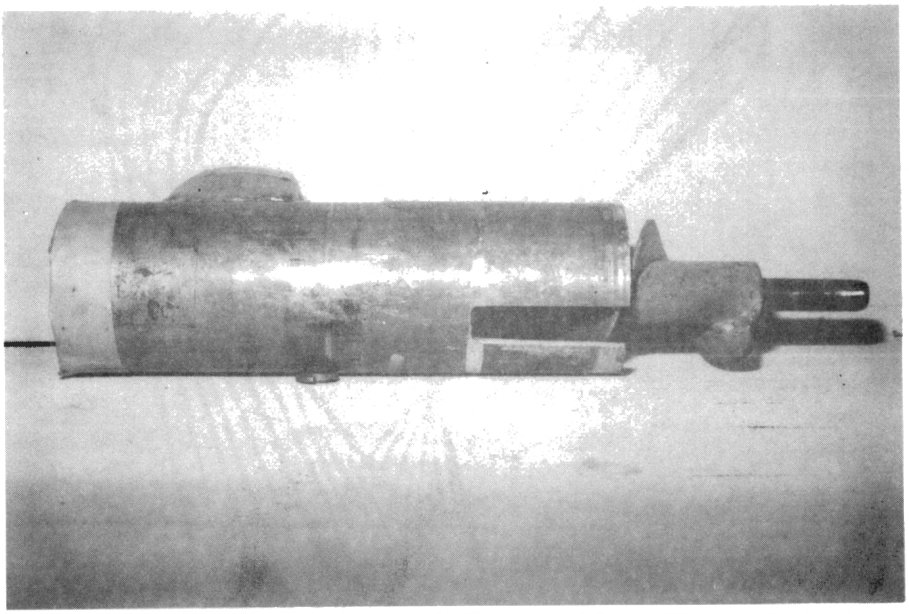


Figure 18. Auger Feeding Orifice

# CHAPTER V

# EQUIPMENT AND PROCEDURE

For this experiment, the procedure involved the equipment which was used, the test material, the variables affecting the nature of the investigation, method of conducting the tests and evaluation of the distribution.

## Equipment

The facilities used in this experiment consisted of the following:

1. Massey Ferguson tractor 245.
2. The vertical wheel slinger which was described in Chapters I and III.
3. Collection Boxes: The collecting boxes used for all the tests were 102 mm deep inside, 305 mm wide and 228.6 mm long (the length and width are outside dimensions. Groups of five boxes, 13 groups, placed in line to provide a total length of 15.5 m as shown in Figure 19.
4. Series of Tyler sieves: The Tyler sieves were employed to measure the size classification of the pellets.

## Materials

Clay pellets were chosen as the test material. Physical properties of the clay pellets were as follows:

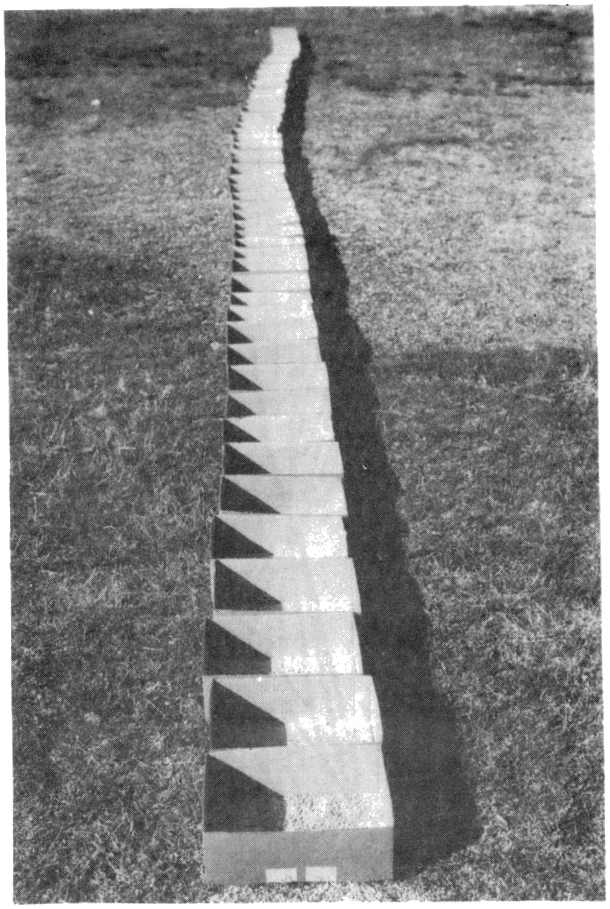


Figure 19. Boxes in Collection Position

1. Shape - Cylindrical
2. Size - the diameter was 3.5 mm and the length less than 10 mm.
3. Density - pellet density varied from 723 $kg/m^3$ to 835 $kg/m^3$
4. Sieve Classification - inspection of five samples of a 100 grams each, resulted in sieve classification shown in Figure 20.
5. Coefficient of Friction - pellet coefficient of friction at 45% humidity, 75°F, and in contact with steel was 0.4

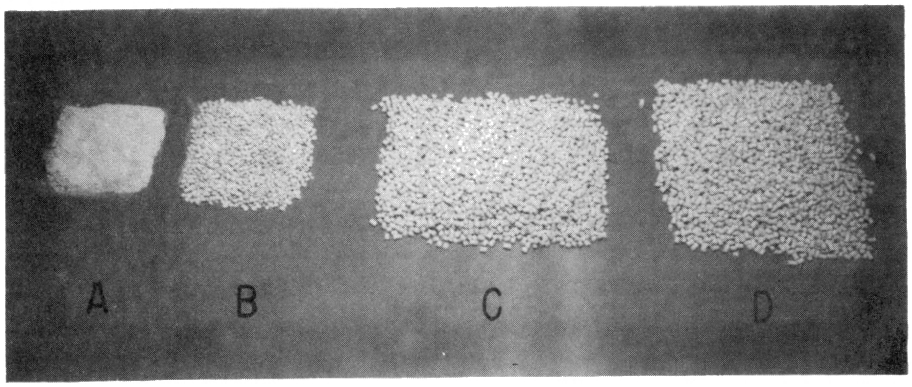
The material was furnished by Elanco Company, Dallas, Texas.

## Procedure

As was discussed in Chapter III, the blades in the vertical slinger wheel were designed based on the formula which was developed to forecast the trajectory motion of granular material.

Among many factors affecting the distribution, the following are the most important regarding this study.

1. Feeding mechanism - According to Rice (5): more accurate placement of material on the horizontal disc will permit more efficient use of the centerifugal distributor for the application of fertilizer, seeds, or a mixture of these materials. The importance of feeding position was evaluated for a vertical slinger wheel by a preliminary investigation and found to be a significant factor. Therefore, a central feeding auger was used to give the




A = Sieves 10, 11, 12 5% of total weight

B = Sieves 8, 9 3% of total weight

C = Sieve 7 67% of total weight

D = Sieve 6 25% of total weight

Figure 20. View of Pellet Classification by Sampling

proper feeding position and establish minimum initial velocity to the pellets, Figure 21.

2. The blade's shape and the amount of particle impact, reference equation 3.01 - The relative velocity component perpendicular to the blade face is reduced. This directional changing of the velocity component reduces the total amount of impact of the pellets on the blade. In all 7 treatments the same arc curve blades shape was used.
3. The blade's length - Because six different blades were designed based on the formula and the clay pellets to give uniform distribution, each blade's length was kept constant in all the tests.
4. The blade's material and friction coefficient - Blades were made of steel and the coefficient of friction was assumed not to change throughout the entire experiment.
5. The pellet's shape and size - The only kind of material used in this experiment was the granular clay pellets with cylindrical shape and 3.5 mm diameter and less than 10 mm length.
6. Slope of the land - The slope of the testing surface has influence on the uniformity of the distribution. All the tests were run on a field with slope of less than 5% and relatively smooth surface.
7. Enviromental conditions - The only way available to control this factor was to choose a day with the wind below eight kmph. The humidity and temperature were not controlled.

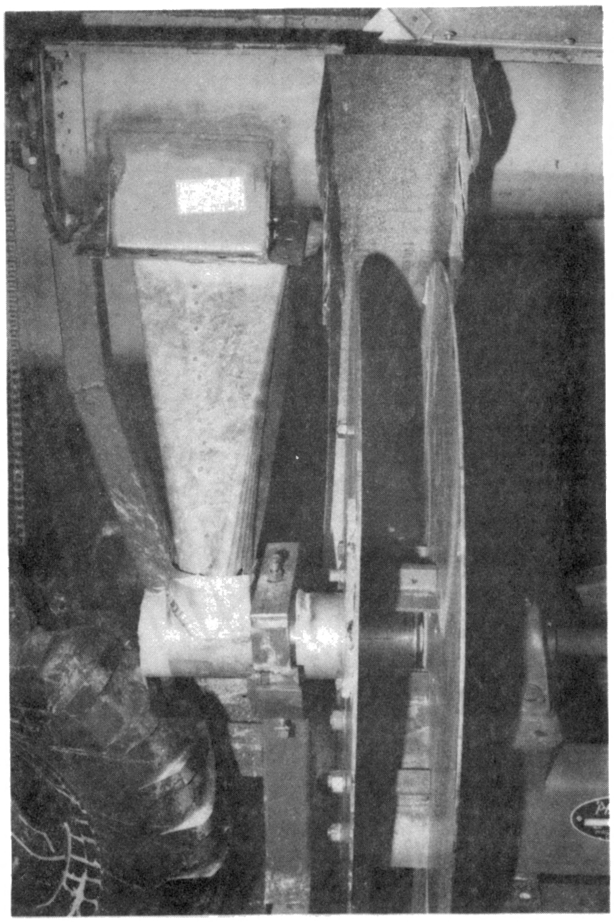


Figure 21. Side View of Feeding Auger in Position of Operation

8. RPM of the wheel - The wheel RPM is one of the more important factors involved in this experiment. The blades were designed for a RPM of 750 and this was kept constant throughout the experiment.

9. Discharge blade's angle - The varying factor in this work, the only key variable in this experiment, is the blade's discharge angle.

Due to the number of factors believed to affect the nature of the distribution process of the slinger, it was decided to hold the first eight factors constant and vary the last one, Table IV. Discharge angle was thus used as the independent variable for evaluation of the distribution performance.

## Test Procedure

A preliminary investigation was done to verify that the optimum discharge angle, assumed to be 55° for six blades in the vertical wheel. This investigation was made with the same conditions, pellets and equipment, as the actual test. The result obtained indicated that 55° was satisfactory for four blades, numbers two, three, four, and five. However, the two remaining blade angles, number one and six, had to be increased and decreased respectively. In this evaluation, the effect of air flow into the wheel was obvious, Figure 11 shows this result. As mentioned in the design procedure, the optimum combination of the six blade discharge angles was termed, "The Main Combination Discharge Angles" (MCD) which are shown in Table III.

TABLE III

MAIN COMBINATION OF DISCHARGE ANGLES (MCD)

| Variable | | | | | | |
|---|---|---|---|---|---|---|
| Blades | 1 | 2 | 3 | 4 | 5 | 6 |
| Discharge Angle Degrees | 60 | 55 | 55 | 55 | 55 | 45 |

TABLE IV

EXPERIMENT TREATMENTS

| | Blade Angles (Degrees) | | | | | |
|---|---|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 | 5 | 6 |
| $T_1$ (MCD) | 60 | 55 | 55 | 55 | 55 | 45 |
| $T_2$ | 55 | 55 | 55 | 55 | 55 | 45 |
| $T_3$ | 65 | 55 | 55 | 55 | 55 | 45 |
| $T_4$ | 60 | 55 | 60 | 55 | 55 | 45 |
| $T_5$ | 60 | 55 | 65 | 55 | 55 | 45 |
| $T_6$ | 60 | 55 | 55 | 55 | 50 | 45 |
| $T_7$ | 60 | 55 | 55 | 55 | 45 | 45 |

## Test Conditions

The test conditions for determining the effect of discharge angle on the distribution uniformity of the vertical slinger wheel were controlled such that all factors except discharge angle were held constant. Due to space limitation inside the slinger wheel, blades number one, three, and five were selected for variation of discharge angles. These variation was provided by several holes on the wheel's plates with two angles being tested in addition to the main angle. Discharge angle of blades number one, three, and five were varied one at a time. Blades number two, four, and six were fixed throughout the entire tests with discharge angles of 55°, 55°, and 45° respectively.

Since each of blade angles one, three, and five varied two times, resulted seven blade angle combinations. Each of these seven was used as a treatment to determine first, the effect of the changing each individual angle upon uniformity of the distribution and second, to choose the best angle combination by the standard agricultural statistical method. Table IV shows the seven treatment discharge angles.

## Technique

The tractor PTO was operated to give the desired wheel rotation speed, a tachometer was employed to set the wheel speed at 750 RPM.

The 66 boxes were used side by side to cover 15.7 meter length and 0.3 meter width, Figure 19. The pellets were conveyed by an auger to the feed chute and then into the central feeding auger. The driving force for metering the material was transfered from the ground wheel, as was explained in Chapter I and Figure 6. The rotation of the wheel at 750 RPM was kept constant in operation throughout the entire experiment, but the flow of the pellets was started 10 m before reaching the collection boxes. The purpose of operating the slinger 10 m before passing the boxes was to establish a steady state condition for pellets flow.

Pellet flow into the central feeding auger was controlled by a gate installed in the feed chute, Figure 22.

## Sampling

The sampling technique was planned so that the data obtained could be analyzed on the standard statistical, Test Procedure for Dry Fertilizer Spreaders, basis.

Pellets were collected from each collection box after 10 passes of the vertical slinger wheel for each treatment. The contents from boxes were placed in plastic bags to be weighed later. All the passes were in the same direction. Three replication of the seven treatments were made.

## Evaluation of Distribution

The ASAE standard method for testing the distribution of dry fertilizer spreaders involves the following formulas:

1. Standard deviation = $\dfrac{\sqrt{\Sigma(x_i - \bar{x})^2}}{n - 1}$

   where

   $x_i$ = the individual reading in grams

   $\bar{x}$ = mean reading = $\dfrac{\Sigma x_i}{N}$

   N = total number of reading

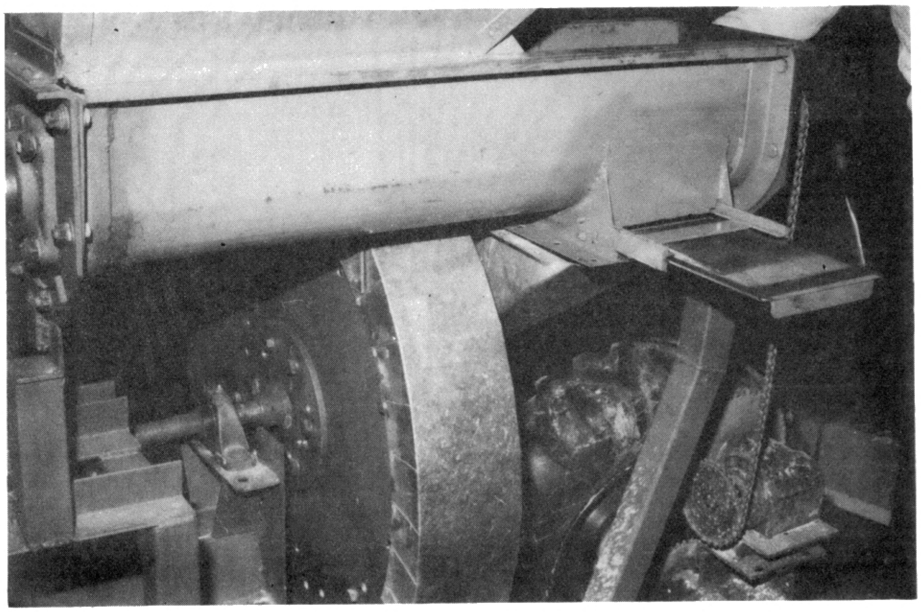


Figure 22. Side View of the Pellet's Flow Controlling Gate

2. Coefficient of variation (C.V.) = $\frac{\text{(Standard deviation)(100)}}{\bar{x}}$

This coefficient shows the variation at the actual application rate.

To follow the standard procedure for evaluation of distribution, the effective spread width and mean application rate line had to be obtained. This is described in Chapter VI in more detail.

# CHAPTER VI

# PRESENTATION AND ANALYSIS OF DATA

## Distribution Uniformity for Different Angle Combinations

The main purpose of this study as stated in Chapter I, was to investigate the distribution of relatively small particles by a newly designed vertical distributor.

The data from each treatment was measured and recorded. These data were used as a measure of uniformity separation of the particles for each of several slinger blade angle combinations. The weight of the particles collected in the area covered by each collection box (kg/ha) was plotted against the distance of each collection box from the center line of the wheel. This was done for all seven treatments. An equation was obtained for each data curve through use of a computer stepwise analysis. The data analysis parameter, and the curves are presented in Figures 23-29.

The data was analyzed by the statistical analysis system (SAS) program to compute the analysis of variance, regression analysis, and stepwise (backward elimination) technique for comparison of the curves obtained. Thus, the effect of each blade angle was determined by curve comparisons. From the stepwise technique, the relationship between the application rate and distance from the tractor wheel center may be written in the following form:

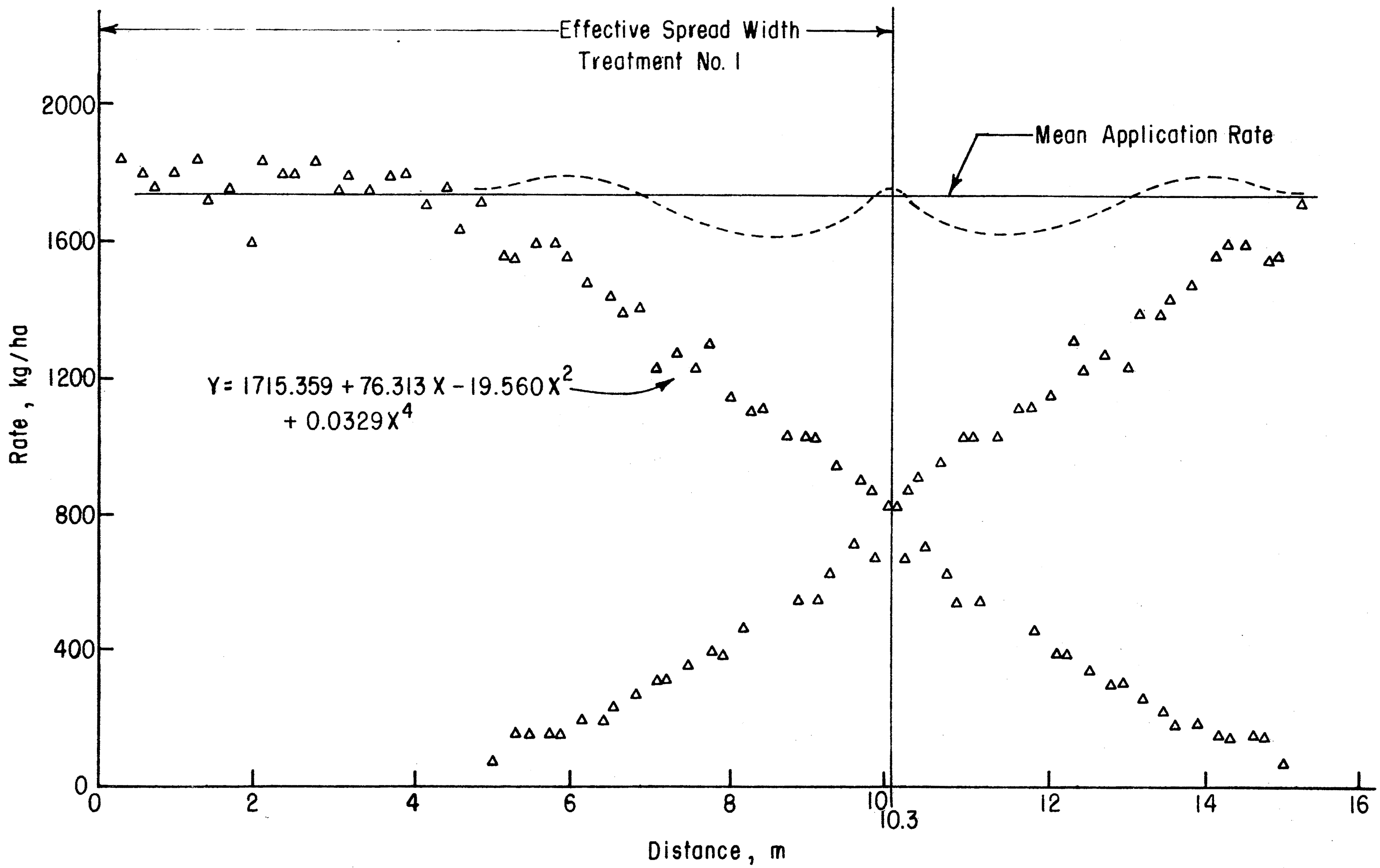



Figure 23. Distribution Pattern for Treatment Number One, Three Replications

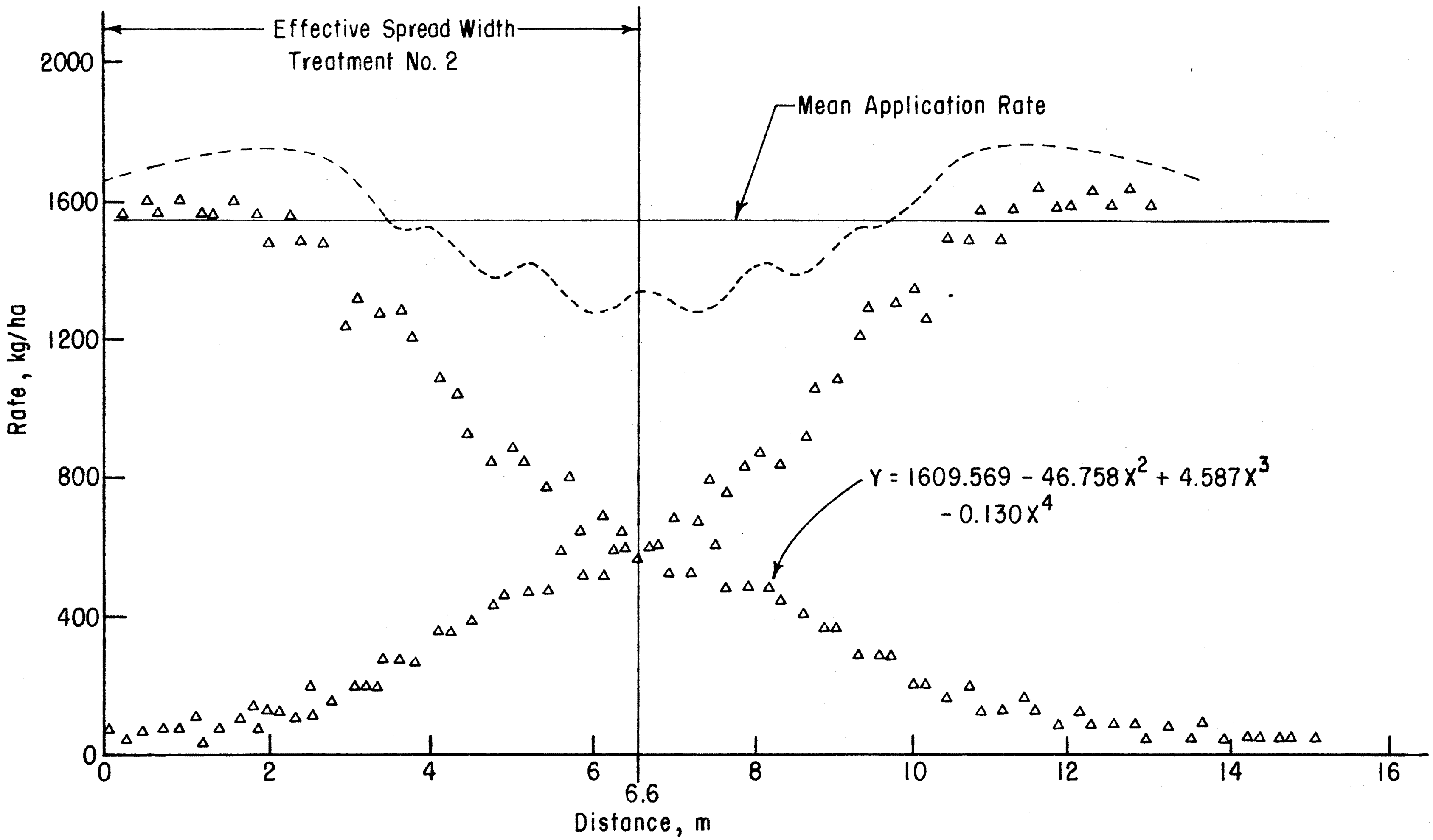



Figure 24. Distribution Pattern for Treatment Number Two, Three Replications

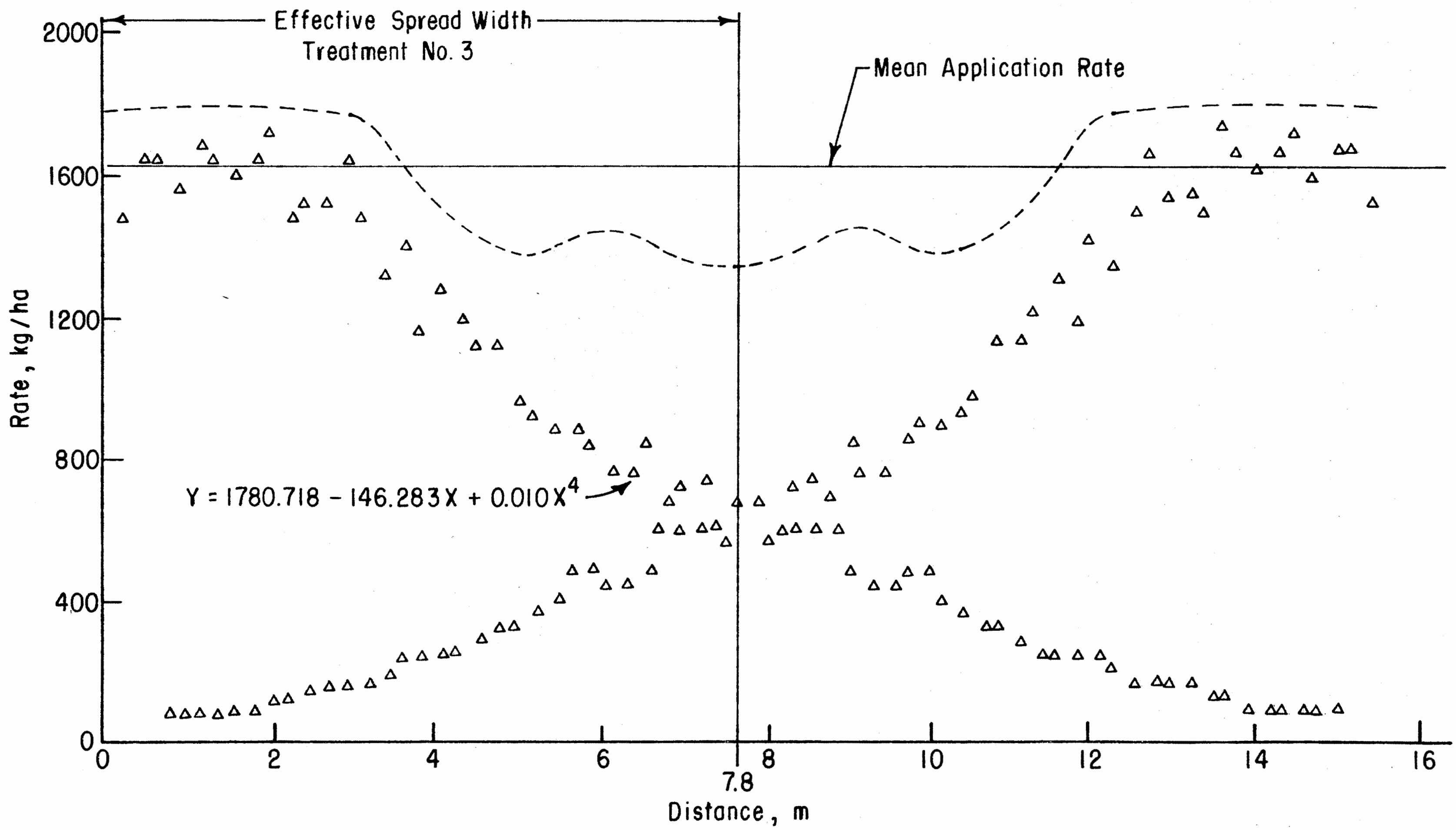



Figure 25. Distribution Pattern for Treatment Number Three, Three Replications

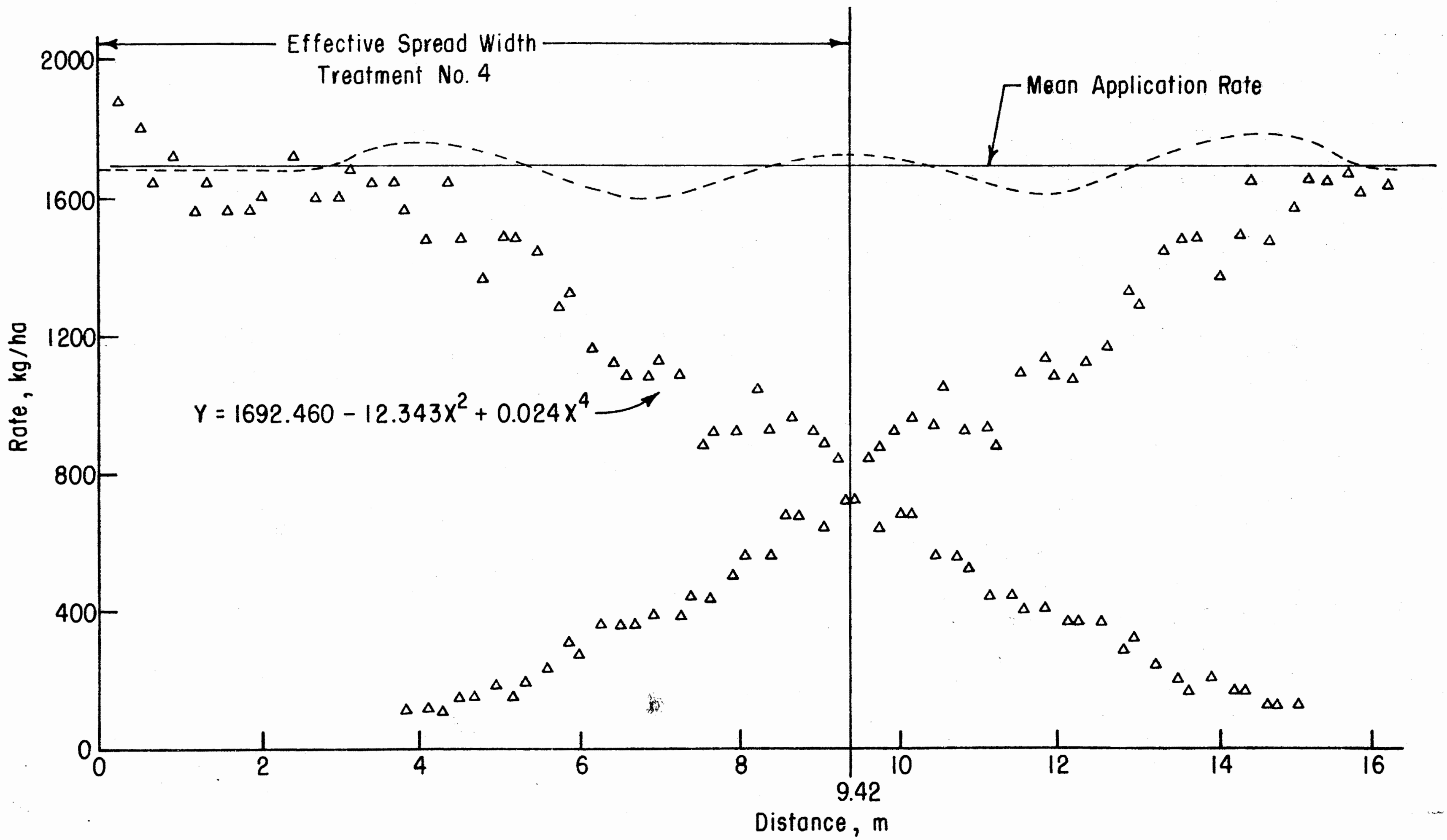



Figure 26. Distribution Pattern for Treatment Number Four, Three Replications

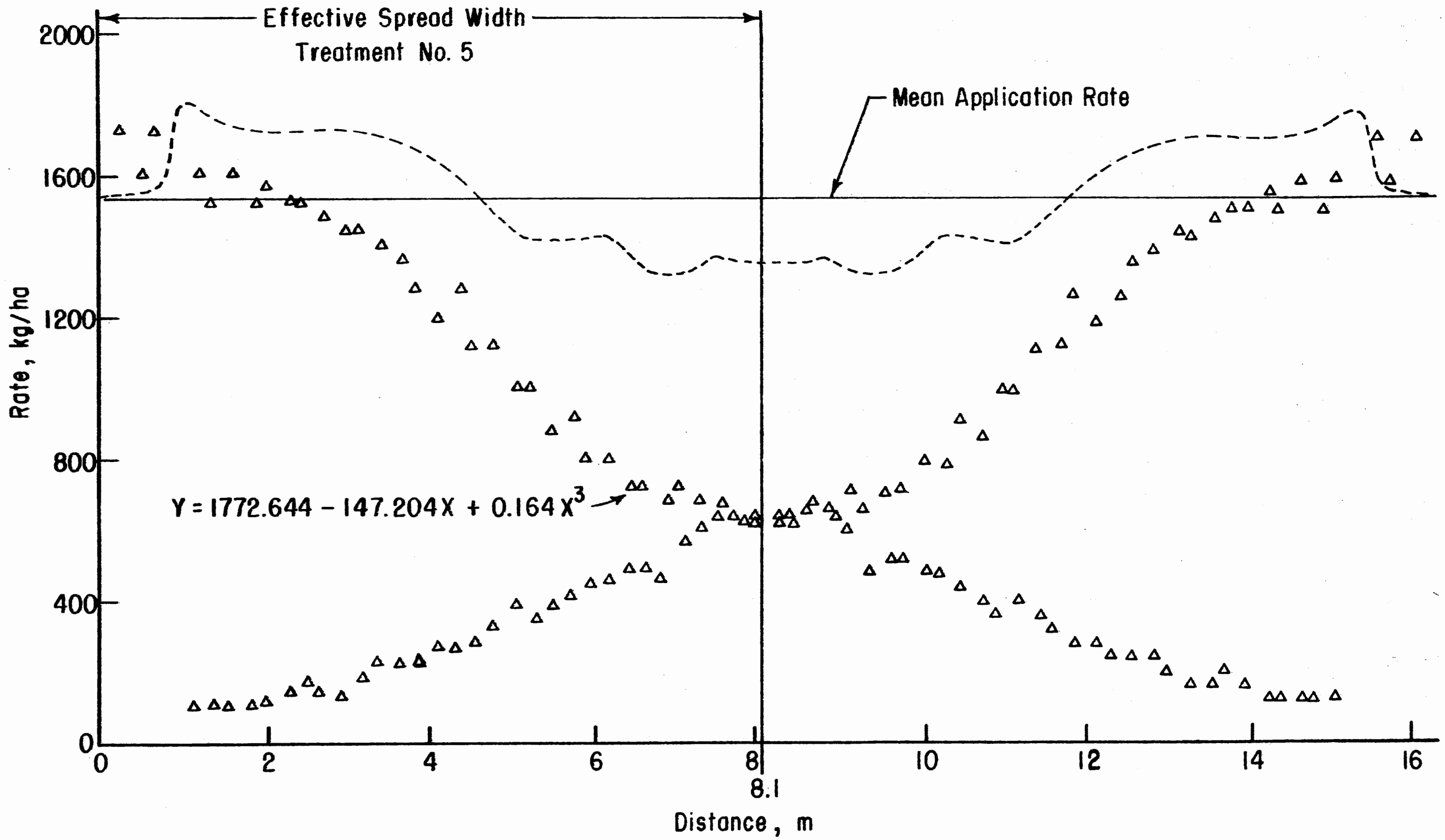



Figure 27. Distribution Pattern for Treatment Number Five, Three Replications

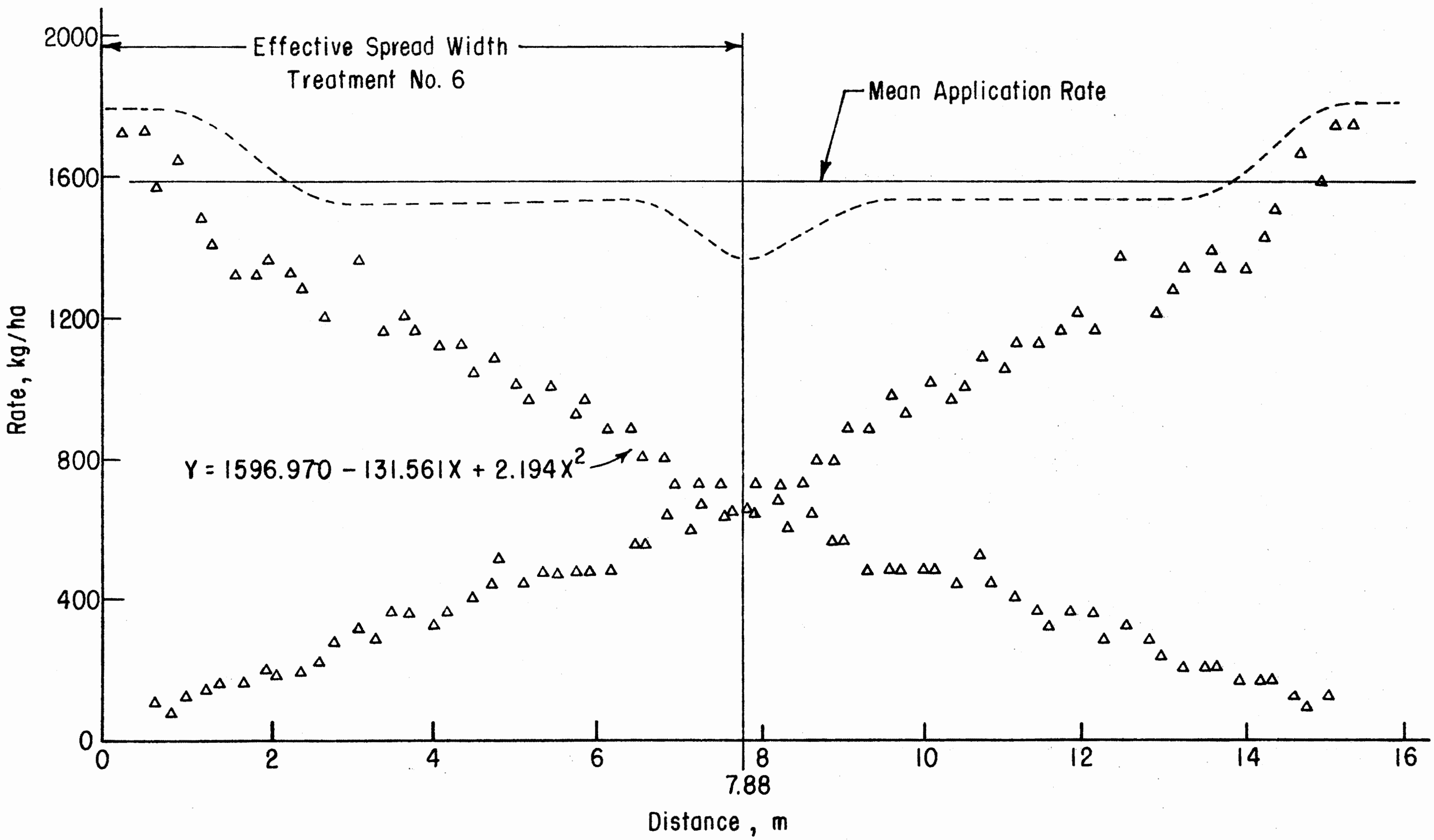



Figure 28. Distribution Pattern for Treatment Number Six, Three Replications

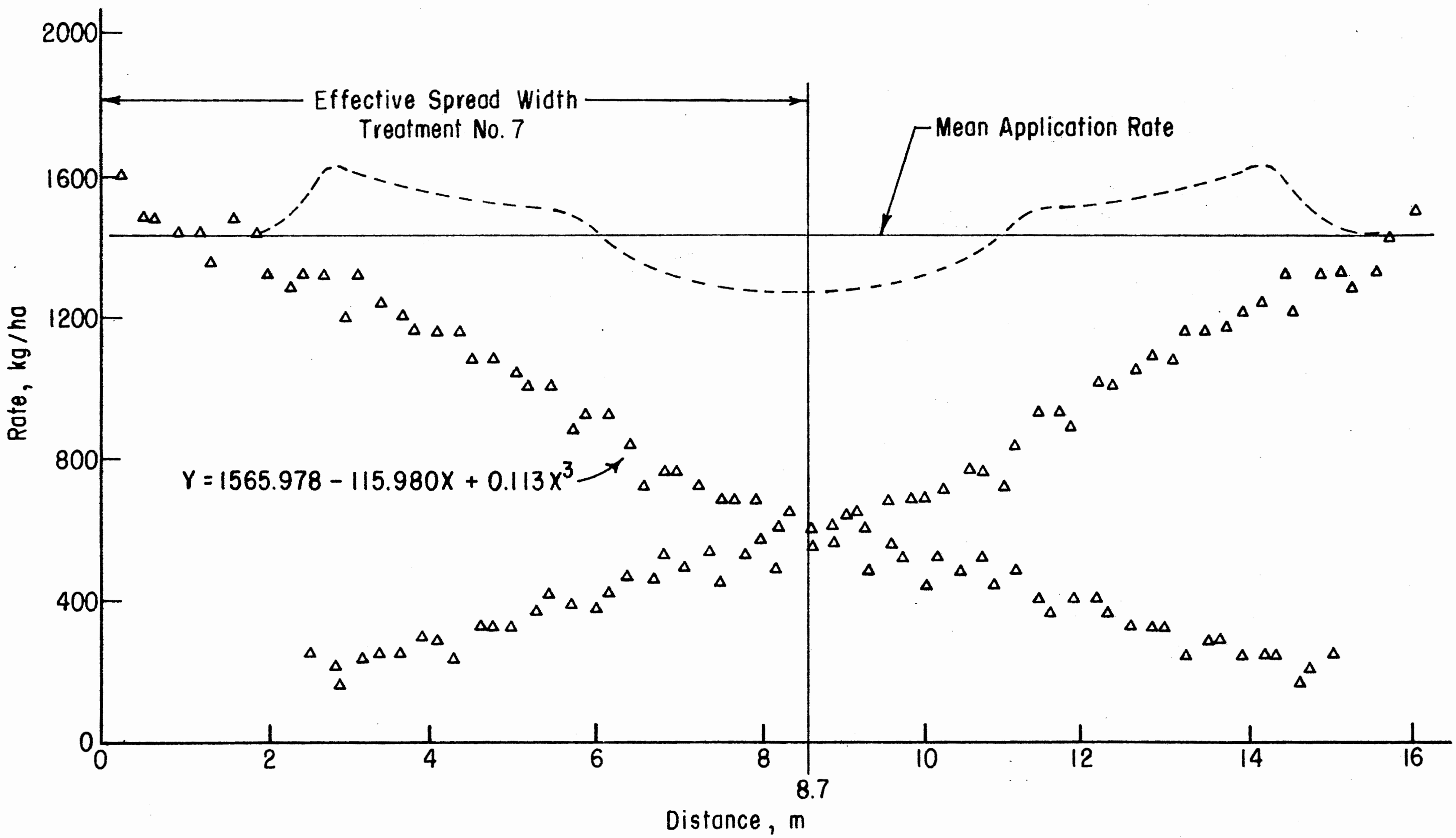



Figure 29. Distribution Pattern for Treatment Number Seven, Three Replications

$$Y = A + B\,(X)^1 + C\,(X)^2 + \ldots\ I\,(X)^n$$

Y = Application rate kg/ha

X = Distance m

A, B, C, ... I = Constant Coefficients

The specific polynomial equation in the above form describes the best curve fit for each treatment's data. The necessary parameters analyzed by computer are given in Table V for further investigation of the treatments.

As the distribution pattern figures show lateral distribution patterns resulting from the slinger for the seven treatments are flat top patterns.

The test procedure for dry fertilizer spreaders, ASAE standard method of presentation of spread pattern was used to calculate the effective spread width and the mean application rate. For example, in Figure 23, the effective spread width for treatment number one was 10.3 meters when the maximum overlap of overall pattern width was chosen to be 40%. The amount of overlapping was chosen based on superposition of the distribution patterns (the dotted lines on the figures).

It should be noted that the method of overlap spreading was assumed to be used to get the results shown in Figures 23-29.

### Optimum Combination of Blade Angles Resulting from the Experiment

As Table IV shows, seven blade combination angles were chosen to evaluate the performance of the distributions. The Figures 23, 24, ..., 29 show the result of distributions after overlapping of the patterns.

According to these distribution figures, maximum effective spread width, 10.3 m, belongs to treatment number one which is the predicted

TABLE V

STATISTICAL PARAMETERS FOR THE TREATMENTS

| Source | EMS | F-Value | Prob. F | R-Square | C.V.% |
|---|---|---|---|---|---|
| $T_1$ | 2232.8 | 3567.0 | 0.0001 | 0.994 | 4.3 |
| $T_2$ | 2966.8 | 2234.1 | 0.0001 | 0.991 | 8.7 |
| $T_3$ | 7598.6 | 1230.0 | 0.0001 | 0.975 | 11.7 |
| $T_4$ | 5393.1 | 1837.4 | 0.0001 | 0.983 | 7.6 |
| $T_5$ | 4315.7 | 1976.9 | 0.0001 | 0.984 | 8.5 |
| $T_6$ | 4754.3 | 1407.0 | 0.0001 | 0.978 | 9.2 |
| $T_7$ | 1929.1 | 2955.9 | 0.0001 | 0.989 | 5.8 |

angle combination (MCD), Table III. In this treatment the maximum variation of 7.1% from the mean application rate, for 10 passes, was observed. The effective spread width and maximum variation of application rate from the mean are given in Table VI. As this table shows, the best blade combination angles, to obtain a uniform distribution pattern by overlapping, is treatment number four, angles 60, 55, 60, 55, 55, 45, with 5.6% maximum variation of application rate from the mean and 9.4 m the effective spread width.

TABLE VI

DISTRIBUTION RESULTS

| Source | Effective Width m | Maximum Variation Rate % |
|---|---|---|
| $T_1$ | 10.3 | 7.1 |
| $T_2$ | 6.6 | 15.5 |
| $T_3$ | 7.8 | 14.8 |
| $T_4$ | 9.4 | 5.6 |
| $T_5$ | 8.1 | 18.1 |
| $T_6$ | 7.9 | 14.5 |
| $T_7$ | 8.7 | 15.5 |

# CHAPTER VII

# SUMMARY AND CONCLUSIONS

## Summary

The objectives of this study were: (1) to develop a prediction equation for a vertical wheel distributor based on centrifugal, tangential, and ballistic forces affecting the granular material to be distributed; (2) to use the equation to design a vertical wheel distributor with six unequal length blades to obtain a uniform distribution; (3) to determine the uniformity of distribution across the swath width resulting from material application with the designed distributor.

Part one involved the development of a trajectory equation for prediction of the maximum trajectory distance of the clay pellets used in the experiment. The resultant equation was as follow:

$$X_m = 0.096\ V_0^2 - 3X10^{-9}\ Vo^4/M$$

In part two a vertical slinger wheel with six unequal length curved blades was designed based on the above trajectory distance equation to give the uniform distribution pattern for the particles used. For the purpose of uniformity of the distribution, the shape and outlet angle of the blades were given special consideration.

The possibility of uniform distribution was investigated by plotting the distributed pellets weight per area against their projected distance. The parameters required for analyzing the data were found by using the statistical analysis system (SAS). With the help of standard (ASAE) test procedure method, the optimum combination of the angles resulted from comparison of the treatment plots, and was found to obtain the best uniform distribution of the pellets by this equipment.

## Conclusions

The following conclusions can be drawn from interpretation of the experiment results:

1. Although many assumptions were made in the development of the theoretical equation, it gave adequate results for the prediction of the maximum trajectory distance of the pellets from the wheel center line.
2. By changing the discharge angles, a wide variety of distribution patterns could be obtained, Figures 23-29.
3. Due to the influence of air pumping to the inside of the wheel, Figure 11, a relatively uniform distribution was obtainable for only 4.5 m distance from the wheel (treatment one on Figure 23). Overlapping the patterns however, was an effective means of obtaining the uniform distribution.

## Suggestions for Further

1. Construct a test stand to evaluate the effect of RPM.
2. Construct a dual vertical slinger wheel, the wheels rotating in opposite directions, therefore discharging to both sides of the unit. The schematic diagram of this idea is presented in Figure 30.

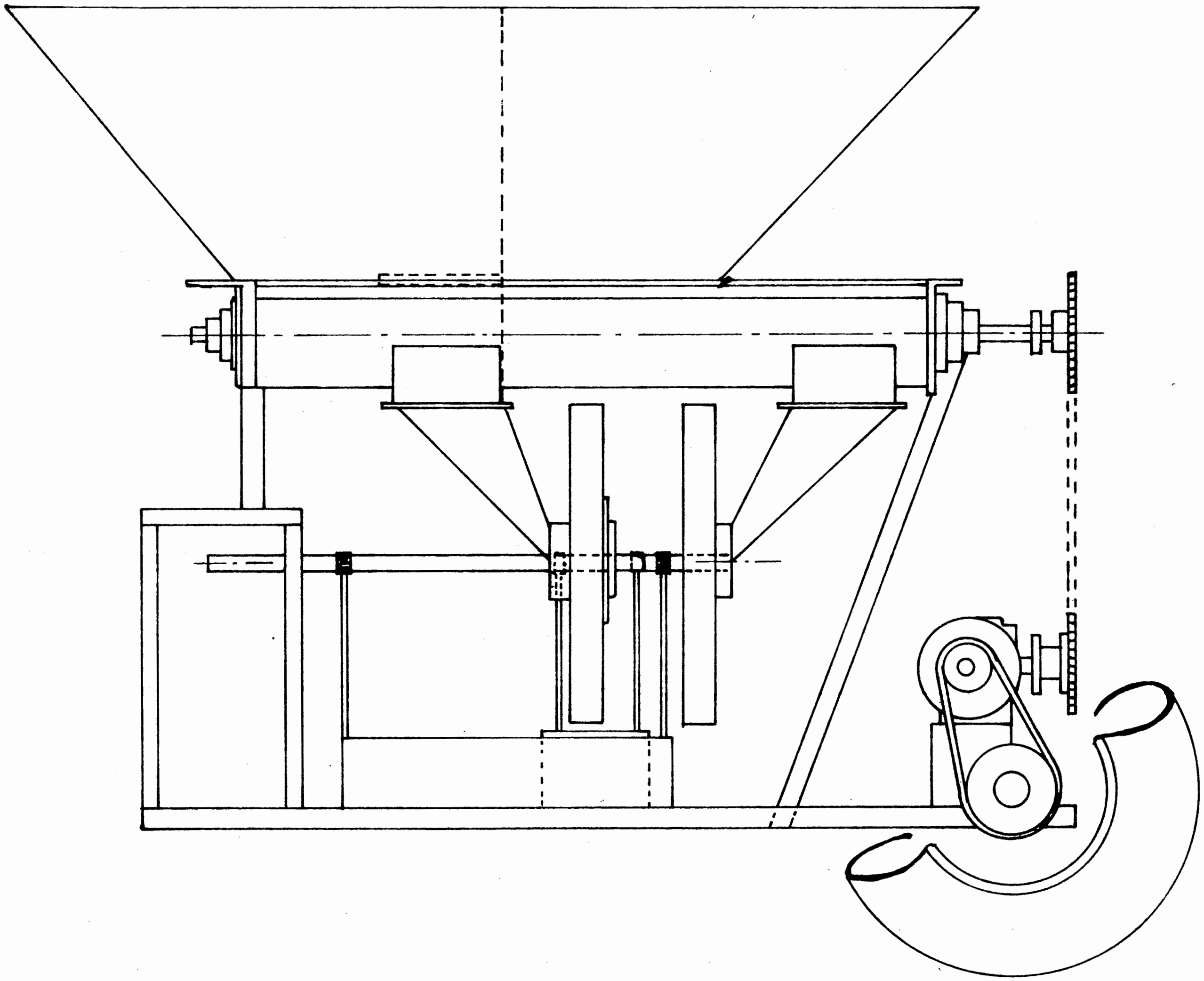


Figure 30. Proposed Dual Vertical Distributor Wheel Design

3. Reduce the pitch of the helix of an auger feeding system to prevent cyclic variation in material handling.
4. Investigate the uniformity of the distribution using a distributor wheel with a combination of six arc circular blades with equal length and unequal discharge angles.

## A SELECTED BIBLIOGRAPHY


1. Alizadeh, H. "Computer Solution of Equations for Three Centrifugal Distributor Configuration." Unpublished Master of Science Thesis, Virginia Polytechnic Institute, July 1965.

2. Crowther, A. J. "The Distribution of Particles by a Spinning Disc." Journal of Agricultural Engineering Research, Vol. III, 1958, p. 288-291.

3. Cunningham, F. M., E. Y. S. Chao. "Design Relationships for Centrifugal Fertilezer Distributors." Am. Soc. Agr. Engr. Trans., Vol. 10 n1, 1967, p. 91-95.

4. Cunningham, F. M. "Performance characteristics of Bulk Spreaders for Granular Fertilizer." Am. Soc. Agr. Engr. Trans., Vol. 6 n2, 1963, p. 108-1014.

5. Davis, J. B., C. E. Rice. "Predicting Fertilizer Distribution by a Centrifugal Distributor Using CSMP, A Simulation Language." Am. Soc. Agr. Engr. Trans., Vol 17 n6, 1974, p. 1091-1093.

6. Hepherd, R. Q., J. A. Pascal. "The Transverse Distribution of Conventional type of Distributors." Journal of Agricultural Engineering Research, Vol. III, 1958, p. 95.

7. Inns, F. M., A. R. Reece. "The Theory of the Centrifugal Distributor, II: Motion on the Disc, Off-Centre Feed." Journal of Agricultural Engineering Research, Vol. 7 n4, 1962.

8. Jorgensen, R. "Fan Engineering." Buffalo Forage Company, 1970, Buffalo Forage Company, New York.

9. Law, S. E., J. A. Collier. "Aerodynamic Resistance Coefficients of Agricultural Particulates Determined by Elutriation." Am. Soc. Agr. Engr. Trans., Vol. 16 n5, 1973, p. 913-921.

10. Mennel, R. M., A. R. Reece. "The Theory of the Centrifugal Distributor, III." Journal of Agricultural Engineering Research, Vol. 8, 1963, p. 78-84.

11. Patterson, D. E., A. R. Reece. "Theory of the Centrifugal Distributor, I: Motion on the Disc, Near Center Feed." Journal of Agricultural Engineering Research, Vol. 7 n3, 1962, p. 232-240.

12. Reeder, Randall C., R. G. Diener, and K. C. Elliott. "Design and Development of an Extra - Wide Swath Fertilizer Spreader." Am. Soc. Agr. Engr. Trans., 1973, p. 435-439.

13. Symon, K. "Mechanics." Addison - Wesley Publishing Company, 1971, University of Wisconsin.

14. West, W. J., W. H. Cashmore, and H. C. Green. "The Effect of An Unevenly Distributed Top-dressing on the Yield of Wheat." Agri. Eng. Record, June 1940, p. 23.

15. Whitney, R. W., L. O. Roth. "A $CO_2$ - Pesticide Distribution System for Tick Control." Am. Soc. Agr. Engr., Paper No. 77-1505.

## APPENDIX

### ORIGINAL DATA FOR ALL TREATMENTS

### EXPLANATION OF TABLES

The numbers appearing in the following tables are the weight of the pellets in each box in grams, distance in inches from the tractor tire, application rate in kilogram per hectare, and distance from the tractor tire in meters.

TABLE VII

ORIGINAL DATA FOR TREATMENT ONE
(AVERAGE OF THREE REPLICATIONS)

| OBS | GR | IN | KG/HA | M |
|---|---|---|---|---|
| 1 | 13.17 | 4.7 | 1809.72 | 0.12 |
| 2 | 13.02 | 14.1 | 1789.10 | 0.36 |
| 3 | 12.67 | 23.5 | 1741.01 | C.60 |
| 4 | 13.02 | 32.9 | 1789.10 | 0.84 |
| 5 | 13.10 | 42.3 | 1800.10 | 1.07 |
| 6 | 12.33 | 51.7 | 1694.29 | 1.31 |
| 7 | 12.75 | 61.1 | 1752.00 | 1.55 |
| 8 | 11.48 | 70.5 | 1577.49 | 1.79 |
| 9 | 13.29 | 79.9 | 1826.21 | 2.03 |
| 10 | 13.09 | 89.3 | 1798.72 | 2.27 |
| 11 | 12.97 | 98.7 | 1782.23 | 2.51 |
| 12 | 13.21 | 108.1 | 1815.21 | 2.75 |
| 13 | 12.72 | 117.5 | 1747.88 | 2.98 |
| 14 | 12.90 | 126.9 | 1772.61 | 3.22 |
| 15 | 12.69 | 136.3 | 1743.76 | 3.46 |
| 16 | 12.88 | 146.0 | 1769.87 | 3.71 |
| 17 | 12.83 | 155.4 | 1763.00 | 3.95 |
| 18 | 12.50 | 164.8 | 1717.65 | 4.19 |
| 19 | 12.54 | 174.2 | 1723.15 | 4.42 |
| 20 | 11.71 | 183.6 | 1609.09 | 4.66 |
| 21 | 12.47 | 193.0 | 1713.53 | 4.90 |
| 22 | 11.19 | 202.4 | 1537.64 | 5.14 |
| 23 | 11.31 | 211.8 | 1554.13 | 5.38 |
| 24 | 11.46 | 221.2 | 1574.74 | 5.62 |
| 25 | 11.42 | 230.6 | 1569.25 | 5.86 |
| 26 | 11.26 | 240.0 | 1547.26 | 6.10 |
| 27 | 10.67 | 249.4 | 1466.19 | 6.33 |
| 28 | 10.38 | 258.8 | 1426.34 | 6.57 |
| 29 | 10.14 | 268.2 | 1393.36 | 6.81 |
| 30 | 9.93 | 277.6 | 1364.50 | 7.05 |
| 31 | 9.02 | 287.0 | 1239.46 | 7.29 |
| 32 | 9.19 | 296.4 | 1262.82 | 7.53 |
| 33 | 8.92 | 305.8 | 1225.72 | 7.77 |
| 34 | 9.50 | 315.2 | 1305.41 | 8.01 |
| 35 | 8.21 | 324.6 | 1128.15 | 8.24 |
| 36 | 8.09 | 334.0 | 1111.66 | 8.48 |
| 37 | 8.03 | 343.4 | 1103.42 | 8.72 |
| 38 | 7.37 | 352.8 | 1012.73 | 8.96 |
| 39 | 7.31 | 362.2 | 1004.48 | 9.20 |
| 40 | 7.40 | 371.6 | 1016.85 | 9.44 |
| 41 | 6.97 | 381.0 | 957.76 | 9.68 |
| 42 | 6.69 | 390.4 | 919.29 | 9.92 |
| 43 | 6.12 | 399.8 | 840.96 | 10.15 |
| 44 | 6.01 | 409.2 | 825.85 | 10.39 |
| 45 | 4.93 | 418.6 | 677.44 | 10.63 |
| 46 | 5.00 | 428.0 | 687.06 | 10.87 |
| 47 | 4.56 | 437.4 | 626.60 | 11.11 |
| 48 | 4.03 | 446.8 | 553.77 | 11.35 |
| 49 | 3.86 | 456.2 | 530.41 | 11.59 |
| 50 | 3.62 | 465.6 | 497.43 | 11.83 |
| 51 | 3.57 | 475.0 | 490.56 | 12.06 |
| 52 | 3.22 | 484.7 | 442.47 | 12.31 |
| 53 | 2.84 | 494.1 | 390.25 | 12.55 |
| 54 | 2.79 | 503.5 | 383.38 | 12.79 |
| 55 | 2.51 | 512.9 | 344.90 | 13.03 |
| 56 | 2.16 | 522.3 | 296.81 | 13.27 |
| 57 | 2.07 | 531.7 | 284.44 | 13.51 |
| 58 | 1.75 | 541.4 | 240.47 | 13.75 |
| 59 | 1.46 | 550.8 | 200.62 | 13.99 |
| 60 | 1.17 | 560.2 | 160.77 | 14.23 |
| 61 | 1.37 | 569.6 | 188.25 | 14.47 |
| 62 | 1.01 | 579.0 | 138.79 | 14.71 |
| 63 | 0.97 | 588.4 | 133.29 | 14.95 |
| 64 | 0.92 | 597.8 | 126.42 | 15.18 |
| 65 | 0.98 | 607.2 | 134.66 | 15.42 |
| 66 | 0.46 | 616.6 | 63.21 | 15.66 |

TABLE VIII

ORIGINAL DATA FOR TREATMENT TWO
(AVERAGE OF THREE REPLICATIONS)

| OBS | GR | IN | KG/HA | M |
|---|---|---|---|---|
| 1 | 11.22 | 4.7 | 1541.76 | 0.12 |
| 2 | 11.53 | 14.1 | 1584.36 | 0.36 |
| 3 | 11.12 | 23.5 | 1528.02 | 0.60 |
| 4 | 11.63 | 32.9 | 1598.10 | 0.84 |
| 5 | 11.21 | 42.3 | 1540.39 | 1.07 |
| 6 | 11.19 | 51.7 | 1537.64 | 1.31 |
| 7 | 11.38 | 61.1 | 1563.75 | 1.55 |
| 8 | 11.08 | 70.5 | 1522.52 | 1.79 |
| 9 | 10.72 | 79.9 | 1473.06 | 2.03 |
| 10 | 11.15 | 89.3 | 1532.14 | 2.27 |
| 11 | 10.53 | 98.7 | 1446.95 | 2.51 |
| 12 | 10.64 | 108.1 | 1462.06 | 2.75 |
| 13 | 8.99 | 117.5 | 1235.33 | 2.98 |
| 14 | 9.32 | 126.9 | 1280.68 | 3.22 |
| 15 | 9.11 | 136.3 | 1251.82 | 3.46 |
| 16 | 9.17 | 146.0 | 1260.07 | 3.71 |
| 17 | 8.70 | 155.4 | 1195.48 | 3.95 |
| 18 | 7.80 | 164.8 | 1071.81 | 4.19 |
| 19 | 7.32 | 174.2 | 1005.86 | 4.42 |
| 20 | 6.63 | 183.6 | 911.04 | 4.66 |
| 21 | 6.02 | 193.0 | 827.22 | 4.90 |
| 22 | 6.13 | 202.4 | 842.34 | 5.14 |
| 23 | 5.86 | 211.8 | 805.23 | 5.38 |
| 24 | 5.36 | 221.2 | 736.53 | 5.62 |
| 25 | 5.62 | 230.6 | 772.26 | 5.86 |
| 26 | 4.65 | 240.0 | 638.97 | 6.10 |
| 27 | 4.82 | 249.4 | 662.33 | 6.33 |
| 28 | 4.12 | 258.8 | 566.14 | 6.57 |
| 29 | 3.86 | 268.2 | 530.41 | 6.81 |
| 30 | 4.16 | 277.6 | 571.63 | 7.05 |
| 31 | 3.73 | 287.0 | 512.55 | 7.29 |
| 32 | 3.52 | 296.4 | 483.69 | 7.53 |
| 33 | 4.26 | 305.8 | 585.38 | 7.77 |
| 34 | 3.21 | 315.2 | 441.09 | 8.01 |
| 35 | 3.47 | 324.6 | 476.82 | 8.24 |
| 36 | 3.36 | 334.0 | 461.70 | 8.48 |
| 37 | 3.18 | 343.4 | 436.97 | 8.72 |
| 38 | 2.73 | 352.8 | 375.13 | 8.96 |
| 39 | 2.35 | 362.2 | 322.92 | 9.20 |
| 40 | 2.47 | 371.6 | 339.41 | 9.44 |
| 41 | 1.98 | 381.0 | 272.08 | 9.68 |
| 42 | 1.79 | 390.4 | 245.97 | 9.92 |
| 43 | 1.99 | 399.8 | 273.45 | 10.15 |
| 44 | 1.42 | 409.2 | 195.13 | 10.39 |
| 45 | 1.40 | 418.6 | 192.38 | 10.63 |
| 46 | 1.00 | 428.0 | 137.41 | 10.87 |
| 47 | 1.20 | 437.4 | 164.89 | 11.11 |
| 48 | 0.79 | 446.8 | 108.56 | 11.35 |
| 49 | 0.83 | 456.2 | 114.05 | 11.59 |
| 50 | 0.93 | 465.0 | 127.79 | 11.81 |
| 51 | 0.80 | 475.0 | 109.93 | 12.06 |
| 52 | 0.47 | 484.7 | 64.58 | 12.31 |
| 53 | 0.61 | 494.1 | 83.82 | 12.55 |
| 54 | 0.53 | 503.5 | 72.83 | 12.79 |
| 55 | 0.54 | 512.9 | 74.20 | 13.03 |
| 56 | 0.49 | 522.3 | 67.33 | 13.27 |
| 57 | 0.15 | 531.7 | 20.61 | 13.51 |
| 58 | 0.37 | 541.4 | 50.84 | 13.75 |
| 59 | 0.27 | 550.8 | 37.10 | 13.99 |
| 60 | 0.35 | 560.2 | 48.09 | 14.23 |
| 61 | 0.22 | 569.6 | 30.23 | 14.47 |
| 62 | 0.18 | 579.0 | 24.73 | 14.71 |
| 63 | 0.12 | 588.4 | 16.49 | 14.95 |
| 64 | 0.03 | 597.8 | 4.12 | 15.18 |
| 65 | 0.13 | 607.2 | 17.86 | 15.42 |
| 66 | 0.13 | 616.6 | 17.86 | 15.66 |

TABLE IX

ORIGINAL DATA FOR TREATMENT THREE
(AVERAGE OF THREE REPLICATIONS)

| UBS | GR | IN | KG/HA | M |
|---|---|---|---|---|
| 1 | 10.67 | 4.7 | 1465.73 | 0.12 |
| 2 | 11.83 | 14.1 | 1625.13 | 0.35 |
| 3 | 11.80 | 23.5 | 1621.46 | 0.58 |
| 4 | 11.13 | 32.9 | 1529.85 | 0.81 |
| 5 | 12.15 | 42.3 | 1669.10 | 1.04 |
| 6 | 11.79 | 51.7 | 1619.63 | 1.27 |
| 7 | 11.49 | 61.1 | 1579.32 | 1.50 |
| 8 | 11.65 | 70.5 | 1601.31 | 1.73 |
| 9 | 12.37 | 79.9 | 1700.24 | 1.96 |
| 10 | 10.76 | 89.3 | 1478.55 | 2.19 |
| 11 | 10.80 | 98.7 | 1484.05 | 2.42 |
| 12 | 10.93 | 108.1 | 1502.37 | 2.65 |
| 13 | 11.67 | 117.5 | 1603.14 | 2.88 |
| 14 | 10.49 | 126.9 | 1441.91 | 3.11 |
| 15 | 9.40 | 136.3 | 1291.67 | 3.34 |
| 16 | 10.09 | 146.0 | 1386.94 | 3.58 |
| 17 | 8.36 | 155.4 | 1148.76 | 3.81 |
| 18 | 9.13 | 164.8 | 1255.03 | 4.04 |
| 19 | 8.67 | 174.2 | 1190.90 | 4.27 |
| 20 | 8.04 | 183.6 | 1104.79 | 4.50 |
| 21 | 7.92 | 193.0 | 1088.30 | 4.73 |
| 22 | 6.92 | 202.4 | 950.89 | 4.96 |
| 23 | 6.67 | 211.8 | 916.08 | 5.19 |
| 24 | 6.39 | 221.2 | 877.60 | 5.42 |
| 25 | 6.21 | 230.6 | 853.79 | 5.65 |
| 26 | 5.83 | 240.0 | 800.65 | 5.88 |
| 27 | 5.29 | 249.4 | 727.37 | 6.11 |
| 28 | 5.35 | 258.8 | 734.70 | 6.34 |
| 29 | 5.89 | 268.2 | 809.81 | 6.57 |
| 30 | 4.73 | 277.6 | 650.42 | 6.80 |
| 31 | 5.21 | 287.0 | 716.37 | 7.03 |
| 32 | 4.27 | 296.4 | 586.29 | 7.26 |
| 33 | 4.04 | 305.8 | 555.14 | 7.49 |
| 34 | 4.89 | 315.2 | 672.40 | 7.72 |
| 35 | 4.79 | 324.6 | 657.75 | 7.95 |
| 36 | 4.12 | 334.0 | 566.14 | 8.18 |
| 37 | 4.99 | 343.4 | 685.23 | 8.41 |
| 38 | 4.19 | 352.8 | 575.30 | 8.64 |
| 39 | 4.13 | 362.2 | 567.97 | 8.87 |
| 40 | 3.44 | 371.6 | 472.70 | 9.10 |
| 41 | 3.17 | 381.0 | 436.05 | 9.33 |
| 42 | 3.11 | 390.4 | 426.89 | 9.56 |
| 43 | 3.31 | 399.8 | 454.38 | 9.80 |
| 44 | 3.37 | 409.2 | 463.54 | 10.03 |
| 45 | 2.85 | 418.6 | 392.08 | 10.26 |
| 46 | 2.41 | 428.0 | 331.62 | 10.49 |
| 47 | 2.15 | 437.4 | 294.98 | 10.72 |
| 48 | 2.25 | 446.8 | 309.63 | 10.95 |
| 49 | 1.77 | 456.2 | 243.68 | 11.18 |
| 50 | 1.60 | 465.0 | 219.86 | 11.39 |
| 51 | 1.61 | 475.0 | 221.69 | 11.64 |
| 52 | 1.61 | 484.7 | 221.69 | 11.88 |
| 53 | 1.60 | 494.1 | 219.86 | 12.11 |
| 54 | 1.19 | 503.5 | 163.06 | 12.34 |
| 55 | 1.00 | 512.9 | 137.41 | 12.57 |
| 56 | 0.97 | 522.3 | 133.75 | 12.80 |
| 57 | 0.99 | 531.7 | 135.58 | 13.03 |
| 58 | 1.13 | 541.4 | 155.73 | 13.26 |
| 59 | 0.85 | 550.8 | 117.26 | 13.49 |
| 60 | 0.80 | 560.2 | 109.93 | 13.72 |
| 61 | 0.55 | 569.6 | 75.12 | 13.96 |
| 62 | 0.47 | 579.0 | 64.13 | 14.19 |
| 63 | 0.48 | 588.4 | 65.96 | 14.42 |
| 64 | 0.57 | 597.8 | 78.78 | 14.65 |
| 65 | 0.56 | 607.2 | 76.95 | 14.88 |
| 66 | 0.53 | 616.6 | 73.29 | 15.11 |

TABLE X

ORIGINAL DATA FOR TREATMENT FOUR
(AVERAGE OF THREE REPLICATIONS)

| OBS | GR | IN | KG/HA | M |
|---|---|---|---|---|
| 1 | 13.49 | 4.7 | 1853.69 | 0.12 |
| 2 | 12.94 | 14.1 | 1778.11 | 0.36 |
| 3 | 11.84 | 23.5 | 1626.96 | 0.60 |
| 4 | 12.31 | 32.9 | 1691.54 | 0.84 |
| 5 | 11.19 | 42.3 | 1537.64 | 1.07 |
| 6 | 11.67 | 51.7 | 1603.60 | 1.31 |
| 7 | 11.26 | 61.1 | 1547.26 | 1.55 |
| 8 | 11.08 | 70.5 | 1522.52 | 1.79 |
| 9 | 11.44 | 79.9 | 1571.99 | 2.03 |
| 10 | 11.95 | 89.3 | 1642.07 | 2.27 |
| 11 | 12.26 | 98.7 | 1684.67 | 2.51 |
| 12 | 11.59 | 108.1 | 1592.61 | 2.75 |
| 13 | 11.53 | 117.5 | 1584.36 | 2.98 |
| 14 | 12.22 | 126.9 | 1679.17 | 3.22 |
| 15 | 11.81 | 136.3 | 1622.84 | 3.46 |
| 16 | 11.68 | 146.0 | 1604.97 | 3.71 |
| 17 | 11.21 | 155.4 | 1540.39 | 3.95 |
| 18 | 10.68 | 164.8 | 1467.56 | 4.19 |
| 19 | 11.77 | 174.2 | 1617.34 | 4.42 |
| 20 | 10.53 | 183.6 | 1446.95 | 4.66 |
| 21 | 9.64 | 193.0 | 1324.65 | 4.90 |
| 22 | 10.67 | 202.4 | 1466.19 | 5.14 |
| 23 | 10.64 | 211.8 | 1462.06 | 5.38 |
| 24 | 10.46 | 221.2 | 1437.33 | 5.62 |
| 25 | 9.15 | 230.6 | 1257.32 | 5.86 |
| 26 | 9.55 | 240.0 | 1312.28 | 6.10 |
| 27 | 8.18 | 249.4 | 1124.03 | 6.33 |
| 28 | 7.88 | 258.8 | 1082.81 | 6.57 |
| 29 | 7.68 | 268.2 | 1055.32 | 6.81 |
| 30 | 7.83 | 277.6 | 1075.94 | 7.05 |
| 31 | 8.02 | 287.0 | 1102.04 | 7.29 |
| 32 | 7.65 | 296.4 | 1051.20 | 7.53 |
| 33 | 6.39 | 305.8 | 878.06 | 7.77 |
| 34 | 6.41 | 315.2 | 880.81 | 8.01 |
| 35 | 6.65 | 324.6 | 913.79 | 8.24 |
| 36 | 7.42 | 334.0 | 1019.60 | 8.48 |
| 37 | 6.50 | 343.4 | 893.18 | 8.72 |
| 38 | 6.95 | 352.8 | 955.01 | 8.96 |
| 39 | 6.41 | 362.2 | 880.81 | 9.20 |
| 40 | 6.29 | 371.6 | 864.32 | 9.44 |
| 41 | 5.03 | 381.0 | 691.18 | 9.68 |
| 42 | 5.95 | 390.4 | 817.60 | 9.92 |
| 43 | 4.54 | 399.8 | 623.85 | 10.15 |
| 44 | 4.68 | 409.2 | 643.09 | 10.39 |
| 45 | 4.67 | 418.6 | 641.71 | 10.63 |
| 46 | 4.06 | 428.0 | 557.89 | 10.87 |
| 47 | 3.91 | 437.4 | 537.28 | 11.11 |
| 48 | 3.67 | 446.8 | 504.30 | 11.35 |
| 49 | 3.05 | 456.2 | 419.11 | 11.59 |
| 50 | 2.98 | 465.0 | 409.49 | 11.81 |
| 51 | 2.70 | 475.0 | 371.01 | 12.06 |
| 52 | 2.84 | 484.7 | 390.25 | 12.31 |
| 53 | 2.46 | 494.1 | 338.03 | 12.55 |
| 54 | 2.54 | 503.5 | 349.03 | 12.79 |
| 55 | 2.47 | 512.9 | 339.41 | 13.03 |
| 56 | 1.82 | 522.3 | 250.09 | 13.27 |
| 57 | 2.08 | 531.7 | 285.82 | 13.51 |
| 58 | 1.56 | 541.4 | 214.36 | 13.75 |
| 59 | 1.39 | 550.8 | 191.00 | 13.99 |
| 60 | 1.12 | 560.2 | 153.90 | 14.23 |
| 61 | 1.21 | 569.6 | 166.27 | 14.47 |
| 62 | 1.07 | 579.0 | 147.03 | 14.71 |
| 63 | 1.01 | 588.4 | 138.79 | 14.95 |
| 64 | 0.66 | 597.8 | 90.69 | 15.18 |
| 65 | 0.82 | 607.2 | 112.68 | 15.42 |
| 66 | 0.74 | 616.6 | 101.68 | 15.66 |

TABLE XI

ORIGINAL DATA FOR TREATMENT FIVE
(AVERAGE OF THREE REPLICATIONS)

| OBS | GR | IN | KG/HA | M |
|---|---|---|---|---|
| 1 | 12.38 | 4.7 | 1701.16 | 0.12 |
| 2 | 11.44 | 14.1 | 1571.99 | 0.36 |
| 3 | 12.37 | 23.5 | 1699.79 | 0.60 |
| 4 | 11.40 | 32.9 | 1566.50 | 0.84 |
| 5 | 11.62 | 42.3 | 1596.73 | 1.07 |
| 6 | 11.06 | 51.7 | 1519.78 | 1.31 |
| 7 | 11.63 | 61.1 | 1598.10 | 1.55 |
| 8 | 11.03 | 70.5 | 1515.65 | 1.79 |
| 9 | 11.29 | 79.9 | 1551.38 | 2.03 |
| 10 | 10.79 | 89.3 | 1482.68 | 2.27 |
| 11 | 10.81 | 98.7 | 1485.42 | 2.51 |
| 12 | 10.52 | 108.1 | 1445.57 | 2.75 |
| 13 | 10.42 | 117.5 | 1431.83 | 2.98 |
| 14 | 10.28 | 126.9 | 1412.60 | 3.22 |
| 15 | 9.92 | 136.3 | 1363.13 | 3.46 |
| 16 | 9.67 | 146.0 | 1328.77 | 3.71 |
| 17 | 9.24 | 155.4 | 1269.69 | 3.95 |
| 18 | 8.62 | 164.8 | 1184.49 | 4.19 |
| 19 | 9.26 | 174.2 | 1272.44 | 4.42 |
| 20 | 7.90 | 183.6 | 1085.55 | 4.66 |
| 21 | 8.15 | 193.0 | 1119.91 | 4.90 |
| 22 | 7.26 | 202.4 | 997.61 | 5.14 |
| 23 | 7.14 | 211.8 | 981.12 | 5.38 |
| 24 | 6.34 | 221.2 | 871.19 | 5.62 |
| 25 | 6.58 | 230.6 | 904.17 | 5.86 |
| 26 | 5.81 | 240.0 | 798.36 | 6.10 |
| 27 | 5.71 | 249.4 | 784.62 | 6.33 |
| 28 | 5.15 | 258.8 | 707.67 | 6.57 |
| 29 | 5.16 | 268.2 | 709.05 | 6.81 |
| 30 | 4.72 | 277.6 | 648.58 | 7.05 |
| 31 | 5.08 | 287.0 | 698.05 | 7.29 |
| 32 | 4.74 | 296.4 | 651.33 | 7.53 |
| 33 | 4.87 | 305.8 | 669.20 | 7.77 |
| 34 | 4.44 | 315.2 | 610.11 | 8.01 |
| 35 | 4.40 | 324.6 | 604.61 | 8.24 |
| 36 | 4.49 | 334.0 | 616.98 | 8.48 |
| 37 | 4.51 | 343.4 | 619.73 | 8.72 |
| 38 | 4.79 | 352.8 | 658.20 | 8.96 |
| 39 | 4.46 | 362.2 | 612.86 | 9.20 |
| 40 | 4.21 | 371.6 | 578.50 | 9.44 |
| 41 | 3.46 | 381.0 | 475.45 | 9.68 |
| 42 | 3.69 | 390.4 | 507.05 | 9.92 |
| 43 | 3.66 | 399.8 | 502.93 | 10.15 |
| 44 | 3.47 | 409.2 | 476.82 | 10.39 |
| 45 | 3.36 | 418.6 | 461.70 | 10.63 |
| 46 | 3.08 | 428.0 | 423.23 | 10.87 |
| 47 | 2.90 | 437.4 | 398.49 | 11.11 |
| 48 | 2.45 | 446.8 | 336.66 | 11.35 |
| 49 | 2.74 | 456.2 | 376.51 | 11.59 |
| 50 | 2.46 | 465.6 | 338.03 | 11.83 |
| 51 | 2.28 | 475.0 | 313.30 | 12.06 |
| 52 | 1.95 | 484.7 | 267.95 | 12.31 |
| 53 | 2.01 | 494.1 | 276.20 | 12.55 |
| 54 | 1.65 | 503.4 | 226.73 | 12.79 |
| 55 | 1.63 | 512.9 | 223.98 | 13.03 |
| 56 | 1.48 | 522.3 | 203.37 | 13.27 |
| 57 | 1.26 | 531.7 | 173.14 | 13.51 |
| 58 | 1.12 | 541.4 | 153.90 | 13.75 |
| 59 | 1.07 | 550.8 | 147.03 | 13.99 |
| 60 | 1.20 | 560.2 | 164.89 | 14.23 |
| 61 | 1.11 | 569.6 | 152.53 | 14.47 |
| 62 | 0.67 | 579.0 | 92.07 | 14.71 |
| 63 | 0.64 | 588.4 | 87.94 | 14.95 |
| 64 | 0.71 | 597.8 | 97.56 | 15.18 |
| 65 | 0.66 | 607.2 | 90.69 | 15.42 |
| 66 | 0.63 | 616.6 | 86.57 | 15.66 |

TABLE XII

ORIGINAL DATA FOR TREATMENT SIX
(AVERAGE OF THREE REPLICATIONS)

| OBS | GR | IN | KG/HA | M |
|---|---|---|---|---|
| 1 | 12.48 | 4.7 | 1714.90 | 0.12 |
| 2 | 12.41 | 14.1 | 1705.28 | 0.36 |
| 3 | 11.31 | 23.5 | 1554.13 | 0.60 |
| 4 | 11.80 | 32.9 | 1621.46 | 0.84 |
| 5 | 10.75 | 42.3 | 1477.18 | 1.07 |
| 6 | 10.03 | 51.7 | 1378.24 | 1.31 |
| 7 | 9.46 | 61.1 | 1299.92 | 1.55 |
| 8 | 9.48 | 70.5 | 1302.67 | 1.79 |
| 9 | 9.79 | 79.9 | 1345.26 | 2.03 |
| 10 | 9.33 | 89.3 | 1282.05 | 2.27 |
| 11 | 9.11 | 98.7 | 1251.82 | 2.51 |
| 12 | 8.70 | 108.1 | 1195.48 | 2.75 |
| 13 | 8.51 | 17.5 | 1169.38 | 0.44 |
| 14 | 9.75 | 126.9 | 1339.77 | 3.22 |
| 15 | 8.27 | 136.3 | 1136.40 | 3.46 |
| 16 | 8.63 | 146.0 | 1185.87 | 3.71 |
| 17 | 8.18 | 155.4 | 1124.03 | 3.95 |
| 18 | 7.91 | 164.8 | 1086.93 | 4.19 |
| 19 | 8.15 | 174.2 | 1119.91 | 4.42 |
| 20 | 7.52 | 183.6 | 1033.34 | 4.66 |
| 21 | 7.65 | 193.0 | 1051.20 | 4.90 |
| 22 | 7.22 | 202.4 | 992.11 | 5.14 |
| 23 | 6.94 | 211.8 | 953.64 | 5.38 |
| 24 | 7.10 | 221.2 | 975.63 | 5.62 |
| 25 | 6.57 | 230.6 | 902.80 | 5.86 |
| 26 | 6.89 | 240.0 | 946.77 | 6.10 |
| 27 | 6.20 | 249.4 | 851.95 | 6.33 |
| 28 | 6.23 | 258.8 | 856.08 | 6.57 |
| 29 | 5.71 | 268.2 | 784.62 | 6.81 |
| 30 | 5.55 | 277.6 | 762.64 | 7.05 |
| 31 | 5.03 | 287.0 | 691.18 | 7.29 |
| 32 | 5.03 | 296.4 | 691.18 | 7.53 |
| 33 | 4.99 | 305.8 | 685.69 | 7.77 |
| 34 | 4.43 | 315.2 | 608.74 | 8.01 |
| 35 | 4.51 | 324.6 | 619.73 | 8.24 |
| 36 | 4.80 | 334.0 | 659.58 | 8.48 |
| 37 | 4.24 | 343.4 | 582.63 | 8.72 |
| 38 | 4.52 | 352.8 | 621.10 | 8.96 |
| 39 | 3.96 | 362.2 | 544.15 | 9.20 |
| 40 | 3.84 | 371.6 | 527.66 | 9.44 |
| 41 | 3.48 | 381.0 | 478.19 | 9.68 |
| 42 | 3.47 | 390.4 | 476.82 | 9.92 |
| 43 | 3.40 | 399.8 | 467.20 | 10.15 |
| 44 | 3.47 | 409.2 | 476.82 | 10.39 |
| 45 | 3.45 | 418.6 | 474.07 | 10.63 |
| 46 | 3.05 | 428.0 | 419.11 | 10.87 |
| 47 | 3.62 | 437.4 | 497.43 | 11.11 |
| 48 | 2.96 | 446.8 | 406.74 | 11.35 |
| 49 | 2.77 | 456.2 | 380.63 | 11.59 |
| 50 | 2.55 | 465.6 | 350.40 | 11.83 |
| 51 | 2.11 | 475.0 | 289.94 | 12.06 |
| 52 | 2.48 | 484.7 | 340.78 | 12.31 |
| 53 | 2.48 | 494.1 | 340.78 | 12.55 |
| 54 | 1.98 | 503.5 | 272.08 | 12.79 |
| 55 | 2.08 | 512.9 | 285.82 | 13.03 |
| 56 | 1.98 | 522.3 | 272.08 | 13.27 |
| 57 | 1.70 | 531.7 | 233.60 | 13.51 |
| 58 | 1.20 | 541.4 | 164.89 | 13.75 |
| 59 | 1.35 | 550.8 | 185.51 | 13.99 |
| 60 | 1.18 | 560.2 | 162.15 | 14.23 |
| 61 | 0.94 | 569.6 | 129.17 | 14.47 |
| 62 | 0.89 | 579.0 | 122.30 | 14.71 |
| 63 | 0.88 | 588.4 | 120.92 | 14.95 |
| 64 | 0.62 | 597.8 | 85.20 | 15.18 |
| 65 | 0.55 | 607.2 | 75.58 | 15.42 |
| 66 | 0.70 | 616.6 | 96.19 | 15.66 |

TABLE XIII

ORIGINAL DATA FOR TREATMENT SEVEN
(AVERAGE OF THREE REPLICATIONS)

| OBS | GR | IN | KG/HA | M |
|---|---|---|---|---|
| 1 | 11.42 | 4.7 | 1569.25 | 0.12 |
| 2 | 10.65 | 14.1 | 1463.44 | 0.36 |
| 3 | 10.49 | 23.5 | 1441.45 | 0.60 |
| 4 | 10.22 | 32.9 | 1404.35 | 0.84 |
| 5 | 10.37 | 42.3 | 1424.96 | 1.07 |
| 6 | 9.80 | 51.7 | 1346.64 | 1.31 |
| 7 | 10.51 | 61.1 | 1444.20 | 1.55 |
| 8 | 10.25 | 70.5 | 1408.47 | 1.79 |
| 9 | 9.32 | 79.9 | 1280.68 | 2.03 |
| 10 | 9.27 | 89.3 | 1273.81 | 2.27 |
| 11 | 9.55 | 98.7 | 1312.28 | 2.51 |
| 12 | 9.38 | 108.1 | 1288.92 | 2.75 |
| 13 | 8.57 | 117.5 | 1177.62 | 2.98 |
| 14 | 9.35 | 126.9 | 1284.80 | 3.22 |
| 15 | 9.01 | 136.3 | 1238.08 | 3.46 |
| 16 | 8.50 | 146.0 | 1168.00 | 3.71 |
| 17 | 8.41 | 155.4 | 1155.63 | 3.95 |
| 18 | 8.28 | 164.8 | 1137.77 | 4.19 |
| 19 | 8.35 | 174.2 | 1147.39 | 4.42 |
| 20 | 7.82 | 183.6 | 1074.56 | 4.66 |
| 21 | 7.60 | 193.0 | 1044.33 | 4.90 |
| 22 | 7.48 | 202.4 | 1027.84 | 5.14 |
| 23 | 7.20 | 211.8 | 989.37 | 5.38 |
| 24 | 7.04 | 221.2 | 967.38 | 5.62 |
| 25 | 6.35 | 230.6 | 872.57 | 5.86 |
| 26 | 6.47 | 240.0 | 889.06 | 6.10 |
| 27 | 6.42 | 249.4 | 882.19 | 6.33 |
| 28 | 6.04 | 258.8 | 829.97 | 6.57 |
| 29 | 5.22 | 268.2 | 717.29 | 6.81 |
| 30 | 5.29 | 277.6 | 726.91 | 7.05 |
| 31 | 5.29 | 287.0 | 726.91 | 7.29 |
| 32 | 5.13 | 296.4 | 704.92 | 7.53 |
| 33 | 4.91 | 305.8 | 674.69 | 7.77 |
| 34 | 4.88 | 315.2 | 670.57 | 8.01 |
| 35 | 4.73 | 324.6 | 649.96 | 8.24 |
| 36 | 4.22 | 334.0 | 579.88 | 8.48 |
| 37 | 4.50 | 343.4 | 618.35 | 8.72 |
| 38 | 4.08 | 352.8 | 560.64 | 8.96 |
| 39 | 4.04 | 362.2 | 555.14 | 9.20 |
| 40 | 4.37 | 371.6 | 600.49 | 9.44 |
| 41 | 3.46 | 381.0 | 475.45 | 9.68 |
| 42 | 4.06 | 390.4 | 557.89 | 9.92 |
| 43 | 3.68 | 399.8 | 505.68 | 10.15 |
| 44 | 3.19 | 409.2 | 438.34 | 10.39 |
| 45 | 3.71 | 418.6 | 509.80 | 10.63 |
| 46 | 3.24 | 428.0 | 445.21 | 10.87 |
| 47 | 3.58 | 437.4 | 491.93 | 11.11 |
| 48 | 3.08 | 446.8 | 423.23 | 11.35 |
| 49 | 3.37 | 456.2 | 463.08 | 11.59 |
| 50 | 2.89 | 465.6 | 397.12 | 11.83 |
| 51 | 2.60 | 475.0 | 357.27 | 12.06 |
| 52 | 2.85 | 484.7 | 391.62 | 12.31 |
| 53 | 2.62 | 494.1 | 360.02 | 12.55 |
| 54 | 2.47 | 503.5 | 339.41 | 12.79 |
| 55 | 2.32 | 512.9 | 318.80 | 13.03 |
| 56 | 2.21 | 522.3 | 303.68 | 13.27 |
| 57 | 2.05 | 531.7 | 281.69 | 13.51 |
| 58 | 1.67 | 541.4 | 229.48 | 13.75 |
| 59 | 1.85 | 550.8 | 254.21 | 13.99 |
| 60 | 1.77 | 560.2 | 243.22 | 14.23 |
| 61 | 1.59 | 569.6 | 218.49 | 14.47 |
| 62 | 1.70 | 579.0 | 233.60 | 14.71 |
| 63 | 1.53 | 588.4 | 210.24 | 14.95 |
| 64 | 1.02 | 597.8 | 140.16 | 15.18 |
| 65 | 1.17 | 607.2 | 160.77 | 15.42 |
| 66 | 1.72 | 616.6 | 236.35 | 15.66 |

VITA 2

# Kamaleddin Jazayeri

Candidate for the Degree of

Master of Science

Thesis: DEVELOPMENT OF A CENTRIFUGAL DISTRIBUTOR HAVING VERTICAL DISPROPORTIONATE BLADES FOR GRANULAR PARTICLES

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Khoramabad, Iran, July 23, 1953, the son of H. and A. Jazayeri.

Education: Graduated from Jundi Shapur University (Iran) in 1975 with a Bachelor degree, majoring in Irrigation; completed the requirements for Master of Science degree from Oklahoma State University in May, 1978.

Professional Experience: During college, worked for Jundi Shapur Agricultural College, and one summer for Agricultural Station in Khoramabad. After graduation employed as temporary Instructor in Selseleh Regional Development Project in Aleshtar from July 1975 to January 1976.

Professional Organizations: Member of American Society of Agricultural Engineers. Member of National Society of Professional Engineers. Member of Inter-University Research and Information Center.