AUGER METERING STUDIES FOR FINE PRILLED UREA

BY

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DECLARATION

I, Francis Fabian Mwombeki, hereby declare to the Senate of Sokoine University of Agriculture that this dissertation has not been submitted for any degree award in any other University.

(SIGNED)

28/5/1988

(DATE)

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ABSTRACT

The performance of sheet and wire augers was studied for metering prilled urea fertilizer. First the physical characteristics of prilled urea was established. It was found that the angle of repose and the coefficient of fricition on galvanized steel surface increased with increased moisture content.

The opening of the hopper bottom, inclination of hopper walls and modes of agitation were studied for maximizing fertilizer flow into the metering chamber. A bottom opening width of 30 mm, hopper wall angle of 60° with the horizontal and a rotary or eliptical agitation modes were found to provide optimum flow.

Succeeding experiments were conducted to study the rate and consistency of fertilizer metering by sheet and wire auger under varying pitch/diameter ratio, delivery tube inclination, auger speed and fertilizer moisture. Rate of fertilizer injection into flooded soils was studied under simulated field conditions. Assessment was also made of the amount of fertilizer adhering to the augers during metering. A pitch diameter ratio of 1.25 was found to give a maximum discharge. Also, fertilizer discharge increased with greater inclination of the delivery tube and decreased with increasing fertilizer moisture contents. The metering accuracy generally decreased with greater inclination of the delivery tube. The wire auger was able to discharge fertilizer more accurately than the sheet auger. Increasing fertilizer granule size decreased metering accuracy.

The experiments of injecting fertilizer in flooded soils were conducted in a rotating soil bin to simulate actual field conditions. The inclination of the delivery tube along the direction of the bin movement gave a higher injection rate than an inclination against the bin movement. The wire auger exhibited a greater injection capability than the sheet auger and produced higher pressure at the tube opening. This auger also encountered less sticking of fertilizer on the flight than the sheet auger.

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NOMENCLATURE

Agitator	A component of fertilizer applicator that loosens fertilizer for improved fertilizer flow into metering chamber
Arching	accumulation of fertilizer above the metering chamber hindering flow
Auger - Sheet	a spiral like metal coiled from a metal sheet
- Wire	a spiral or spring like metal coiled from a wire
Auger speed	the rate at which the auger revolves per time - given in revolutions per minute (rpm)
Bridging	refer to arching
Consistency of fertilizer metering	variation of fertilizer metering with prolonged discharge
Delivery tube	a tube which houses the auger to deliver fertilizer
Delivery tube inclination angle	the angle the delivery tube forms with the horizontal or the vertical
Drillability	the ease at which fertilizer responds to discharge from the applicator
Fertilizer	in this text refers to prilled urea

Fertilizer metering	transfering of fertilizer from the hopper to the discharge mechanism at a regulated rate
Fertilizer injection	Mechanical transfer of fertilizer from applicator to zone of application in the soil
Gravity flow	vertical flow of the material due to being acted on by the force of gravity
Hopper bottom opening	the opening which the hopper forms to the metering chamber
Hopper wall angle	the angle the Hopper wall forms with the horizontal
Hygroscopicity	the characteristic of the fertilizer to absorb atmospheric moisture
Metering chamber	a section of fertilizer applicator where fertilizer metering takes place
Moisture content	amount of water in fertilizer particles (as % wet basis)
Soil bin	a container as a part of an experimental rig which holds soil for experiment
Puddled soil	clay soil mixed with water to form pastery for injection experiments.

1. INTRODUCTION

Urea is the major kind of nitrogenous fertilizer used in rice production. Although modern varieties respond well to nitrogen fertilization, utilization efficiency is usually low.

One of the reasons for low utilization efficiency is improper placement. When fertilizer is broadcasted into floodwater, losses as high as 22 to 47% can occur (De Datta et al, 1984). It has been found that there is a considerable increase in yields when fertilizer is deep placed. (Yamada et al, 1979, Brady et al, 1974, De Datta, 1984).

To achieve the best method of fertilizer application, appropriate machinery must be used. Several machines have been developed at IRRI's Agricultural Engineering Department for deep placement of fertilizer. This was coupled with studies related to mechanism of nitrogen transfer into flooded water, evaluation of furrow closers for minimum transfer to floodwater, evaluation of metering devices for accurate metering, evaluation of injection mechanisms for appropriate placement (Ressurreccion 1978, Khan 1983, Bautista 1983, Mahmood 1984). Poor metering results in uneven application of the fertilizer, which further results in poor fertilizer utilization, uneven crop growth and maturity. A number of deep placement applicators have been developed at the IRRI Agricultural Engineering Department which utilize wire and sheet augers for both metering and injection of fertilizers. Although the augers have been used in fertilizer applicators, their physical performance has not been extensively evaluated, i.e. auger speed pitch/diameter ratio (or helix angle). Auger have also not been studied extensively relative to physical behavior of the fertilizer i.e. hygroscopicity, granule size distribution and internal friction.

This study was undertaken to evaluate the meterability of fine prilled urea by auger and to establish the performance characteristics of wire and sheet auger for metering and injecting prilled urea fertilizer in flooded soils.

The specific objectives of this study are:

1) To analyze some of the physical properties of fine prilled urea with influence on drillability, i.e. hygroscopicity, kinetic angle of response, and the coefficient of friction between the fertilizer and galvanized steel.
2) To determine the optimum hopper wall angle of inclination and bottom opening that would permit free flow into the metering chamber.
3) To evaluate agitators and their movement modes.

4) To study the quantity and accuracy of fertilizer delivery from sheet and wire augers as affected by pitch/diameter ratio, angle of inclination of the delivery tube, auger speed, fertilizer texture and moisture content.
5) Determination of delivery pressure at the fertilizer outlet at different rational speeds of the auger.
6) Evaluation of the rate of fertilizer injection into puddled clay soils at different rational speeds of the auger and the angle of inclination of the delivery tube from the vertical axis.

2. REVIEW OF LITERATURE

2.1 Fertilizer metering and metering mechanisms

Ritchey et all (1961) described metering mechanisms developed for fertilizer distribution. The simplest method of metering is plain gravity feed through a hole where rate of flow is controlled by the size of the hole. This mechanism works only with a free flowing material like dry sand and the rate of application varies with ground speed. Another is a sort of agitator over the hole to keep the material flowing, preferably in direct ratio to speed of ground travel resulting to a uniform rate of application. The fertilizer rate for the feed opening and agitator speed vary widely according to flow characteristics of the fertilizer. An ideal fertilizer metering mechanism should be easily ajustable, simple, rugged, inexpensive, capable of pulverizing lumps, corrosion resistant and easily cleaned.

Some of these devices could be classified as top delivery, side delivery and bottom delivery.

IRRI engineers have developed the following manual applicator metering mechanisms.

1. Wire auger. This is in a straight delivery tube from the funnel hopper. A part of the shaft holding the auger extends inside the hopper tube to prevent the free flowing of fertilizer. The auger is driven by a ground driven wheel through a right angle sprocket arrangement (Kiamco 1982).

An improved version of the above is one with an inclined hopper where metering is done by the plunger and injection done by the auger (Khan 1984).

2) Osicllating plunger. Here a saw tooth semi-circular agitator, inside a delivery tube is connected to the hopper. The semi-circular agitator is driven by a ground driven wheel with linkages resulting to a reciprocating action, metering and injecting fertilizer to the ground (Tiangco et al 1983).
3) Cup type metering device. This device meters fertilizer as it rotates, picking a cup full of the fertilizer and pouring it to the delivery guide chutes for ground placement (Bautista 1983).
4) Fluted roller. As the roller rotates the flutes carry fertilizer and drop it into a delivery pipe. Regulation of metered amount of fertilizer is by increase or reduction of flute exposure to fertilizer (Ressurreccion 1978).
5) Spot injection mechanism. Here, a hopper with a nozzle at its bottom, and two injection rods move alternately in and out of the nozzle, injecting fertilizer into the mud (Kiamco 1982).

Bautista (1983) rated different metering mechanisms for granular fertilizer applicators (Table 1)

Table 1. Rating of different metering devices applicable to granular fertilizer (Bautista, E.U. 1983).

Metering Device	Design and manufacturing simplicity	Ability to cope with different granule size and shape	Metering uniformity	Total	Rank
Adjustable orifice with agitator	1	2	4	7	4
Horizontal wheel	2	3	4	9	5
Indented or fluted wheel	1	1	2	4	1
Internal force feed	3	1	3	7	4
Vertical cup plate	1	1	2	4	1
Inclined wheel	3	1	2	6	3
Auger feed	1	2	1	4	1
Belt feed	3	1	1	5	2
Platelet disc with fingers	4	1	1	6	3
Internal cup pick-up	3	1	1	5	2
Cam actuated cups	4	1	1	6	3
Reverse-action wheel	4	2	1	7	4
Centrifugal metering device	4	3	2	9	5
Vacuum feed	4	4	2	10	6
Pneumatic metering system	4	4	2	10	6

Remarks: Rank 1 - Excellent 2 - Good 3 - Fair 4 and above - poor considering the following parameters.

1) Designing and manufacturing simplicity
2) Ability to cope with different granule size and shape
3) Metering uniformity.

2.2 Design parameters for metering devices.

To design an ideal metering device, Kepner, Bainer and Barger (1972), suggested to consider the following characteristics.

i) Discharge proportional to the forward speed of the applicator making application rate independent on forward speed.
ii) Positive dispensing action with fertilizer covering a wide range of drillability.
iii) Discharge rate independent of depth of fertilizer in the hopper and reasonable inclination of distribution.
iv) Free of cyclic variation in discharge.
v) Discharge rate adjustable in small increments with a definite relation to suitable reference scale provided on the unit.
vi) Practical parts-accuracy requirements so that multiple units will have equal delivery rates.
vii) Easy to disassemble for thorough cleaning.

viii) Corrosion resistant material, where feasible, particularly for the working parts.

2.3 Metering and Fertilizer Properties

2.3.1 Fertilizer properties affecting metering

Physical properties of fertilizer govern its response to metering mechanism. The fertilizer property of ease in metering and placement into soil is generally termed as drillability. Mehring and Cuming (1930) attributed fertilizer drillability as being affected by the following properties:

i) Hygroscopicity - this refers to the tendency to absorb moisture from the atmosphere. When relative humidity exceeds the hygroscopic point of the fertilizer, it absorbs moisture rapidly and tends to dissolve. This will have an effect on its drillability by affecting its adhesion and cohesion properties (Mohsenin 1970).

Highnet (1977) summarized the drillability of urea after exposure to high relative humidity (Table 2).

ii) Particle size and shape are some of the major factors influencing drillability. Coarse particles flow more uniformly than fine particles due to their larger ratio of total surface area to volume. Fine

TABLE 2 Drillability of urea after exposure to high humidity environment. (Highnet 1977)

Exposure in hrs	Moisture content after exposure % W.B (a)	Relative drillability after exposure % (a, b)	Drilling consistency after exposure % (a,c)
18	1.3	68	66
24	1.7	69	70
30	1.4	68	67
31	2.0	73	54

a) After exposure for the indicated number of hours at 33 centigrade and 86% RH.

b) Ratio of drilling rate after exposure to drilling rate before exposure x 100.

c) Percent of material in hopper drilled at a rate of 90% more of the initial drilling rate.

particles are affected more by relative humidity than coarse particles. Smooth spherical particles flow easily but irregular particles tend to interlock. Granular and pelleted fertilizer have much better drillability than rough surfaced fertilizer.

iii) Heterogenousity - Fertilizer consists of widely different sizes and types of particles. Ressurreccion (1978) in anlyzing particle size distribution of urea found out that size ranges between 2.38 mm to less than 0.8 mm in diameter. The variation was great both within and between bags. Such variation causes segregation in the hopper with finest and heaviest settling to the bottom where they get distributed first, while the coarsest and lightest particles remain. The result may be much variation in the composition and amount of nutrient spread in the field. Such materials when broadcasted by throwing spinner spreader, show much segregation over the width of spread. Figure 1 shows different particle sizes of prilled urea.

iv) Specific gravity - Metering devices work on volumetric basis while recommendation rates for field application are on weight basis. Lack of uniformity in specific gravity may affect weight delivered.

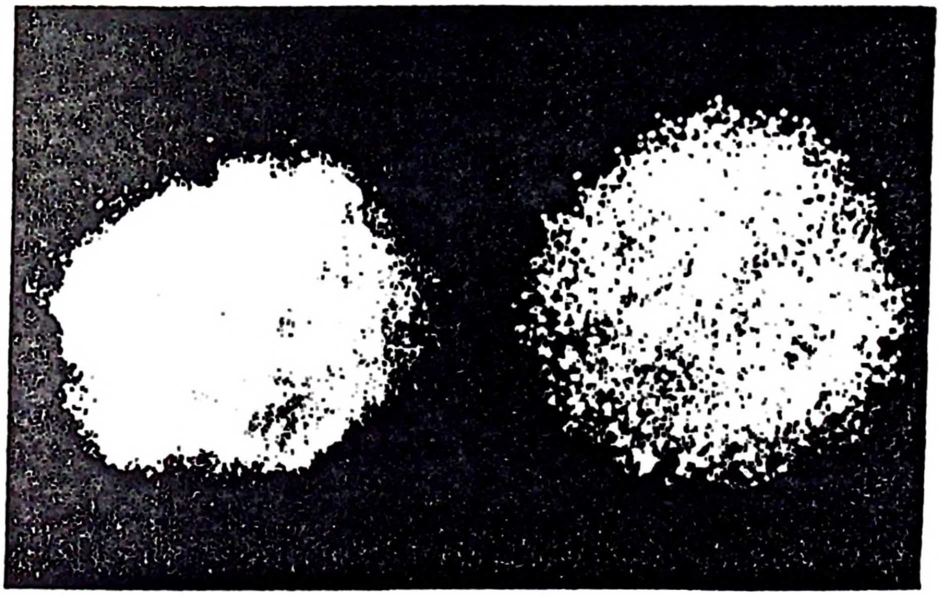

Fig. 1. Different Granule Size of Prilled Urea.

v) The kinetic angle of repose of the fertilizer material affects drillability. It influences (a) the rate of delivery, (b) the size of gate opening through which fertilizer will escape, (c) delivery rate variation with depth change in the hopper, and (d) uniformity of discharge. Common fertilizer material gives an angle of not more than 40 degrees.

2.3.2 Problems associated with fertilizer metering.

Many metering mechanisms have been developed but there are still various problems. Some of these are:

i) Metering accuracy, speed of metering device, characteristics and conditions of fertilizer, and design of discharge tube affect the degree of uniformity of the fertilizer metered volumetrically (Bainer 1947, Kepner et al, 1978, Cumming et al, 1930, Richey et al, 1961, Kiamco 1983).

ii) Bridging - When granular material flows in a hopper, there is a tendency to form a bridge. Briding stops fertilizer flow. This behavior is dependent on the angle of friction between the fertilizer and the hopper, the shape of the hopper bottom, the outlet size, the angle of internal friction of the fertilizer material, the distribution of fertilizer particles, their size and moisture content (Mohsenin 1970).

The problem of bridging caused the modification of the hopper bottom shape for IRRI designed oscillating plunger applicator (Kiamco 1983). Earlier machines had a narrow opening which could not permit smooth flow of fertilizer into the metering chamber. The bottom width between hopper walls was increased to reduce the bridging tendency.

iii) Wedging - Fertilizer granules tend to wedge between moving parts of metering mechanisms. This interferes with the smooth rotation of metering device resulting to either crushing of the granules or erratic rotation of metering mechanisms. It can also, clog metering cells resulting in excessive misses, since no more material can be picked up by clogged cells (Bautista 1983).

iv) Granule breakage - During metering, the moving parts of applicators tend to crush fertilizer. This causes a delay of the smooth flow and therefore poor metering (Kiamco 1983).

v) Non-uniformity in granule size and shape results to erratic metering (Partridge 1947).

vi) Caking - This refers to the lumping of fertilizer granules due to crystal bonds. This characteristic results in bridging and therefore poor drillability. Environmental moisture enhances urea bonding (Hoffmeester 1979).

2.4 Hopper Geometry and Fertilizer Gravity Flow

2.4.1 Hopper shape

Hopper shapes govern the flowability of fertilizer and consequently metering. An important flow property of solids known as "critical flow factor" for hoppers, depend on the angle of friction between the solids and the wall of the hopper, hopper slope, outlet diameter, internal angle of friction of the solids, solid size distribution and moisture content. To avoid obstruction to flow, erratic flow, development of dead zones resulting in degredation of solids, segregation and other problems, proper design of hopper is essential (Mohsenin 1970).

2.4.2 Hopper openings

For appropriate metering, the opening into the metering chamber should not be smaller than the critical opening size. To determine the critical dimension of hopper openings, failure conditions must be established for the two basic obstructions. These are bridging or arching, which causes no flow and/or piping, which reduces or limits flow (Mohsenin 1970).

Considering granular material with bulk density W, forming an arch with a uniform thickness, T, and in hopper

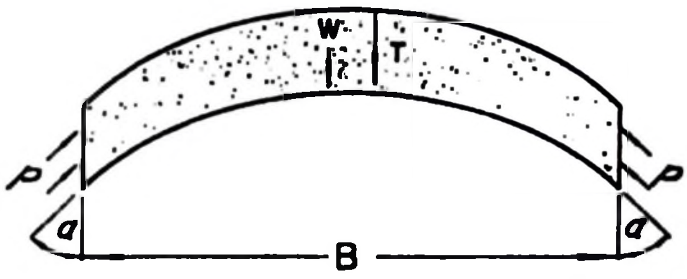

Fig. 2. An arch formed by a mass of granular material above the bottom opening of a hopper.

with a diameter of circular hole, or width of slot B, with length L, the equilibrium forces, resulting from the weight of the mass acting downwards and the vertical component of force due to comprehensive pressure P in the arch (Fig. 2) is given as follows (Mohsenin, (Johnson and Colign), 1970).

$$WBLT = 2\ PLT \cos\alpha \ \sin\alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1$$

where

α = angle of the arch with the vertical

Therefore

$$B = (P/W) \sin 2\alpha \text{ for slots}$$

and

$$W (\pi/4) B^2 = P \pi B T \cos\alpha \sin\alpha \quad \ldots\ldots\ldots \quad 2.2$$

Therefore

$$B = (2P/W \sin 2\alpha \text{ for circles.} \quad \ldots. \quad 2.3$$

In order for the failure to occur, the major compressive pressure P, should be equal to unconfined yield strength, σ_c. Substituting σ_c for P in the above expression, and assuming $\sin 2\alpha = 1$, which considers the strongest possible arc that may form, the critical opening dimension B, becomes

$$B \geq \frac{\sigma_c}{W} \quad \text{for slot opening} \ \ldots\ldots\ldots \quad 2.4$$

$$B \geq 2\frac{\sigma_c}{W} \quad \text{for circular opening} \ \ldots\ldots \quad 2.5$$

2.3.3 Gravity flow

Mohsenin (1970) describes two kinds of flow in hoppers: mass flow and funnel flow. When the cone is sufficiently steep and surface coefficient of friction is small, the channel expands from the outlet upward along the wall of the hopper and the solids are in motion. This happens in mass flow. Since the mass channel coincides with the wall of the hopper, the shape and frictional effects of the walls have a great influence on flow.

An ideal flow has no dead zones and all the solids in the hopper are in motion, whenever any of it is drawn out of the outlet.

Another situation is funnel flow where the solids flow towards the outlet in a funnel formed by the channel itself. The solids surrounding this channel are at rest (dead zone) and has a tendency to spoil or cake. This situation develops if the hopper slope angle to vertical is large or hopper wall is not sufficiently smooth. Some of the problems associated with gravity flow of granular materials from hopper are erratic feeding, flooding, sticking to the wall and formation or obstructions such as "piping" or arching. When the granular material has sufficient strength to support its own weight, it may form an arch across the outlet of the hopper and thus form an obstruction to the flow. The strength of the solid depends on its moisture content, surface roughness and degree of consolidation (Mohsenin 1970).

2.4.4 Flow rate

Deming and Mehring (1929) applied dimensional analysis to the flow of solid particles through funnels and found that when the coefficient of internal friction (assumed equal to angle of repose) and cone include angle were kept constant, the flow rate could be defined by the following functions:

$$tB^{2.5}W = f(\frac{d}{B}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.6$$

Where t = time fo flow in minutes of 100 gms of solids

B = diameter of orifice in mm

w = bulk density in gms/cc

d = average diameter of the assumed spherical particle in mm.

Experimental data using various materials gave the form of function as follows:

$$Q = \frac{100B^{2.5}W}{\tan\Phi_r\left[(34.6+(67.4 \quad +444\sin\frac{1}{2}\theta^{\circ}))(\frac{d}{B}+0.13-0.161\tan\Phi_r\right]} \quad 2.7$$

Where:

Q is the flow rate in grams per minute

is the tangent of the angle of repose.

Based on their experimental data, they concluded that the above equation was valid for estimating the rate of flow of solid particles through funnels with included angles between 20 degrees and 110 degrees.

2.5 Agitators

Agitators are used in fertilizer applicators to aid flowing of fertilizer from the metering chamber. This is achieved by weakening the bonds between fertilizer granules, thus limiting arch or bridge formation above the opening of metering chamber.

Kiamco et al (1983) cited the problems of bridging for oscillating plunger applicator. Among the remedial steps taken was the use of agitators. The first agitator used was made of 3.2 mm (1/8 in) wire with bent leg at its end and attached directly to the plunger. It oscillated in the same frequency with the plunger and agitated fertilizer just above the plunger opening in the hopper. It had a fixed path giving minor effect. The second kind which was connected to main drive sprocket had a slower eliptical path. This was more effective than the first (Fig. 3).

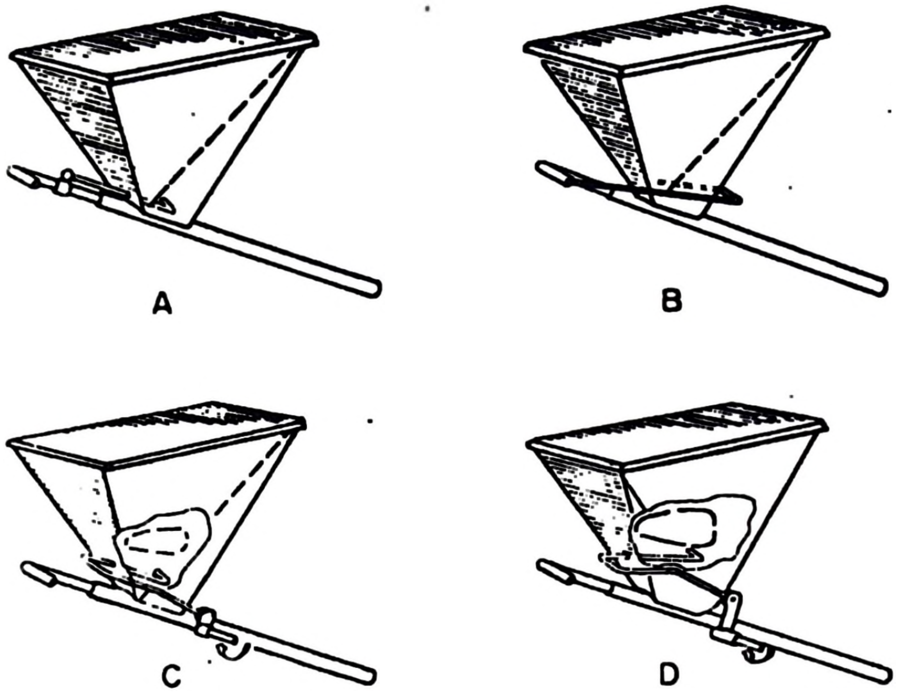

Fig 3. Different hopper agitator arrangement tried with the oscillating plunger applicator.

2.6 Augers

The principle of augers or screw conveyors is accredited to Archimedes 300 B.C. who used them to pump water out of ships (Burkhardt. 1967). Since then, augers have been used to convey grains in storage bins, elevating grains in combines, conveying of slurries in pastery plants and many other applications dealing with granular and pastery conveyance.

IRRI adapted the use of small conveyors (below 20 mm diameter) for applicators as metering mechanisms in 1980s. The spring wire auger was used in power tiller attached applicators, spot applicators, band applicators, both manual and power dirven (Kiamco, 1983).

2.6.1 Types of auger conveyors

Screw conveyors are classified as follows (Cereal Millers Handbook, 1967):

i) Standard helical screw used in most conveying installations

ii) Double flight auger conveyors

iii) Cut flight auger for handling material that tends to pack

iv) Paddle spiral auger, which is essentially a standard helical auger with small paddle between flights

v) Ribbon spiral auger with hollow axis used for conveying and mixing

vi) Variable pitch auger used when variable delivery is required.

2.6.2 Screw theory

To be effective as a feeder, a screw must have a constant output per revolution over a satisfactory speed range. In practice this has never been achieved (Burkhardt 1967).

Auger action is achieved by helical flights. When it turns, the flight pushes the material forward. The auger flights have a slope which increases from periphery to the axis. The slope (S) is given by the following relationship (Gutyar 1956).

$$S = \frac{P}{\pi d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.8$$

Where,

P = pitch

d = auger diameter

Theoreticallyl the auger moves the volume of one pitch per revolution. Its volumetric efficiency can be taken as the volume of material delivered per pitch divided by its volume per pitch (Stevens 1962).

O'Callaghan (1961) described the theoretical action of the auger working in a horizontal direction and when rotating at a low speed in a trough. When the angle of the screw is greater than the angle of friction between the material and the screw, the gravity forces on the particles are greater than the combined friction and centrifugal forces, so that the blades slide the particles and move them forward a fraction of the pitch for every revolution of the screw. The distance moved depends on the properties of the particles, the geometry and speed of the screw.

For inclined conveyors, the effective helix angle of the screw is decreased as the angle of inclination is increased. This way, the particles tend to be carried around the blades rather than to be moved forward. The capacity of the screw conveyor decreases as the angle of inclination increases

Gutyar (1956), Thusing (1958), O'Callaghan (1961) investigated screw conveyors and established various relationship of delivery with auger angular velocity, flight helix angle, angle of friction between the conveyed material and conveyor, angle of inclination of casing and other physical characteristics of conveyed material. They established among other things that there is a critical angular speed of the auger below which upwards conveyance would not take place.

2.6.3 Design parameters influencing simple screw conveyors

Burkhardt (1967) listed some design factors affecting simple screw conveyors as:

i) outer diameter
ii) inside diameter
iii) pitch
iv) number of flights
v) flight thickness
vi) length of flight
vii) material of manufacture

He also listed some factors affecting the screw systems as:

i) Screw design
ii) Radial clearance
iii) Hopper exposure
iv) Hopper shape or design
v) Tube or housing material

Stevens (1962) investigated the effects of auger speed, angle of elevation, radial clearance between the tube and flight, and moisture content of the conveyed material for experimental conveyor. He found out that for grains, when moisture content is above 20% conveyance and power requirement are adversely affected. He also found out that at higher speed, power increases disproportionately, while conveyance per time decreases with an increasing clearances between auger flights and casing, delivery rate is lowered. A clearance about 2.5 cm could not allow conveyance at all. These experiments were for upward conveyance with augers of diameter over 75 mm.

Mahmood (1964) investigated the effect of auger speed, pitch/diameter ratio on conveyance of fertilizer by small sheet and wire augers. He found out that discharge increases with increased auger speed and pitch diameter ratio.

3. METHODOLOGY

The experiment was composed of the following components:

1) Evaluation of physical characteristics of fine prilled urea.
    a) Evaluation of moisture absorption behavior.
    b) Determination of the angle of repose as it varies with moisture content.
    c) Determination of coefficient of friction of the fertilizer to galvanized steel as it varies with moisture content.
2) Gravity flow experiments to determine the optimum wall angle to the horizontal that can minimize bridging and determination of optimum hopper bottom slot opening that can allow flow of the fertilizer. The experiment considered the variations in moisture content.
3) Evaluation of agitators for efficient intake into metering chamber.
4) Characterization of wire and sheet augers. Th· first was to elevate pitch/diameter ratios, and determine which among the three chosen (1.0, 1.25, 1.5) has the higher discharge. The second step was to characterize the augers in terms of their general conveyance ability. The factors considered were

rotational speed, discharge tube inclination angle, fertilizer moisture content and particle size for both augers.

5) Determination of discharge pressure for both horizontal and vertical discharge.

6) Evaluation of injection into mud by both augers at various angle of inclination of delivery tube with simulated movement.

7) Investigation of adhesive behavior of wet fertilizer on augers.

3.1 Physical Properties of Fine Prilled Urea

The fertilizer used was the imported Korean prilled urea with the particle size of less than 0.042 mm to over 1.00 mm (Appendix Table 1).

3.1.1 Evaluation of moisture absorption characteristics

Fertilizer samples of 5 gms each were dried in a microwave oven until they registered no decrease in weight. Dried samples were placed in phytotron cabinets with artificially stabillized Relative humidity of 70%, 80%, and 90% and temperature of between 29°, to 30°C.

For each set of experiments, three samples were used. These samples were exposed to the above conditions for six hours and weighed hourly. The samples were exposed to controlled environment to determine the hygroscopicity of fertilizer with specific environment.

Other sets of experiments were done in paddy fields. Petri dishes were placed on a fixed platform half a meter above the ground to simulate applicator position. The dishes were exposed for six hours and were weighed every one hour. A thermohygrometer was used to record atmospheric temperature and relative humidity changes of the surroundings.

A replication of the above experiment was done indoors. Experiments were done in both conditions to analyze the behavior of the fertilizer when applied in the field (outdoor), and analyze the behavior of the leftover fertilizer after opening the bag (indoor).

These experiments were pre-requisites for succeeding experiments to determine moisture content levels of fertilizer to be used.

3.1.2 Angle of repose

Different samples of fine prilled urea were mixed with different quantity of water to attain various levels of moisture content. Also wooden box of 50 cm x 50 cm was used.

Five kgs. of fertilizer were poured at one corner of the box at one meter from the heap, until it formed a constant angle with the horizontal. This angle was measured.

For every heap, 10 samples of fertilizer were taken randomly and moisture content analyzed.

3.1.3 Coefficient of friction between fertilizer and galvanized steel sheet

An adjustable platform was adopted from the experimental hopper (Fig. 4). It is one of the adjustable side wall which was constructed to facilitate easy adjustment of the angle of inclination of the wall to the horizontal. Hard paper rolled into a cylinder of 80 mm diameter and height of 50 mm was used to hold fertilizer.

Fertilizer of non-predetermined moisture content but at various levels of wetness was filled into the above mentioned cyliner at near horizontal position. Then, the paper cyliner with fertilizer was raised about two millimeters from the platform surface so that it did not influence sliding of the fertilizer. The platform had its inclination angle increased to the point that sliding of fertilizer commenced. The angle was measured from the vertical wall of the experimental hopper. Then fertilizer samples had their moisture content analyzed.

3.2 Gravity Flow Experiments

This experiment was conducted to principally evaluate

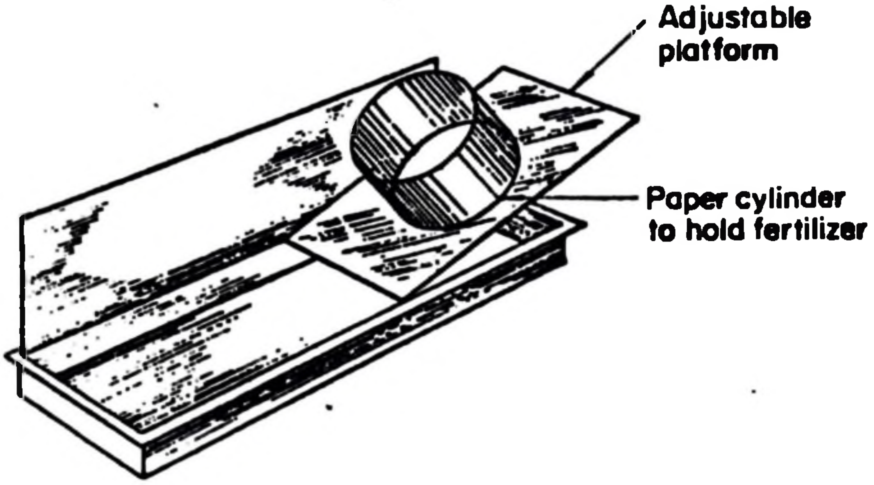

Fig. 4. Apparatus for determination of coefficient of friction between fine prilled urea and galvanized steel.

the optimum hopper geometry which would permit easy flowing of fertilizer into the metering chamber. Parameters considered were angle of inclination of the hopper wall to the horizontal, size of the opening, and fertilizer moisture content.

An experiment hopper (Fig. 5) was used for this experiment. All hopper walls were detachable for easy variation of parameters to be studied. Two of the walls were vertical and non-adjustable, one inclined and adjustable and mounted on a frame which slides for adjustment of the slot size.

The slot made of the four walls had a hinged door to facilitate opening and closing. The wall dimensions were as follows:

Erect walls - 200 mm x 320 mm
Adjustable walls - 100 mm x 250 mm

The walls were mounted to a frame made of angle bar.

The adjustable walls had a graduated ajustment of 50° to 80° to the horizontal. These graduations were marked directly on the vertical walls.

For slot adjustment, the graduation was 15 mm to 45 mm, and had a fixed length of 100 mm.

With such construction, any slot size could be easily selected, depending on the wall angle required.

The moisture content of the fertilizer used was

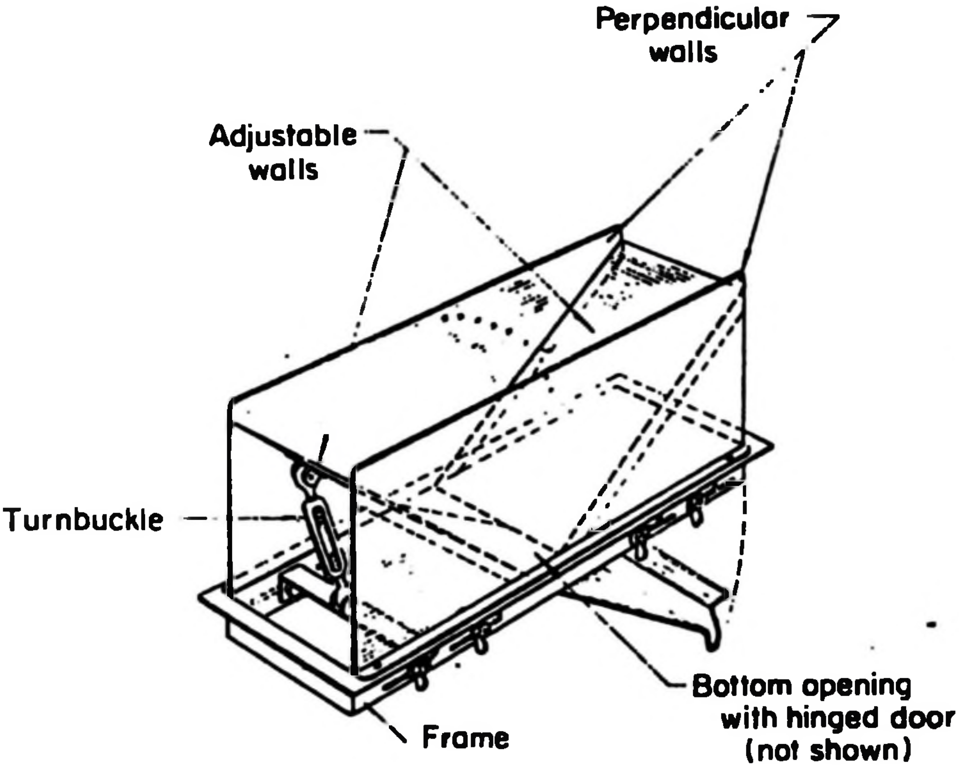

Fig. 5. An experimental hopper for gravity flow experiments .

standardized. Moisture content levels were 0.4% to 1.5% wet basis.

The factors considered and their levels were as follows:

1) slot size opening -
   15 mm x 100 mm, 25 mm x 100 mm
   35 mm x 100 mm and 45 mm x 100 mm.
2) Angle of inclination of the adjustable wall
   50°, 60°, 70°, 80° to horizontal
3) Fertilizer moisture content-
   0.4%-0.6%, 0.7%-0.9%, 1.0%-1.2%
   1.3%-1.5% wet basis

Half a kilogram of fertilizer of duly standardized moisture was poured in a hopper while the botton opening door was closed. Then, the door was opened to release the fertilizer. Time required to empty the hopper was recorded. Trials with no flow were also recorded.

3.3 Evaluation of Agitators

This experiment was originally based on the mode of movement of the agitator and the volume being agitated by it with the aim of evaluating the shape and type of the agitator. However, the idea was dropped because different shapes, agitating same volume at same position would give same effect.

The experiment was performed using the hopper in the proceeding two experiments (Fig. 5).

3.3.1 Agitators and their movement mode

The following movement mode were considered:

1) Eliptical; The agitator makes an oblong circuitous path in a vertical plane during action (Fig.6).
2) Rotary; The crankshaft shaped wire agitator turns about its axis (Fig. 7).
3) Jerking; The pegtoothed wire makes an abrupt swinging movement as it is trigered by a cam and restored by a spring (Fig. 8).
4) Oscillating; The pegtooth wire swing uniformly back and forth (Fig. 8).

An eliptical mode was selected because it is most popular in the manual application being developed at IRRI and due to its ease of installation and ability to use applicator dirve mechanism without need for complex drive linkages.

Rotary mode was selected because it is the most popular in large machines used for application of fertilizer, granular insecticides, and herbicides. In some machines, they are used as aids to gravity flow in metering mechanisms, Its drive linkage requirement is not complicated.

Osillating and jerking modes were selected as one possibilities for agitation. The jerking agitation mechanism is being used in the auger/flutted roller applicator currently under development at IRRI.

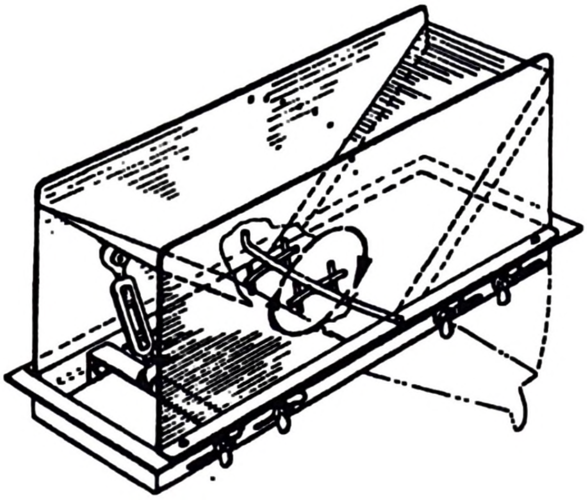

Fig. 6. An experimental eliptical agitator in an experimental hopper.

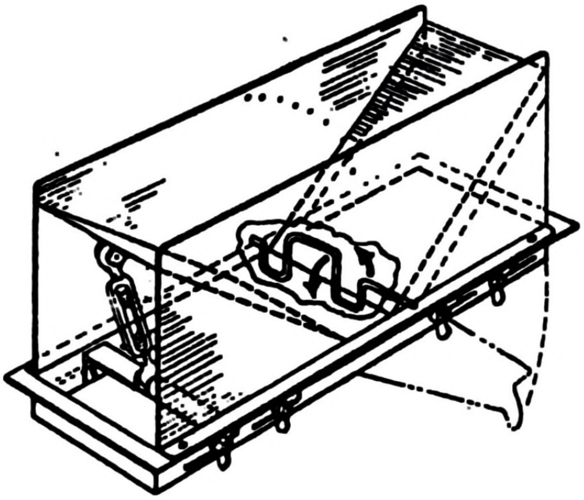

Fig. 7. An experimental rotary agitator in an experimental hopper.

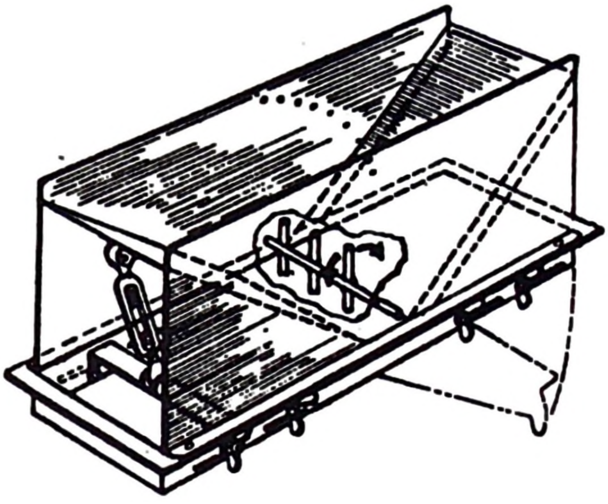

Fig. 8. An experimental agitator for oscillating and jerking modes in an experimental hopper.

3.3.2 Power source

The agitators obtained power from an electric motor with a reduction gearbox. Speed was further reduced by sprocket and chain arrangement and finally transmitted by a shaft. The final shaft speed used was 25 rpm.

3.3.3 Hopper volumetric dimensions

The hopper bottom opening size was 25 mm x 100 mm. The 25 mm width opening was slected because this opening gave uninterrupted free flow during gravity flow experiment. The inclination angle for the adjustable wall was selected to be 65° to the horizontal because of the low resistance to fertilizer flow as found in earlier experiments. The total accomodating volume of the hopper was about 2.96 x $10^4 m^3$.

The volumetric swath for the agitators was standardized to be between one quarter to one third of the total volume of the hopper.

3.3.4 Configuration of agitators

All the agitators were made of 3.2 mm steel wire. The one used for eliptical mode was made of a series of branches to gave a desired swath coverage (Fig. 6). The rotary agitator were made of the same wire like the eliptical agitator but it was simply bent in a way form of a "crankshaft" (Fig. 7). The agitator for the oscillating and jerking mode were of the same configuration. They however differed in movement pattern. They were made out of straight wire with downward pointing pegs which swayed during agitator action (Fig. 8).

The hopper was filled with fertilizer and the agitator was operated to check the flow. The hopper opening was left open and the time of emptying was recorded. Fertilizer with 1.0-1.2% and 1.3-1.5% (wet basis) moisture level was used in the experiment because the combined effect of the wall angle, the hopper bottom opening and the moisture content of the fertilizer resulted in no free flow due to gravity in the gravity flow experiment.

3.4 Characterization of Auger for Fertilizer Conveyance 1

The augers used in the manual applicators designed by IRRI were wire and sheet auger made of wire and sheet metal respectively. Their diameter do not exceed 20 mm width pitch/diameter ratio ranging between 1 to 2. and the geometry of auger used was based on this. The pitch/diameter ratio refers to the pitch divided by the diameter of the auger. The pitch of the sheet auger used was double that of wire auger because the sheet auger flight essentially forms a double flight auger whereas wire auger is single flighted. For this discussion half a pitch of the sheet auger was considered as a pitch to give a fair comparison with the wire auger pitch (Fig. 9).

The first section was concerned with the evaluation of the pitch/diameter ratio to select the better performing auger. For both augers 3 pitch/diameter ratios of 1, 1.25, 1.5 were considered.

3.4.1 Hopper

The shape of the hopper used in the experiment was based on the results derived on gravity flow experiments. Two of its adjacent walls were vertical to facilitate the drive and driven sprocket fixation. For the remaining two, one wall was 65° to horizontal and the other was 67° (Fig. 10). The opening size connecting the hopper bottom and the metering chamber was 30 mm x 80 mm which was widened to facilitate easy feeding of the fertilizer as determined from the gravity flow experiment.

The bottom of the hopper formed a trough of 30 mm diameter. Two 17 mm diameter auger tube were welded on each end of the trough in which the auger was installed. One of the 17 mm tubes had a brass bearing for anchoring the auger while the other 17 mm tube was for delivery of fertilizer (Fig. 10).

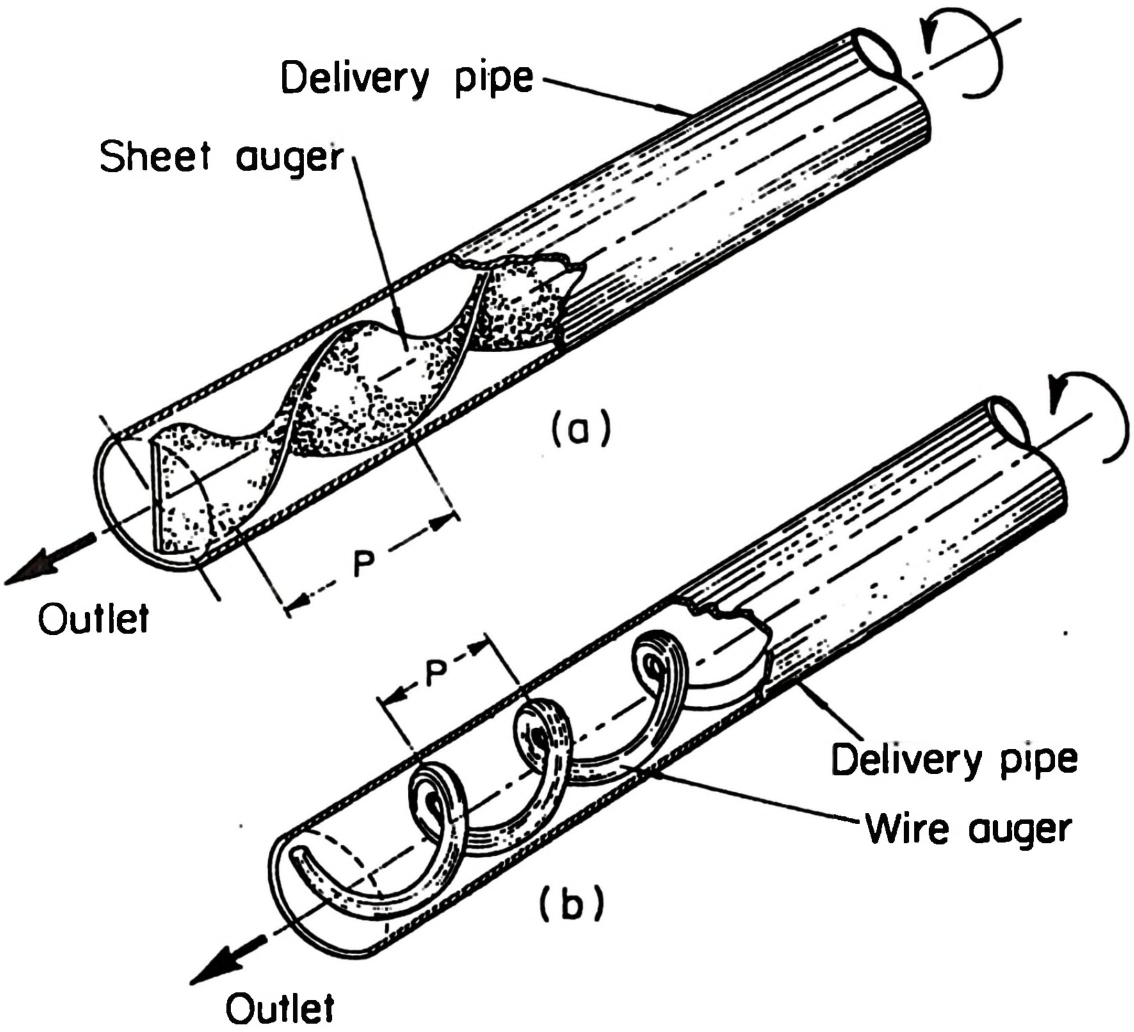

Fig. 9 . Sheet (a) and wire (b) augers used in experimental hopper.

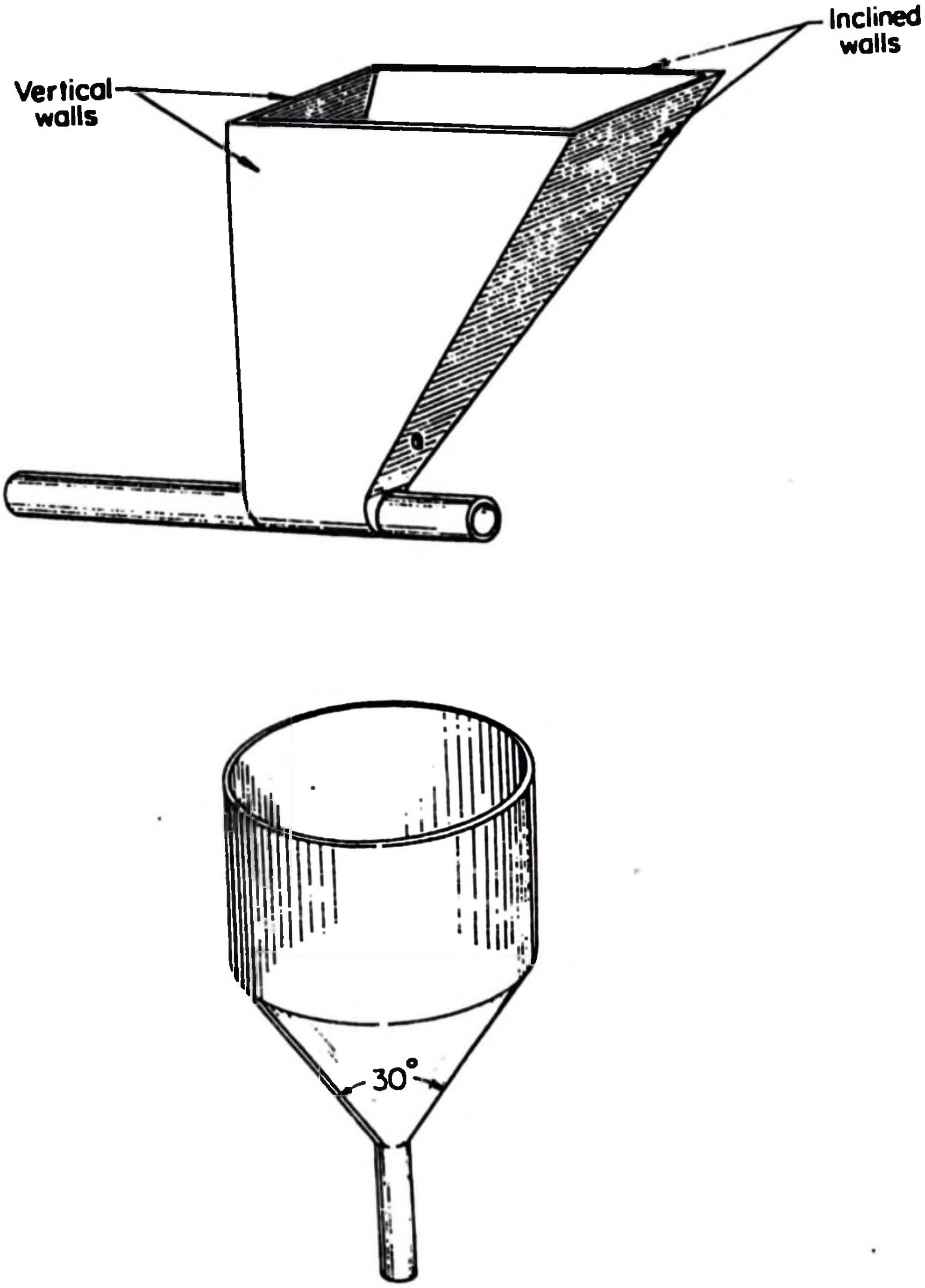

Fig.10. Experimental hoppers for characterization of augers.

3.4.2 Agitation

To ensure thorough fertilizer feeding into the metering mechanism, an agitator was installed into the hopper. Based on agitation experiments, a wire agitator was selected for the mechanisms to give eliptical motion. This was connected directly to the drive sprocket.

3.4.3 Final Assembly

The hopper/auger/agitator assembly was bolted to the frames by means of brackets. The auger sprocket was meshed to the drive sprocket through a right angle arrangement, which in turn was hubbed to a shaft getting its drive from the motor with a speed reduction box.

Fine prilled urea with moisture contents of 0.1-0.3% (wet basis) was used. The augers were run at speed of 50, 100, 150, 200 revolutions per minute. The four speeds were selected to confirm closely with the speed of IRRI applicator walks in muddy clay fields. An operator can walk comfortably in paddy fields at speeds ranging from 1.6 to 2.4 km per hour. The paddle drive wheel that would fit a regular applicator (6-10 kg) is 0.35-0.4 meter in diameter. Using the popularly available bicycle sprockets as drive sprockets and fabricating a small driven sprockets one could obtain wheel-auger drive ratios 1:3.6 to 1:5.2. This is possible with 8 to 10 teeth auger sprocket (driven) and a

36 to 52 teeth for ground wheel sprocket (drive). These are shown in appendix Table 10.

The hopper was filled with fertilizer to the brim before the test rig was operated. Ten samples of fertilizer delivery for one minute were collected at random.

3.5 Characterization of Auger for Fertilizer Conveyance 11

3.5.1 Quantity of discharge

c

The second and main section of the experiment was to analyze variation of discharge of the augers with rotational speed, angle of inclination of the discharge tube, fertilizer moisture content and particle size distribution.

The selected pitch/diameter ratio was based on the result of the preceeding section of this experiment. The parameters were:

Auger rotational speed 50, 100, 150, 200 revolutions per minute.

Angle of inclination of discharge tube was 0°, 30°, 60°, 90° to the horizontal.

Fertilizer moisture content-0.4-4-0.7%, 0.8-1.1%, 1.2-1.5% wet basis.

Granule size distribution - fine and coarse prilled urea.

The instrumentation set-up for horizontal conveyance was based on arrangement of the preceeding experiment.

For inclined delivery, the frame anchoring the hopper/auger/agitator assembly had steel bars of different configurations. This enabled the changing of inclination angle from 0° to 30° to the horizontal.

For delivery angles of 60° and 90° to the horizontal, a funnel type hopper with an included angle of 30° was used. The funnel was tapered into a 17 mm diameter tube (Fig. 10). The auger used with the funnel type of hopper had longer shaft for convenience of power source linkage. The shaft for spring auger extended a bit into the delivery tube to prevent free flow through the central hollow core that may take place without the mechanical action of the auger (Mahmood 1984).

The hopper was fixed to the stand by means of a bracket and the auger obtained its drive from the motor with a reduction gearbox.

The following procedure were then followed:

The hopper was filled to the brim with fertilizer and test the rig was operated. Samples of ome minute delivery were collected.

The experiment was run on 2 x 2 x 3 x 4 x 4 split-split design.

3.5.2 Consistency

The second part was to analyze the consistency of discharge. The analysis was not combined with analysis of the rate of discharge because this required higher replication.

The instrumentation and procedure was based on the preceeding experiment. The only difference was fertilizer moisture content factor level.

The factors and factor levels were as follows;

Auger type - sheet and wire auger

Fertilizer type - coarse and fine prilled urea

Auger rotational speed - 50, 100, 150, 200 rpm

Discharge tube inclination angle - 0^{o}, 30^{o}, 60^{o}, 90^{o}, to horizontal.

Ferilizer moisture content - 0.4-0.7% wet basis.

3.5.3 Injection Experiments

This experiments determined the rate of injection of fertilizer into the mud. To stimulate field conditions, a rotary bin was used.

The same hopper as in the auger characterization experiment was used, but was inclined at 15^{o} to the horizontal. Wire auger was used for metering. The hopper was welded to a delivery tube such that the tube was 30^{o} to the vertical. This tube could carry either a wire or sheet auger for injection. A 52 teeth sprocket was used to drive both metering and injection augers which had 10 tooth sprockets. An agitator (eliptical type) was linked to drive sprocket. The drive was from the electric motor through a sprocket, chain and shaft arrangement.

The soil bin was filled with paddled mahaas clay, to 120 mm depth and topped with 50 mm of water. The bin was rotated with and against the direction of fertilizer delivery at 8.6 and 7.4 rev/min for 100, 200 revolution per minute of auger speeds, respectively. (Fig. 11). Delivery tube path was 80 mm from the bin centre. This arrangement approximately simulated an operator walking at 1.30, 2.6 km per hour with an applicator with a wheel-auger speed ratio of 1:5.2 and wheel diameter of 0.36 m. Fine and coarse urea of 0.1-0.4% moisture content W.B. was used. And both sheet and wire augers were used.

One half a kilogram of fertilizer was put in a hopper, the machine was run and the time needed to empty the hopper was recorded.

3.6 Discharge Pressure Determination

Two kinds of pressure were determined. The horizontal delivery pressure, to give an indication of the ability of the augers to meter, and the vertical (downward) delivery pressure, was an indication of the auger's ability to inject.

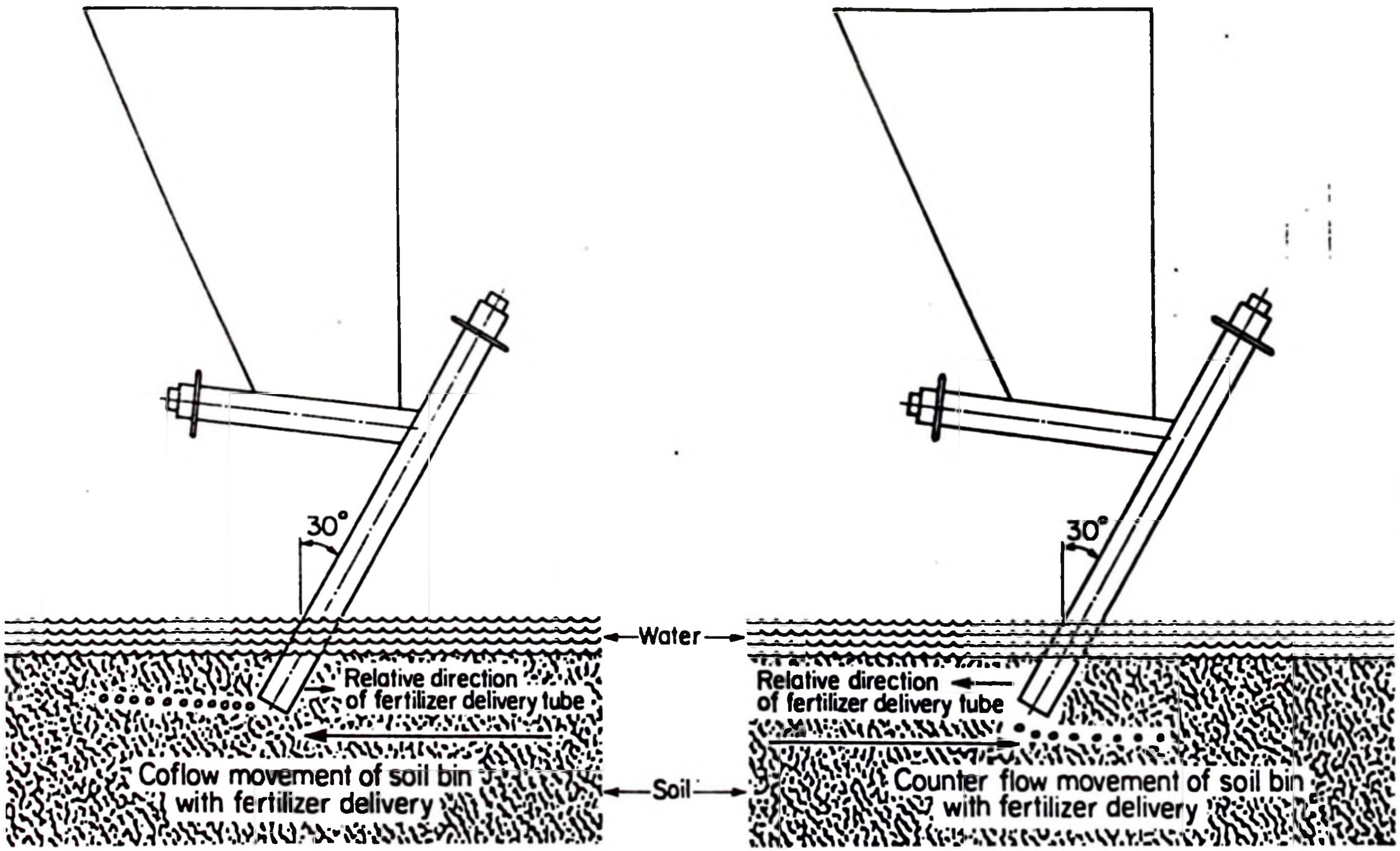

Fig. 11. Schematic presentation of relative soil bin and fertilizer delivery tube movement used in injection experiments.

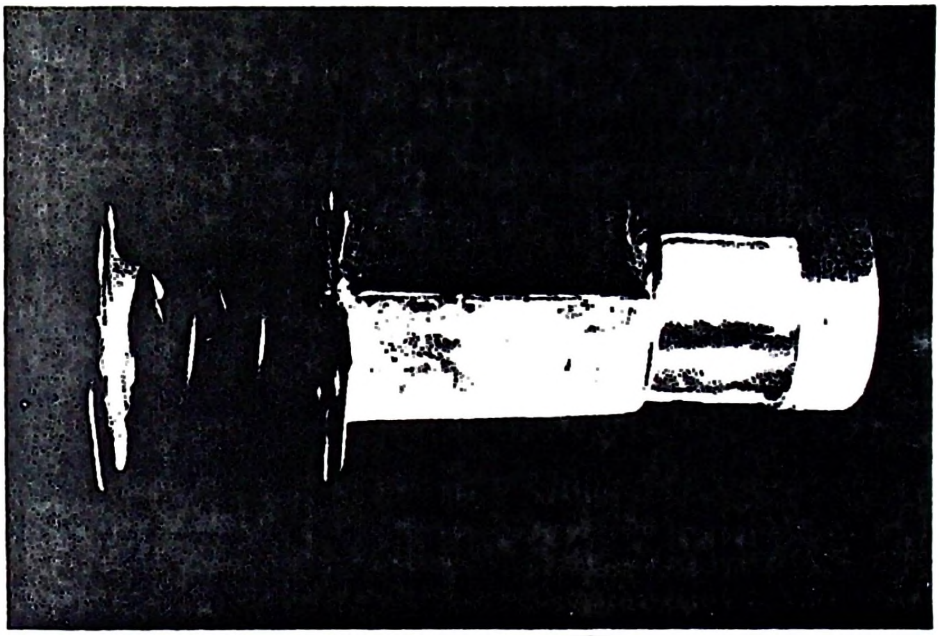

Fig. 12. Alminium cup used to sense discharge pressure.

The instruments used for this experiment were those used in the previous experiment. The hopper auger/agitator assembly was that used in the auger characterization experiment. Power source was the same.

The pressure was measured by the aluminum cap shaped instrument (Fig. 12) with cut away part to allow fertilizer flowing. This was connected to a compression spring which was pressing against a load cell, this assembly was connected to the end of discharge tube. Fertilizer was filled in hopper and the rig was run. The discharge pressure was sensed by the load cell. The load cell gave direct signal to an electronic sensor (data logger) resulting in a direct pressure reading. Fertilizer used was of two moisture levels 0.4 - 0.1% and 1.2 - 1.5.

3.7 Investigation of Adhesive Behavior of Wet Fine Prilled Urea on Sheet and Wire Auger Surface

When fertilizer sticks and builds up on the auger flight surface, it increases solid auger volume and many change the physical characteristics of auger surface. This could have an effect on auger performance. After noting this phenomenon during experimentation, it was decided to conduct this experiment to investigate its effect on auger performance.

The hopper, agitator and auger used were similar to those used in the other experiments on characterization of augers. Fertilizer used was fine prilled urea with moisture content of 0.2% and 1.0% wet basis. The machine was run for 5,10 and 20 minutes and fertilizer collected. Augers were weighed before and after the single run to determine the weight difference.

4. RESULTS AND DISCUSSION

4.1 Moisture Absorption Characteristics of Fine Prilled Urea

Fertilizer samples which were exposed to controlled relative humidity environment had shown a steady increase of moisture content (Table 3).

With 70% RH, fertilizer moisture level increased up to 4.38% MC Wet basis and this was attained on the fifth hour. From this point, there was no more increase in moisture. This means that the equilibrium moisture with the surroundings was attained. Between the fourth and the fifth hour, the fertilizer tended to cake. With 80% RH, samples increased the moisture level to 10.47% MC Wet Basis and like the former, the tendency to cake was between the fourth and the fifth hour. This maybe attributed more to the length of exposure to moisture rather than the level moisture content of the fertilizer as the two kinds of samples exhibited the same behavior with same duration of exposure to different Relative humidity (Fig. 13).

The third set of samples which was in a 90% RH environment also indicated a steady increase in moisture, unlike the former two sets of samples, this set liquified between the fourth and fifth hour of exposure.

The samples which were exposed in rice fields reached the highest level, 0.59% MC Wet Basis, within the second

TABLE 3. Moisture absorbtion by fine prilled urea in controlled relative humidity environment.

RH level (temperature) (29-30 Deg c)	Moisture content % (wb) increase with time					
	hr 1	hr 2	hr 3	hr 4	hr 5	hr 6
70 %	2.60	3.29	3.36	4.15	4.38	4.38
80 %	3.74	6.00	8.15	8.62	9.25	10.47
90 %	12.92	22.54	32.10	40.42	45.22	48.29

Average of 3 samples

TABLE 4. Moisture absorbtion by fine prilled urea in paddy field

Time of exposure in hrs	1	2	3	4	5	6
Moisture Content wet basis %	0.40	0.59	0.40	0.40	0.40	0.40

RH % variation is from 65 to 85 % in 6 hours
Temperature variation 32 - 35 Deg. C

TABLE 5 . Moisture absorbtion by fine prilled urea under indoor exposure

Time of exposure in hours	1	2	3	4	5	6
Moisture Content % Wet basis	1.0	0.69	0.53	0.55	0.59	0.55

RH various is from 55 % to 90 % temperature variation is 28 - 32 Deg. C

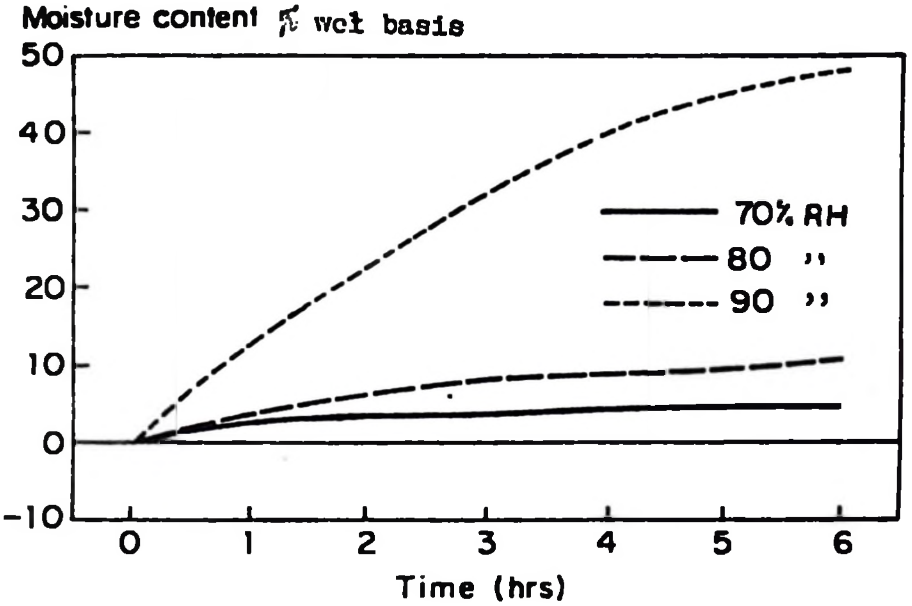

Figure 13. Moisture increase of fine prilled urea under controlled environment.

hour of exposure. For the succeeding hours, it maintained the 0.4% MC level. (Fig. 14, Table 4). The experiment was performed on a sunny day and during the data collection, temperatures were between 32^{o} - 35^{o}C and relative humidity between 65-32%. Half of the time, relative humidity was between 65% to 75% (Fig. 15). Humidity for the day was not very high and many be the reason for the low moisture content level of the fertilizer.

The last set of samples was exposed to indoor environment. The increase in moisture content was abrupt during the first hour of exposure. It was up to 1% Wet Basis (Table 5). As the ambient temperature increased and relative humidity decreased (Fig. 15), moisture content decreased to 0.53%. At this range, it was increasing and decreasing and depending on the psychometric state of the surroundings. The experiment was performed during a cloudy day. This behavior showed a high sensitivity of the fertilizer to moisture absorption. Based on this, it was learned that under normal conditions the farmer can use wet fertilizer with a moisture content between 1.0-1.5% Wet Basis in high humidity climates. From the above results, it was decided that the highest moisture content for the fertilizer to be used in succeeding experiment be 1.5% Wet Basis.

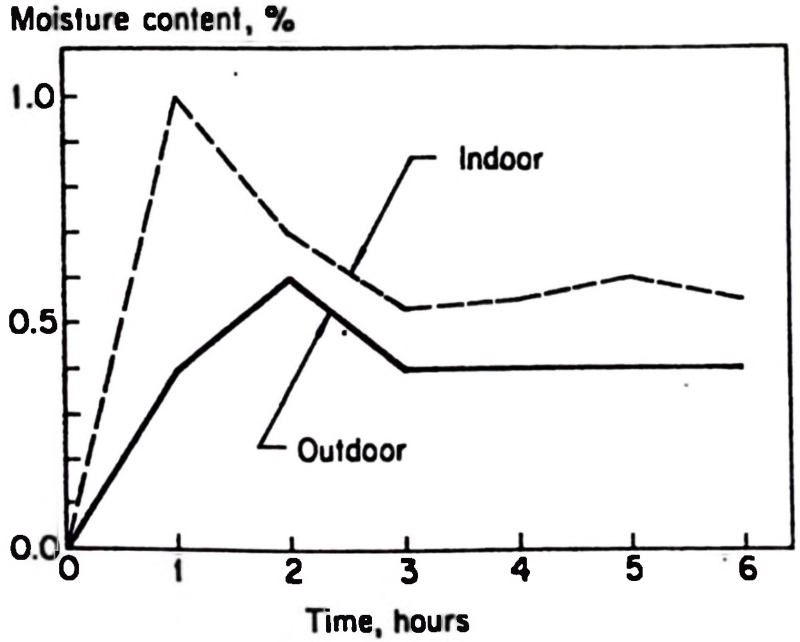

Fig. 14. Moisture absorbtion of fine prilled urea under uncontrolled environment.

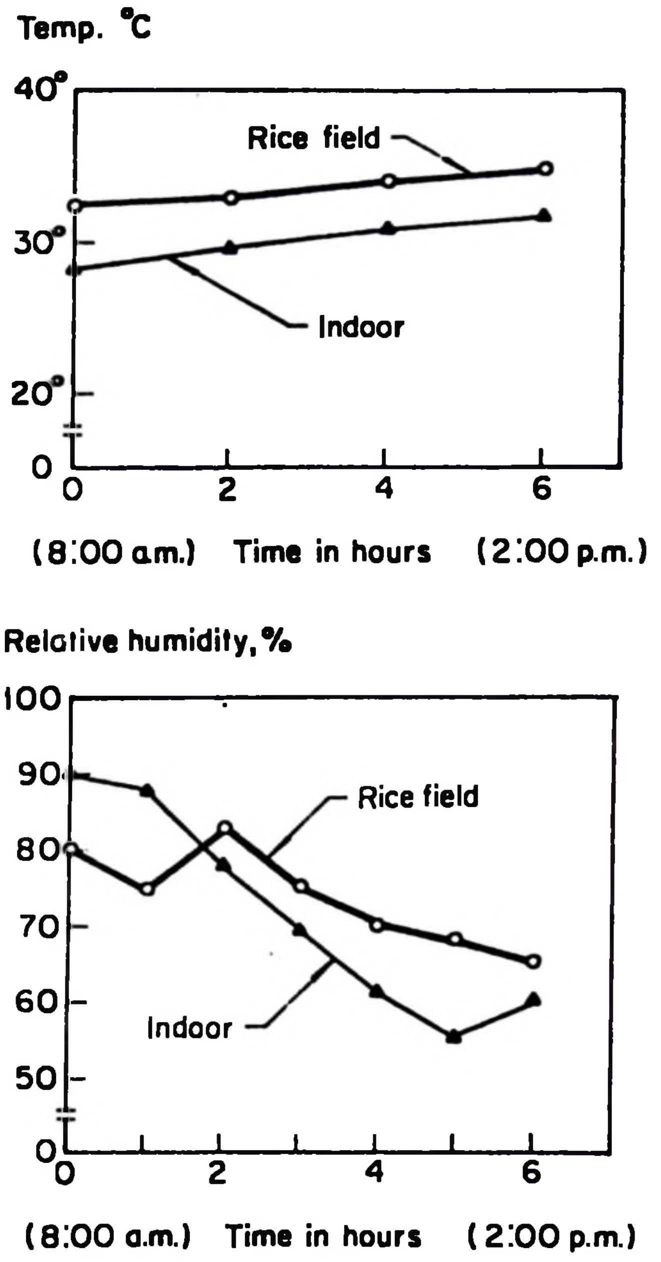

Fig. 15. Temperature and humidity changes at experimental sites for fine prilled urea moisture absorption experiments.

4.2 Kinetic Angle of Repose for Fine Prilled Urea

The fertilizer samples that were used for this experiment included those taken from a freshly opened bag which had an average moisture content (Wet Basis) of about 0.18% and water added sample of average moisture content as high as 1.09% Wet Basis.

From the prediction equation, $y = 35.28 + 5.8$ MC the angle of repose for dry fine prilled urea (assuming 0% MC Wet Basis) is 35°. The regression plot (Fig. 16) shows the effect of moisture content on the angle of repose. The angle repose increases with increase in moisture content. For instance, the fertilizer with 1.5% moisture content Wet Basis has an angle of repose of about 44°. The apparent season for increase of angle of repose with increase in moisture is due to the increased surface tension effect that help hold fertilizer particles together.

The range of fertilizer wetness (0.00%–1.5% MC W.B.) could be used in fertilizer applicators. For the purpose of the fertilizer flow study, the minimum angle for the hopper wall to the horizontal was limited to 50°. The hopper with wall angle lower than the angle of repose, tree flow of fertilizer into metering chamber cannot take place.

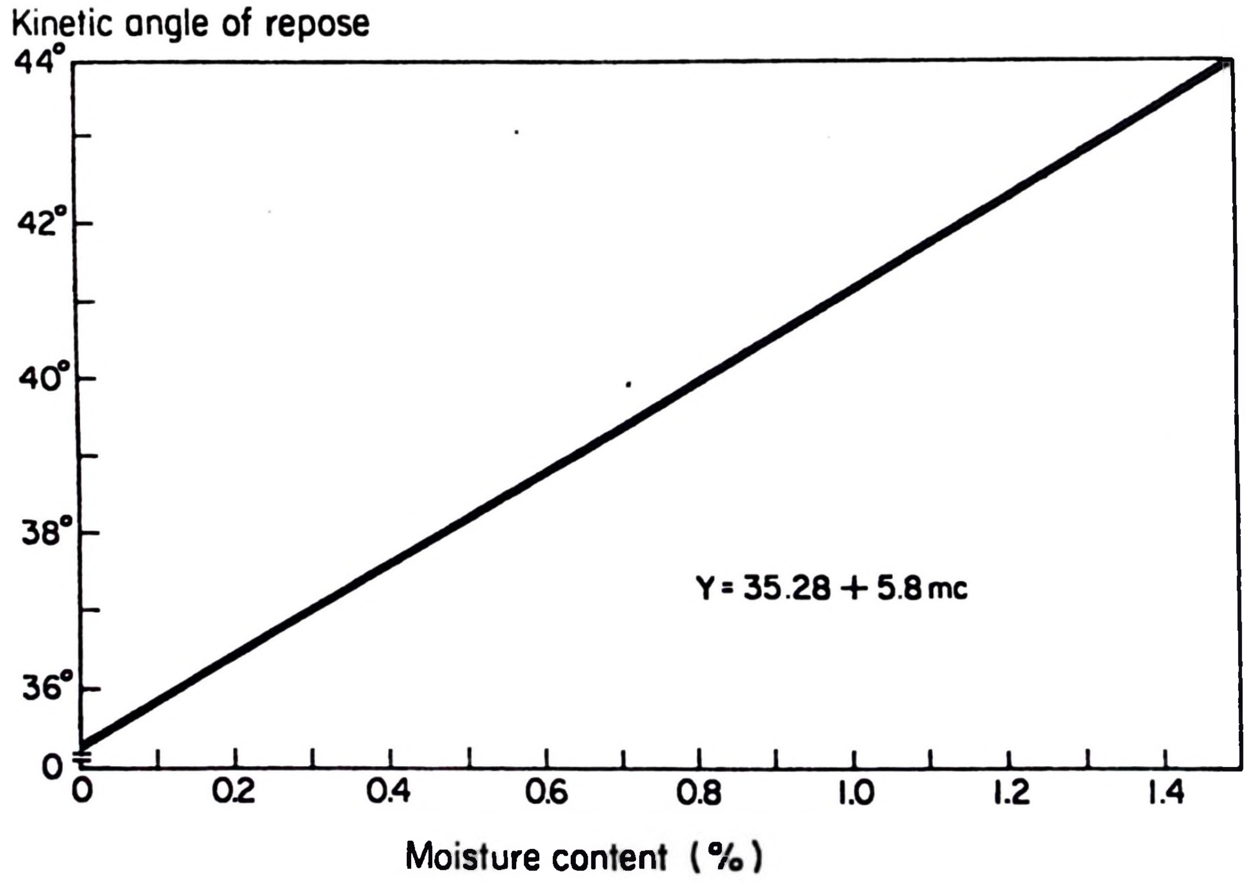

Fig. 16. The effect of moisture content on the angle of repose of fine prilled urea.

4.3 Coefficient of Friction of fine Prilled Urea to Galvanized Steel

Figure 17 shows the regression plot for the coefficient of friction of fine prilled urea on galvanized steel.

The coefficient of friction f, was determined from the tangent of angle to the horizontal, where fertilizer started to slide on the galvanized steel.

$$f = \tan \phi \qquad (4.1)$$

where

f = coefficient of friction

ϕ = the angle of platform to horizontal at which fertilizer started to slide downwards

This method of inclined plane was used for rough rice (Kramer, 1944).

From the regression plot, the coefficient of friction of the lowest moisture content (MC of nearly 0.0%) is 0.6 and for higher moisture content - 1.5% Wet Basis is 0.7. This shows that coefficient friction increases with increase in moisture content. The presence of moisture causes increased friction due to increased adhesion caused by surface tension.

With increased moisture content and increased friction coefficient, fertilizer flow along hopper walls is impared and feeding into metering chamber cannot be carried on smoothly.

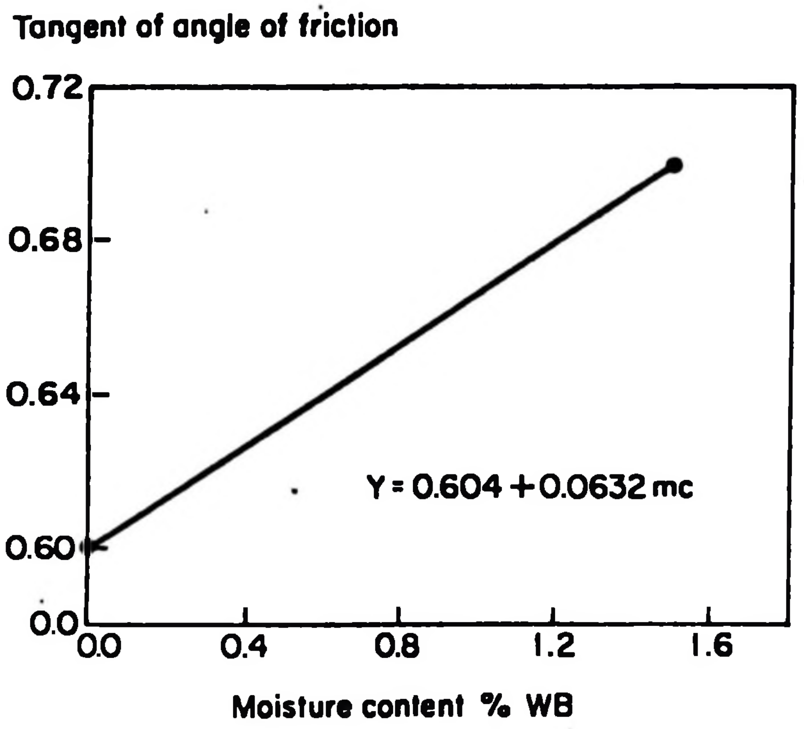

Fig. 17. Effect of moisture content on the coefficient of friction of fine prilled urea on galvanized steel.

4.4 Gravity Flow - Fine Prilled Urea

4.4.1 Effect of Bottom Opening on Gravity Flow

Granular materials flow with difficulty from hoppers because of erratic feeding, flooding, sticking to the wall or due to formation of obstruction such as "piping" and "arching". An arch is formed across the hopper outlet when the granular material has sufficient strength to support its own weight. The arch formation, among other factors will depend on the size of the opening. The smaller the opening, the more the possibility of formation of the arch. It is also enhanced by the degree of moisture content because it promotes adhesive forces between fertilizer granules. From the experimental results, no flow took place at opening of 15 mm x 100 mm, at all levels of hopper wall angle and moisture content (Table 6). Opening of 25 mm x 100 mm had only a single flow. This had the lowest moisture content (0.4-06% W.B) at the steepest opening of 35 mm x 100 mm and had an average flow of 6 trials out of 16. This was concentrated on the steepest wall angle and lowest moisture content. The opening of 45 mm x 100 mm had an average flow of 13 out of 16. Easy flowing with larger opening is due to the large opening to discourage fertilizer granules to form an arc that will support overlying weight.

TABLE 6. Gravity flow trend for fine prilled urea from an experimental hopper

Moisture content % w.b.	Hopper bottom openning(slot)	Rate of flows in Kg/Sec at various hopper wall angle to horizontal			
		50 Deg.	60 Deg.	70 Deg.	80 Deg.
0.4-0.6	15 mm •100 mm	nil	nil	nil	nil
	25 mm •100 mm	nil	nil	nil	0.34
	35 mm •100 mm	nil	0.58	0.66	0.67
	45 mm •100 mm	nil	0.60	0.69	0.70
0.7-0.9	15 mm •100 mm	nil	nil	nil	nil
	25 mm •100 mm	nil	nil	nil	nil
	35 mm •100 mm	nil	nil	nil	0.56
	45 mm •100 mm	0.76	0.58	0.37	0.74
1.0-1.2	15 mm •100 mm	nil	nil	nil	nil
	25 mm •100 mm	nil	nil	nil	nil
	35 mm •100 mm	nil	nil	nil	0.57
	45 mm •100 mm	nil	0.22	0.53	0.69
1.3-1.5	15 mm •100 mm	nil	nil	nil	nil
	25 mm •100 mm	nil	nil	nil	nil
	35 mm •100 mm	nil	nil	nil	0.49
	45 mm •100 mm	nil	0.38	0.34	0.50

Average of 3 replication

The arcs (or bridges) that were formed across the hopper bottom opening had curvature height of 8 mm to 10 mm from the opening.

4.4.2 Effect of Wall Angle on Gravity Flow

The hopper wall angle to the horizontal is another geometrical factor which influences the rate of flow. It is related to the angle of repose, and the angle of friction between fertilizer granule and hopper wall. When the hopper wall have flatter angle than the numerical values of the angles stated above, free flow over walls is expected to be difficult, or may not take place at all.

Mohsenin (1970) analysed the influence of hopper wall angle and kinetic angle of friction between the flowing material and wall on flow. When the hopper walls are sufficiently steep and surface coefficient of friction is sufficiently small, the flow channel expands from the outlet upward along the walls of the hopper and the solids are in motion forming a mass flow. With this kind of flow, the shape and frictional effect of the hopper wall have a great influence on flow since the flow channel coincides with the hopper wall. Channel flow develops where the solids surrounding the channel are at rest when the slope angle of the hopper wall is not steep or when the hopper wall is not sufficiently smooth.

From the experimental data, the flattest hopper wall angle 50° to horizontal, had only a single flow. The trend of the experiment indicates that the higher the angle, the higher the rate of flow. Mostly smooth flow starts with 60° to horizontal and this is with the largest opening (Table 6).

4.4.3 The influence of Moisture content on gravity flow

Moisture has great influence on frictional properties of granular material. The nagle of repose increases with increase in moisture content. The inter-granular cohesive strength increases with increase in moisture content (Mohsenin, 1970). Also the coefficient of friction between the granular material and hopper wall increases with an increase in moisture content.

In the experiments, tests with the most dry sample, 0.4-0.6% (W.B.), maximum flow rates were obtained in 7 tests out of 16. The second driest sample (0.7-0.9% W.B.) had 4 flows each (Table 6). Overall the trend was that the lower the moisture content, the higher the flow rate.

From the result of these experiments, it is noted that free flow from the 100 mm long rectangular opening starts with a minimum opening width of 25 mm and with hopper wall angle of less than 60° to horizontal. Flow is also smooth

TABLE 7. Agitator aided fertilizer flow trend in kg sec^{-1}

AGITATOR	Coarse prilled urea M.C. 1.0-1.2 % W.B. Mean flow rate	 Standard deviation	Fine prilled urea M.C. 1.0-1.2 % W.B. Mean flow rate	 Standard deviation
Eliptical	0.303	0.093	0.16	0.12
Rotary	0.41	0.12	0.26	0.08
Reciprocating	nil	-	nil	-
Jerking	nil	-	nil	-

with low moisture content as a result of reduced surface tension between fertilizer particles.

A manually operated fertilizer applicator has to be compact and light of appropriately 6 to 10 kg. (Khan 1982). Considering this fact, the reasonable bottom opening for easy manoeuvrability hopper with auger metering mechanisms should be about 25-30 mm wide. The hopper wall angle to horizontal for any slanting wall should not be flatter than 65^o from the horizontal.

4.5 Evaluation of Agitators for Metering Mechanisms

Ideally, analysis of agitation should involve shape of agitator, swath, agitation speed, and movement mode. It is difficult to standardize factors mentioned for various agitators. For the purpose of this experiment, it was decided to standardize the swath volume of coverage during agitation movement for comparison purposes.

The four modes tested, two of them (jerking and oscillating) did not aid gravity flow. No fertilizer flowed out of the hopper when operated. Of the remaining two, rotary and eliptical, the former gave a high mean discharge of 0.41 kg/sec. and 026 kg/sec. for both fertilizer type at moisture content level of 1.0-1.2% MC Wet Basis. The latter gave 0.303 kg/sec. and 0.16 kg/sec., respectively (Table 7).

4.6 Characterization of Sheet and Wire Augers 1

with low moisture content as a result of reduced surface tension between fertilizer particles.

A manually operated fertilizer applicator has to be compact and light of appropriately 6 to 10 kg. (Khan 1982). Considering this fact, the reasonable bottom opening for easy manoeuvrability hopper with auger metering mechanisms should be about 25-30 mm wide. The hopper wall angle to horizontal for any slanting wall should not be flatter than 65° from the horizontal.

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4.6 Characterization of Sheet and Wire Augers 1

4.6.1 Pitch/Diameter Ratio Evaluation

The mean of fertilizer discharge in grams per revolution for each treatment was compiled as shown in Table 8 and 9. Tables 13 and 14 give the metering rates in equivalent kg N per ha, when using a drive wheel of 0.36 m diameter and a wheel auger speed ratio of 1:4.

As shown in Table 8 and 9, the sheet auger gives the highest discharge rate at 1.25 pitch/diameter ratio at the two higher speeds (150 and 200 rpm), this auger gave the highest discharge rate at 1.25 pitch/diameter ratio for auger speeds of 100 rpm.

Considering the discharge per revolution, the auger with a pitch/diameter ratio of 1.25 have shown the highest discharge in general compared with the remaining pitch/diameter ratio, except in isolated cases.

To analyse the theoretical relationship of pitch and diameter, the augers cross sectional area should be considered. O'Callaghan et al (1961) gave the formulae of the effective cross section area A, when the shafted auger is filled with conveyed particles, as:

$$A = \frac{\pi}{4}(D^2 - d^2)\eta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 4.2$$

where d = shaft diameter

η = volumetric efficiency
D = Total auger diameter

Auger used in this experiment have no central shaft. This formulae can therefore be modified for these augers as

$$A = \frac{\pi}{4} D^2 \tag{4.3}$$

The particles moved by the auger in one revolution equals the volume of its pitch multiplied by its area. Therefore this can be represented by the following relationship:-

$$Q = A_p \tag{4.4}$$

Where Q = volumetric quantity

p = pitch

Combining equation 4.3 and 4.4, the volume moved in one pitch is:-

$$Q = \frac{\pi}{4} D^2 p\eta \tag{4.5}$$

And the theorectical volume in one pitch can be represented by elimination of η. This becomes Q theor. cap.

$$Q \text{ theor. capa. } \frac{\pi}{4} D^2 p \tag{4.6}$$

The pitch has an effect on the volume of particles moved by the auger. In theory, the higher the pitch, the greater the quantity of particles moved. This is a general trend in this experiment, but with a decreased efficiency.

Using Gutyars (1956) formulae;

$$\frac{p}{D} = S \tag{4.7}$$

Where S = flight slope

The pitch p is:-

$$p = SD \tag{4.8}$$

If $\frac{p}{D}$ is denoted by K,

$$K = S \tag{4.9}$$

Combining equation 4.5, 4.8 and 4.9, the theoretical volumetric capacity of a single revolution becomes:-

$$Q \text{ theor. cap.} = \frac{\pi}{4} D^3 K \text{ .... } 4.10$$

The theoretical rate of discharge, Q (theoretical capacity) at a given auger speed is

$$Q \text{ theor. cap.} = \frac{\pi}{4} D^3 KV \text{ .... } 4.11$$

Using the above relationship and taking a standard bulk density of prilled urea as 740 kg/m3 (Fertilizer Manual, 1978) the theoretical capacities of one revolution of the augers in question are obtained (Table 10).

From Table 8 and 9 where the discharge per revolution are shown, the volumetric efficiencies of each auger at each pitch/diameter ratio and speed were computed. The values obtained are given in Table 11 and 12.

Results show that the higher the ratio the lower the efficiency. This can be explained by the fact that the higher the helix angle of flighting, thus the higher the ptich/diameter ratio the ability of the flight to push the fertilizer forward is lessened. Therefore, there is a higher tendency for the auger flight to carry the fertilizer granules around with it as it rotates.

Table 13 and 14 show the computed metering rates of nitrogen per hectare. This is based on a wheel diameter of 0.36 mm and speed multiplication ratio of 1:4 (drive to driven sprocket wheel) Appendix Table 10).

The trend is similar to the rate per revolution pitch/diameter ratio of 1.25 for both auger type. This pitch/diameter ratio gave better discharge, thus it is possible that this ratio could be a choice for metering for both kind of augers.

TABLE 8. Discharge in grams per revolution of sheet auger at various pitch / diameter ratio and speed~~s~~.

Auger Speed (rpm)	Pitch / Diameter ratio 1.00	 1.25	 1.50
50	1.16	1.40	1.31
100	1.10	1.39	1.30
150	1.05	1.17	1.22
200	0.98	1.22	1.28

Average of ten replications

TABLE 9. Discharge in grams per revolution of wire auger at various pitch / diameter ratio and speed.

Auger Speed (rpm)	Pitch / Diameter ratio 1.00	 1.25	 1.50
50	1.38	1.41	1.43
100	1.41	1.43	1.40
150	1.34	1.35	1.36
200	1.24	1.24	1.15

Average of ten replications

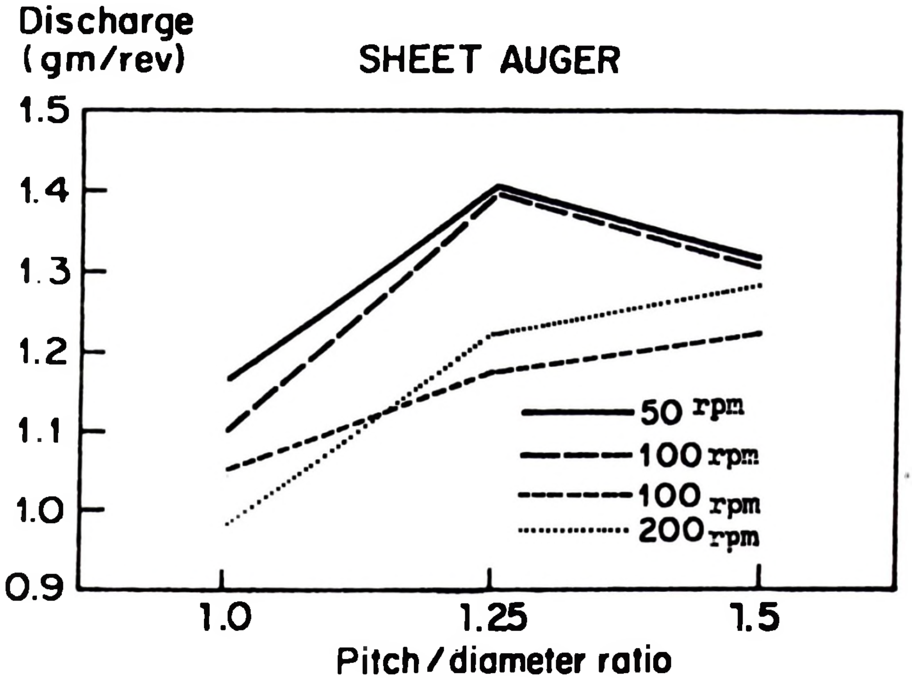


Fig.18. The variation of discharge rate with pitch/diameter ratio.

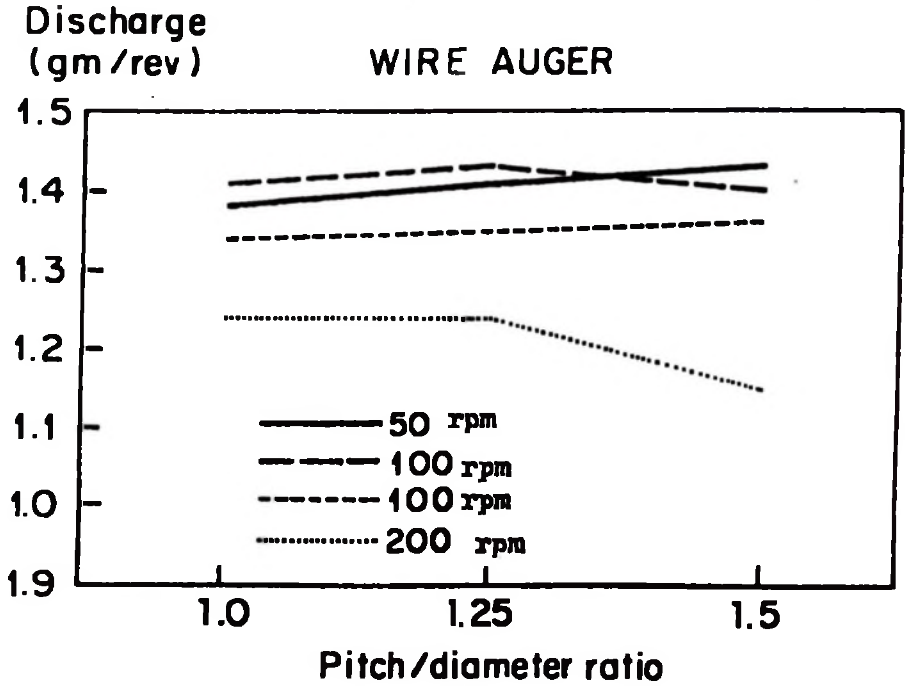


Fig.19. The variation of discharge rate with pitch/diameter ratio.

Table 10. Theoretical capacities of 15 mm diameter sheet and wire augers at their specified pitch/diameter ratios in grams per revolution neglecting the volume of auger material.

Pitch/diameter ratio	Discharge in grams per revolution
1.0	5.66
1.25	7.08
1.5	8.49

Volumetric efficiency (%) would be given as

$$= \frac{\text{Actual throughput}}{\text{Theoretical capacity}} \times 100$$

TABLE 11. Volumetric efficiencies of sheet auger at various pitch per diameter ratio and auger speed in percentage.

Auger Speed rpm	Pitch / Diameter ratio 1.00	 1.25	 1.50
50	20.50	19.60	15.44
100	19.44	19.46	15.32
150	18.56	16.54	14.38
200	17.32	17.24	15.08

TABLE 12. Volumetric efficiencies of wire auger at various pitch per diameter ratio and auger speed in percentage.

Auger Speed rpm	Pitch / Diameter ratio 1.00	 1.25	 1.50
50	24.38	19.93	16.84
100	24.91	20.21	16.49
150	23.67	19.08	16.02
200	21.91	17.50	13.55

TABLE 13. Metering rate equivalent of Nitrogen in Kg per hectare when using a 0.36 m diameter paddle wheel for metering mechanism drive at speed multiplication ratio of 1:4

Sheet Auger

	Pitch / Diameter ratio		
Auger Speed rpm	1.00	1.25	1.50
50	47.16	57.08	53.15
100	44.94	56.55	53.01
150	42.74	47.47	49.54
200	39.84	49.68	52.03

Average of 10 replications

TABLE 14. Metering rate equivalent of Nitrogen in Kg per hectare when using a 0.36 m diameter paddle wheel for metering mechanism drive at speed multiplication ratio of 1:4

Wire Auger

	Pitch / Diameter ratio		
Auger Speed rpm	1.00	1.25	1.50
50	62.95	64.39	65.58
100	64.56	65.61	63.84
150	61.31	61.83	62.39
200	56.88	56.80	52.45

Average of 10 replications

4.7 Characterization of Sheet and Wire Auger 11
(Quanity and Consistency of discharge)

In studying the quantity and consistency of the discharge of fine prilled urea from sheet and wire augers the range of rotational speed, angle of inclination of delivery tube and fertilizer moisture content levels of both coarse and fine urea were considered. In manual applicator, the auger rotational speed can vary with varied drive to driven sprocket ratio and operator's speed. The angle of inclination of the delivery tube can be varied depending on the designer and manufacturer's choice.

Moisture content is dependent on the condition of the available fertilizer and ambient condition however the machine must be able to handle a wide range of moisture level..

4.7.1 Effect of Delivery Tube Inclination on Discharge Rate

Figure 20 and 21 give a trend of the effect of delivery inclination on auger discharge rate. In all cases, delivery increased with inclination. This is more pronounced with dry coarse urea which flows rather steadily due to gravity at inclination angle of over 60°. With fine urea and at higher moisture levels generally both angles gave similar discharge irrespective of auger speed and auger inclination.

The increase in discharge as the delivery tube is inclined downward is due to the action of gravity forces on

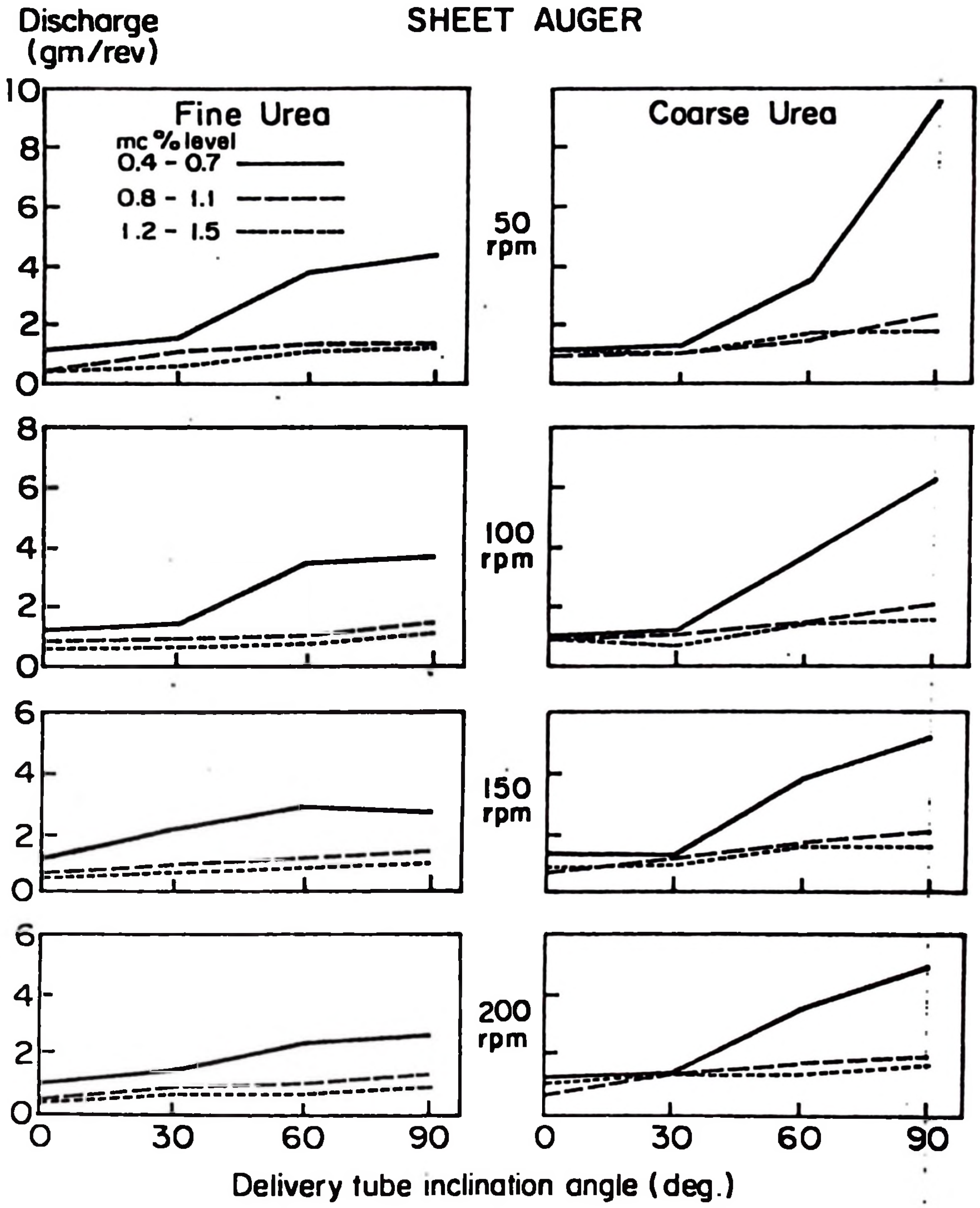


Fig. 20. Variation of rate of discharge with delivery tube inclination angle.

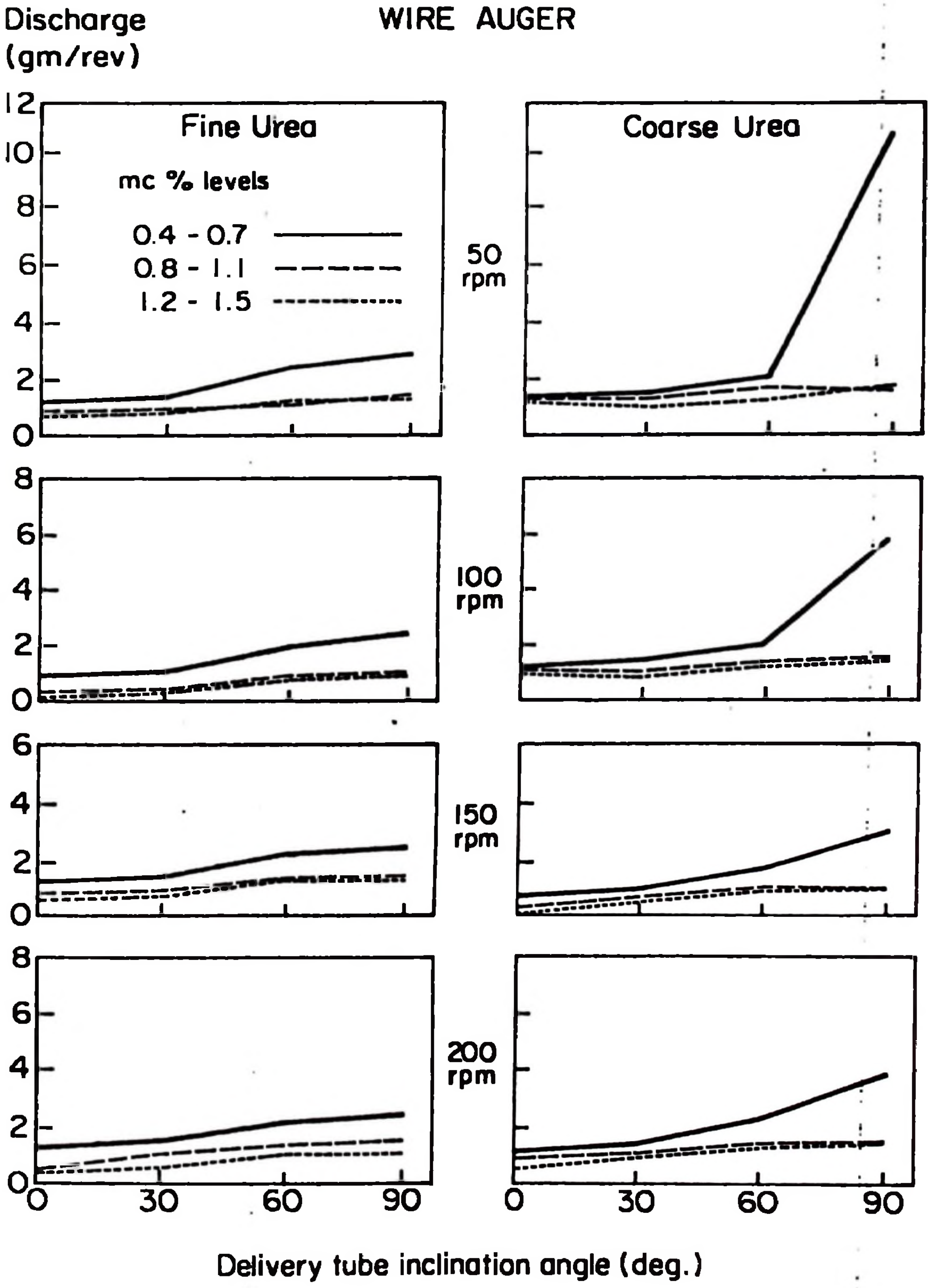


Fig. 21. Variation of rate of discharge with delivery tube inclination angle.

the fertilizer mass. With slight inclination, the fraction of gravity force is small. Fertilizer conveyance is still due to the positive action of the auger and the tube and due to the centrifugal forces exerted by the rotating auger. For the steeper angles, gravity force is high and in such cases, fertilizer may even flow on its own if not impaired. Free flow is impaired by the frictional forces exerted by both the delivery tube and the auger as well as by the centrifugal forces. Flow can best be explained by laws governing flow of solids in chutes and law conveyance.

The reduced flow with increasing speed in Fig. 21 could be due to increased centrifugal forces produced by the rotating auger. The force interferes with flow and causes the fertilizer particles to be thrown radially against the auger tube. The increase in moisture level increases the frictional effect of the auger and the delivery tube on fertilizer, thus impairing flow.

Gravity has effect on vertical conveyance. With inclined conveyance, the gravity force effect in the delivery tube is reduced. The less the angle of inclination from the horizontal the less is the gravity force effect on fertilizer flow. The effect is nil when the delivery tube is at horizontal position.

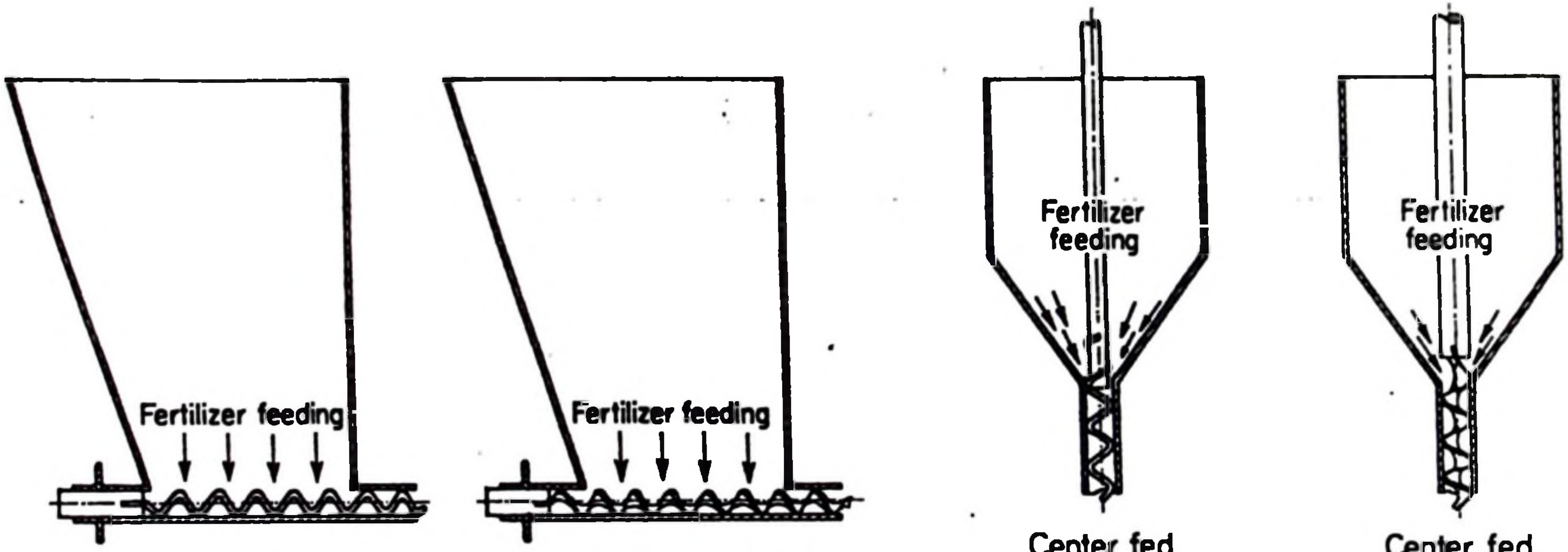
The differences between wire and sheet auger on discharge do not show a uniform trend. At flat angles, wire auger has a higher discharge rate and at steeper angles sheet auger has higher rates.

This is true in fertilizer with low moisture content. At steeper angles (60°and 90° to horizontal) a funnel type of hopper which is centerfed was used (Fig. 10). The difference in this case seems to be due to the intake capacity. At flatter inclination wire auger takes in more fertilizer into open-core cavity than sheet auger. It should be noted that with steep inclination fertilizer intake is from all directions of the auger (centerfed) but with horizontal position, fertilizer intake is from the upper side only (side fed). As the moisture content increases, fertilizer intake tends to change. Wire auger maintains a higher discharge while sheet auger reduces.

Coarse urea has generally shown higher flow rate that fine urea. This can be attributed to the fact that coarse urea has ferwer granules at a given mass than fine urea causing it to have less friction resistance to flow. (Tables 15, 16, 17, and 18).

4.7.1.1 Consistency

Discharge consistency is an important property. Inconsistent fertilizer metering results in poor fertilizer distribution. This can result in univen crop growth and maturity. Table 19 gives variances of discharge rate amoung 6 replications for the angle of inclination. This was computed in kg of N per hectare, on the basis of 0.36 m applicator drive wheel and wheel/auger speed ratio of 1:4. The variance is at its lowest when the delivery tube is horizontal and increases considerably with increase of inclination angle.



Side fed wire auger

Side fed sheet auger

Center fed wire auger

Center fed sheet auger

Fig. 22 Side and center fed fertilizer metering mechanisms.

TABLE 15. Mean discharge rate of fine prilled urea in gms per revolution - sheet auger

	Delivery Tube Inclination Angle											
	0 deg.			30 deg.			60 deg.			90 deg.		
	Moisture Content (%) wet basis											
Auger speed (rpm)	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5
50	1.190	0.545	0.552	1.536	1.164	0.650	3.684	1.422	1.148	4.370	1.415	1.312
100	1.166	0.872	0.620	1.508	0.967	0.680	3.537	1.019	0.793	3.836	1.491	1.076
150	1.140	0.666	0.530	1.139	0.900	0.695	2.885	1.113	0.866	2.693	0.977	0.977
•200	1.098	0.533	0.509	1.440	0.922	0.808	2.385	1.165	0.910	2.598	0.962	0.962

Average of 4 replication
• Average of 6 replication

TABLE 16. Mean discharge rate of coarse prilled urea in gms per revolution - sheet auger

	Delivery Tube Inclination Angle											
	0 deg.			30 deg.			60 deg.			90 deg.		
	Moisture Content (%) wet basis											
Auger speed (rpm)	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5
50	1.254	0.998	1.288	1.302	1.132	1.146	3.540	1.580	1.706	9.586	2.262	1.792
100	1.094	0.990	1.047	1.221	1.129	0.831	3.258	1.635	1.519	6.320	2.158	1.652
150	1.397	0.821	0.873	1.283	1.195	0.959	3.837	1.657	1.564	5.195	2.038	1.611
•200	1.236	0.784	1.033	1.351	1.345	1.342	3.549	1.790	1.442	4.536	2.015	1.711

Average of 4 replications
• Average of 8 replications

TABLE 17. Mean discharge rate of fine prilled urea in gms per revolution - wire auger

	Delivery Tube Inclination Angle											
	0 deg.			30 deg.			60 deg.			90 deg.		
	Moisture content (%) wet basis											
Auger speed (rpm)	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5
50	1.292	0.876	0.750	1.404	0.902	0.908	2.434	1.196	1.316	2.910	1.474	1.356
100	1.247	0.767	0.600	1.382	0.853	0.763	2.145	1.241	1.133	2.579	1.363	1.296
150	1.223	0.785	0.565	1.403	0.887	0.704	2.143	1.310	1.207	2.381	1.377	1.275
*200	1.250	0.702	0.663	1.460	1.053	0.781	1.820	1.312	1.106	2.017	1.425	1.257

Average of 4 replications

* average of 8 replications

TABLE 18. Mean discharge rate of coarse prilled urea in gms per revolution - wire auger

	Delivery Tube Inclination Angle											
	0 deg.			30 deg.			60 deg.			90 deg.		
	Moisture Content (%) wet basis											
Auger speed (rpm)	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5	0.4 to 0.7	0.8 to 1.1	1.2 to 1.5
50	1.348	1.252	1.120	1.427	1.236	1.034	2.060	1.594	1.222	10.72	1.540	1.621
100	1.311	1.148	1.052	1.542	1.146	1.003	2.140	1.511	1.313	5.857	1.530	1.719
150	1.263	0.933	0.887	1.543	1.178	1.060	2.391	1.541	1.372	3.062	1.615	1.536
200	1.284	0.926	0.803	1.487	1.212	1.090	2.090	1.556	1.454	2.994	1.484	1.492

TABLE 19. Means and variance of metering rates for various delivery tube inclination angles in N Kg / ha.

(MEAN)

Delivery Tube Inclination Angle

	Auger Speed (rpm)	0 deg.	30 deg	60 deg.	90 deg.
Sheet Auger	50	51.43 c	53.08 c	151.91 b	404.94 a
Coarse Urea	100	45.07 d	50.76 c	154.37 b	261.53 a
	150	45.93 d	53.61 c	156.45 b	213.14 a
	200	51.64 d	56.10 c	143.15 b	105.63 a
Fine Urea	50	48.73 d	63.35 c	157.52 b	172.56 a
	100	47.93 d	61.64 c	145.24 b	152.93 a
	150	47.17 c	58.05 b	117.31 b	115.37 a
	200	45.02 d	58.67 c	96.44 b	107.81 a
Wire Auger					
Coarse Urea	50	55.05 c	57.83 c	86.35 b	425.80 a
	100	52.88 d	63.20 c	87.29 b	239.52 a
	150	52.11 d	62.55 c	86.13 b	166.99 a
	200	52.95 d	61.92 c	85.39 b	120.80 a
Fine Urea	50	52.67 d	58.80 c	90.92 b	117.70 a
	100	51.32 d	56.62 c	85.80 b	106.43 a
	150	49.70 d	57.59 c	86.61 b	98.48 a
	200	51.66 d	60.48 c	74.97 b	84.49 a
		50.08	58.40	13.37	106.38

TABLE 19. Contnd.

(VARIANCE)

Delivery Tube Inclination Angle

	Auger Speed (rpm)	0 deg.	30deg.	60 deg.	90 deg.	Bart Let's Test
Sheet Auger Coarse Urea	50	1.86	0.73	7.37	53.25	21.96••
	100	1.12	0.61	4.57	54.03	26.45••
	150	1.24	1.67	5.26	14.01	8.43•
	200	3.11	1.25	5.94	12.40	5.94•
Fine Urea	50	0.35	0.88	1.30	38.63	30.46••
	100	0.24	1.03	1.22	29.75	28.40••
	150	0.31	0.82	5.58	17.77	18.55••
	200	1.13	1.44	2.26	0.38	3.33(ns)
Wire Auger Coarse Urea	50	0.26	2.64	7.62	87.79	30.62••
	100	0.22	2.36	4.47	12.74	13.89••
	150	2.34	0.26	10.58	8.00	12.58••
	200	2.36	1.71	3.26	12.22	5.85(ns)
Fine Urea	50	0.05	1.85	5.25	10.30	19.76••
	100	0.37	0.30	1.16	3.07	8.03••
	150	0.11	4.55	3.00	7.86	13.64••
	200	0.33	0.05	1.23	5.61	20.93••
		0.96	1.38	4.38	23.00	

• Significant at 5%
ns not significant

Means with the same letter donot have significantly different variance

The average variance is 0.96, 1.38, 4.38, and 23.00, for delivery tube inclination angle of 0, 30, 60, and 90 to horizontal. For the purpose of metering accuracy, it can be concluded that the nearer the inclination angle to the horizontal, the better the accuracy. This implies that to get the most accurate delivery metering, auger must be positioned in an almost horizontal position in applicators.

Considering the quantity of discharge, the horizontal position of delivery tube has the least discharge rate. When designing applicator, a compromise must be reached between discharge rate and metering consistency.

4.7.2 The effect of Auger Rotational Speed on Discharge Rate

In order to get a uniform fertilizer distribution from a manual fertilizer application, the fertilizer discharge per auger revolution should not vary with speed. The auger rotational speed can be partially controlled in a fertilizer applicator by varying the wheel - auger drive ratio.

If discharge per revolution is constant with varying auger rotational speed, no variation in fertilizer distribution will occur due to changes in auger rotational speeds. Figure 28 and 29 give the effect of auger rotational speed on discharge rates of discharge per revolution have no significant difference with varying speed with drier fertilizer. Discharge per revolution decreases significantly with increase in rotational speed especially at steeper

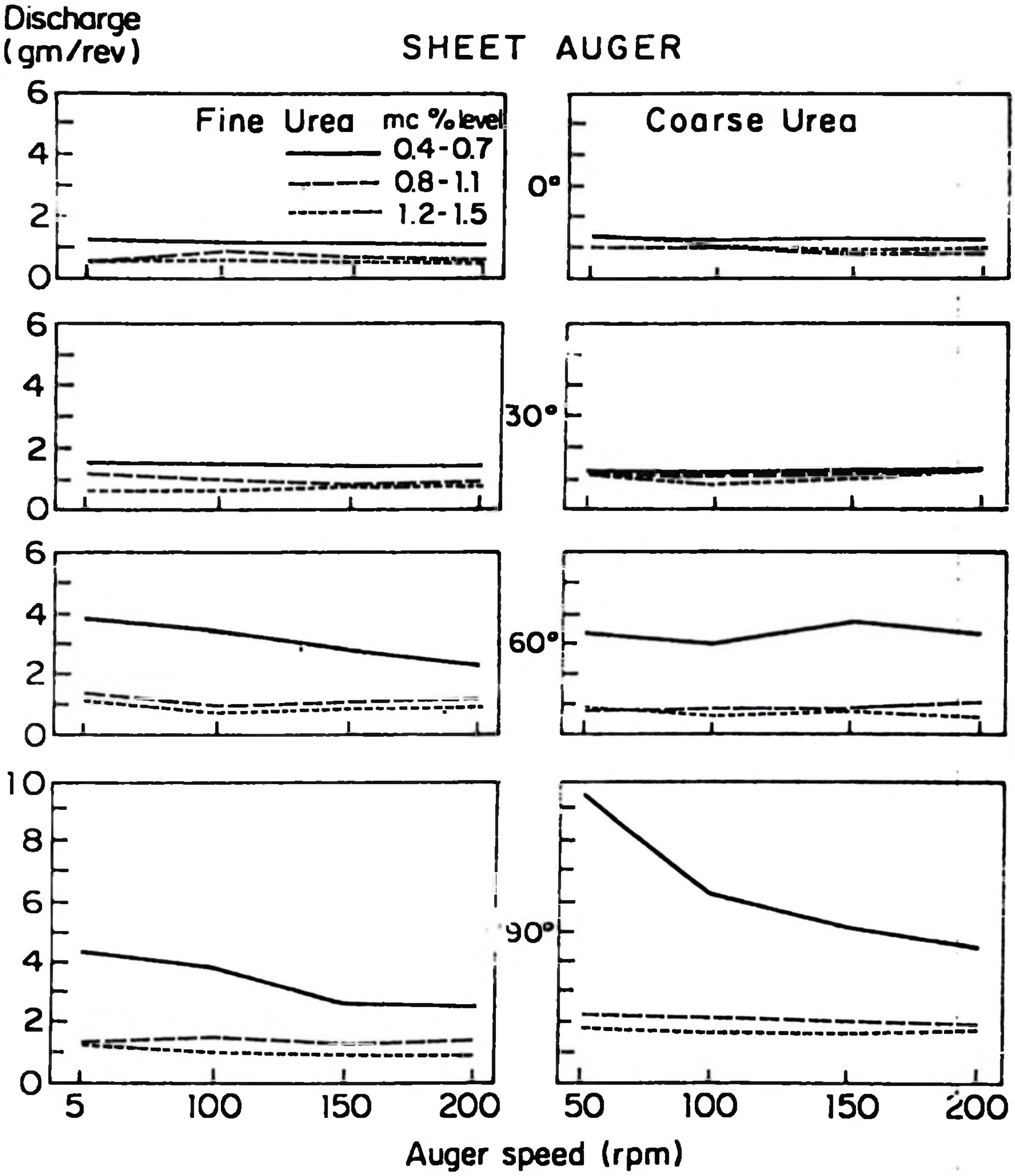


Fig. 23 Variation of rate of discharge with auger rotational speed.

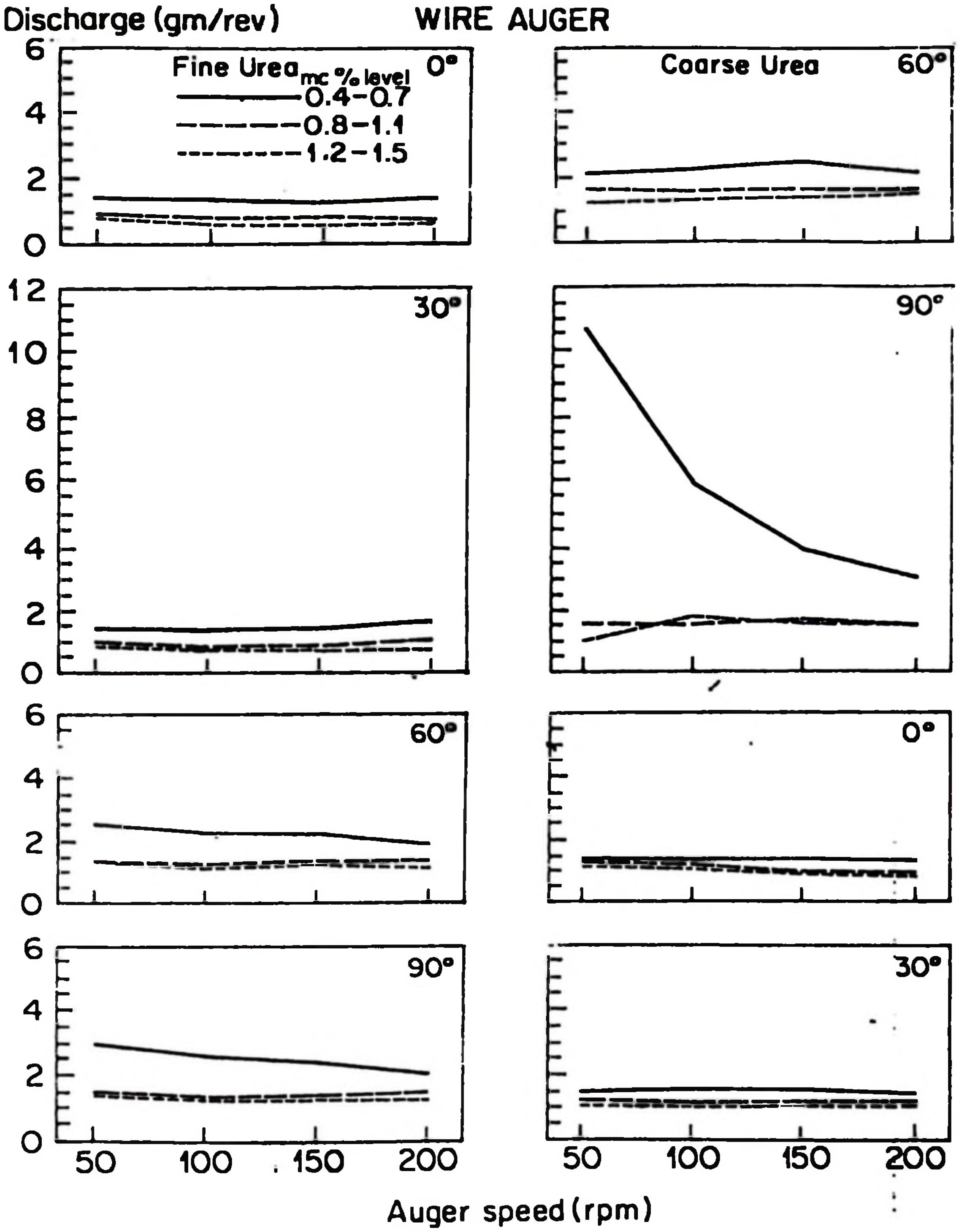


Fig. 4 . Variation of rate of discharge with auger rotational speed.

TABLE 20. Means and variances of metering rates for various auger rotational speeds (N Kg / ha)

(MEAN)

	Auger Tube (rpm)	Delivery Tube Inclination Angle			
		50	100	150	200
Sheet Auger Coarse Urea	0	51.43 a	45.07 b	45.93 b	51.64 a
	30	53.08 ab	50.76 b	53.61 ab	56.10 a
	60	151.90 b	154.37 ab	156.45 a	143.15 c
	90	404.94 a	261.53 b	213.14 c	185.63 d
Fine Urea	0	48.73 a	47.93 ab	47.17 ab	45.02 b
	30	63.35 a	61.64 ab	58.05 c	58.67 bc
	60	157.52 a	145.24 b	117.31 c	96.44 d
	90	172.56 a	152.93 b	115.37 c	107.81 d
Wire Auger Coarse Urea	0	55.05 a	52.88	52.11 a	52.95 a
	30	57.83 a	63.20 a	62.55 a	61.92 a
	60	86.35 a	87.29 a	86.13 a	85.39 a
	90	425.80 a	239.50 b	166.99 c	128.80 d
Fine Urea	0	52.67 a	51.32 a	49.70 a	51.66 a
	30	58.88 ab	56.62 b	57.59 ab	60.48 a
	60	98.92 a	85.80 b	86.61 b	74.97 c
	90	117.70 a	106.43 b	98.48 c	84.49 d
		128.54	103.91	91.70	84.07

TABLE 20. Contd

(VARIANCE)

Delivery Tube Inclination Angle

	Auger Speed (rpm)	50	100	150	200	Bartlet's Test
Sheet Auger						
Coarse Urea	0	1.86	1.12	1.24	3.11	1.56(ns)
	30	0.73	1.61	1.67	1.25	1.50(ns)
	60	7.37	4.57	5.26	5.94	0.29(ns)
	90	53.25	54.03	14.06	12.40	4.21(ns)
Fine Urea	0	0.35	0.24	0.31	1.13	3.75(ns)
	30	0.88	1.03	0.82	1.44	0.45(ns)
	60	1.30	1.22	5.58	2.26	3.74(ns)
	90	39.83	29.75	17.78	0.38	15.43**
Wire Auger						
Coarse Urea	0	0.26	0.22	2.34	2.36	10.09*
Fine Urea	30	2.64	2.36	0.26	1.71	5.55(ns)
	60	7.62	4.47	10.58	3.26	1.88(ns)
	90	87.77	12.74	8.00	12.22	9.36(ns)
Fine Urea	0	0.05	0.37	0.11	0.33	5.34(ns)
	30	1.85	.30	4.55	0.05	19.21**
	60	5.25	1.16	3.00	1.23	3.70(ns)
	90	10.30	3.07	7.86	5.61	1.73(ns)
		13.77	7.33	5.21	3.42	

** Significant at 1 %
* Significant at 5 %
ns Not significant

Means with the same letter donot have significantly different variance auger angles. This could be attributed to centrifugal force effect (Fig. 24) which acts negatively on flow by increasing radial dispersion of fertilizer mass.

4.7.2.1 Consistency

Consistency increased with speed. Table 20 gives the variance of discharge rates of kg N per hectare among 6 replications of the auger speed. The average variance for auger speeds of 50, 100, 150, and 200 revolutions per minute were 13.77, 7.33, 5.21, and 3.42, respectively. This was computed based on an applicator with a 0.36 m drive wheel and a wheel-auger speed ratio of 1:4. Greater consistency at increased speed could be due to the fact that with increased auger speed, the fertilizer mass is subjected to more centrifugal force. This decreases the forward movement of fertilizer by increasing wall friction. And as fertilizer is moved to the delivery tube wall, the auger flight give a positive push to it and the effect of gravity is minimized.

4.7.3 Effect of Fertilizer Moisture Content on Discharge Rate

The presence of the moisture film on solid surfaces increases their frictional properties. As discussed earlier, coefficient of friction between fertilizer and galvanized steel increases with fertilizer moisture content increase, as shown in Fig. 17. This is due to the increased

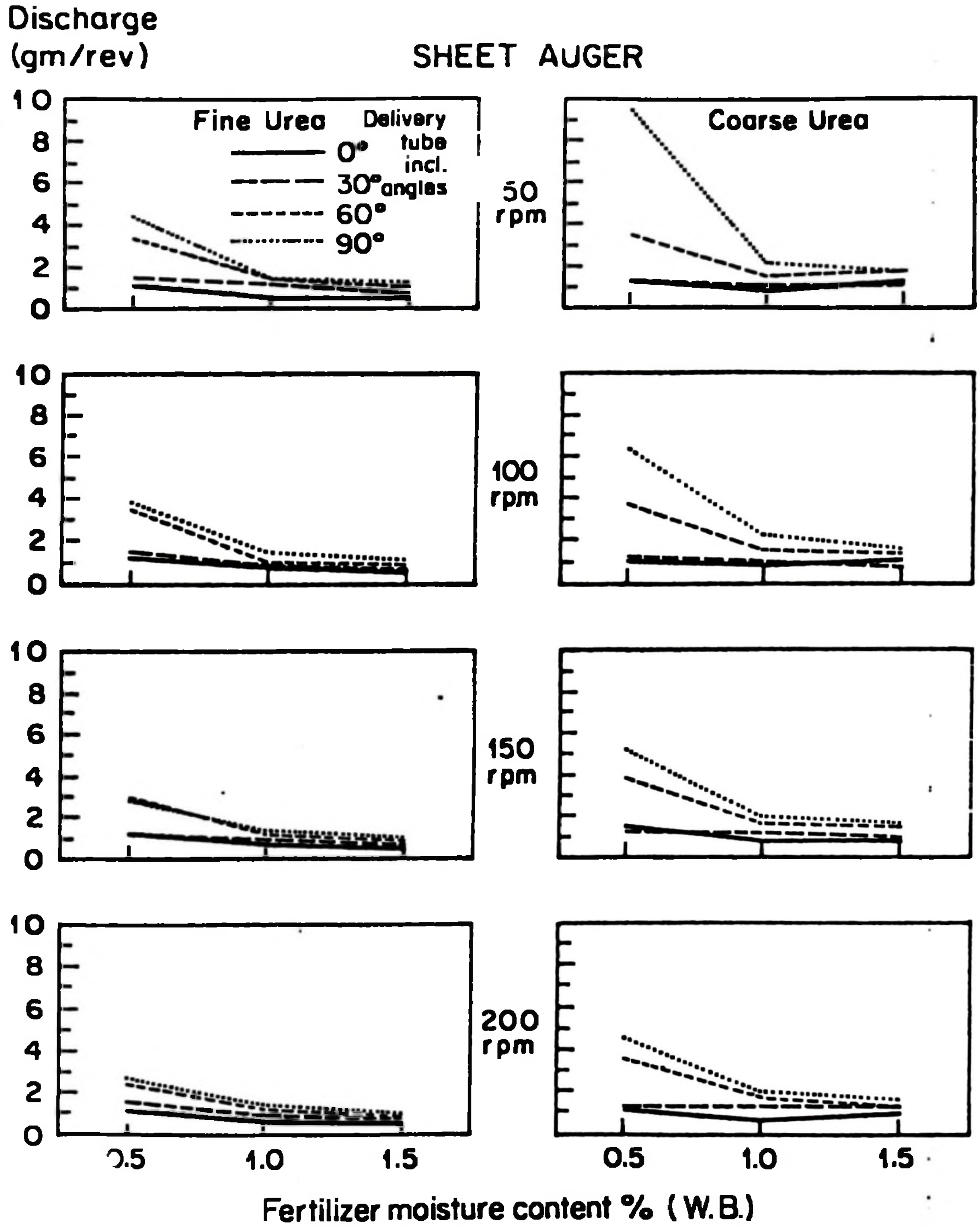


Fig.25 Effect of fertilizer moisture content on discharge rate.

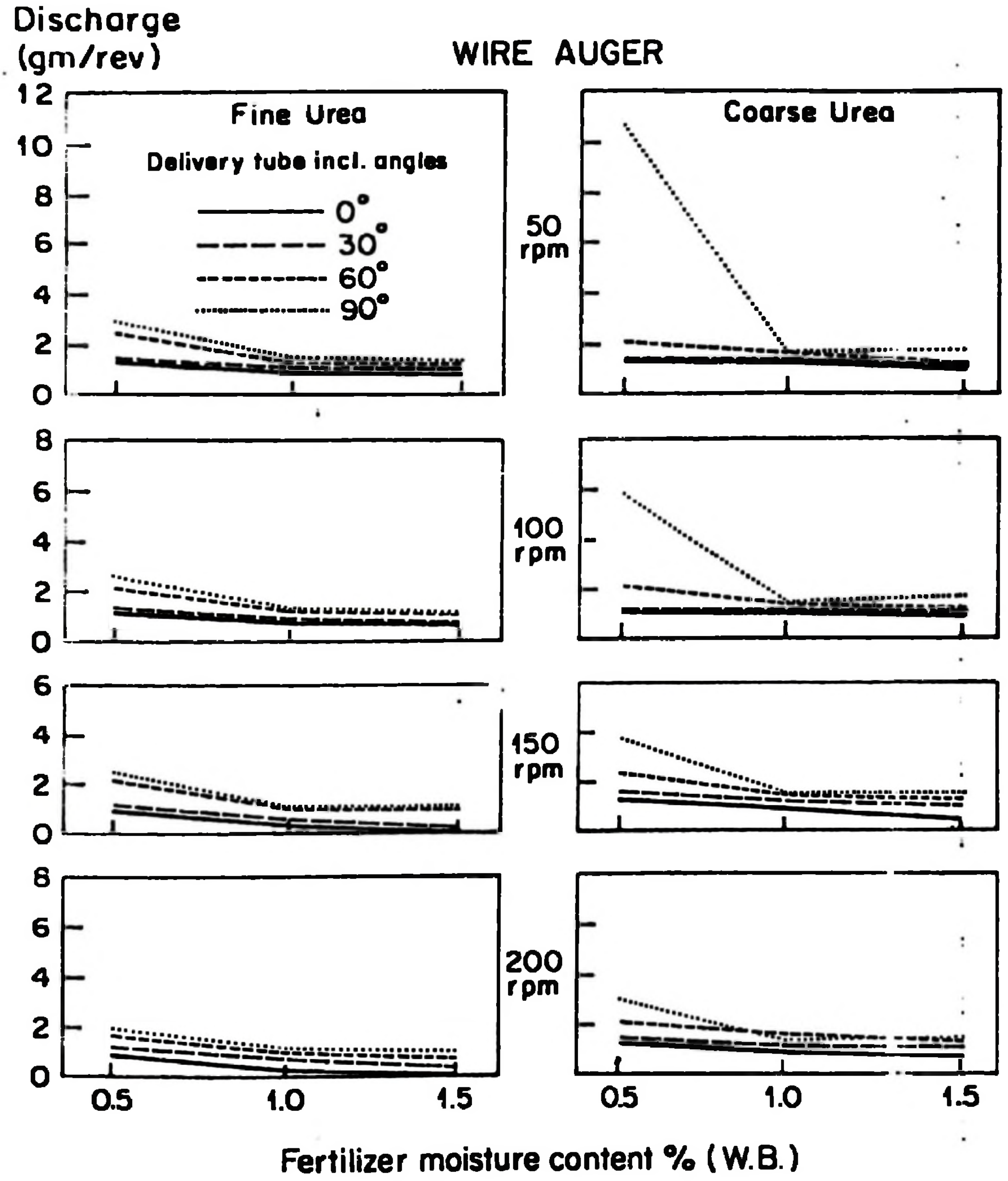


Fig. 26. Effect of fertilizer moisture content on discharge rate.

adhesive properties between fertilizer granule to contacting surfaces. Figs. 30 and 31 give the general trend of the effect of moisture content on discharge. The higher the moisture content the less the rate of discharge. In this case, the coefficient of friction between fertilizer and both the auger surface and delivery tube surface increases, increasing the component of force that retards conveyance.

Increased moisture content increases the internal friction between fertilizer granules. Figure 18 gives the regression plot of the angle of repose with moisture content. From the figures it can be noted that with increased moisture content, the angle of repose increases. As internal friction increases, the gravity will have a reduced effect on the inclined delivery. Fertilizer will be conveyed as a single lump than in dependent granules. This can explain the drastic drop in discharge with increased angle of inclination at high moisture content levels.

4.7.4 Sheet versus Wire Auger

Sheet and augers differ in geometry. Sheet auger is constructed from a sheet metal strip and twisted into a spiral. It is double flighted without any central core. The wire auger is constructed from a steel wire twisted to form a coil (single flight) with a large hollow core. When in action, the sheet auger separates the conveyed fertilizer into two lots. Wire auger having a central hollow cavity conveys fertilizer as a single lot. The fertilizer in the hollow cavity is being packed by the action of internal friction between particles.

The sheet auger has a larger contact surface than the wire auger. More fertilizer granules come into contact with the sheet auger surface than the wire auger. This means that friction plays a greater role in retarding flow with sheet auger than with wire auger. Centrifugal forces diverting fertilizer radially are high with sheet auger than wire auger because all fertilizer in a sheet auger is subject to the rotating action of the auger whereas the wire auger has an open core which is not positively rotated.

With the exception of vertical discharge of fine urea at moisture content of 0.4 — 0.7% (wet basis) the general trend was that wire auger gave a higher discharge rate.

This can be summarized by the following facts:

1. The wire auger, due to its hollow cavity, allows

TABLE 21. Means and variance of metering rates of prilled urea for sheet and wire auger N Kg / ha

			AUGER							
			MEAN				VARIANCE			
			Sheet Auger	Wire Auger	Diff.		Sheet Auger	Wire Auger	F-Test	
Coarse urea	0	50	51.43	55.05	3.62	*	1.86	0.26	7.15	*
		100	45.07	52.88	7.81	**	1.11	0.22	5.05	
		150	45.93	52.11	6.18	**	1.24	2.34	1.89	
		200	51.64	52.95	1.31		3.11	2.36	1.32	
	30	50	53.08	57.83	[illegible].75	**	0.73	2.64	3.62	
		100	50.76	63.20	[illegible].44	**	0.61	2.36	3.87	
		150	53.61	62.55	8.94	**	1.67	0.26	6.42	*
		200	56.10	61.92	5.82	**	1.25	1.71	1.37	
	60	50	151.91	86.35	-65.56	**	7.37	7.62	1.03	
		100	154.37	87.27	-67.10	**	4.57	4.47	1.02	
		150	156.45	86.13	-70.32	**	5.26	10.58	2.01	
		200	143.15	85.39	-57.76	**	5.94	3.26	1.82	
	90	50	404.94	425.80	20.86	**	53.25	87.77	1.65	
		100	261.53	239.52	-20.01	**	54.03	12.74	4.24	
		150	213.14	166.99	-46.15	**	14.01	8.00	1.75	
		200	185.63	128.80	-56.83	**	12.40	12.22	1.01	
Fine urea	0	50	48.73	52.67	3.94	*	0.35	0.05	7.00	*
		100	47.93	51.32	3.39	*	0.24	0.37	1.54	
		150	47.17	49.70	2.53		0.31	0.11	2.82	
		200	45.02	51.66	6.64	*	1.13	0.33	3.42	
	30	50	63.35	58.88	-4.47	**	0.88	1.85	2.10	
		100	61.64	56.62	-5.02	**	1.03	0.30	3.43	
		150	58.05	57.59	-0.46		0.82	4.55	5.55	*
		200	58.67	60.48	1.81		1.44	0.05	28.80	**
	60	50	157.52	98.92	-58.60	**	1.30	5.25	4.04	
		100	145.24	85.80	-59.44	**	1.22	1.16	1.05	
		150	117.31	86.61	-30.70	**	5.58	3.00	1.86	
		200	96.44	74.97	-21.47	**	2.26	1.23	1.84	
	90	50	172.56	117.70	-54.86	**	38.83	10.30	3.77	
		100	152.93	106.43	-46.50	**	29.75	3.07	9.69	*
		150	115.37	98.48	-16.89	**	17.78	7.86	2.26	
		200	107.81	84.49	-23.32	**	0.38	5.61	14.76	**
Mean			111.70	92.41			8.49	6.37		

** Significant at 1 %

* Significant at 5 %

more fertilizer intake than the sheet auger.

2. The sheet auger, having a greater contact area, has a higher frictional and centrifugal activity than the wire auger.

4.7.4.1 Consistency

Table 21 gives the variances of discharge among 6 replications for sheet and wire augers at different speeds and the angle of inclination of the delivery tube. The wire auger shows better discharge consistency than sheet auger. This can be explained by the fact that the wire auger has a more uniform intake than the sheet auger. When rotating at a certain instance the edge of the sheet auger directly faces the entrance of the metering chamber, allowing fertilizer to enter the full width of the auger cavity. When the open cavity of this auger faces the entrance, fertilizer is allowed in, half the width. This tendency causes the differences in fertilizer feeding and therefore variation in conveyance. The wire auger at any point of rotation allows fertilizer to penetrate fully into its cavity, giving a reduced variation.

4.7.5 Fertilizer Particle Size Response to Auger Metering (Fine Versus Coarse Prilled Urea)

Prilled urea is a composite of various particle sizes. These sizes range from less than 420 to more than 1 mm in

TABLE 22. Means and variance of metering rate for coarse urea and fine urea N Kg / ha

	Angle of inclination	Auger rotat. speed (rpm)	FERTILIZER					
			MEAN			VARIANCE		
			Coarse	Fine	Diff.	Coarse	Fine	F-Test
Sheet Auger	0	50	51.43	48.73	2.70	1.86	0.35	5.31 *
		100	45.07	47.93	-2.86	1.12	0.24	4.67
		150	45.93	47.17	-1.24	1.24	0.31	4.00
		200	51.64	45.02	6.62 **	3.11	1.13	2.75
	30	50	53.08	63.35	-10.27 **	0.73	0.88	1.21
		100	50.76	61.64	-10.88 **	0.61	1.03	1.69
		150	53.61	58.05	-4.44 **	1.67	0.82	2.04
		200	56.10	58.67	-2.57	1.25	1.44	1.15
	60	50	151.91	157.52	-5.61	7.37	1.30	5.67 *
		100	154.37	145.24	9.13 **	4.57	1.22	3.75
		150	156.45	117.31	39.14 **	5.26	5.58	1.06
		200	143.15	96.44	46.71 **	5.94	2.26	2.63
	90	50	404.94	172.56	232.38 **	53.25	38.83	1.37
		100	261.53	152.93	108.60 **	54.03	29.75	1.82
		150	213.14	115.37	97.77 **	14.01	17.78	1.27
		200	185.63	107.81	77.82 **	12.40	0.38	32.63 **
Wire Auger	0	50	55.05	52.67	2.38	0.26	0.05	5.20 *
		100	52.88	51.32	1.56	0.22	0.37	1.68
		150	52.11	49.70	2.41	2.34	0.11	21.27 **
		200	52.95	51.66	1.29	2.36	0.33	7.15 *
		50	57.83	58.88	-1.05	2.64	1.85	1.43
		100	63.20	56.62	6.58 **	2.36	0.30	7.87 *
		150	62.55	57.59	4.96 **	0.26	4.55	17.50 **
		200	61.92	60.48	1.44	1.71	0.05	34.20 **
	60	50	86.35	98.92	-12.57 **	7.62	5.25	1.45
		100	87.29	85.80	1.49	4.47	1.16	3.85
		150	86.13	86.61	-0.48	10.58	3.00	3.53
		200	85.39	74.97	10.42 **	3.26	1.23	2.65
	90	50	425.80	117.70	308.10 **	87.77	10.30	8.52 *
		100	239.52	106.43	133.09 **	12.74	3.07	4.15
		150	166.99	98.48	68.51 **	8.00	7.86	1.02
		200	128.80	84.49	44.31 **	12.22	5.61	2.18
Mean			120.11	84.00		10.23	4.64	

* Significant at 5 %

** Significant at 1 %

diameter (Appendix Table 1). Course urea has 87% of its particles greater than 1 mm diameter while fine urea has only 59.5%. Due to reduced total surface area, coarse urea has less internal frictional effect than fine urea.

Table 22 gives the variances and mean metering rates in N kg/ha. Generally, coarse urea has a higher discharge rate than fine urea. Th variation is greater with steeper angles. This is apparently due to reduced frictional effect of coarse urea. Coarse urea has a greater reduction in discharge with increased moisture content than fine urea.

The average discharge variance was 10.23 for coarse urea as compared to 4.64 for fine urea. The reason for less variance of fine urea is because of the fewer particles being more cohesive, move togethereasily than coarse particles. This property gives fine urea a more uniform discharge than coarse urea.

4.8 Injection Experiments

Table 23 is a compilation of the mean injection rates for both fine and coarse prilled urea by sheet and wire auger at varied auger rotational speed and delivery tube inclination.

Auger rotational speed has a significant effect on injection rate per auger revolution. The auger rotational sp . of 100 revolution per minute give a significantly

TABLE 23. Mean injection rate of prilled urea by sheet and wire auger at clockwise and anticlockwise delivery tube inclination to vertical in grams per revolution

SHEET AUGER / FINE UREA
Delivery tube inclination angle

Auger Speed	30 Deg. clockwise	30 Deg. anticlockwise
100	2.229 b	1.777 g
200	1.807 fg	1.362 k

SHEET AUGER / COARSE UREA
Delivery tube inclination angle

Auger Speed	30 Deg. clockwise	30 Deg. anticlockwise
100	2.104 a	2.142 c
200	1.712 h	1.640 j

WIRE AUGER / FINE UREA
Delivery tube inclination angle

Auger Speed	30 Deg. clockwise	30 Deg. anticlockwise
100	2.237 b	2.004 d
200	1.903 e	1.415 j

WIRE AUGER / CAORSE UREA
Delivery tube inclination angle

Auger Speed	30 Deg. clockwise	30 Deg. anticlockwise
100	2.281 a	2.261 ab
200	1.818 g	1.731 i

Means with a common letter are not significantly different at 5 % level (DMRT) higher injection rate than that of 200 revolutions per minute for both augers, both kind of fertilizer and at both inclination angles. The delivery tube which was dipped 2.5 cm into mud and 5 cm below the water surface caused water and mud to enter the delivery tube and wet the fertilizer at the outlet. When the auger outlet is submerged, the auger fills-up fully and flights push the fertilizer out with gravity free flow playing very little effect in the fertilizer delivery. The higher the auger rotational speed, the higher the centrifugal action and the more reduction in injection rate. The difference was significantly greater when the delivery tube was inclined against soil bin rotation.

The effect of delivery tube inclination on injection rate was significant with all the factor combinations except the combination at 100 rpm auger speed of coarse urea fertilizer. When the delivery tube is inclined 30° against soil bin rotation the tube tip is pointing against the mud movement. This caused the mud to be forced inside the tube. The auger head conveys fertilizer out against the increased soil pressure.

To reduce this effect, inclination of the auger against the soil movement be avoided in the design of fertilizer applicators.

Wire auger gave a significantly higher injection rate than sheet auger, with the exception of rates in the combination of fine urea, auger rotational speed of 100 revolutions per minute and inclination with soil bin rotation. This means wire auger is less affected by frictional and centrifugal force opposing the flow than sheet auger because it has less contact surface area than sheet auger which reduces its frictional resistance. With sheet auger, moisture can creep upward along its spiral surface due to the capillary effect and further increase frictional effect.

Coarse and fine urea differed in response to injection. Coarse urea gave higher response than fine urea. Among all experiments, coarse urea gave a significantly higher discharge except with the combination of sheet auger rotating at 100 rpm and inclined at 30^{0} with the direction of the soil bin rotation.

The low injection rate of fine urea compared to coarse urea is primarily due to the high frictional resistance.

4.9 Practical Application of Augers for Metering and Injection

Table 24 is a compilation of injection rate for prilled urea in kg N/Hectare. This was computed based on:

1. 0.36 m rolling diameter of drive wheel.
2. A wheel-auger drive ratio of 1:5.2.
3. An auger revolutions of 114945 per hectare (assuming a single hopper) (Appendix Table 10).

TABLE _4. Mean injection rate of prilled urea by sheet and wire auger at clockwise and anticlockwise delivery tube inclination in equivalent N Kg / ha.

SHEET AUGER / FINE UREA
Delivery tube inclination angle

Auger Speed	30 Deg. clockwise	30 Deg. anticlockwise
100	117.86	93.96
200	95.54	72.02

SHEET AUGER / COARSE UREA
Delivery tube inclination angle

Auger Speed	30 Deg. clockwise	30 Deg. anticlockwise
100	111.25	113.26
200	90.72	86.71

WIRE AUGER / FINE UREA
Delivery tube inclination angle

Auger Speed	30 Deg. clockwise	30 Deg. anticlockwise
100	118.28	105.96
200	100.62	74.82

WIRE AUGER / CAORSE UREA
Delivery tube inclination angle

Auger Speed	30 Deg. clockwise	30 Deg. anticlockwise
100	120.61	119.55
200	96.13	91.53

The rates were computed using a 5.2 paddle to auger sprocket speed multiplication ratio and the paddle wheel diameter was assumed as 0.36 meters

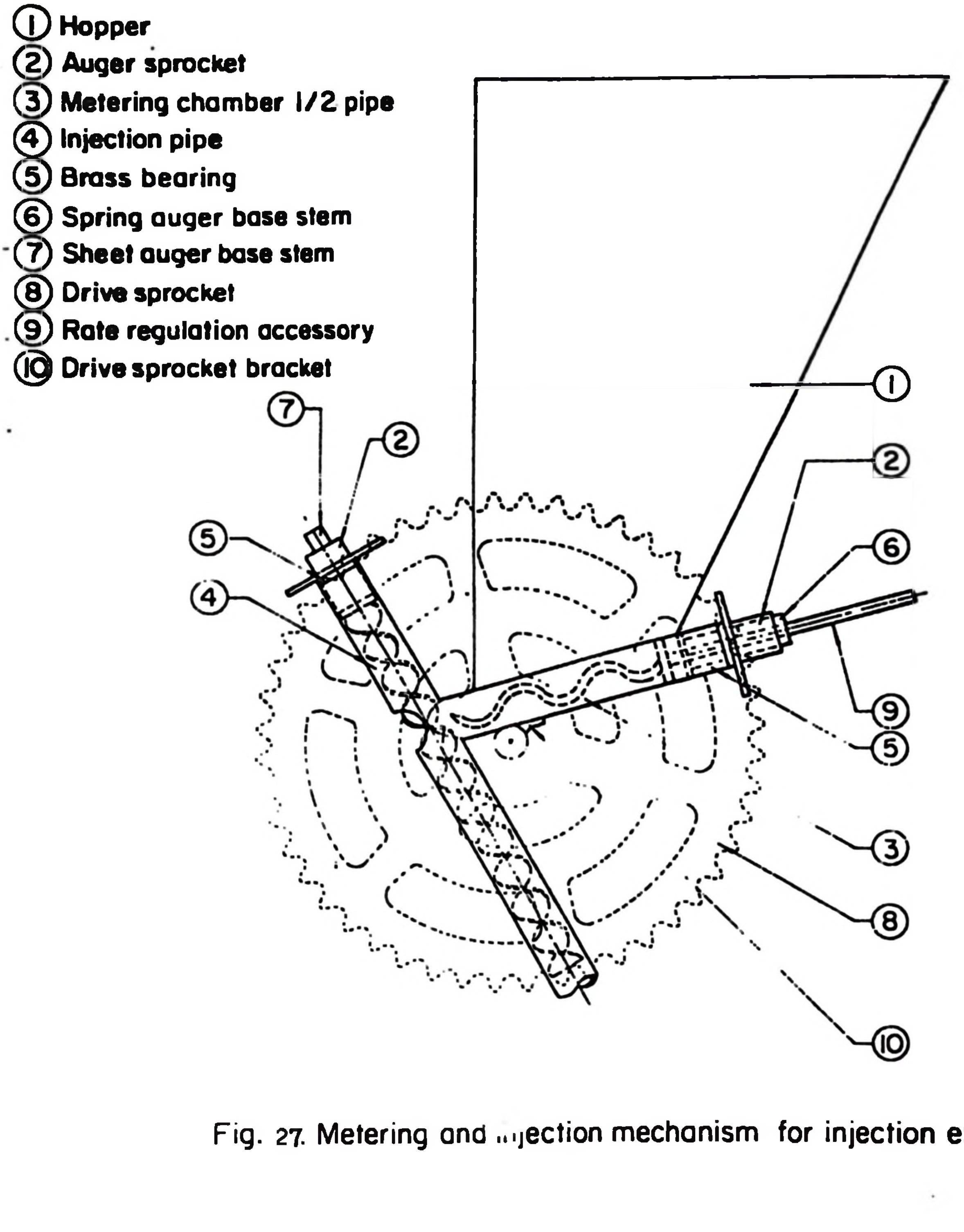


Fig. 27. Metering and injection mechanism for injection experiments.

Under the above condition the minimum injection rate was 72.02 kg N/hectare from a factor combination of sheet auger, fine urea, rotational speed of 200 revolutions per minute. The maximum rate was 120.61 kg N/hectare for the factor combination of wire auger, coarse urea at delivery tube inclination angle of 30^{o} to direction of soil movement and auger rotational speed of 100 revolutions per minute.

The metering and injection mechanism used in this experimental machine (Figure 32) was tested under simulated field condition. Fertilizer recommendation rates are within the range of 30 to 60 kg N/hectare that are recommended for rice production in the Phillippines (IRRI Annual Report, 1983). These recommended rates are still much lower than the minimum rates obtained in this experiment.

4.10 Dishcharge Pressure

Discharge pressure exerted by augers is of importance because it reflects the ability of the auger to inject fertilizer into the mud. Table 25 gives the mean discharge pressure by sheet and wire auger in horizontal positions. An average of 200 observations were made. The results showed that the wire auger has a higher discharge pressure in all tried factors.

Among the two positions tried, the vertical positions had a higher discharge pressure due to the assistance of gravity force.

Table 25. Discharge pressure by sheet and wire augers in horizonal and vertical positions.

	DISCHARGE PRESSURE IN K Pa			
	Horizontal		Vertical	
	Fine urea mc 0.4 - 0.7% WB	Fine urea mc 1.2 - 1.5% WB.	Fine urea 0.4-0.7% WB	Fine urea mc 1.2 - 1.5% mc
Sheet Auger	1.52	1.50	1.74	1.63
Wire Auger	1.84	1.81	1.88	1.86

An average of 200 observations (by data logger)

The fertilizer moisture levels used in the experiment were 0.4-0.7% and 1.2-1.5% (wet basis). In all categories, lower fertilizer moisture content gave higher pressures. This is due to reduced frictional effect.

4.11 Investigation of Adhesive Behavior of Wet Fine Prilled Urea on Sheet and Wire Augers

During the experiments, it was noticed that prilled urea particularly with higher moisture, had a tendency to stick and build up on the augers flights.

Tables 26 and 27 give discharges grams/min of fine prilled urea (mc 1.0% WB) the sheet and wire augers respectively. These delivery rates were measured after five, ten, fifteen and twenty minutes of continuous operation. Also the amount of fertilizer adhering to the auger surface after respective time of use was recorded.

The sheet auger gave a significant decrease in discharge rate with increasing time of continuous operation.

This indiceates that fertilizer accumulating increases on auger surface during the first ten minutes and then levels off. Fertilizer sticking on auger (and in the delivery tube) change the frictional resistance. Referring to Figure 18 and 19 and comparing the angle of internal friction of the fertilizer (angle of repose) and the angle of friction of fertilizer on galvanized steel, the former is

TABLE 26 Wet Fertilizer adherence on sheet auger surface versus conveyance

Fine prilled urea 1 % moisture content (w.b.)
Auger rotational speed - 100 rpm

Discharge time in minutes	5 min	10 min	15 min	20 min
Fertilizer discharge in gms per minute	70.73	58.87	54.90	49.32
Fertilizer adherence in gms for the total time the auger was run	1.44	4.63	5.98	5.95

Average of 8 observations

TABLE 27. Wet Fertilizer adherence on wire auger surface versus conveyance

Fine prilled urea 1 % moisture content (w.b.)
Auger rotational speed - 100 rpm

Discharge time in minutes	5 min	10 min	15 min	20 min
Fertilizer discharge in gms per minute	87.56	87.25	87.87	82.94
Fertilizer adherence in gms for the total time the auger was run	1.3	2.1	2.2	2.3

Average of 8 observations

higher. This suggest that with layer of fertilizer deposited on the auger and delivery tube surfaces, increases the friction coefficient and hence reduces delivery.

With wire auger, the fertilizer coating increases up to minutes and from there on, the increase in the coating is not significant. The change in delivery is not significant. Wire auger has a smaller contact surfaces, than sheet auger giving it an advantage of having less increased frictional effect than sheet auger.

Table 28 shows the delivery of sheet auger with drier fertilizer (0.2% wet basis). The result indicate that fertilizer did not accumulate on auger and so the discharge had no significant variation.

TABLE 28. Dry Fertilizer adherence on sheet auger surface versus fertilizer conveyance

Fine prilled urea 0.2 % moisture content (w.b.)
Auger rotational speed - 100 rpm

Discharge time in minutes	5 min	10 min	15 min	20 min
Fertilizer discharge in gms per minute	207.52	209.81	212.33	206.82
Fertilizer adherence in gms for the total time the auger was run	nil	nil	nil	nil

Average of 8 observations

5 CONCLUSION

5.1 Properties of Fine Prilled Urea

Fine prilled urea is very hygroscopic. Under an ambient temperature of 29-30°C, with exposure to 70%, 80% and 90% relative humidity, the fertilizer attained a moisture level of 2.6%, 3.74% and 12.92% W.B. respectively. Under ambient condition the temperature and relative humidity generally fluctuate, depending on the prevailing psychometric state. The fertilizer attained moisture content of 1% W.B. When handling fine prilled urea, exposure to ambient condition should be minimized to obtain good performance from applicators.

The angle of repose (internal friction) and the coefficient friction between the fertilizer and galvanized steel, increases with increase in moisture contents. The angle of repose increased from 36° to 44° when the fertilizer and galvanized steel increased from 0.6 to 0.7 when the moisture content increase from 0% to 1.5% (W.B.)

5.2 Gravity Flow and Agitation

The gravity flow of fine prilled urea is highly dependent on the size of the hopper bottom, opening hopper wall angle and the moisture content of the fertilizer. When the bottom opening and the angle of inclination of the wall to the horizontal is very small, there is a tendency for the fertilizer to form a bridge. This reduces gravity flow of fertilizer into the metering chamber. This effect is more pronounced when the fertilizer has high moisture content resulting in a high coefficient of friction between fertilizer and hopper wall as well as increased cohesion between fertilizer particles.

When designing hopper for fine prilled urea with up to 1.5% WB. moisture content, the hopper bottom opening should not be less than 30 mm wide, and the angle of inclination of the hopper wall should no be less than 60° from the horizontal to reduce bridging. The experimental hopper used is succeeding experiments was based on these findings. The size of the experimental hopper were: opening size - 30 m x 100 m and inclination of two walls - 65° and 67° with the horizontal, and remaining two were in a vertical orientation.

Out of four kinds of agitators tested (eliptical, rotary, reciprocating and jerking), the former two were found to work satisfactorily. The latter two did not function at all. Among the two that performed satisfactorily the final choice will depend on the ease of fabrication and of connecting it to the drive mechanism. In all the experiments that required agitation, the eliptical path was preferred over the rotary agitation because it was easy to fabricate, and to connect to the drive mechanisms.

5.3 Characterization of Augers

The first experiment done on the characterization of augers was to select the auger pitch/diameter ratio that will give maximum discharge rate and reasonable consistency. The pitch/diameter ratio that gave maximum delivery was 1.25.

The above pitch/diameter ratio was for the augers used in conveyance analysis. The analysis of fertilizer conveyance was done on a generalized basis. The factors for analysis were selected on the basis of possible practical application in applicator design.

In analyzing the effect of the angle of inclination of the delivery tube it was found out that discharge increases as inclination increases from horizontal to vertical. It was also found out that as the delivery tube inclination angle increases, discharge consistency decreases.

The delivery tube inclination angle can be categorized separately in three functions namely:

1. Metering. For metering, the metering auger must be positioned from a horizontal to 30° downward inclination. With this angular position, a good compromise can be obtained between discharge rate and metering accuracy.

2. Injection. This process involves placement of fertilizer into flooded soils. Maximum injection is possible when the auger tube is positioned vertically or in

near vertical position. The preferred range of auger inclination should be between vertical to 30° from vertical. An inclination with the direction of travel is preferred as it reduces soil pressure at the outlet.

3. Combined Metering and Injection. When it is desired that the same auger shall both meter and inject fertilizer the inclination of the fertilizer delivery tube should be closer to that of injection. In such case only centerfed auger should be used.

The moisture content of fertilizer affected the peformance of the auger by increasing the angle of friction between fertilizer and the metering mechanism. With larger opening of the hopper bottom and proper agitation, bridging can be minimized.

5.4 Injection

Injection experiments were done to analyze the performance of the two types of augers as influenced by angle of delivery tube inclination and auger rotational speed. The wire auger had a higher injection rate than the sheet auger. When the delivery tube was inclined along with the soil bin movement discharge was higher than when inclined against the soil bin movement. Slower auger rotational speeds resulted in increased discharged per revolution of the auger.

In assessing the combined metering and injection mechanisms used in experiment, the unit did not indicate any problem of metering. The minimum rate of injection obtained in the experiments (74.82 N kg/ha) was beyond the maximum fertilizer recommendation of 60 kg N/ha) in the Phillippines.

One of the problem encountered with augers was that a fertilizer coating builds upon the flight during operation. Thus, a gradual reduction in delivery occurs due to the changing frictional conditions. This tendency reduces the auger capacity during initial operation until a stabilized state is reached. This phenomenon was observed more with the sheet auger than the wire auger. This is due to large flight surface area. Perhaps the inside surface of the discharge tube is also affected by a coating of fertilizer. To minimize this problem, augers must be made of materials to which fertilizer may not easily stick. Stainless steel or polished mild steel coated with low friction material may be a possibility.

5.5 Recommendations

Augers can be a promising tool for use in manual fertilier applicators for both metering and injection mechanisms. This is due to their ability to forcefeed fertilizer into puddled soils with reduced problems. Further studies need be done on type of material to be used for auger construction particularly as regards to the properties of the auger material when in contact with fertilizer. Similar studies can be done on delivery tube. Studies can also be done on the effect of fertilizer on the auger material life. This is due to the fact that fertilizers are corrosive particularly to metals usually used in auger construction.

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Appendix Table 1. Particle size distribution for prilled urea.

	Less than 420 u	Between 1 mm and 420 u	Greater than 1 mm
Fine prilled urea	10.2%	30.3%	59.5%
Medium coarse prilled urea	5.7%	7.2%	87.1%

Appendix table 2. The variation of angle of repose of fine prilled urea at different moisture content levels.

Moisture content Wet Basis (Average of 4 samles)	Angle of Repose
0.90	37° 40'
0.99	42° 10'
0.51	38° 55'
0.53	39° 00'
0.88	42° 55'
0.70	39° 15'
1.99	42° 30'
0.18	37° 45'
0.19	35° 10'
0.31	34° 00'
0.27	36° 15'
0.49	39° 00'

Linear Regression Analysis

$$y = 35.28 + 5.8x$$

$$r = 0.74$$

Appendix table 3. The variation of angle of friction between fine prilled urea and galvanised mild steel at different moisture content levels.

Moisture Content % Wet Basis (Average of 4 samples)	Tangent of Angle of friction between fertilizer and galvanized steel
0.00	0.52
0.00	0.51
0.00	0.52
0.53	0.62
0.07	0.56
0.00	0.55
0.49	0.68
2.28	0.73
1.75	0.79
0.92	0.73
2.14	0.82
0.17	0.65

Regression analysis

$y = 0.60 + 0.63x$

$r = 0.77$

APPENDIX TABLE 4. COMPARISON OF MEANS FOR GRAVITY FLOW OF FINE PRILLED UREA

TREATMENTS				
Hopper bottom openning(slot)	Hopper wall angle to horizontal	Moisture content % w.b.	Rank	Mean
25 mm *100 mm	80	0.4-0.6	18	0.34 AB
35 mm *100 mm	60	0.4-0.6	9	0.58 B
35 mm *100 mm	70	0.4-0.6	7	0.66 B
35 mm *100 mm	80	0.4-0.6	6	0.67 B
35 mm *100 mm	80	0.7-0.9	12	0.56 B
35 mm *100 mm	80	1.0-1.2	11	0.57 B
35 mm *100 mm	80	1.3-1.5	15	0.49 B
45 mm *100 mm	50	0.7-0.9	1	0.76 B
45 mm *100 mm	60	0.4-0.6	8	0.60 B
45 mm *100 mm	60	0.7-0.9	9	0.58 B
45 mm *100 mm	60	1.0-1.2	20	0.22 A
45 mm *100 mm	60	1.3-1.5	16	0.38 AB
45 mm *100 mm	70	0.4-0.6	4	0.69 B
45 mm *100 mm	70	0.7-0.9	17	0.37 AB
45 mm *100 mm	70	1.0-1.2	13	0.53 B
45 mm *100 mm	70	1.3-1.5	18	0.34 AB
45 mm *100 mm	80	0.4-0.6	3	0.70 B
45 *100 mm	80	0.7-0.9	2	0.74 B
45 mm *100 mm	80	1.0-1.2	4	0.69 B
45 mm *100 mm	80	1.3-1.5	14	0.50 B

(1) Means followed by a common letter are not significantly different at 5 % level by JMRT

(2) Means are average of three replications.

APPENDIX TABLE 5. ANALYSIS OF VARIANCE FOR TIME OF GRAVITY FLOW (SEC) OF FINE PRILLED UREA

SOURCE OF VARIATION	D.F.	SUM OF SQUARES	MEAN SQUARES	F- VALUES
Total	55	0.1545979333E + 02		
Replication	2	0.4950633333E +0.0	0.2475316666E	
Treatment	19	0.8789260000E +0.1	0.4625926315E	1.36(ns)
Error	34	0.6175470000E +01	0.1816314705E	2.54**

C.V.= 43.4 %

APPENDIX TABLE 6. Means of Fertilizer Discharge Rate (Kg N/ha)
(average of 4 reps)

Sheet Auger Coarse Prilled Urea

ANGLE of INCL. (I)	SPEED (S)				
	50	100	150	200 1/	I-Mean
	MOISTURE CONTENT =0.4 -0.7				
0	43.48	44.48	46.63	49.64	46.77
30	53.35	49.42	52.17	54.16	52.65
60	144.55	152.86	159.06	144.33	148.43
90	410.21	257.06	211.32	182.48	248.71
S- Mean	162.90	125.95	116.54	107.65	124.14
	MOISTURE CONTENT =0.8-1.1				
0	40.57	40.26	33.37	31.68	35.51
30	46.00	46.92	48.58	54.71	50.18
60	64.22	66.51	72.36	70.38	68.77
90	92.00	87.77	82.29	81.99	85.21
S- Mean	60.70	60.36	59.15	59.69	59.92
	MOISTURE CONTENT =1.2-1.5				
0	52.41	42.56	35.51	41.79	42.81
30	46.61	33.79	38.98	54.68	45.75
60	69.37	61.79	63.61	57.12	61.80
90	72.88	70.24	65.50	69.09	69.36
S- Mean	60.32	52.10	50.90	55.67	54.43

1/ average over 8 reps

APPENDIX TABLE 7. Means of Fertilizer Discharge Rate (Kg N/ha)
(average of 4 reps)

Sheet Auger Fine Prilled Urea

ANGLE of INCL. (I)	SPEED (S) 50	100	150	200 1/	I-Mean
	MOISTURE CONTENT =0.4 -0.7				
0	48.26	47.40	46.36	44.48	46.20
30	62.50	61.28	58.31	58.56	59.84
60	157.16	145.30	117.34	96.98	122.25
90	178.76	156.08	109.53	105.66	131.14
S- Mean	111.62	10[illegible].52	82.88	76.42	89.98
	MOISTURE CONTENT =0.8-1.1				
0	22.19	35.45	27.08	21.65	25.60
30	47.34	39.31	37.16	36.47	39.35
60	57.86	41.13	45.24	47.33	47.78
90	57.55	60.64	54.47	56.40	57.09
S- Mean	46.23	44.13	40.99	40.46	42.46
	MOISTURE CONTENT =1.2-1.5				
0	22.47	25.23	21.65	20.69	22.15
30	26.96	27.67	28.26	32.61	29.62
60	46.65	32.24	35.22	37.04	37.64
90	53.39	43.76	39.84	39.12	43.05
S- Mean	37.37	32.22	31.24	32.37	33.11

1/ average over 8 reps

APPENDIX TABLE 8. Means of Fertilizer Discharge Rate (Kg N/ha
(average of 4 reps)

Wire Auger Coarse Prilled
Urea

ANGLE of INCL. (I)	SPEED (S) 50	100	150	1/ 200	I-Mean
		MOISTURE CONTENT =0.4 -0.7			
0	54.79	53.33	51.34	52.35	52.83
30	58.04	62.72	62.74	60.54	60.92
60	83.79	87.02	96.92	85.15	87.61
90	436.09	235.15	157.07	117.85	212.8
S- Mean	158.18	109.55	92.02	78.97	103.54
		MOISTURE CONTENT =0.8-1.1			
0	50.94	46.69	37.94	37.91	42.28
30	50.70	46.60	47.94	49.28	48.76
60	64.85	61.40	62.68	63.31	63.11
90	62.67	62.25	65.67	60.26	62.22
S- Mean	57.29	54.24	53.56	52.69	54.09
		MOISTURE CONTENT =1.2-1.5			
0	45.51	42.74	34.83	32.69	37.69
30	42.24	40.78	42.93	43.67	42.66
60	50.58	83.39	55.79	59.14	55.61
90	65.96	69.94	62.47	60.89	64.03
S- Mean	51.07	51.71	49.01	49.1	50

1/ average over 8 reps

APPENDIX TABLE 9, Means of Fertilizer Discharge Rate (Kg N/ha)
(average of 4 reps)

Wire Auger Fine Prilled Urea

ANGLE of INCL. (I)	SPEED (S) 50	100	150	1/ 200	I-Mean
	MOISTURE CONTENT =0.4 -0.7				
0	52.53	50.73	49.74	50.84	50.94
30	57.1	56.21	57.05	59.39	57.83
60	99.17	87.14	85.64	74	83.99
90	118.38	104.88	96.82	87.5	99.02
S- Mean	81.8	74.74	72.32	67.93	72.94
	MOISTURE CONTENT =0.8-1.1				
0	35.64	31.2	31.93	28.55	31.13
30	39.96	34.68	36.08	42.83	39.28
60	48.66	50.46	53.52	51.98	51.32
90	59.97	55.45	56.02	58	57.49
S- Mean	46.06	42.95	44.39	45.53	44.89
	MOISTURE CONTENT =1.2-1.5				
0	30.74	24.4	22.98	26.96	26.41
30	36.95	31.04	28.64	31.77	32.04
60	53.54	46.07	49.08	44.99	47.74
90	55.12	52.7	51.86	51.13	52.39
S- Mean	44.09	38.56	38.14	38.9	39.22

1/ average over 8 reps

APPENDIX TABLE 1C ANOVA DISCHARGE RATE (Kg [illegible] ia)

SV	df	MS			
		SHEET AUGER		WIRE AUGER	
		COARSE	FINE	COARSE	FINE
Total	239				
Rep	3	0.79(ns)	15.57(ns)	1.07(ns)	6.70(ns)
Ang.of Incl. (I)	3	110523.78**	28029.96**	57622.69**	14439.15**
Speed (S)	3	4769.42**	3024.25**	9149.33**	494.10**
Mois.Content (M)	2	119187.74**	74401.40**	71046.68**	25690.30**
I*S	9	4739.14**	731.90**	8137.85**	117.96**
I*M	6	41730.20**	7255.99**	28952.62**	765.23**
S*M	6	3382.64**	1411.35**	7110.79**	187.34**
I*S*M	18	4020.59**	535.60**	8054.35**	104.82**
Error	141	23.72	8.04	5.52	4.44
Runs w/in	48	17.11	5.34	8.77	10.42
Common tests					
C.V (%)		6.1	5.1	8.0	6.2

F-Test between Error J Runs w/in	1.39(ns)	1.51(ns)	1.59*	2.35**

Common tests				
LSD 5%	6.81	3.96	3.28	2.96
LSD 1%	8.99	5.24	4.34	3.91

APPENDIX TABLE 11 ANOVA for rate of injection for prilled urea by sheet and wire auger

Source of Variation	Degree of freedom	Sum of Square	Mean Square	Computed F
Replication	2	0.00588818	0.00294409	
Treatment	15	3.88214533	0.258809688	15.430934 *
Error	30	0.5031849	0.01677283	
Total	47	3.938352		

* Significant at 5 %

APPENDIX TABLE 12 The relationship between operators ground speed, paddle wheel diameter, paddle wheel sprocket, auger sprocket, and auger operating speed for mannual fertilizer applicator (auger metering type)

Paddle wheel diameter (m)	Operator ground speed km / hr	Paddle wheel sprocket teeth	Auger sprocket teeth	Auger rotational speed revolution per minute	Auger revolution per hectare
0.36	3.0	36	10	159.2	79577.5
			9	176.8	88419.4
			8	198.9	99471.8
			7	227.4	113682.1
		40	10	176.8	88419.4
			9	196.5	98243.8
			8	221.1	110524.3
			7	252.6	126313.4
		44	10	194.5	97261.4
			9	216.1	108068.2
			8	243.2	121576.7
			7	277.9	138944.8
		48	10	212.2	106103.3
			9	235.8	117892.6
			8	265.3	132629.1
			7	303.2	151576.1
		52	10	229.9	114945.2
			9	255.4	127716.9
			8	287.4	143681.5
			7	328.4	164207.5

APPENDIX TABLE 12 The relationship between operators ground speed, paddle wheel diameter, paddle wheel sprocket, auger sprocket, and auger operating speed for mannual fertilizer applicator (auger metering type)

Paddle wheel diameter (m)	Operator ground speed km / hr	Paddle wheel sprocket teeth	Auger sprocket teeth	Auger rotational speed revolution per minute	Auger revolution per hectare
0.36	3.0	36	10	159.2	79577.5
			9	176.8	88419.4
			8	198.9	99471.8
			7	227.4	113682.1
		40	10	176.8	88419.4
			9	196.5	98243.8
			8	221.1	110524.3
			7	252.6	126313.4
		44	10	194.5	97261.4
			9	216.1	108068.2
			8	243.2	121576.7
			7	277.9	138944.8
		48	10	212.2	106103.3
			9	235.8	117892.6
			8	265.3	132629.1
			7	303.2	151576.1
		52	10	229.9	114945.2
			9	255.4	127716.9
			8	287.4	143681.5
			7	328.4	164207.5

Paddle wheel diameter (m)	Operator ground speed km / hr	Paddle wheel sprocket teeth	Auger sprocket teeth	Auger rotational speed revolution per minute	Auger revolution per hectare
0.36	2.0	36	10	106.1	79577.5
			9	117.9	88419.4
			8	132.6	99471.8
			7	151.6	113682.1
		40	10	117.9	88419.4
			9	131.0	98243.8
			8	147.4	110524.3
			7	168.4	126313.4
		44	10	129.7	97261.4
			9	144.1	108068.2
			8	162.1	121576.7
			7	185.3	138944.8
		48	10	141.5	106103.3
			9	157.2	117892.6
			8	176.8	132629.1
			7	202.1	151576.1
		52	10	153.3	114945.2
			9	170.3	127716.9
			8	191.6	143681.5
			7	128.9	164207.5

Paddle wheel diameter (m)	Operator ground speed km / hr	Paddle wheel sprocket teeth	Auger sprocket teeth	Auger rotational speed revolution per minute	Auger revolution per hectare
0.36	2.5	36	10	132.6	79577.5
			9	147.4	88419.4
			8	165.8	99471.8
			7	189.5	113682.1
		40	10	147.4	88419.4
			9	163.7	98243.8
			8	184.2	110524.3
			7	210.5	126313.4
		44	10	162.1	97261.4
			9	180.1	108068.2
			8	202.6	121576.7
			7	231.6	138944.8
		48	10	176.8	106103.3
			9	196.5	117892.6
			8	221.1	132629.1
			7	252.6	151576.1
		52	10	191.6	114945.2
			9	212.9	127716.9
			8	239.5	143681.5
			7	272.7	164207.5

Paddle wheel diameter (m)	Operator ground speed km / hr	Paddle wheel sprocket teeth	Auger sprocket teeth	Auger rotational speed revolution per minute	Auger revolution per hectare
0.36	1.5	36	10	79.6	79577.5
			9	88.4	88419.4
			8	99.5	99471.8
			7	113.7	113682.1
		40	10	88.4	88419.4
			9	98.2	98243.8
			8	110.5	110524.3
			7	126.3	126313.4
		44	10	97.3	37261.4
			9	108.1	108068.2
			8	121.6	121576.7
			7	138.9	138944.8
		48	10	106.1	106103.3
			9	117.9	117892.6
			8	132.6	132629.1
			7	151.6	151576.1
		52	10	115.0	114945.2
			9	127.7	127716.9
			8	143.7	143681.5
			7	164.2	164207.5

Paddle wheel diameter (m)	Operator ground speed km / hr	Paddle wheel sprocket teeth	Auger sprocket teeth	Auger rotational speed revolution per minute	Auger revolution per hectare
0.36	1.0	36	10	53.1	79577.5
			9	59.0	88419.4
			8	66.3	99471.8
			7	75.8	113682.1
		40	10	59.0	88419.4
			9	65.5	98243.8
			8	73.7	110524.3
			7	84.2	126313.4
		44	10	64.8	37261.4
			9	72.1	108068.2
			8	81.1	121576.7
			7	92.6	138944.8
		48	10	70.7	106103.3
			9	78.6	117892.6
			8	98.4	132629.1
			7	101.1	151576.1
		52	10	76.6	114945.2
			9	85.2	127716.9
			8	96.0	143681.5
			7	109.5	164207.5

Paddle wheel diameter (m)	Operator ground speed km / hr	Paddle wheel sprocket teeth	Auger sprocket teeth	Auger rotational speed revolution per minute	Auger revolution per hectare
0.36	0.5	36	10	26.5	79577.5
			9	29.5	88419.4
			8	33.2	99471.8
			7	37.9	113682.1
		40	10	29.5	88419.4
			9	32.8	98243.8
			8	36.9	110524.3
			7	42.1	126313.4
		44	10	32.4	37261.4
			9	36.0	108068.2
			8	40.5	121576.7
			7	46.3	138944.8
		48	10	35.4	106103.3
			9	39.3	117892.6
			8	44.2	132629.1
			7	50.5	151576.1
		52	10	38.3	114945.2
			9	42.6	127716.9
			8	47.9	143681.5
			7	54.7	164207.5

How to get fertilizer rate per hectare using the above table as a guide (Appendix 10).

Obtain the fertilizer data for discharge in revolution per minute at a particular auger speed. Knowing the speed multiplication ratio for the drive/driven sprockets and paddle wheel diameter, select the appropriate auger revolution per hectare. Multiply the data with the selected value. Finally, multiply the product with nutrient element factor.

Example:

Discharge per revolution is 1.8 gms of urea per revolution

Paddle wheel diameter - 0.36 m

Speed multiplication ratio - 36:9

From the table, the paddle wheel and speed multiplication ration combination has 88419.4 revolution per hectare

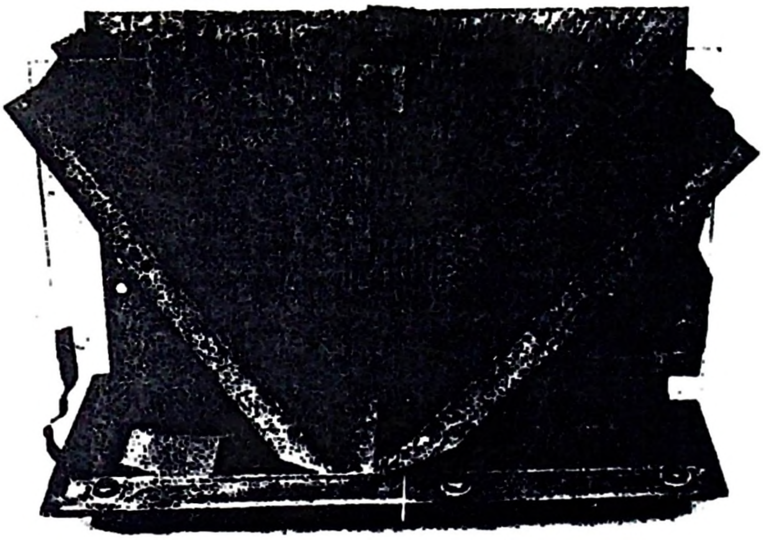
Urea = 0.46 Nitrogen

Therefore, rate of nitrogen per hectare is:

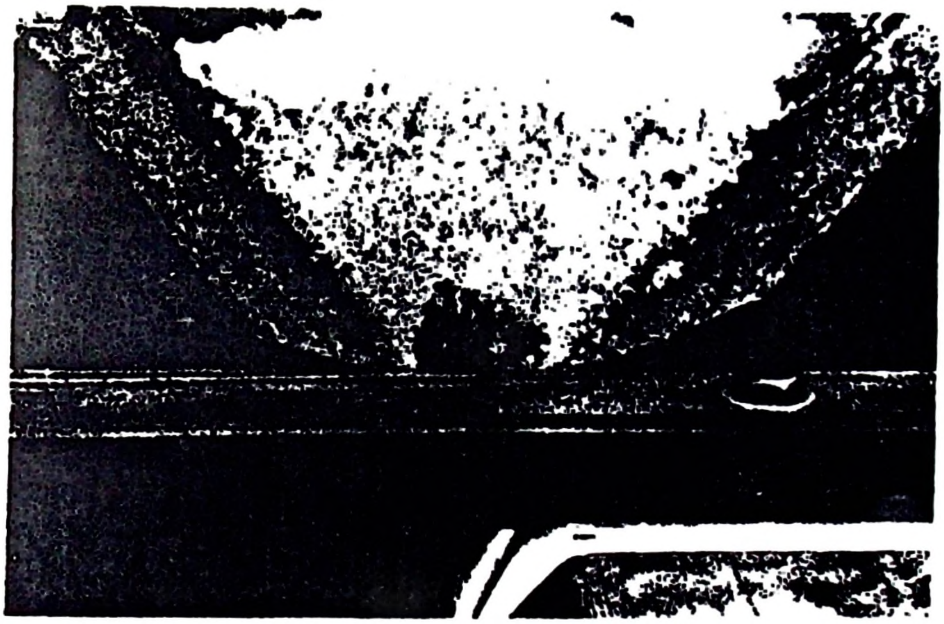
$$88419.4 \times 1.8 \text{ gms/ha}$$

$$= \frac{88419.4 \times 1.8 \times 0.46}{1000} \text{ Kg N/ha}$$

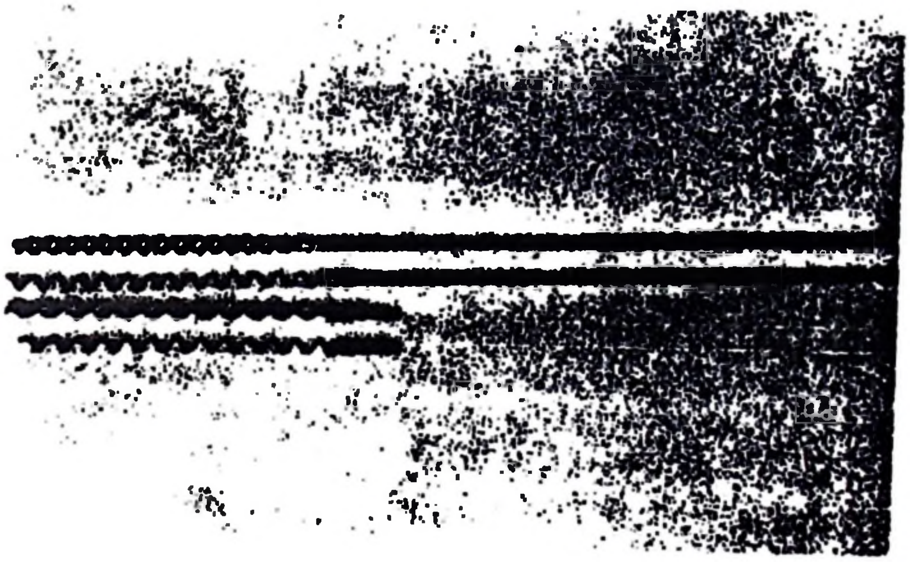
$$= 73.2 \text{ kg N/ha}$$



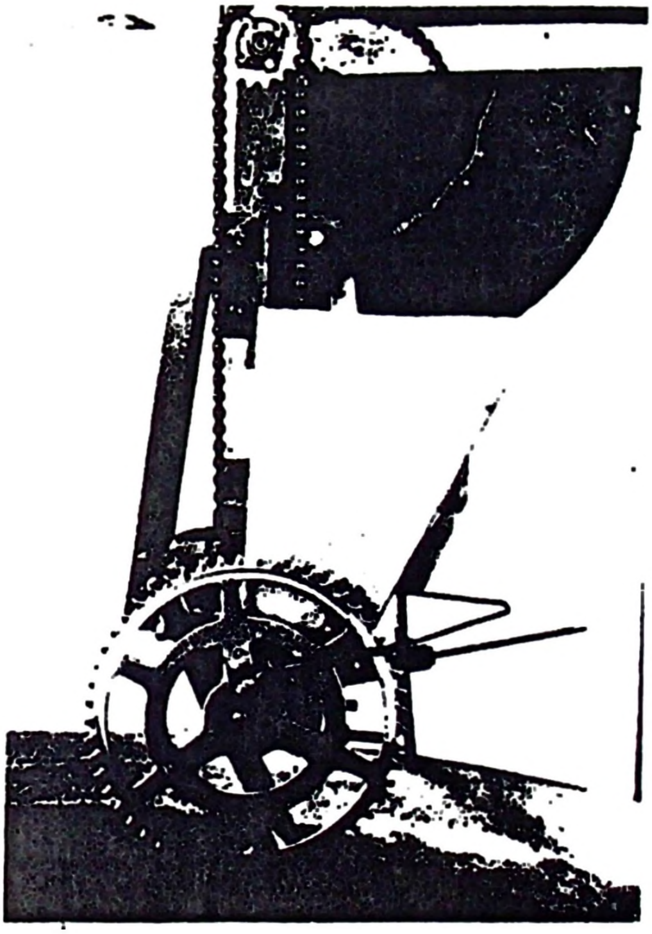
Appendix Figure 1. An experimental hopper used for gravity flow experiments.



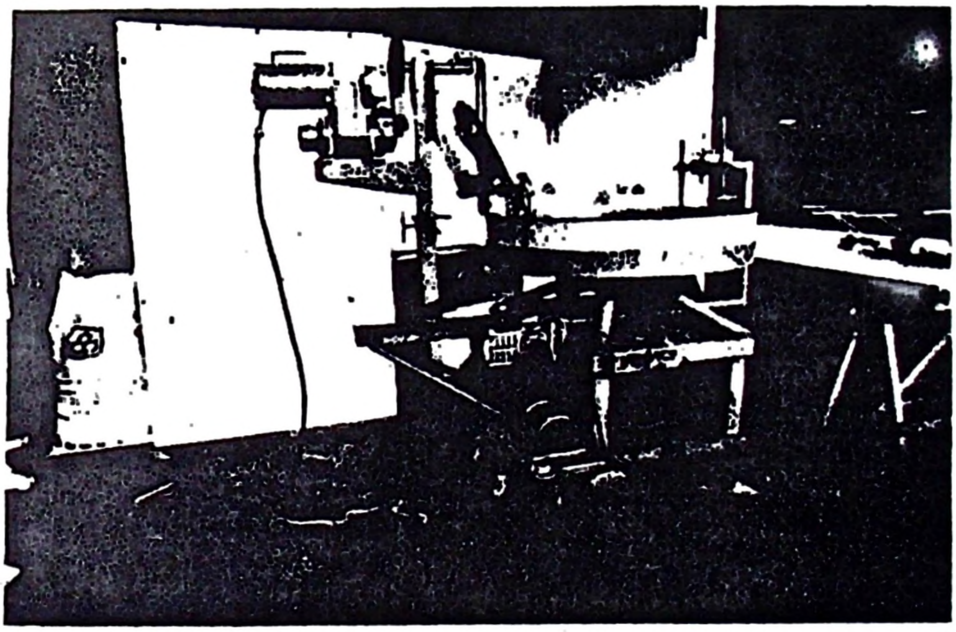
Appendix Figure 2. Typical bridge formation by wet fertilizer in an experimental hopper.



Appendix Figure 3. Sheet and wire augers used for fertilizer metering and injection experiments



Appendix Figure 4. Hopper / auger assembly unit used in injection experiments



Appendix Figure 5. Hopper rotary bin assembly used for injection experiments