DESIGN OF FERTILIZER APPLICATOR FOR SMALL SCALE FARMING UNDER NIGERIAN CONDITIONS

by

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INTRODUCTION

Until recently, fertilizer application by most Nigerian farmers was made with hand labor. This method, beside being laborious, is also time consuming.

In the past, a high percentage of Nigerian farmers operate on small size farms. Where acreages were large, labor cost was very low and the traditional method of farming made mechanization of Nigerian farms very difficult.

Small size farms often engender low income for the farmers. This further served to promote farmers' lack of incentive towards the purchase and use of applicable machinery. Even now that mechanical application of fertilizer is possible, the high cost associated with applicable equipment is above what most farmers can afford. Hence, simple and relatively inexpensive equipment is more than welcome until farmers' holdings can economically justify the use of more sophisticated and therefore more efficient machinery.

Previously, there were doubts as to whether application of fertilizer really improved yields substantially and enough to economically justify its use on a large scale in the farming industry.

Oyenuga (1967) however pointed out that the probable causes of such low response to fertilizer were attributable to limits imposed by factors such as the level of exchangeable bases in the soil, limited requirements of crop variety and water.

The widespread increase in use of fertilizer in the farming

industry according to Cumings (1931) has now called for application equipment aimed at achieving better placement in relation to seed, accurate metering of the fertilizer and a further reduction in operating costs.

The positive (continuous) action of the metering device for presently available fertilizer applicators poses a challenging problem to Nigerian agriculture where ridge cultivation is still practiced and low plant populations per acre are used. The solution to this rests in the continuation of the present trend of practices where flat cultivation and mixed cropping respectively are used.

Oyenuga (1967) claimed that between 1954 and 1958, the amount of fertilizer consumed in Nigeria rose from 1900 metric tons to 6600 metric tons. He further asserted that this went up to 75,461 metric tons in 1962. Ever since, the demand for fertilizer has been on the upward trend.

Factors that now favor mechanical application of fertilizer in Nigeria include: a) increase in total acreage beyond the labor capacity of farmers' households, b) intensive production of such economic crops as cotton, groundnuts, benniseed, etc, c) growing shortage of hand labor, d) need to overcome perpetual labor bottlenecks, and e) realization that a simple and inexpensive applicator can pay for itself in a short while and yet overcome labor problems.

Of the three different forms of fertilizer presently available--gas, liquid and dry forms, the one employed at large by Nigerian farmers is the dry granular form. Hence equipment available in the country or machines being developed are those that will dispense this dry form.

None the less, there are problems associated with mechanizing

fertilizer application in Nigeria. The most important is the low economic return from farming.

The occurrence of many small size farms rather than a large one (fragmentation) makes mechanization difficult and expensive.

The chemical nature of dry forms of fertilizer calls for profound attention in handling the material. The relative humidity and temperature are the two variables that rapidly affect their use.

Absence of farmers' cooperatives contributes to low level of mechanization since few farmers can and will be willing to purchase equipment needed for mechanizing their farms.

Smerdon (1971) recommended that such farmers' cooperative bodies could cooperatively own and use machinery and equipment needed on the farms.

The low level of literacy among farmers places greater reliance on the Government and the University Extension Services for the success of any attempt to mechanize agriculture on nation wide basis. Various posters and demonstration plots that emphasize the need to adopt new innovations have been very helpful in the past.

The high illiteracy among farmers also calls for simple and sturdy equipment that can withstand the extreme conditions under which they have to operate. It will also be stimulating to the farmers if replacement parts are locally available or easily built by village blacksmiths.

Lack of technical bias on the part of the farmers calls for assistance from the ministry personnel on the use and maintenance of new equipment. A pilot run of such new ideas on farmers' farms may quicken their acceptance and use by farmers. Government subsidy, at

least initially, could help in overcoming farmers' economic problems and hasten the purchase of these farm equipment.

REVIEW OF LITERATURE

The main objectives for the application of fertilizer to crop, according to Martin,et. al. (1967) are the promotion of greater plant growth and better quality crops. Fertilizer application for continued cropping has been shown to be indispensable in the world's agriculture considering the rapidly increasing world population.

Cumings (1931) claimed that the widespread increase in use of fertilizer demands application equipment in order to achieve better placement of fertilizer in relation to the seed, to reduce operating costs, and to accurately meter the material.

Methods of Fertilizer Placement

In most developing countries, particularly in Nigeria, hand placement of fertilizer is common. This could be in band form around the crop or by side dressing. In either case, the material is applied below the soil surface and three to four inches away from the base of the seedlings.

Cook,et. al. (1958), in their experiment with small grains observed that band placement was more effective. Cumings,et. al. (1930) also observed better fertilizer placement in band form for cotton. They also observed a higher cotton yield with side placement of fertilizer than when the fertilizer was in contact with the seed. Cook,et. al. claimed that irregular distribution often leads to a reduction in yield. Nelson (1958) made the same observation with his

experiment. He recommended that allowance must be made for free soil between the fertilizer and seedling or seed to avoid fertilizer "burn" since nitrogen, phosphorus and potassium in contact with seedlings or seeds are injurious.

Cook also observed better results with side fertilizer placement. He further confirmed that the solubility of chemicals of a fertilizer type influences the rate of intake of the elements. Cook, however, advised that the depth of fertilizer placement, for effective utilization of the nutrients by the roots of crops, should be determined.

Guelle (1954) recommended that improvement in fertilizer equipment should embrace a better metering device, bigger capacity of the hopper to reduce the number of stops, and more accurate placement of fertilizer in relation to seed or seedlings.

Cumings (1931) observed that in most cases, germination was ruined by direct contact of fertilizer with seed. He further observed an increase of 350 lbs. seed cotton when fertilizer was placed one inch to the side of seed as compared with five inches away.

According to Walker (1957), accuracy and timeliness of fertilizer placement are most essential where there is growing competition for agricultural lands.

Martin, et. al. (1967) discussed various methods of fertilizer application; these include a) injecting liquid material into the soil with machines, b) broadcasting or drilling dry materials before or after plowing the soil, c) placing fertilizer materials in bands or hills during planting, d) side-dressing between or beside the crop rows, e) drilling into slits opened by deep tillers, and f) metering liquids into the irrigation water being applied with sprinklers or by gravity

flow.

Physical Properties of Fertilizer

The physical properties of fertilizers are important in attempting to evaluate dispensing actions of the application equipment.

Guelle (1950) pointed out that caking and bridging of fertilizer materials over applicator feeding mechanisms constitute great threats to the design of applicators.

Lee, et. al. (1965) pointed out that the range of particle size, size distribution, temperature and relative humidity are some physical factors that affect the mechanical application of fertilizers. They recommended mechanical application at a relative humidity under 45% and at a temperature of about 70°F.

Cumings,et. al. (1930) indicated that moisture content and the angle of repose of fertilizer materials are two of the factors affecting its mechanical application. They recommended frequent drying of the material when the relative humidity is higher than optimum. Doing this, they said, will prevent caking of the material in the hopper and its subsequent bridging over the feed mechanism.

Guelle (1954) reported that the widespread increase in use of fertilizer has increased the demand for application equipment having a longer life, reduced operational cost, accurate metering device, better placement in relation to the seed to produce maximum return from fertilizer investment.

Cumings,et. al. (1930) and Hyland (1950) independently recommended that the hopper should be so designed that it can easily be disassembled and cleaned since fertilizer absorbs moisture from the

atmosphere causing it to cake and corrode metal parts.

Basic Considerations in the Design of Fertilizer Equipment

Fertilizer applicators are needed for proper placement of fertilizer in relation to the seed or seedlings to allow efficient growth and yield of crops. There are many fertilizer distributing machines. Martin, et. al. (1967) made the following classification: a) machines used solely for fertilizer application, b) combination machines for applying fertilizer as well as planting, c) combination machines for applying fertilizer and tilling the soil in one operation and d) machines for applying fertilizer in solution with irrigation water.

Hopfen (1960) provided some guidelines for design consideration in developing countries where the level of mechanization is still low. He stated that equipment should be a) selected for appropriate and speedy performance causing relatively little human fatigue, b) adapted to man or animal so that health is not harmed, c) of simple design, thus permitting easy reproduction, d) light in weight, thus permitting easy transportation, e) immediately ready for use at any time, and f) made of materials which are easily available and can subsequently be used for other purposes.

Cumings, et. al. (1930) and Kepner, et. al. (1972) pointed out the following pertinent points for the design of fertilizer equipment: weight of the machine, variation of delivery rate, uniformity of fertilizer distribution, depth of fertilizer in the hopper, speed of operation, inclination of the machine, drillability, and hopper size.

Other points worth considering include a positive dispensing

action with fertilizers of a wide range of delivery, avoidance of a high amplitude in delivery rate, provision for ready emptying and cleaning, provision for ready determination of the actual delivery rate, and availability and ease of replacement of dispensing parts.

Lee, et. al. (1965) confirmed from his experiment that the rate of flow of fertilizer depends on the speed of operation and the flow characteristics of the fertilizer material. He further said that at low speed, flow is due mainly to gravity.

Reed, et. al. (1970) discussed the merits of fertilizer spreading equipment. He claimed that an uneven application often leads to uneven plant growth and varying dates of maturity. The proper design of the hopper calls for corrosion resistant materials. Guelle (1950) mentioned corrosion of machine parts as one of the design problems facing manufacturers of fertilizing equipment. Cumings (1935) pointed out that fertilizer greatly accelerates corrosion and requires corrosion resistant metals and coatings for the hopper.

Guelle, et. al. (1954) emphasized that bearings, gears and other working parts of fertilizer equipment should be protected from the corrosive effects of fertilizers. They recommended using coatings for the hopper or using stainless steel at least for the bottom portion to eliminate corrosion.

Laboratory tests conducted by some manufacturers showed that castings offer some degree of protection. Such castings include grey iron.

Guelle also pointed out that since the most glaring of all problems is the corrosive action of the chemicals used in fertilizers, so bearings and gears should be protected against it by reducing

corrosion.

Walker (1957) said that the development of a machine for better operation in the field as well as the maintenance of existing units against corrosion will further the mechanical application of fertilizers.

Cumings, et. al. (1930) and Anderson (1952) independently discussed the factors contributing to the ease of machine operation. Such factors include light weight and light construction of walking-type applicators, adequate hopper capacity, ease of accessibility for cleaning, convenient adjustments for delivery rates and provision for an effective depth gauge for furrow openers.

From the experiments that Cumings, et. al. conducted with cotton, they observed that irregular distribution of fertilizer resulted from variable wheel slippage, non-uniform flow of fertilizer, tilting of the machine, changes in depth of fertilizer in the hopper and lack of adequate distributing mechanisms. They also observed from their experiment that the inclination of the machine has some effect on the delivery rate. They found that tilting their machine would increase the rate of one delivery unit and diminish the rate of the other unit in a two-unit hopper. They also pointed out that the ease of guiding and handling walking-type machines depend on the size of wheel, design and width of tires, weight supported, power requirement and the characteristics and condition of the soil.

They showed that the average slippage of walking-type applicators they experimented with was 24% on coarse sand and 16% on sandy loam. They further showed that walking machines with narrow wheels have the tendency to sink into the soft ground and incline forward. The shovels at the rear end also have the tendency to cause wheel sinkage and incline

the machine rearwards.

The capacity of a hopper depends on whether the machine is hand pushed or motorized. Cumings, et. al. (1930) said that the hopper size, they experimented with, ranged from 86 lbs. to 176 lbs. for walking-types and about 500 lbs. for riding-types.

Fairbanks (1950) used a rotating brush machine built by Kansas State University Agricultural Engineering Department to insure uniform fertilizer distribution. The power to operate this unit was from a sprocket on the main axle of the driving tractor. The machine was used extensively on test plots and was said to distribute fertilizer accurately.

Agriculture is so diversified by nature, according to Hopfen (1960), that abundant production can be secured from a variety of systems. The mechanization of agriculture will therefore not render man-powered methods superfluous.

Hopfen claimed that a man normally works at a rate of 7-10 kilogram-meters per second. He went further by saying that during continuous work, a man produces about 8 kilogram-meters per second or approximately one-tenth horsepower. The average draft created by man, according to Hopfen, is about one-tenth of his own weight.

Hopfen confirmed that animals have higher carrying and pulling abilities than men per unit weight and hence constitute a cheap source of power for agriculture particularly if raised by the farmer himself.

Hopfen claimed that the strength of an animal is a function of its weight and for short periods, one animal can produce a force, equal

its own weight. Hopfen compiled a table of drafts for working animals (see Appendix A). He pointed out that the average draft of an animal is about 15% of its weight. He also pointed out that 85% of the total draft power used in agriculture throughout the world is still provided by animals. Such animals include horses, cattle, mule and donkeys.

INVESTIGATION

Research Objectives

The main objectives of this study were:

a) To come up with a modified design of a fertilizer equipment that is applicable to Nigerian Agriculture.

b) To calibrate the metering unit of such equipment to apply the required rate of fertilizer in kilogram per hectare.

c) To make power measurements on the machine in order that the mode of operation might be ascertained.

d) To test the equipment so as to ensure conformity with the intended purpose.

Materials and Equipment

The initial design of this equipment was made by the Gandy Manufacturing Company. The machine was, however, redesigned and built by the author to suit the outlined intended purpose. The main features of the fertilizer equipment are as discussed below:

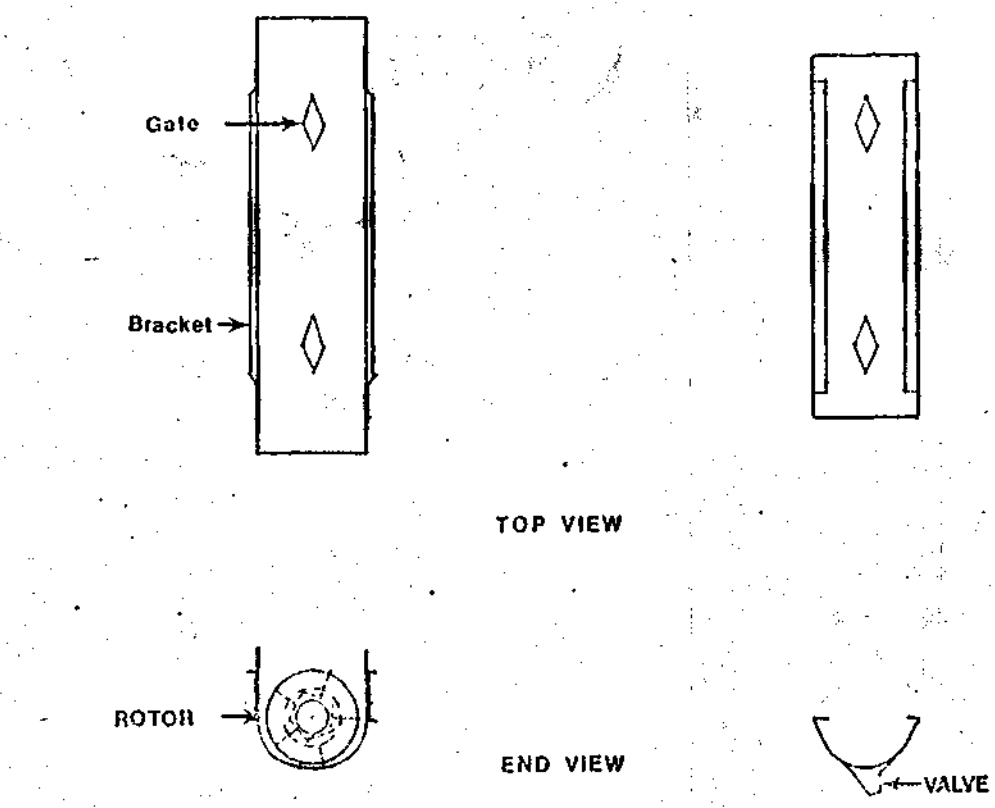
The hopper was designed to hold about 11.35 kg. of fertilizer material. The top part of the hopper has a cross sectional area of 33.02 x 30.48 cm. and the unit is 38.10 cm. deep. The hopper sidewalls slope and decrease gradually to a narrow bottom where it adjoins the metering unit (fig. 1). The hopper is constructed of mild steel and has been painted to prevent corrosion. The shape of the hopper is such that it will permit free flow of the material. The hopper unit is clamped to a mounting rail by side brackets.

The metering units consist of a U-shaped rotor housing which is longer than it is wide. The general shape is shown in fig. 2. This U-shaped structure is constructed of stainless steel. Close to each end of the unit is a gate opening through which the material is metered. External to this is a U-shaped slider that has another corresponding set of gate openings. When the gates are in the fully opened position, the diamond shaped holes in the rotor housing and the slider merge. The action of the slider varies the size of the hole which is directly opposite the rotor blades. The slider is constructed of stainless steel. The maximum area of each of the holes in the fully opened position is 1.55 sq. cm.

Inside the U-shaped housing is the rotor (fig. 3), with its blades made of stainless steel and positioned directly opposite to each of the gate openings. There are five blades mounted on the rotor shaft and spaced 72 degrees apart. The rotor shaft is pentagonal in shape where it carries the blades but machined to a round shaft just before it traverses the hopper to connect to another shaft carrying one of the sprockets that drive the rotor. The blades on the rotor were designed not to be continuous on the rotor shaft since the gates which were used are at each end of the hopper bottom. Leaving them in their original continuous form would lead to excessive grinding of the material at places devoid of openings.

The position of the gates is controlled by a cam mechanism originally designed by Gandy. The cam is scaled along its periphery with each scale corresponding to a specific opening size. The cam is operated by a lever arm.

There are two sprockets, one mounted on the shaft that connects



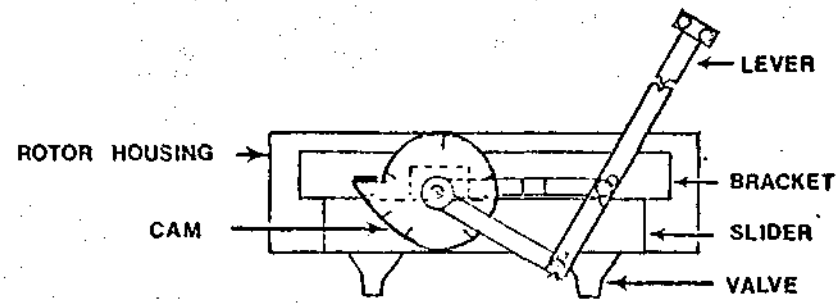


Fig. 2. Metering Units for the Applicator.

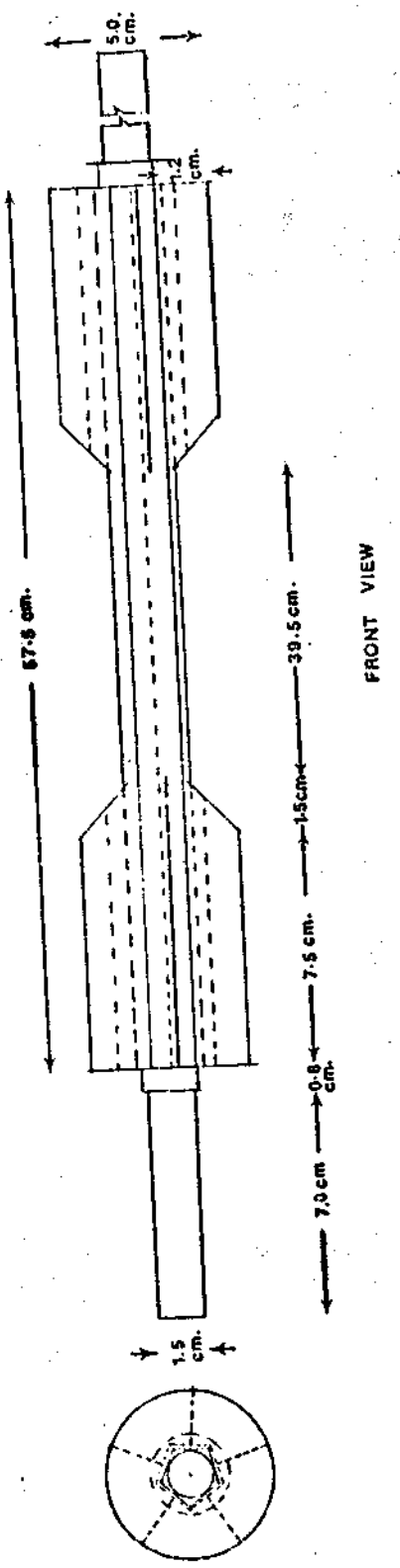


Fig.3. Rotor for the Metering Units.

to the rotor shaft and the other is mounted on the axle of one of the ground (rear) wheels. There are ten teeth per sprocket. The two sprockets are driven by a detachable link chain. Both the sprockets and the chain are made of cast iron.

There are two ground (rear) wheels and a caster at the front. The rear wheels use hard rubber tires mounted on a circular platelike rim. Each wheel has a diameter of 63.5 cm. and is 5.08 cm. wide. Each wheel is mounted on a 1.59-cm. diameter axle running through the side (vertical) frame of the machine. The wheels are fastened in place on the axle by cotter pins. Mounted on the axle of the left wheel is one of the sprockets that serves to drive the rotor of the metering unit.

The front wheel is a caster wheel with a pneumatic rubber tire of size 12.19-20.32 cm. and is capable of making 360 degrees rotation so as to permit easy turning at the end of the field. The caster shaft is grooved and kept in place by a bolt screw to prevent it from coming loose, but still permitting the 360 degrees rotation. It also serves as a depth gauge and hence prevents the furrow openers from sinking too deeply into the ground.

The frames for the equipment consist of two side (vertical) members, each of which is a 5.08 x 5.08 cm. square mild steel. The 1.59 cm. axle for each of the ground wheels passes through the lower end of the side members. The replaceable bronze bushings inside these side frames prevent the wearing of the axles.

Clamped to these side frames is another 5.08 x 5.08 cm. square mild steel member, the mounting rail, which runs horizontally and carries both the hopper and the handle bars. Also clamped to the center of this mounting rail is the L-shaped caster shaft holder.

The side frames also carry the furrow openers and their closing device (fig. 4). Each opener consists of a 1.91 cm. steel pipe at the end of which is a V-shaped mild steel tool that makes the groove in the soil.

The handle bars are of mild steel and are 0.318 x 5.08 cm. in cross sectional area. Hydraulic cylinder mounted on the handle bars, 5.08 cm. in inside diameter with a pressure gauge graduated from zero to 100 lb./in.^{2} or zero to 7.03 $\frac{\text{kg.}}{\text{cm.}^2}$ pressure, was used for the draft measurement in the field.

The flow rate was determined in the laboratory using a ¼ horse-power electric motor which has been geared down to 30 rpm. Different pulley sizes were used on the motor shaft and the rotor shaft respectively so as to achieve desired speed of rotation for the rotor. The two pulleys were connected by a "V" belt (fig. 5).

The experimental material, used for the investigation, was granular urea containing 45 percent Nitrogen. This material is close to sulphate of Ammonia in particle size.

Timed tests were used to make flow rate measurements and the power determinations.

Two plastic delivery tubes were used to guide the flow of the material (urea) from the metering unit into containers during the flow rate determination in the laboratory.

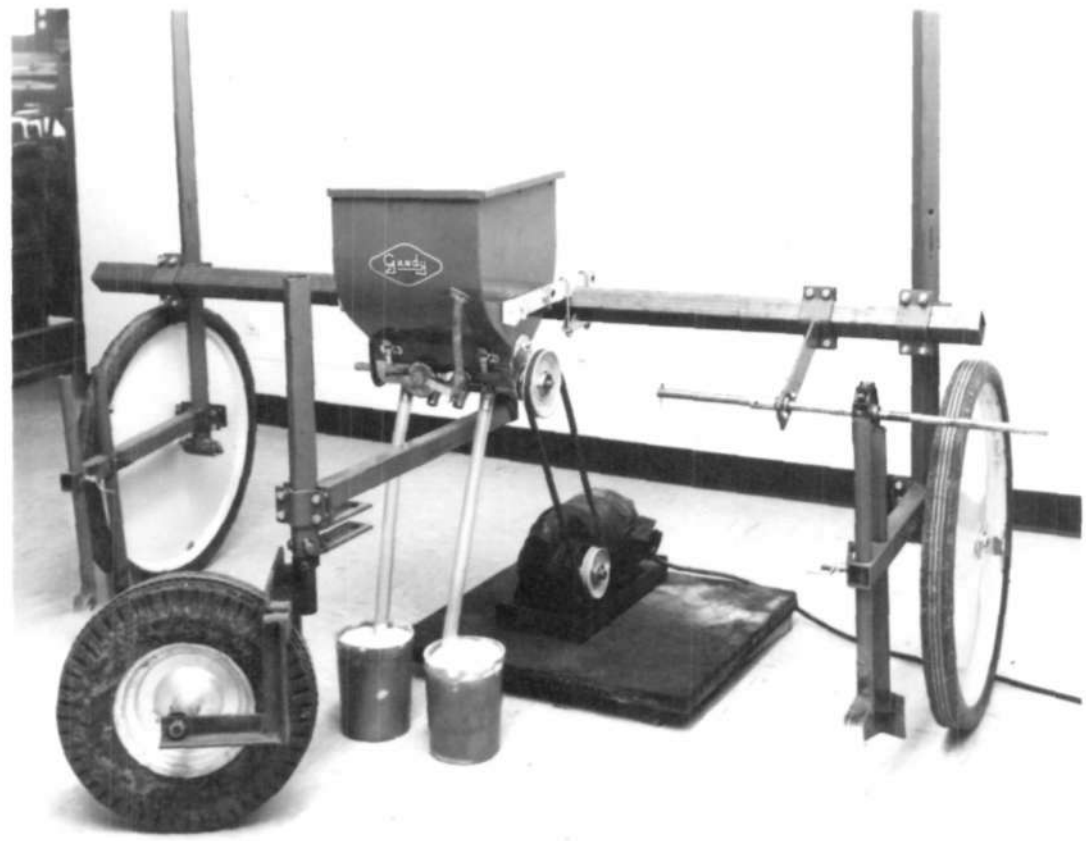


Fig. 4. Machine showing Furrow Opener and closing device clamped to the Vertical Members.

METHODS OF PROCEDURE

Flow Rate Measurement

The metering unit of this machine was initially calibrated so as to achieve the desired rates of application of the material for each of the chosen speeds.

Three rotational speeds of the rotor shaft were chosen for the operation of the equipment. These speeds were 25, 30 and 35 rpm respectively.

The pulley ratio was calculated. The gear motor pulley and rotor shaft pulley were connected as shown in fig. 5. An electric motor which has been geared down to 30 rpm was used. It was possible to operate the rotor shaft at these different speeds by changing pulley sizes on the shaft, changing the one on the electric motor shaft or both.

The equation used for the calculation of the pulley sizes was:

$$\frac{Ng}{Nr} = \frac{Dr}{Dg} \qquad (1)$$

where Ng = number of revolutions per minute of the motor shaft

Nr = number of revolutions per minute of the rotor shaft

Dg = diameter of the pulley on motor shaft

Dr = diameter of the pulley on rotor shaft

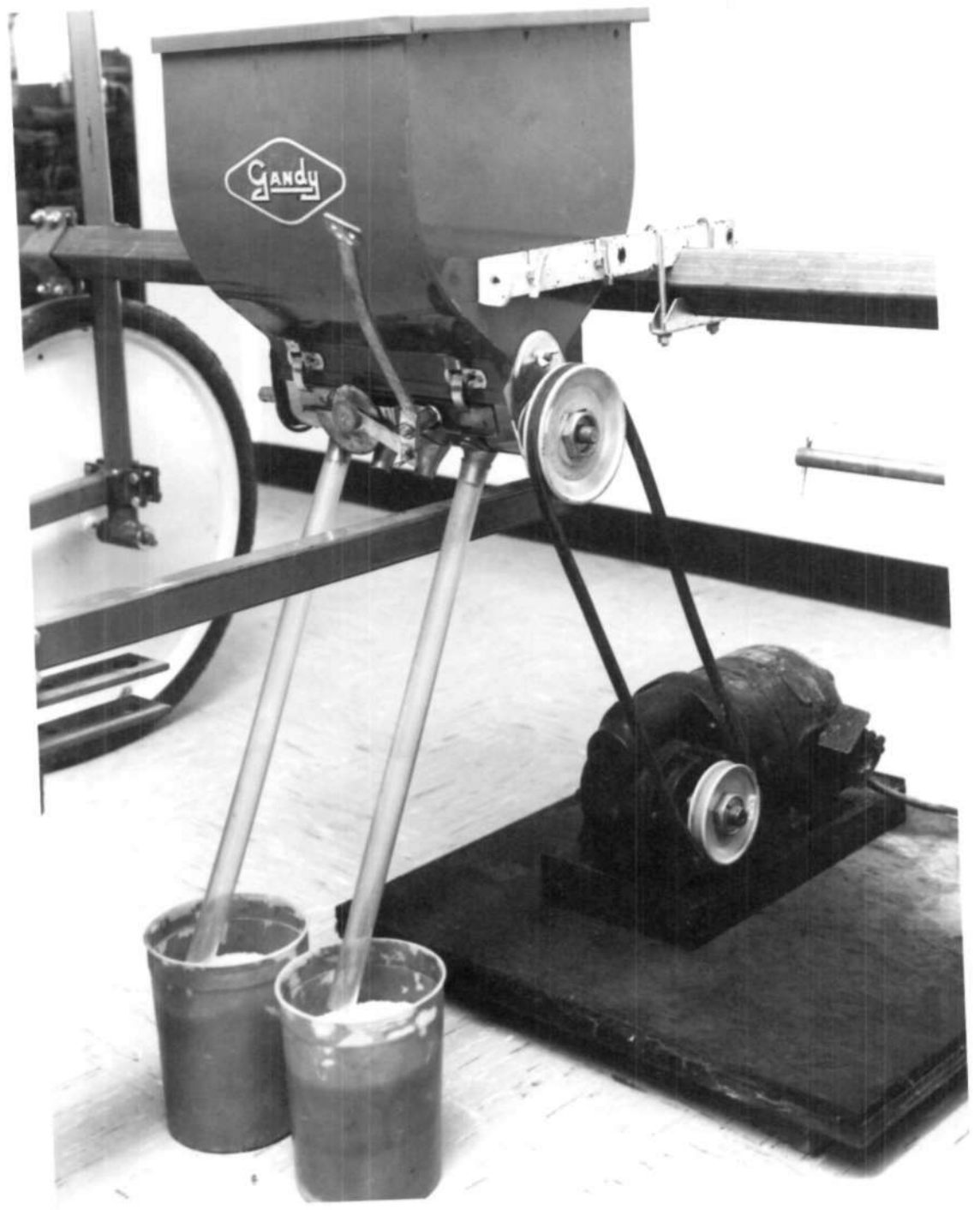


Fig. 5. Machine showing Arrangement for Flow Rate Determination.

In the first instance:

Rotor shaft speed = 25 rpm

Electric motor speed = 30 rpm

Pulley size on motor shaft = 4"

$$Dr = \frac{(30 \text{ rpm})(4 \text{ inches})}{25 \text{ rpm}} = 4.80 \text{ inches, pulley diameter, use 5.0" pulley}$$

Hence, for this speed of 25 rpm, a 5-inch (12.70 cm.) pulley was used on the rotor shaft.

With the same procedure, pulley sizes for 30 and 35 rpm of the rotor shaft were calculated.

For the 25 rpm of the rotor shaft shown above, the corresponding ground speed of the machine was:

$$S = 25 \frac{\text{rev}}{\text{min}} \times \frac{2\pi r}{\text{rev}} \times \frac{60 \text{ min}}{\text{Hr}} \times \frac{1 \text{ mile}}{5280 \text{ ft.}} \times \frac{1.60934 \text{ Km}}{\text{mile}}$$

where r = radius of the rear wheel

$$r = \frac{25 \text{ ft.}}{(2)(12)} = 1.042 \text{ ft.}$$

$$S = 25 \frac{\text{rev}}{\text{min}} \times \frac{(2)(2.142)(1.042 \text{ ft})}{\text{rev}} \times \frac{60 \text{ min}}{\text{Hr}} \times \frac{1 \text{ mile}}{5280 \text{ ft}} \times \frac{1.60934 \text{ Km}}{\text{mile}}$$

$$= 2.99 \frac{\text{Km}}{\text{Hr}} \qquad (2)$$

Other ground speeds were 3.59 and 4.18 Km/hr for 30 rpm and 35 rpm respectively.

After selecting a speed for the rotor shaft, the electric motor was started and the number of revolutions of the rotor shaft was checked to make sure the expected number of revolutions per minute was as chosen. The material (urea) was then poured into the hopper. There were two sets of runs. One in which the hopper was nearly full before commencement of flow rate measurement and the other in which the hopper

was nearly empty. For the latter, enough material was put into the hopper to just complete each flow measurement. In either case, each flow rate was replicated twice for each of the gate settings. The gate settings used were designated as 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 and 80 as indicated on the cam mechanism. The area of opening represented by each of these gate settings is given in Appendix B. A plastic tubing connected each of the two valves with the collecting container.

For each setting, the motor was allowed to run for one minute and the amount of material collected was weighed and recorded. The average flow rate for each gate setting was calculated in kilograms per hectare in conformation with the flow rate under the field conditions.

Sample calculation of flow rate:

$$A = \left(X \frac{\text{rev}}{\text{min}}\right)\left(\frac{6.55\text{ft}}{\text{rev}}\right)\left(\frac{1\text{ min}}{\text{RUN}}\right)(3\text{ ft width row})\left(\frac{\text{Acre}}{43560\text{ ft}^2}\right)\left(\frac{0.40469\text{ hectare}}{\text{Acre}}\right)$$

where A = equivalent area for one minute revolution of the ground wheels

X = specified speed of the equipment in rpm

For X = 25 rpm:

$$A = \left(25 \frac{\text{rev}}{\text{min}}\right)\left(\frac{6.55\text{ ft}}{\text{rev}}\right)\left(\frac{1\text{ min}}{\text{RUN}}\right)(3\text{ ft. width})\left(\frac{\text{Acre}}{(43560\text{ ft}^2)}\right)\left(\frac{0.40469\text{ hectare}}{\text{Acre}}\right)$$

$$= 0.00457 \text{ hect.}$$

Assuming Y kg = amount material collected in one minute, then flow rate, $\bar{W}$ in kilogram per hectare:

$$\bar{W} = \frac{Y}{0.00457}\frac{\text{kg}}{\text{hect.}} = 218.82\ Y\ \frac{\text{kg}}{\text{hect.}} \qquad (3)$$

The same procedure was used in calculating the flow rate for the remaining speeds of 30 rpm and 35 rpm for each case of nearly full

hopper and nearly empty hopper. The laboratory temperature and the relative humidity were noted.

The flow rate data collected were analyzed statistically by analysis of variance.

Power tests

Before the draft measurements in the field, the pressure gauge on the hydraulic cylinder was first calibrated in the laboratory using known weights. A graph of indicated pressure (in psi) versus actual force (in lbs) were made on a logarithmic paper and a linear curve used in converting the draft measured in the field from pressure reading to force reading (fig. 6). The power test was carried out on the machine in order that the appropriate means of operating it might be ascertained. The horsepower needed to drive the machine would indicate whether it is most suited for man power (hand push) or animal power.

The machine was taken to the field and operated on land that had been plowed and disked. The soil was moist due to recent rains but not muddy. The soil was of silty-clay nature.

Before the draft measurements, the hydraulic cylinder together with the pressure gauge, was connected to the handle bars and a hand grip was also connected to the cylinder (fig. 7). The furrow opener was set at a 1½-in. (3.81 cm.) depth and the furrow closing device set into place.

In the first instance, the time taken to push the machine through a prechosen distance of 100 ft. (30.48 m.) was recorded. The average gauge pressure reading was also recorded and, using the calibration curve, the actual force for the draft was established.

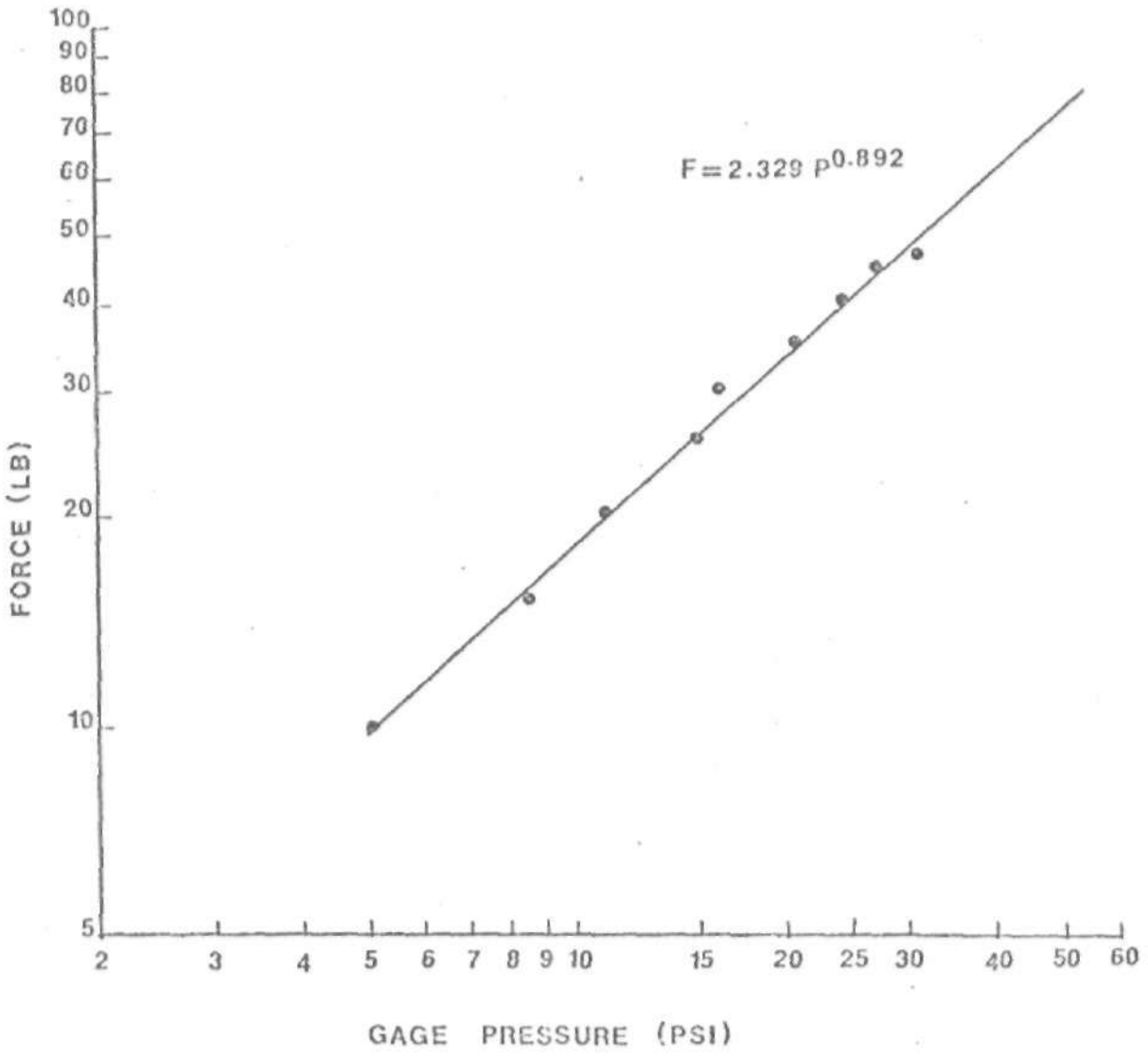


Fig. 6. Calibration Curve For Power Determination.

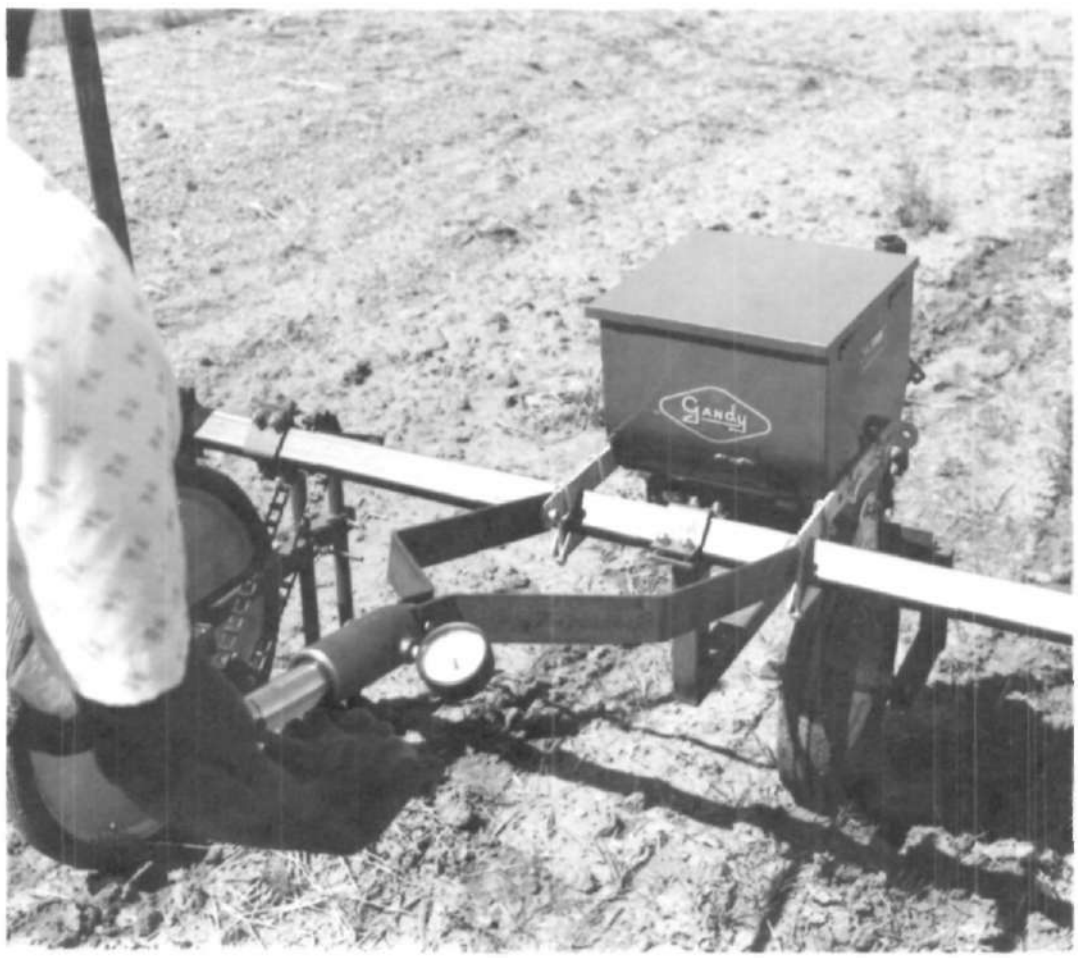


Fig. 7. Machine showing Hydraulic cylinder and Pressure gauge arrangement for Power Determination.

There were a few problems associated with this initial draft measurement. First, the machine was unstable when operating it on a sloping soil. Second, there was too much side draft accounting for inconsistent pressure readings on the gauge. These two problems were thought to be associated with the 25-in. (65.50 cm.) tread width of the machine's rear wheels. Hence, the machine was returned to the laboratory for further modification.

The tread width was increased from 65.50 cm. to 182.88 cm. (1.8288 m.) and again returned to the field for further draft tests.

The hopper was filled with experimental material, the furrow openers were set to a 1½-in. (3.81 cm.) depth as for the previous trial and the furrow closing device set in place (fig. 8). The time taken to push the machine through the same distance as before (30.48 m.) was recorded, so was the average pressure readings (in psi). Pressure readings were converted to actual force (in lbs.). This was repeated several times so as to get a better indication of the draft by hand push.

The machine was pulled using a spring scale. The force was read from the scale and recorded. This procedure was carried out several times as done for the hand pushing.

The horsepower requirements for pushing and pulling the machine were computed using:

$$HP = \frac{F(lb) \times D(ft)}{33000 \left(\frac{ft\text{-}lb}{min}\right) \times t(min)}$$

$$= \frac{F(kg) \times D(meters)}{4585.62 \left(\frac{kg\text{-}m}{min}\right) \times t(min)} \qquad (4)$$

where F = force resulting from push or pull of the machine in kilogram



Fig. 8. Photograph showing grooves made by Furrow Openers.

D = distance the machine was moved, meters

t = time taken to cover this distance, minutes

In either case of pull or push, the highest force was used in computing the maximum horsepower requirement for driving the machine.

RESULTS AND DISCUSSION

Three operational speeds of the rotor shaft were chosen for the flow rate determination. Eleven different gate settings were used to vary the size of gate opening and each flow measurement was replicated twice. The compiled data were analysed statistically by an analysis of variance through AADVARK programing and the results presented in graphical form.

Figure 9 is a graph of the flow rate (in Kg./hect.) plotted against the gate opening for each of the three speeds. The curves are neither linear on semilogarithmic paper nor on logarithmic paper. The flow rate equation for each curve was determined by a regression analysis. This curvilinear regression involves the second degree polynomial as shown by the equations. The flow rate equations for the 25, 30 and 35 rpm curves are;

$$\overline{W}_{25rpm} = 1.10 + 119.75G + 113.21G^2 \qquad (5)$$

$$\overline{W}_{30rpm} = 16.82 + 84.28G + 143.32G^2 \qquad (6)$$

$$\overline{W}_{35rpm} = 20.36 + 82.64G + 145.11G^2 \qquad (7)$$

where $\overline{W}$ = flow rate, Kg./hect.

each costant = the intercept of the curve

and G = gate opening, $cm.^2$

Figure 10 is a graph of the average flow rate plotted against the gate opening over all speeds and depth of material in the hopper. The flow rate equation as determined by regression analysis is:

$$\overline{W} = 12.76 + 95.56G + 133.88G^2 \qquad (8)$$

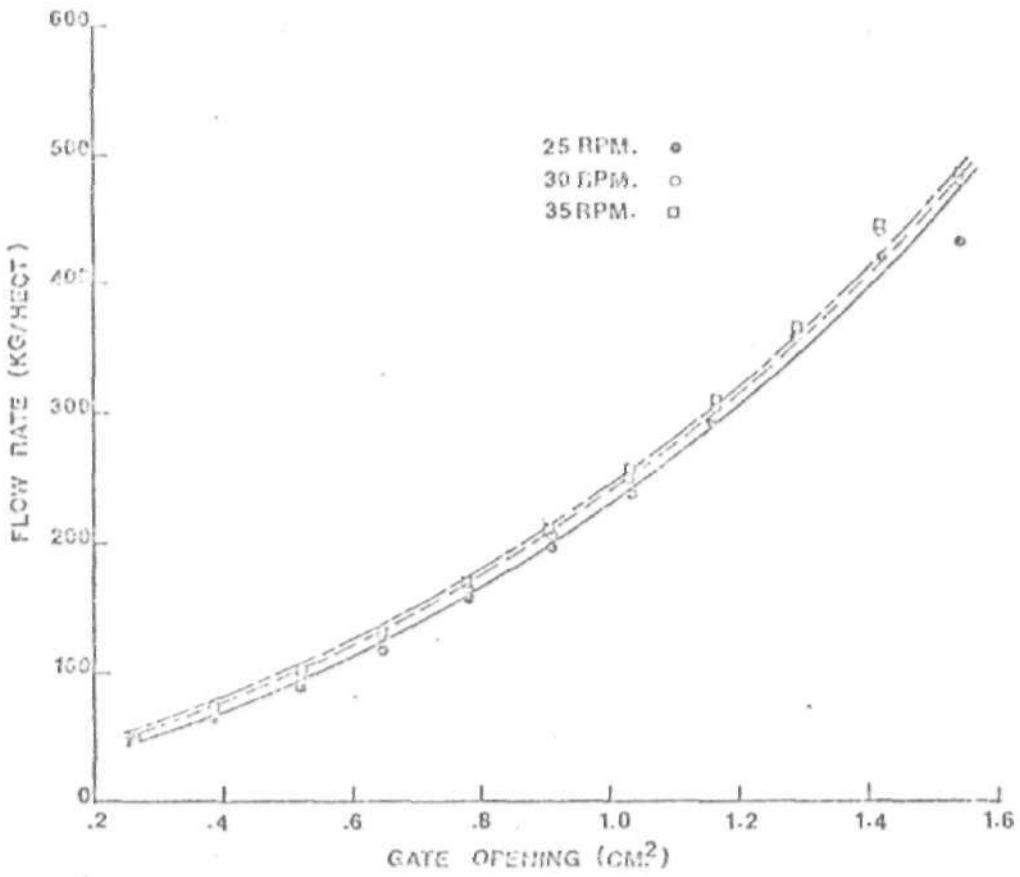


Fig. 9. Flow Rate vs. Gate Opening For Three Different Speeds.

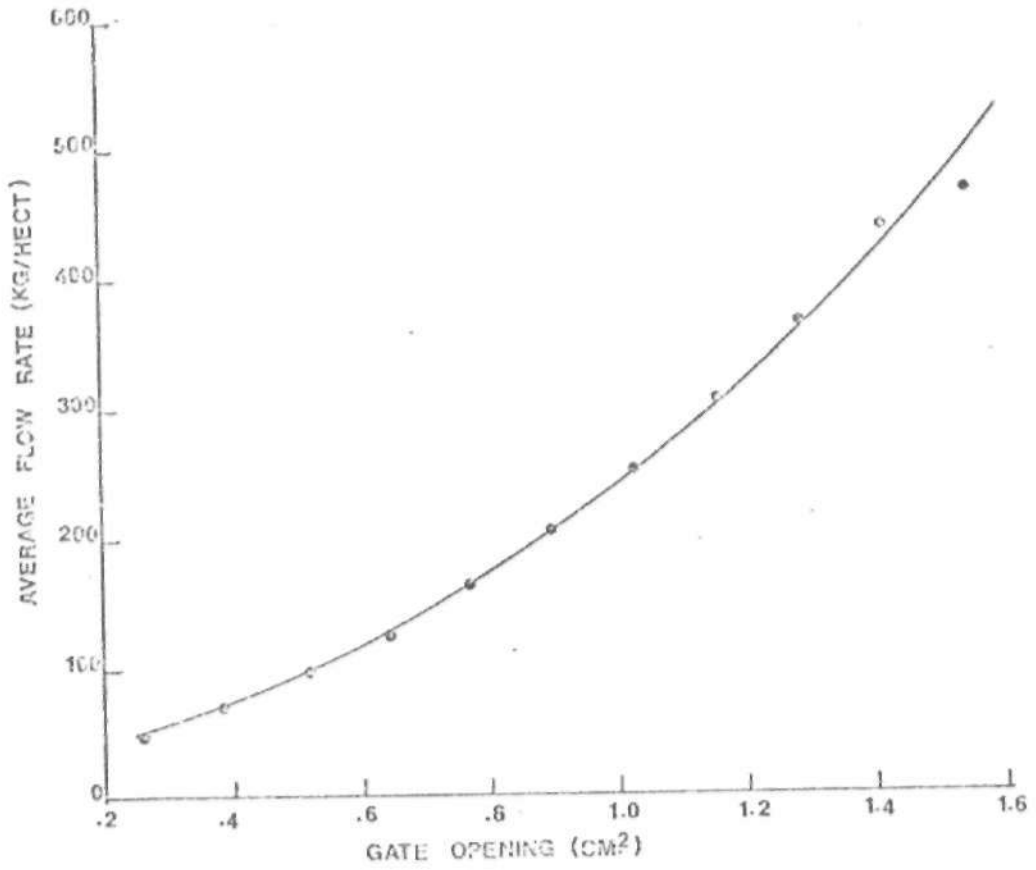


Fig. 18. Average Flow Rate vs. Gate Opening For All Speeds.

These two figures are very important from the designer's viewpoint since they relate flow rate to the amount of gate opening for a specified speed.

Figures 9 and 10 show that doubling the gate opening more than doubles the flow rate. This is far from expected and could be attributable to the nature of the fertilizer material (urea), and the shape of the gates. This high change could also have accounted for the non-linearity of the curves on logarithmic and semilogarithmic papers. The flow rate at any gate opening within the range experimented with can be calculated by using the appropriate equation above.

The visible gate settings on the cam mechanism of the metering unit are of great importance to the farmer since each represents a given area of opening. Hence some graphs of flow rate (in Kg./hect.) and gate settings have been plotted as shown by figures 11 and 12.

Figure 11 is a graph of the average flow rate (in Kg./hect.) plotted against gate settings over all speeds and depths of the material in the hopper. The curve increases linearly with a positive slope. This shows that holding all other factors constant (speed, environmental influence, etc.), flow rate will increase as the size of gate opening is increased.

Figure 12 presents three curves of flow rate plotted against various gate settings for each speed. An important result was obtained here. The three curves are almost parallel to one another with the curve for 35 rpm having the highest slope and that for 25 rpm the lowest slope. This demonstrates the fact that changing the speed for a specified gate setting will vary the flow rate. The fact that the curve for 30 rpm is closer to that for 35 rpm than it is to the curve

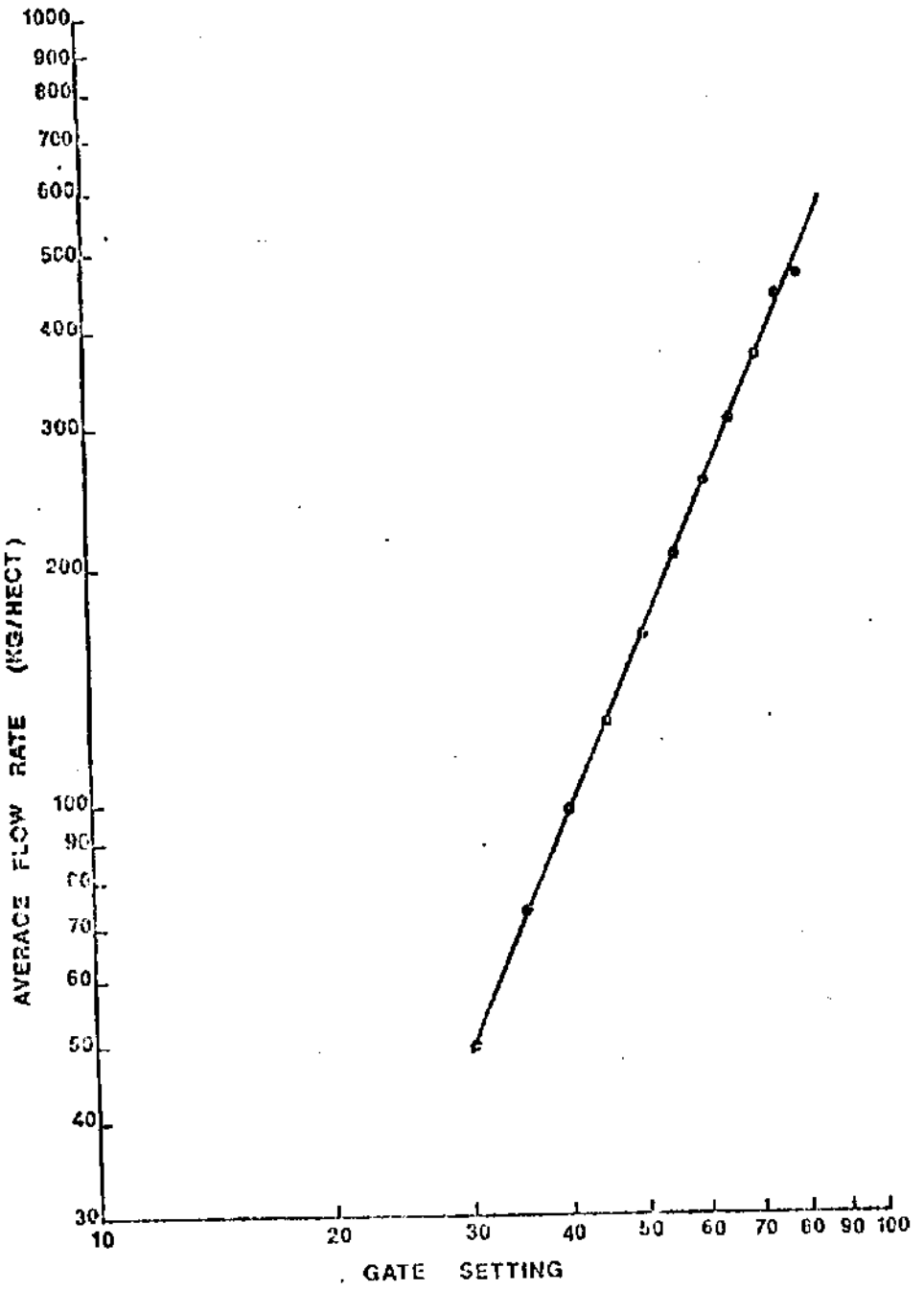


Fig. 11. Average Flow Rate vs. Gate Setting For All Speeds.

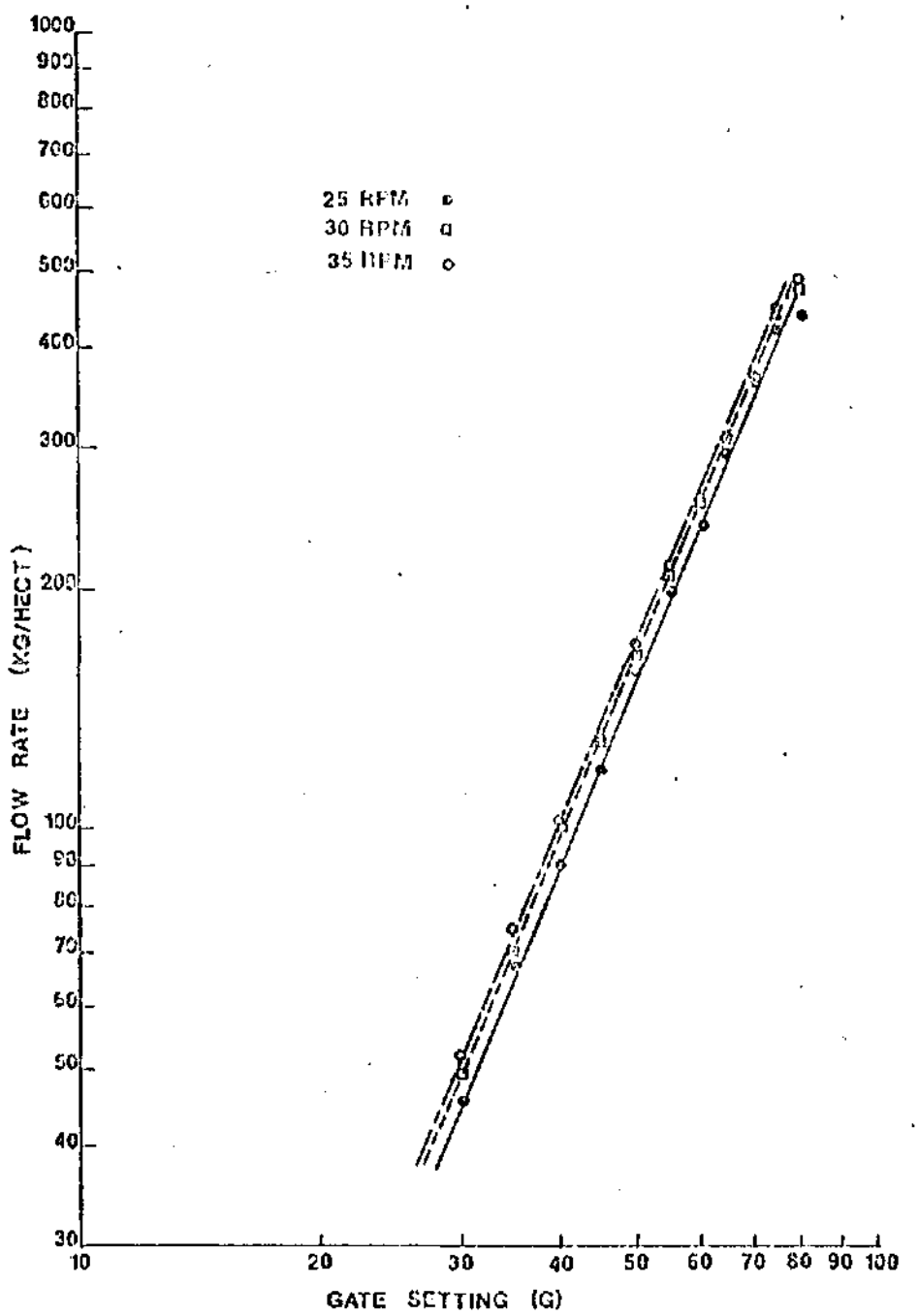


Fig. 12. Flow Rate vs. Gate Setting For Three Different Speeds.

for 25 rpm confirms the fact that increasing the speed increases the flow but at a decreasing rate. It is highly probable that if the speed is increased indefinitely, a point will be reached where the speeds will not have pronounced effect on flow rate.

Figure 13 shows the effect of hopper head on flow rate. This figure shows that the depth of material in the hopper has no influence on flow. The governing factor in this case appears to be the speed at which the rotor turns. The slight positive slope of the curves shows that increasing the speed increases the flow rate, other factors held constant. The clearance of the rotor blades from the hopper side walls prevents any possible gravity feed between the blades and hopper side walls.

A slight difference is noticeable between the two curves at lower speed but the difference becomes inperceptible at higher speeds as demonstrated by the two curves tending to merge at 35 rpm. It should be realized that average values of flow rate over all possible gate settings were used to plot the curves.

It is also significant to note the interractions of the parameters used in the statistical analysis. Table 1 gives the F values and levels of significance (alpha hat) for the parameters used in the investigation. Will all effects fixed, F values were calculated using the error mean square as the denominator and the mean square of the parameters as the numerator.

The 100-percent significant level (shown in the alpha hat column) for the speed and gate opening explains the influence of one or both of these parameters on the flow rates.

It is important to note that the curves in figures 11 and 12 are

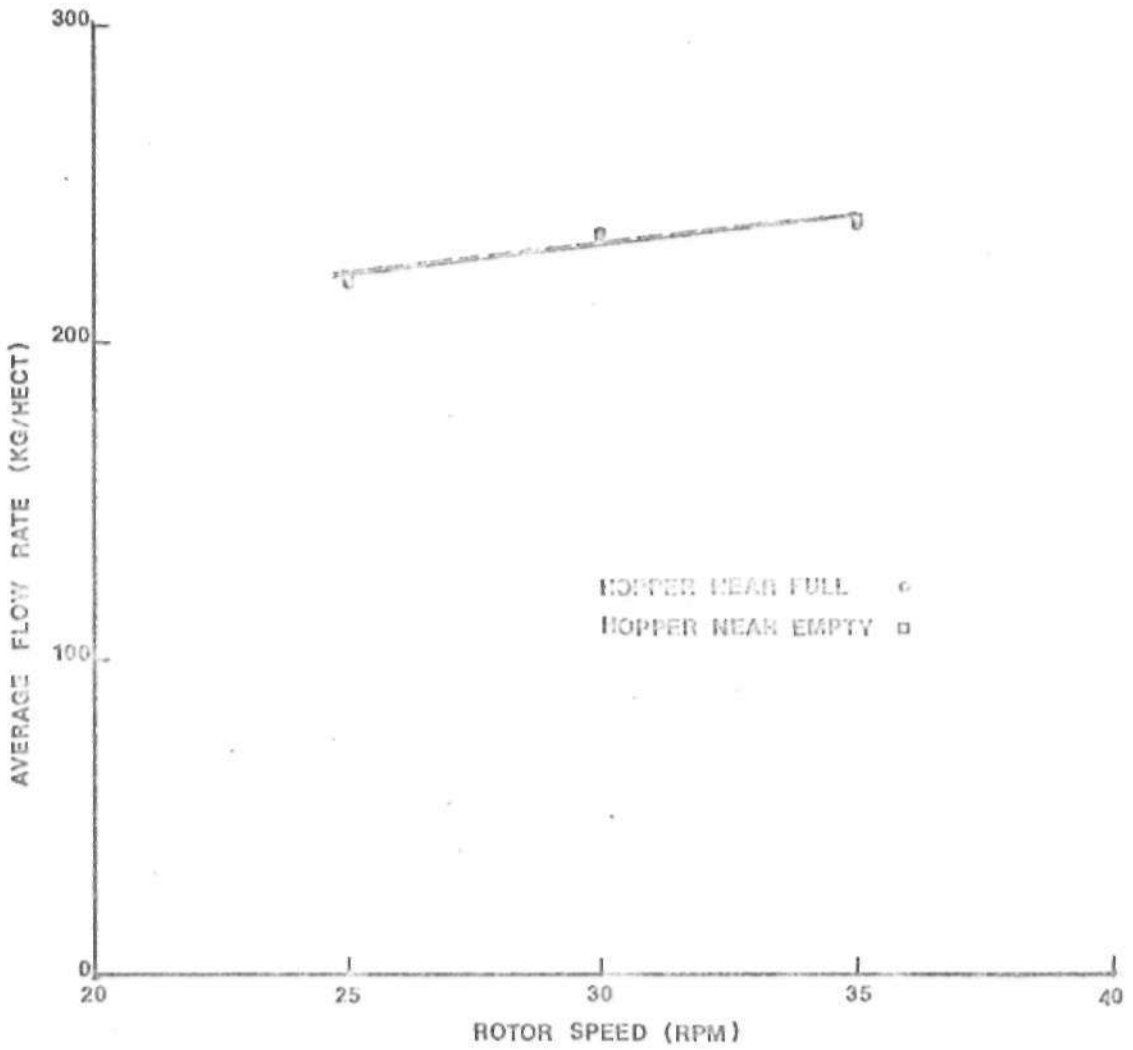


Fig.13. Effect of Hopper Head on Flow Rate .

Table 1. Analysis of Variance for flow rate data showing F values and Level of Significance.

Variation due to	DF	Mean Square	F	Alpha Hat
Speed (S)	2	5292.426	2853.483	0.0
Hopper depth (H)	1	29.993	16.171	0.000
Gate opening (G)	10	383994.875	207036.000	0.0
S x H	2	43.814	23.623	0.000
S x G	20	338.871	182.707	0.0
H x G	10	4.484	2.417	0.011
S x H x G	20	2.714	1.464	0.105
ERROR	132	1.855		

linear curves on logarithmic paper.

The linearity of the curves on logarithmic paper shows that Y, the dependent variable is a function of X, the independent variable or precisely

$\log Y = f(\log X)$

The empirical equations for the curves in figures 11, 12 and the previous calibration curve were developed using the log-log function:

$Y = a X^b$ where Y = the dependent variable

a = intercept of the curve with the crdinate

X = the independent variable

b = the slope of the curve

In natural logarithmic form:

$\ln Y = \ln a + b \ln X$

Using the method, of least square, the constants "a" and "b" can be evaluated:

$Y' = (a' - b\overline{X}') + bX'$ where $Y' = \ln Y$

$(a' - b\overline{X}') = \ln a$

b = slope of the curve

$X' = \ln X$

From the results obtained by statistical analysis of the data,

$$a' = \overline{Y}' = \sum_{i=1}^{n} \frac{Y'i}{n}$$

$$b = \frac{\sum_{i=1}^{n} XiYi}{\sum_{i=1}^{n} Xi^2} = \frac{\sum_{i=1}^{n} X'iY'i - \sum_{i=1}^{n} X'i \sum_{i=1}^{n} Y'i/n}{\sum_{i=1}^{n} X'i^2 - (\sum_{i=1}^{n} X'i)^2/n}$$

$$\overline{X}' = \frac{\sum_{i=1}^{n} X'i}{n}$$

Since $Y' = \ln Y$, Y can be obtained from the relation:

$$\ln Y = (a' - b\overline{X}') + bX' = \ln a + b \ln X$$

$$Y = e^{a} X^{b}$$

With this general equation the equations for the curves were obtained. In figure 11, the equation of the curve is given as

$$\overline{W} = 0.0163G^{2.353} \qquad (9)$$

where $\overline{W}$ = flow rate and is equivalent to Y in the general equation

0.0163 = the intercept and is equivalent to "a" of the general equation

G = the gate setting and is equivalent to X

2.353 = the slope and is equivalent to b in the general equation.

And for the curves in figure 12, the equations of the curve for each of the three speeds was found using the relation:

$$\overline{W}_{\overline{R}} = f(G)$$

where $\overline{W}$ = the flow rate

G = gate setting

For each speed:

$$\overline{W}_{\overline{R}1} = a_1 G^{n}$$

$$\overline{W}_{\overline{R}2} = a_2 G^{n}$$

$$\overline{W}_{\overline{R}3} = a_3 G^{n}$$

where $\overline{R}_1$ = constant speed of 25 rpm

$\overline{R}_2$ = constant speed of 30 rpm

$\overline{R}_3$ = constant speed of 35 rpm

n = slope of each curve

a = the intercept for each curve

Final evaluation by least square method yields:

$$\overline{W}_{R_1} = 0.0132G^{2.394} \quad (10)$$

$$\overline{W}_{R_2} = 0.0163G^{2.367} \quad (11)$$

and $$\overline{W}_{R_3} = 0.0199G^{2.311} \quad (12)$$

The usefulness of this equation arises from the fact that at each speed of operation, the flow rate can be obtained for any gate setting by the farmer, within the range experimented with. For example, assuming that a farmer desires to set the gate to 42, the anticipated flow rate in Kg./hect. at a speed of 25 rpm equals

$$\overline{W}_{25rpm} = 0.0132(42)^{2.394}$$

$$= 0.0132(7692.346)$$

$$= 101.54 \text{ Kg./hect.}$$

This same flow rate is obtained by reading directly from the graph in figure 12.

Looking through table 1, one observes that the mean square values for speed and gate opening are much higher than that for any other parameter or interacted parameters. It can also be observed that the mean square value for gate opening is greater than that for speed. This fact was further justified by the closeness of the curves in figure 9 and 12 to one another.

To further convey the fact that the flow rate is a function of both speed and gate setting, a more refined function and equation were developed as shown below:

$\overline{W} = f(R,G)$ where R = speed of operation

G = gate setting.

From equations (2), (3) and (4), the values of "a", the intercepts were plotted against the speeds as shown in figure 14. The equation of the curve in figure 14 is

$$a = a' + b(R) \qquad (13)$$

Substituting this into the previous general expression, $W = aS^n$ we have:

$$\overline{W} = \left[a' + b(R)\right] G^n \qquad (14)$$

where a' = intercept of the curve in figure 14

b = the slope of the curve in figure 14

R = specified speed of operation

G = gate setting for specified speed

n = average slope of the curves in figure 12 and numberically equal to 2.354.

Constants a' and b can be readily found since b is the slope of the linear curve and a' is a known value for each specified speed. Values for a' and b can also be obtained by method of least square.

If these values are substituted into equation (14) the flow rate at any gate setting and specified speed can be calculated.

The significance of this refined equation is that it gives the flow rate as a function of both speed and gate setting in one expression.

In analysing the results for power determination, the horsepower required to push the machine was significantly higher than Hopfen (1960) suggested for man powered machine, under continuous working condition.

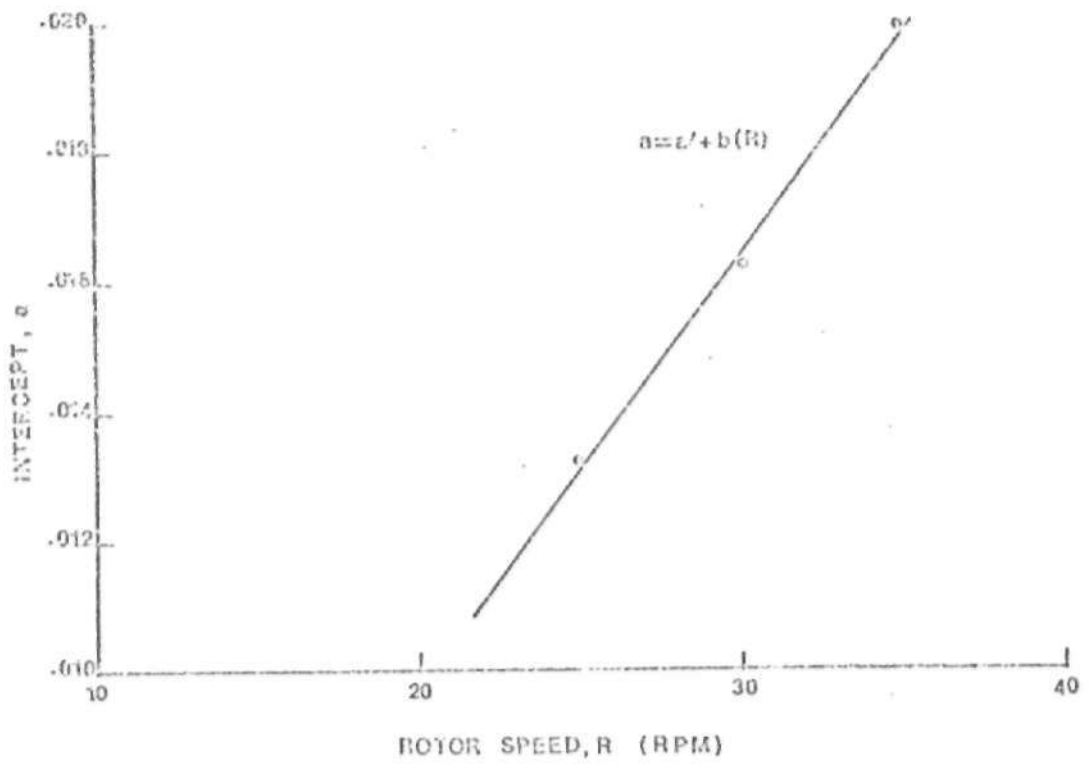


Fig.14. Curve For Refined Flow Rate Equation.

Using the mechanical power equation (eq.(4)) and the calibration curve (fig. 6), horsepower required to push the machine was calculated to be 0.387 and that to pull it was found to be 0.329. The difference between the two arises from the fact that the foward push had a tendency to cause the rear wheels and shovels to sink a little bit more into the soft soil whereas the front pull counteracts this tendency by the forward and upward movement of the wheels and the shovels.

According to Hopfen, a man working continuously can only develop one-tenth horsepower. This casts some doubt as to the ability of any man to push this machine for a prolonged period of time. For large size farms, a more appropriate means of operating the machine would be by animal power.

Hopfen stated that the average draft of an animal is about 15 percent of its weight. Appendix A shows that a bullock with an average weight of about 700 kilograms can develop about 0.75 hp when walking at a speed of 0.6-0.85 meters per second. These facts make bullocks very suitable working animals.

The estimated cost of building this machine is $300. (N187.5). This cost can be further reduced by mass production of the final design of the machine.

SUMMARY AND CONCLUSIONS

From this study, it can be inferred that the calibration of fertilizer machine is of great importance to ensure desired application rates. The speed of travel and the gate opening were the two parameters that greatly influenced the flow rate of the material from the hopper. The rotor blades' clearance prevents any gravity feed of the material.

Three speeds (25, 30 and 35 rpm) were used for operating the machine, and, with eleven different gate openings, the machine was calibrated for its flow rate in the laboratory. The outcome of the statistical analysis of the data were presented in graphical form and discussed under results.

Field determinations of the draft and horsepower requirements of the machine gave a good indication as to how the machine should be powered--man power or animal power.

Therefore, based on the results obtained from this experiment, the following pertinent conclusions can be drawn:

1) The rotor speed and gate opening were the two parameters that greatly influenced the rate of flow of the material out of the hopper.
2) As the rotor speed was increased, the flow increased but at a decreasing rate for each gate setting.
3) The depth of the material in the hopper had no influence on the flow rate as long as there was enough to be metered during each trial.

4) The close clearance of the rotor blades to the hopper side walls prevented any possible gravity feed of the material.

5) The horsepower output during this investigation was so high as to make continuous or prolonged operation of the machine by human effort undesirable.

6) The high horsepower required to operate the machine tends to favor the use of an animal as the source of power to drive the machine wherever this is possible.

7) The cost of building this unit is slightly higher than expected but can be reduced considerably by mass production of the final design.

SUGGESTIONS FOR FUTURE WORK

Since the draft and horsepower requirement of the machine are higher than anticipated, future work should investigate if using lighter material for the framework could reduce these factors to a desirable level.

Attempts should be made to verify if wider pneumatic rubber tires for the rear wheels would improve on its floatation and consequently make the machine more maneuverable.

The possibility of driving the metering unit off the front wheel should also be investigated. By so doing, the casters in the front would have to be replaced by a regular wheel. this is aimed at eliminating any side draft on the machine. The likely problem such an attempt might pose would be how to stop the metering action at the end of a row. This could be overcome by raising the front wheel off the ground and using the two rear wheels for the turn around.

It should also be investigated if modifying the machine to a one row applicator could reduce its horsepower requirement and its over all cost.

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APPENDICES

APPENDIX A

Normal draft power of various animals.*

Animal	Average Weight	Approximate Draft	Average Speed of Work	Power Developed	Horsepower
	Kilograms		m/sec	Kgm/sec	HP
Horse (Light)	400-700	60-80	1.0	75	1.0
Bullock	500-900	60-80	0.6-0.85	56	0.75
Cow	400-600	50-60	0.7	35	0.45
Mule	350-500	50-60	0.9-1.0	52	0.70
Donkey	200-300	30-40	0.7	25	0.35

*Taken from Farm Implements for Arid and Tropical Regions. FAO Agricultural Development Paper no 67.

APPENDIX B

Mean values of flow rate in kilogram per hectare for the three speeds and different hopper heads.

Speed (RPM)	Head	
	Hopper nearly full	Hopper nearly empty
25	219.140	221.630
30	234.016	233.262
35	237.144	237.743

APPENDIX B (continued)

Mean values of flow rate in kilogram per hectare for each gate opening over all speeds and hopper heads.

Gate Setting	Gate Opening ($cm.^2$)	Flow Rate (Kg/hect.)
30	.258	49.018
35	.387	71.320
40	.516	97.390
45	.645	125.438
50	.774	164.394
55	.903	205.578
60	1.032	252.300
65	1.161	303.814
70	1.290	364.082
75	1.419	437.696
80	1.548	464.348

APPENDIX B (continued)

Mean values of flow rate in kilogram per hectare for each speed and each gate opening.

Gate Setting	Gate Opening ($cm.^2$)	Speed (RPM)		
		25	30	35
30	0.258	45.338	49.560	52.156
35	0.387	67.336	70.930	75.694
40	0.516	89.590	100.255	102.323
45	0.645	118.282	128.308	129.726
50	0.774	157.554	166.237	169.392
55	0.903	196.346	205.875	214.512
60	1.032	240.106	256.827	259.969
65	1.161	294.287	307.369	309.788
70	1.290	362.423	362.774	367.048
75	1.419	421.379	445.268	446.443
80	1.548	431.594	476.623	484.828

APPENDIX B (continued)

Mean values of flow rate in kilograms per hectare for the three speeds at each gate opening and different hopper heads.

Gate Setting	Gate Opening ($cm.^2$)	25 RPM		30 RPM		35 RPM	
		Nearly Full	Nearly Empty	Nearly Full	Nearly Empty	Nearly Full	Nearly Empty
30	0.258	44.191	46.485	50.034	49.085	51.174	53.139
35	0.387	66.025	68.648	71.599	70.262	74.896	76.691
40	0.516	87.900	91.281	100.360	100.151	102.687	101.959
45	0.645	116.093	120.471	127.708	128.907	129.580	129.871
50	0.774	156.480	158.628	167.640	164.834	169.829	168.955
55	0.903	194.708	197.984	204.220	207.531	213.975	215.048
60	1.302	239.034	241.178	257.015	256.638	259.474	260.464
65	1.161	292.927	295.647	308.761	305.977	310.248	209.328
70	1.290	362.751	362.094	363.349	362.198	367.119	366.977
75	1.419	420.441	422.317	446.796	443.740	445.200	447.685
80	1.548	429.991	433.196	476.692	476.554	484.598	485.057

APPENDIX C

Draft Measurement

Test No	Trial	Hopper Head	Shovel Depth (cm.)	Time (min.) for 100 ft.	Pressure, (psi)
1	Push	Full	3.81	0.56	22
2	Push	Full	3.81	0.515	24
3	Push	Full	3.81	0.63	30
4	Push	Full	3.81	0.60	30
5	Push	Full	3.81	0.58	42
6	Pull	Full	3.81	0.61	40
7	Pull	Full	3.81	0.65	40
8	Pull	Full	3.81	0.62	38

DESIGN OF FERTILIZER APPLICATOR FOR SMALL SCALE FARMING UNDER NIGERIAN CONDITIONS

by

KAYODE CARROLL ONI

B. Sc., Ahmadu Bello University, Zaria, Nigeria, 1971

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1974

ABSTRACT

The objectives of this study were a) to design a simple and relatively inexpensive fertilizer machine applicable to Nigerian Agriculture, b) to calibrate such machine to apply desired rates of fertilizer per hectare, and c) to investigate if the machine can be powered by man or animal by determining its horsepower requirement.

The metering action of the designed machine was controlled by a rotor. The rotor has five blades equally spaced around the pentagonal rotor shaft which has been machined to a circular shaft where it traverses the hopper walls. Fertilizer was metered through two gate openings in the "U" shaped hopper bottom. The size of each opening was varied by another "U" shaped slider. The rotor shaft was connected to the sprocket shaft with cotter pins and driven by a detachable link chain. The other sprocket was mounted on the axle of one of the rear wheels. Three operational speeds (25, 30 and 35 rpm) were chosen for the rotor shaft and the eleven different gate openings were selected by using the gate settings (numbers) on the cam mechanism of the metering unit.

The flow rate determination was carried out in the laboratory using an electric motor that has been geared down to 30 rpm to drive the rotor shaft. The flow rate data collected for each of the three speeds over all gate openings were analysed statistically, the outcome of which has been presented graphically. The results of this study showed that speed and gate opening were the two parameters that greatly influenced

the flow rate. The effect of head of the material in the hopper was relatively insignificant as shown by the mean square values in table 1 and figure 13.

The mechanical power requirement of the machine was also investigated. It's draft and horsepower requirement were measured in the field using a hydraulic cylinder whose pressure gauge readings had been previously calibrated in the laboratory. The maximum horsepower required to push or pull the machine was obtained by filling the hopper completely with fertilizer, setting the furrow openers to a depth of 3.81 cm., and setting the furrow closing device in place. From this field determination, it was discovered that the horsepower required for either the push or pull test was three times higher than that suggested by Hopfen (1960) for man power. They were, however, within the range of that for animal power.

Based on the results obtained, it was suggested that future work should include using lighter material for the framework of the machine, using wider tires on the rear wheels, and driving the metering unit from the front wheel to overcome any possible side draft.