Design of a Banana Fertilizer Applicator

Submitted by

Lael Parrott

Dept. of Agricultural Engineering
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ABSTRACT

The present method of applying fertilizer in small holding banana plantations in St. Lucia is to scatter the granules on the soil surface at the base of each plant. This method results in excessive materials wastage and water pollution, as much of the fertilizer is washed away by rain. As a solution to this problem, an implement to insert a metered amount of granular fertilizer beneath the soil surface at the base of a banana plant was designed. The implement is manually operated and uses an auger to feed fertilizer from the base of a backpack into a shaft leading to the tip of a shovel. The design presents a promising alternative to the existing situation, and it is recommended that its full potential be evaluated through construction and testing of a prototype in St. Lucia.

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INTRODUCTION

The customary method of fertilization in small holding banana plantations in St. Lucia is to scatter a fistful of granular fertilizer on the ground at the base of each plant. A considerable amount of fertilizer is subsequently washed away by precipitation, resulting in higher material costs and excessive water pollution. It is believed that if the granules were to be inserted below the soil, the same amount of nutrient could be supplied to the plant by applying a smaller amount of fertilizer (Figure 1). In this manner, both the production cost and water pollution could be reduced. Although deposition of the fertilizer below the soil could be done manually with a shovel, the use of a specialized applicator to mechanize the metering and insertion process would greatly reduce labour and increase overall efficiency. The design of such an applicator presents an interesting materials handling problem due to the inconstant characteristics of granular fertilizer.

Chemical fertilizers must be water soluble in order to become available to the plants, and consequently have a tendency to absorb moisture from the atmosphere, with an ensuing change in physical properties, usually becoming more difficult to spread. The hygroscopicity of the fertilizer being handled will influence the internal cohesiveness of the material, causing it to lump and bridge across orifices. This tendency to cake causes numerous material handling problems, as flow of fertilizer from an orifice can only be ensured with auxiliary equipment (Klenin et al, 1986; Richey, 1961). The difficulties with spreading granular fertilizers are exacerbated in the very humid tropic and sub-tropic regions where most banana plantations are located. Sims, Jimérez and Aragón (1989), after testing various applicator designs in Mexico, stated that "at times it is impossible to continue field application of

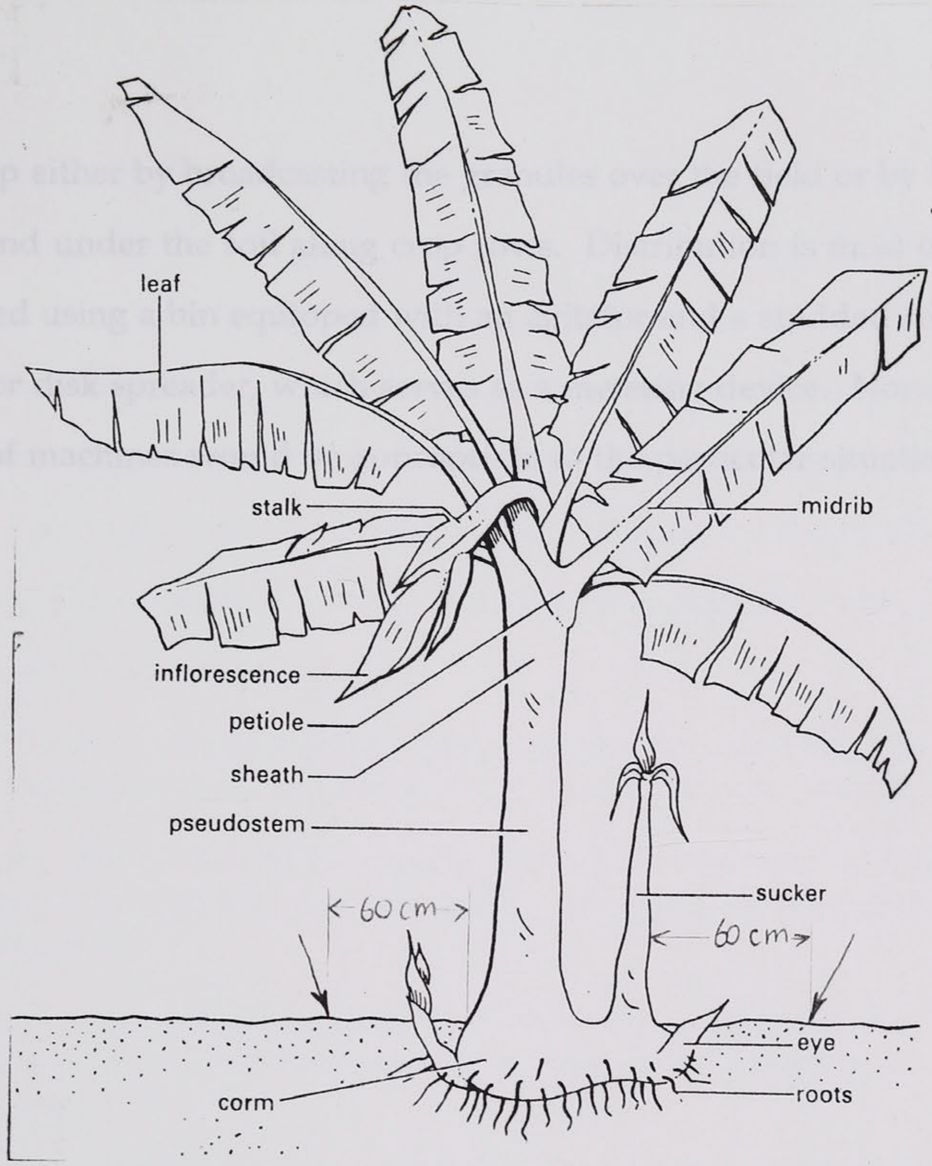


Figure 1: *Diagram of a typical banana plant, showing points of fertilizer application.* (Reproduced in part, from Hugues, 1987)

hygroscopic products even though on opening the bag the fertilizer is free flowing". They concluded that, of all the machines tested, the best was one designed by the International Institute for Tropical Agriculture (IITA) in Nigeria, which used an auger distribution mechanism that also acted as an agitator to prevent bridging of moist fertilizers.

Although many types of fertilizer distributors are in use, no methods of discharging a uniform volume of granular fertilizer at the base of a large plant or tree have been documented. Most fertilizer applicators are designed to deliver a specified mass flow rate that is a function of the forward speed of the machine. In this manner, the required kg/ha of nutrients is supplied to the crop either by broadcasting the granules over the field or by laying them in a band under the soil along crop rows. Distribution is most commonly achieved using a bin equipped with an agitator and a studded roller, rotating plate, or disk spreader, which serves as a metering device. None of these types of machines would be appropriate to the particular situation at hand.

OBJECTIVE

The objective is to design an implement that will facilitate the deposition of granular fertilizer below the soil surface at the base of a banana plant. The implement will be specifically targeted for use in small holding banana plantations in St. Lucia. The following considerations must be integral to its construction:

- Because a steady energy supply cannot be guaranteed, the implement must not require fuel or electricity to operate.
- The device should be rugged and involve minimal maintenance, hence component parts should be corrosion resistant and easily cleaned.
- Since one of the intents of the procedure is to reduce production costs, the expected purchase price of the applicator should be as low as possible.
- The applicator should include a metering device that is capable of pulverizing lumps and that delivers the required dose of fertilizer per plant in two shots (one for each side of the plant).
- The design should be in keeping with the physical properties of the fertilizer.

PROCEDURE

In accordance with the above discussion, it can be seen that the design should contain certain basic components, namely: a) a knapsack or other container to carry the contents of a 25 kg bag of fertilizer; b) a metering mechanism; c) a spade of some sort to break open the soil surface, and d) a shaft or tube through which fertilizer can flow from the container to the tip of the spade. Of the many possible designs, three alternatives are considered in detail below.

The first alternative is one that has already been designed and built by a worker in St. Lucia. The implement is sketched in Figure 2. Metering of the

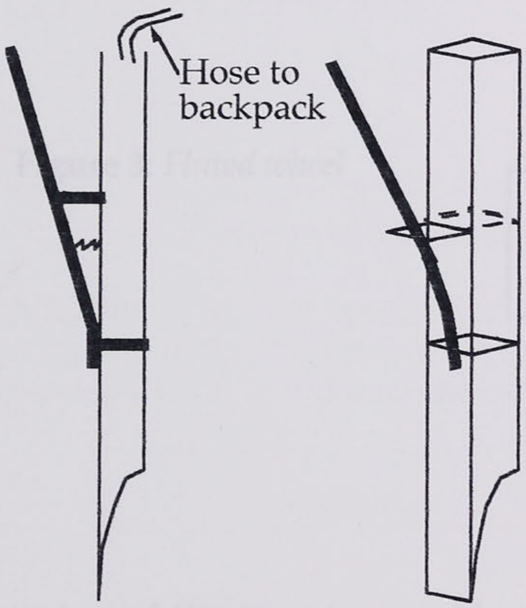


Figure 2: *Sketch of the design which has been tested in St. Lucia*

fertilizer is attained by using the two valves, which alternate positions, and fertilizer continuously fills the hose from the backpack to the shaft of the shovel. Although, in principle, the design provides a delightfully simple solution to the problem, its faults very quickly became apparent in field tests. The hygroscopicity of the fertilizer prevents it from flowing freely down the shaft, so that the operator must continuously shake and prod the mechanism to force the fertilizer to fall. The smaller particles cake along the sides of the tube and shaft, and lumps form that cannot be broken up. Given the poor success of this implement, it has been concluded that any new design should incorporate a metering mechanism at the base of the backpack, so that only a small amount of fertilizer be required to fall through the distribution tube and down the shovel at any one time.

Two potential backpack meters were considered. The first was a simple fluted wheel that would hold the desired volume of fertilizer in each indentation (see Figure 3). The wheel would be located at the base of a rigid

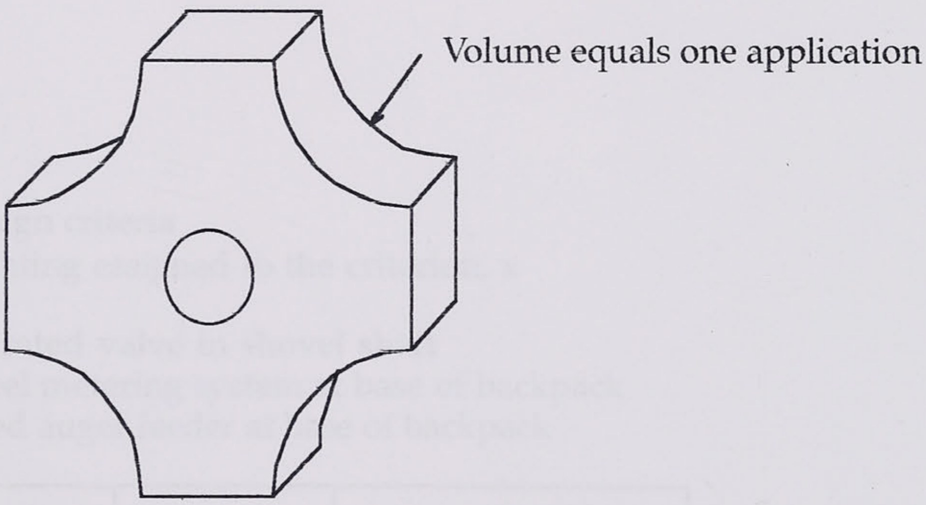


Figure 3: *Fluted wheel*

pack, and the operator would release the desired amount of fertilizer simply by turning the wheel a quarter turn. This alternative was rejected because it was uncertain whether the wheel would be able to provide sufficient agitation without being operated in conjunction with some other kind of agitator. The second metering alternative was to locate a long feed auger along the base of the pack. Operation of this meter would be similar to that for the fluted wheel, i.e. the worker is expected to turn a handle to deliver the required amount of fertilizer into the feed tube to the shovel. It was hoped that the large size of such an auger relative to the volume of the pack might provide sufficient agitation to prevent any bridging.

The three alternatives are compared quantitatively in Table 1: *Selection of Optimal Design.* The expected "success" criterion is a subjective value that incorporates the overall probability of the acceptance of the machine by banana plantation holders according to how effectively it will work. Although durability and operation time are important design criteria for the

Table 1 *Selection of Optimal Design: The totals shown in the table were determined using the criterion function. Values of a_i and x_i were selected arbitrarily.*

CRITERION FUNCTION:

$$CF = \sum x_i a_i$$

where: x_i = weight of design criteria
a_i = relative weighting assigned to the criterion, x

Alternative 1: Spring operated valve in shovel shaft
Alternative 2: Fluted wheel metering system at base of backpack
Alternative 3: Hand turned auger feeder at base of backpack

CRITERIA	WEIGHT	ALTERNATIVES		
		A1	A2	A3
Agitation	0.25	0.2	0.45	0.8
Accuracy in metering	0.25	0.9	0.85	0.8
Ease of operation	0.2	0.7	0.6	0.6
Cost to build	0.1	0.9	0.65	0.65
Expected "success"	0.2	0.4	0.6	0.8
TOTALS	1	0.585	0.63	0.745

banana fertilizer applicator, they were not added to the criterion function because it was felt that each alternative deserved an equal score on those counts, and that therefore, comparison on that basis would yield no useful conclusion. It can be seen that, although Alternative 1 received high scores for cost and accuracy of the metering system, it fared poorly with respect to agitation and overall success. Alternative 3 is seen to be the optimal design, leading Alternative 2 mostly due to increased agitation by the auger.

RESULTS

The contraption (refer to Figures 4, 5 & 6) consists of an aluminum hopper with a stainless steel feeder auger that is manually driven at one end by a rotating handle and which discharges one half-dose per turn out a circular orifice at the opposite end. From the orifice, the fertilizer flows through a connecting hose and then down a cylindrical shaft into a hole made by a spade. The hopper can be mounted onto a rigid backpack frame so that the drive handle is conveniently located by the right arm and the hose leads out the left side to a shovel held in the left hand. Existing backpack frames are manufactured so that the hopper can be mounted with several inches of clearance between the operator's back and the side of the hopper, and the height can be adjusted with proper settings of straps. A hip belt can be used to reduce the weight strain on the spine. With this type of arrangement, any worker will be able to comfortably carry the weight of a full hopper (approximately 30 kg).

The hopper and chain guard should be constructed from aluminum sheeting with an approximate thickness of 2 mm (American or Brown & Sharpe Wire Gage 32 or 33). Aluminum was chosen over steel because it is lightweight and corrosion resistant. Plastic was considered as a possible construction material, but was rejected because of its tendency to crack, particularly if left out for long periods in the sunlight. In addition, the coefficient of friction between fertilizers and aluminum is substantially less than that with plastics (see Hofstee, 1992).

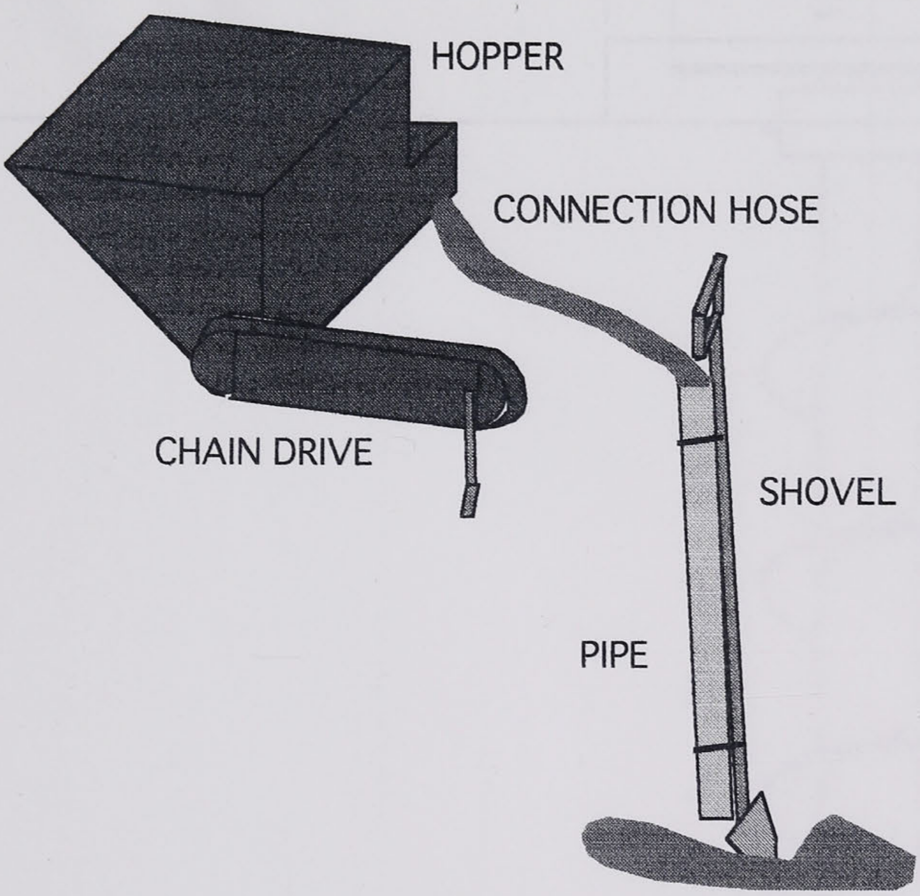


Figure 4: *Overall conceptual design: The operator will wear the hopper mounted on a backpack frame, hold the shovel in the left hand, and turn the auger with the right.*

The auger is a standard pitch, 500 mm long helical screw with a flighting diameter of 65 mm. The auger shaft has a diameter of 30 m and is mounted on bearings at each end. Bearing seals should be used to keep dust and fertilizer granules out of the bearings. The auger is mounted in a U-shaped trough, with a clearance of 2.5 mm between the flightings and the trough walls (based on an average particle diameter of 3 mm).

The torque involved in turning the loaded auger is estimated to be less than 2.5 N-m (see Appendix), which means that, maximally, a force of 10-15 N would be required to turn the operating handle. A movement requiring such a force can be easily repeated many times a day by the average human operator. Since the forces involved are not excessive, and the mechanical

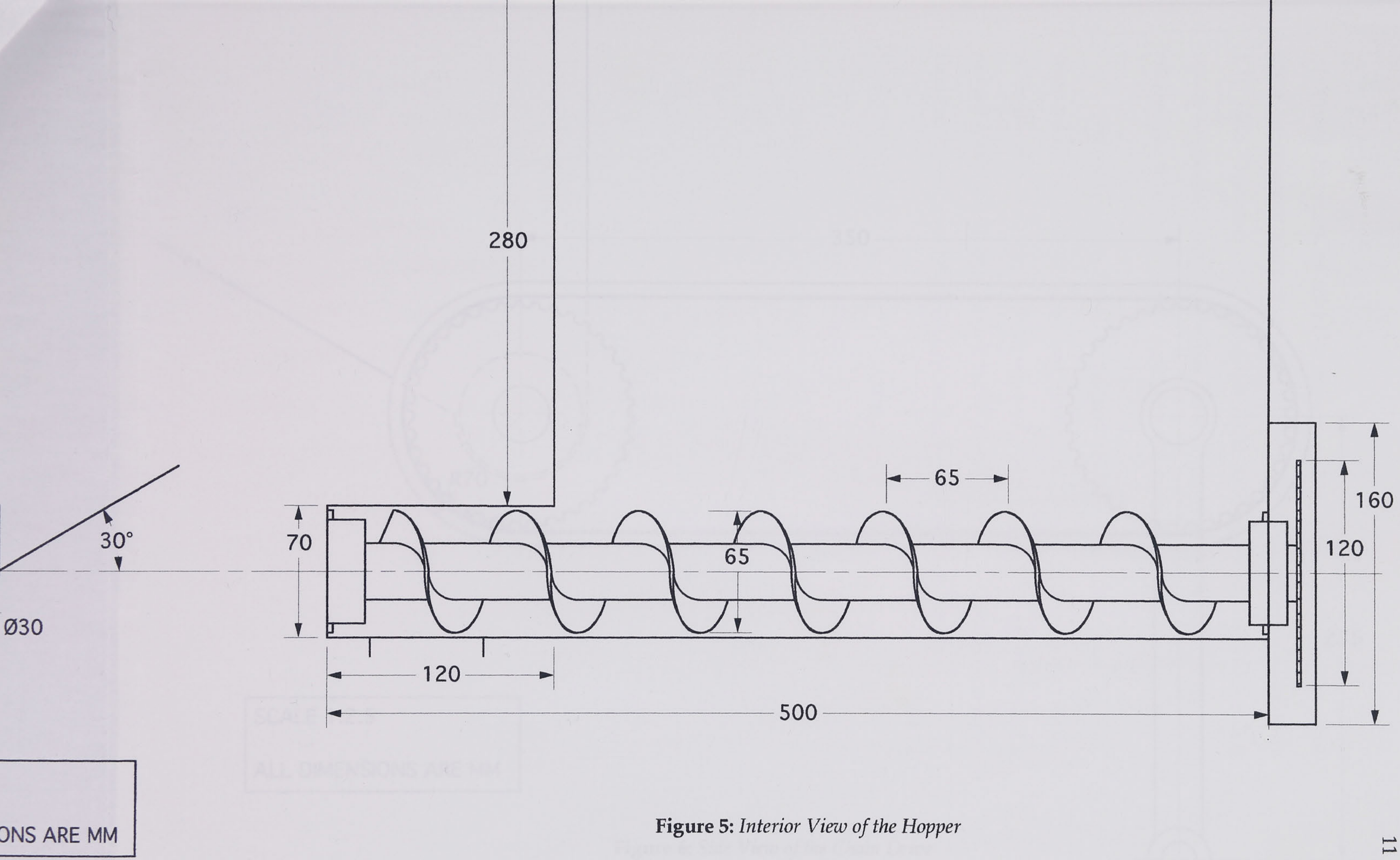
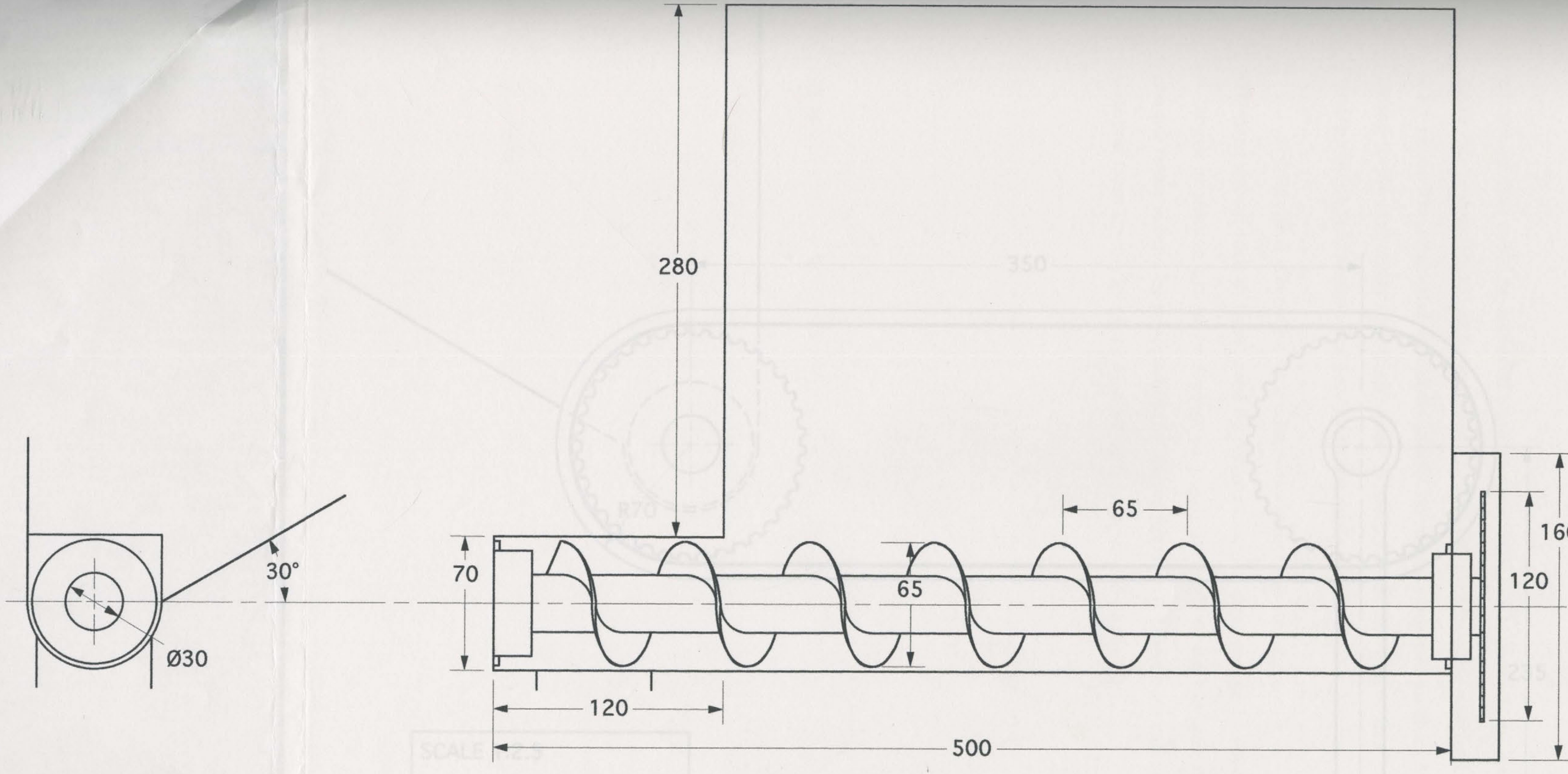


Figure 5: *Interior View of the Hopper*



SCALE 1:2.5

ALL DIMENSIONS ARE MM

Figure 5: *Interior View of the Hopper*

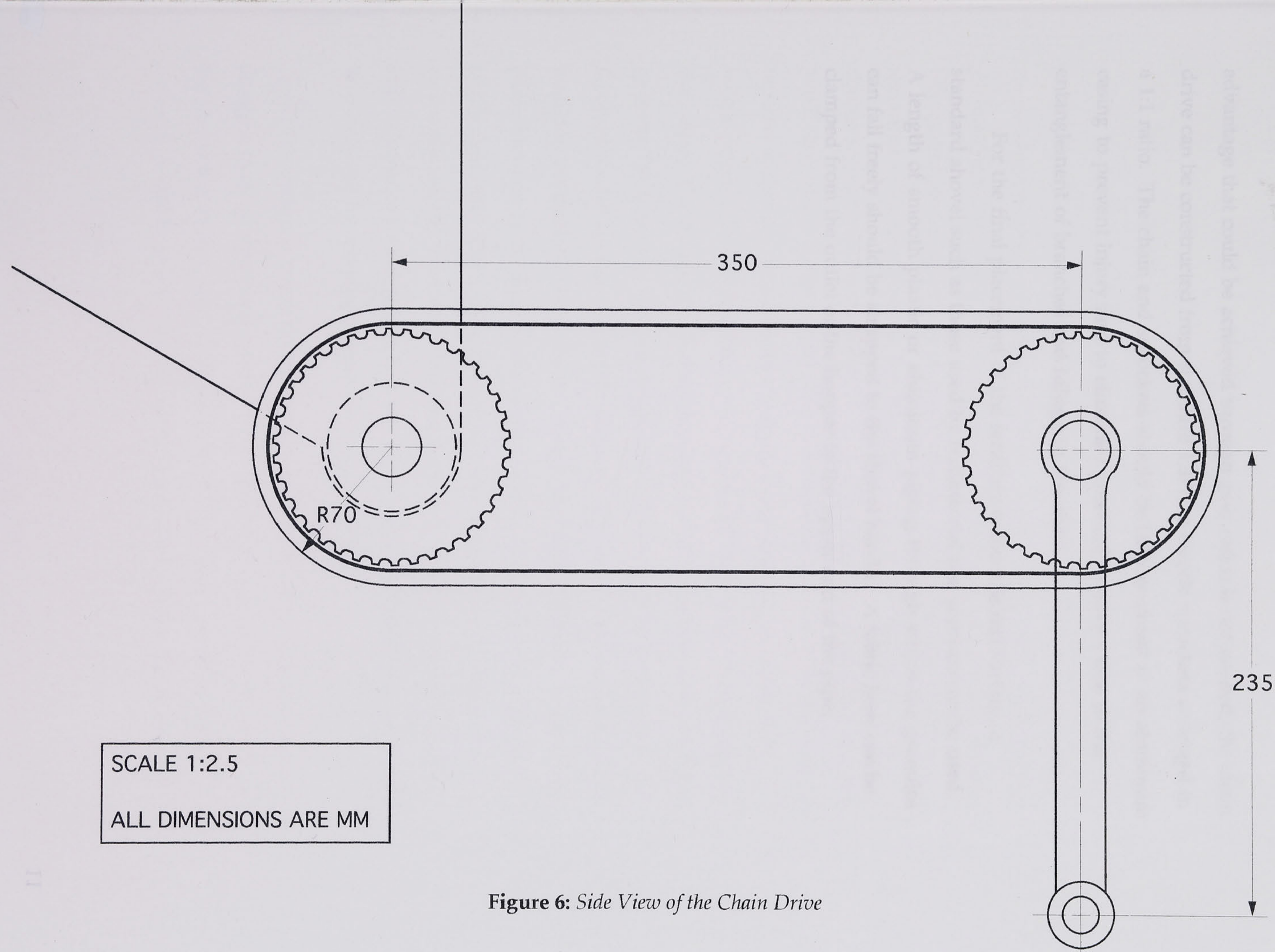


Figure 6: *Side View of the Chain Drive*

advantage that could be achieved through gear ratios is not needed, the chain drive can be constructed from standard 120 mm bicycle sprockets arranged in a 1:1 ratio. The chain and sprockets should be fully enclosed in an aluminum casing to prevent injury and to eliminate potential problems due to the entanglement of branches and foliage in the chain.

For the final placement of the fertilizer below the soil surface, a standard shovel such as those used by commercial tree planters can be used. A length of smooth plastic or aluminum piping through which the granules can fall freely should be strapped to the shovel handle. A fabric hose can be clamped from the outlet of the hopper to the upper end of the pipe.

DISCUSSION

The drawings appear to represent a feasible solution to the problem at hand. It would be useful to build a prototype in order to better evaluate the potentials of the implement. Should a prototype be built, there are a couple items which might be investigated further in order to optimize operation of the machine. The first is the choice of auger type. In most agricultural feeder bin applications, a tapered or stepped diameter screw is used to ensure a smoother unloading process. For this application, a standard screw was chosen instead because it was felt that the short length of the hopper and the small scale of the design would not merit a specialized screw. In addition, the tapered screws are considerably more expensive than the standard pitch helical screws. The second item to be considered also concerns the design of the auger. The trough size is dimensioned to allow for a clearance of 2.5 mm between the flightings and the trough wall. This is slightly smaller than the fertilizer's estimated mean particle diameter of 3 mm. When augering a material, the clearance between the trough and the flightings is a very critical parameter and performance tests of the fertilizer applicator may suggest a better clearance. This tight clearance was chosen based on the range of clearances usually used when augering fertilizer. It was also felt that such a small clearance would ensure that any large lumps reaching the auger would be pulverized by scraping against the trough walls.

The design is based on estimated values of fertilizer properties and dosages, most of which were provided by the people who presently work on the plantation in St. Lucia. Although these values may indeed be fairly accurate, it would be advisable to verify them before continuing further to ensure the correctness of the design. Since the auger is designed to deliver one half dose per turn, changes in application rate or fertilizer density would have a considerable influence on the overall effectiveness of the metering system. Minimally, a particle size analysis and a density test should be performed under similar climatic conditions to those encountered during application.

CONCLUSIONS

1. The fertilizer applicator meets all of the design objectives; it is a simple, manually operated machine that should be capable of effectively inserting fertilizer below the soil surface.

2. A feeder auger appears to be the most effective method of providing a specific volumetric quantity of fertilizer while maintaining a manageable product. Rotation of the auger will not only pulverize any clumps that form due to moisture, but should also provide sufficient agitation to prevent bridging in the hopper.

3. After verifying the design with experts in the field and making any recommended adjustments, it would be profitable to build and test a prototype.

APPENDIX

Calculation of Fertilizer Dosage

Given: 1 dose is approximately 0.5 lb.
each plant receives one-half dose in 2 locations around the base

0.5 lb/dose * 0.4536 kg/lb = 0.2268 kg/dose

0.2268 kg/dose * 1/2 = <u>0.1134 kg per application</u>

A density of 880 kg/m^3, as per Agriculture Canada Handbook (1989) ammonium sulfate, is assumed for the fertilizer.

Calculation of Auger Flighting Diameter

The desired flighting diameter can be calculated using the following formula:

$$d = \sqrt[3]{\frac{4T}{k\pi nb}}$$

where

d = screw diameter (m)
T = application rate (kg)
k = loading factor (0.3-0.75)
n = number of revolutions per application
b = fertilizer bulk density (kg/m^3)

(Agriculture Canada, 1979)

As the auger is operating as a feeder, and can be assumed to always be buried in fertilizer, a loading factor of 0.75 is chosen, which allows space for the auger shaft and flightings.

Thus,

$$\sqrt[3]{\frac{4(0.1134kg)}{(0.75)\pi(1)(880kg/m^3)}} = 0.06025m = 60.25mm$$

A value of 65 mm is chosen for good measure.

Volumetric Capacity

A radial speed of one turn per 2 seconds is assumed.

$$0.1134\frac{kg}{turn} * \frac{1}{880\frac{kg}{m^3}} * 0.5\frac{turn}{s} = 6.443 \times 10^{-5}\, m^3/s$$

Estimation of Torque Required to Turn the Auger

It is exceedingly difficult to calculate an accurate estimate of the power required to auger a material, particularly fertilizer, as most analytical equations are derived based on the performance of non-cohesive materials such as dry agricultural grains. Srivasta et. al state that, "[t]he process of conveying by a screw conveyor is a complex process. It is difficult to develop analytical models to predict volumetric capacity and power requirements without making overly simplified assumptions. Purely empirical models, on the other hand, are not general enough in nature and can not be used to predict auger performance in a variety of applications"(p. 510). Srivasta et. al do, nevertheless, give a general equation for estimating conveyor performance that was developed empirically using published data for auger feeders conveying wheat, oats, and shelled corn. It is used here to give a general estimate about the behaviour of the fertilizer applicator.

$$P = 64.32\left(\sqrt{\frac{l_p}{g}}\right)^{0.18}\left(\frac{d_{sf}}{l_p}\right)^{-9.02}\left(\frac{l_i}{l_p}\right)^{0.29}[f(\theta)]^{0.35}(\mu_1)^{1.62}(\mu_2)^{2.08}Q\rho_b gL$$

where

l_p	=	pitch length (m)
d_{sf}	=	flighting diameter (m)
l_i	=	screw intake length (m)
$f(\theta)$	=	$0.0223\exp(0.068\theta) + 0.342$
θ	=	conveyor angle measured from the horizontal (degrees)
Q	=	volumetric capacity (m^3/s)
r_b	=	bulk density (kg/m^3)
L	=	screw length (m)
g	=	acceleration due to gravity (9.81 m/s^2)

$0.414>\mu_1>0.374$ material-metal friction

$0.532>\mu_2>0.466$ material-material friction

Thus, the required torque can be calculated as:

$$64.32\left(\sqrt{\frac{0.065}{9.81}}\right)^{0.18}\left(\frac{0.065}{0.065}\right)^{-9.02}\left(\frac{0.38}{0.065}\right)^{0.29}(0.3643)^{0.35}(0.374)^{1.62}(0.532)^{2.08}$$

$$\left(6.443\times10^{-5}\right)(880)(9.81)(0.5) = 0.73\,N\cdot m$$

Based on this torque value, the force required to turn the 23.5 cm handle on the chain drive would be only 3 N. If allowances are made for possible inaccuracies due to errors in the constants used, and bearing friction is considered, the maximum force would still only be about 10 N.

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