Development of Indigenous Fertilizer Applicator for Row Crops - Part I

By

Tanam U. I.
isaactanam@yahoo.com

Department of Agricultural and Biosystem Engineering, University of Ilorin, Ilorin - Nigeria

ABSTRACT

Transforming the agricultural sector of the Nigerian economy requires the development of local technology to boost food production. Among Nigeria peasant farmers, granular fertilizer is most commonly applied to farms to increase yield. Manual labour, employing hand placement, was most common among them. This is partly due to the high of cost agricultural machineries and partly to their sophistication. This paper therefore wasfocused on the design of a fertilizer applicator that is cheap, simple and can be operated without the requirement of any special training or expertise. Four types of fertilizers, Nitrogen Phosphorus Potassium (NPK), Single Superphosphate (SSP), Calcium Ammonium Nitrate (CAN), and Urea, with average bulk density of 957.83kg/m^3, were considered in this design. The machine, with a field capacity of 0.21ha/h while operating at a speed of 3.5km/h, wasoperated by pushing by the handle and has variable rate of application ranging from 80kg/ha to over 250kg/ha.

1.1 INTRODUCTION

The population of Nigeria is growing at the rate of about 3.2% (Kumolu, 2011). The implication of this is that more land has to be developed for shelter purposes, thereby reducing the little land available for agriculture, yet more food has to be produced to feed the ever-growing population. Since farmable land cannot be increased, there is the need for maximized use of the little available through maintenance of soil fertility.

In a bid to produce more food for the large populace of Nigeria, lands have been under continuous cultivation for several year. This has led to the rapid decrease of plant nutrient and a consequent decrease in farm productivity. Fertilizers have been known to contribute to the maintenance of soil fertility, and have therefore attracted the attention of governments at all levels.

Fertilizer is defined by Cooke (1981) as any substance added to the soil to provide one or more of the chemical elements essential for plant nutrition. Tisdele and Nelsen (1975) added that fertilizer could be organic, inorganic or synthetic. Two major types a fertilizer are in common use in Nigeria, namely phosphate fertilizer and nitrogenous fertilizers. DeGeus (1973) Divided nitrogenous fertilizer into four groups.

1. Ammonium fertilizers: those that contain their nitrogenous in NH_4 form.
2. Nitrate fertilizers: containing their nitrogenous in NO_3 form.
3. Nitrate fertilizers: contain their nitrogenous partly in NH_4 and partly in NO_3 forms.
4. Amide fertilizers: those whose nitrogen in broken down in the soil into NH_4 and eventually to NO_3, which is the form into which all form of nitrogenous fertilizers are broken for absorption by plants.

Fertilizers used in Nigeria are available in two states: Liquid and solid. The solid state fertilizers can be in powder, granular or pellet forms. Granular form of fertilizers are most common and are the easiest to apply.

1.2 METHOD AND RATE OF APPLICATION

Use of fertilizer to increase crop yield can only be made realistic if the correct rate is applied by the best method at the right time. Factors affecting rates of application include:

1. Kind of crop and stage of growth
2. Physical and chemical properties of the fertilizer
3. Amount of fertilizer actually required by the crop
4. Physical nature of the soil
5. Hydrogen ion concentration (PH) of the soil.

Broyer (1982) stated that there are basically two method of fertilizer application. These are bulk spreading and precision placement. Bulk Spreading involves broadcasting. This saves time and labour but wastes the material. Precision placement is placing the fertilizer in a precise manner in relation to the crop, thereby requiring more time and care. It however gives the expected increase in yield. Another common method used by most farmers is placing the fertilizer in bands or hills a few days or weeks after planting. This method is very effective since at this time, the plant would have germinated and proper spacing of fertilizer from crop can be achieved. DeGeus (1973) recommended band placement for row crops.

1.3 THE NEED FOR MECHANIZATION OF FERTILIZER APPLICATION

Machine application to agriculture has been one of the outstanding needs in Nigerian agriculture for many decades. Cultural methods have continued to dominate the application of fertilizer and most other farm operations. A review of some factors favoring the mechanization of fertilizer application in Nigeria show the following:

1. Intensive production of crop
2. Increase in farm size, beyond the labor capacity of farmer household
3. Growing shortage of hand labor
4. Overcoming perpetual labor bottlenecks
5. Overcoming drudgery involved in traditional methods

6. Attracting youths to the farm.

1.4 TYPES OF FERTILIZER APPLICATORS

Different types of machines have been used for fertilizer application, depending on the nature of the fertilizers. Fertilizers are available as liquids or solids. Liquid fertilizers are stored and handled under pressure in special cylinders. The rate of application is controlled by the size of nozzles and the gage vapor pressure. Most liquid applicators are engine powered.

Solid dry fertilizer applicators which are either motorized or manually operated can be placed into two categories.

1. Broadcasters
2. Drill or band applicators

1.5 FACTOR AFFECTING RATE OF DISCHARGE

Some applicators depend on the positive action of their metering devices in dispensing the fertilizer and partly on gravity. Gravity plays a major role in stationary opening arrangement (Kepner et-al, 1978). A major factor affecting application rate is the drillability of the fertilizer. Drillability is define by Mehvings and Cumings (1930) as the ease of flow of the material. Drillability is affected by the following factors:

1. Hygroscopicity of the fertilizer
2. Relative humidity of storage
3. Particle size and shape of fertilizer
4. Bulk density of the fertilizer
5. Kinetic angle a repose

1.6 DESIGN CONSIDERATION

The Essential requirement of all fertilizer applicators is uniformity of distribution over a wide range of conditions. Other factors considered in this design are

1. Cost,
2. Durability
3. Simplicity
4. Accessibility
5. Weight

2.1 MACHINE DESCRIPTION AND DESIGN

The machine which is made for granular fertilizers, is designed to be manually operated. It consists of the following parts: Frame, Handle, Hopper, Drive Wheels, Agitator, Rotor and delivery compartment.

The frame is made of 25mm x 25mm angle iron and gives support to the entire machine. The handle is made from 25mm diameter galvanized steel pipe. The machine is operated by pushing through the handle. See appendices A and B.

Two drive wheels are provided to support the entire weight of the machine. Apart from supporting the weight of the machine, the wheels produce the rotational motion for all moving parts of the machine. The wheels selected are 250mm in diameter and their distance apart can be adjusted to accommodate different crop row spacing. The circumference (Cw) of the wheel is 0.79m. This represents the horizontal distance traveled by the machine per revolution of the wheel. Number of revolutions per minute (N) of the wheel is given as

$$N = \frac{\omega}{2\pi} \qquad 1$$

but $$\omega = \frac{V_w}{R_w}$$

where ω = angular velocity, V_w = linear velocity, R_w = radian of wheel.

$$V_w = 0.79N \qquad 2$$

The rotor is the metering mechanism. It consists of eight 20mm x 169mm vanes attached perpendicularly on a 64mm diameter cylinder. The vanes are made from a gage 16 galvanized iron sheet. The theoretical capacity of the rotor is given by equation 3.

$$C_R = \left(A_{SV} - A_{SC}\right) \times L \times 8N_R \qquad 3$$

where C_R = Capacity of rotor

A_{SV}= Area of sector formed by the vanes at the centre of the rotor

A_{SC}= Area of sector formed by cylinder at the centre of the rotor

L = Effective length of vane

N_R = Rotational speed of rotor (rpm)

$$\therefore \quad C_R = 6.85 \times 10^{-3} N_R \qquad 4$$

Equation 4 shows that C_R a is function of N_R only and is directly proportional to the drive wheel speed (rpm).

The purpose of the agitator is to stir the fertilizer to prevent clogging due to its hygroscopicity. The design of the hopper allows free flow of material. ASABE (2004) specifies that hoppers shall be rated both volumetrically and gravimetrically. The average bulk density of the fertilizer considered in this design is 957.83kg/m^3. Since this is close the 1000kg/m^3 specified by ASAE (2004) for general purpose hoppers, this hoppers may be used for any type of fertilizer. The volumetric rating (V_h) of the hopper was found to be 2.055 x 10^{-2}m^3, while gravimetric rating (G_h) was 19.68kg. This represents the average mass of fertilizer that would fill the hopper. The hopper is provided with a cover to reduce moisture absorption.

2.2 POWER REQUIREMENT

Power, P, is defined as the rate of work

$$P = \frac{Work(W)}{Time(T)} \qquad 5$$

but Work = Force (F) x Distance (D),

$$\therefore P = \frac{F \times D}{T} \text{ but } \frac{D}{T} = Velocity(V)$$

$$\Rightarrow P = FV \qquad 6$$

From Newtons 2nd law of motion, F= ma

where m=total mass of machine with full hopper, estimated as 32kg

a = angular acceleration of machine wheel = $\omega^2 r$

$$\therefore \quad P = m\omega^2 rV \qquad 7$$

But $\omega = 2\pi N$

$$\therefore \quad P = m(2\pi N)^2 rV \qquad 8$$

From equation 2

V = 0.78N

P = m x 2π x N x V^2 = 125.44N^3 (Nm/min) = 125.44(N/60)^3 (Nm/s)

For most manually operated machines, speed varies from 0.8m/s to 1.5m/s. Using the upper limit, $N = \frac{1.15 \times 60}{0.79} = 87.34\ (rpm)$

At this speed, the maximum power required to push the machine on a flat level ground is 0.387KW

To compensate for

1. Frictional resistance at the bearings and chains
2. Force needed to move rotor vanes and agitator through the material
3. Resistance at the wheel as they move over rough terrain on the farm

a 15% factor of safety is added, bringing total power requirement to 0.445KW or 0.6hp. This is very adequate in view of human average power output of 0.8KW or 1.1hp.

The diameter of the main shaft is obtained from equation 9.

$$d = \left[\frac{16}{\pi BS} \left(\left(K_m BM \right)^{2\cdot} + \left(K_t TM \right)^2 \right)^{1/2} \right]^{1/3} \qquad 9$$

where

BS = Allowable bending stress for steel shafts. 40×10^6 N/m^2 is special by ASME

K_m = Combine shock and fatigue factor applied to bending moment for rotating shafts. 1.5-2.0 is specified.

K_t = Combine shock and fatigue factor applied to torsional moment. 1.0 - 1.5 is specified for sudden load shock.

BM = Computed maximum bending moment (Nm)

TM = Computed maximum torsional moment (Nm)

By considering the tension in chain drive and other loads on the shaft, TM was found to be11.61Nm. By drawing sheer force and bending moment diagrams, BM was found to be 8.52Nm. With these values determined, d was found to be 0.0142m or 14.2mm. With this known, the next standard shaft, 15mm, was selected for this design.

2.3 POWER TRANSMISSION

Power is transmitted from the ground wheel to various parts through chain drives. Approximate chain length is given as

$$L_c = 2C + \left(\frac{n_2 - n_1}{2}\right) + \frac{n_2 - n_1}{4\pi^2 C} \qquad 10$$

where

C = sprocket centre distance (in chain pitches)

n_1 = number of teeth on smaller sprocket

n_2 = number of teeth on larger sprocket

If the sprocket have teeth ratio of 1:1, then equation 10 reduces to

$$\mathbf{L_c = 2C + n}$$

Estimated centre distance = 155mm and sprockets have 24 teeth. The chains used are roller chains with a pitch of 12.5mm. This gives a chain length of 48.8 chain pitches.

Since it is not possible to have a fraction of pitches in the chain, L_c must be adjusted to a whole number, that L_c = 49 chain pitches. This value is used to correct the centre distance through equation 11.

$$C = L_c - \left(\frac{n_2 - n_1}{2}\right) + \left[L_c - \left(\frac{n_2 - n_1}{2}\right)^2 - 8\left(\frac{n_2 - n_1}{4\pi^2}\right)^2\right]^{1/2} \qquad 11$$

Where $n_1 = n_2$, equation 11 reduces to

$$C = \frac{2(L_c - n)}{4}$$

$\therefore C = 156.25mm$

The rated capacity of the bearing selected was found to be 870.52N, with a life of 2500h. Therefore, a bearing with basic load rating of 930N with a bore of 8mm was selected.

3.0 TESTS AND RESULTS

3.1 BULK DENSITY

The bulk density of each of the fertilizers was determined in order to establish the quantity that will fill the hopper. The analysis shows that the bulk density of the NPK, SSP, CAN and Urea is 1181.48kg/m3, 944.44kg/m3, 865.38kg/m3 and 840.00kg/m3 respectively. This implies that the quantity of material to fill the hopper is 24.28kg, 20.43kg, 17.78kg, and 17.28kg respectively.

3.2 THEORETICAL PERFORMANCE

The volume of material trapped between the vanes of the rotor was $9.36 \times 10^{-5} m^3$. This is equivalent to 0.09kg. Quantity of fertilizer discharged in a complete rotation of the rotor = 0.72kg. With a 1:1 speed ratio, this represents the quantity of discharge over a distance of 0.785m

$$\therefore \text{Discharge} = \frac{0.72}{0.785} = 0.917 kg/m$$

With a row spacing of 0.75m,

$$\text{Application rate} = \frac{0.92}{0.75} = 1.227 kg/m^2 = 122.7 kg/ha$$

This represents the metering rate with a teeth ratio of 1:1. However, if higher or lower rate of application is desired, the ratio of sprocket teeth may be varied as appropriate. The theoretical field capacity of the machine was found to be 0.32 ha/h. At a field efficiency of 65%, the effective field capacity was 0.21ha/h.

4.1 CONCLUSION

The aim of this work was to design a granular fertilizer applicator for row crops, that is simple to operate and affordable by peasant farmers. The average bulk density of the fertilizers for which the machine was designed was957.83kg/m^3. The rate of application was determined by the ratio of the driving sprocket teeth to the driven sprocket teeth. While operating at a speed of 3.5km/h, the effective field capacity of the machine was 0.21 ha/h.

Materials for fabrication of the machine were obtained locally, making its production low and therefore affordable by peasant farmers. Simplicity of the machine makes it to operate and maintain.

4.2 RECOMMENDATIONS

1. Extensive performance analysis should be done with a view of improving its performance and determine optimum levels of its parameters.
2. Some fertilizers are acidic while others are alkaline in nature. They therefore tend to corrode metal sheets. Corrosion resistant materials should be used in fabrication of parts that come in direct contact with the fertilizer or these parts be coated.
3. Since some fertilizers are of very fine aggregates, the use of gaskets could be introduced between relevant parts to avoid wastage through leakage.

BIBLIOGRAPHY

ASAE. 2004. Standards 48th Edition. ASAE D497. American Society of Agricultural Engineers, St. Joseph, MI.

Broyer T. C. 1982: Fertilizing. McGraw Hill Encyclopedia of Science and Technology. Vol 5 5th Ed.

Cooke, G. W. 1981: Fertilizer. Encyclopedia Americana vol II. International Ed.

DeGues J. G. 1973: Fertilizer Guide for Tropics and sub-tropics. Cntre d'ettude de L'azote, Zurich. 2nd Ed

Kepner, R.A, Bainer, R and Barger E.L.1987. Principles of Farm Machinery 3rd Ed AVI, Westport, Connecticut. pp 112-166

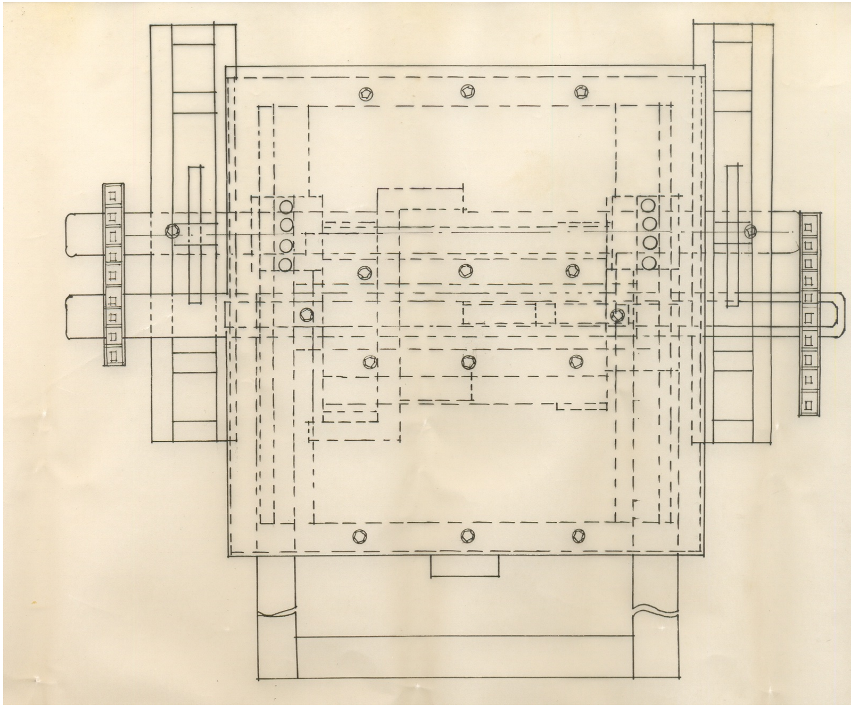
Kumolu C. 2011: Before a ticking bomb explodes: Nigeria's population projected @ 433 million by 2050. www.vangardngr.com/2011/10/ nigerias-population-projected-433-million-by-2050/

Mehring A. L and G. A Cumings 1930: Factors Affecting the mechanical application of fertilizer to soil. USDA Tech Bul 182.

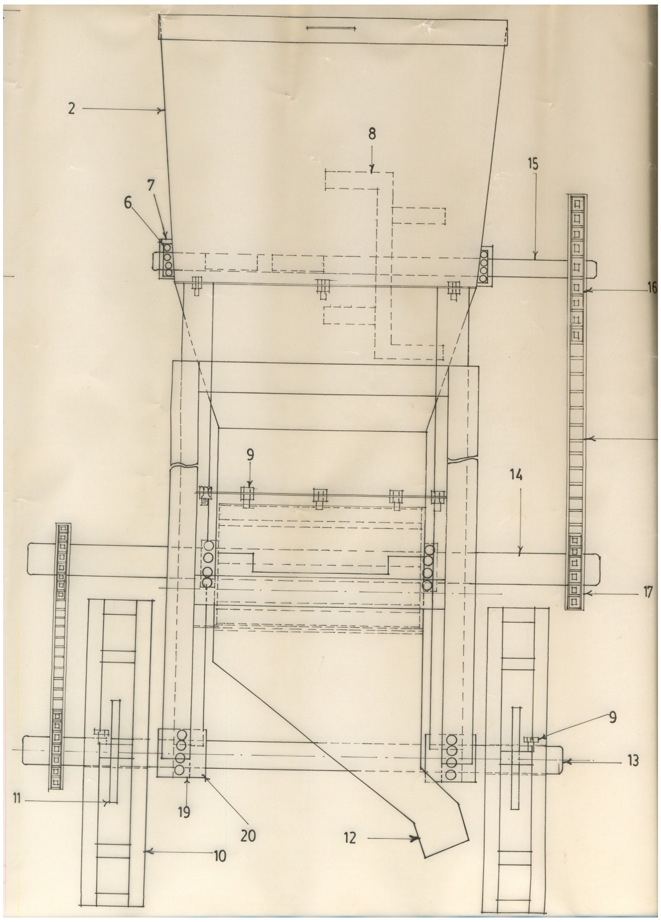
Smith, H.P., and Wilkes, L.H. 1976. Farm Machinery and Equipment McGraw-Hill publ., New York. pp 114-159.

Tisdale S. L. and W. L. Nelson 1975: Soil fertility and Fertilizers. MacMillan Publ co Inc. 3rd Ed.

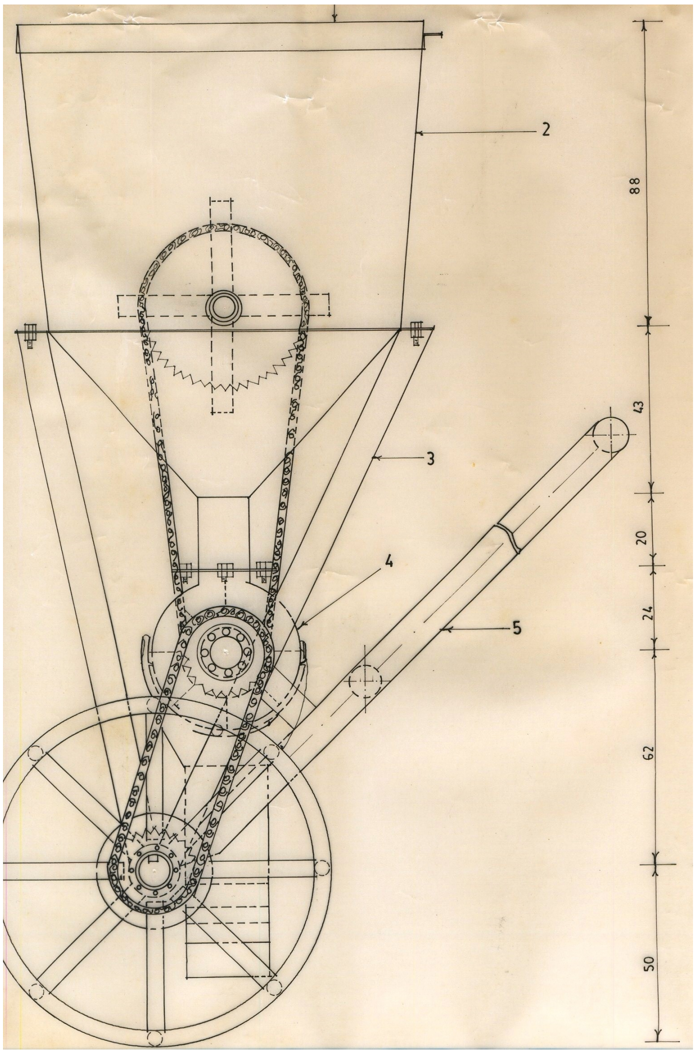
APPENDIX A



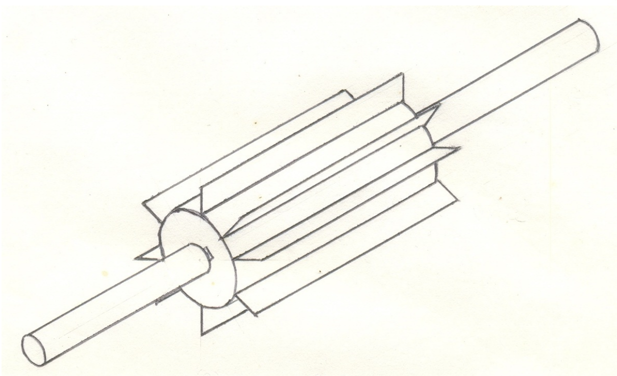
Machine Top view



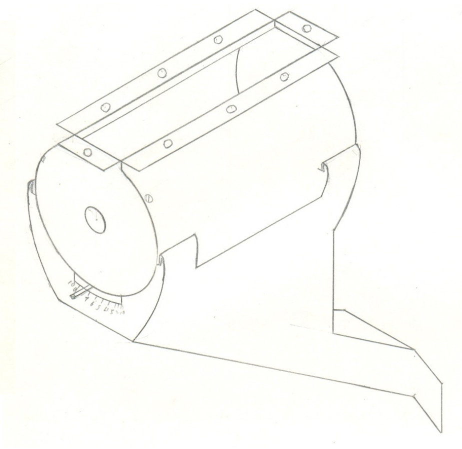
Machine Front View



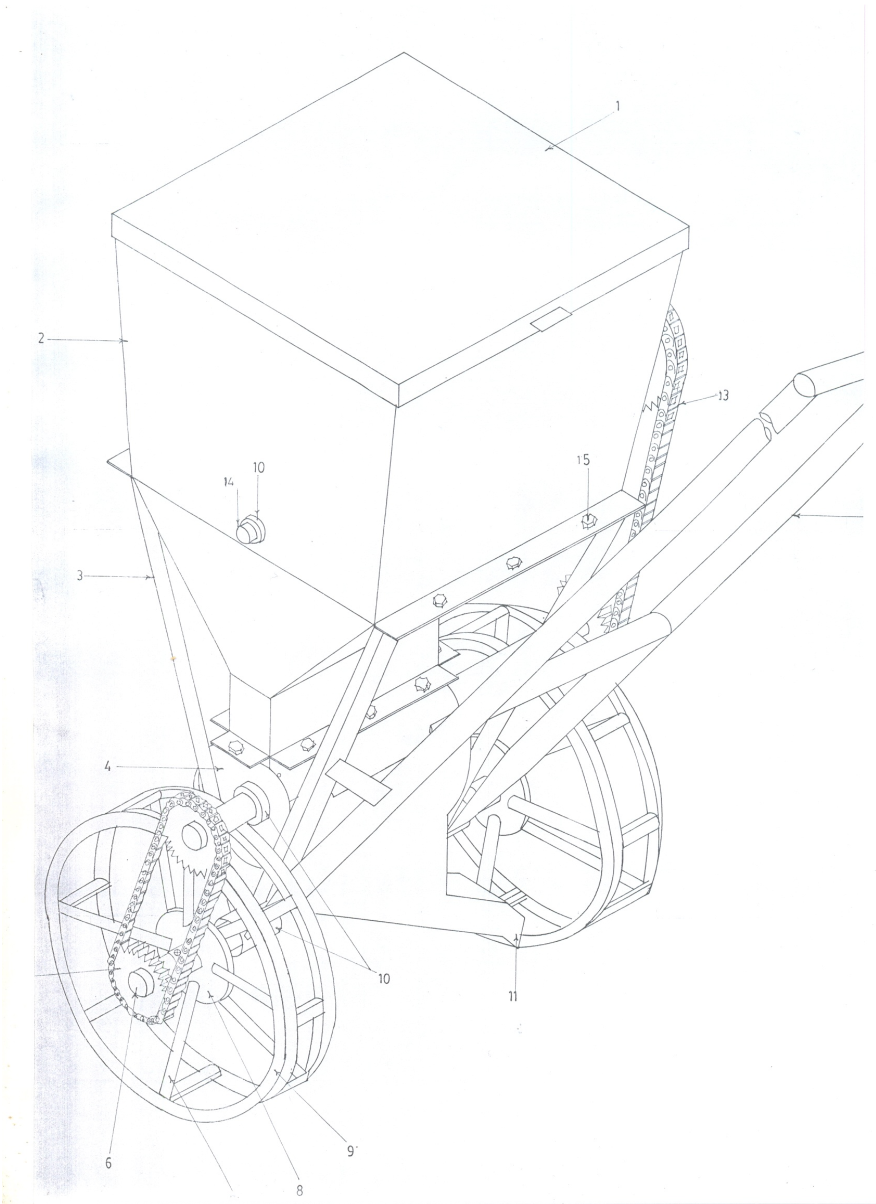
Machine Left Side View



Rotor



Rotor Housing



Machine Isometric View

Legend

1	Hopper Cover	9	Wheel Rim
2	Hopper	10	Bearing Housing
3	Frame	11	Spout
4	Rotor Housing	12	Handle
5	Sprocket	13	Chain
6	Drive Shaft	14	Agitator Shaft
7	Wheel Spoke	15	Bolt
8	Wheel Hub		