THE DESIGN AND CONSTRUCTION OF RAINFALL SIMULATOR

BY

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PGD/SEET/AGRIC ENG/2004/177

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A PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENT FOR THE AWARD OF POST GRADUATE DIPLOMA
IN THE DEPARTMENT OF AGRICULTRUAL ENGINNERING,
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CERTIFICATION

This is to certify that this project titled Design and construction of rainfall simulator designed and fabricated by Dauda Ademolu Musa under the supervision of Engr. Professor Ajisegiri Akin and submitted to the Agricultural Engineering Department, Federal University of Technology, Minna in partial fulfillment of the requirement for the award of Post –Graduate Diploma in Agricultural Engineering (soil and water option.)

Engr Professor Akin Ajisegiri.
Project Supervisor

27-04-05

Date

Engr. Dr D. Adgidzi
Head of Department

4-07-05

Date

DEDICATION

This project is dedicated to Humanity and the profession of Engineering.

ACKNOWLEDGEMENT

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ABSTRACT

The construction of Morin type (nozzle) rainfall simulator is described. Its suitability for field and laboratory uses in the studies of Erosion control processes is stressed. The simulator is designed and constructed based on the modification of the nozzle type rainfall simulator. The slot of the rotating disc is directly under the spraying nozzle and simultaneously above the pan aperture. The fixed nozzle sprays continuously, while the nozzle is directed vertically downward and just below it is a metal disc which rotates in the horizontal plane. It functions with the aid of a pumping machine, electric motor, and the excess water is drained back to the reservoir.

CHAPTER ONE

1.1 INTRODUCTION

Many researchers have used rainfall simulator for soil erosion studies. However, it is often difficult to find one source of reference regarding the potential and actual use and misuse of this technique (although see Hudson, 1967). Some literature exists on specific experiments using rainfall simulators (e.g. Deploey, 1983), but usually these do not give an overview to the research technique.

Before undertaking rainfall simulator studies, common question arise regarding the design, costs and performance of rainfall simulators as well as the practical problems and scientific advantages associated with them.

There is no standard procedure for the evaluation of simulator performance in representing real life natural-rainfall events. Likewise, there are no guidelines as to how accurate the simulation should be in order to produce meaningful and worthwhile data.

1.2 Definition of Rainfall Simulator

Simulation of rainfall is that process whereby water is applied in a form similar to natural rainfall and in doing this rainfall simulator is used.

Rainfall simulator is a very effective approach to the study of soil erosion processes and the evaluation of possible conservation strategies to reduce erosion.

This is because, the use of natural rainfall to acquire erosion data in a given location is very slow since it is un-predictable and therefore takes a long time to obtain a fairly representative data.

Desired rain-storms can easily be obtained at anytime by controlling and manipulation of the various characteristics of rainfall such as drop diameter, kinetic energy, duration and intensity, using simulated rainfall from the simulator

1.3 Aims and Objectives

1.3.1 Aim

- To design and construct a rainfall simulator

1.3.2 Specific Objectives

1. To design a cost effective rainfall simulator.
2. To use available and cheap materials to construct or fabricate the design rainfall simulator.

CHAPTER TWO

LITEARATURE REVIEW

2.1 Types of Simulator

There is a huge amount of literature on the design, construction and operation of rainfall simulators. Large simulators using test plots of $100m^2$ or more are available for the study of cropping treatment under something approaching field conditions and examples from the U.S.A, Australia, and that of Israel is illustrated in plate 1

These machines are expensive and needs trained operators, in this wise, they are outside the scope of this write-up which the intension is to design an in-expensive rainfall simulator.

2.1.1 Desirable Characteristics of Simulated Rain.

It is desirable that all the physical characteristics of natural rain should be re-produced as accurately as possible, but some latitude may be acceptable in the interest of simplicity and cost. The main characteristics are:

i. Drop Size: Raindrops vary from the minute droplets in mist up to a maximum of 6mm or 7mm diameter. This is a physical upper limit to drop size and above this any drops which form from the coalescence of more than one drop are un-stable and will break-up into smaller drops.

ii. The median drop diameter by volume lies between 2mm and 3mm and varies with intensity as shown in fig 1.

iii. The distribution of drops of different sizes varies. Cyclonic rain in temperate climates is mainly composed of small and average size drops, but high-intensity tropical thunderstorms have a greater proportion of large drops.

iv. Fall Velocity: - Falling raindrops reach a maximum (or terminal) velocity when the force of gravitational acceleration is equalled by the resistance of the drop falling through the air. The terminated velocity is a function of drop size and increases up to about 9m/s for the largest drops, as shown in fig 2.

v. Kinetic Energy is the energy of a moving body, and the kinetic energy of rainfall is the sum of the kinetic energy of individual drops. Kinetic energy is a function of the size and fall velocity and is often used as a desirable parameter for a simulator because it is known that kinetic energy is closely related to the ability of rainfall to cause erosion, the kinetic energy of rainfall varies with intensity as shown in fig 3 with an upper limit at about 5mm/h. This upper limit is a consequence of the upper limit of the size of raindrops in that the highest intensities have more drops but not of an ever increasing size. So the energy per volume of rain does not increase above intensities of 75mm/h the energy per seconds does, of course, increase with intensity at all levels of intensity. The intensity of rainfall is not related to mean annual rainfall – arid or semi-arid rainfall can reach intensities as high as in the humid tropics, although less frequently.

vi. Rainfall intensity:- Or rate of rainfall can vary rapidly in natural rainfall, but it is usually not necessary to build into rainfall simulators the ability to change intensity during a test. It is usual to choose and design for single value of intensity, for example 25mm/h to simulate temperate rainfall, or 75mm/h for tropical or semi-arid rainfall.

vii. Uniformity of distribution of rainfall over the test plot is desirable.

Plate 1: A field scale simulator from Israel (law 1941)

2.2 Making Artificial Rainfall.

2.2.1 Non-Pressure Droppers.

Many simple simulators have used the principle of drops forming, another very simple simulator using a reciprocating garden spray is shown in fig 4. The oscillation is controlled by a simple water turbine whose rotary action is converted into simple harmonic motion. This means that the distribution is not uniform as there is a dwell at each extreme, so a test plot using this principle should be located in the central part of the spray pattern.

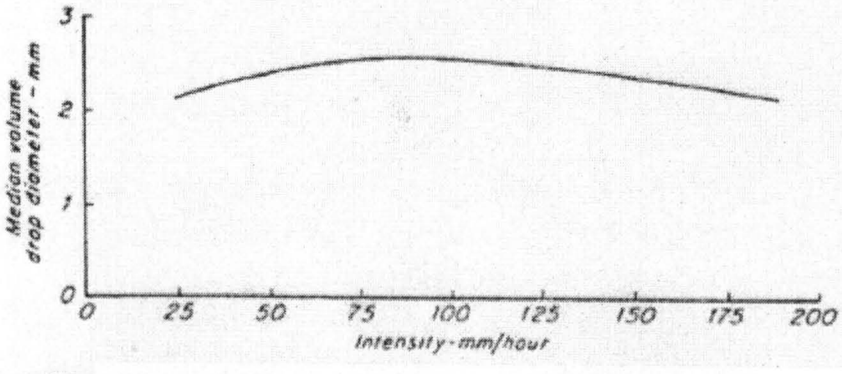


Fig: 1 Media volume drop diameter (law 1941)

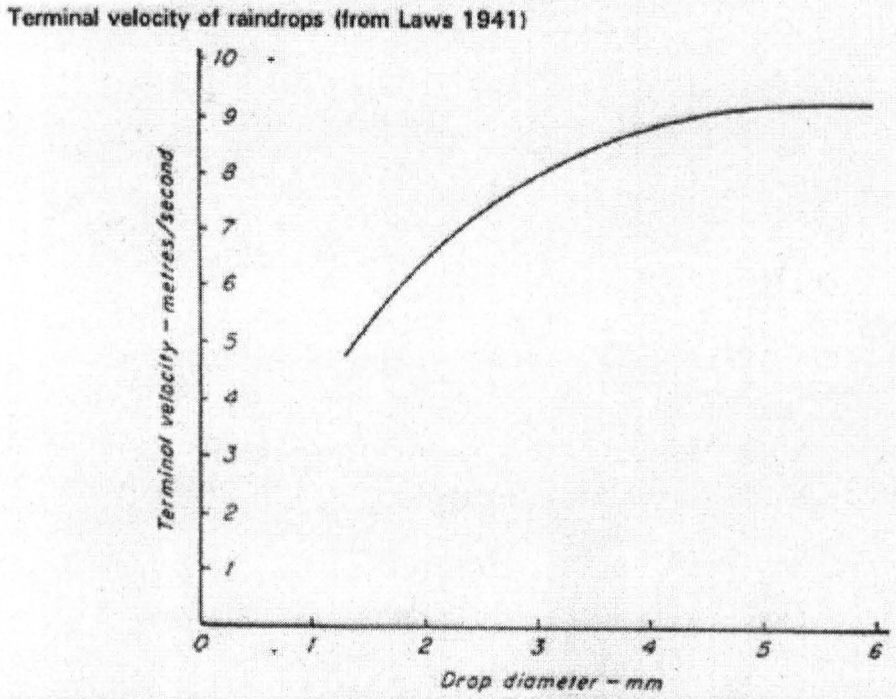


Fig: 2 terminal velocity of rain drops (law 1941)

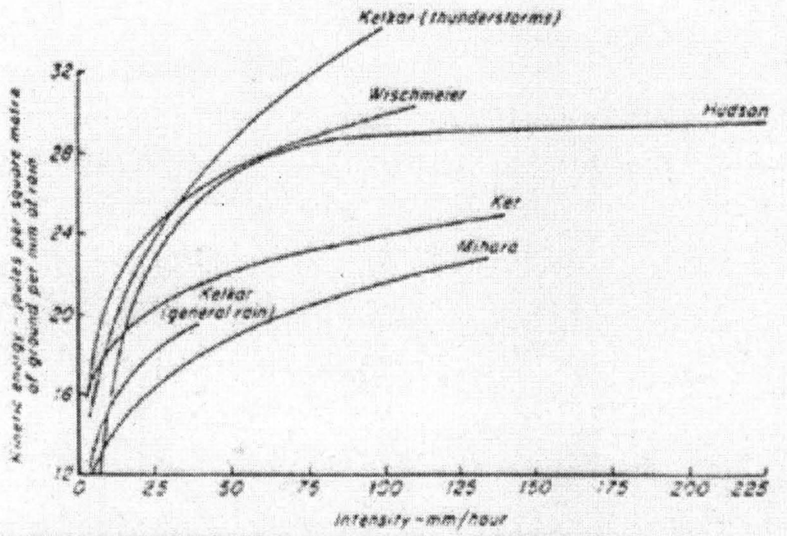


Fig.3: Relation between kinetic energy of rainfall and intensity. Each curve extends to the highest intensity recorded (from Hudson 1981b)

The studies were carried out in the following countries: Zimbabwe (Hudson): India (Kelkar): Trinidad (Ker); Japan (Mihara); USA (Wischmeier).

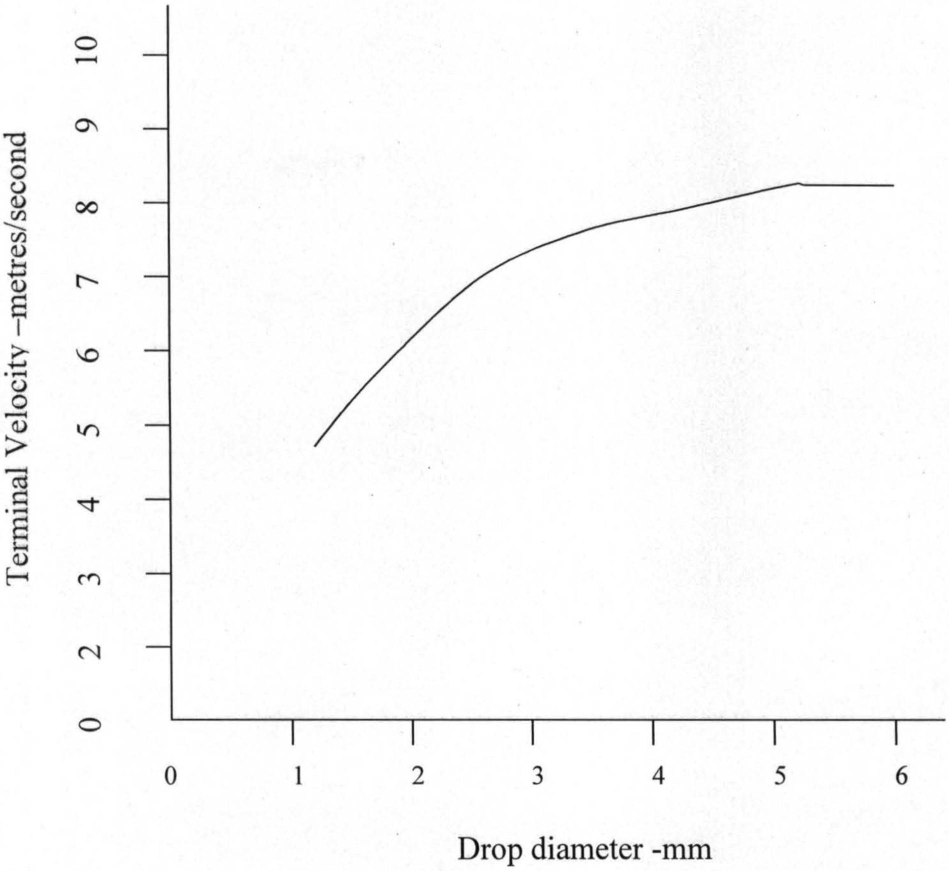


FIGURE 20: The Terminal Velocity Data from Laws 1941

15

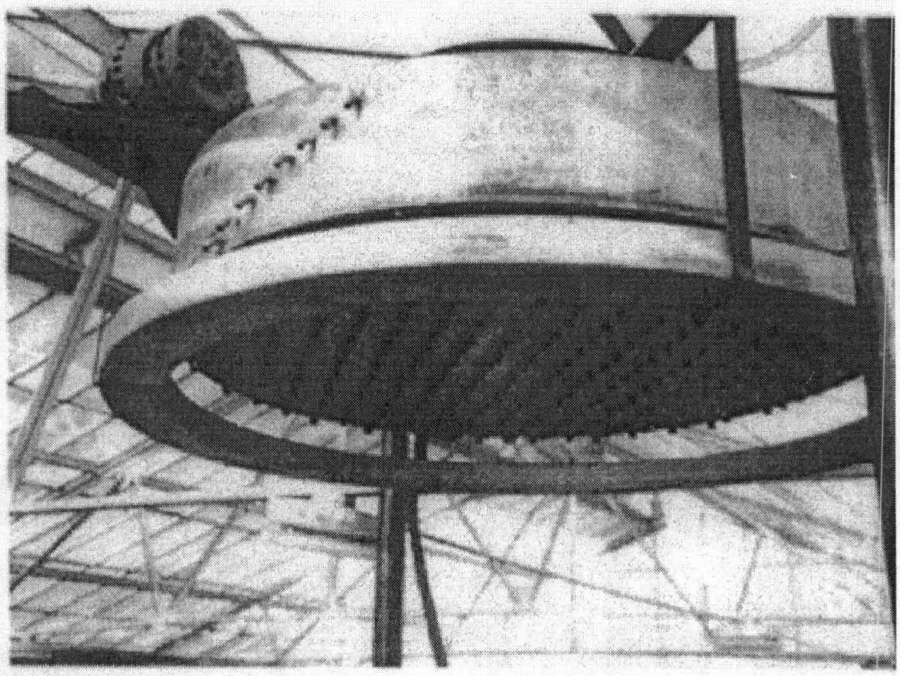


Plate 2: a laboratory dropper simulator

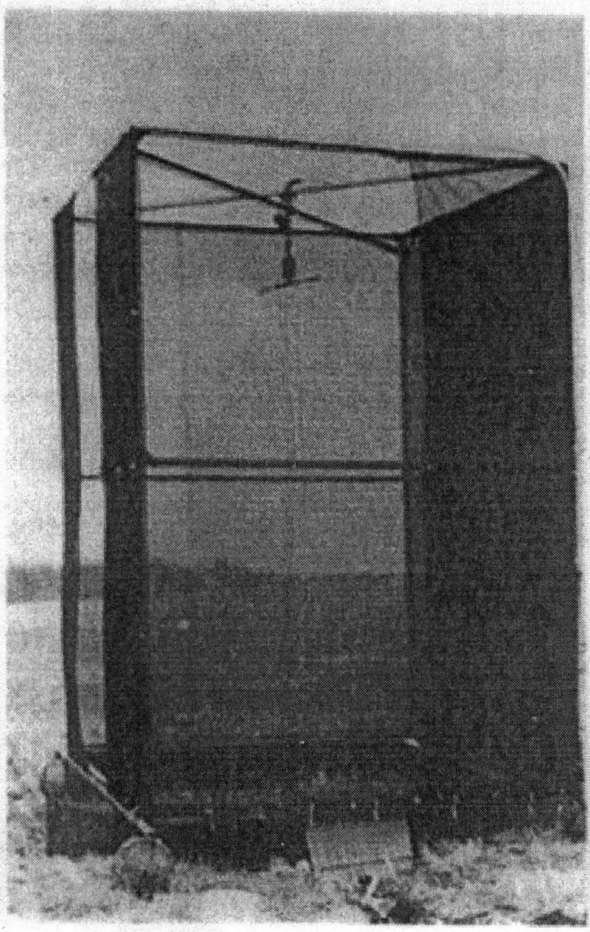


PLATE 3: the Silson College rainfall simulator in China (J. Rickson)

FIGURE 53
A simple garden spray simulator

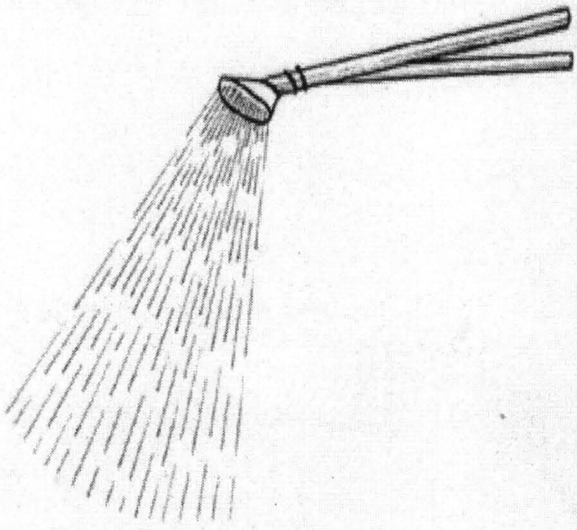


Fig 4: Reciprocating garden spray

FIGURE 54
A reciprocating garden sprayer

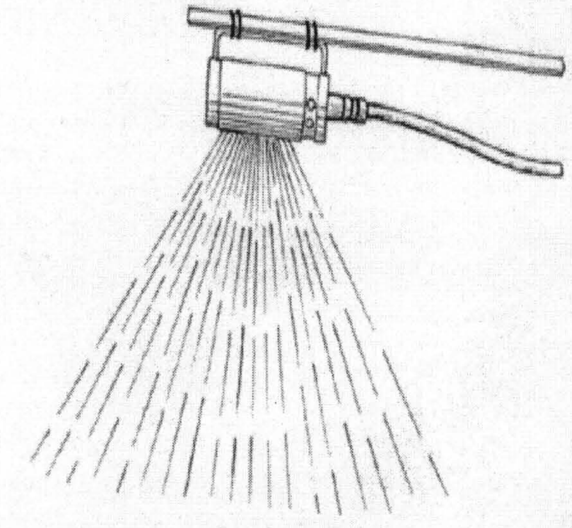
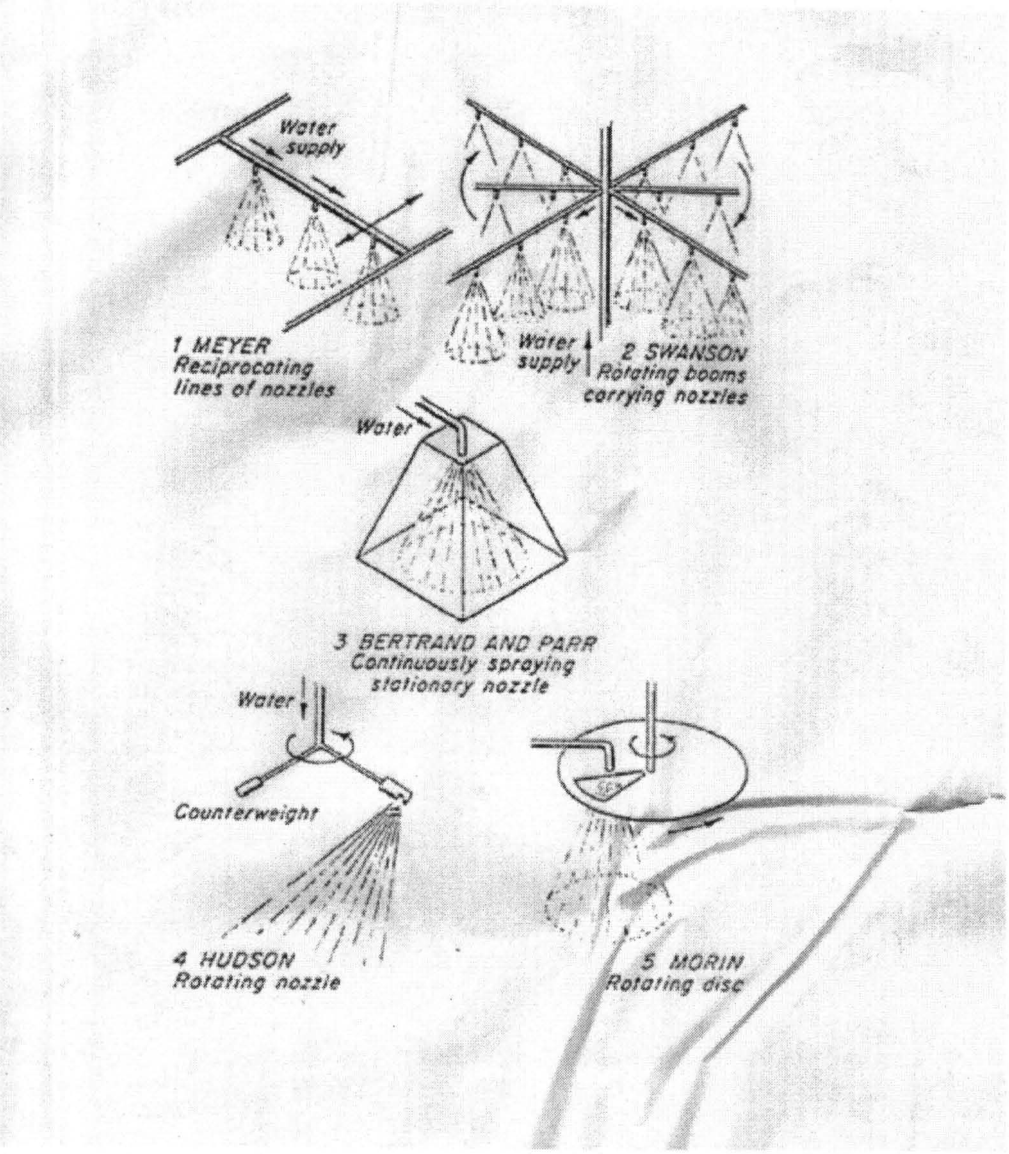


Fig: 5: Pressure Spray



2.2.2 Pressure Dropper

2.2.2.1 Pressure spray

The simplest possible form of spray, but which may be perfectly suitable for some simple applications, is a spray from a watering can, or the hose connected to a pressurized hosepipe-fig 4. Most commercial hoses are drilled with all the holes of the same size, but it is easy to achieve a mixed drop distribution by drilling holes of different sizes. A basic problem with sprinkles of this type is that, like non-pressure drop formers, they only achieve a low impact velocity unless falling from a considerable height. With pressure sprays the impact velocity can be increased by pointing the spray down ward so

Advantages: - This simulator and its derivatives are very efficient.

Disadvantages: - Because they were designed for operations on large plots they are complicated and expensive.

Most subsequent developments have therefore been concerned with designing simple or smaller machines. One such variation was designed by Dunne, Dietrich and Brunengo (1980) for field use in Kenya, shown in fig 7. a trolley carrying the spray nozzle Is pulled backwards and forwards along an overhead track by two operators pulling on ropes.

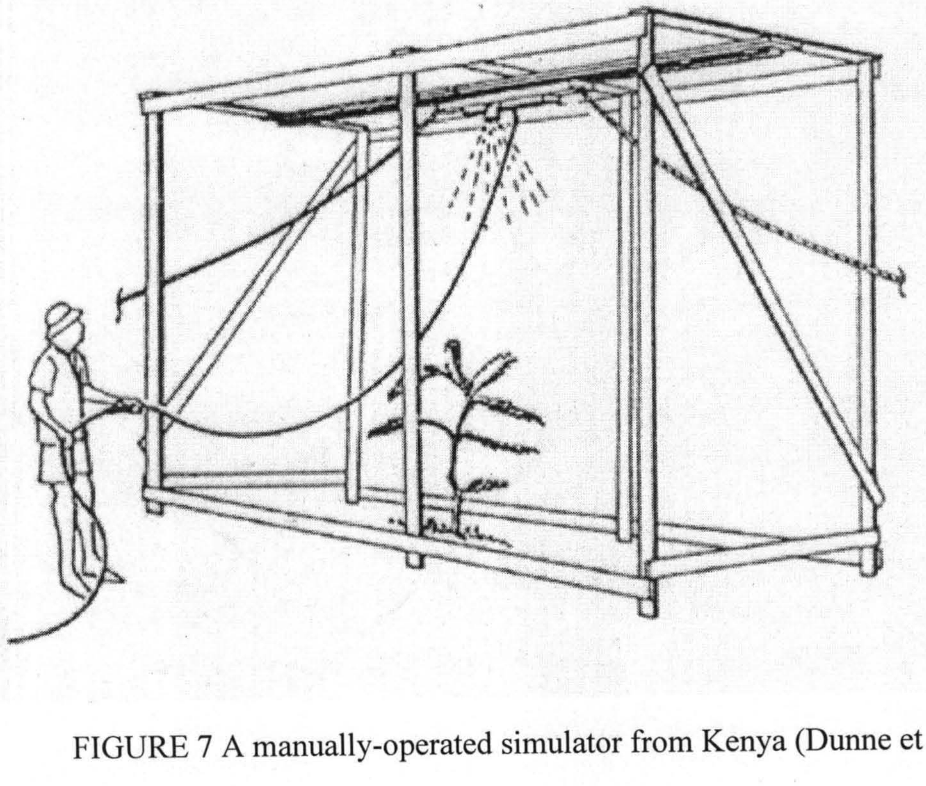


FIGURE 7 A manually-operated simulator from Kenya (Dunne et al, 1980)

2.2.2.2 Rotating-Boom

Another approach is a machine based on a commercial rotating-boom. Irrigation machine shown in plate 2. Each boom carries the water supply to a number of nozzles on each boom which rotate slowly, powered by a water turbine. The machine is set up between two test plots so that rain can be rained on by one machine, or for longer plots two machines can be used (Swanson 1965, Hinkle 1990).

2.2.2.3 Rotating Disc -Morin, Goldberg and Seginer.

Another very popular device which has been copied and developed in many countries is the rotating, disc originally designed by Morin, Goldberg and Seginer (1967) and illustrated in plate 4.

A fixed nozzle spray continuously, but the soil is intermittently shielded from the spray. The nozzle is directed vertically downwards, and just below it is a metal disc which rotates in the horizontal plane. A radial slot is cut in the disc, and each time this passes under the nozzle a short burst of rain passes through to the plot below. The proportion of the spray which passes is determined by the angle of the slot. This design allows the use of large nozzles which give the right drop size distribution and kinetic energy but which, when spraying continuously, produces excessive intensities.

Plate 4 A rotating disc rainfall simulator

2.3.0 Common components of rainfall simulators

Different materials have been used to support the rainfall simulator head, whether it is a nozzle or drip type. The ideal frame would be made of cheap, robust and light – weight material. Dexion is quickly assembled. But prone to warping, especially in above average wind speed. Angled iron is studier but heavier and less suited to field work. Speed frame is quickly assembled, but costly, but the joints are relatively weak, and can snap off if not handled with care, aluminium is light-weight, but expensive. A compromise would be to use aluminium ladders as the frame. Here the ladder will support the simulate head, and provide access to clip up the nozzle to check operation pressure of the head, nozzle blockages and so on. These ladders are expensive and should not be left un-attended in the field as they have a variety of uses from these scientific one!

Most frames are four sided, although tripod have been used, the problem here is the interference with the spray at the top of the simulator. All frames should have telescopic legs if possible so that the simulator will be steady and the nozzle or drop formers vertical. The problem is that on steep slopes, however, upslope have less fall distance than the down slope drops. Providing the shortest fall height is sufficient to reach their terminal velocity, then this difference may be treated as un-important.

A large proportion of equipment cost can be spent on the frame, at the unfortunate expense of the simulated head itself, providing the robustness is not a major consideration material such as thick bamboo should be sturdy and strong enough to support most rainfall simulator head both pressurized and non-pressurised.

2.3.1 Types of Spraying Nozzle:

Many types of spraying nozzle are commercially available, some designed for other purposes and some designed especially for rainfall simulators. One major difficulty is that if the spray is to include drops of the largest size which occur in natural rain then the nozzle opening has to be large, about 3mm diameter. But even with low water pressures the intensity produced from nozzles of this size is higher than natural rain **(Elwell and Marwanya 1980)**. It is therefore necessary to have some kind of interruption of the spray to reduce the intensity of that natural rain. In Meyer's 'Rainulator' two methods were used fig 6. The spray nozzles were mounted on an overhead carriage which traversed backwards and forwards across the plot achieve in field condition. To some extent this can be compensated by using large drops than unnatural rainfall.

Another disadvantage is that the size of the test plot is limited by the practicalities of constructing a very large drop forming tank. A simulator using this approach and mounted on a small trailer has been successfully used for many years in Venezuela.

2.3.2 Wind Shield

Field experiments with rain simulator are at the mercy of wind. Ideally, most simulators should work in above average wind conditions, but this is only possible if a wind shield is used. Even on apparently calm days, wind shield are essentially for field use of rainfall simulators.

The best time of day to avoid wind is very early in the morning. Even laboratory simulators are subject to air currents. This may distort the repeatability of distribution between experimental runs. Plastic sheeting can be used in low velocity or winds, but because it is not permissible to air current, it can act as a huge sail, making the whole simulator rig susceptible to blowing over or even taking-off! Following the principles of shelter shield should be slightly porous to allow air flows to be retarded but not resisted altogether. Fabric such as tafita and synthetic alternatives or vegetable bags meets these requirement. They also have an advantage of being partially absorbent, so that any stray spray reaching the wind shield is absorbed and drained through the fabric, rather than being splashed back, as would occur with plastic. Fabric is also more droppable, and conforms to the frame used, unlike the more rigid plastic sheeting. Specially synthetic geotextiles (such as netton products) are manufactured as wind breaks, but this would be costly in this application.,

2.3.3 Water Supply

Water supply for rainfall simulator is often the biggest practical problem, especially in remote field sites. Not only is quantity a problem but quality as well. If the water sources is a natural stream or lake etc. it is necessary to attach a filter on the end of the input pipe (usually running to the pump) to avoid contamination and blockage. A fine wiremesh is usually sufficient, but this will not filter out any fine particulate material (including clay and silt, which can absorb high levels of pollutants and contaminants). Textile filter materials with very low porosity are available, but these are costly.

In countries with a marked raining and dry season, water courses may be completely dry up when experimentation is to take place. Serious drought makes rainfall simulator not only difficult as far as water supply is concerned but tactless if water resources are crucial to the farmers or the area. Using natural streams and rivers as a source of water can be unreliable, being in valley bottoms. These Sources are often found far from hillside erosion plots. Large containers such as oil drums can be used, but their portability when full makes this very difficult in the field. In the laboratory, mains water can be used, although this is subject to fluctuations depending on other users. This specific problem is easily overcome by constructing a sump into which mains water feed. Water supplied to the rainfall simulators comes out at the sump rather then directly linked to the mains water supply.

2.3.4 Pumps.

Unless a gravity fed system is used, pressurized rainfall simulator require a pump to supply water under pressure to the simulator head.. Non- pressurised simulator do not. In the laboratory, electrical pumps can be used, but field application needs an independent power source. Petrol or diesel pumps are used, often, the problem in over capacity, as many pumps have been used for other water supply experiments, such as irrigation tests. This require much higher pressures than used for rainfall simulator and these means the pumps used are too large for the application rate required. One solution in to use “bleeder-pipe” which recycle a large proportion of the pumped water back to the water reservoir. This helps to keep the water supply to the head itself at a more realistic rate.

Using an electric pump may have problems in the reliability of electricity, as well as health and safety regulation when electricity, is used in close proximity to water. In the field, a generator in often required to run electric pump. It is the author's view that an increase in equipment means an increase in the thing that can (and will) be unreliable. Petrol and diesel do not require a generator, but may require a lot of fuel for continuous and lengthy experimental work. Whilst fuel supply may be a problem in some remote area the fuel has to be carried out to the field, which is bulky and potentially hazardous.

2.3.5 Pipe work

Most rainfall simulators use a variety of pipes from the input supply pipe to that used to supply water to the simulator head. Flexible pipes can be more portable and manoeuvrable, although coiling may lead to friction losses. Rigid pipes would be too cumbersome to use in the field. Different diameter pipes can be joined by adapters, and quick, snap action coupling joints are extremely useful for simulators that have to be assembled and disassembled rapidly. The actual diameters of the pipe work used will depend on the size of the pump a simulator head uses.

Even minor changes in the experimental set up such as minor water leaks and coiling of the hoses used can affect the temporal performance of a simulator (Bowyer-Bower and Burt, 1989).

2.3.6 Motor

Rotating disc and oscillating nozzle rain simulators require an independent motor for motion. This is yet another piece of apparatus and should be treated with caution, as to its reliability. These motors are commonly run on electricity, supplied from the mains in the laboratory, or from a generator or 12 volt car battery in the field . as mentioned above electricity supplies may be unreliable, a generator in costly and cumbersome to transport in the field, and a car battery requires re-charging at constant intervals (depending on the number of experimental runs carried out). These potential difficulties can be overcome by using the pressure of (see above), which makes the need for an independent power supply radiant.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Design Considerations.

The design of a rainfall simulator is complex and certain consideration has to be met. These criteria are:

a) Rainfall characteristics

b) Plot size

c) Simulator portability and cost

Meyer and Mecune (1958), Betrand and Parr (1961), Meyer (1965, 1979) Hall (1970), Meyer and Harmon (1979); and Bubenzer (1979a, 1979b,) described the criteria which includes;

1) Drop size distribution which should be as close to natural rainfall as possible
2) Drop impact velocities
3) Uniform rainfall intensities and random size distribution over entire plot.
4) Angle of impact not greatly different from vertical
5) Rainfall application nearly continuous over the entire plot.
6) Satisfactory characteristics, when used during common field conditions such as high temperature and moderate winds.
7) Area coverage sufficient to represent the treatments and conditions being examined.
8) Reproducible storm patterns of duration and intensities of interest.
9) Highly portable

10) Low cost

If criteria 1, 2, and 8 are closely approximated, then the total kinetic energy of the simulated rainfall will approximate that of natural rainfall, more et al (1983) therefore.

3.2 Simulator Design

The simulator was designed to meet the 10 design criteria listed above as nearly as possible, taking the strength of the machine members into consideration. The design of the various component of the rainfall simulators are discussed below.

In building an applicator, a drop forming device has to be made. For this, small copper tubes external diameter of 6mm and length 30mm were used, through which a hole of 2mm for a length of 12mm and widened to 3mm in diameter over a length of 18mm. (Ajisegiri et al 1994) and not based on theoretical approaches. A uniform distribution was approached by rotating the applicator and by proper spacing of the drop former. Radial distribution was obtained by dividing the annuls area covered by the applicator into annuluses of equal area and using the same number of drop-formers in such area.

For operational convenience, the application tank was made in eight sectors, with drop-formers in the Plexiglas bottom to achieve the uniform radial distribution.

The total annular area of the applicator tank

$$A = \frac{\pi D^2}{4} \quad \text{..(1)}$$

$$= \frac{\pi (600)^2 mm^2}{4}$$

$$= 2827.43\text{mm}^2$$

Where D = 600mm = Diameter of tanks applicator

A = Area of the cylindrical tank

3.3 Simulator frame

The main frame work holds the catchments pan with the nozzle and disc inside. The shaft bearing housing; nozzle holder it can also hold the D.C motor, battery and charger. The framework is rectangular in shape and built from 38mm angle iron, has four legs each 2.6m long. These legs were formed by welding two 38mm, angle iron, each of length 1.3m. to ensure stability of the framework, two 25.4mm angle iron bracings were welded to the stands at a height of 1.3m and 0.6m respectively from the ground surface.

For sector A

$$8M = \pi(r_{A.}C + 1^2 - r_{Ai}{}^2)i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

(Adanijo 1985)

M = Annular area in mm^2 covered by each drop former

A = sector number ;

i = whole number

r = radius in mm

Therefore

$$R_{A,}\,i + 1 = \left(\frac{18M}{\pi} + r_{Ai^2}\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

(Adanijo 1985)

If Ai = 20mm

Then

$$r_{A,}\, i + 1 = \left(\frac{18M}{\pi} + 4\right)^{\frac{1}{2}}$$

Since 40 drop formers were used, M, the area covered by one (1) drops former is

M = A/N ....(4)

$$M = \frac{2827.43}{40} = 7068.575\text{mm}$$

= 7069mm

$$\text{Therefore } r_{A,}\, I + 1 = \left[\frac{(8x7068.575) + 4}{\pi}\right]^{\frac{1}{2}}$$

$$= \sqrt{178432.1611}$$

= 422.41mm

For sector B

$$r_{BI} = \frac{r_{AI} + r_{A2} - r_{AI}}{B}$$

For sector C

$$r_{CI} = \frac{r_{AI} + 2(r_{A2} - r_{AI})}{8}$$

These drop formers are carried by the applicator tanks, which also contains water when the rainfall simulator is in operation. The applicator tank, whose dimensions was chosen for convenience and to suit its purpose, has a diameter of 600mm and a height of the tank is 150mm. the thickness is 2mm thick galvanised metal sheet joined by welding. Table 1: shows the distributions of the drop formers with the annular and their distances from the centre of rotation of the applicator tank.

A	B	C	D	E	F	G	H
2.00	3.46	4.89	6.34	7.78	9.23	10.67	12.12
13.56	14.25	14.94	15.63	16.32	17.70	17.70	18.39
19.08	19.61	20.14	20.67	21.20	21.73	22.26	22.79
22.32	23.77	24.22	24.66	25.11	25.56	26.01	26.42
26.90	27.30	27.69	28.48	28.48	28.88	29.27	29.67
30.06							

3.4 Overflow Tank

Excess water not going through the drop-formers overflows through the head control tube into the overflow into the overflow tank, from where it flows into a drain. The tank is positioned in a way such that it does not intercept the water dripping from the drop-formers onto the soil sample. The following dimension was therefore used.

Inner diameter of overflow tank = 61cm

Outer diameter of overflow tank = 71cm

Height of the overflow tank = 5cm

Thickness of the galvanized metal sheet used =0.95mm

The maximum capacity of the overflow tank is therefore

$$V = \frac{\Pi}{4}\left(D^2{}_2 - D^2{}_1\right)xh$$

$$= \frac{\Pi}{4}\left(71^2 - 61^2\right)x5cm^2$$

= 5183.63 cm^3

D$_1$ and D$_2$ are the inner and outer diameter of over-flow tank.

Table 2; Comparison of Rainfall Characteristics

ors	Disc-slot angles	Pressure range (kpa)	Simulated rainfall intensities mmf	Median drop mm	Coeltic of uniformity	Unit kinetic energy
giri 4)	3X15 (45) 3X25 (75)	54-104 54-104	36-167 54-288	3.1 3.1	62-75 70-90	34.2 27.6
n et 7)	5-40	30-61	8-142	1.9-3.7	77-93	15.0-28.0
itz 2)	-	51	3-72	73-95	-	--
son s 7)	5-40	35-69	6-153	77-92	2.3-2.9	-
ton 2)	5-40	70	58-115	79-80	2.6-2.8	33.0
t al	5-40	30-101	10-180	76-89	-	-

Ajisegiri et al (1994).

3.5 Soil Bin

Bin size was chosen to be 30cm x 40cm long 20cm high and a soil depth of 6.3cm. a review of similar studies with soil bin on slope (Molden Hauer and Lonsi 1994; Cluff and Boyer (1971); young and Wiersma, 1973; Mitchell and Gunther, (1976) ; indicated that soil bin sizes varies from 30cm x 30cm to 152cm by 42cm long with depth of about 10-20cm.

The soil bin used for this project was constructed in such a way as to minimise wastage of water from the simulator, allow for runoff, and for the whole catchments model to be covered by the raindrops.

Table3: uniformity coefficients (%) of different disc sizes, nozzle sizes and operating pressure

Disc Lot Size	**Nozzle Size mm**	**Operating Pressure (cpa)**			
		52	69	86	104
Disc 1 (3x15)	2	68	62	62	69
	3	66	65	75	74
	4	68	62	62	70
	5	65	65	74	74
Disc 2	2	71	70	74	74
	3	74	75	80	78
	4	81	82	83	89
	5	74	89	92	90

Source: Agisegiri et al 1995

A wind shield for the simulated rainfall was provided by using a water proof material to cover three sides of the frame from the ground level to the water nozzle position. The fourth side is left open for entering the test place

3.6 The Drive Mechanism

Uniform distribution of rainfall is achieved by rotating the application tank which is driven by an electric motor. These include efficiency, speed range, cost per horse power, starting torque range, weight and physical size. Therefore a 0.3kw electric motor with a speed of 56r.p.m was chosen for the design.

Sprocket and chain are used because chain drive is positive engagements and does not work on friction. It is used to transmit power from the motor to the shaft that rotates the applicator tank

The driving sprocket of diameter 8cm and 18 teeth was attached to the motor while the driven sprocket 18cm diameter and 44 teeth was attached to the applicator tank through the shaft that passes through a tapered roller bearing housed on the support-unit of the simulator.

The speed of the applicator tank is given by

$$n_1 d_1 = n_2 d_2 \quad \text{...(8)}$$

n_1 = speed of the driving sprocket

n_2= speed of the driven sprocket

d_1= diameter of the driven sprocket

d_2= diameter of the driven sprocket.

From equation 8 above

$$n_2 = \frac{n_1 d_1}{d_2} \qquad = \frac{56 \times 8}{18} \qquad = 24.99\text{rpm}$$

Therefore speed of the applicator tank = 25rpm

The chain speed (fpm) = $\frac{p.t.m}{12}$ ……………………………………………………(9)

(Adanijo 1985)

Where p = pitch

t= no of the sprocket (driving) = 18

n = sprocket speed = 56 rpm

Therefore fpm = $\frac{1x\ 18\ x\ 56}{2\ x\ 12}$ = 42 rpm

3.7 Shaft Design

A hollow shaft was designed because water from the pipe goes into the applicator tank through the hollow section of the shaft. The design of the shaft was based on torsion and axial load, elongation of the shaft and twist of the shaft due to the torque, considering the design based on torsion and axial load, which gave the biggest diameter.

di = inner diameter of the shaft

do = outer diameter of the shaft

$\frac{di}{do}$ = 0.6 ……………………………………………………………………(10)

d = outer diameter of the shaft below the bearing

$\frac{do}{d}$ = 1.25

σ_X = Axial stress

τ = torque

r = radius of shaft

J = Polar moment of inertial of the cross-section

Max. Stress, $\sigma\text{max} = r_x + r_y + ½ (r_x - r_y)^2 + 4\tau^2$ ....(11)

(Adanijo 1985)

But $r_y = 0$ therefore

$$\sigma\text{max} = \frac{r_x}{2} \pm r^2 x + 4T^2$$

$$T = \frac{Tr}{J}$$ ....(12)

poler moment of inertia

This then but $J = \frac{\pi}{32}(do^4 - di^4) forhollowshaft$ ....(13)

$$\sigma x = \frac{force}{area} =$$ ....(14)

$$\frac{501.17 + \frac{\pi}{4}(d^2o - d^2o)x13x10^{-2}x9.81x7850}{\frac{\pi}{4}(d^2 - d^2i)}$$

Where

501.17 = weight of the applicator tank and its content

$\frac{\pi}{4}(d^2 - d^2i)x13x10 - 2x9.81x7850 = weight$

of the section of the shaft subjected to maximum axial stress

$\frac{\pi}{4}(d^2 - d^2i)$ = cross sectional area of the section subjected to axial stress

$$\sigma x = \frac{501.1 + 2201.56d^2o}{0.22do}$$

$$torgue = \frac{T^{(do-di)}/_2}{\frac{\pi}{32}(d^2o - d^2i)} + \frac{(d-di)/_2}{\frac{\pi}{32}(d^2 - d^4i)} \qquad \text{....................................(15)}$$

but the torgue of the motor = 6.60N-M

Using factor of safety of 4

σw = σmax = 65.5 x 10^6 N/m^2

Substituting σmax in above equation and solving σy = 9.395x 10^{-2}m because of corrosion that would occur in the hollow section of the shaft, do was taken as 20mm.

i.e. do = 20mm

di = 12mm

d = 16mm

length of shaft = 18cm.

A tapered roller bearing was used to support the shaft of the rainfall simulator support after the bearing had been housed in a bearing housing. This is because the shaft would be subjected to both radial and axial loads due to the weight of applicator tank and its content see fig 12 for shaft diagram.

Therefore the intensity of the rainfall

$$I = \frac{Disch/_{hr}}{Area} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

$$= \frac{2.02x10^{-4}x60}{1200x1} = 0.101m/hr.$$

therefore the intensity of the rainfall simulator = I= 101mm/hr.

3.8 Kinetic Energy

a lot of research has been done to find a relationship between rainfall intensity and kinetic energy. Wischmier and smith found that KE = 210 + 89.0 log 1 (joules/m^2/hr).

therefore K.E of simulated rainfall

= (12.138.9log100) 100

K.E = 3.027 joules/m^2/hr.

3.9 operational procedures

The pump takes water from the water container, passes it through a stop valve to a union connector ¾" pipe(20mm) and subsequently through ½" pipe (12.5mm) leading on to the nozzle and orifice. The applicator tank is supported by the shaft which passes through the sprocket that is powered by electric motors, at the top of the applicator tank water from the nozzle passes through the slot into the drop former. As the applicator tank rotates water from the drop former passes through the only slot on the overflow tank located below the applicator tank.

The water collector by the over flow tank is recycled.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION.

The rainfall simulator was designed and constructed using galvanized iron. The water pump 2horse power was connected to a power source. The water pump operated.

The orifice and the nozzle were constructed of brass due to its resistance to corrosion.

The result of the rainfall simulator when operated was that water passes form the tank through the pipes is not the orifice and the drop former simulated the iron.

The frame of the simulator is very study and heavy. It can withstand reasonable wind pressure. It is suitable for both laboratory and field use.

4.1 Cost Analysis

i. Cost of Production of the Simulator

No.	Items	Quantity	Unit cost (₦)	Total cost (₦)
1	Pressure pump	1	13,500	13,500
2	Electric motor with speed reducer (0.3 KW)	1	15,000	15,000
3	Steel angle sections	3	120.00	460.00
4	Hose ($\frac{1}{2}$")	5m	200.00	1,000
5	Galvanized pipe ($\frac{1}{2}$")	1 length	1,200	1,200
6	Galvanized pipe ($\frac{3}{4}$")	11m	3,500	3,500
7	Bearing housing	1	300	300
8	Galvanized sheet (4'x 8') G. 20	1	3,500	3,500

9	Sprockets (14 teeth and 44 teeth)	2	500	1,000
10	Chain (bicycle chain)	1	300	300
11	Square steel pipe (1"x 20')	3	1,600	4,800
12	Tapered roller bearing	1	100	100
13	Bolts and nuts	2 dozens	30	720
14	Paint and brush	1	500	500
15	Welding electrodes	1 packet	750	750
18	Fittings	Nos	1,160	1,160
19	Union connector ($\frac{3}{4}$")	3	100	300
20	socket ($\frac{1}{2}$")	1	150	150
21	Copper rods for drop formers	2	350	700
22	Saw blades	2	150	300
23	Sealant for drop formers	1	400	400
24	Tin of putty	1	150	150
25	$\frac{1}{2}$"x$\frac{3}{4}$" elbow	1	150	150
26	yarn	1	100	100
27	switchboard	1	750	750
28	$\frac{1}{2}$"x$\frac{3}{4}$" elbow	1	150	150
29	Wire	10m	40	440
			Total	**N 50,790**

4.2 Labour cost analysis

The cost of transportation of materials which is not included. A technician earning N1000.00 per day can successfully construct this machine in ten days. Therefore N10,000.00 is the estimated cost of production of this machine.

If maintenance and repair cost is assumed to be 10% of the total cost. It means that N5,079.00 would be spent on maintenance and repairs. Hence the total cost of the simulator is N55, 869.00 as analyzed below:

Cost of materials	- N50,790.00
Cost of labour	- 10,000.00
Maintenance cost	- N5,079.00
Total cost	- N65,869.00

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion.

A rainfall simulator was constructed using galvanized steel. The construction is cost effective considering the imported option which runs into hundreds of thousands of American Dollars. It is more expensive when the current used is either generators or battery. In fact, the more accountrement and accessories the more expensive.

5.2 Recommendations

Further improvement should be done on the rainfall simulator by the production of more nozzles. Soil test could also be run to further the enlightenment, with respect to soil erosion and soil conservation studies.

Due to the expensive nature of the rainfall simulator and its diverse uses, professionals like Electrical, Mechanical, Agricultural Engineers and related fields can come together to further the research.

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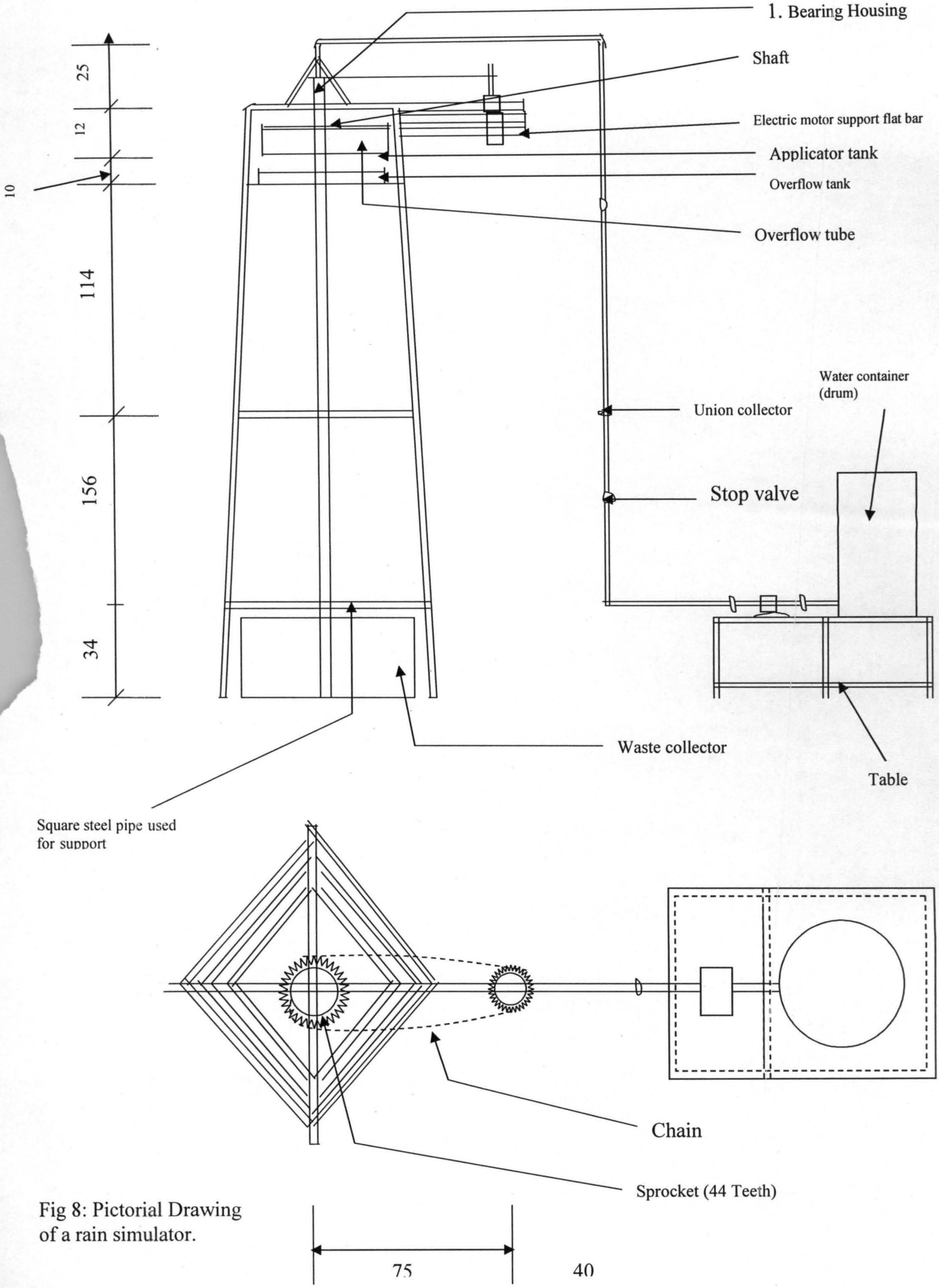
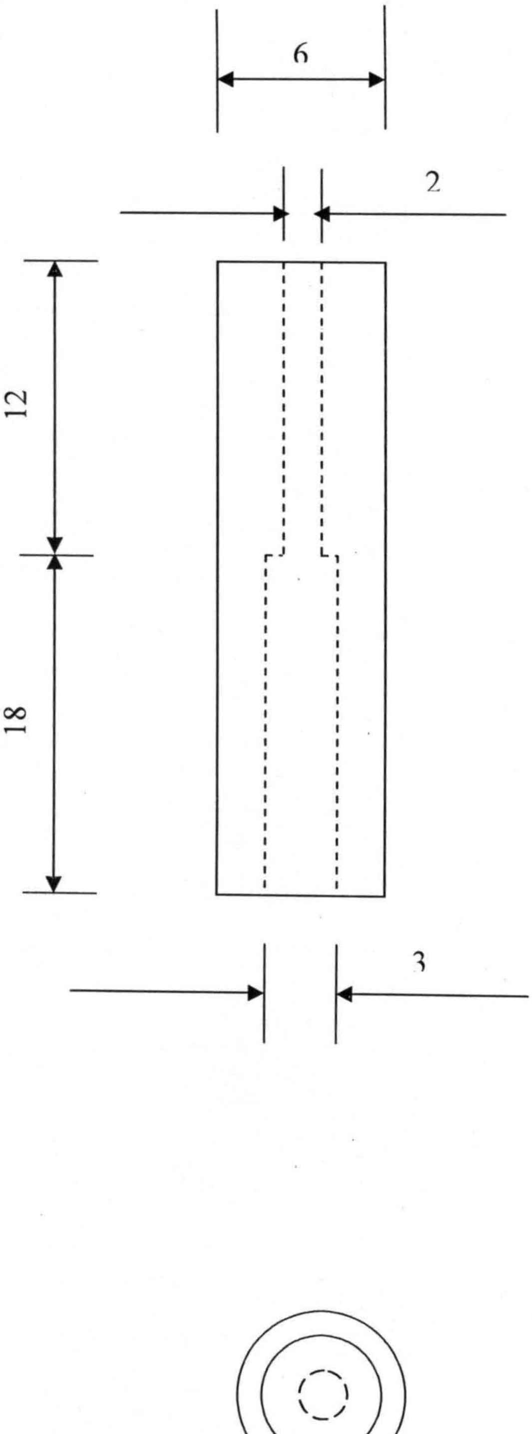
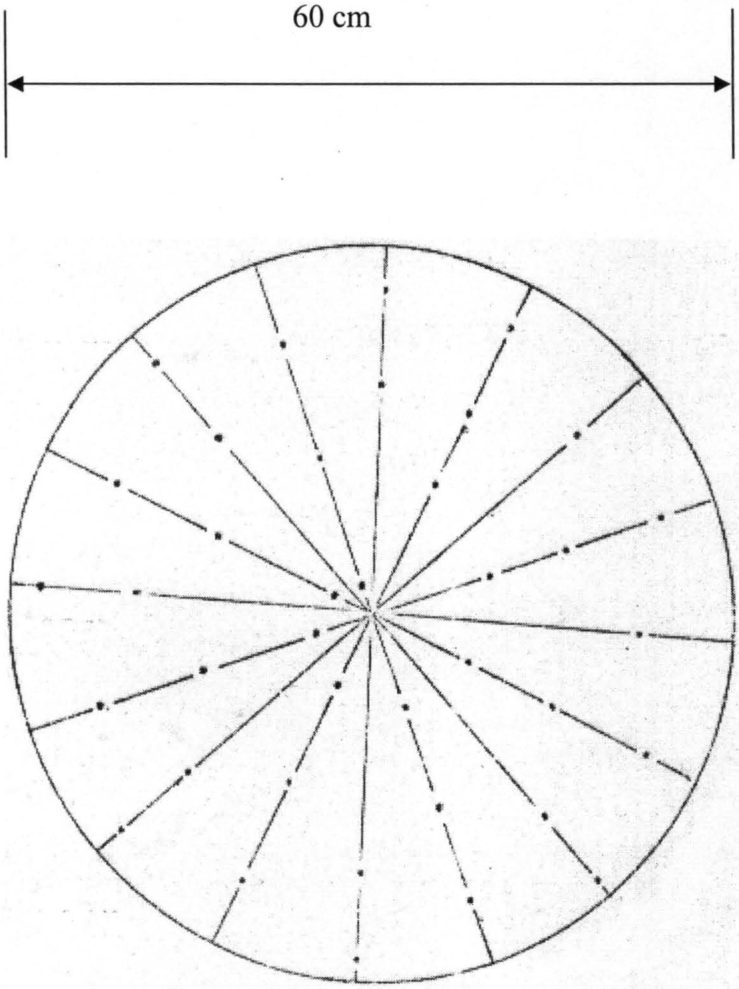


Fig 8: Pictorial Drawing of a rain simulator.



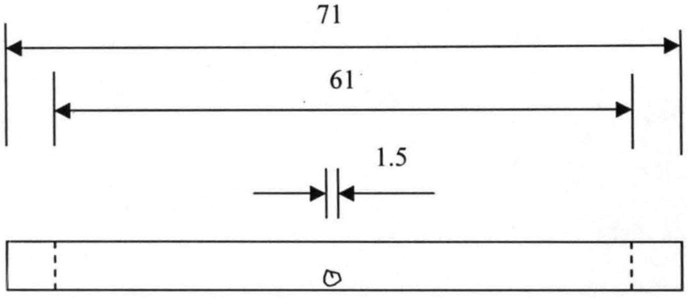
SCALE Imm: 0.5mm
All dimensions in mm

FIG 9: DROP FORMER

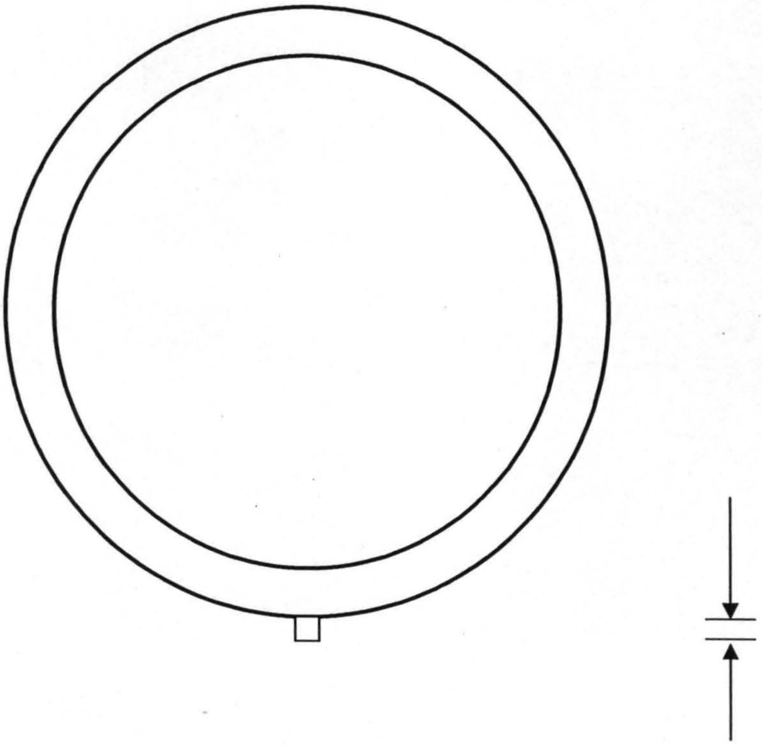


SCALE: 1mm: 0.5mm

Fig 10 HOLE SPACING FOR THE DROP FORMER

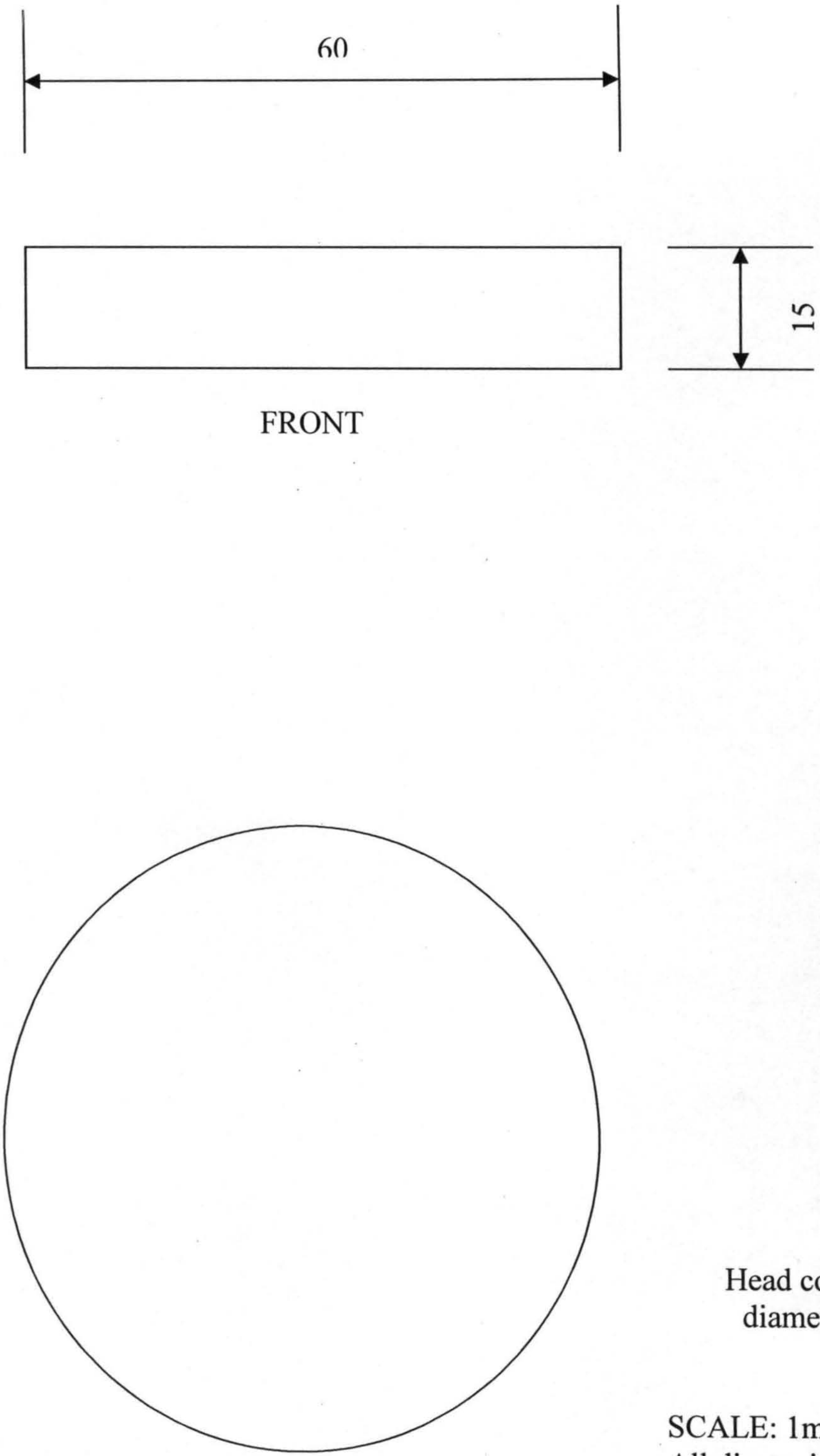


FRONT



SCALE: 1mm: 1cm
ALL DIMENSIONS IN MM

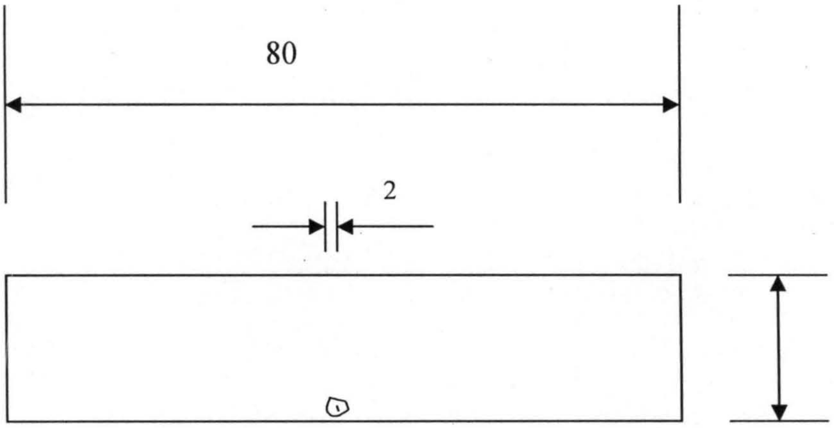
FIG 12: OVERFLOW TANK



KEY
Head control tubes of
diameter 1cm each

SCALE: 1mm: 1cm
All dimensions in 1mm

FIG 11: APPLICATOR TANK



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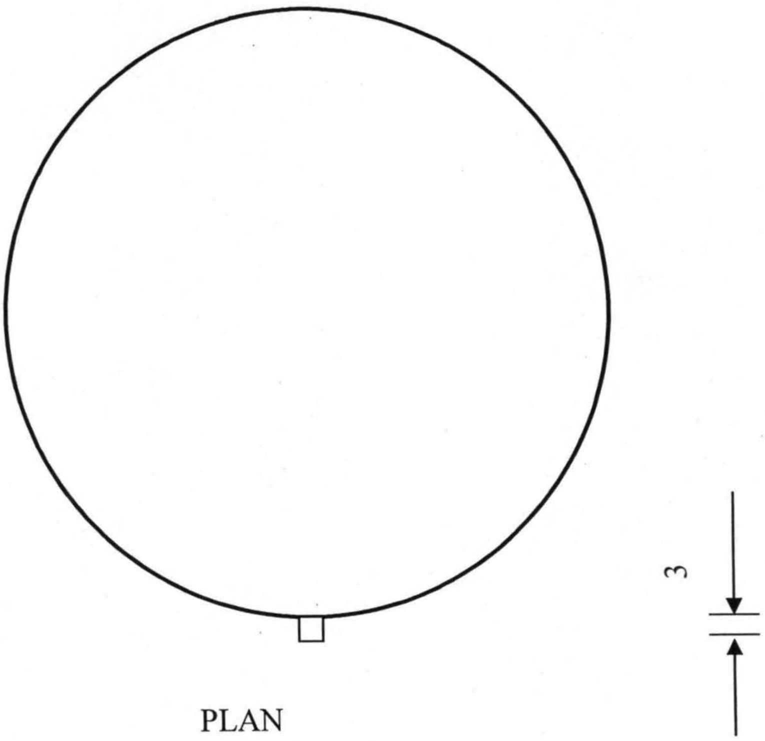


PLAN

SCALE: 1mm: 1cm
ALL DIMENSIONS IN MM

FIG 13 WASTE WATER COLLECTOR

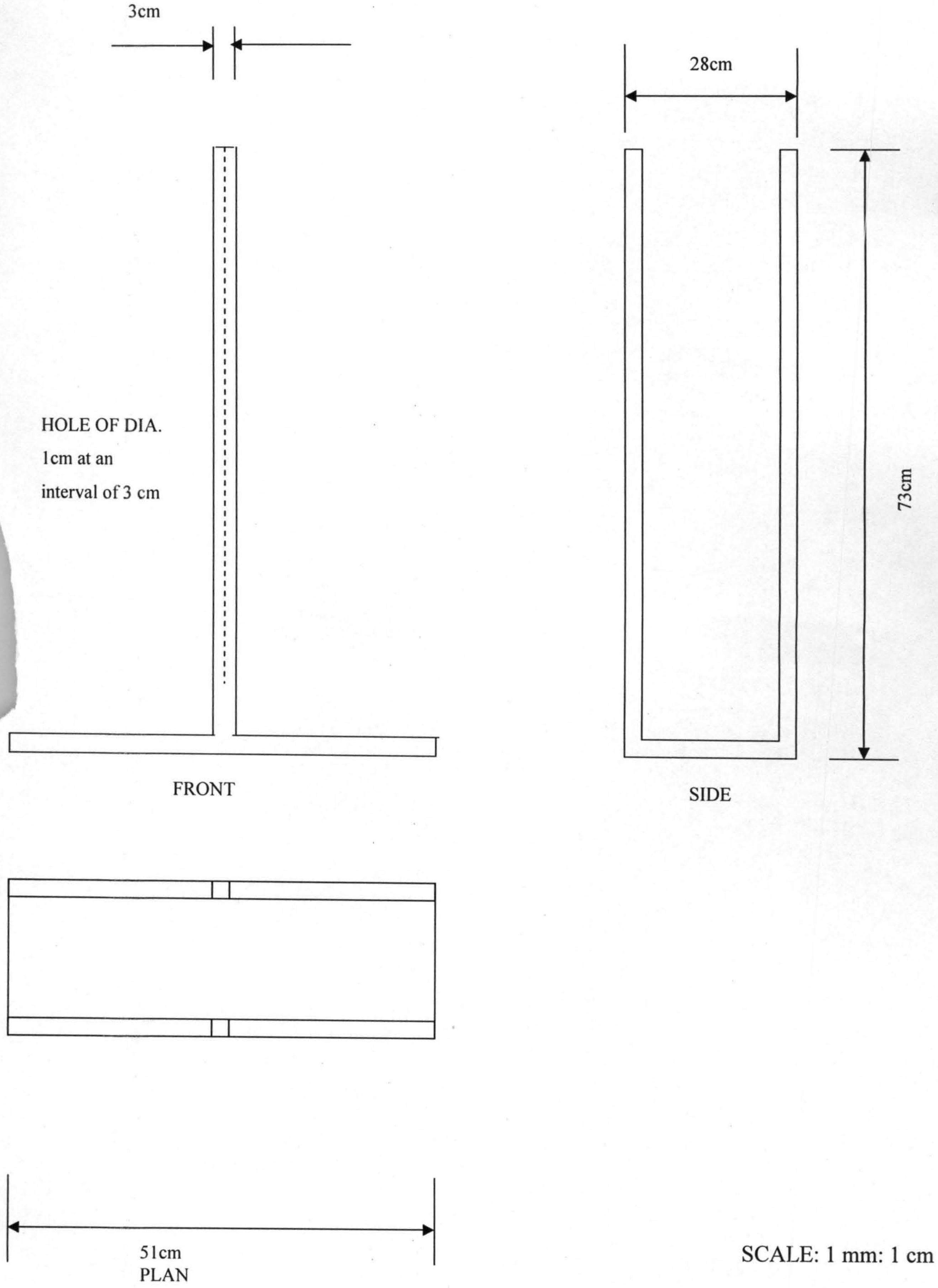
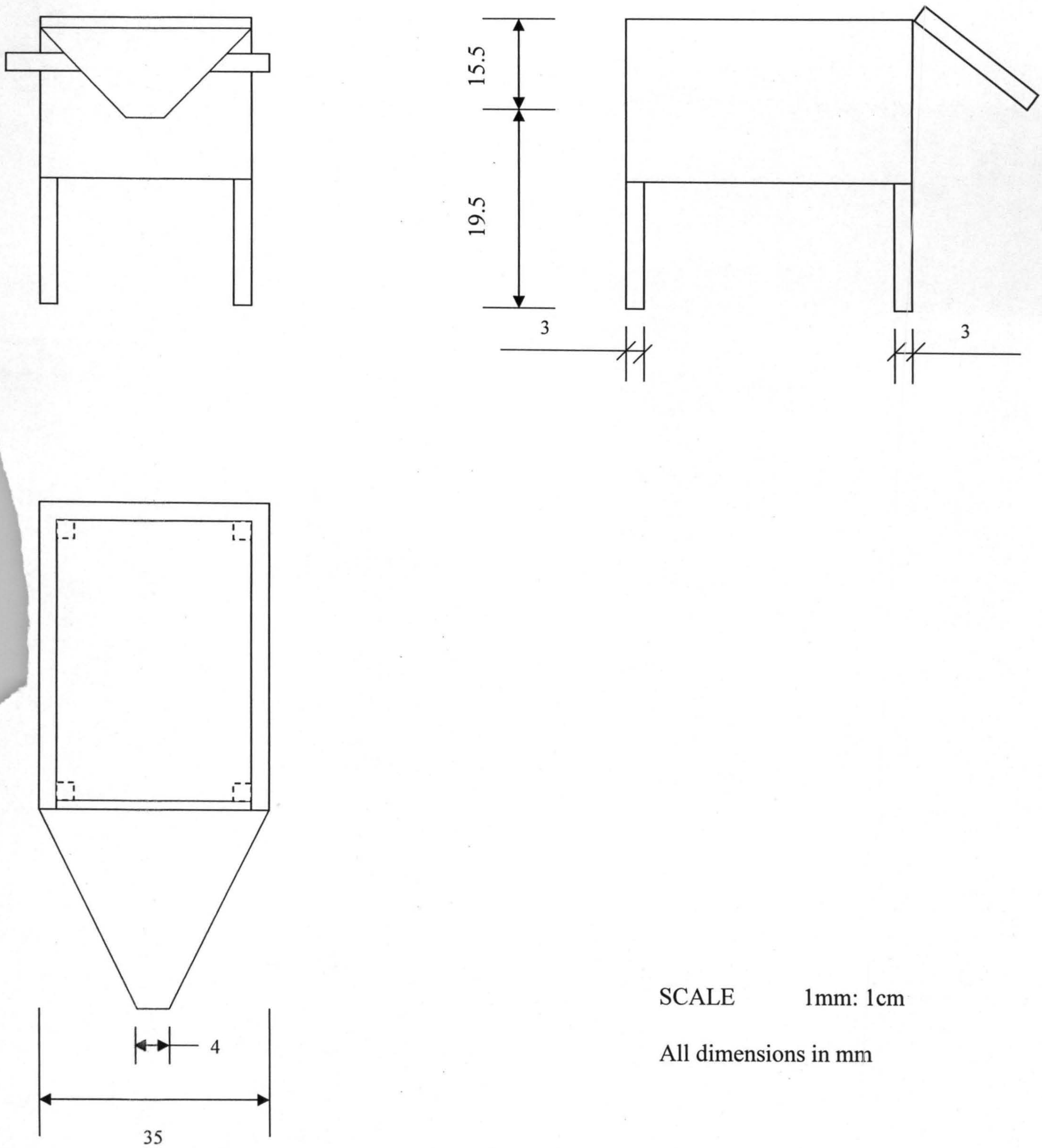


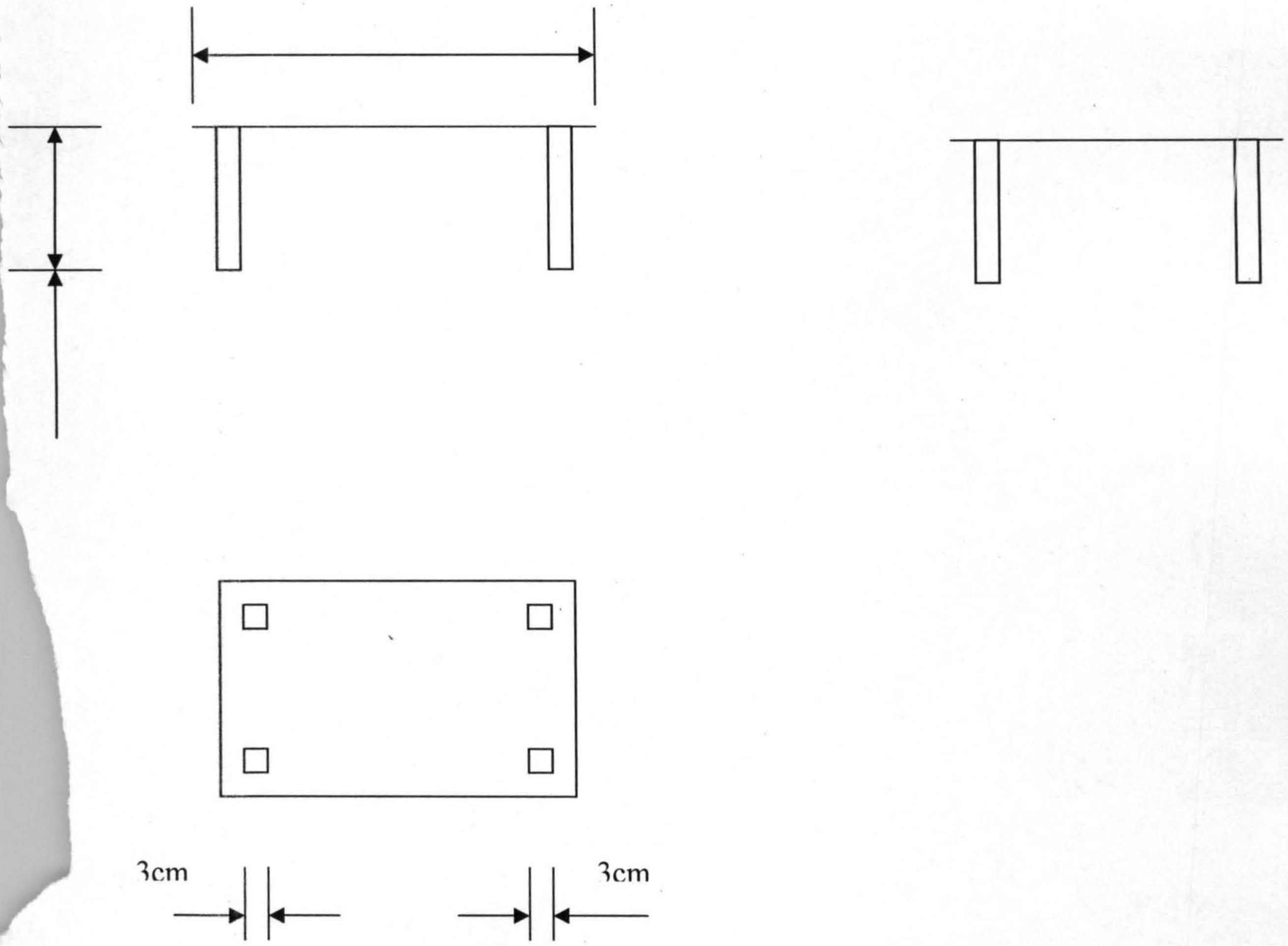
FIG 14: SLOPE ADJUSTMENT STAND



SCALE 1mm: 1cm

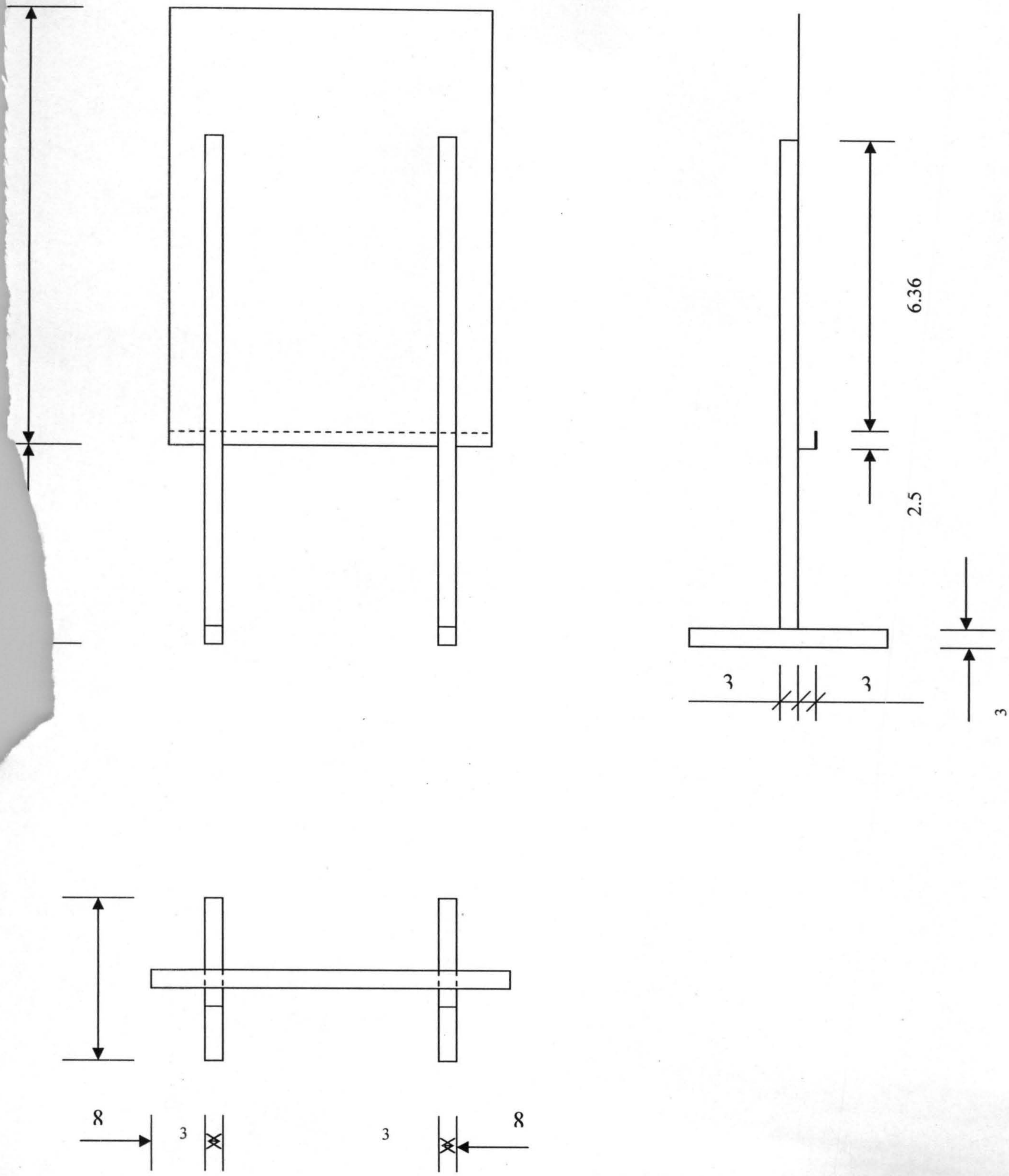
All dimensions in mm

FIG.15 SOIL BIN



SCALE: 1cm: 1cm

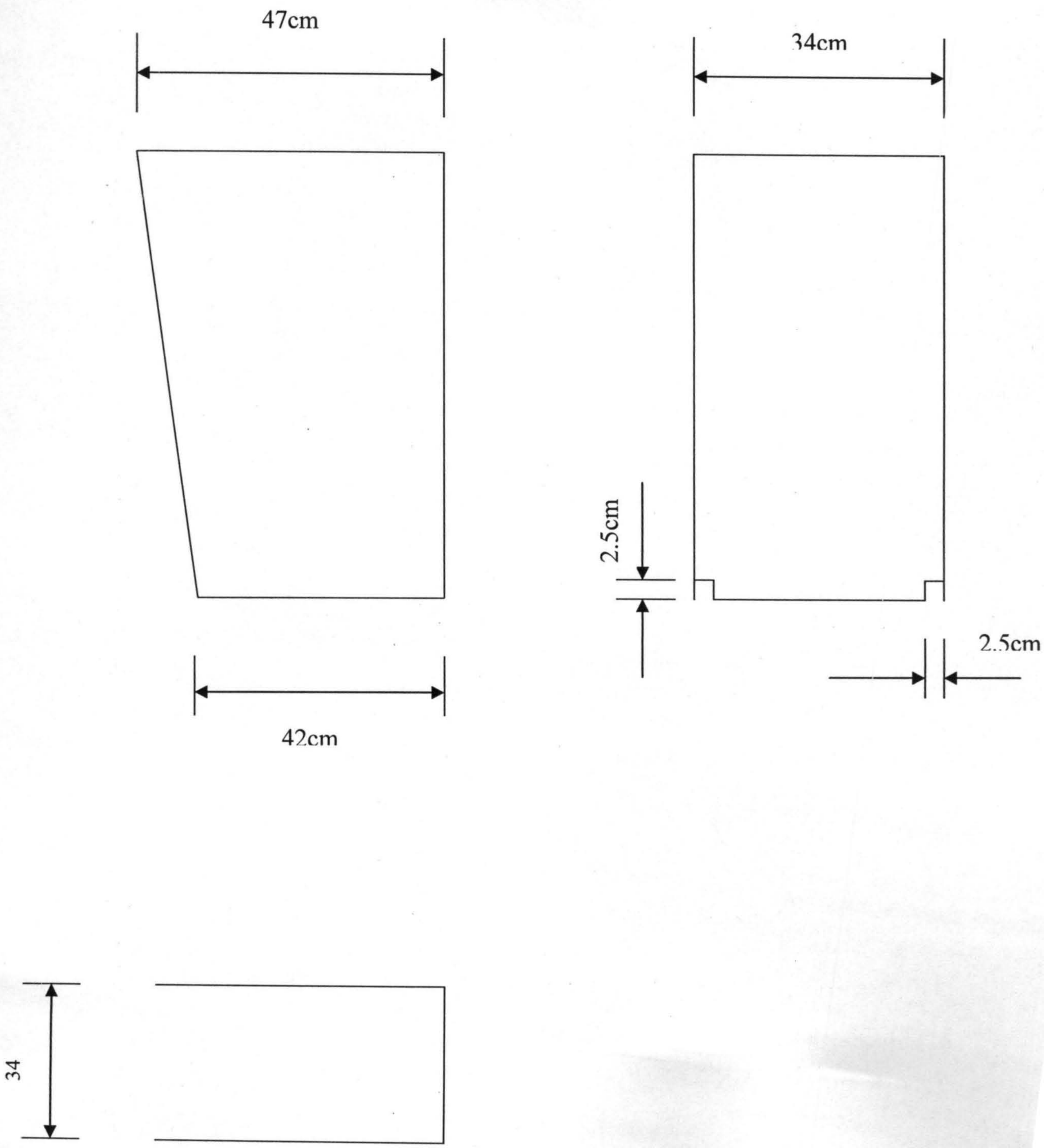
FIG 16 SOIL SCREEN



SCALE: 1mm: 1cm

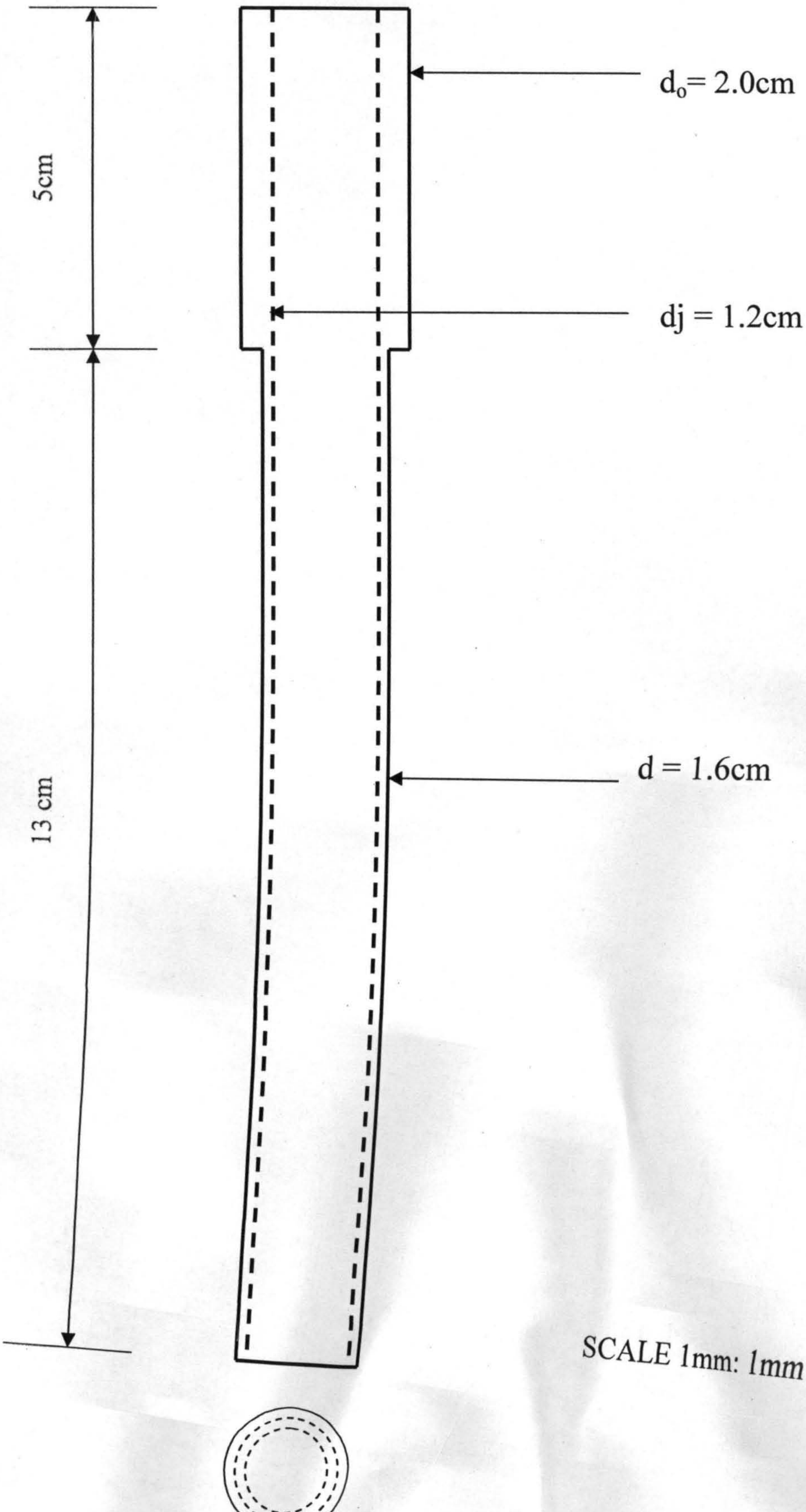
All dimensions in mm

FIG 17 SPLASH SHIELD



SCALE: 1mm: *1cm*

FIG 18 SPLASH SHIELD



G 19 FRONT VIEW AND
AN OF THE SHAFT