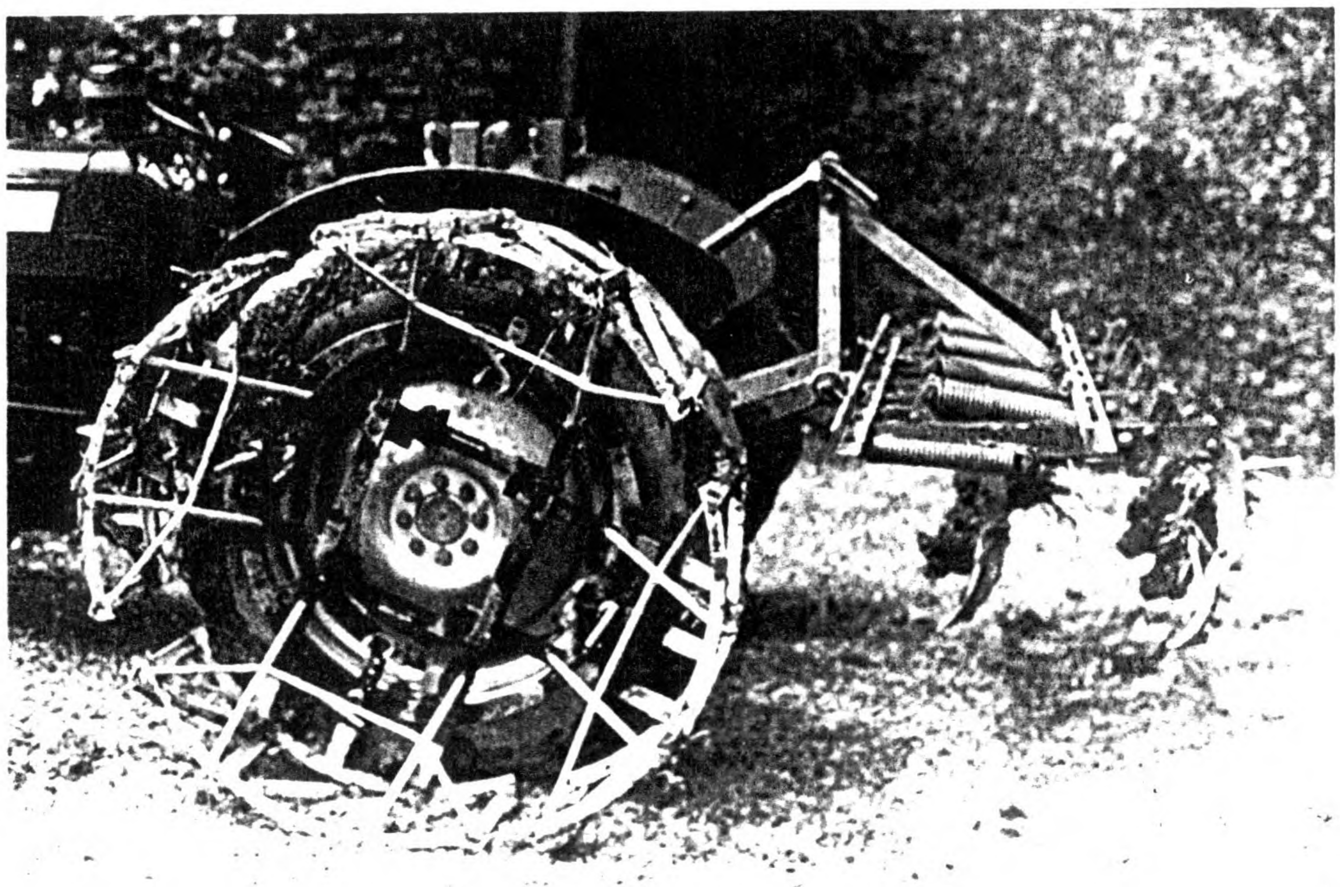


FINAL REPORT

30th April 1999

Contract Number : RG/97/AG/02

Title of Project :

Development of swinging Lugs reversible Cage wheels for small and medium power Tractors

Institute where Research is being carried out :

Dept. of Agric. Engineering , Faculty of Agriculture , University of Ruhuna .

Chief Scientific Investigator

Dr. P. L. A. G. Alwis

Date of award of the grant

15th January 1997

FINAL REPORT

A.

1. A). **Contract Number** : RG/97/AG/02

   B). Title of Project : Development of swinging Lugs reversible Cage wheels for small and medium power Tractors

   C). **Institute where Research is being carried out** :
   Dept. of Agric. Engineering
   Faculty of Agriculture , University of Ruhuna .

   D). **Chief Scientific Investigator** : Dr. P. L. A. G. Alwis

   E). **Date of award of the grant** : 15th January 1997

   F). **Date of completion** : 15th January 1999

   G). **Total Allocation** : 1997 : RS 243750.00
   1998 : RS 95000.00 + 25000

   H). Amount spent : Total

   I). No of Research assistants/Technical Assistants and period of service: One Technical Assistant for 6 month

2. Description of Research carried out : (See Page 1 - 29)
3. Results obtained : (See Page 30 - 85)
4. Conclusions : (See Page 85)
5. Relevant literature references : (See Page 88-102)
6. Is the Research work is on schedule : Yes
   Forward the Progress Report: (see next page)

B. (Annexes)

C. (Annexes)

D. (not relevant)

FINAL REPORT

Contract Number : RG/ 97/ AG/02

Title of Project : Development of swinging Lugs reversible Cage Wheels for small and medium power Tractors

Institute where Research is being carried out : Dept. of Agric. Engineering
Faculty of Agriculture
University of Ruhuna

Chief Scientific Investigator : Dr. P.L.A.G. Alwis

Signature

Date 10/5/99

Forward the Progress Report:

Comments of the Head of the Department Dr. P.L.A.G. Alwis has designed and field tested a cage wheel for both two and four wheel tractors. This is a significant contribution to improve Rice Agronomy in the region. It has given a good solution to a burning problem in wetland rice and the report is recommended [illegible] be forwarded.

Signature of Head of Department

Prof. [illegible] Head / [illegible]

Dr. Alwis has made excellent progress in his research project. Final report is recommended to forward [illegible].

Signature of Dean of the Faculty

Date

25-05-99

2. DESCRIPTION OF RESEARCH CARRIED OUT :

2.1. INTRODUCTION

Historically the agricultural systems of the country based on the rice based cropping systems, which make Sri Lankans one of the most experienced rice growing nation. Considerable land area that is 7,300,000 ha (11.3% from total land area of the country) has been used to cultivate the paddy in 1997. But, due to the poor productivity , paddy farmers were unable to supply the demand of the country.

machinery application for land preparation is one possible solution in order to improve timeliness in operation and land and labour productivity. Application of small and medium power tractors for paddy land preparation has become more popular in Sri Lanka and the use of small and medium power tractor has increased exponentially over the past decade as farm mechanisation has taken place.

Various kinds of research projects are being carried out by manufactures and researchers all over the world to improve the efficient use of tractors in farm operations. The performances of a tractor depend on a number of parameters, but the soil surface on which the tractor operates is the main factor affecting efficient or inefficient operations. It is already well understood that a tractor with ordinary high lugged rubber tiers performance poorly in wetland operations due to slip and sinkage (GEE CLOUGH 1980) To overcome this problem, different types of traction aids have been introduced including chains , Tracks and cage Wheels.

For paddy fields above traction aids become important for improving traction, since tire performs poorly in Wet land operations. In our country most popular Traction aid is Cage wheel due to its easy fabrication, Cheaper costs and

easy maintenance. Also it significantly reduces soil compaction in soft soil conditions and its can use with the tire mounted along side. But the present available cage wheels called "Mud wheels" in Sri Lanka for four wheel tractor have smaller outer diameter than the tire to facilitate road transportation. Therefor when operating in the field tires touches the hard pan first and high slip take place. Because of this high travel reduction is occurred and wasted additional time, fuel and labour. It is a considerable economic losses for Farmers and tractor owners. Therefor present available cage wheel should be still further developed to improve its performance.

2.2. OBJECTIVES OF THE STUDY

2.2.1 General objectives

Design and develop a suitable mechanism for a folding type cage wheels for small and medium power tractors.

2.2.2 Specific objectives

1). Design and construct a folding type cage wheels for :

a) . Two wheel tractor

b) . Four wheel tractor

and introduce a simple mechanism for wheel expansion.

2). Compare the performance of the above designed cage wheels with conventional cage wheel .

3). Find the easy ways of fabricating the cage wheel with minimum cost in a village level work shop.

2. To make recommendations for further developments and modifications of the wheel in order to find the possibility of adapting in difficult soil conditions.

2.3. METHODOLOGY

2.3.1. STUDY THE FEATURES AND MECHANISM OF THE CONVENTIONAL CAGE WHEELS

For wet land operations Cage wheel become important for improving traction. The popularity of the cage wheel is due to its easy fabrication , cheaper cost and easy maintenance. It can use with the tyre mounted along side and it can be removed whenever necessary.

2.3.1.1. Conventional Cage wheel for 2 Wheel Tractor:

The present available cage wheel for Two wheel Tractor has larger outer diameter than the tyre is not to facilitate road transportation due to its unfolding ability. In order to fix the cage wheel the tyres need to be removed. This is too laborious as far as the farmer is concerned to be considered practical, and also it waste additional time in the field . So this type of cage wheel is needed having folding mechanism, or retractable lugs by which it can achieve larger outer diameter only when operating in the field . (see photo:1 and figure:2.1)

2.3.1.2. Conventional Cage wheel for 4 Wheel Tractor:

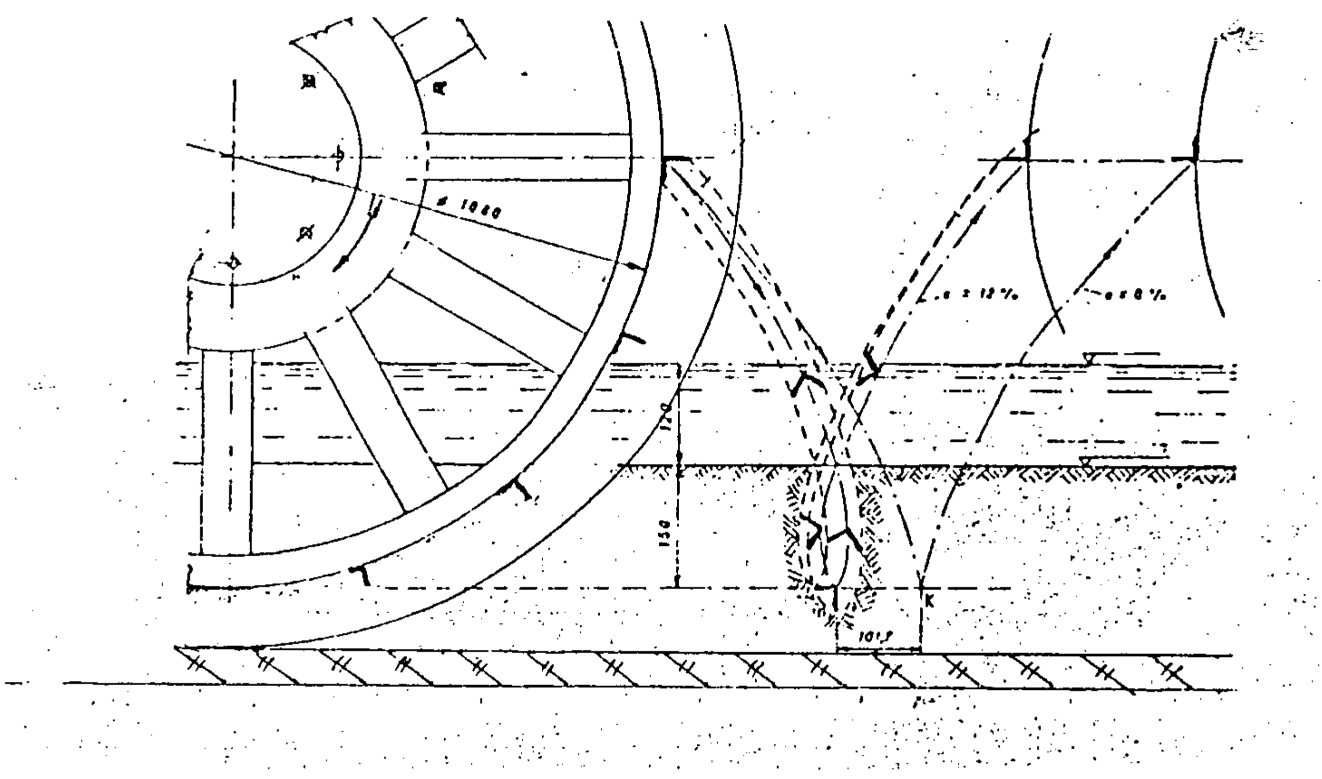


Figure: 01. Conventional Cage wheel for 4 Wheel Tractor in the field

The present available cage wheels for , 4 Wheel Tractor (see fig:2.2, 2.3 and photo:2) have smaller outer diameter than the tyre to facilitate road transportation . Therefore, when operating in the field , tyre touches the hard pan first and high slip was observed. (see figure: 1). Because of this, a cage wheel is needed having retractable lugs by which it can achieve larger outer diameter only when operating in the field.

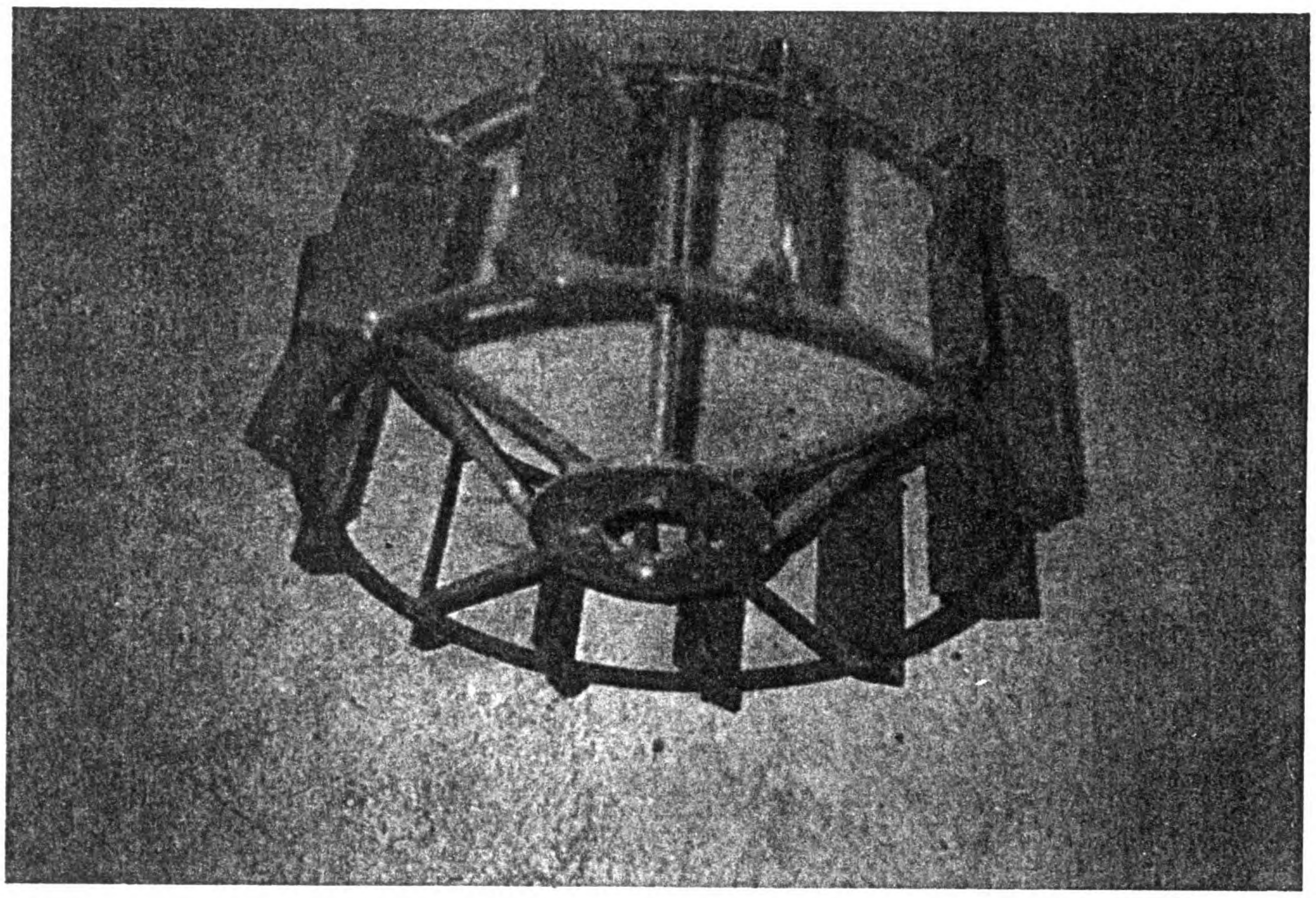


Photo 01: Conventional Cage wheel for Two wheel tractor

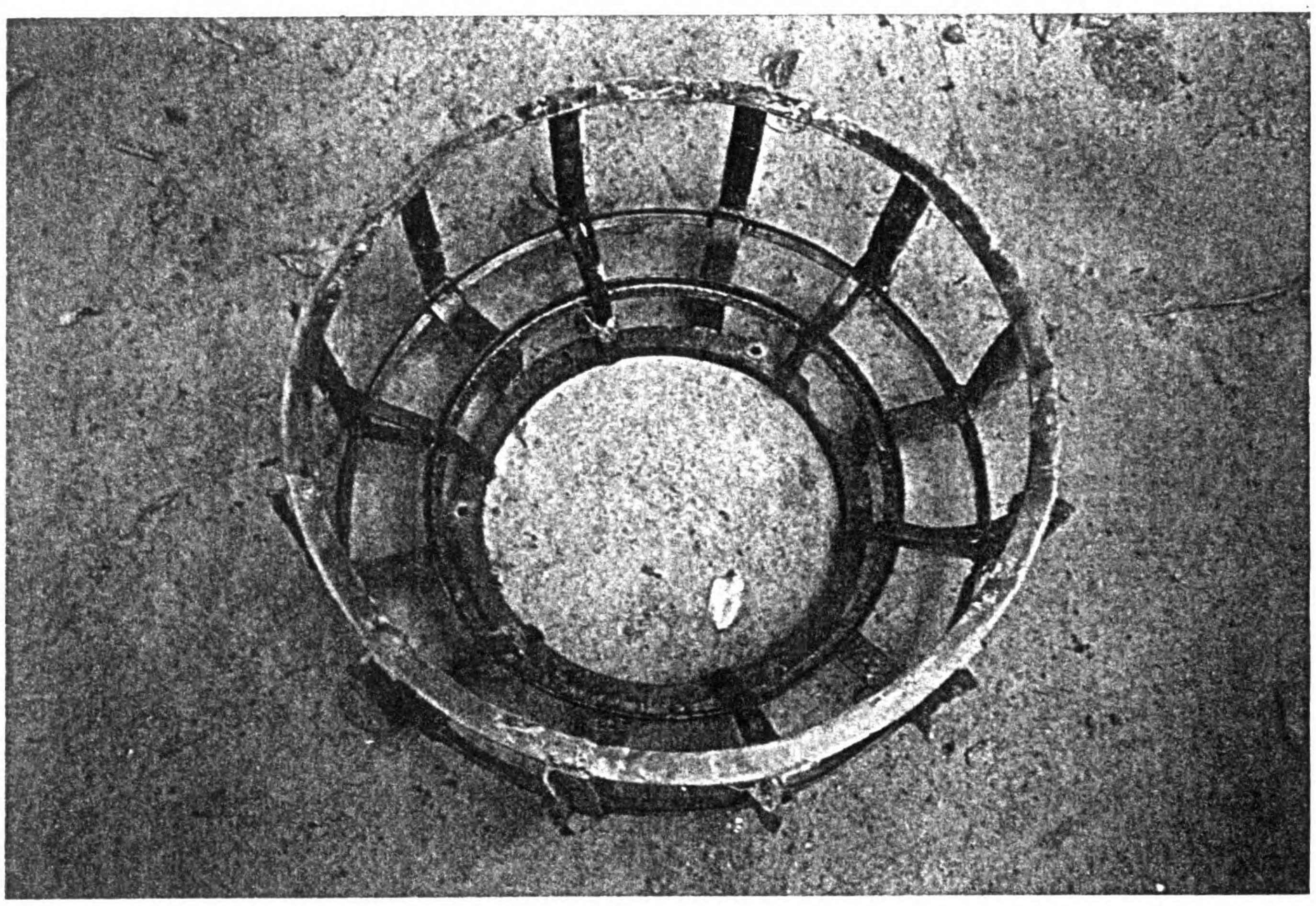


Photo 02: Conventional Cage wheel for four wheel tractor

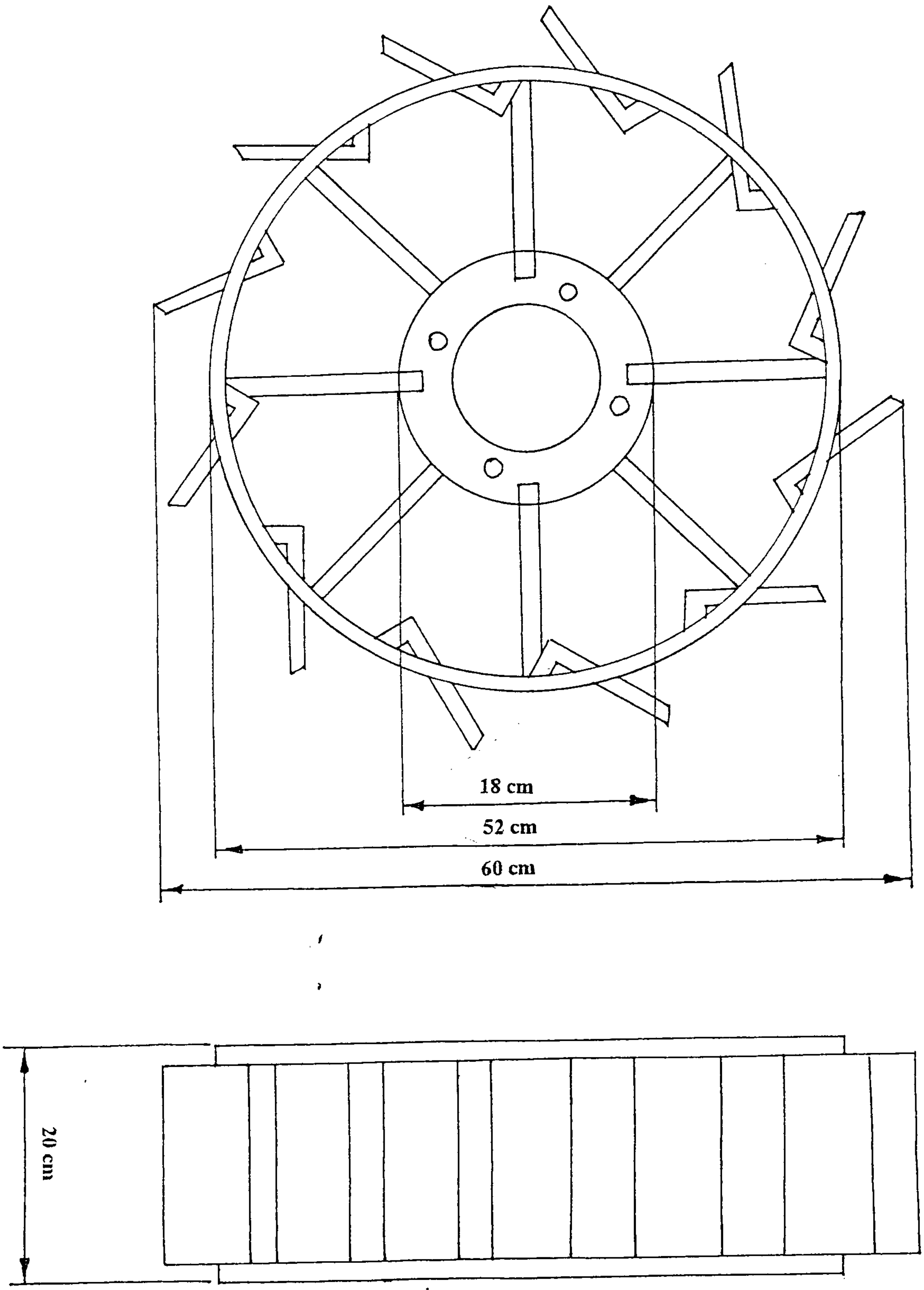


Figure 2.1A part drawing of the conventional cage wheel.

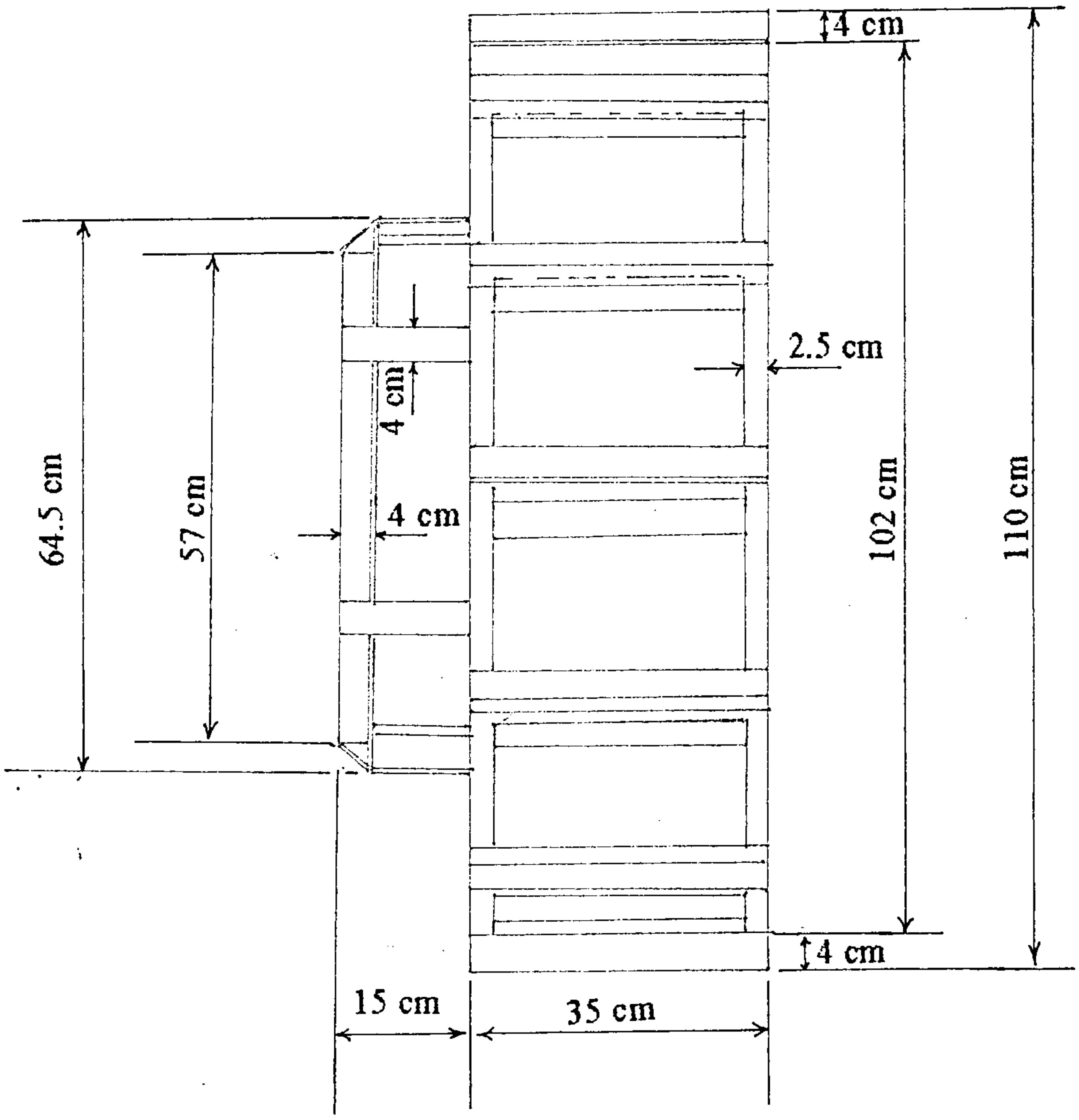


Figure 2.2 Side view of Conventional cage wheel

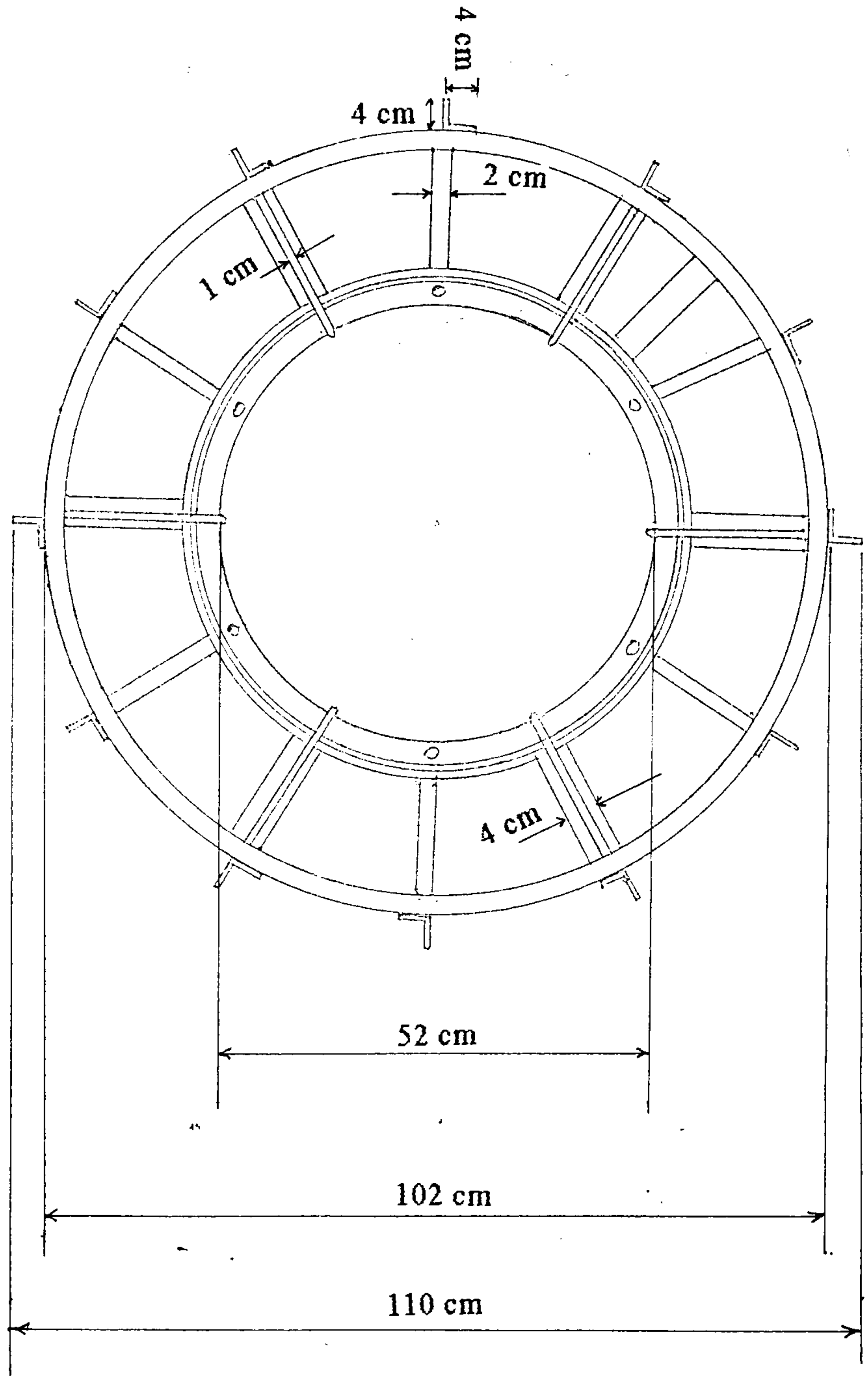


Figure 2.3 Plan of Conventional cage wheel

2.3.2. DESIGN DETAILS OF NEW CAGE WHEELS.

For this cage wheel design, some previous experimental results obtained were considered. As examples, Lug Angle, Lug spacing, Lug height etc. were selected according to previous results. According to figures:3 and 4 , two design were considered.

A M F 240, 4 wheel tractor and KUBOTA ,two wheel tractor were selected for test for wheel functioning . The dimensions of the cage wheels were chosen corresponding to the selected tractors size .

In this research, greater emphasis is given to provide a simple mechanism for retraction of lugs which farmer could readily employ in the field in addition , the design includes following features;

a). The lugs were able to be swing up to an angle of 30 degrees in both directions, facilitating reverse travel as well as forward travel. (for model-2)

b).The outer diameter of the cage wheel when expanded was greater than the tyre diameter an smaller when retracted, facilitating more traction in the field and also easy road transportation. (for model-2)

c). The effort required to retract the lugs was independent of the number of lugs. (using one operation, all lugs will be able to be retracted or expanded ; but in previous mechanism this had to be done individually for each lugs).

2.3.2.1. CAGE WHEEL MODEL 01

The part drawing of the Cage wheel model 01 is given in figure 3:. It consist of four main folders as shown in the figure. In fabricating the first model, a greater emphasis was given to reduce the wheel weight. Therefor , ` L` iron bars were used for outer cage and rolled to the correct diameters. A spring loaded key mechanism was provided to lock wheel for retracted or expanded positions . The key change could be done by pulling out the key from first key way and by releasing it directed to the next key way. In the modification stage "Umbrella" type lever was designed and introduced for wheel expansion or folding.

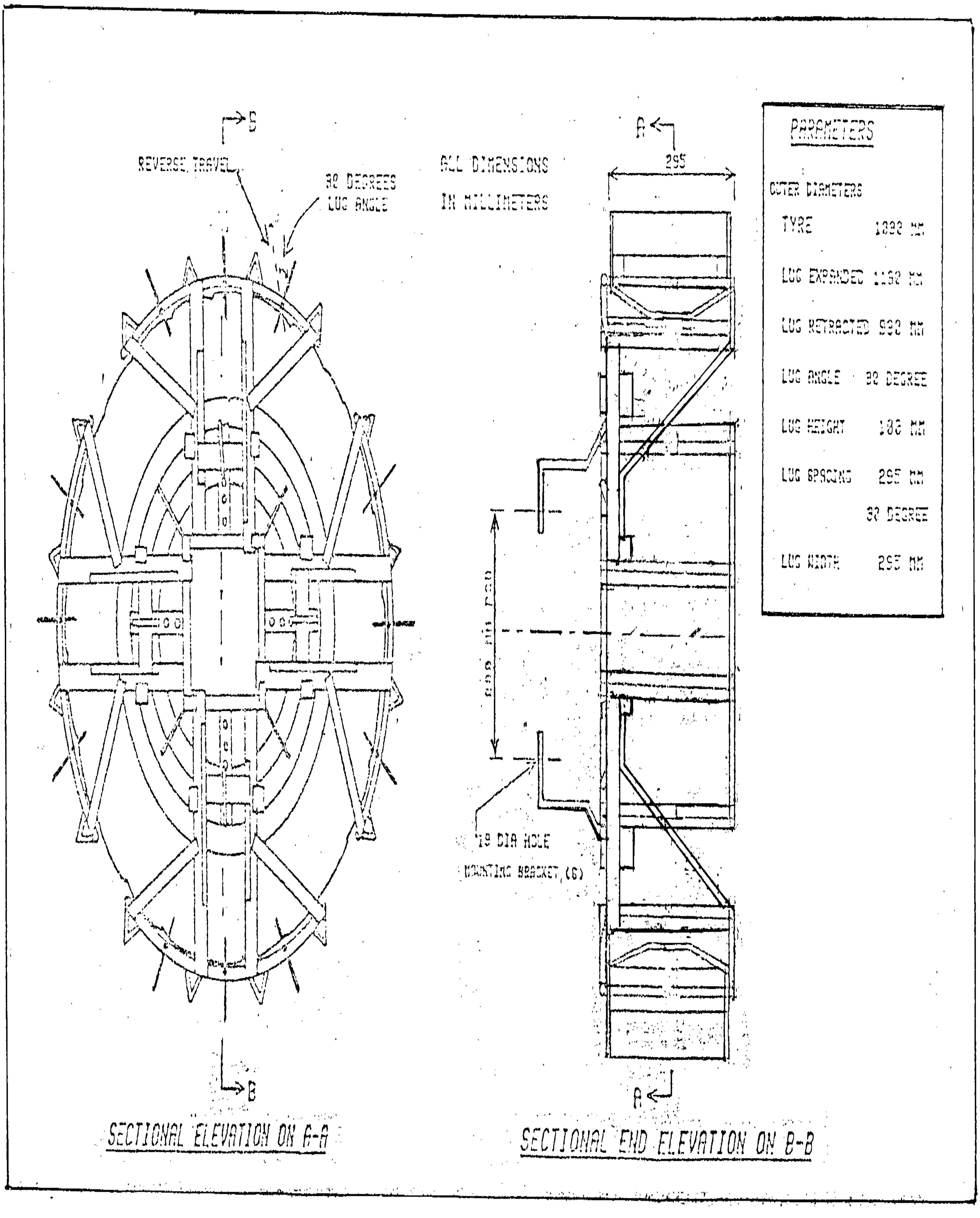


Figure. 3. The retractable lugged cage wheel- model 01.

2.3.2.2. CAGE WHEEL MODEL 02

The part drawing of the Cage wheel model 02 is given in figure 4. It consist of inner ring and outer cage as shown in the figure 4. The 16 lugs were hinged on the inner ring resting on cross bars of outer cage guiding the lugs when the wheel was expanding or retracting. The 6 pulleys were provided on inner side of the inner ring for facilitating a smooth rotation of the inner ring when the lugs were expanding or retracting.

2.3.3. CONSTRUCTION OF THE DESIGNED CAGE WHEELS

2.3.3.1. Developments of the first model Wheels

The cage wheels were designed for M F 240, four wheel tractor and KUBOTA diesel, two wheel tractor. The cage wheel outer diameter was selected as 100 millimetres smaller when it was retracted and 100 millimetres bigger when expanded, for road transportation and for field, respectively.

Because of the difficulties exist in estimating actual dynamic loads on some wheel parts, firstly, approximated values were used for design calculation and checked during first functioning test. After that, in the modification stage ,those parts were redesigned. (material use for conventional wheel also considered). Design of lug fame was one of the most important part design among others, since it takes the direct loads and also free to get directions while travelling. Also the cross bar and inner ring on which the lugs rest, considered important.

(for designed detail, see appendix A)

The whole procedure was followed according to the flow diagram shown in figure no : 05 .

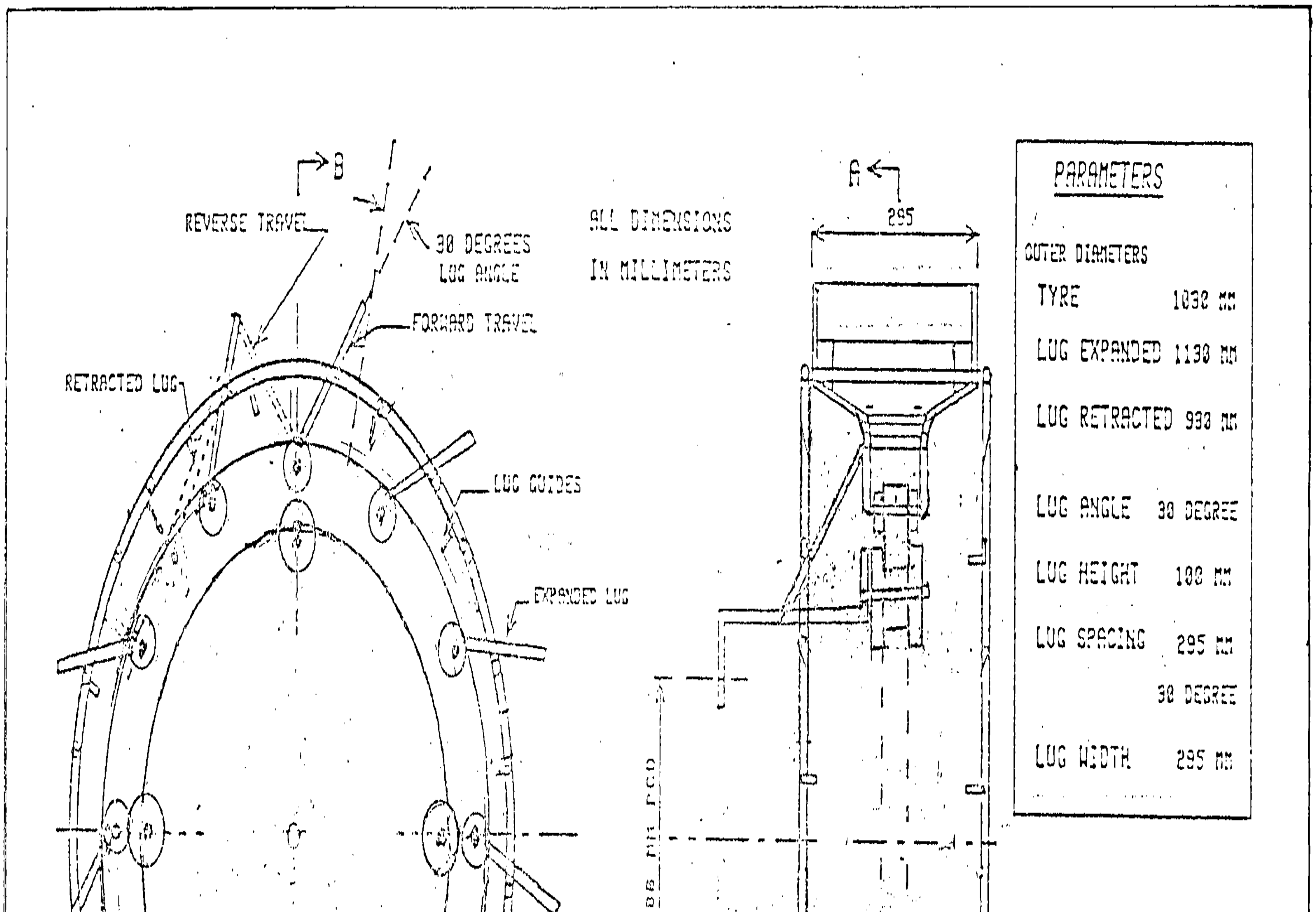


Figure. 4 The retractable lugged cage wheel- model 02.

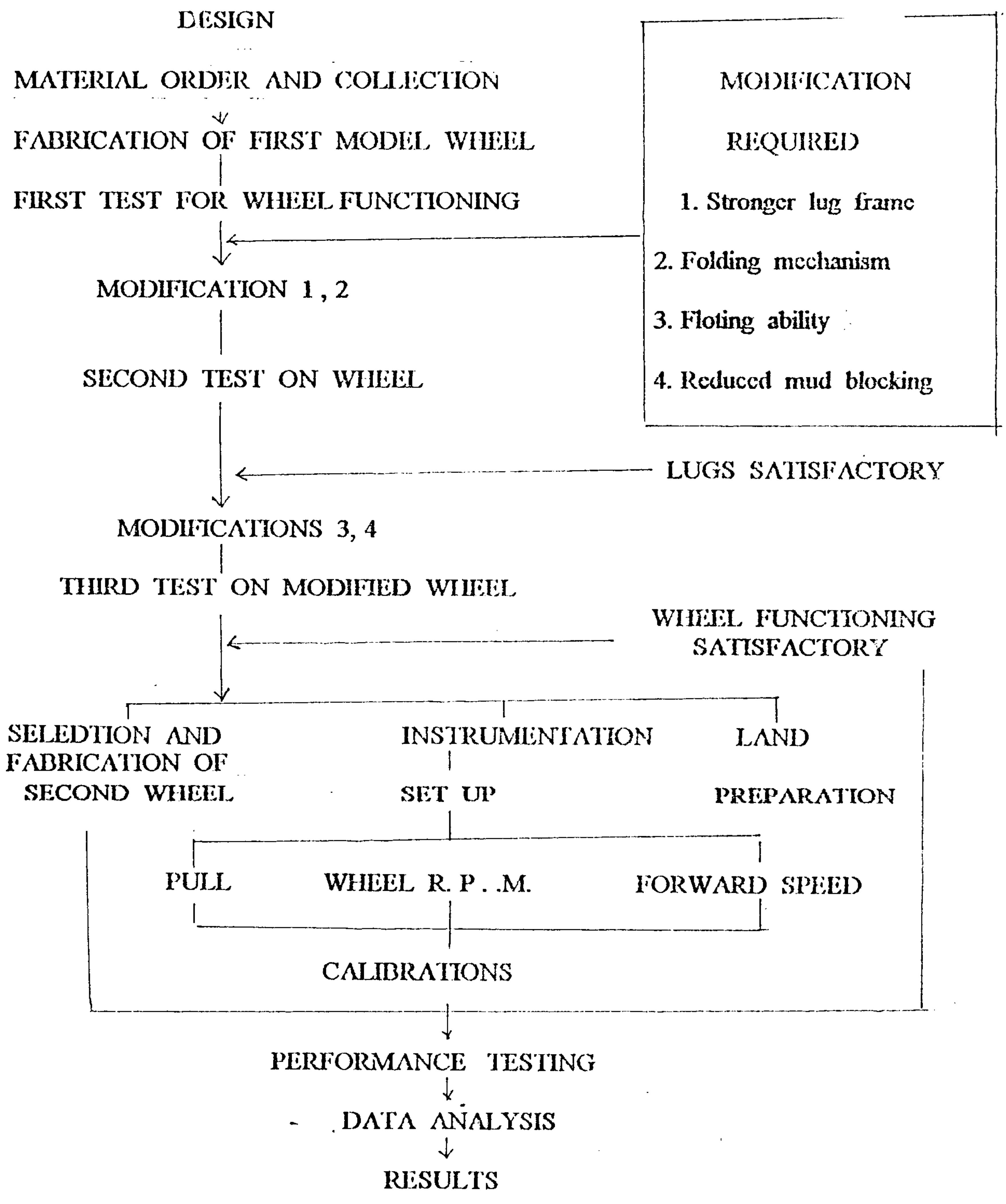


Figure : 05 Flow chart for work procedure.

2.3.3.2. First test for wheel functioning

The first model wheel was tested for road transportation and in a puddled soil condition to find any draw backs in functioning, For the road the wheel did not show any problem, but in few test runs in the paddy field condition , wheel shown that the necessity of more stronger lugs. Therefor the following modifications were done after the first test runs.

1. Stronger lug frame to avoid bending of lugs;
2. Key mechanism was design for easy engaging of inner ring;
3. add more lugs.

2.3.4. TEST OF TRACTOR PERFORMANCE

The designed cage wheels were tested for field performance in the following manner .

2.3.4.1. LAND SELECTION

Performance test of small and medium power Tractors with cage wheels were carried out during January 1998 to January 1999 in two blocks of lands in two different locations.

2.3.4.1.1. FIRST LOCATION (on Station Trial)

1st experiment was conducted at First location (Research farm of the Faculty of Agriculture at Mapalana) under controlled field condition. (See photo:3)

2.3.4.1.2. SECOND LOCATION (Farmer Trial)

2nd Experiment was conducted at Second Location (Mangalawela Paddy field at Akurassa) under practical field condition. (See photo:4)

Photo 03: On station Trial - Location - 1

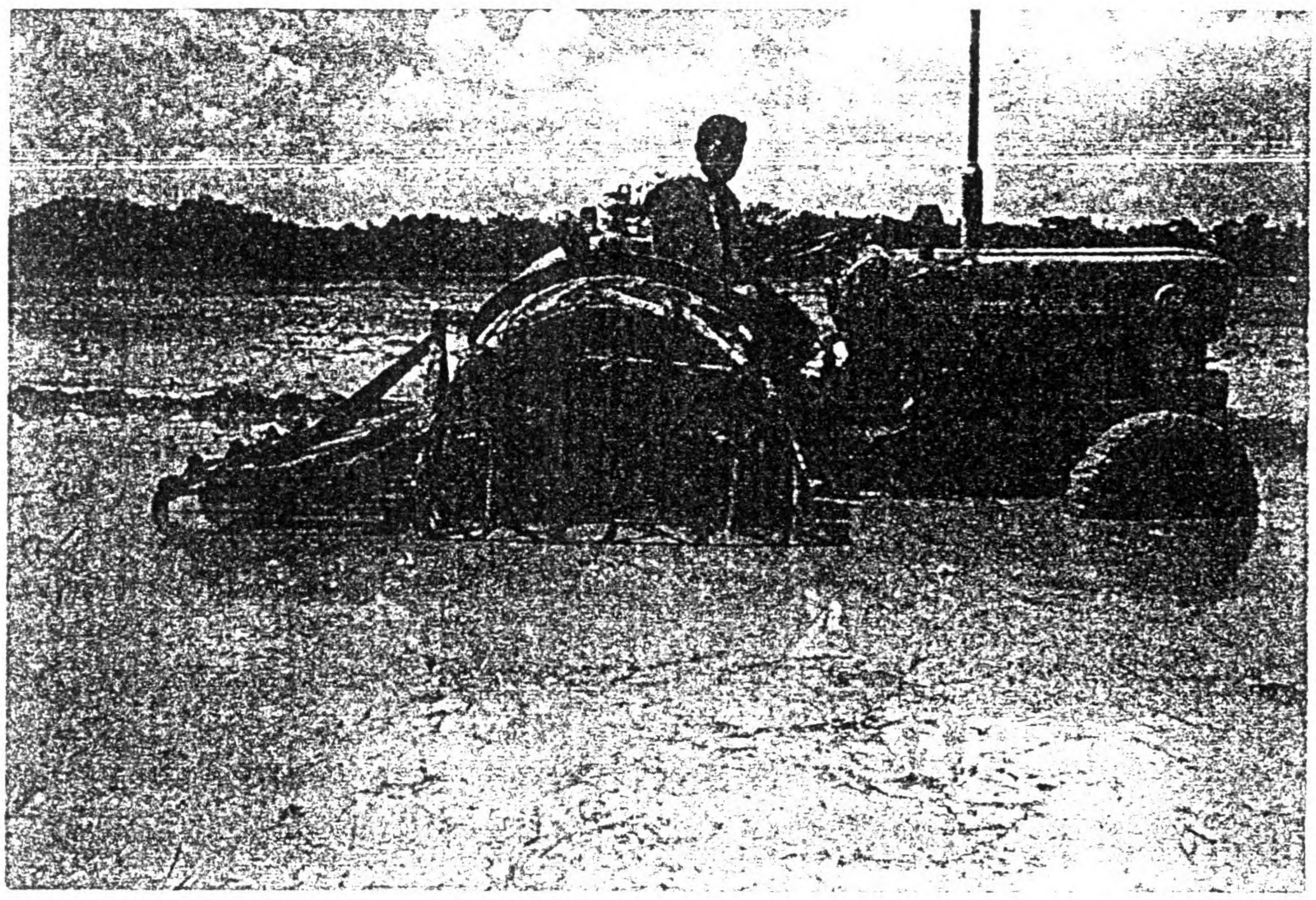


Photo 04: Farmer Trial - Location - 2

2.3.4.2. SOIL CONDITION FOR THE TEST

Mapalana and Akurassa area are located in the Agro -ecological region WL2. The predominant soil of these areas are Red yellow Podzolic soils with strongly motteled sub soils and low humic gley soils .

In order to ensure the uniformity of the soil condition throughout the field, following soil tests were conducted. For each test 3 random soil samples (or three replicates) of the each field strip were obtained and tested in Laboratary.

Those tests are given below.

1.	Bulk Density	by Core sampler method
2.	True Density	by specific gravity bottle method
3.	Plastic Limit	by Glass plate method
4.	Liquid Limit	by standard casagrande apparatus
5.	Soil Texture	by Sedimentation and decantation
6.	Soil Compaction	by standard Proctor mould
7.	Mechanical Analysis	by Dry and Wet sieving
8.	Ploughing depth	by profile meter and drop penitro meter
9.	Cone Index	by penitrometer (soil hardness)
10	Hard pan depth	by profilemeter
11.	Cone depth	by drop penitrometer (wet land soil hardness)

2.3.4.3. DESIGN AND LAY OUT OF THE EXPERIMENT

In order to achieve the objectives of the Research, each field trial was laid out using a Randomised Complete Block Design (RCBD).

2.3.4.3.1. Traction aid

1. Conventional cage wheel
2. Design cage wheel

2.3.4.3.2. Performance criteria

Effective Field capacity , Pull developed at 100% slip (maximum pull), time per hectare , travelling speed, travel reduction were considered as criteria for the evaluation of cage wheel. In additionally cost analysis also was effected for two traction aid. (Conventional and Designed).

2.3.4.3.3. Measurement and calculation

1. Maximum pull

In order to determine the maximum possible pull carried by each traction aids the testing tractor was set to pull another tractor (pulling tractor) which was connected to the drawbar of the testing tractor by a code with the dynamometer mounted front side of the testing tractor.

First the rear tractor was set in normal run and by gradual application of brakes or putting in to loads. The pull developed at 100% slip by testing tractor was obtained. In this case for the safety of the testing tractor rearward over turning possibility, as a safety measure tine tiller was mounted with the testing tractor. For each case testing tractor was set in no:1 high gear in constant engine speed.

Note: In this experiment of Four wheel Tractor, Maximum pull was not obtained. That is because of the testing tractor (with design cage wheel) had more traction power than pulling tractor (with conventional cage wheel) . Therefor when operating in the field high slip was observed in pulling tractor.

2 Travel Reduction (wheel slip)

Travel reduction or wheel slip is define as

Where as $S=1-Va/Vt$

S= Wheel slip or travel reduction

Va = actual travel speed

Vt = theoretical wheel speed = $r\omega$

r = rolling radius of wheel on hard surface

ω= angular velocity of wheel

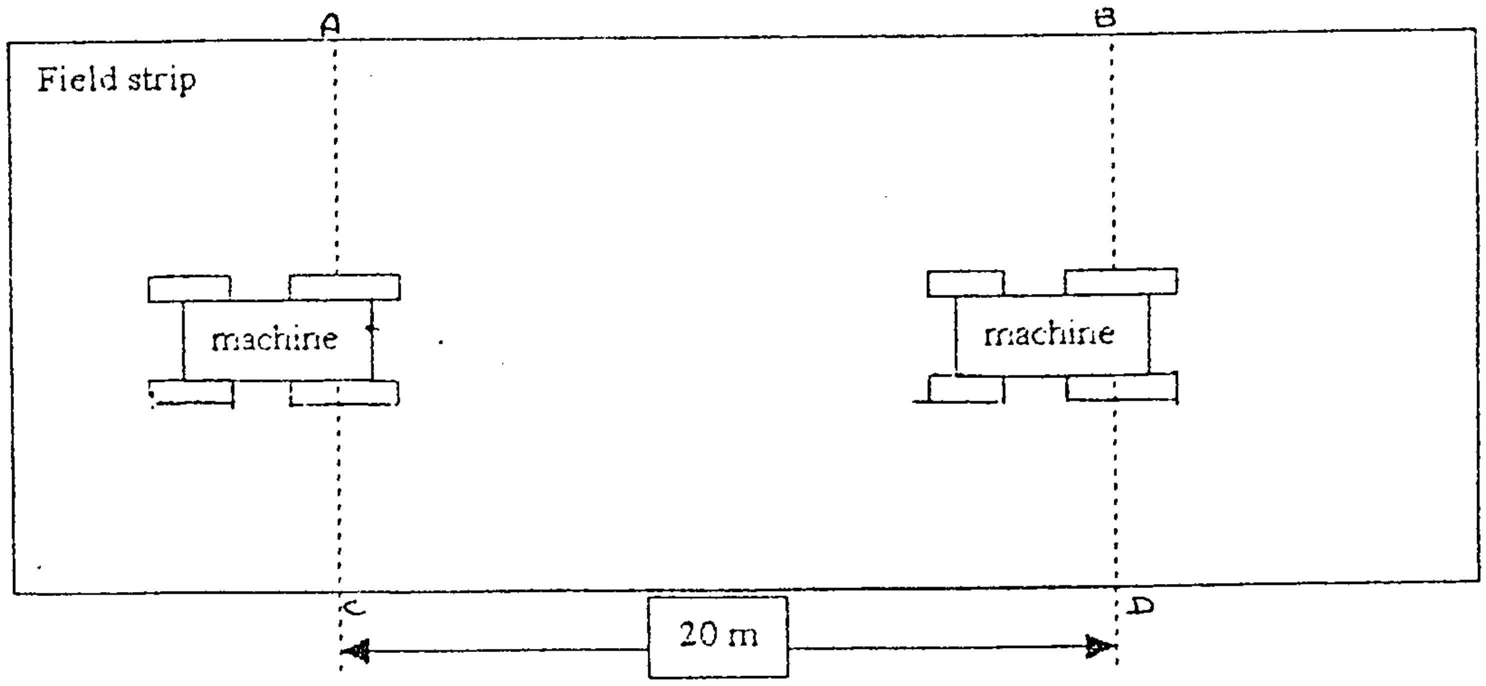
The term "rolling radius" is defined in ASAE 296.2 (ASAE standards 1985) as the distance travelled per revolution of the traction device divided by 2Π When operating at the specified zero condition. the zero condition here is the vehicle operating in a self-propelled conduction on a hard surface, such as a smooth road, with zero drawbar load. This differs from another common zero condition, which is the self-propelled, zero draw bar load condition on the test surface.

a) Measurement of theoretical speed (Vt) by track method

Out side the long boundary of the prepared tar track (road) two raining poles 20m apart , (A , B) were placed approximately in the middle of the test run.(fig: 06) On the opposite side also two poles were placed in a similar position ,20 m apart (C, D) so that all four poles form corners of a rectangle , parallel to at least one long side of the test plot. The theoretical speed was calculated from the time required for the tractor to travel the distance (20 m) between the assumed line connecting two poles on opposite sides AC and BD. The easily visible point of the Tractor was selected for measuring the time .(eg Rear axle point)

In this test, it was assumed that the travel reduction of the tractor on tar track was zero.

Figure: 06



A, B, C, D, -Ranging poles

b) Measurement of real speed (Va)

Above same procedure was continued on each experiment plots and real speed was calculated from the time required for the tractor to travel the distance (20 m) between the assumed line connecting two poles in each plot.

$$\text{So Travel reduction is (s)} = 1 - \frac{Va}{Vt}$$

3 Effective field capacity.

Time lost for every event such as turning, loading and unloading the machine with seed, seedling , fertilizer, harvest grain, adjustment, refueling, and machine trouble should be recorded. However in calculating field capacity the time consumed for real work and that lost for other activities such as turning, loading and unloading and adjustment depending on field and crop condition should be used. Time for refuelling should be deleted because usually filling-up before starting test can make refuelling unnecessary except for especially large field.

Time for rectifying machine trouble will vary widely to various factors and its inclusion in time factor some times unreasonably lowers the effective field capability.

$$S = A / Tp + T_l$$

S= Effective field capacity (ha/hr)

A= Area covered (ha)

Tp= Productive time (Hr)

Tl= Non- productive time (Hr) (Time lost turning, to loading and adjustment excluding refuelling and machine trouble)

2.3.4.3.4. Introduction of new designed Instrument for this experiment.

1. Hammer type Cone penetrometer

(especially designed for hard and dense soil condition)

This penetrometer (see Fig : 7) measures the strength of the soil by penetration cone shape resistor in to the soil. Particularly, this meter is designed to calculate the resistance value (Cone index) at each depth, especially hard and dense soil, very accurately.

Note: Cone Index is an indication of soil hardness and is expressed as force per square centimetre required for a cone to penetrate into soil.This proportion is called Cone index.

2.Drop penetrometer

(especially designed for puddle soil condition)

This drop cone penetrometer measures the soil hardness of the paddy soil, is expressed with the depth of penetration of a drop type cone penetrometer and called `` Cone depth ".

cone penetrometer (drop type) shown in figure: 8 has an apex angle of 45 degrees and weight about 135 grams. This cone penetrometer is dropped from a height of 1 metre from the soil surface to the cone tip. When the cone has penetrated in the soil ``Cone depth" is measured as the distance centimetre between the cone tip and soil surface.

3.Profile meter

(especially designed for measuring in situ soil stresses due to cage Wheel traffic.)

A profile measuring Device was designed and developed for use in a study to quantify Micro-relief surface depression storage and for measuring in insitu soil stresses due to cage wheel traffic in Wet land condition.

Fig : 9 shows the profilemeter which consists of

a) the carriage -probe unite,

b) steel frame

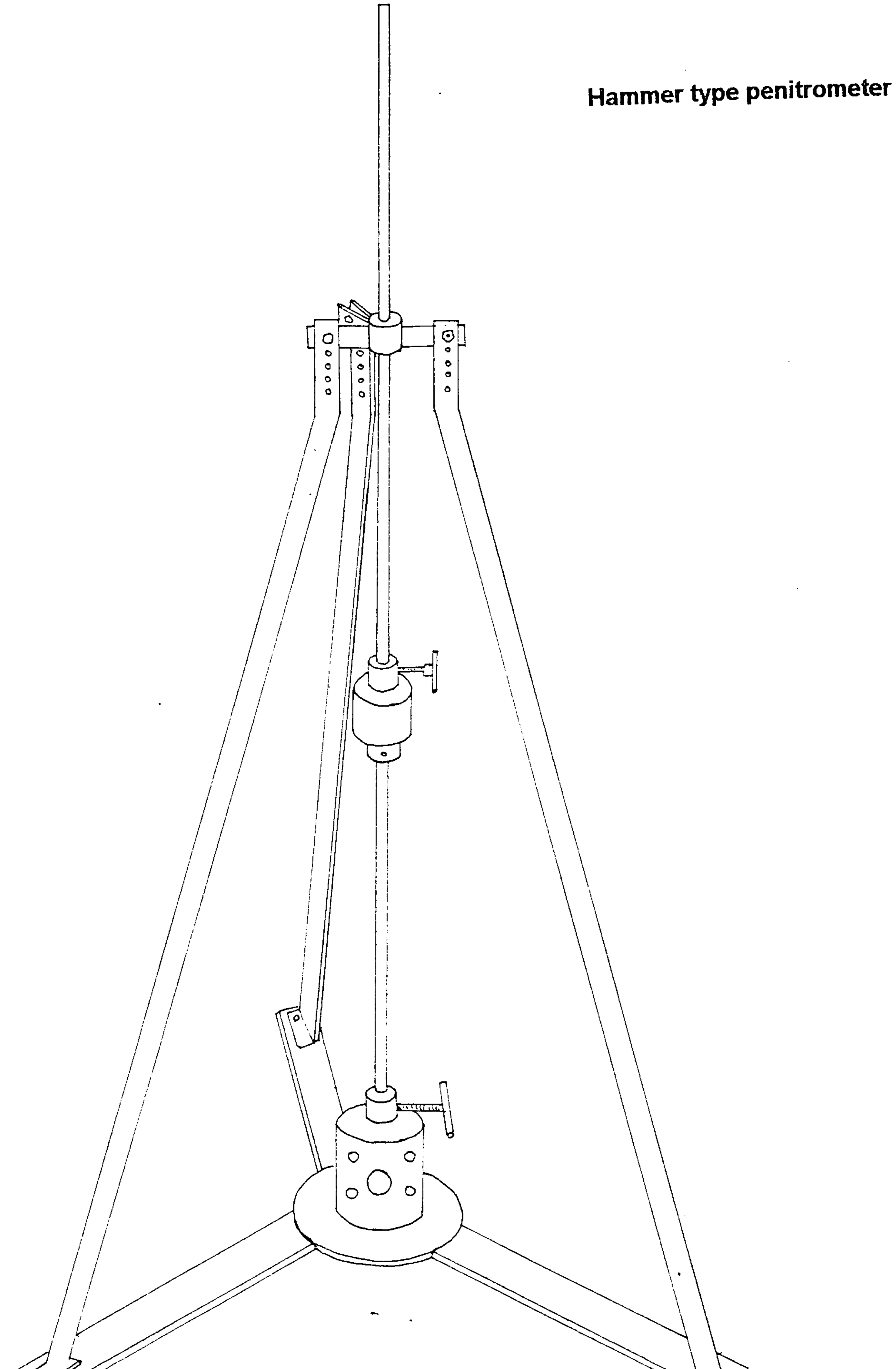
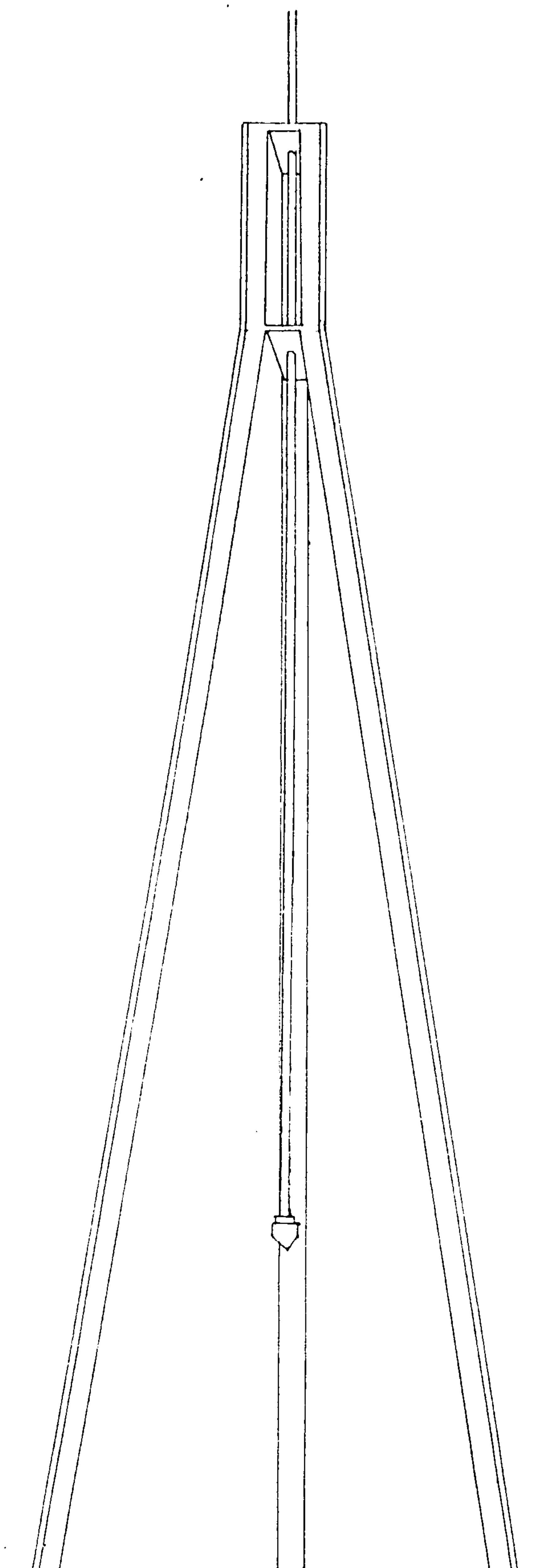


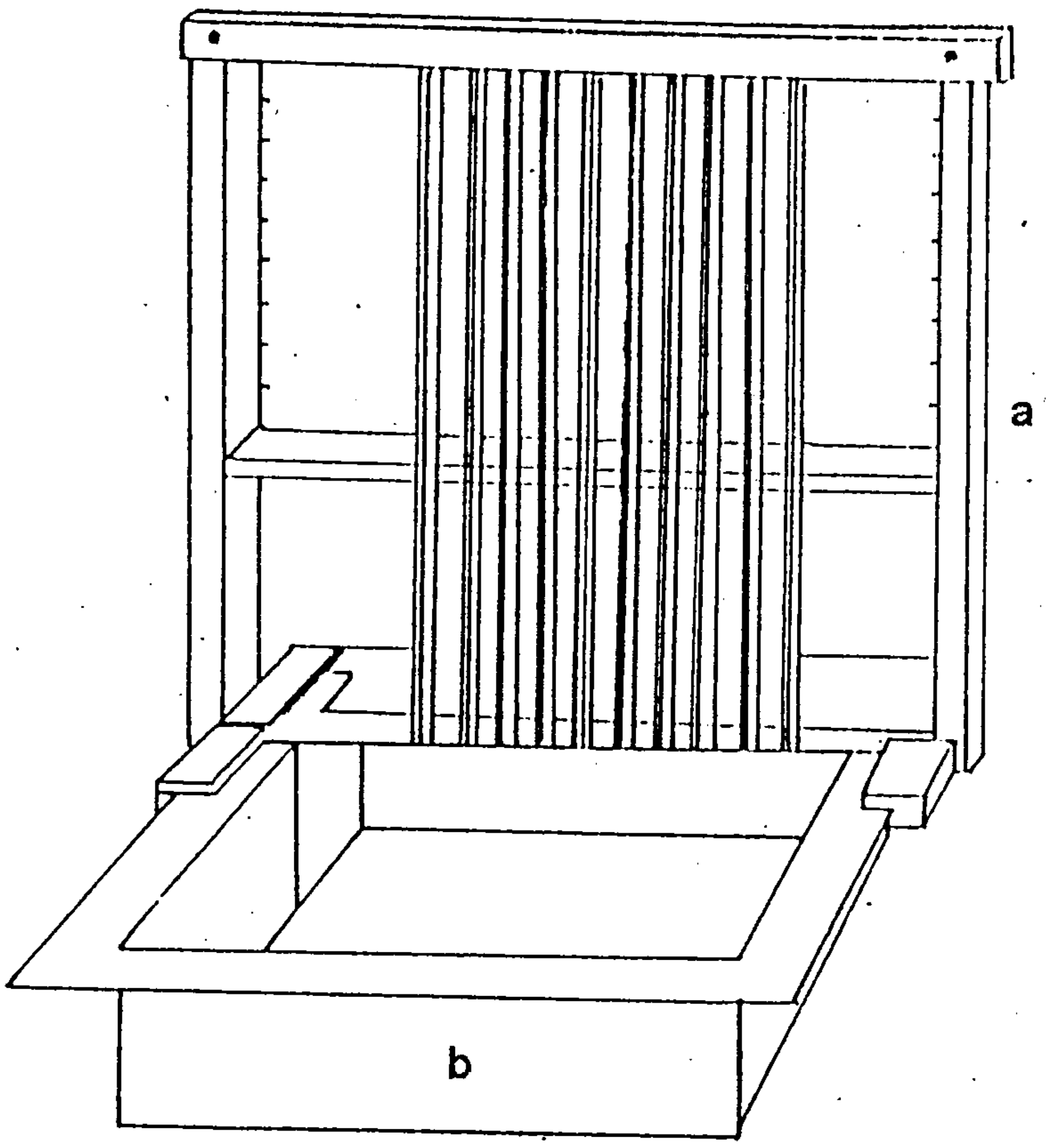
Figure 07: Designed Hammer type Penitrometer
Alwis (1998)



Drop penitrometer

Figure 0.8: Designed Drop type Penitrometer
Alwis (1998)

Figure 09: Designed Profile Meter
Alwis(1997)



Profile meter

The value for the random roughness is based on height measurements of a large number of points in a grid . For this purpose a micro- relief meter was designed .

It consists of a support frame in a fixed position and a line of measuring pins . The latter can move horizontally over the support frame .

At each setting one line of heights can be measured with the pins resting on the soil surface and the top of the pins indicating the heights . after a line of measuremonts, the pins are lifted and shifted to a next position.

2.3.4.4. TEST PROCEDURE

2.3.4. 4.1. TEST OF TRACTOR PERFORMANCE WITH DESIGN CAGE WHEEL FOR TWO WHEEL TRACTOR

The field lay out of performance test ` is illustrated in figure: 11 . First the on station trials were carried out in Location 01. Then the Farmer trials were carried out in Location 02. For on station trial , 9 field strips were prepared (3 comparisons for three traction aids, 3 replications for each traction aids) and then the same field strips were prepared for Farmer trials. For each case maximum pull at 100% slip were obtained.

In order to determine the maximum possible pull carried by each traction aids the testing Tractor was set to pull another tractor which was connected to the drawbar of the testing tractor by a code with the dynamometer mounted front side of the testing tractor.

First the rear tractor was set in normal run and by gradual application of brakes or putting in to loads. The pull developed at 100% slip by testing tractor was obtain. In this case for the safety of the testing tractor rearward over turning possibility, a safety measured used with the testing tractor. For each case testing tractor was set in no: 2 gear and constant engine speed.

Statistical design: Randomized Complete Block (RCB)

Location 01

DH3	DC3	DC2
DC1	DR3	DR1
DR2	DH1	DH2
Location 02		
PR2	PH2	PC2
PR3	PR1	PH1
PC1	PH3	PC3

D = Location 01
P = Location 02
R = Designed wheel
C = Conventional wheel
H = High lugged rubber tyre
1-3 = Replication

Figure 11 Plan for field tests for two wheel tractor

2.3.4.4.2. TEST OF TRACTOR PERFORMANCE WITH DESIGN CAGE WHEEL FOR FOUR WHEEL TRACTOR

2.3.4.4.1. FIRST EXPERIMENT (on Station Trial)

The field lay out of first location and the design of the `on Station Trial ` is illustrated in figure: 12 . For the Trial randomly selected 30 x 3 m2 land strips were prepared for each treatment with three replicates. Therefore 12 land strips were prepared for the test (two Traction aids with and without ploughing and three replicate for each treatment). This procedure was repeated for each gear type.

(First high and low, second high and low, thread low,) For each treatment ploughing depth and engine speed were observed and maintain in constant level.

Field Layout 1

With ploughing	Conventional cage wheel	Replicate 1
		Replicate 2
		Replicate 3
	Designed cage wheel	Replicate 1
		Replicate 2
		Replicate 3
Without ploughing	Conventional cage wheel	Replicate 1
		Replicate 2
		Replicate 3
	Designed cage wheel	Replicate 1
		Replicate 2
		Replicate 3

Figure: 12The experimental design of 1st Location (On station trial)

2.3.4.4. 2. SECOND EXPERIMENT (Farmer Trial)

The field lay out and the experimental design of the second experiment is, shown in figure: 13.1 and 13.2 . For this experiment 5 replicates for each Treatment which was 500 m2 of size were randomly selected at farmer Paddy field. Therefor altogether there were 10 field plots.

On the long boundary of field plots two ranging poles 20 m apart were placed aproximately in the middle of the test run. Using each traction aids, each field plots were ploughed by 4 wheel Tractor with Tine tiller . Selected Gear ratio was First High. Total time of ploughing of each field plots and the time required for the tractor to travel the distance (20m) between the two poles were taken by stop watch. Using this data the travelling speed ,effective field capacity and time per hectare were calculated. .

Field Layout 2

Figure:13.1 2nd Experiment in Location 02 (Farmer field Experiment)

C1	R1		C3	R4	C5

C4		R3	C2	R5	R2

C= conventional cage wheel

R= Designed cage wheel

2.3.4.5. Theoretical consideration for data Analysis

Observed or measured data of this research statistically analysed according to the design of the experiment which was a randamized complete block design by using `SAS` soft ware package.

2.3.4.6. Cost Analysis

Cost Analysis was carried out for each traction aid .

Figure 13.2 Design of Location 02 (farmer field experiment plot)

2.3.4.7. **Farmers Opinions**

Demonstration trial was conducted with the participation of paddy farmers (included Tractor owners) of the area. To collect the farmer opinion and attitudes to new practices, farmer survey (Rapid appraisal method by Beebs 1985) was conducted.

This study was carried out in 1998 Maha season through a survey of the Randomly selected sample of 10 key farmers. Questionnaire with Analytical technique is shown in below .

Questionnaire

a) **Feasibility:** Does it work at all ?

1.excellent	-	1 - y \ N	if yes 100 % marks
2.Very Good	-	2 - y \ N	if yes 80 % marks
3.Good	-	3 - y \ N	if yes 60 % marks
4.Satisfactory	-	4 - y \ N	if yes 40 % marks
5.not Satisfactory	-	5 - y \ N	if yes 20 % marks

b).**Practicality :** Does it work on farmer's land ?

1 - y \ N 2 - y \ N 3 - y \ N 4 - y \ N 5 - y \ N

c). **Adaptability :** Can it be adapted with or without modification on farms ?

1 - y \ N 2 - y \ N 3 - y \ N 4 - y \ N 5 - y \ N

d). **Cost :** Is cost comparable to existing practics ?

1 - y \ N 2 - y \ N 3 - y \ N 4 - y \ N 5 - y \ N

e) . **Cost effectiveness :** Do the benefits exceed the extra costs ?

1 - y \ N 2 - y \ N 3 - y \ N 4 - y \ N 5 - y \ N

f) . **Other inputs (eg labour etc)** Are other in puts greater than with traditional practice

1 - y \ N 2 - y \ N 3 - y \ N 4 - y \ N 5 - y \ N

g). **Farmer opinion**: Do the target farmers like the idea and do they have ideas for modification ?

1 - y \ N 2 - y \ N 3 - y \ N 4 - y \ N 5 - y \ N

H). **Farmer adoption:** Are farmers adopting the new idea voluntarily ?

1 - y \ N 2 - y \ N 3 - y \ N 4 - y \ N 5 - y \ N

i). **Interventions needed** : What conditions (Interventions) are needed to promote adoption ?

1 credit 2 materials 3 Extension 4 market 5 Training

j). **Main Problems faced by the farmers**

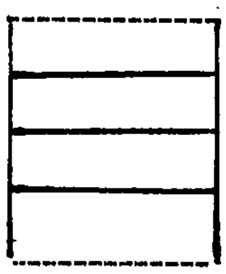
1) shortage of capital for purchase
2) low ploughing rate or efficiency
3) lack of advice
4) shortage of high quality mud wheels
5) others

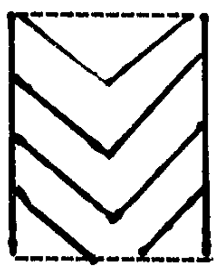
k) **Ideas for improvement**

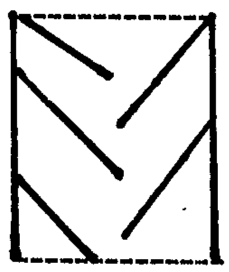
1. ------------------------------
2. ------------------------------
3 ------------------------------

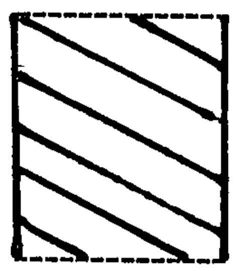
l) **Lug design** (Four types of lug design were tested in farm trial (include simple test , field observation and farmer opinion as a driver).

Type-1	Type-2	Type-3	Type-4
perpendicular	V shape	open V	30^{o}angle









Criteria's for evaluation **marks**

1.Forward running (Traction) previous 1,2,3,4,5, system

2.Scouring ability

3.Wearing

4.Driver comfort

3. RESULTS OBTAINED

3.1 Specification of traction aids

Some important specification of tested traction aids are shown in table :1 and 2

a) Two Wheel Tractor

Specification	Treatment 01 Conventional cage wheel (photo:01)	Treatment 02 Design cage wheel (photo:05)
Diameter	Constant 60cm	Varying 40-62cm
Width	20cm	20cm
No of lugs	12	12
Lug spacing	10 cm	10cm
Cost of production per cage wheel (village level work shop) Retail price /1998 January /Matara	Rs. 3846.00	Rs. 4020.00 (For drawing see figure:14.1 and 14.2)

Note : More details about cost of production is given in Table 14 and 15.

Table 1: Some important specification of tested traction aids for two wheel tractor.

a) Four Wheel Tractor

Specification	Treatment 01 Conventional cage wheel (photo:02)	Treatment 02 Design cage wheel (photo:06)
Diameter	Constant 102cm	Varying 100-127cm
Width	35cm	35cm
No of lugs	12	12
Lug spacing	30 cm	30cm
Cost of production per cage wheel (village level work shop) Retail price /1998 January /Matara	Rs. 5846.00	Rs. 6020.00 (For drawing see figure:15.1 and 15.2)

Note : More details about cost of production is given in table 16 and 17.

Table 2: Some important specification of tested traction aids.

Design cage wheel :

a) . For Two Wheel Tractor

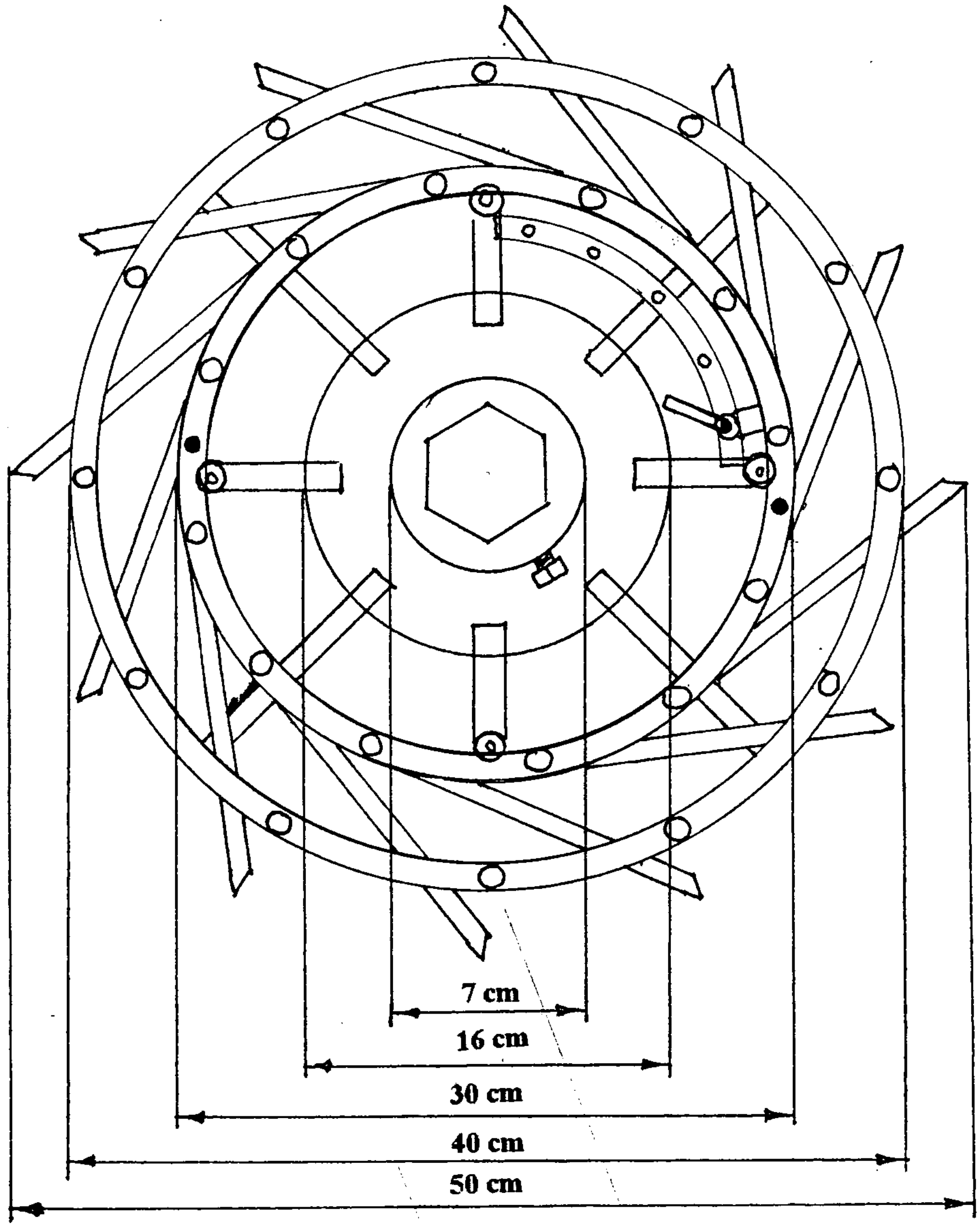
The drawing of the design cage wheel is given in figure.14.1 and 14.2. and photo 5.1 and 5.2. Outer diameter of designed Cage wheel For Two Wheel Tractor is 620 mm larger in the field and 400 mm smaller on road. It consist of 12 flat retractable lugs. The lug spacing is 100 mm.

b). For Four Wheel Tractor

The drawing of the design cage wheel is given in figure.15.1 to 15.3. It consists of four main folders as shown in photo 6.1 and 6.2 Each folder has 3 lugs of 30 angle. A spring loaded key mechanism was provident to lock the wheel for retracted or expanded position. The key change could be done by pulling out the key from first key way and by releasing it directed to the next key way.

3.2 Soil Conditions :

Two different soil conditions were used for the experiment. Table 3 to 5.2 and figure 15 and 17 shows the soil physical conditions obtained in the two fields.



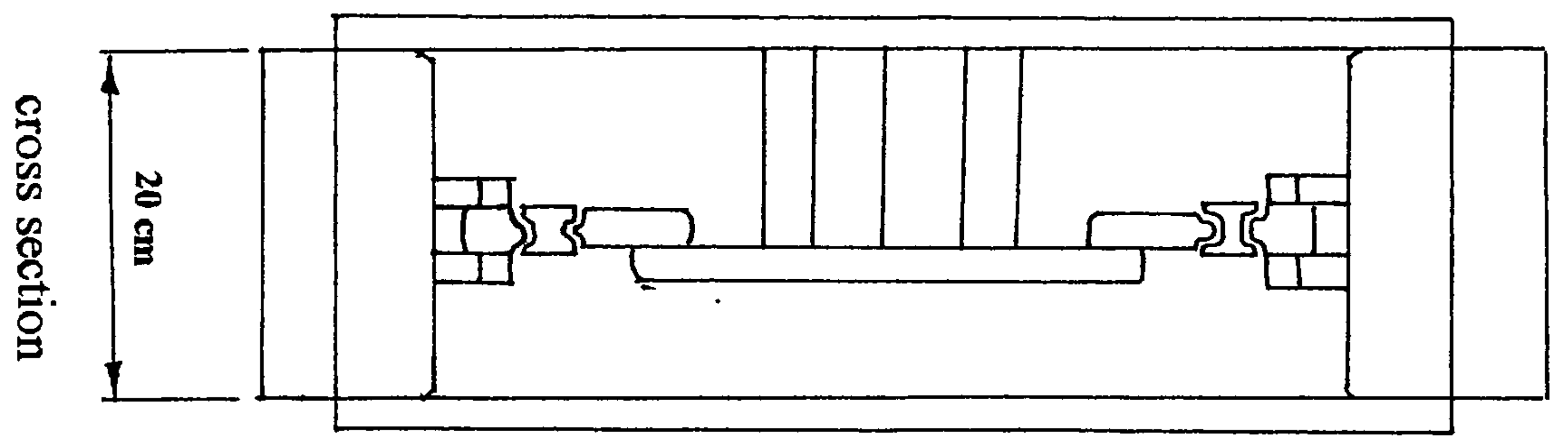


Figure 14.1. The designed cage wheels (Retracted position)

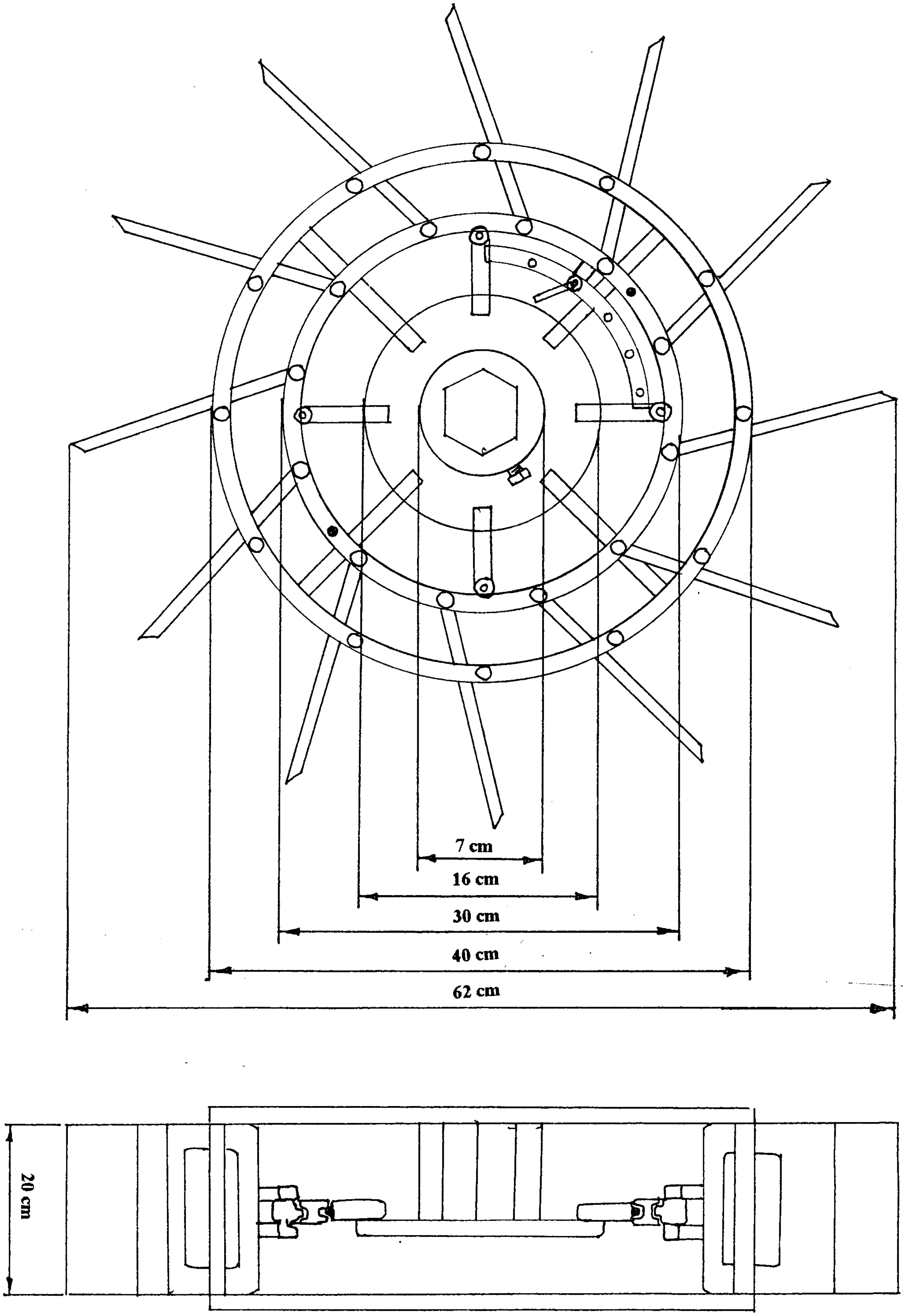


Figure 4.2: The designed cage wheels (Expanded positions)

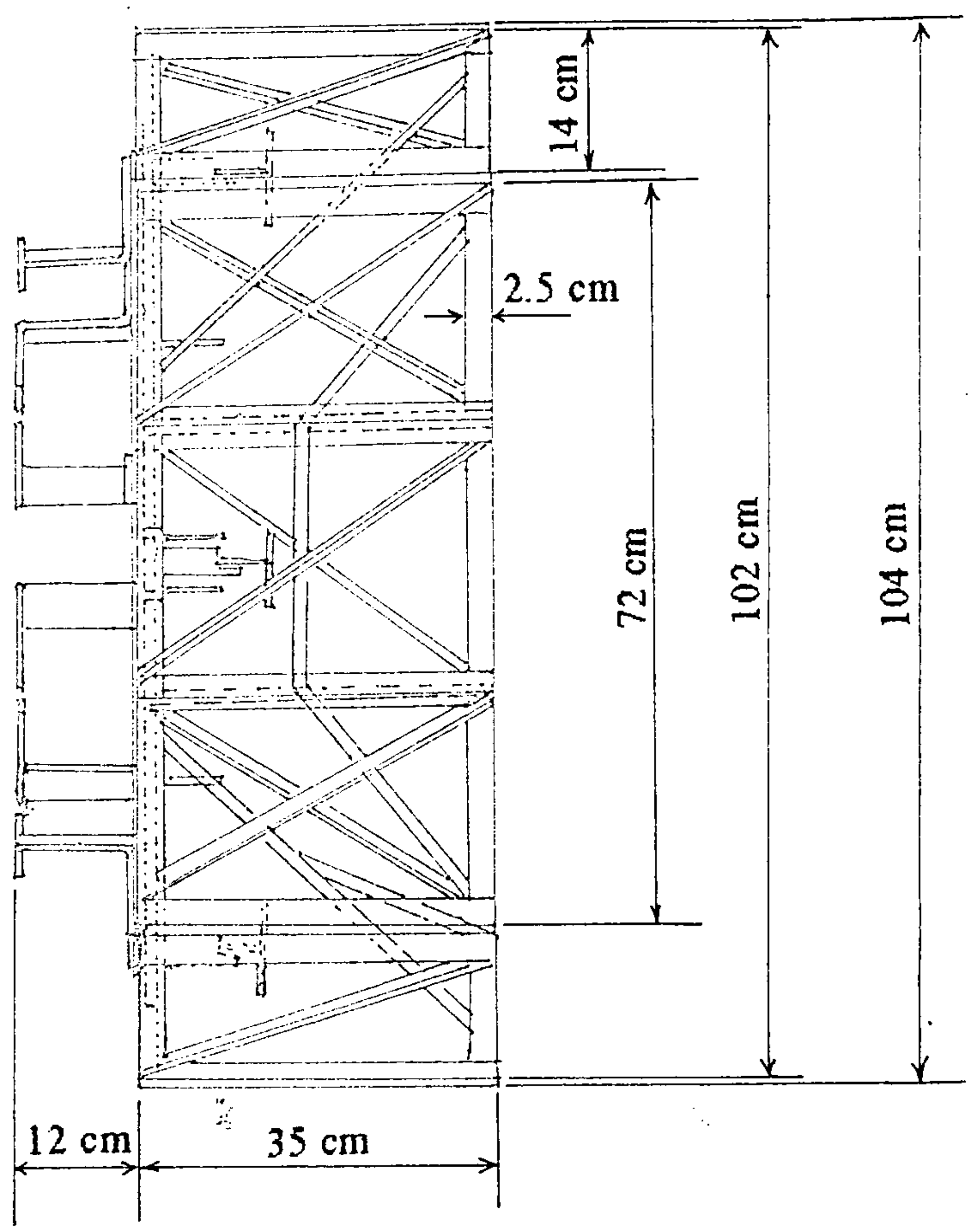


Figure 15.1 Side view of Designed cage wheel (when folding)

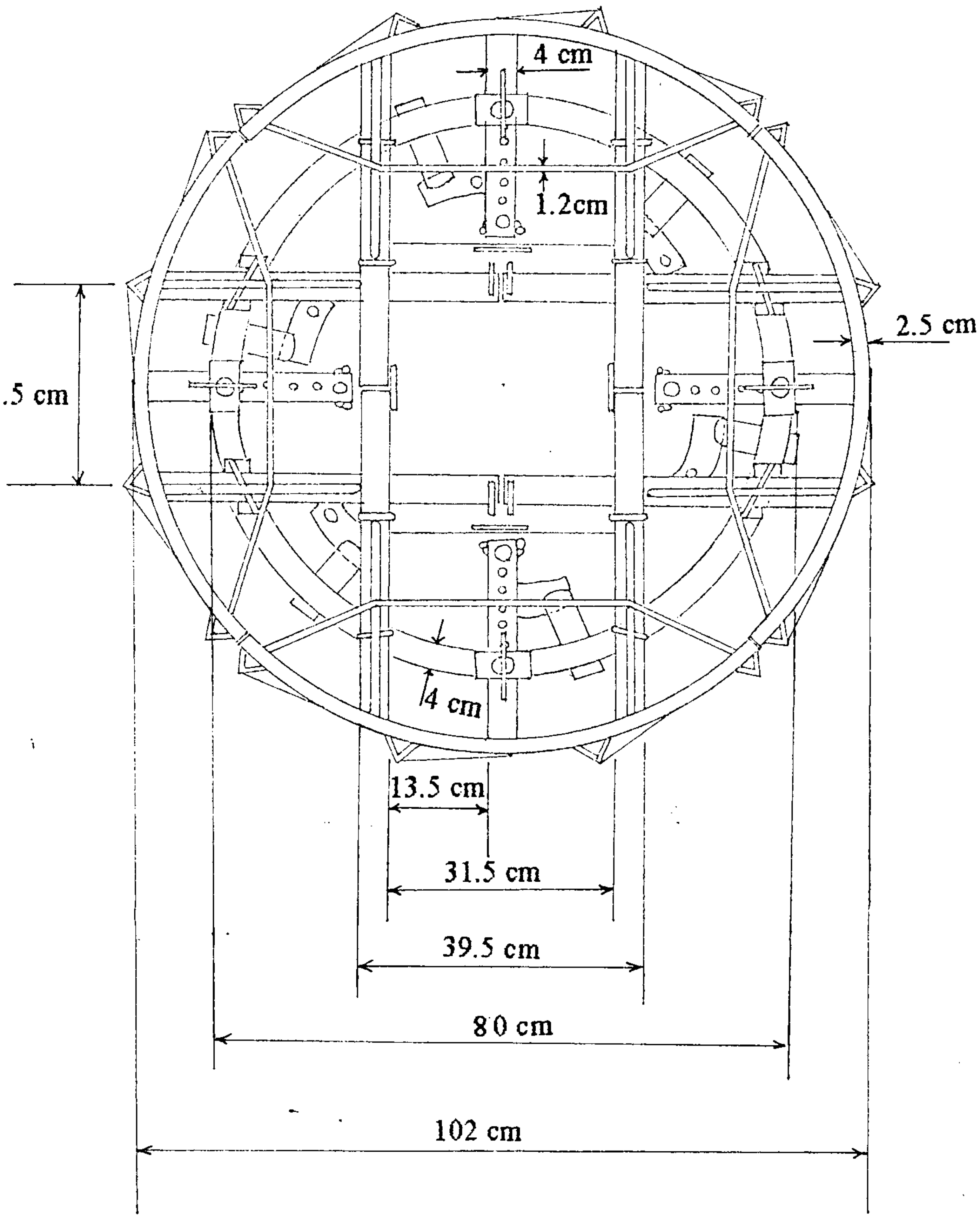


Figure 15.2 Plan of Designed cage wheel (when folding)

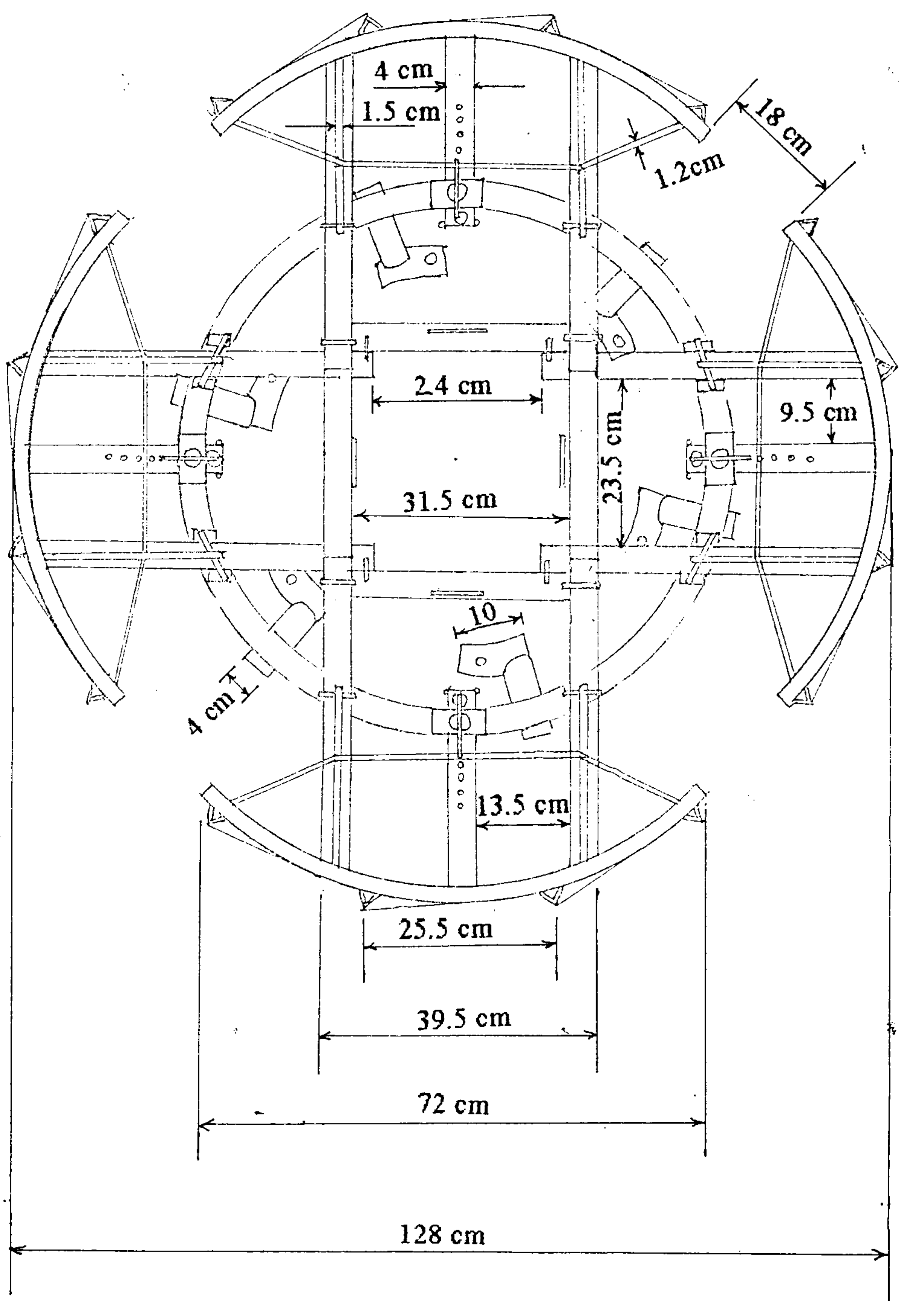
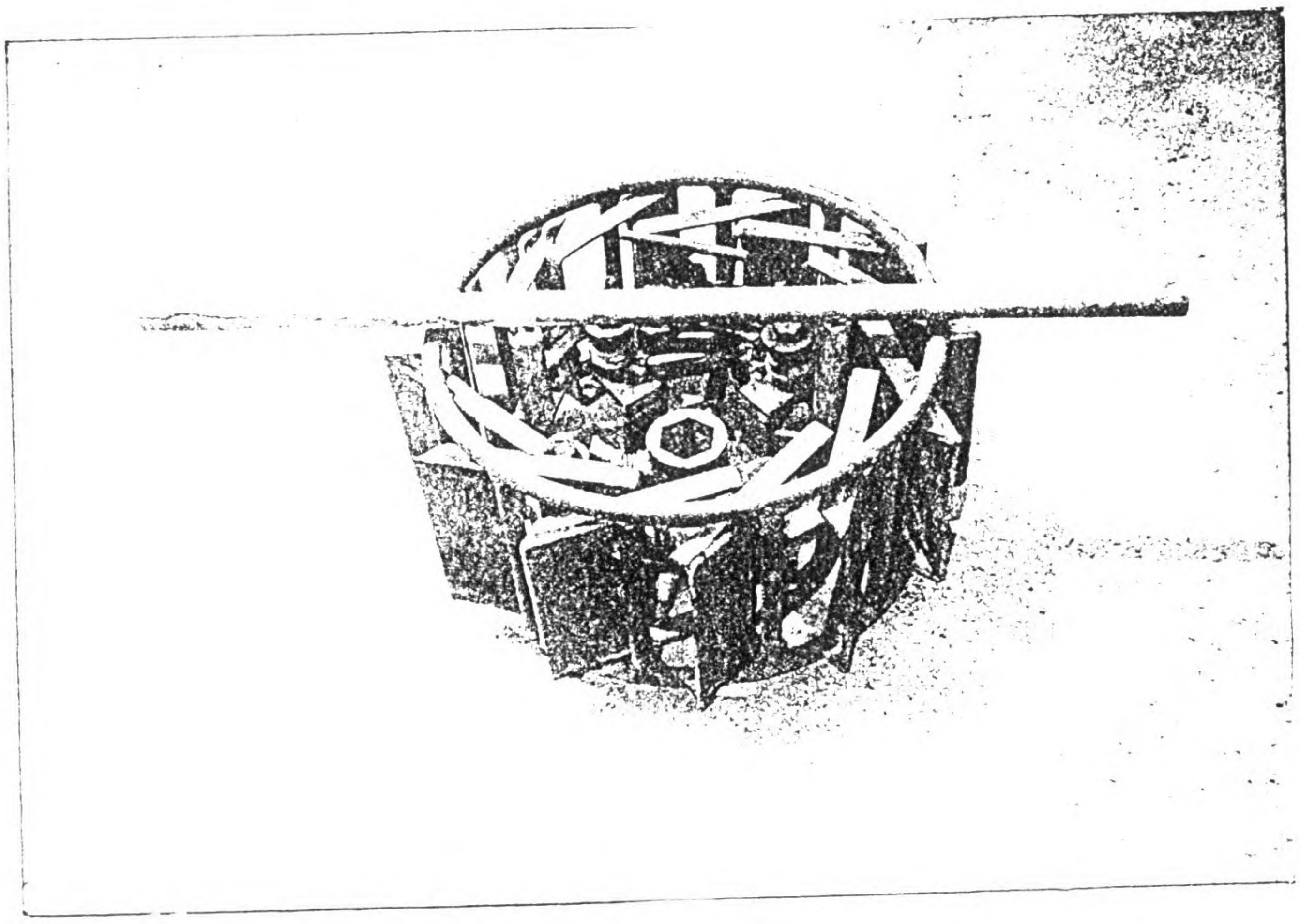
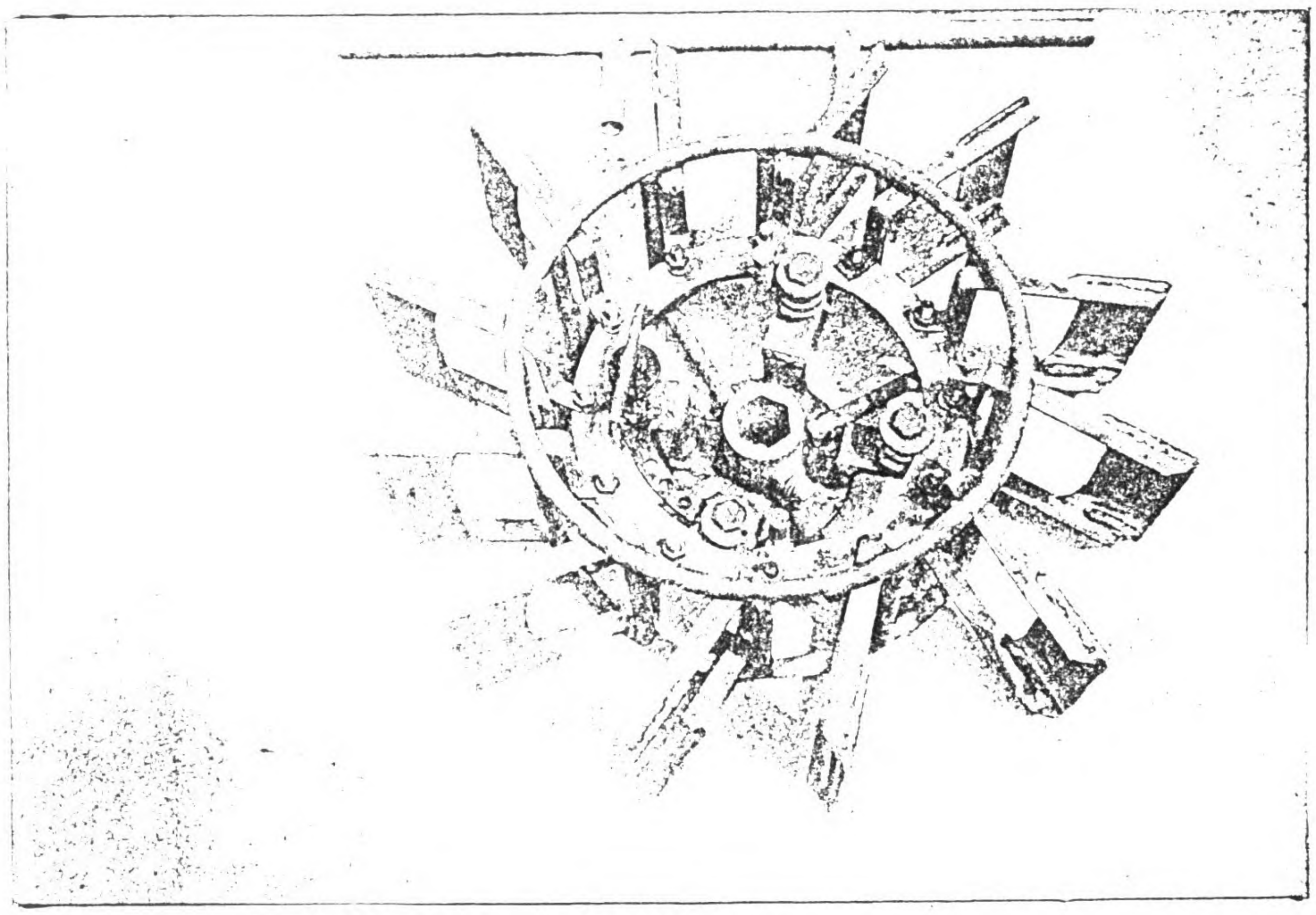


Figure 15.3 Plan of Designed cage wheel (when unfolding)

Photo 05. : Designed Cage wheel -

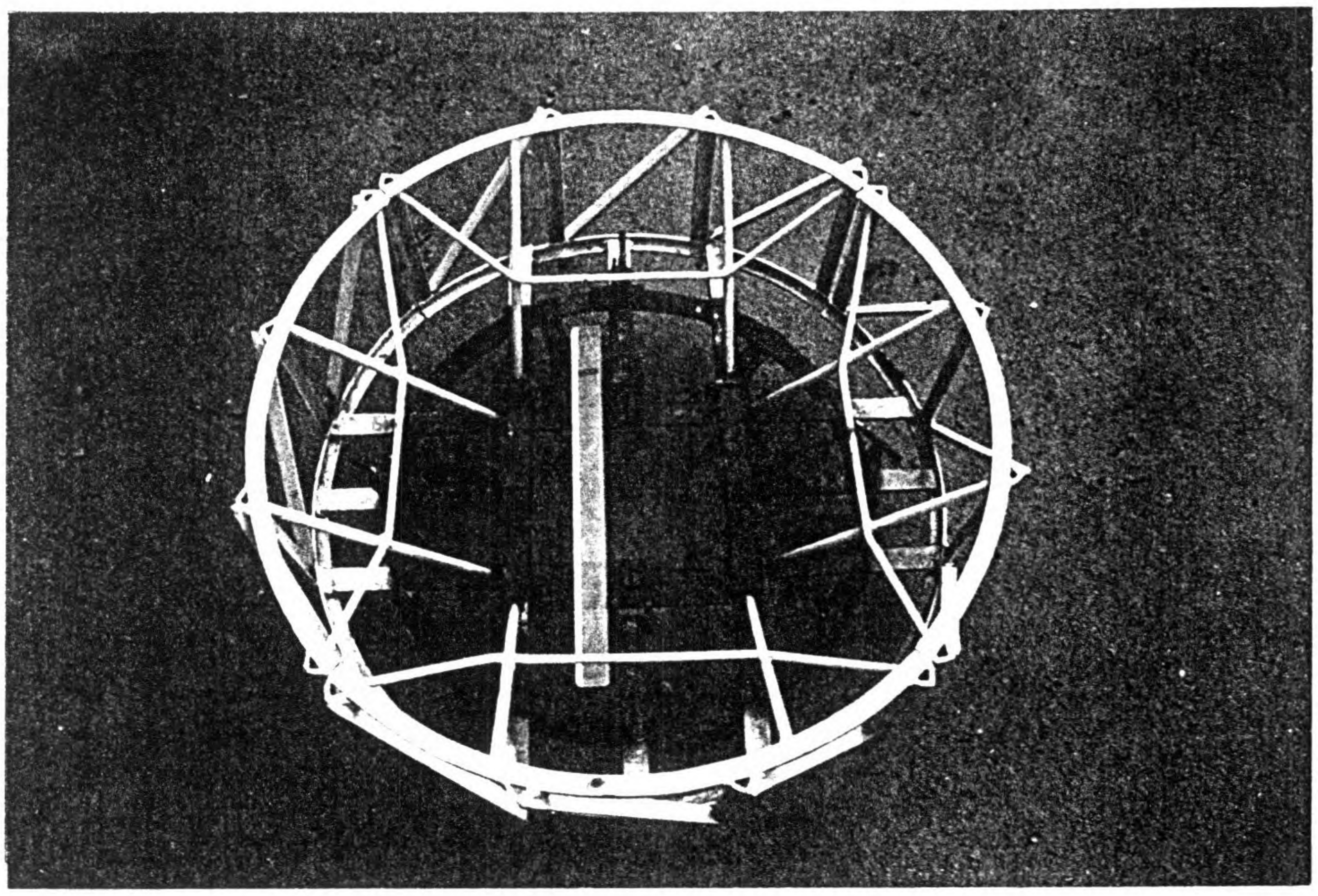


5.1) retracted position.

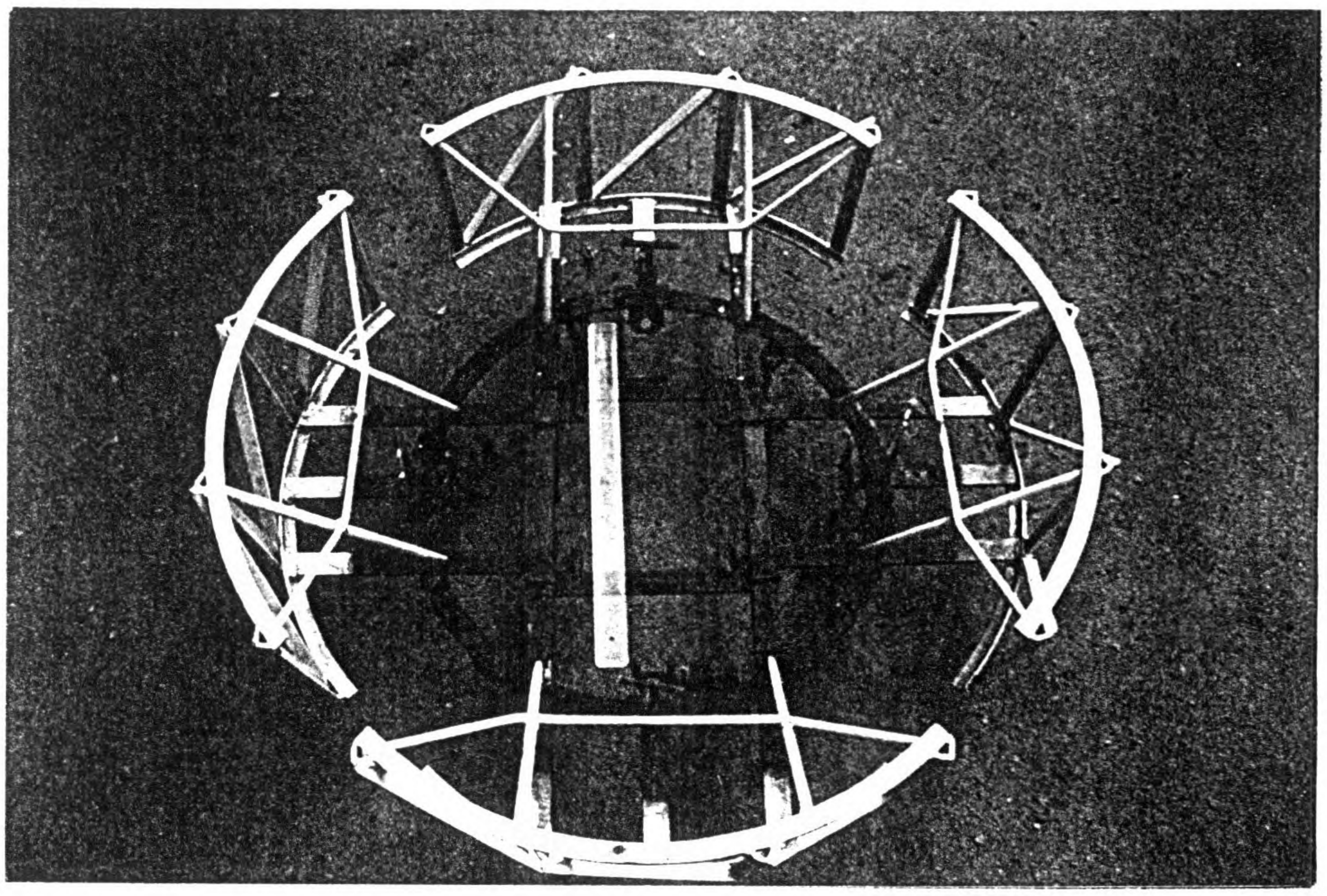


5.2) expanded position

Photo 06. : Designed Cage wheel -



6.1) retracted position.



6.2) expanded position

3.2. 1 Location 1: (Faculty Research Farm)

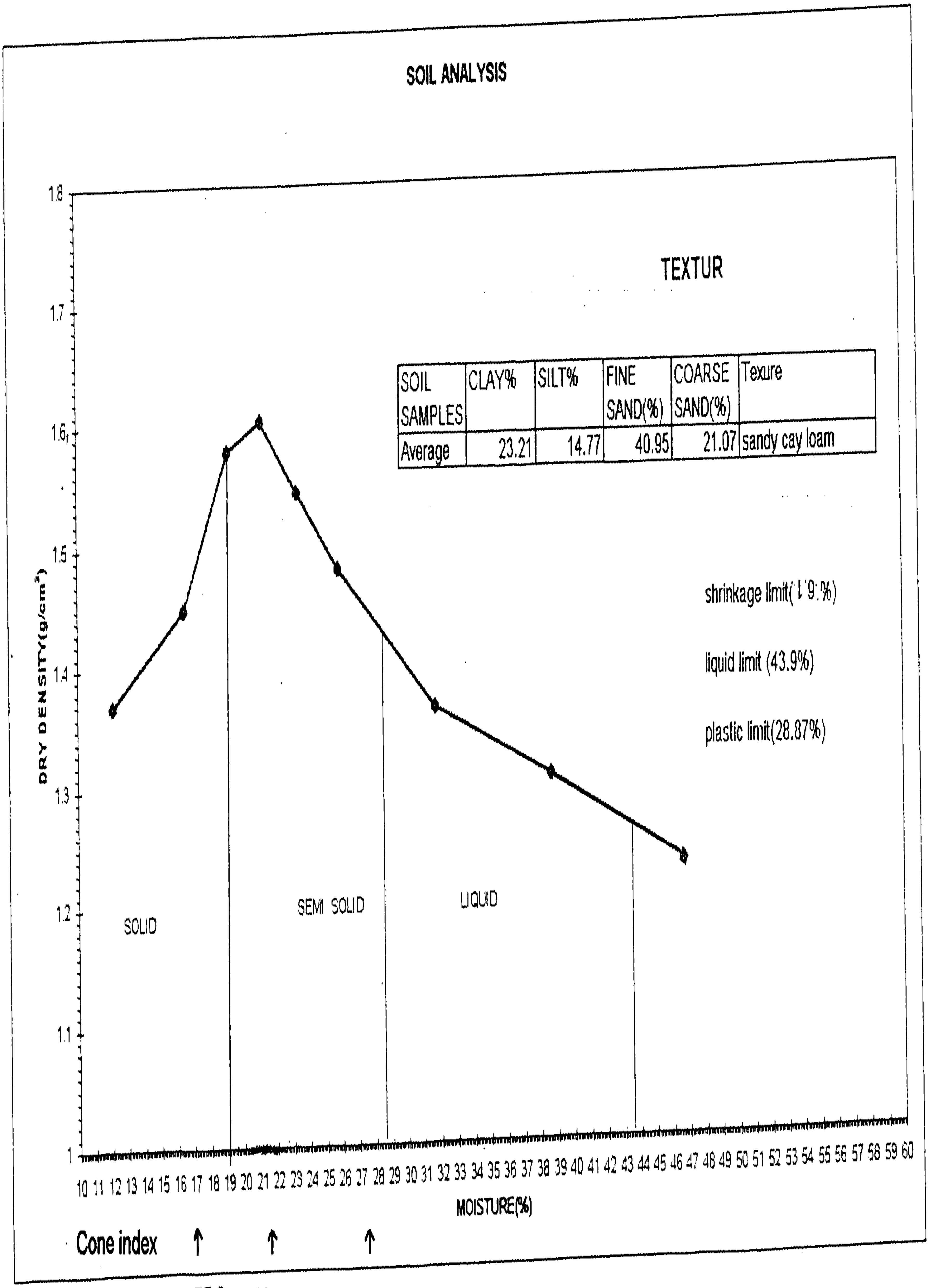
Physical and Technological properties of the soil in test fields were shown in figure 16. The bulk density values and moisture content values in location 01 were observed uniform during the experiment 01. These results are tabulated in tables 3.1 to 3.2 And figure 17.1 to 17.2

3.2.2. Location 2: (Paddy fields)

The bulk density values and Cone depth values of paddy soil in location 02 were observed uniform during the experiment 02. These results are tabulated in tables 4 and 5.1 to 5.2.. The depth to the hard pan in Location 2 was found uniform during the experiment. These results are tabulated in tables in appendix and figures 18 - 26 .The Mean values of the each blocks are tabulated in tables 5.1.

3.3. PERFORMANCE OF DESIGNED CAGE WHEEL

In this chapter, comparison of the relative performance of two traction aids used in two locations is reported. Moreover, the performance of designed cage wheel in field condition and on road is also discussed.



SOIL SAMPLES	CLAY%	SILT%	FINE SAND(%)	COARSE SAND(%)	Texure
Average	23.21	14.77	40.95	21.07	sandy cay loam

Cone index ↑ ↑ ↑

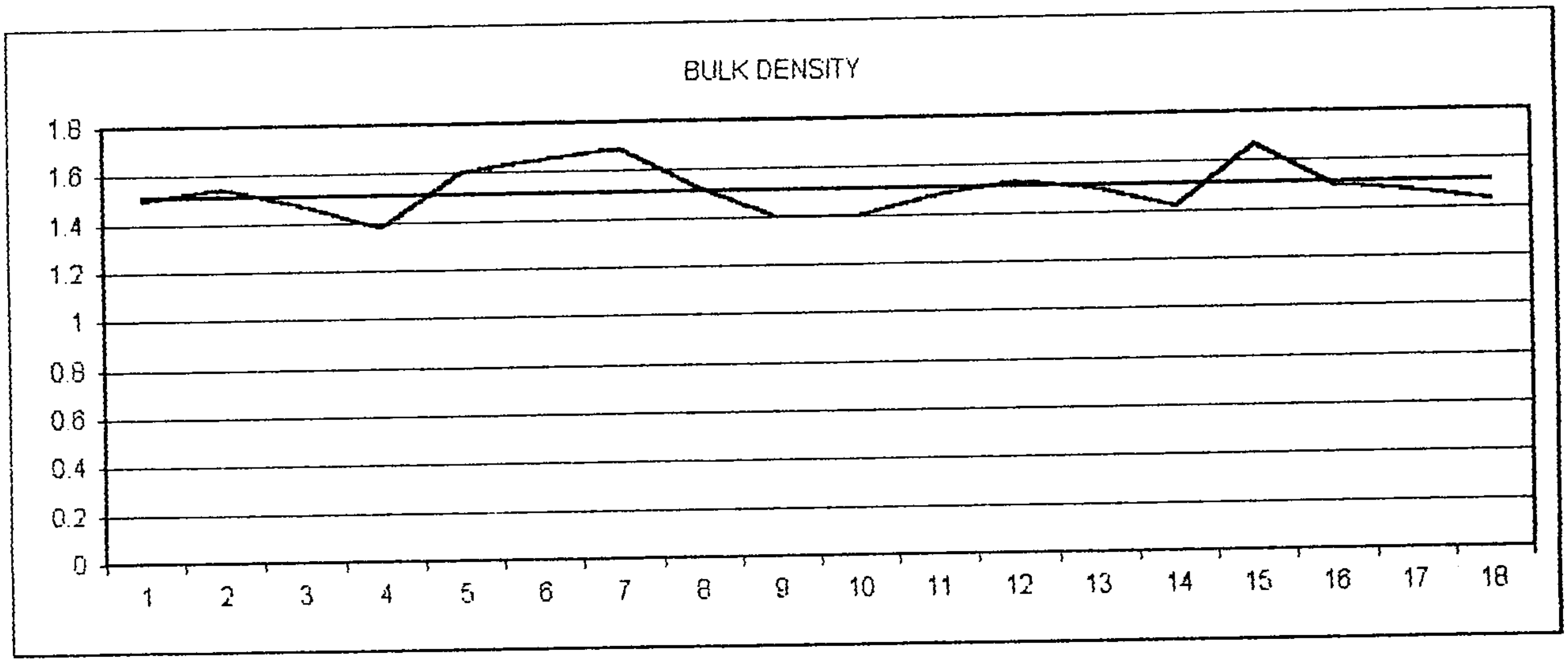
N/cm2 55.0 42.0 25.6

Figure 16:Physical and Technological properties of the soil in test fields.

BULK DENSITY

BLOCK	BULK DENSITY(g/cm^3)		
	1	2	3
C1	1.5	1.65	1.47
C2	1.54	1.52	1.43
C3	1.47	1.38	1.42
D1	1.4	1.4	1.67
D2	1.6	1.48	1.5
D3	1.69	1.42	1.5

Table 3.1



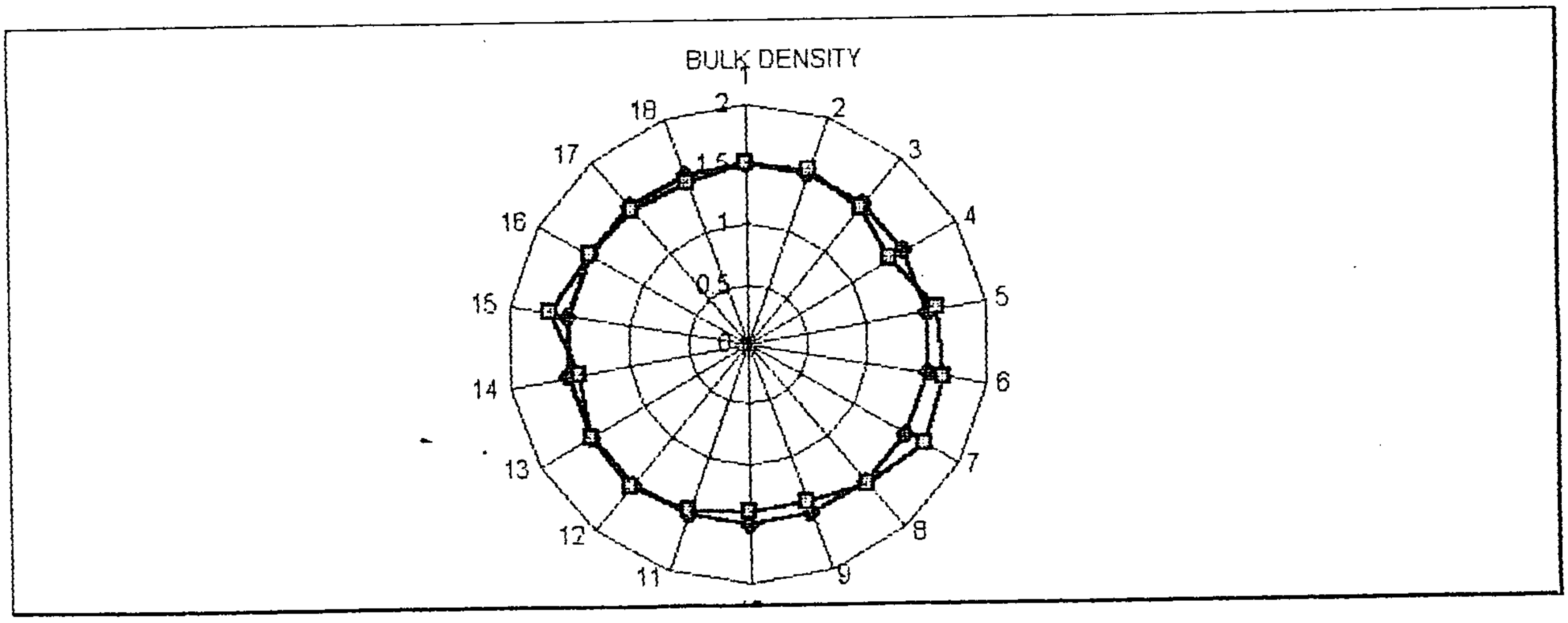
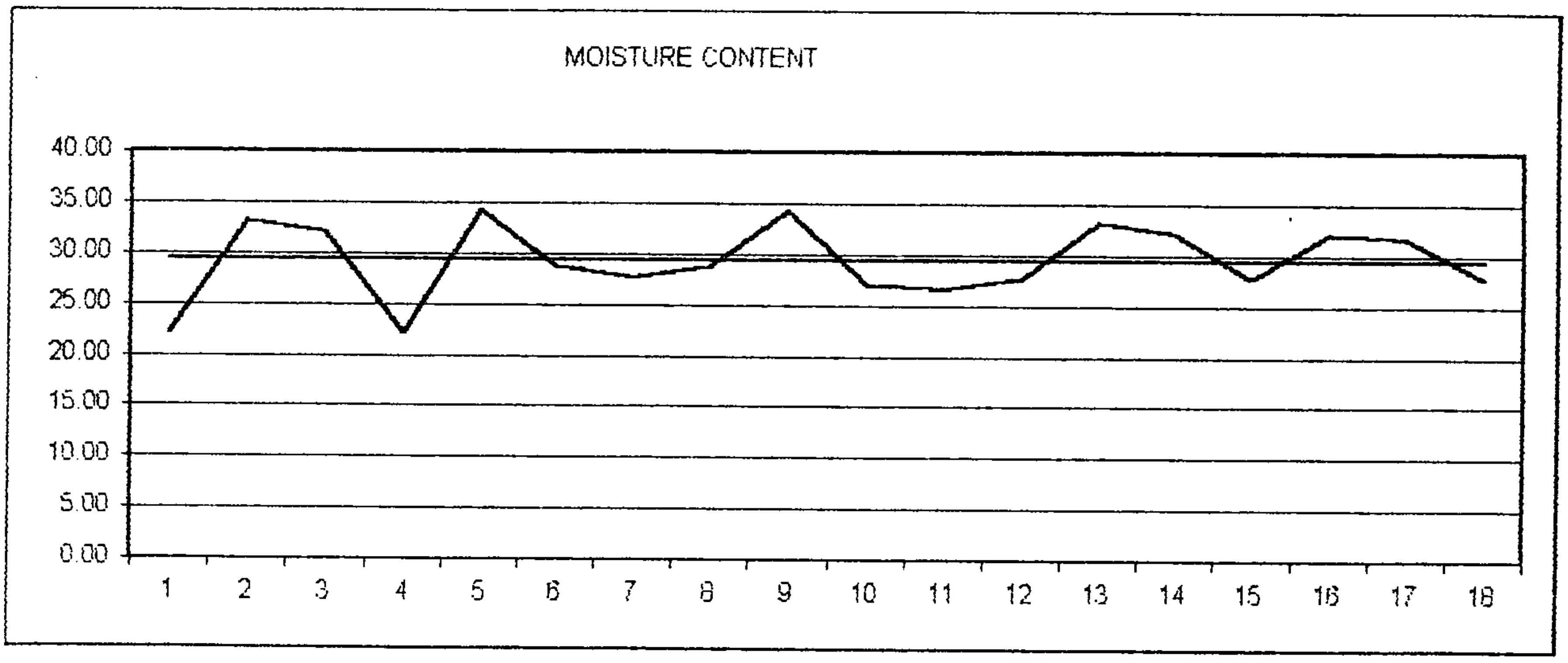


Figure 17.1 **:The bulk density values in Location - 01**

MOISTURE CONTENT

BLOCK	MOISTURE CONTENT(%) (dry basis)		
	1	2	3
C1	22.08	34.22	33.12
C2	33.12	27.05	32.01
C3	32.01	26.49	27.60
D1	22.08	27.60	32.01
D2	34.22	33.12	31.46
D3	28.70	32.01	27.60

Table 3.2 :



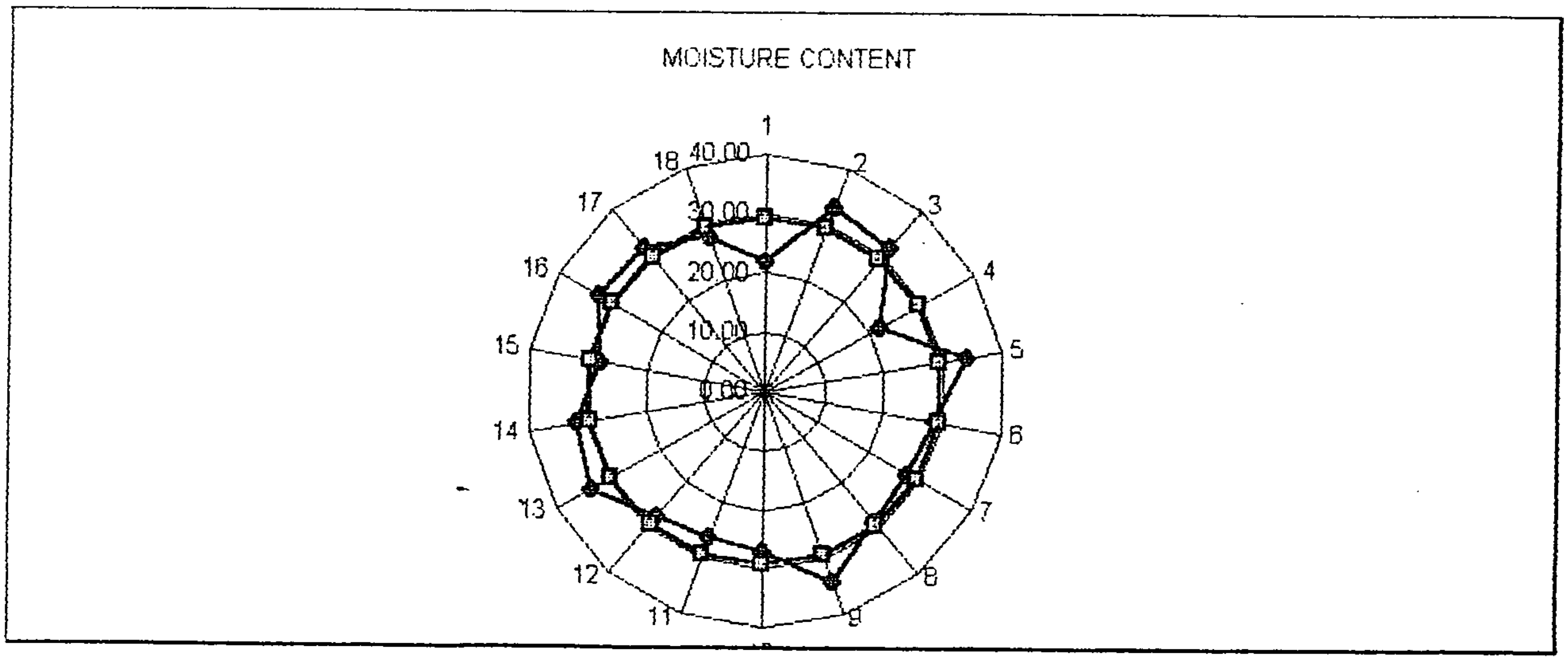


Figure 17.2::Moisture content values in Location - 01

Test Results Under Location 2

block number	moisture content (%) Dry basis			
	2	3	4	5
DH1	50.2	54.4	51.2	51.0
DH2	52.2	51.3	50.0	49.8
DH3	49.5	52.7	50.3	53.8
DC1	50.6	52.4	54.3	49.7
DC2	53.1	55.0	53.2	58.8
DC3	56.5	55.0	52.3	49.9
DR1	48.9	50.2	54.4	51.2
DR2	53.2	58.6	51.2	57.3
DR3	55.6	53.2	58.6	57.3

Table 4: Moisture content obtained in the location 02

Block number	hard pan depth (cm)
PH1	21.9
PH2	22.0
PH3	21.8
mean	21.9
PC1	22.8
PC2	24.5
PC3	24.7
mean	24.0
PR1	23.5
PR2	24.7
PR3	22.3
mean	23.5

Table 5.1: Hard pan depth (mean values) obtained in the puddled Soil condition

DROP PENITROMETER

Place No.	[illegible] depth (cm)				Bulk Density
	Replicate			Average	
	1	2	3		
1	16	15	14	15.00	0.90
2	21	20	20	20.33	1.08
3	21	16	20	19.00	0.86
4	17	16	16	16.33	0.90
5	20	21	20	20.33	1.03
6	23	15	19	19.00	0.88
7	16	19	20	18.33	0.94
8	19	18	20	19.00	1.04
9	14	19	12	15.00	0.88
10	18	16	19	17.67	1.19
11	18	17	15	16.67	1.00
12	23	24	23	23.33	0.89
13	16	16	15	15.67	0.94
14	19	17	19	18.33	1.05
15	16	15	17	16.00	0.81
16	18	13	20	17.00	1.27
17	25	23	26	24.67	1.00
18	27	26	31	28.00	1.65
19	29	31	31	30.33	1.03
20	28	28	33	29.67	1.10
21	26	25	27	26.00	1.32
22	24	22	20	22.00	1.06
23	23	23	18	21.33	1.36
24	24	24	26	24.67	0.76
25	18	20	19	19.00	1.38
26	15	16	19	16.67	1.09
27	26	23	26	25.00	0.85
28	27	31	28	28.67	0.92
29	18	20	26	21.33	0.90
30	26	27	29	27.33	1.01
31	27	27	28	27.33	1.00
32	18	21	22	20.33	1.01
33	30	33	33	32.00	1.10
34	32	37	35	34.67	0.99
35	21	21	22	21.33	1.01
36	31	26	26	27.67	1.01
37	21	22	24	22.33	1.17
38	19	20	24	21.00	1.21
39	26	25	22	24.33	1.08
40	23	22	24	23.00	1.10
41	27	25	21	24.33	1.00
42	26	28	18	24.00	1.50
43	20	21	20	20.33	1.00
44	16	18	18	17.33	1.01
45	28	28	26	27.33	1.01
46	23	20	21	21.33	0.78
47	30	26	29	28.33	1.17
48	19	29	16	21.33	1.03
49	25	21	25	23.67	0.84
50	25	25	22	24.00	0.85
Average	**22.36**	**22.22**	**22.48**	**22.35**	**1.04**

Table 5.2

FIGURE:18 BLOCK NO-PC1

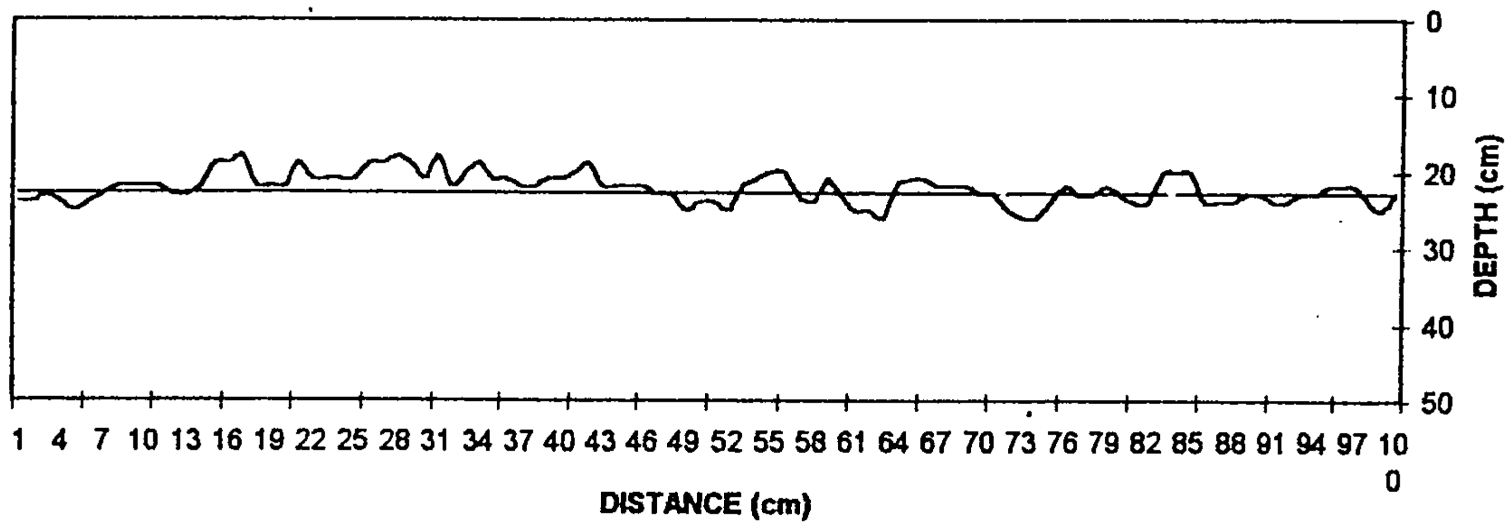


FIGURE:19 BLOCK NO-PR1

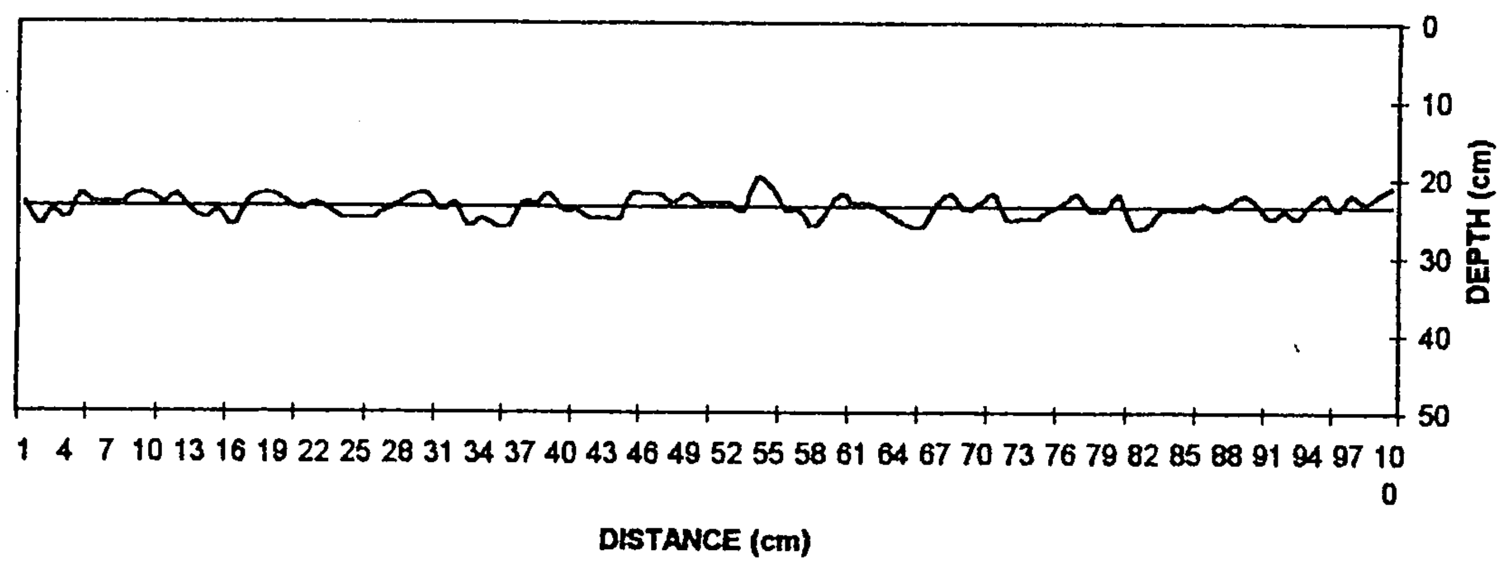


FIGURE:20 BLOCK NO-PH1

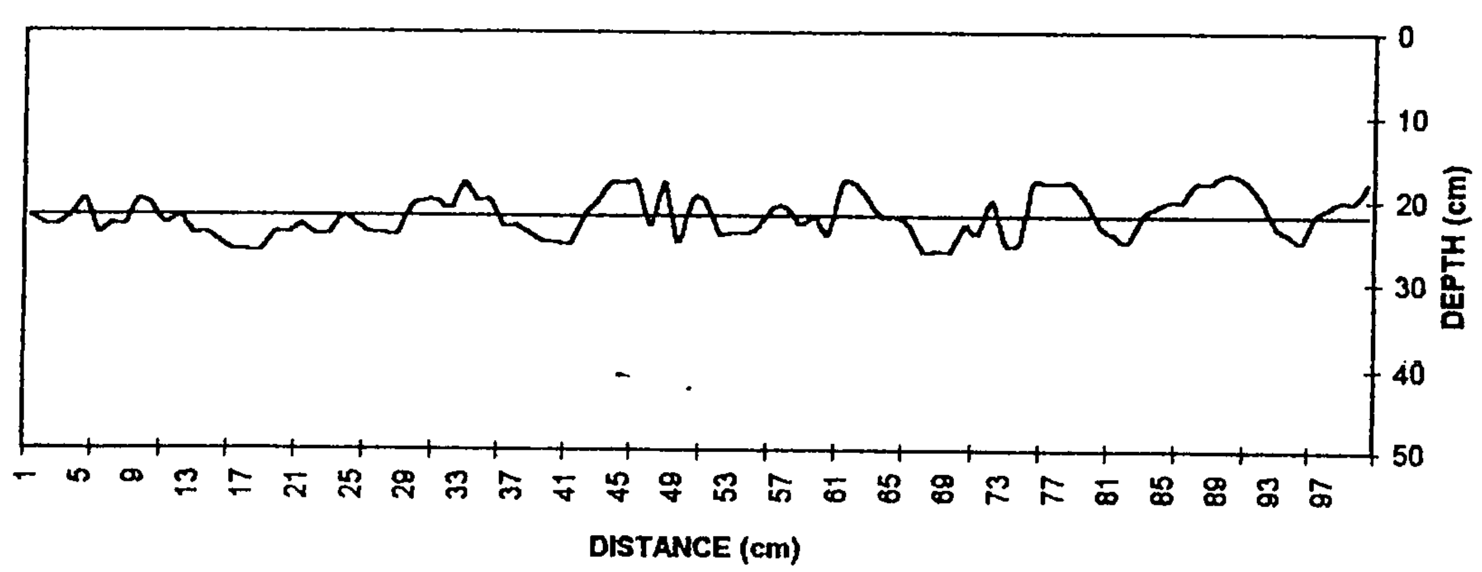


FIGURE:21 BLOCK NO.PC-2

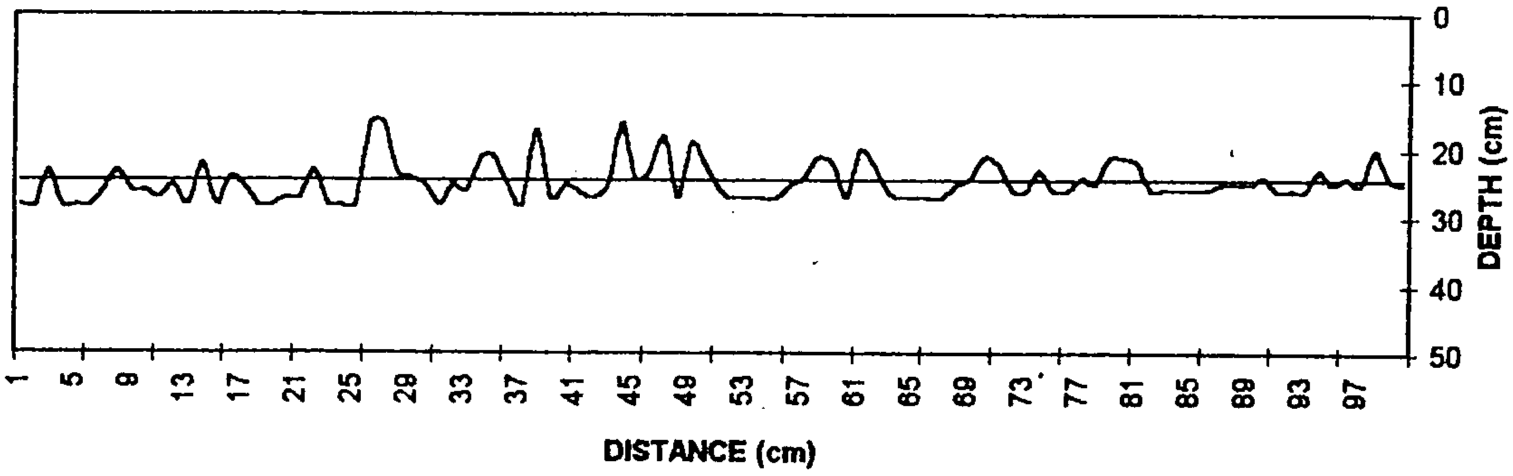


FIGURE:22 BLOCK NO-PR2

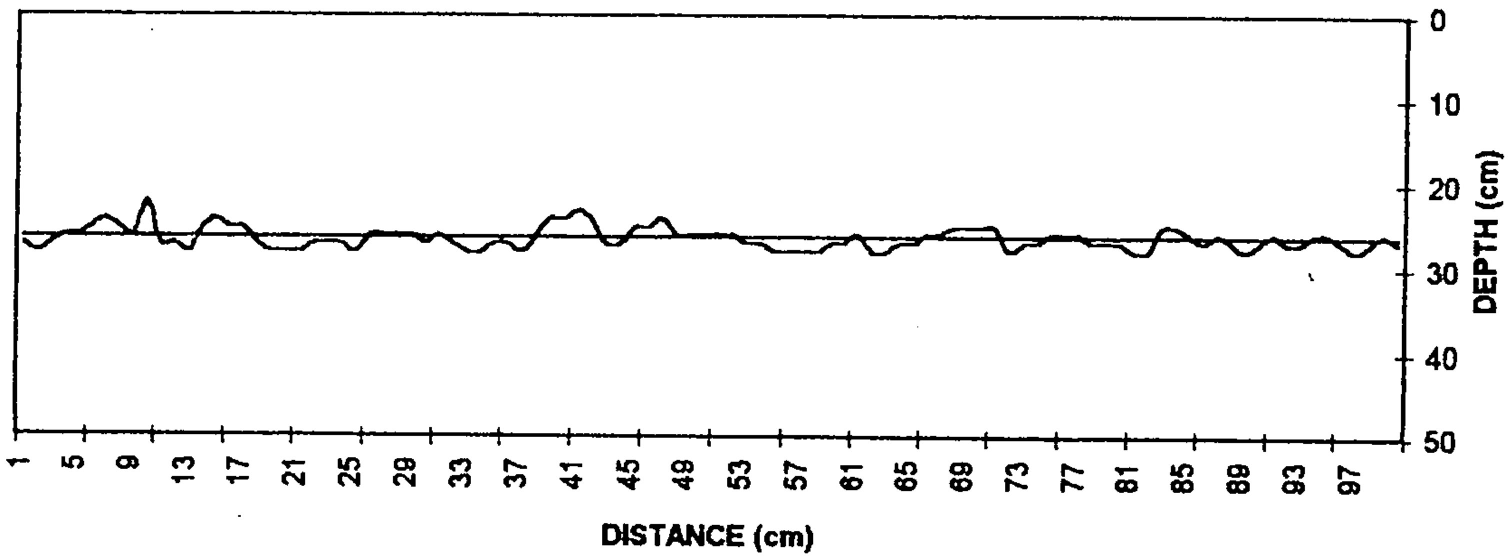


FIGURE:23 BLOCK NO-PH2

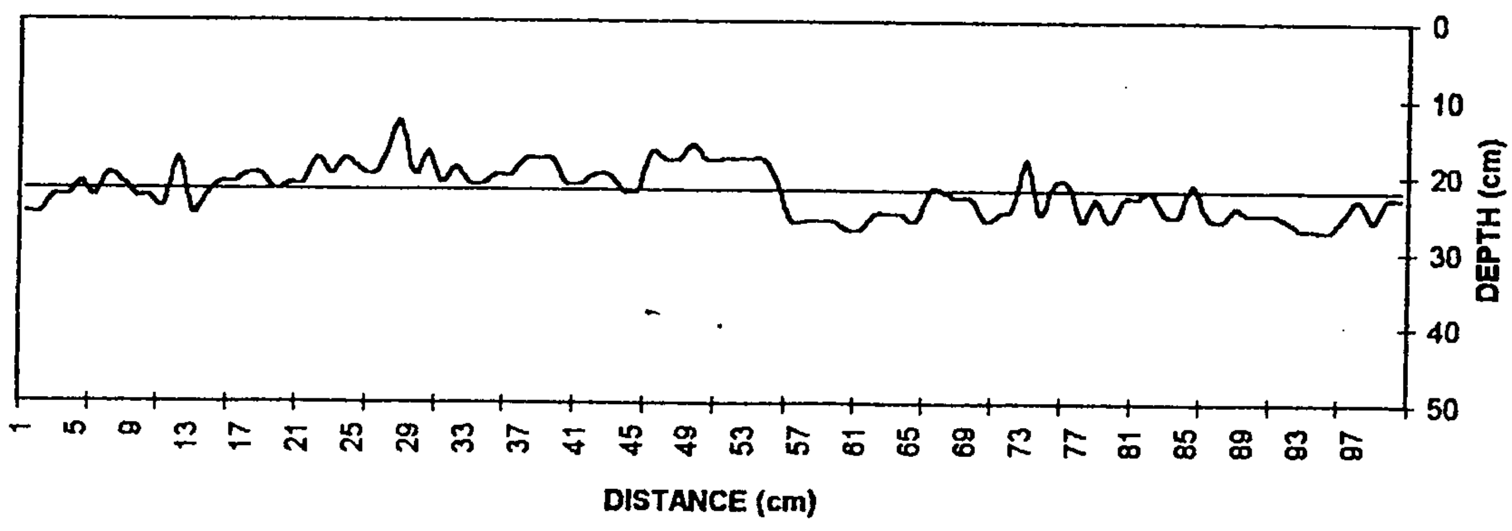


FIGURE: 24 BLOCK NO-PC3

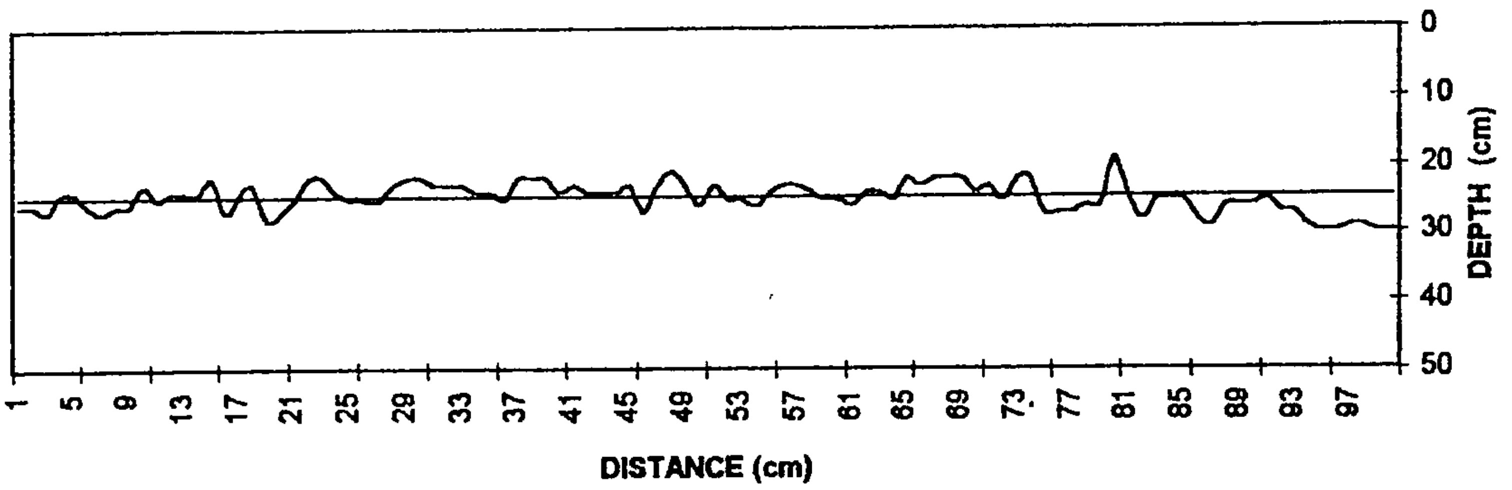


FIGURE: 25 BLOCK N-PR3

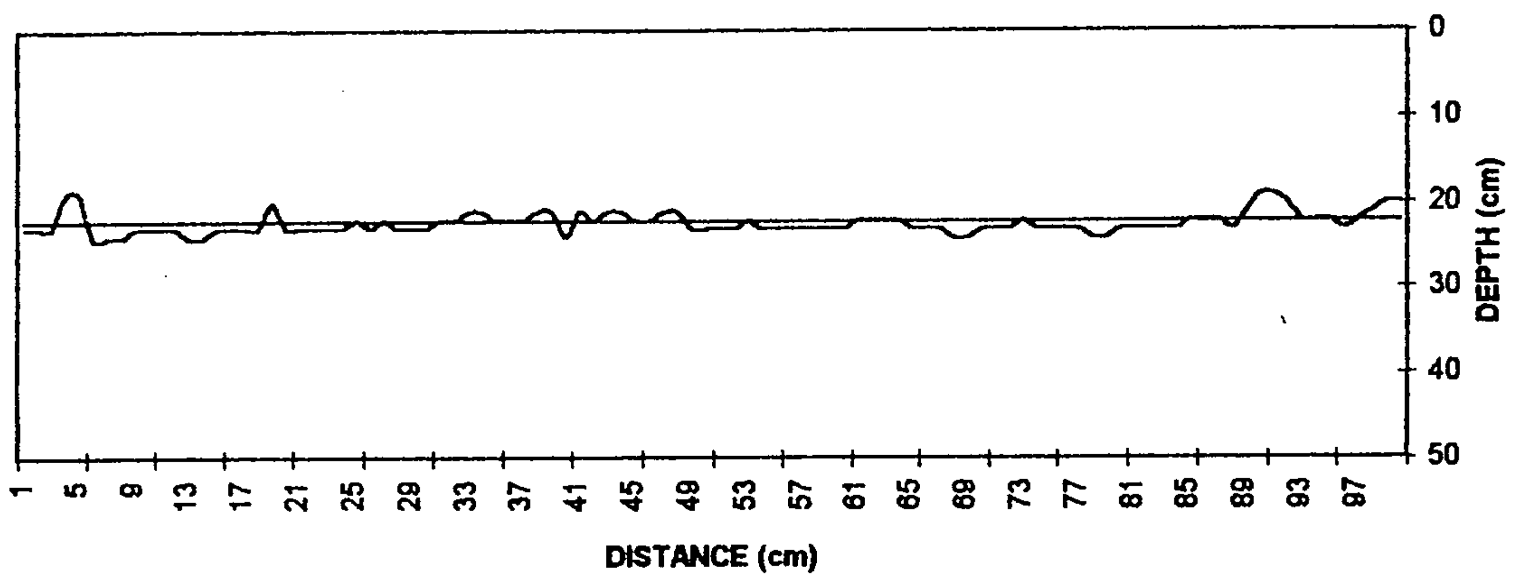
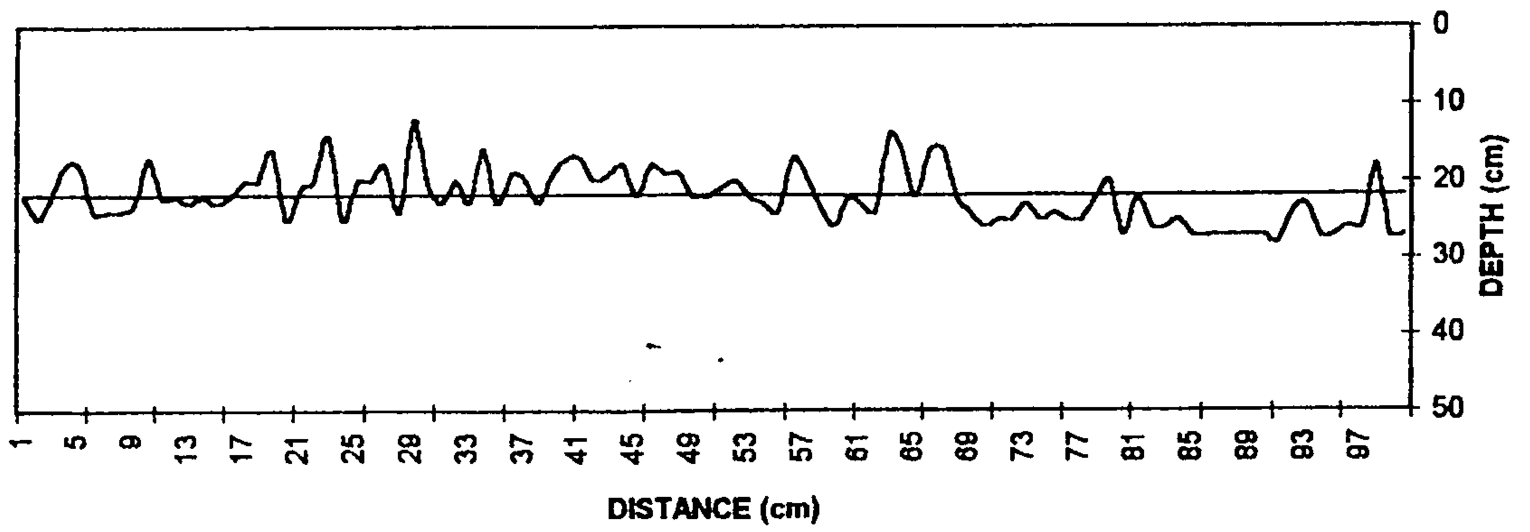


FIGURE: 26 BLOCK NO-PR3



3.3.1 RELATIVE PERFORMANCE OF DESIGNED CAGE WHEEL FOR TWO WHEEL TRACTOR

3.3.1.1 General Observations

3.3.1.1.1 Designed cage wheel on road

The retractable lugged cage wheels used for the test were found capable of being operated for road transportation with out any problem. The hinged type lugs could be locked perfectly at retracted position using inner ring and the key mechanism, making retracted wheel outer diameter 100 mm smaller than that of the tyre.

3 3.1.1.2. Designed cage wheel in field

The designed cage wheel under field conditions was found with many advantages, over the other traction aids. They are as follows:

The retractable lugged cage wheel was capable of having larger diameter than tyre in field operation and smaller on road transportation.

1. Use of hinged flat lugs which can penetrate to the hard pan properly compare to the previous triangular lugged mechanism producing more traction.
2. swinging lug mechanism functioned properly in field condition facilitating ,

a). Reversibility of the tractor , in which lugs automatically changed the direction - 30 or + 30 degree lug angle.

b) Less friction to the wheel rotation , as the rear side lugs near to the soil surface tended to get vertical hanging position that also prevented mud sticking and reduced friction to the wheel rotation .

4. Retraction and expansion of the wheel was functioned well in wet or dry soil . After disengaging key from retracted position of the key way ,driving the tractor in reverse direction with jerking action lugs could be expanded.

3.3.1.2. TEST OF TRACTOR PERFORMANCE (for 2 wheel tractor)

3.3.1.2.1 Presentation of test dada

Test results were obtained for two location, three traction aids and each having three replication, totalling 18 test runs. For the analysis basically maximum pull at 100% slip of the tractor drive wheel were measured. These results are tabulated in table 6 - 7 and figure :27 and 28.

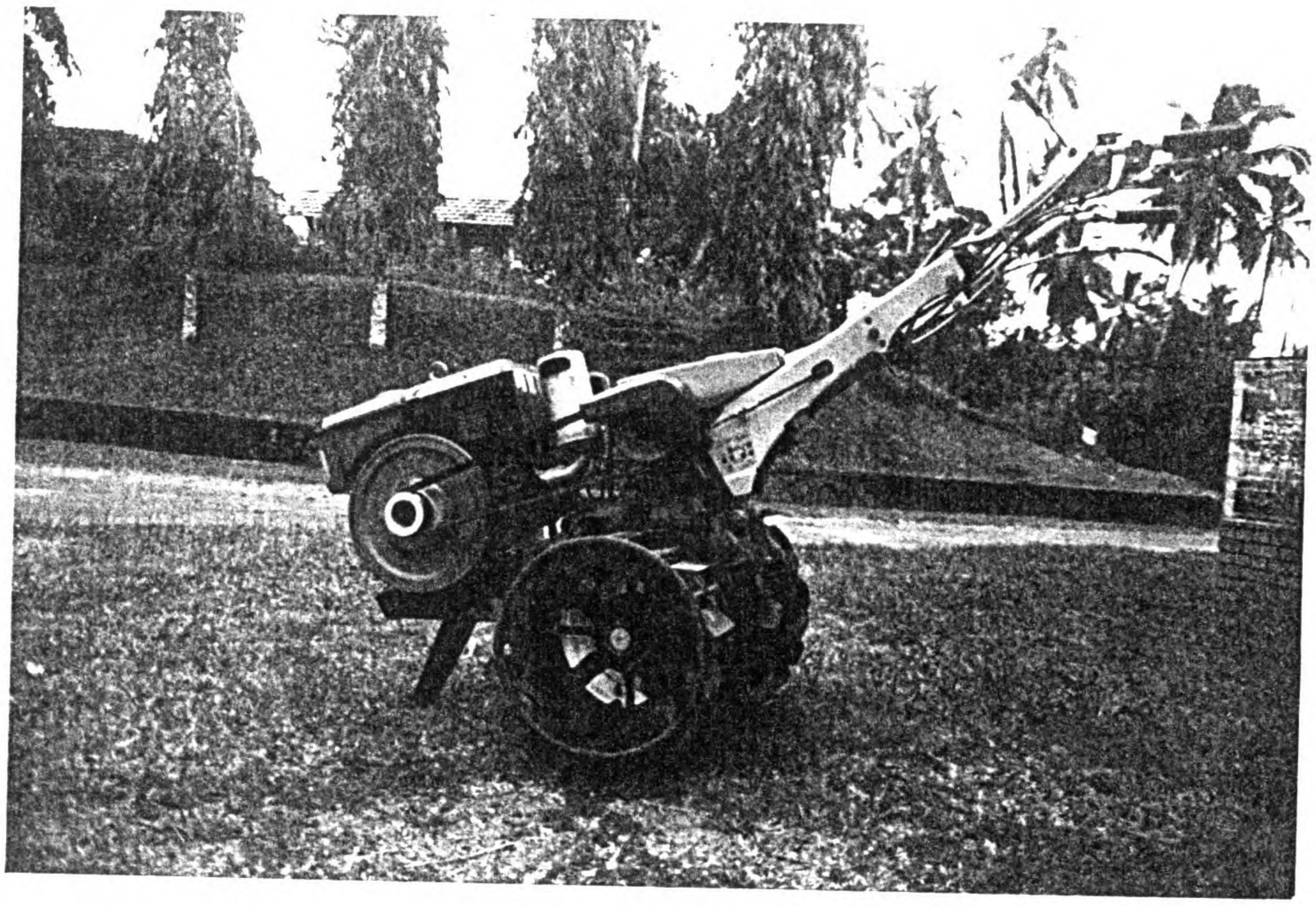


Photo 07: Tested two wheel tractor with designed cage wheel

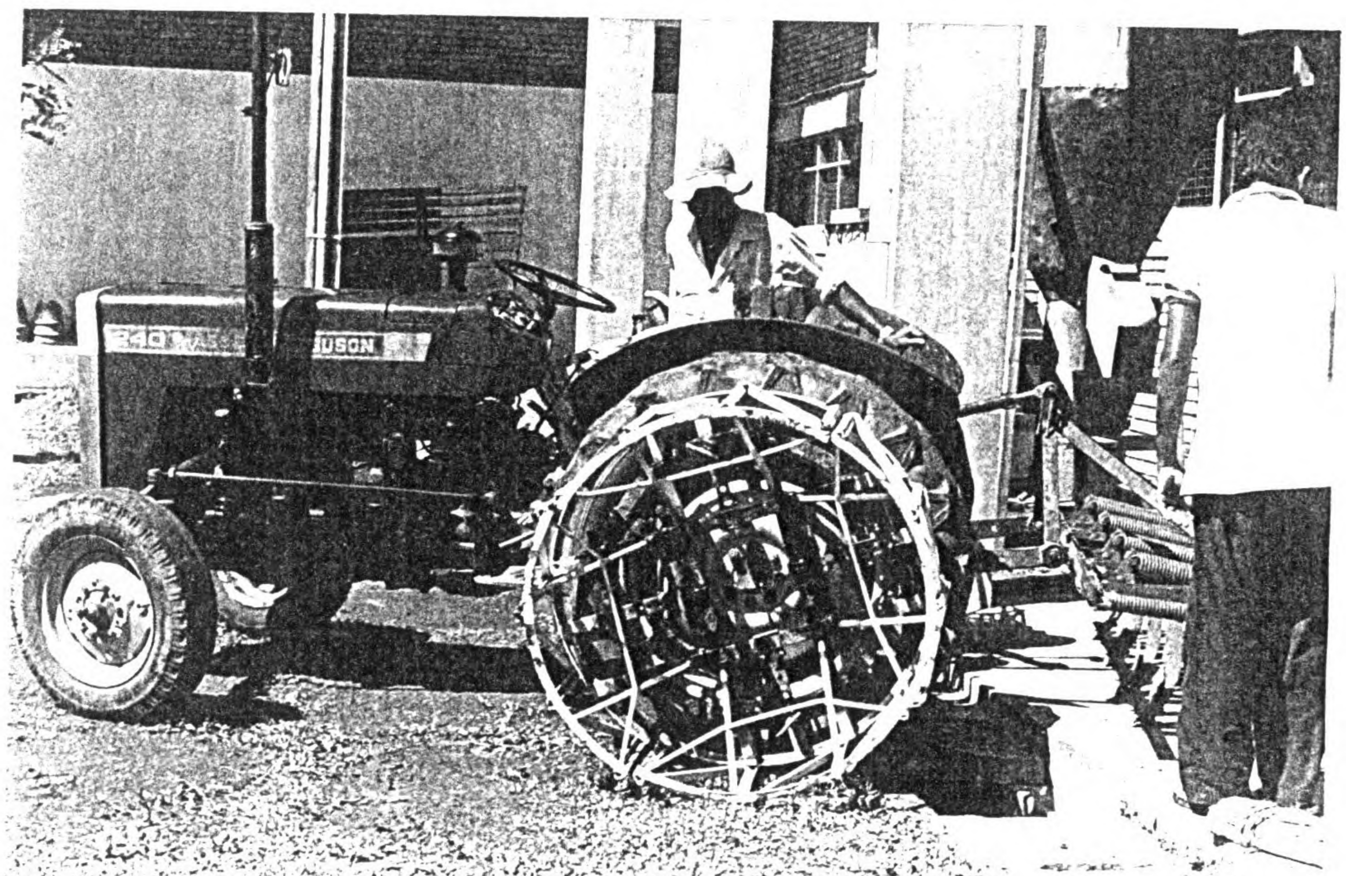


Photo 08: Tested four wheel tractor with designed cage wheel

Traction Aids	Run	Max pull at 100% slip kg	kN
High Lugged Tyre	1	172.5	1.69
	2	169.6	1.66
	3	169.3	1.65
	Mean :	170.47	1.67
Conven Cage Wheel	1	190	1.86
	2	180	1.76
	3	193	1.89
	Mean :	187.67	1.84
Rectr Cage Wheel	1	241	2.36
	2	231	2.26
	3	235	2.3
	Mean :	235.67	2.31

Table 6: Test Results of Location 1

Trac Aids	Run	Max pull at 100% slip kg	kN
High Lugged Tyre	1	135	1.32
	2	123	1.2
	3	113	1.12
	Mean :	123.67	1.21
Conven Cage Wheel	1	139	1.36
	2	142	1.39
	3	144	1.41
	Mean :	141.67	1.39
Rectr Cage Wheel	1	236	2.31
	2	233	2.28
	3	246	2.41
	Mean :	238.33	2.33

Table 7: Test Results of Location 2

3.3.1.2..2 Analysis of test data

From the test results, it can be clearly observed that the performance of Deigned retractable cage wheel was significantly higher in each using soil condition. (see table no 8) .This was proved by Dunken's multiple range test at different precision levels.

Source	DF	Anova SS	mean Square	F Value	Pr > F
SOIL	1	0.38427222	0.38427222	100.24	0.0001
AIDS	2	2.61121111	1.30560556	340.59	0.0001
*					
SOIL	2	0.22881111	0.11440556	29.84	0.0001
* AIDS					

Table 8: ANOVA for test results.

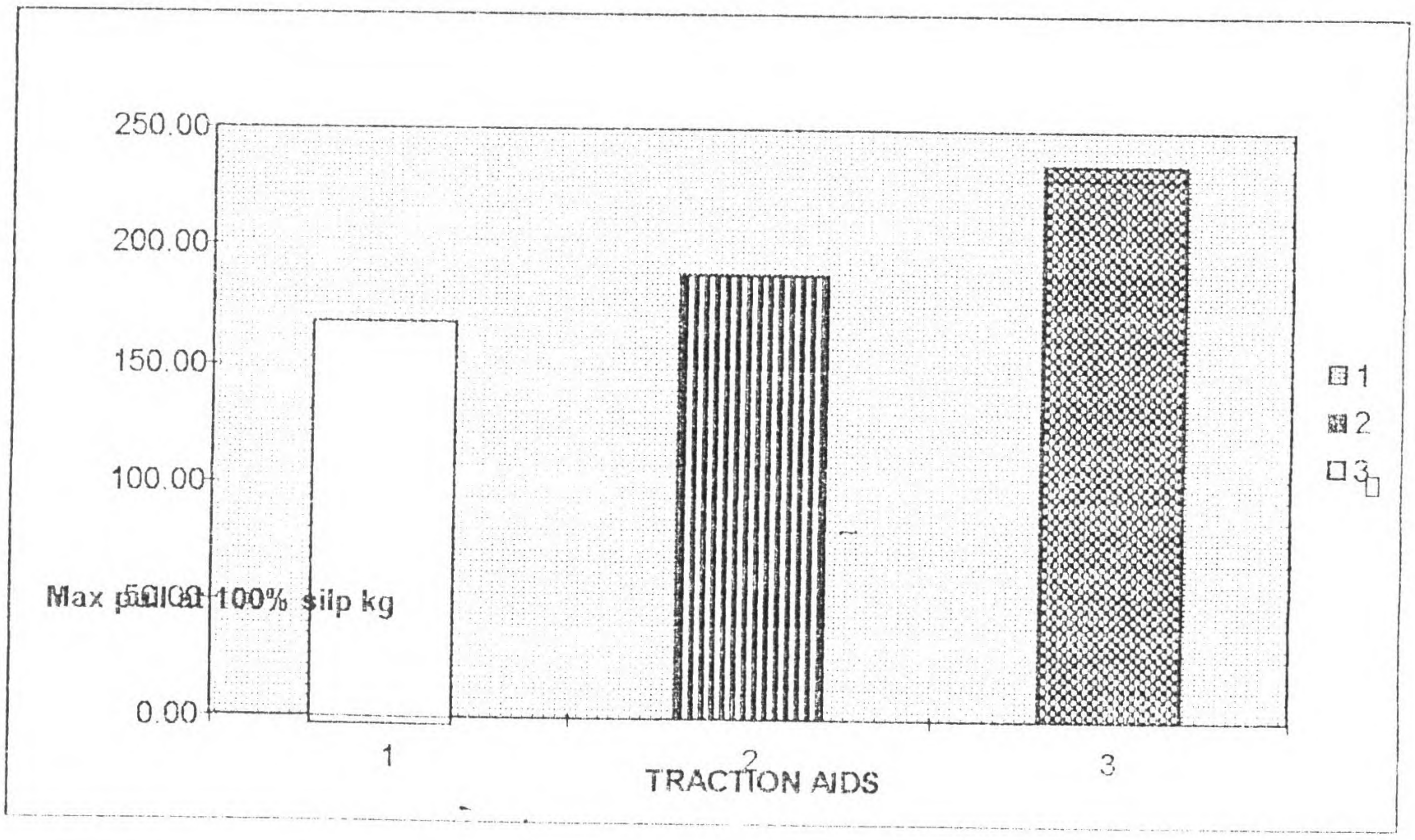


Figure :27. Performance of different traction aids in dry soil.

1 = High lugged tyre

2 = Conventional cage wheel

3 = Retractable cage wheel

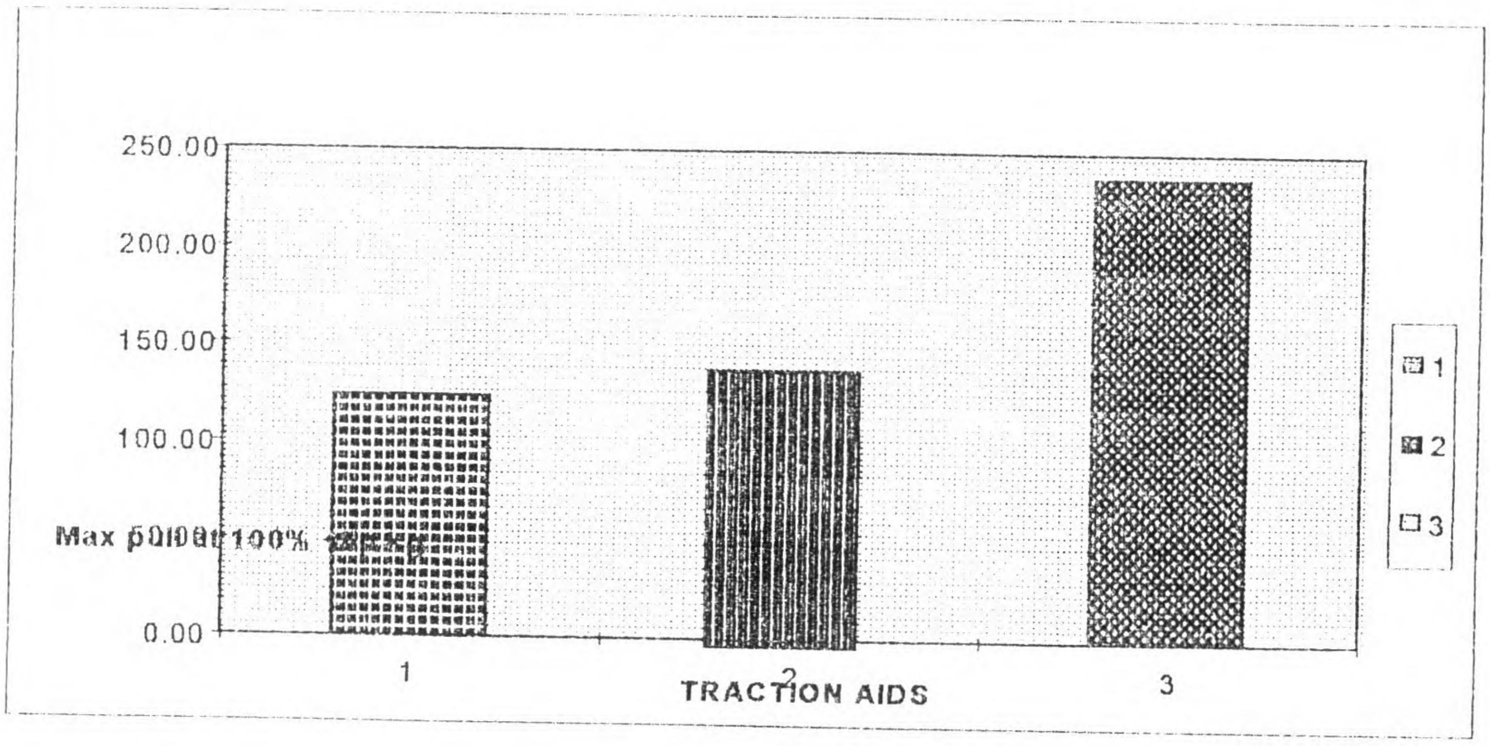


Figure 28. Performance of different traction aid in puddle soil

1 = High lugged tyre

2 = Conventional cage wheel

3 = Retractable cage wheel

Traction aids	Mean (kN) *
R	2.32 a
C	1.61 b

Table 9,1 mean values for maximum pull at 100% slip at deferent traction aids

R = Retractable cage wheel

C = Conventional cage wheel

T = High lugs Tyre

* Mean with same letters are not significantly different.

In addition to that the relative performance of maximum pull at 100% slip of designed cage wheel over conventional cage wheel was found to be about 1.3 for pull in dry soil (Location 1) and 1.7 for puddle soil.(Location 2) (table 9.2.)

Soil type	Traction aids	Mean maximum pull at. 100% slip.
Dry	R	235.67 kg
	C	187.67 kg
Puddle	R	238.33 kg
	C	141.67 kg

Table 9.2: Mean maximum pull of Conventional cage wheel and Retractable cage wheel

R =Retractable cage wheel C = Conventional cage wheel

3.3.2 RELATIVE PERFORMANCE OF DESIGNED CAGE WHEEL FOR FOUR WHEEL TRACTOR

3.3.2.1 General Observations

3.3.2.1.1 Designed cage wheel on road

The Designed cage wheels used for the test were found capable of being operated for road transportation without any problem. The four folders could be locked perfectly at retracted position using the key mechanism, making retracted wheel outer diameter 100 millimetres smaller than that of the tire . Photo 7: shows MF 240 Tractor equipped with design Cage wheel on road having enough ground clearance between road and cage wheel.

3 3.2.1.2. Designed cage wheel in field

The design cage wheel under field conditions was found with many advantage , over the other traction aid. They are as follows:

1. The designed cage wheel was capable of having larger diameter than tire in field operations and smaller on road transportation.
2. Use of 30 angle flat lugs which can penetrate to the hard fan, properly (before tire) compare to the previous triangular lugged mechanism producing more traction.
3. Above lugs prevented mud sticking and reduced friction to the wheel rotation.
4. The main advantage of this Cage wheel is its capability of ploughing with wear tyres. (Cage wheel diameter is larger or similar than the tyre in the field)
5. Comparatively ,design cage wheel cause even soil surface .

3.3.2.2. TEST OF TRACTOR PERFORMANCE (for 4 wheel tractor)

3.3.2.2.1 Presentation of test dada

The designed cage wheel was compared with Conventional cage wheel in two locations for its performance . Test results were obtained for two different experiment in two location .

Experiment 01 (on station trial)

Observed , on station test data were used to calculate the travel reduction. These results are tabulated in table 10 and figures 29 (1 to 4) illustrates the gear type and travel reduction curves obtained for each traction aid.

From the test results, it can be clearly observed that the performance of designed cage wheel was significantly higher in tested field condition. This was proved by using F - tests (tab:12) (Duncan`s multiple range test at different precision levels in SAS (statistical Analysis system) packages. The F test results are shown in appendix-A According to above results , higher significant differences obtained for most of the cases.

The comparisons was proceeded by obtaining the mean values of each performance parameters for pairs of traction aids. Figure 30 (1 to 3) shows the relative performance obtained for each gear ratio.

More descriptively , the mean travel reduction (with and without load) exerted by designed cage wheel over conventional cage wheel were 7.5 and 18 respectively. Therefor it was estimated that the travel reduction of 4 wheel Tractor with design cage wheel has decreased by about 42 % than conventional Cage Wheel.

Experiment 02 (farmer trial)

Test result under practical field condition were obtained for each traction aids with five replicates , totalling 10 test runs. These results are tabulated in table 11 and figures 31(1 to 4) .

DESIGNED MUD WHEEL

With plough :

Gears	Replicate	Time(S)	Distance (m)	Speed(m/s)	Theoriticle Speed(m/s)	Trvel Re duction
1 st high	(i)	14.36	20.00	1.39	1.52	8.47
	(ii)	14.36	20.00	1.39	1.52	8.47
	(iii)	14.98	20.00	1.34	1.52	12.28
2 nd high	(i)	10.27	20.00	1.95	2.22	12.28
	(ii)	10.27	20.00	1.95	2.22	12.28
	(iii)	9.84	20.00	2.03	2.22	8.47
1 st low	(i)	57.60	20.00	0.35	0.40	12.28
	(ii)	55.20	20.00	0.36	0.40	8.47
	(iii)	57.64	20.00	0.35	0.40	12.28
2 nd low	(i)	37.37	20.00	0.54	0.58	8.47
	(ii)	37.63	20.00	0.53	0.58	8.47
	(iii)	37.51	20.00	0.53	0.58	8.47
3 rd low	(i)	19.59	20.00	1.02	1.07	4.31
	(ii)	20.42	20.00	0.98	1.07	8.47
	(iii)	21.35	20.00	0.94	1.07	12.28

Table 10.1

CONVENTIONAL MUD WHEEL

With plough :

Gears	Replicate	Time(S)	Distance (m)	Speed(m/s)	Theoriticle Speed(m/s)	Trvel Re duction
1 st high	(i)	14.98	20	1.34	1.52	12.28
	(ii)	16.85	20	1.19	1.52	22.03
	(iii)	16.23	20	1.23	1.52	19.03
2 nd high	(i)	11.56	20	1.73	2.22	22.03
	(ii)	13.70	20	1.46	2.22	34.21
	(iii)	12.41	20	1.61	2.22	27.40
1 st low	(i)	67.20	20	0.30	0.40	24.81
	(ii)	64.80	20	0.31	0.40	22.03
	(iii)	62.44	20	0.32	0.40	19.03
2 nd low	(i)	43.87	20	0.46	0.58	22.03
	(ii)	47.44	20	0.42	0.58	27.40
	(iii)	45.66	20	0.44	0.58	24.81
3 rd low	(i)	26.72	20	0.75	1.07	29.82
	(ii)	26.63	20	0.75	1.07	29.82
	(iii)	24.91	20	0.80	1.07	24.81

Table 10.2

DESIGNED MUD WHEEL

Without plough :

Gears	Replicate	Time(S)	Distance (m)	Speed(m/s)	Theoriticle Speed(m/s)	Trvel Reduction
1 st high	(i)	13.14	20.00	1.52	1.52	0.00
	(ii)	14.36	20.00	1.39	1.52	8.47
	(iii)	14.36	20.00	1.39	1.52	8.47
2 nd high	(i)	9.42	20.00	2.12	2.22	4.31
	(ii)	10.27	20.00	1.95	2.22	12.28
	(iii)	9.84	20.00	2.03	2.22	8.47
1 st low	(i)	55.20	20.00	0.36	0.40	8.47
	(ii)	52.80	20.00	0.38	0.40	4.31
	(iii)	55.24	20.00	0.36	0.40	8.47
2 nd low	(i)	35.75	20.00	0.56	0.58	4.31
	(ii)	35.99	20.00	0.56	0.58	4.31
	(iii)	34.33	20.00	0.58	0.58	0.00
3 rd low	(i)	19.59	20.00	1.02	1.07	4.31
	(ii)	19.53	20.00	1.02	1.07	4.31
	(iii)	19.57	20.00	1.02	1.07	4.31

Table 10.3:

CONVENTIONAL MUD WHEEL

Without plough :

Gears	Replicate	Time(S)	Distance (m)	Speed(m/s)	Theoriticle Speed(m/s)	Trvel Reduction
1 st high	(i)	14.36	20.00	1.39	1.52	8.47
	(ii)	14.36	20.00.	1.39	1.52	8.47
	(iii)	14.36	20.00	1.39	1.52	8.47
2 nd high	(i)	9.42	20.00	2.12	2.22	4.31
	(ii)	10.27	20.00	1.95	2.22	12.28
	(iii)	10.27	20.00	1.95	2.22	12.28
1 st low	(i)	55.20	20.00	0.36	0.40	8.47
	(ii)	55.20	20.00	0.36	0.40	8.47
	(iii)	55.24	20.00	0.36	0.40	8.47
2 nd low	(i)	40.62	20.00	0.49	0.58	15.79
	(ii)	40.90	20.00	0.49	0.58	15.79
	(iii)	39.14	20.00	0.51	0.58	12.28
3 rd low	(i)	21.38	20.00	0.94	1.07	12.28
	(ii)	26.63	20.00	0.75	1.07	29.82
	(iii)	23.13	20.00	0.86	1.07	19.03

Table 10.4:

DETERMINATION OF TRAVEL REDUCTION

2. Without plough :

Gear Type	Traction Aids	Replicate No.	Travel Reduction	Gear Type	Traction Aids	Replicate No.	Travel Reduction
1 st high	Conventional	(i)	8.47	2 nd low	Conventional	(i)	15.79
		(ii)	8.47			(ii)	15.79
		(iii)	8.47			(iii)	12.28
		Mean	8.47			Mean	14.62
	Designed	(i)	0.00		Designed	(i)	4.31
		(ii)	8.47			(ii)	4.31
		(iii)	8.47			(iii)	0.00
		Mean	5.64			Mean	2.87
2 nd high	Conventional	(i)	4.31	3 rd low	Conventional	(i)	12.28
		(ii)	12.28			(ii)	29.82
		(iii)	12.28			(iii)	19.03
		Mean	9.62			Mean	20.38
	Designed	(i)	4.31		Designed	(i)	4.31
		(ii)	12.28			(ii)	4.31
		(iii)	8.47			(iii)	4.31
		Mean	8.35			Mean	4.31
1 st low	Conventional	(i)	8.47				
		(ii)	8.47				
		(iii)	8.47				
		Mean	8.47				
	Designed	(i)	8.47				
		(ii)	4.31				
		(iii)	8.47				
		Mean	7.08				

Table: 10.5

DETERMINATION OF TRAVEL REDUCTION

WITH PLOUGH

Gear Type	Traction Aid.	Replic-ate No.	Travel Reduction	Gear Type	Traction Aids	Replic-ate No.	Travel Reduction
1 st high	Conventional	(i)	12.28	2 nd low	Conventional	(i)	22.03
		(ii)	22.03			(ii)	27.40
		(iii)	19.03			(iii)	24.81
		Mean	17.78			Mean	24.75
	Designed	(i)	8.47		Designed	(i)	8.47
		(ii)	8.47			(ii)	8.47
		(iii)	12.28			(iii)	8.47
		Mean	9.74			Mean	8.47
2 nd high	Conventional	(i)	22.03	3 rd low	Conventional	(i)	29.82
		(ii)	34.21			(ii)	29.82
		(iii)	27.40			(iii)	24.81
		Mean	27.88			Mean	28.15
	Designed	(i)	12.28		Designed	(i)	4.31
		(ii)	12.28			(ii)	8.47
		(iii)	8.47			(iii)	12.28
		Mean	11.01			Mean	8.35
1 st low	Conventional	(i)	24.81				
		(ii)	22.03				
		(iii)	19.03				
		Mean	21.96				
	Designed	(i)	12.28				
		(ii)	8.47				
		(iii)	12.28				
		Mean	11.01				

Table: 10.6

MEAN OF TRAVEL REDUCTION IN EACH TRACTION AIDS

With plough :

Gear Type	Traction Aid	Mean	Travel Reduction
1 st high(1H)	Conventional(C)	Mean	17.78
	Designed (D)	Mean	9.74
2 nd high(2H)	Conventional(C)	Mean	27.88
	Designed (D)	Mean	11.01
1 st low(1L)	Conventional(C)	Mean	21.96
	Designed (D)	Mean	11.01
2 nd low(2L)	Conventional(C)	Mean	24.75
	Designed (D)	Mean	8.47
3 rd low(3L)	Conventional(C)	Mean	28.15
	Designed (D)	Mean	8.35

2. Without plough :

Gear Type	Traction Aid	Mean	Travel Reduction
1 st high(1H)	Conventional(C)	Mean	8.47
	Designed (D)	Mean	5.56
2 nd high(2H)	Conventional(C)	Mean	9.62
	Designed (D)	Mean	8.35
1 st low(1L)	Conventional(C)	Mean	8.47
	Designed (D)	Mean	7.08
2 nd low(2L)	Conventional(C)	Mean	14.62
	Designed (D)	Mean	2.79
3 rd low(3L)	Conventional(C)	Mean	20.38
	Designed (D)	Mean	4.31

Table: 10.7

MEAN OF TRAVEL REDUCTION IN EACH GEAR TYPE

1. With plough :

Gear Type	Traction Aid	Mean	Travel Reduction
1 st high(1H)	Conventional(C)	Mean	17.78
2 nd high(2H)	Conventional(C)	Mean	27.88
1 st low(1L)	Conventional(C)	Mean	21.96
2 nd low(2L)	Conventional(C)	Mean	24.75
3 rd low(3L)	Conventional(C)	Mean	28.15
1 st high(1H)	Designed (D)	Mean	9.74
2 nd high(2H)	Designed (D)	Mean	11.01
1 st low(1L)	Designed (D)	Mean	11.01
2 nd low(2L)	Designed (D)	Mean	8.47
3 rd low(3L)	Designed (D)	Mean	8.35

2. Without plough :

Gear Type	Traction Aid	Mean	Travel Reduction
1 st high(1H)	Conventional(C)	Mean	8.47
2 nd high(2H)	Conventional(C)	Mean	9.62
1 st low(1L)	Conventional(C)	Mean	8.47
2 nd low(2L)	Conventional(C)	Mean	14.62
3 rd low(3L)	Conventional(C)	Mean	20.38
1 st high(1H)	Designed (D)	Mean	5.56
2 nd high(2H)	Designed (D)	Mean	8.35
1 st low(1L)	Designed (D)	Mean	7.08
2 nd low(2L)	Designed (D)	Mean	2.79
3 rd low(3L)	Designed (D)	Mean	4.31

Table: 10.8

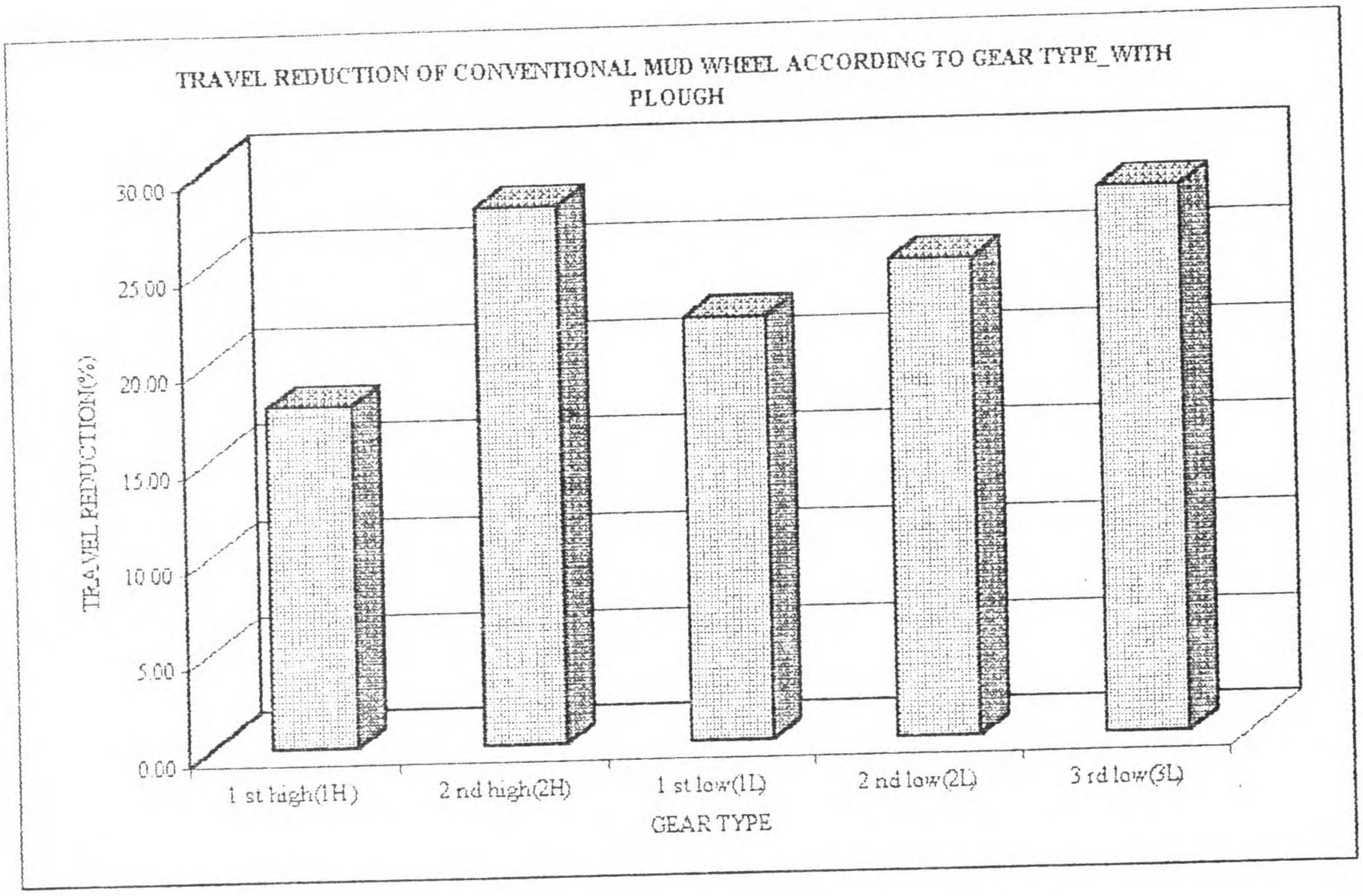


Figure 29.1

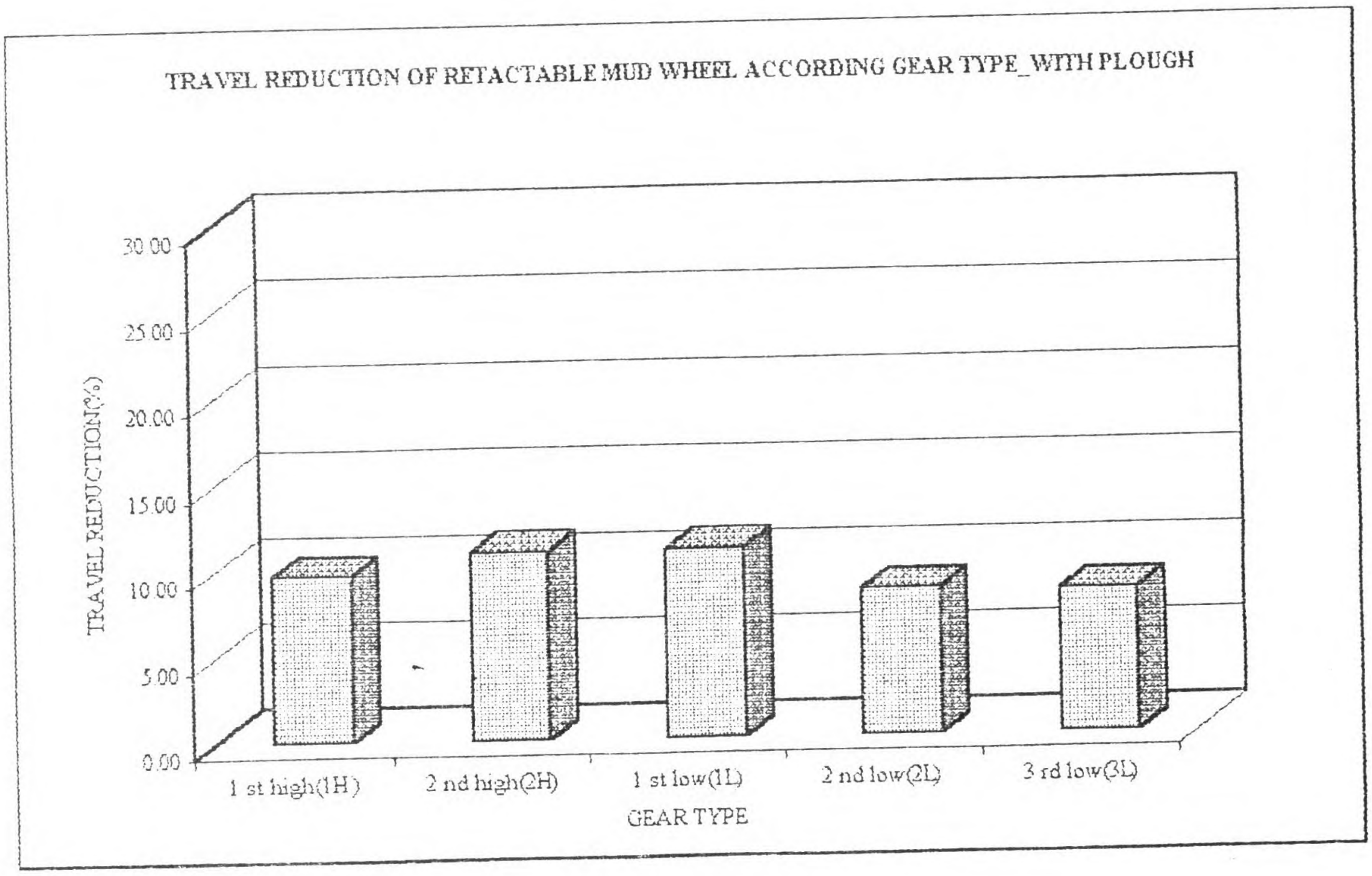


Figure 29.2

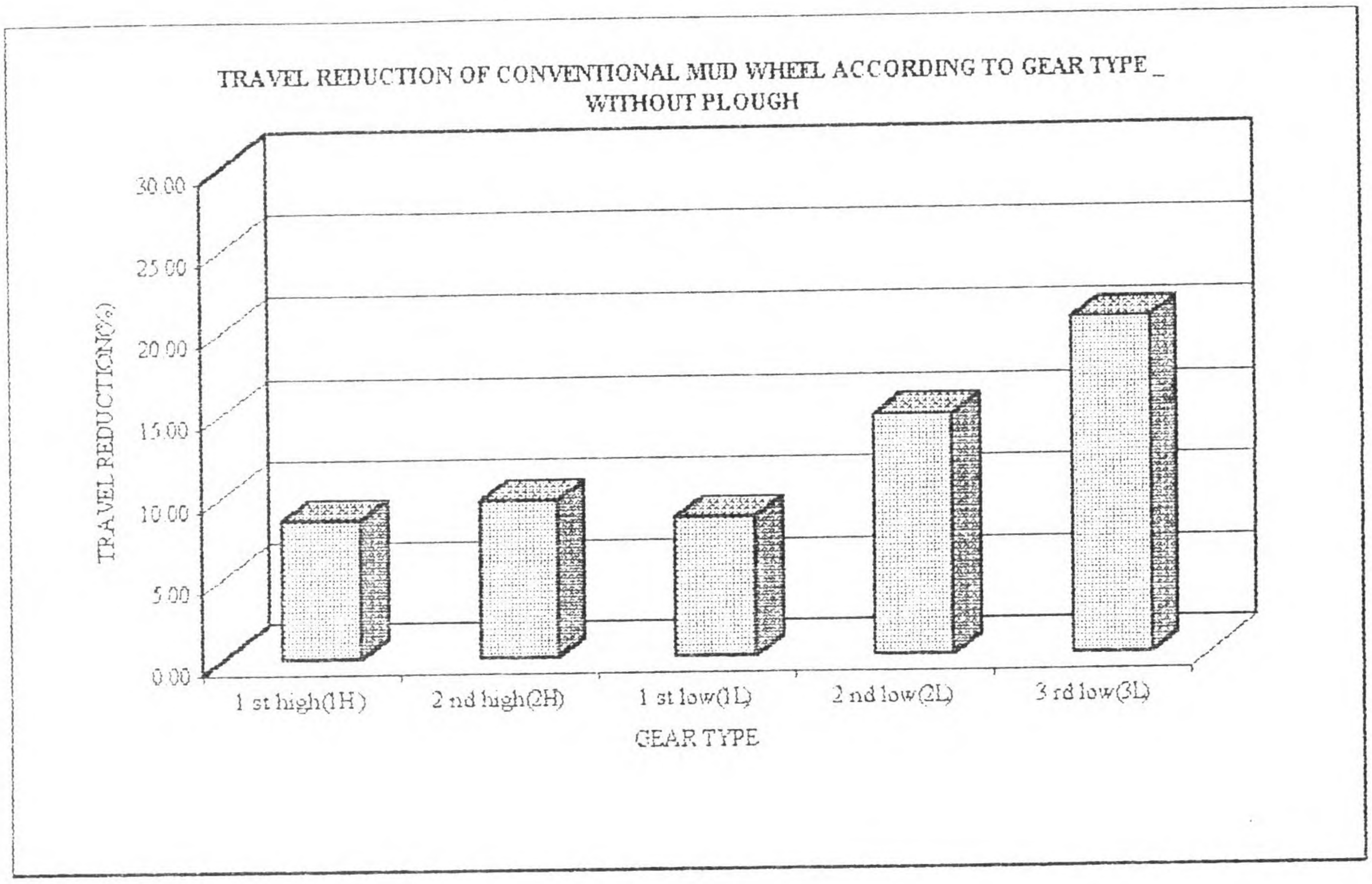


Figure 29.3

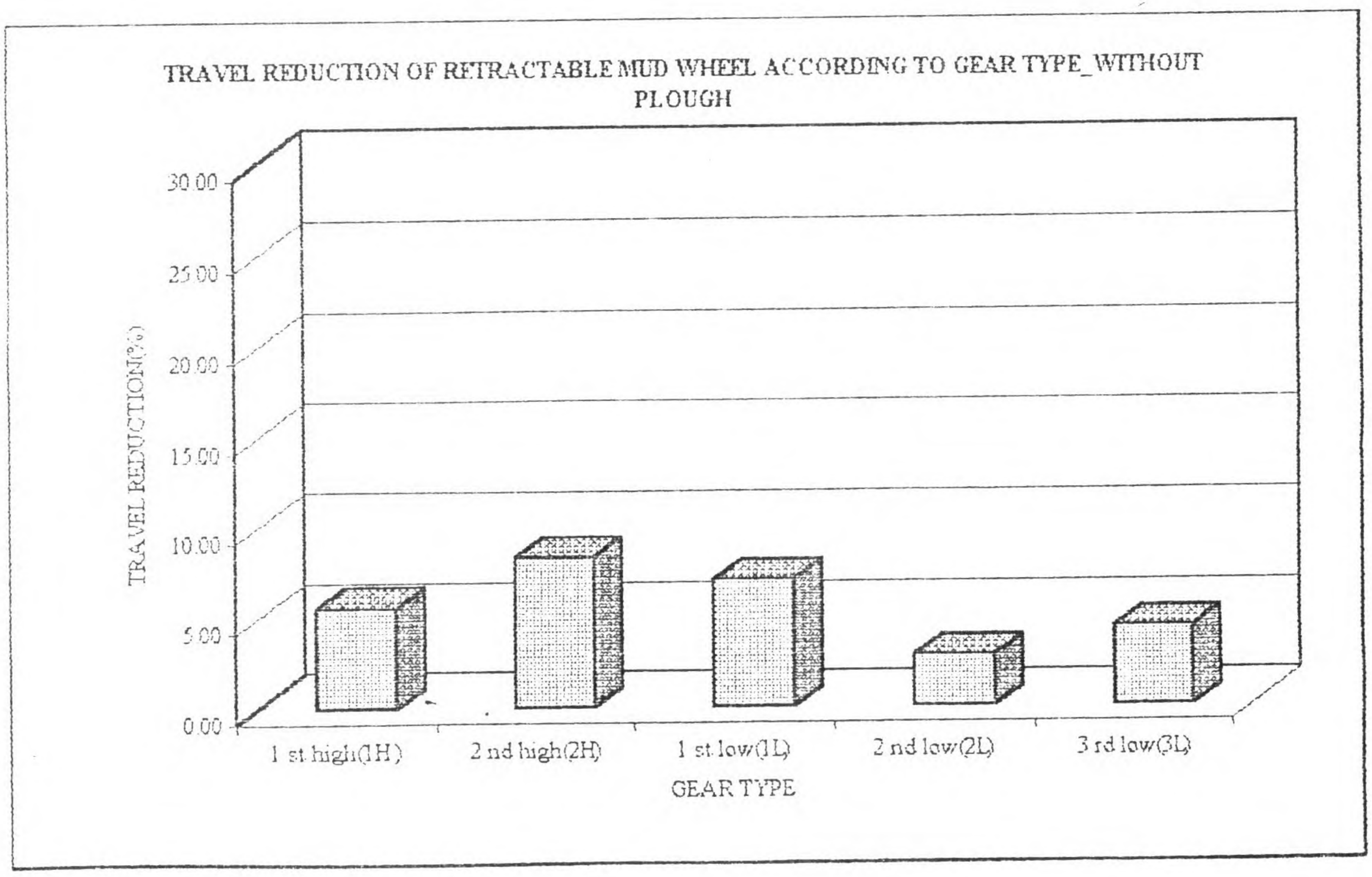
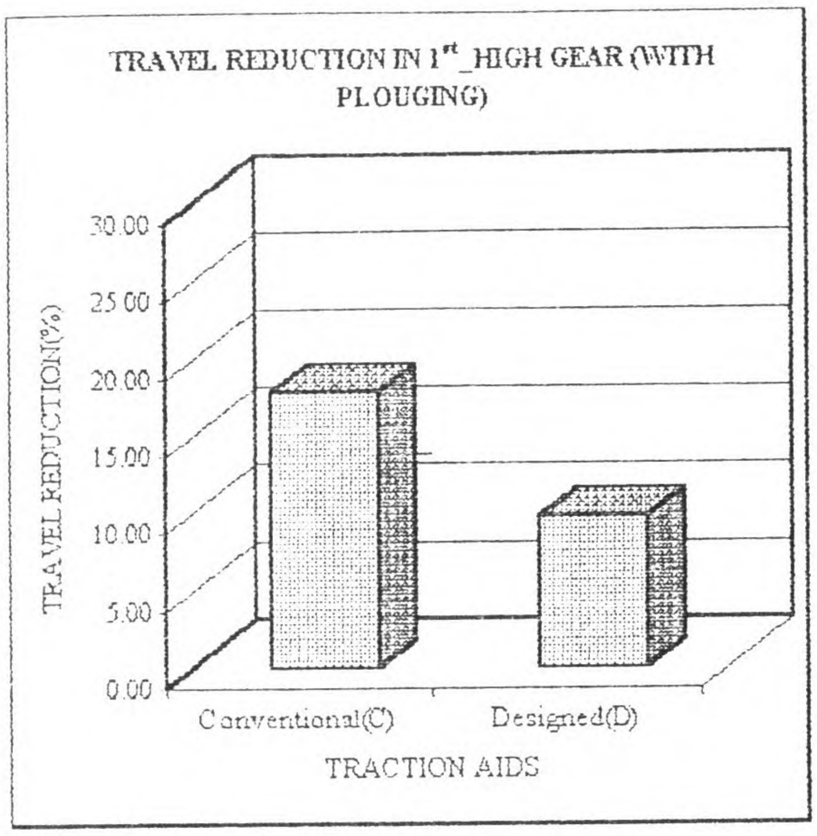
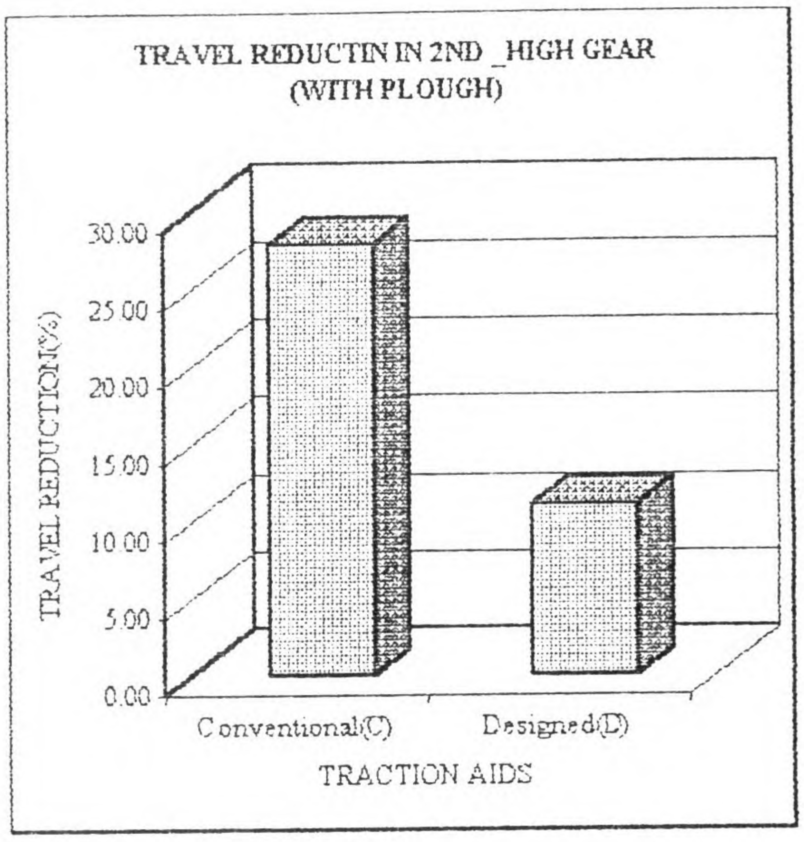
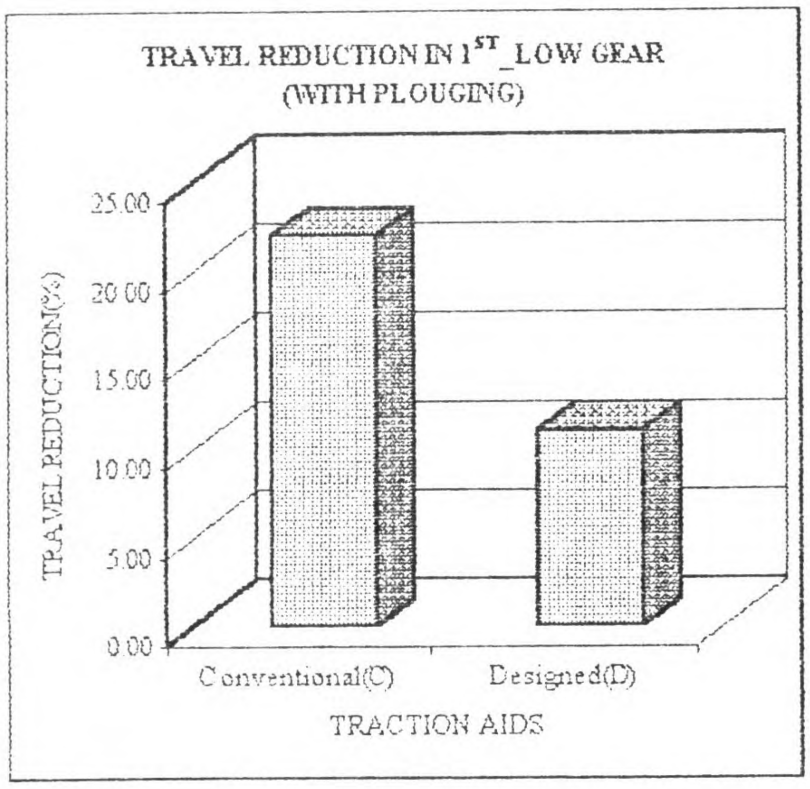
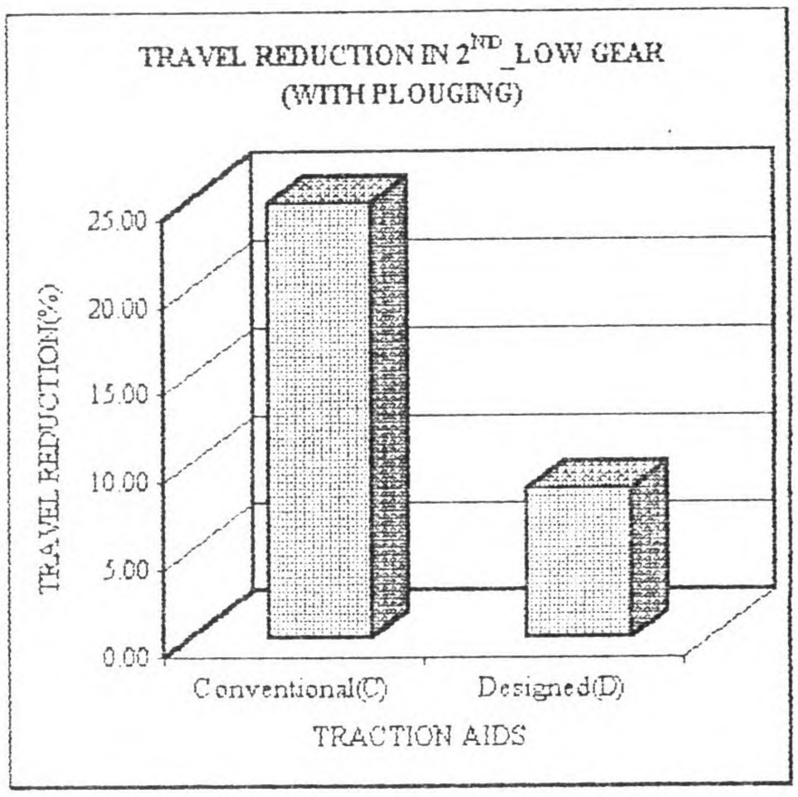


Figure 29.4


TRAVEL REDUCTION IN 1st_HIGH GEAR (WITH PLOUGING)
TRAVEL REDUCTION(%)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Conventional(C)
Designed(D)
TRACTION AIDS


TRAVEL REDUCTIN IN 2ND _HIGH GEAR (WITH PLOUGH)
TRAVEL REDUCTION(%)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Conventional(C)
Designed(D)
TRACTION AIDS


TRAVEL REDUCTION IN 1ST_LOW GEAR (WITH PLOUGING)
TRAVEL REDUCTION(%)
25.00
20.00
15.00
10.00
5.00
0.00
Conventional(C)
Designed(D)
TRACTION AIDS


TRAVEL REDUCTION IN 2ND_LOW GEAR (WITH PLOUGING)
TRAVEL REDUCTION(%)
25.00
20.00
15.00
10.00
5.00
0.00
Conventional(C)
Designed(D)
TRACTION AIDS

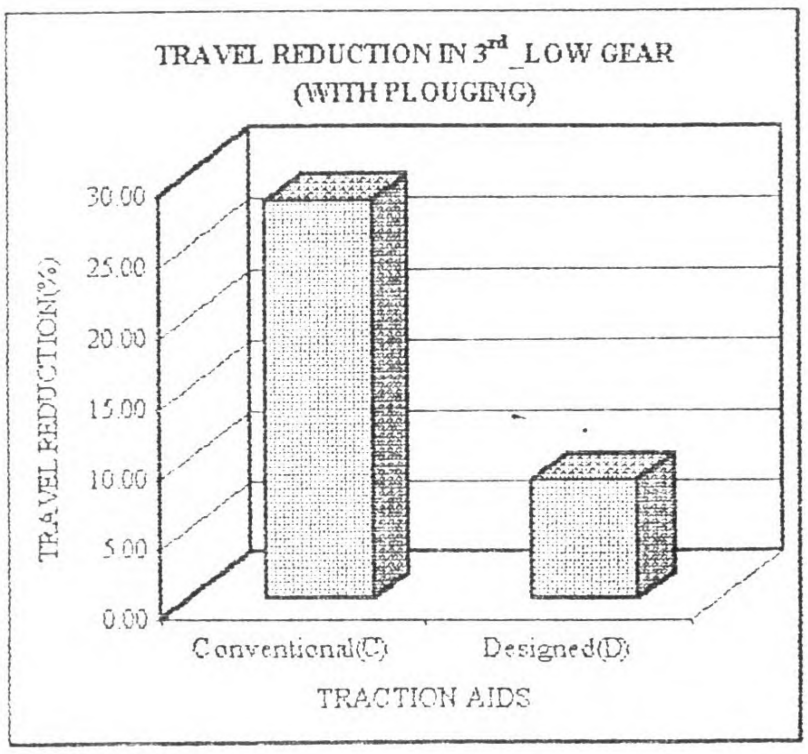
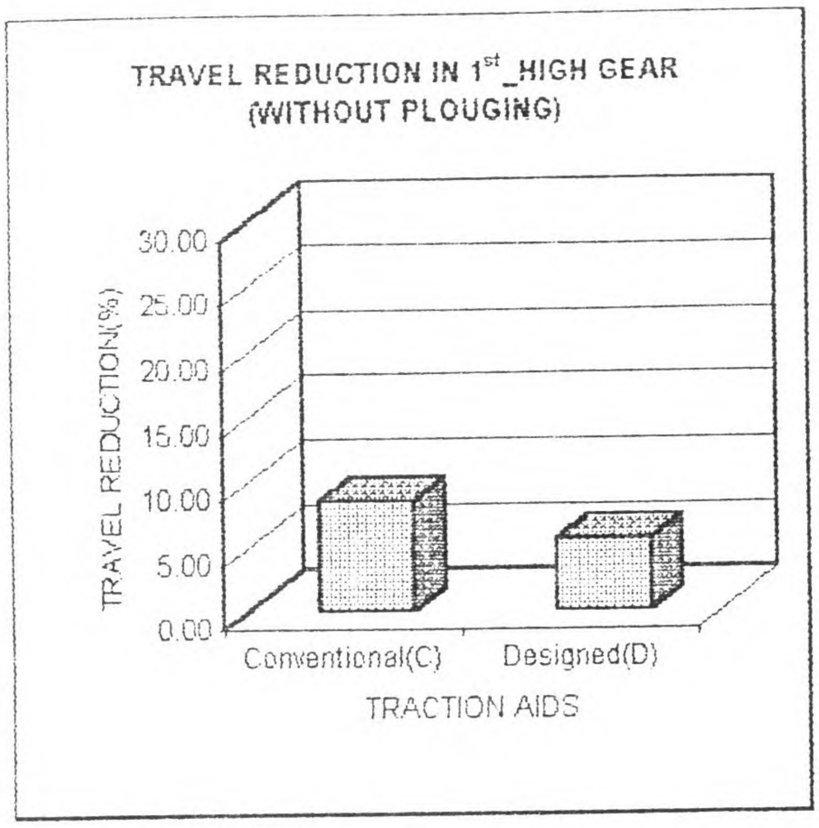
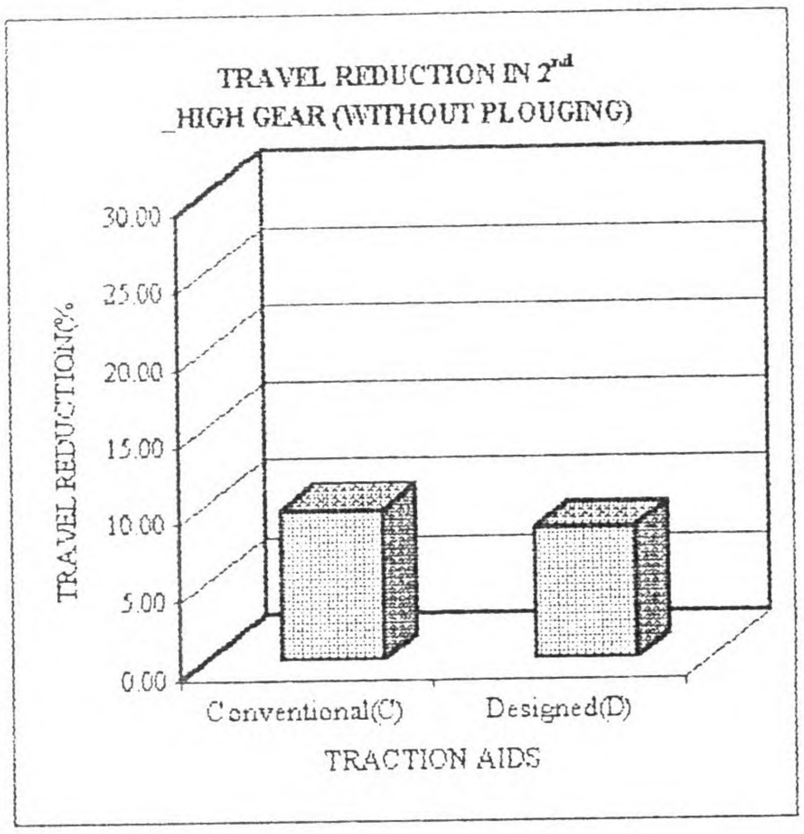

TRAVEL REDUCTION IN 3rd_LOW GEAR (WITH PLOUGING)
TRAVEL REDUCTION(%)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Conventional(C)
Designed(D)
TRACTION AIDS

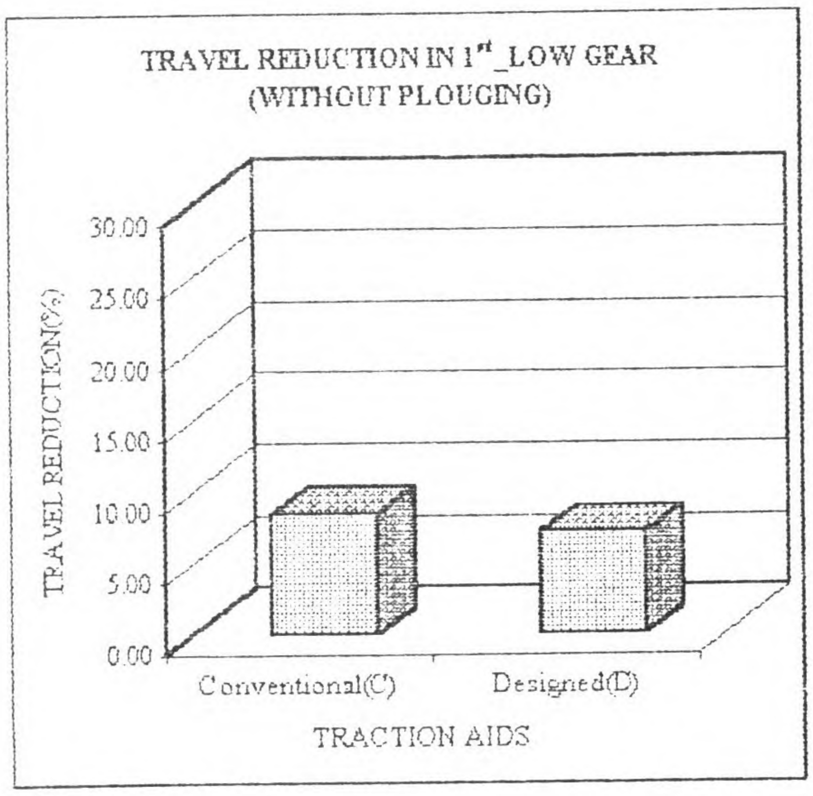
Figure 30.1



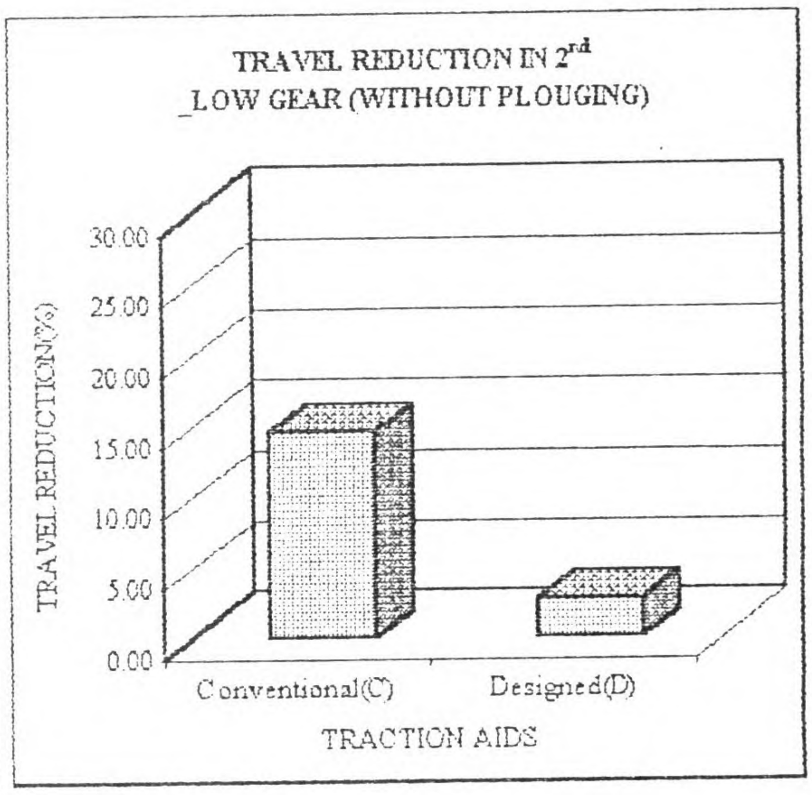
TRAVEL REDUCTION IN 1st_HIGH GEAR (WITHOUT PLOUGING)
TRAVEL REDUCTION(%)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Conventional(C)
Designed(D)
TRACTION AIDS



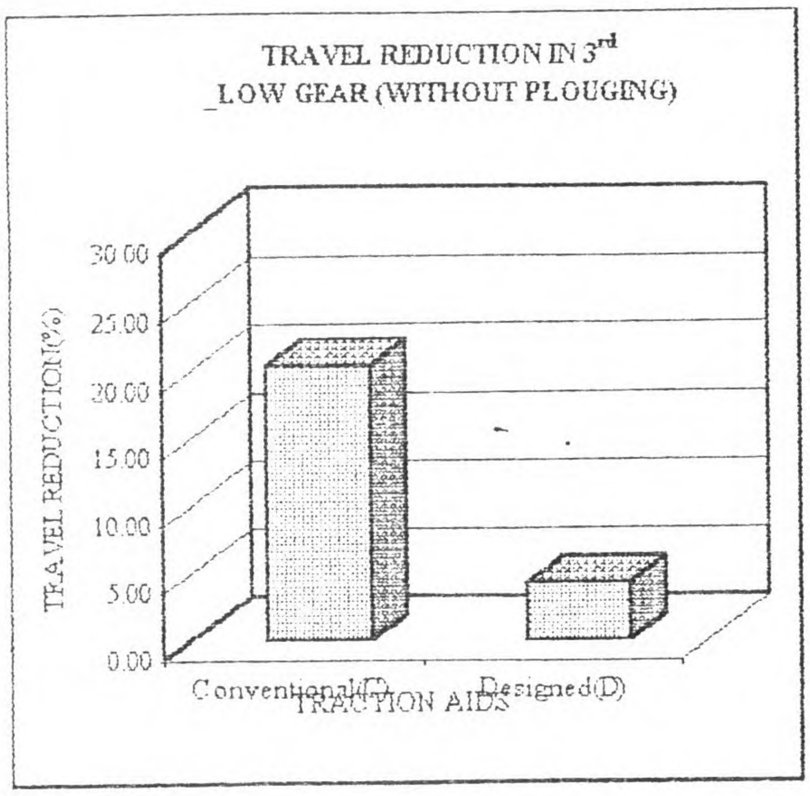
TRAVEL REDUCTION IN 2nd _HIGH GEAR (WITHOUT PLOUGING)
TRAVEL REDUCTION(%
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Conventional(C)
Designed(D)
TRACTION AIDS



TRAVEL REDUCTION IN 1st_LOW GEAR (WITHOUT PLOUGING)
TRAVEL REDUCTION(%)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Conventional(C)
Designed(D)
TRACTION AIDS

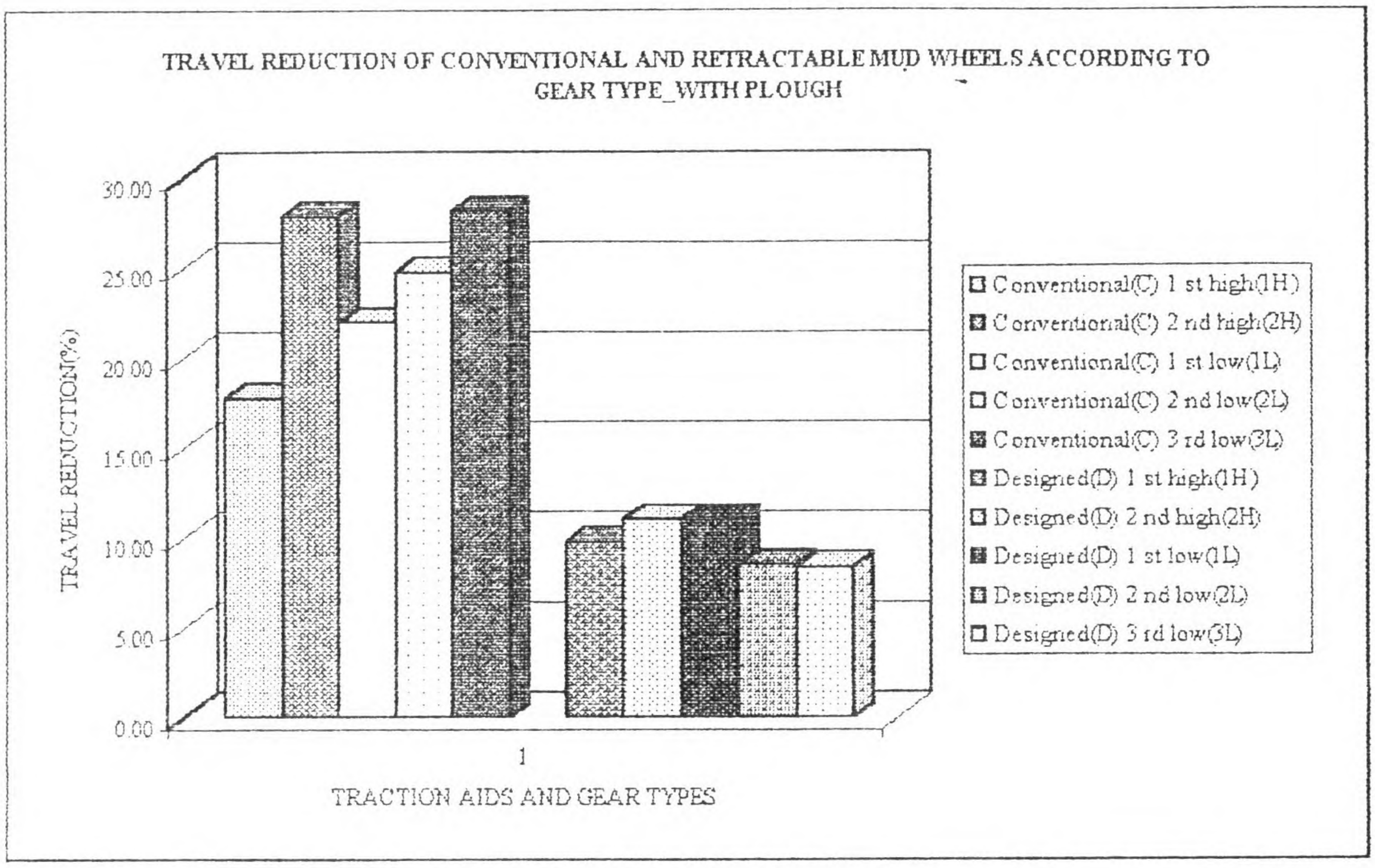


TRAVEL REDUCTION IN 2nd _LOW GEAR (WITHOUT PLOUGING)
TRAVEL REDUCTION(%)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Conventional(C)
Designed(D)
TRACTION AIDS



TRAVEL REDUCTION IN 3rd _LOW GEAR (WITHOUT PLOUGING)
TRAVEL REDUCTION(%)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Conventional(D)
Designed(D)
TRACTION AIDS

Figure 30.2


TRAVEL REDUCTION OF CONVENTIONAL AND RETRACTABLE MUD WHEELS ACCORDING TO GEAR TYPE_WITH PLOUGH
TRAVEL REDUCTION(%)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1
TRACTION AIDS AND GEAR TYPES
Conventional(C) 1 st high(1H)
Conventional(C) 2 nd high(2H)
Conventional(C) 1 st low(1L)
Conventional(C) 2 nd low(2L)
Conventional(C) 3 rd low(3L)
Designed(D) 1 st high(1H)
Designed(D) 2 nd high(2H)
Designed(D) 1 st low(1L)
Designed(D) 2 nd low(2L)
Designed(D) 3 rd low(3L)

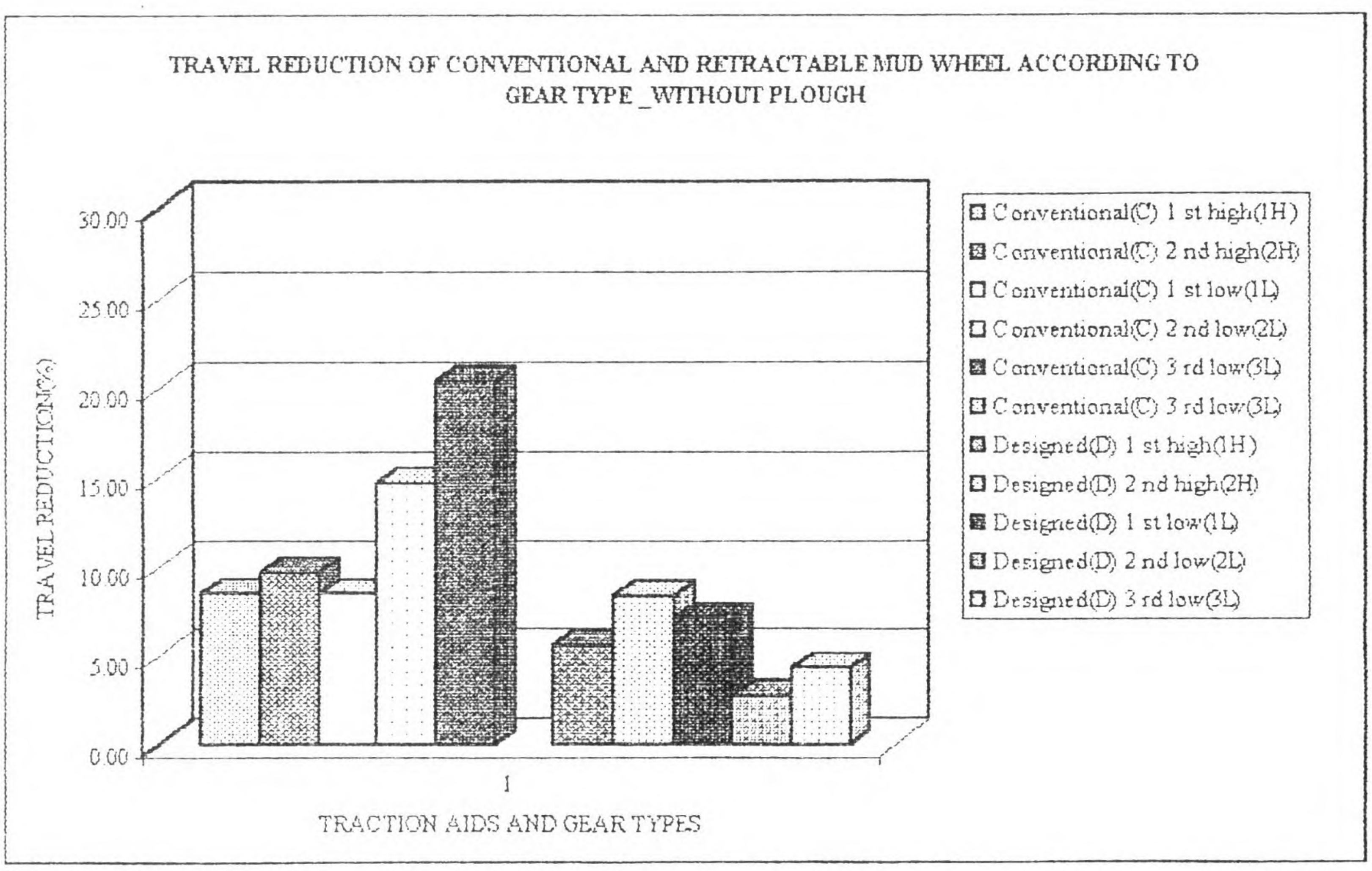

TRAVEL REDUCTION OF CONVENTIONAL AND RETRACTABLE MUD WHEEL ACCORDING TO GEAR TYPE _WITHOUT PLOUGH
TRAVEL REDUCTION(%)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1
TRACTION AIDS AND GEAR TYPES
Conventional(C) 1 st high(1H)
Conventional(C) 2 nd high(2H)
Conventional(C) 1 st low(1L)
Conventional(C) 2 nd low(2L)
Conventional(C) 3 rd low(3L)
Conventional(C) 3 rd low(3L)
Designed(D) 1 st high(1H)
Designed(D) 2 nd high(2H)
Designed(D) 1 st low(1L)
Designed(D) 2 nd low(2L)
Designed(D) 3 rd low(3L)

Figure 30.3

FIELD OBSERVATION

Traction Aid	Blocks	Total area (m2)	Total time(min)	time(hour) per 1 Ha	Effective fi_ eld capaci_ ty ha/hr	Traveling speed (m/s)
Conventional cage wheel	C1	500	20.20	6.73	0.15	1.44
	C2	500	11.63	3.88	0.26	1.52
	C3	500	10.04	3.35	0.30	1.64
	C4	500	12.47	4.16	0.24	1.72
	C5	500	16.32	5.44	0.18	1.69
	MEAN	500	14.13	4.71	0.23	1.60
Designed cage wheel	D1	500	8.24	2.75	0.36	1.82
	D2	500	8.07	2.69	0.37	2.00
	D3	500	8.29	2.76	0.36	2.00
	D4	500	8.40	2.80	0.36	2.22
	D5	500	8.23	2.74	0.36	2.22
	MEAN	500	8.25	2.75	0.36	2.05

Table 11:

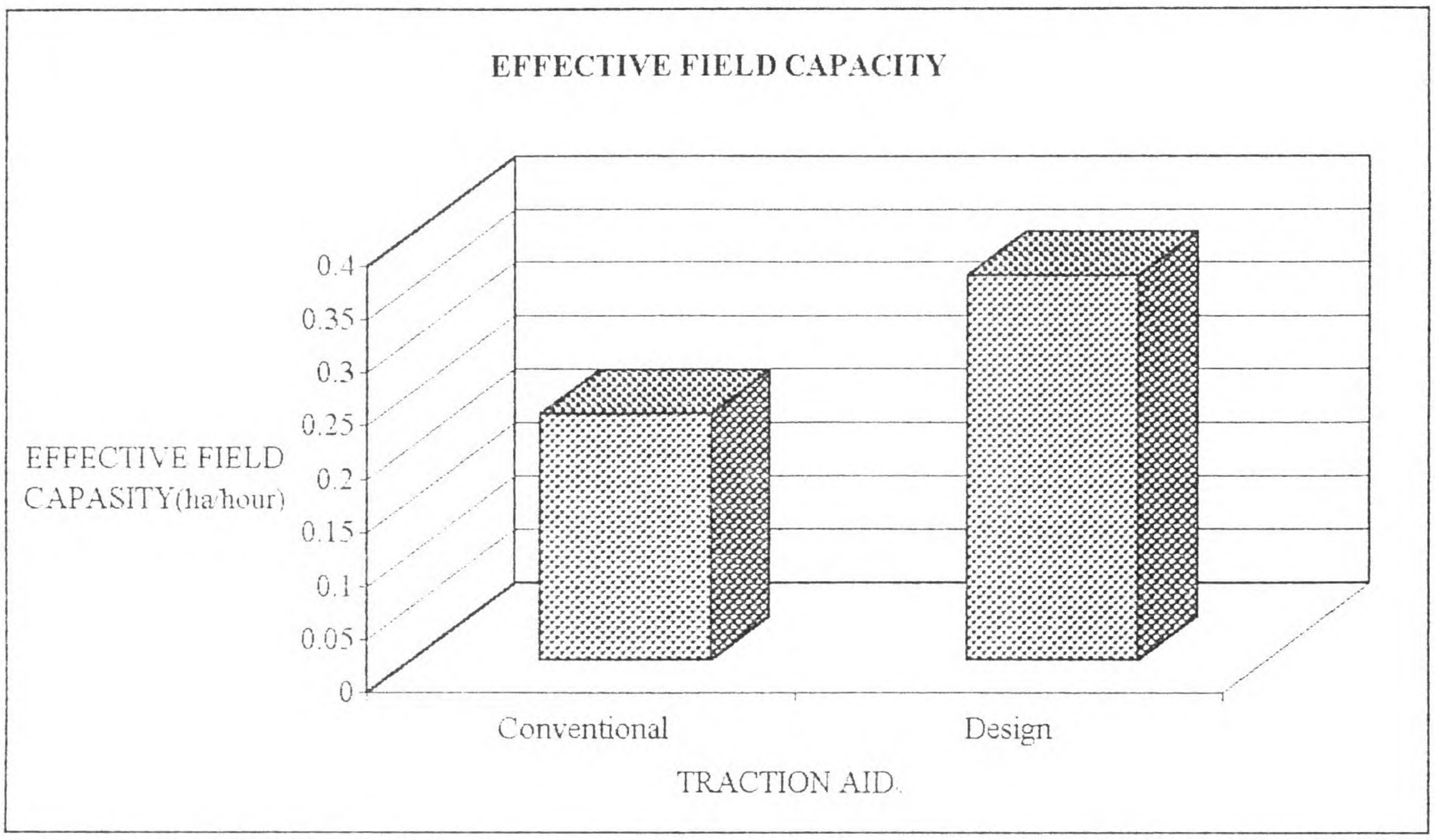


Figure 31.1

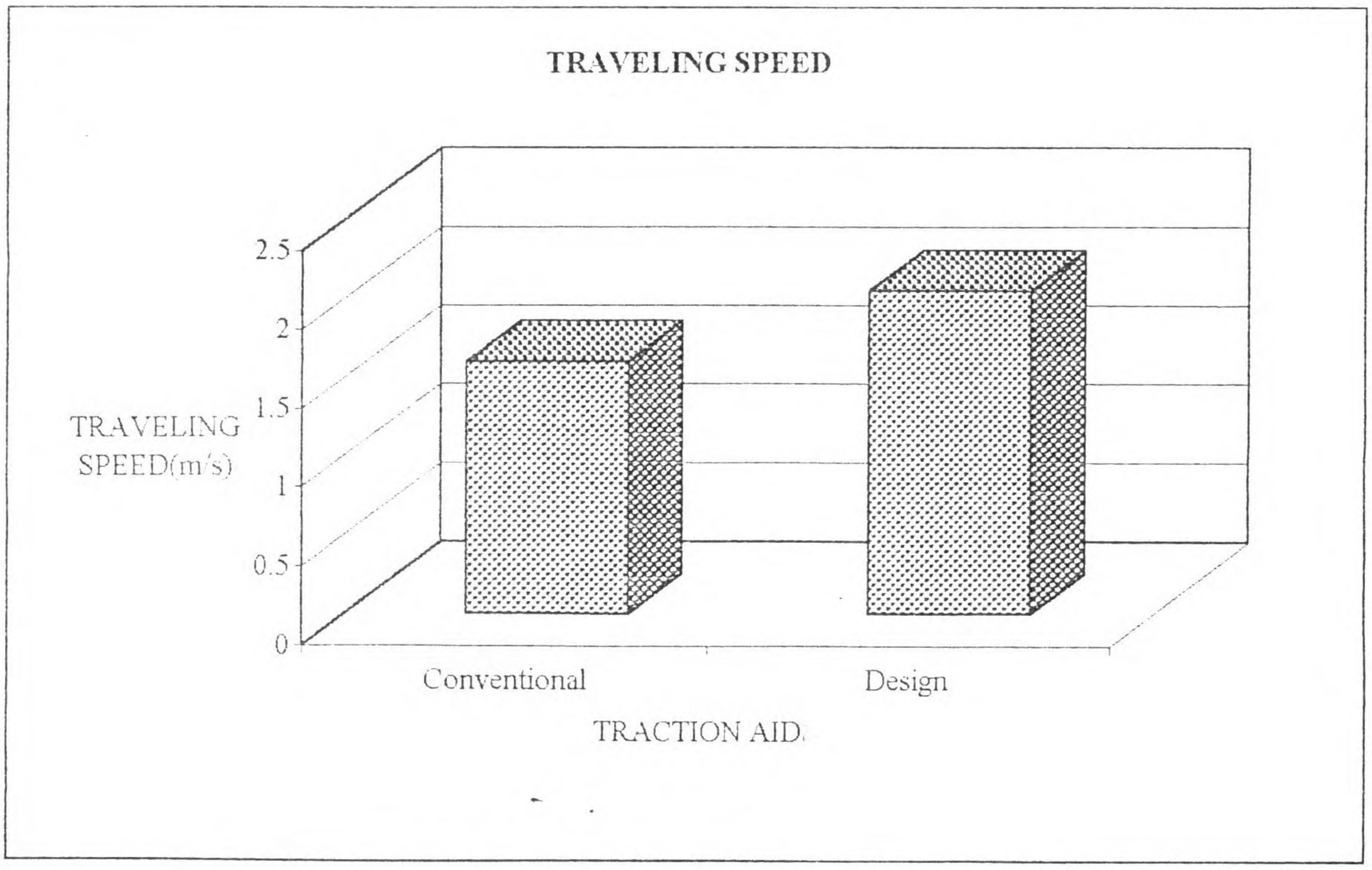


Figure 31.2

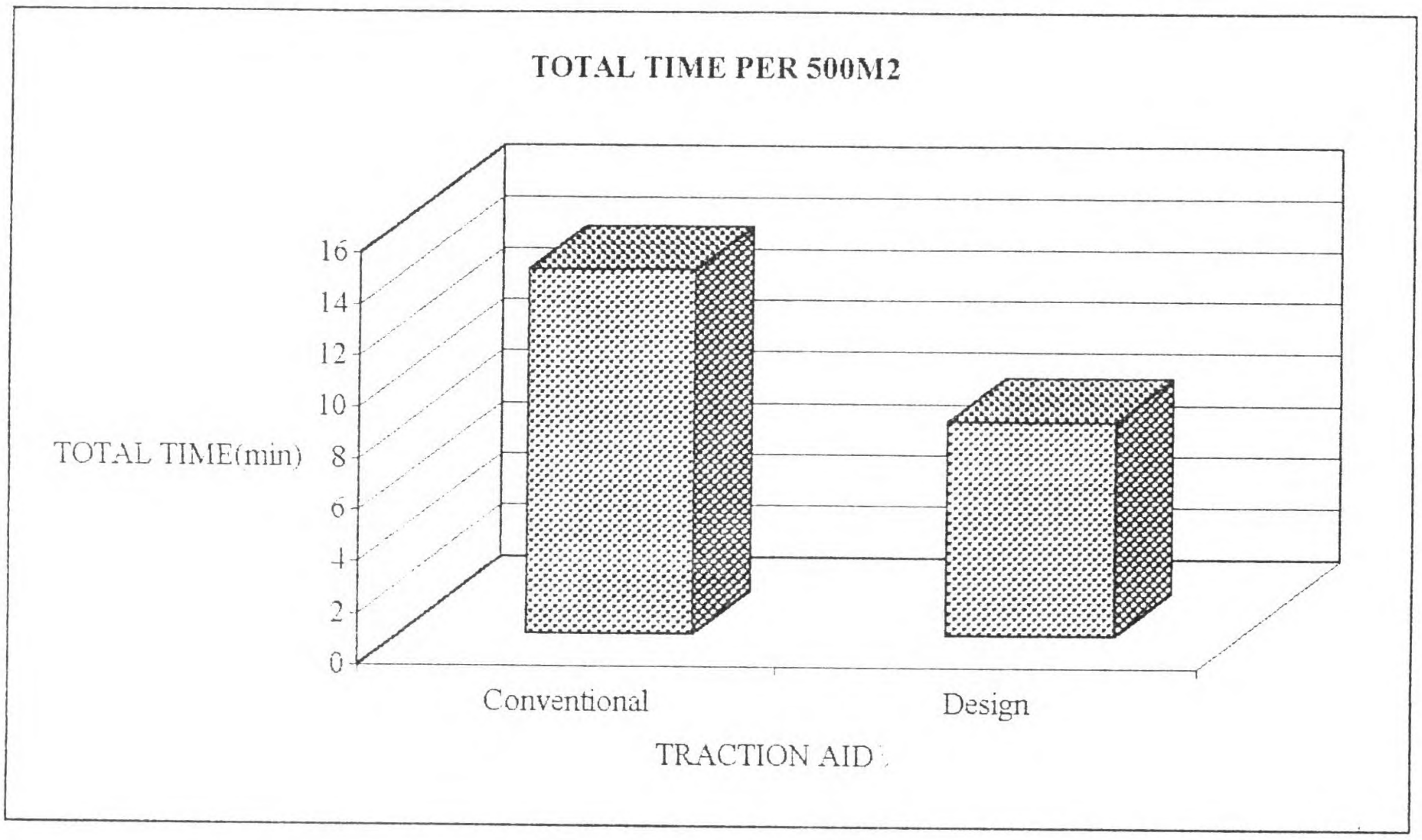


Figure 31.3

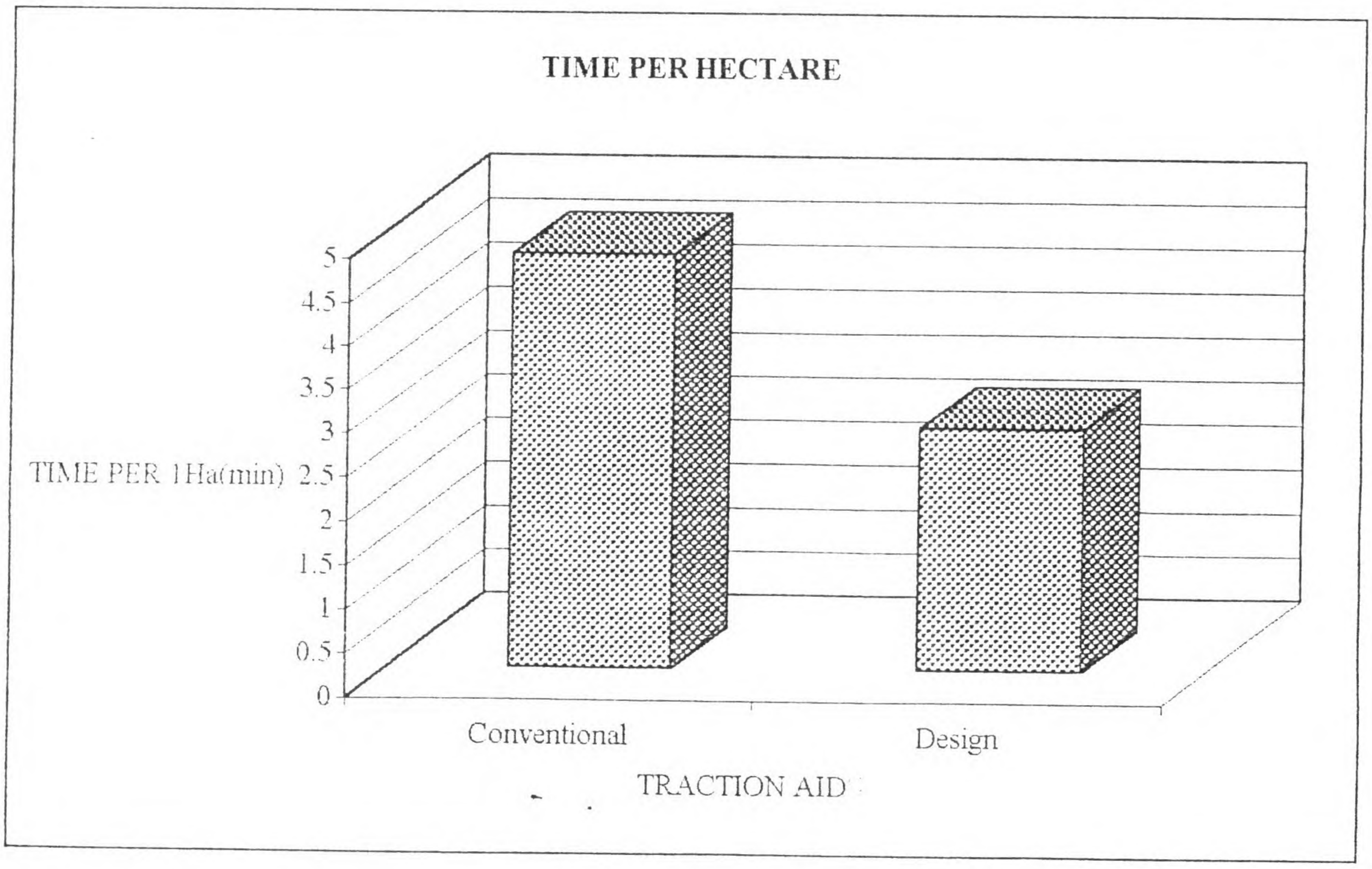


Figure 31.4

Table 12 F_ test results of farmer field observation datas.

(1)

VARIABLES	SOURCE	DF	ANOVA SS	MEAN SQUARE	F VALVE	Pr > F
Time per hectare (hr)	AIDS	1	9.64	9.64	10.34	0.032
	BLOC	4	3.73	0.93	1.00	0.49
Effective field capacity (ha/hr)	AIDS	1	0.046	0.04	26.20	0.006
	BLOC	4	0.007	0.001	1.10	0.46
Traveling speed (ms^{-1})	AIDS	1	0.50	0.50	177.63	0.0002
	BLOC	4	0.16	0.04	14.07	0.0126

(2)

Dependant Variable	Duncan Grouping	Mean	N	AIDS
Time per hectare	A	2.75	5	D
	B	4.71	5	C
Effective field capacity (ha/hr)	A	0.362	5	D
	B	0.226	5	C
Traveling speed (m/s)	A	2.0520	5	D
	B	1.6020	5	C

(3)

PARAMETERS	TRACTION AIDS	MEAN
Time per 1Ha (hour)	Conventional	4.712^{a}
	Designed	2.748^{b}
Effective field capacity (Ha/hr)	Conventional	0.2260^{a}
	Designed	0.3620^{b}
Traveling speed (m/s)	Conventional	1.6020^{a}
	Designed	2.0520^{b}

Note: means with the same letters are not significant

From the test results, it can be clearly observed that the performance of designed cage wheel was significantly higher in practical field condition. This was proved by using F - tests (Duncan`s multiple range test at different precision levels in SAS (statistical Analysis system) package.(see appendix -b) The F test results are shown in table 13. According to above results , higher significant differences obtained for all the cases.

The comparisons was proceeded by obtaining the mean values of each performance parameters for pairs of traction aids. Figure: 32 shows the relative performance obtained for each Traction aids.

More descriptively , the mean Effective Field capacity of designed cage wheel and conventional cage wheel were 0.36 ha/hr and 0.22 ha/hr in respectively. Therefor it was estimated that the mean Effective Field capacity of 4 wheel Tractor with design cage wheel has increased by about 50 % than conventional Cage Wheel.

Mean travelling speed of 4 wheel tractor with design cage wheel was 2.0 m/s and that of conventional cage wheel was1.6 m/s. Therefor it was calculated that the mean travelling speed of 4 wheel Tractor with design cage wheel has increased by about 28% than conventional Cage Wheel.

Cost Analysis

a) Two wheel Tractor

Cost of production of conventional cage wheel and designed cage wheel were 3496 Rs. And 4009.50 Rs. respectively. Difference between cost was miner (513.50 RS) consider the benefit of design cage wheel, this difference is negligible. More details about cost of production is shown in table: 14 and 15.

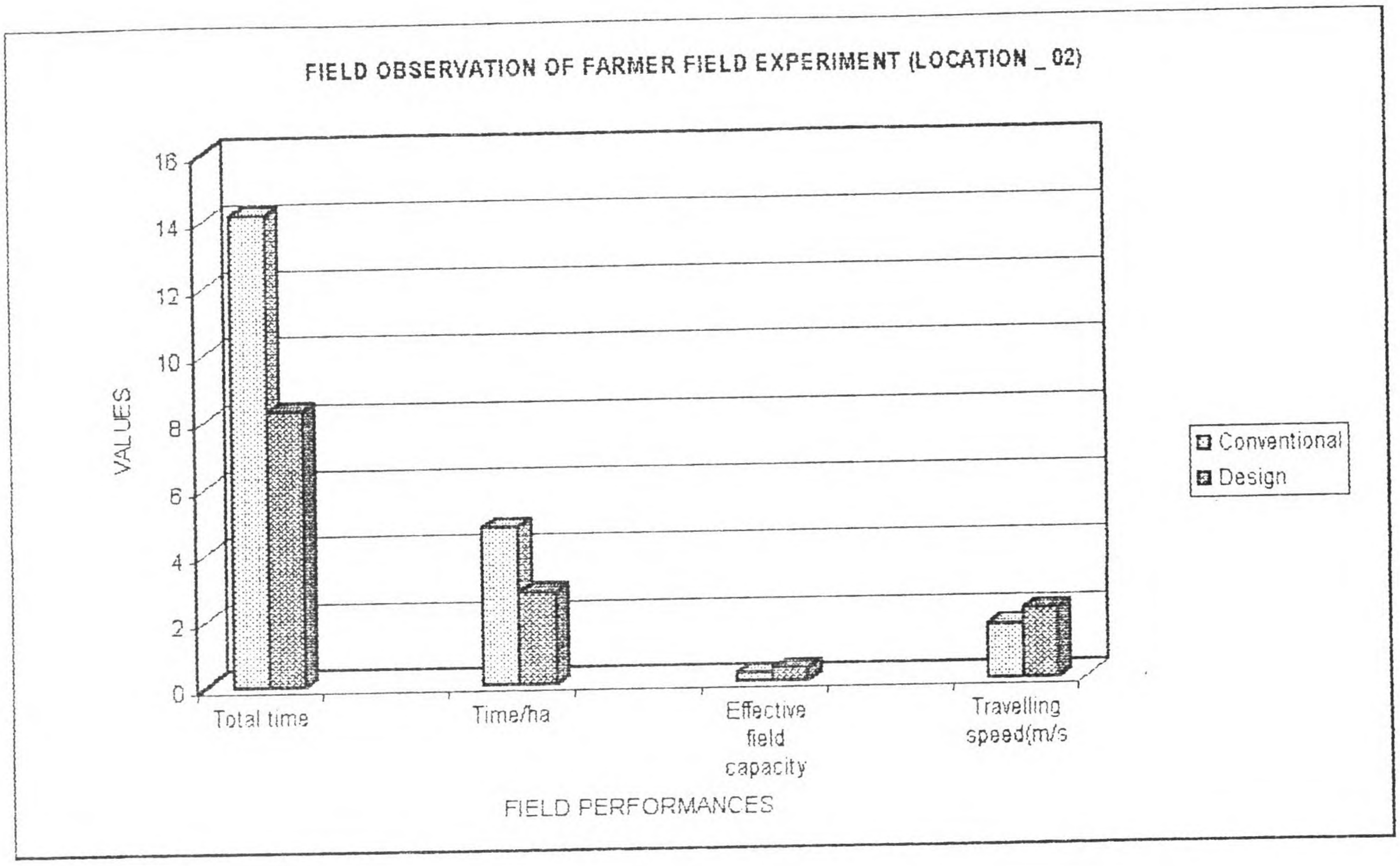

FIELD OBSERVATION OF FARMER FIELD EXPERIMENT (LOCATION _ 02)
16
14
12
10
8
6
4
2
0
VALUES
Total time
Time/ha
Effective field capacity
Travelling speed(m/s
FIELD PERFORMANCES
Conventional
Design

Figure 32:

Table 13.1

Parameters	Traction aids	Mean
Total time (min)	Conventional Designed	14.532[a] 8.246[b]
Time per 1Ha (hour)	Conventional Designed	4.712[a] 2.748[b]
Effective field capacity Ha/hr	Conventional Designed	0.2260[a] 0.3620[b]
Travelling speed (m/s)	Conventional Designed	1.6020[a] 2.0520[b]

Table 13.2: (means with the same letters are not significant)

VARIABLES	SOURCE	DF	ANOVA SS	MEAN SQUARE	F VALVE	Pr > F
Time per hectare (hr)	AIDS	1	9.64	9.64	10.34	0.032
	BLOC	4	3.73	0.93	1.00	0.49
Effective field capacity (ha/hr)	AIDS	1	0.046	0.04	26.20	0.006
	BLOC	4	0.007	0.001	1.10	0.46
Travelling speed (ms^{-1})	AIDS	1	0.50	0.50	177.63	0.0002
	BLOC	4	0.16	0.04	14.07	0.0126
Total time (min)	AIDS	1	98.78	98.78	9.93	0.035

Table 13.3:

Dependent Variable	Duncan Grouping	Mean	N	AIDS
Time per hectare	A	2.75	5	D
	B	4.71	5	C
Effective field capacity (ha/hr)	A	0.362	5	D
	B	0.226	5	C
Travelling speed (m/s)	A	2.0520	5	D
	B	1.6020	5	C
Total time (min)	A	14.532	5	D
	B	8.246	5	C

ITEM	LENGTH (m) or SIZE (m^2)	AMOUNT (RS)
Iron rod		
5/8" (1.6 cm)	[3'.8"]x2 (2.2m)	144.00
	14' (4.2m)	252.00
Steel		
1/8 plate	1.8' ft2	1800.00
Others		
Welding rod etc.		300.00
Welding and Black smithing.		1000.00
Total		**3496.00**

Table: 14 Cost of production of conventional cage wheel for two wheel tractor.
(Retail price /1998 January /Matara)

ITEM	LENGTH (m) or SIZE (m^2)	AMOUNT (RS)
Iron rod		
5/8" (1.6 cm)	14' (4.2m)	252.00
	44" (1.11m)	67.50
	26" (0.65m)	40.00
Steel		
1/8 plate	8' x 3"	2000.00
½ x 1"	30'	350.00
Others		
Welding rod etc.		300.00
Welding and Black smithing.	.	1000.00
Total		**4009.50**

Table: 15 Cost of production of designed cage wheel for two wheel tractor.
(Retail price /1998 January /Matara)

ITEM	LENGTH (m) or SIZE (m^2)	AMOUNT (RS)
L Iron		
1" x 1" (2.5 x 2.5 cm) lost	6.71' (2.015 m)	167.75
additional 2" for each rings	6' (1.8 m)	150.00
(rings) 1 ½" x 1 ½"(3.75 x 3.75 cm)	16' (4.8 m)	600.00
Steel		
1" x 1/8" (0.5 x 2.5 cm)	3.8' (1.14 m)	44.00
1 ½" x 1/8" (3.75 x 0.5 cm)	7.33' (2.2 m)	127.75
Iron rod		
5/8" (1.6 cm)	11.47' (3.44 m)	206.50
Others		
Welding rod etc.		300.00
Bending the 3 L Iron to 3 full rings.		2250.00
Welding and Black smithing.		2000.00
Total		**5846.00**

Table: 16 Cost of production of conventional cage wheel for four wheel tractor.
(Retail price /1998 January /Matara)

ITEM	LENGTH (m) or SIZE (m^2)	AMOUNT (Rs)
L Iron		
1" x 1" (2.5 x 2.5 cm)	35.8' (11.64 m)	970.00
Steel		
1 1/2" x 1/8" (3.75 x 1cm)	37.5' (11.27 m)	1312.50
	01.75' (0.52 m)	30.25
1 ½" x 1/8" (3.75 x 0.5 cm)	1.6' (0.48)	18.75
1" x 1/8" (2.5 x 0.5 cm)	3 ½' (1.02 m)	20.50
½" x 1/8" (1.3 x 0.5 cm)	½' (0.14 m)	2.20
3/8"x 1/8" (1 x 0.5 cm)		
Iron rod		
5/8" (1.6 cm)	12'(3.6 m)	216.00
3/8"(1 cm)	4'(1.2 m)	36.00
2/8" (0.625 cm)	1'(0.3 m)	11.50
1/8" (0.3 cm)	½' (0.12 m)	2.00
Others		
Welding rod etc.		300.00
Bending the 8 L Iron to 1/4 of rings.		1000.00
Welding and Black smithing.		2100.00
Total		**6020.00**

Table: 17 Cost of production of designed cage wheel for four wheel tractor.
(Retail price /1998 January /Matara)

Farmers opinions

The results of the farmer survey (page: 28) are tabulated in table 18 Data on farmer opinion of new ideas was valuable in the choice and design of new Technology. More than 70 % farmers were satisfacted with new Mud wheel. But One aspect not brought out in table 18 is the requirement for long - term assessment of farmer opinion of technology tested in farm trials. eg 2- 5 years after introduction.

Farmers opinion	Farmers response			Total marks	100%
	1	2	3		
a. Feasibility	3	4	2	780	78 good
b. Practicality:	-	4	4	640	64 good
c. Adaptability:	-	7	3	740	74 good
d. Cost			8	560	56 satisfactory
e. Cost effectiveness	2		8	680	68 good
f. Other inputs	6	4		920	92 excellent
g. Farmer opinion:	3	4	3	800	80 very good
h. Farmer adoption (keenness)	3	4	3	800	80 very good
others: Floating ability		1	6	560	56 satisfactory

Table:18 Farmers response to question : a to h

i). Interventions needed

interventions needed	1	2	3	4	5	6	7	8	9	10	Total farmers %
1.Credit	*	*	*	*		*		*	*	*	80
2.Materials(wheels)		*		*	*	*	*		*		60
3.Extension	*		*.	*				*			40
4.Market	*		*	*		*		*		*	60
5.Training	*				*	*				*	50

Table: 19 : Interventions needed

j). Main Problems faced by the farmers

farmers

Problems	1	2	3	4	5	6	7	8	9	10	total marks
1. shortage of capital for purchase	*	*	*			*		*			50
2. low ploughing rate or efficiency		*		*	*				*	*	50
3. lack of advice	*		*		*						30
4. shortage of high quality mud wheels	*		*		*	*	*	*	*		70
5. others											
a. Deep hard pan		*	*	*		*	*	*	*	*	80
b. Travelling on road with mud wheel	*	*		*	*	*	*	*	*	*	90

Table: 20: Main Problems faced by the farmers

k) Ideas for improvement

1. Road Transportation impossible
2 .need quick coupling system (remove when road travelling)
3. conventional wheel is not adaptable for bad field condition Therefor new cage wheel will be designed with more floating ability.

l) **Lug design** (Four types of lug design were tested in farm trial (include simple test , field observation and farmer opinion (as a driver). The results were tabulated in following table.

Table:21 lug design test results

Criteria's for evaluation	lug Types Type -1	Type - 2	Type -3	Type -4(new design)
1.forward running (Traction)	high -80	low - 40	medium - 60	high -85
2.Scouring ability	medium - 60	medium - 50	good - 70	good - 80
3.Wear & tear	low - 40	low - 40	medium - 60	medium - 60
4.Driver comfort	low - 40	medium - 55	medium - 56	medium - 50
5.cost	good - 70	medium -50	not satisfactory -40	good - 60
6.total marks	290	235	286	335

marking systems: high - over 80 medium or satisfactory - 40 - 60

good - 60 - 80 low or non satisfactory - 20 - 40

As indicated in the table 21, Lug design of type 4 (30 angle lug design) is far better than other types. Therefor 30 angle lug design was selected to fabricated the Folding type cage wheel.

3.6 RECOMMENDATIONS FOR FURTHER STUDIES

The developed folding type Cage wheel was tested in the field , obtaining efficient performances comparing with the conventional cage wheel. But it should be still further developed to improve its performance in order to find the possibility of adapting in more difficult soil condition. As evident in farmer survey key requirements in the design of such a new cage wheels are:

1 low cost and simplicity

2.Quick mounting and dismounting system to facilitate road transportation . (That is because, with any type of mud wheel it is prohibited to travel on public road.)

3. High Floating ability (solving the deepening of hard pan in Wet land cultivation

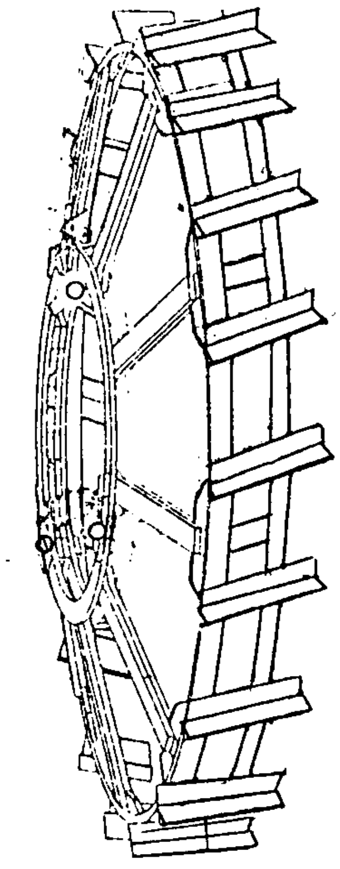
Therefor it can be recommended that the cage wheel to be developed with two parts : 1) compulsory main mounting ring

2) different type of optional cages for different soil conditions

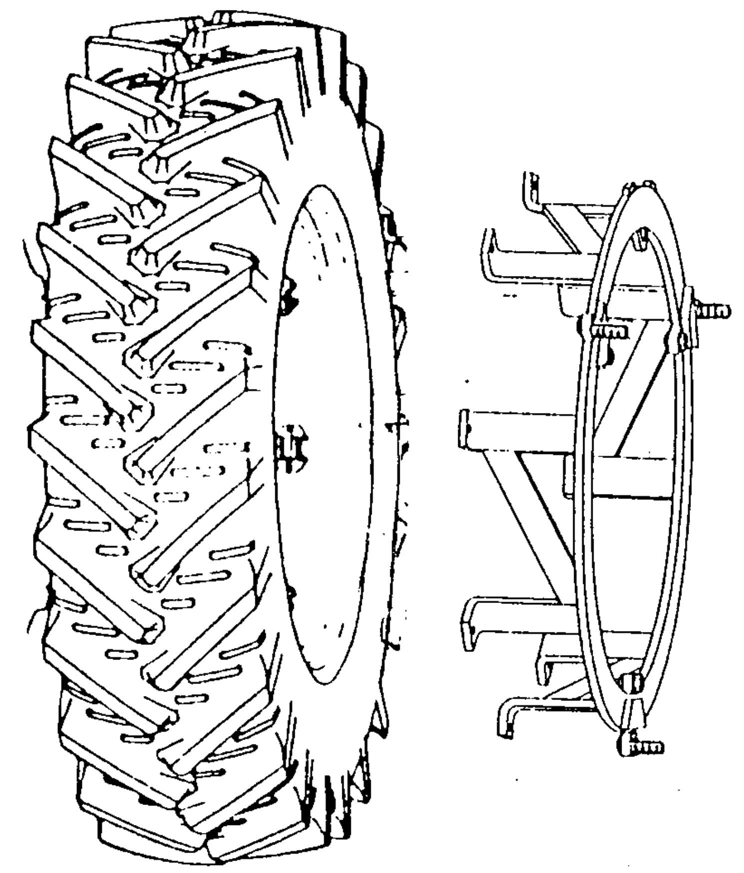
Design detail of the (universal) Multipurpose Cage Wheels:

Multipurpose cage wheel is a new cage wheel system consisting of a main mounting ring to which traction cage, general purpose cage or floating cage is fitted. See figure : 33 and photo : 7. This traction aids could be used satisfactory for both high and wet land conditions with different moisture levels. It could be easily fabricated by village blacksmith.

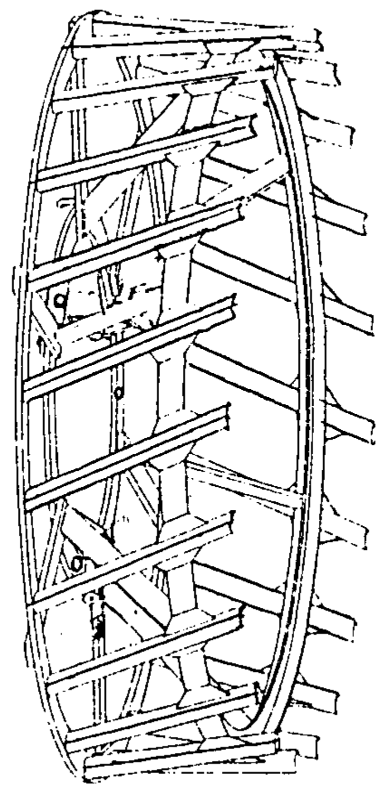
The cage wheel was designed for 4 wheel tractor (or 2 wheel tractor with few modification) which had the tyre outer diameter of 1030 millimetres with high lugs. The cage wheel outer diameter was selected as only 50 millimetres smaller. (Like expanded position of folding type retractable cage wheel and also consider maximum lug height of new rubber tire is about 40 mm). For road transportation cage was removed from main mounting ring .



Traction cage

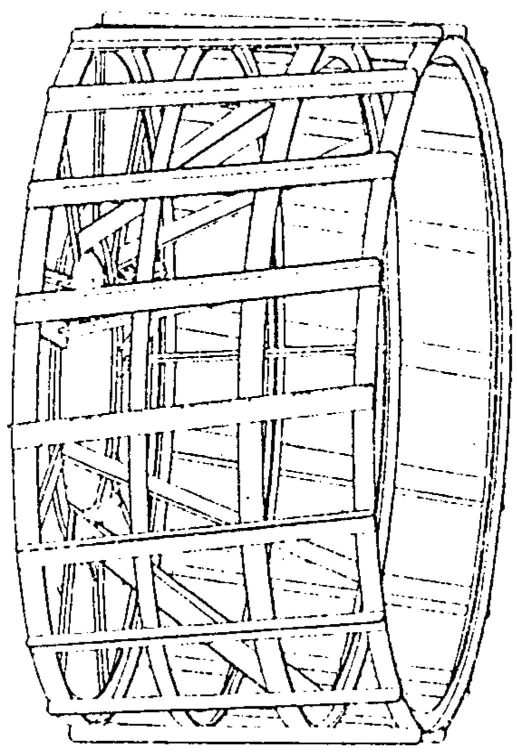


Main mounting ring



General purpose cage

Figure 33 Multipurpose Cage Wheel for Four wheel Tractor



Floater Cage

Traction cage :

Traction cage Was designed for up land cultivation (Ploughing, plant production or harvesting purpose) and shallow clay soil with low moisture condition. This tractor wheel makes scouring easy in difficult soils. The principle of good scouring is to gave a high pressure for every square inch of the cage wheel because of it has comparatively minimum surface. It's cost is lower than conventional cage wheel.

General purpose wheel:

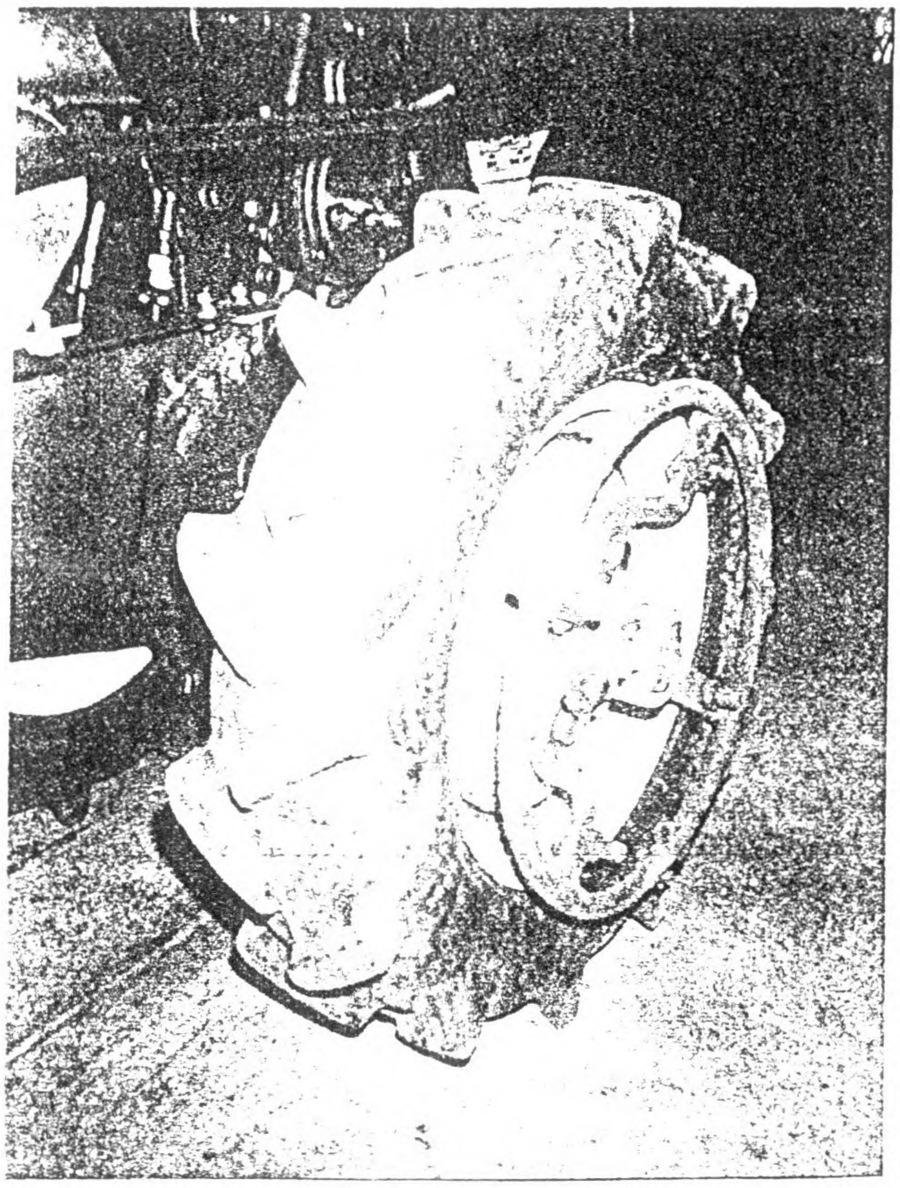
It's diameter is almost same as that of rubber tire. (50 millimetres smaller) Therefor high fields efficiency will be obtained. (as tested and proved with folding type cage wheel) Cost is same as conventional wheel.

Floater Cage :

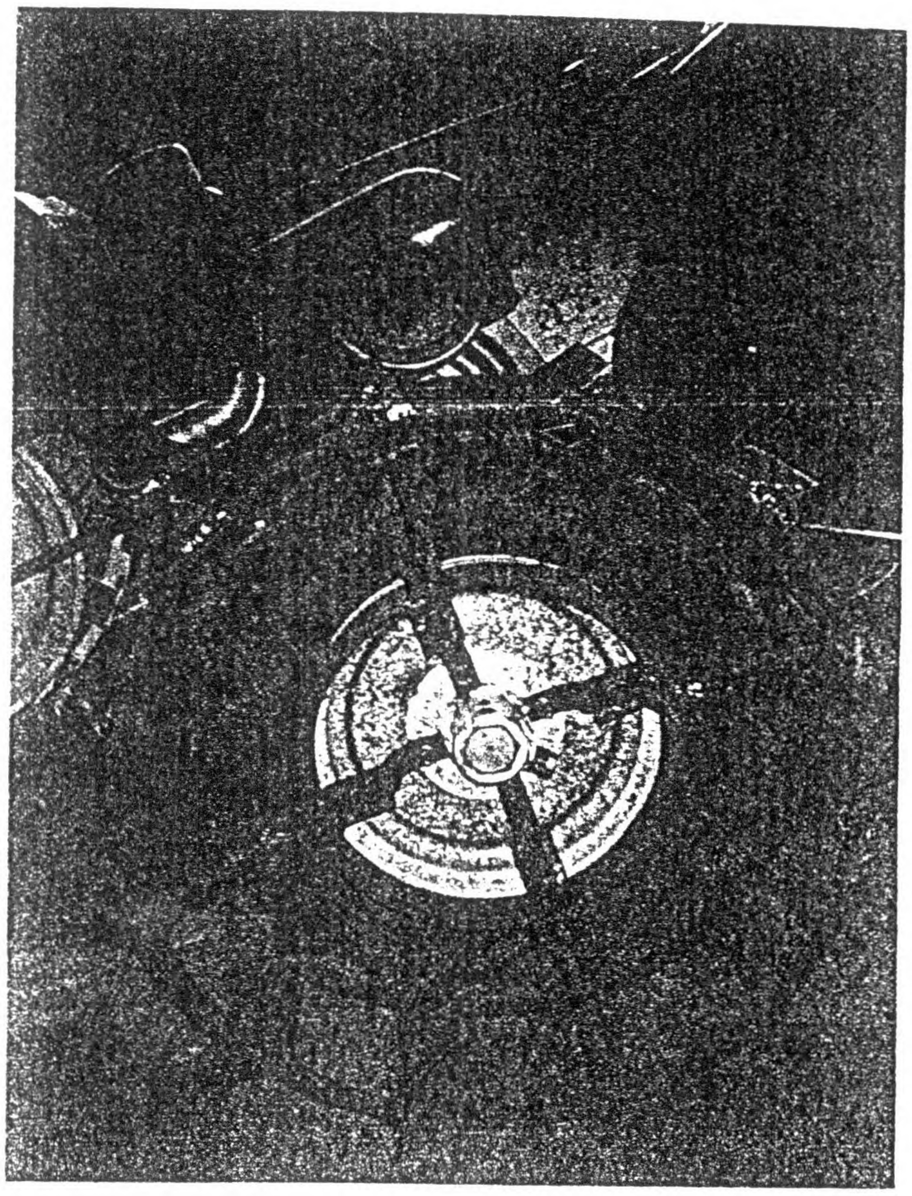
It has high floating ability because of it large surface and it was specially designed for different field conditions which the vehicle operation is expected to be most difficult. It's diameter is same as that of tires to facilitate high field efficiency. It's width in 1 ½ time larger than conventional wheel. In designing this wheel, a greater emphasis was given to reduce the wheel weight. There for steel pipes were used for cage rims.

So Floater cage was specially design for puddling the soil in secondary tillage operation and it was the remedies found with floating ability for solving the deepening of hand pan in wet land cultivation.

One pair of Multipurpose cage wheel was already designed and fabricated for two wheel tractor and successfully tested in the field. see photo : 7 and figure :34.1 and 34.2 .

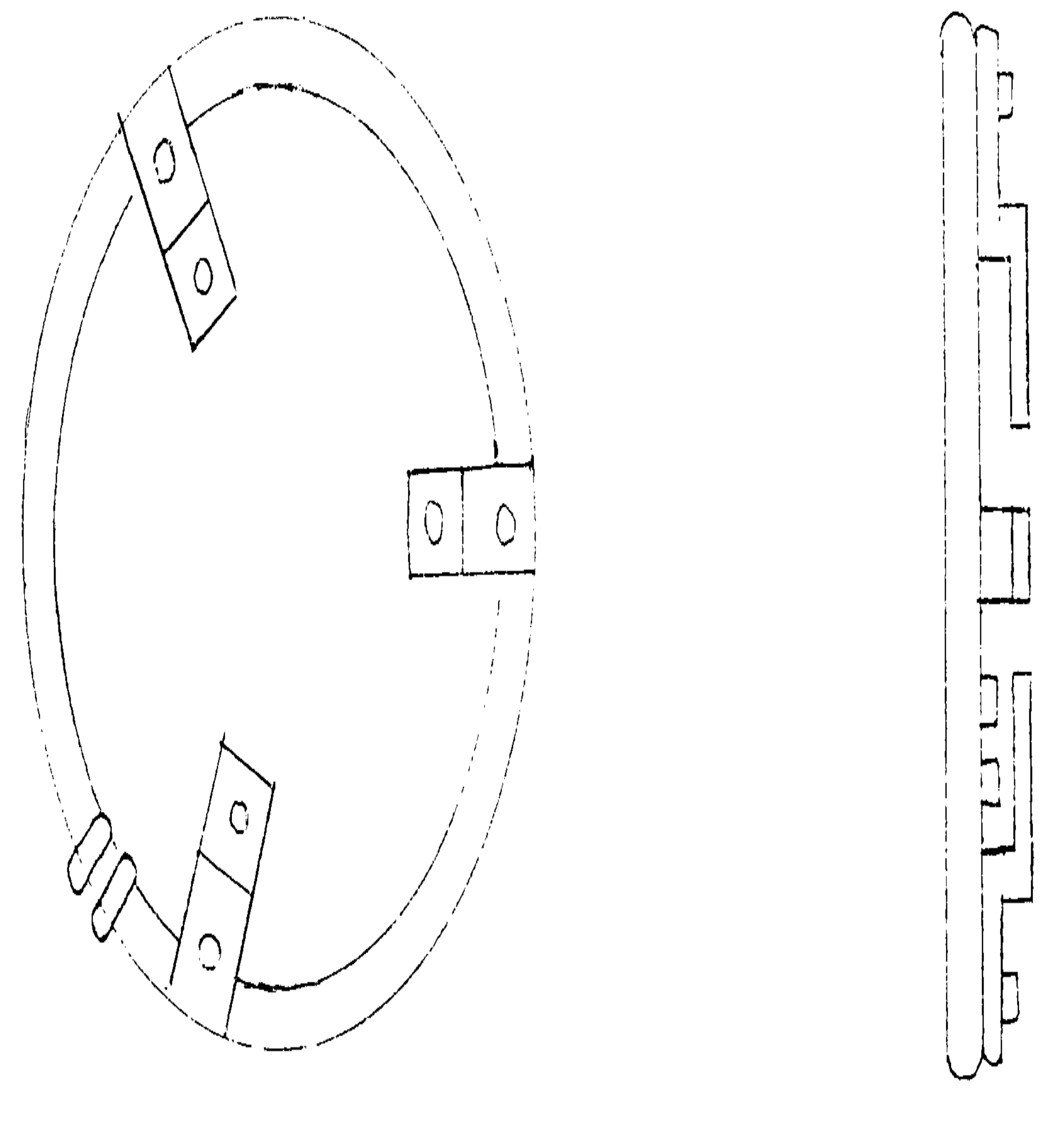


mounting ring



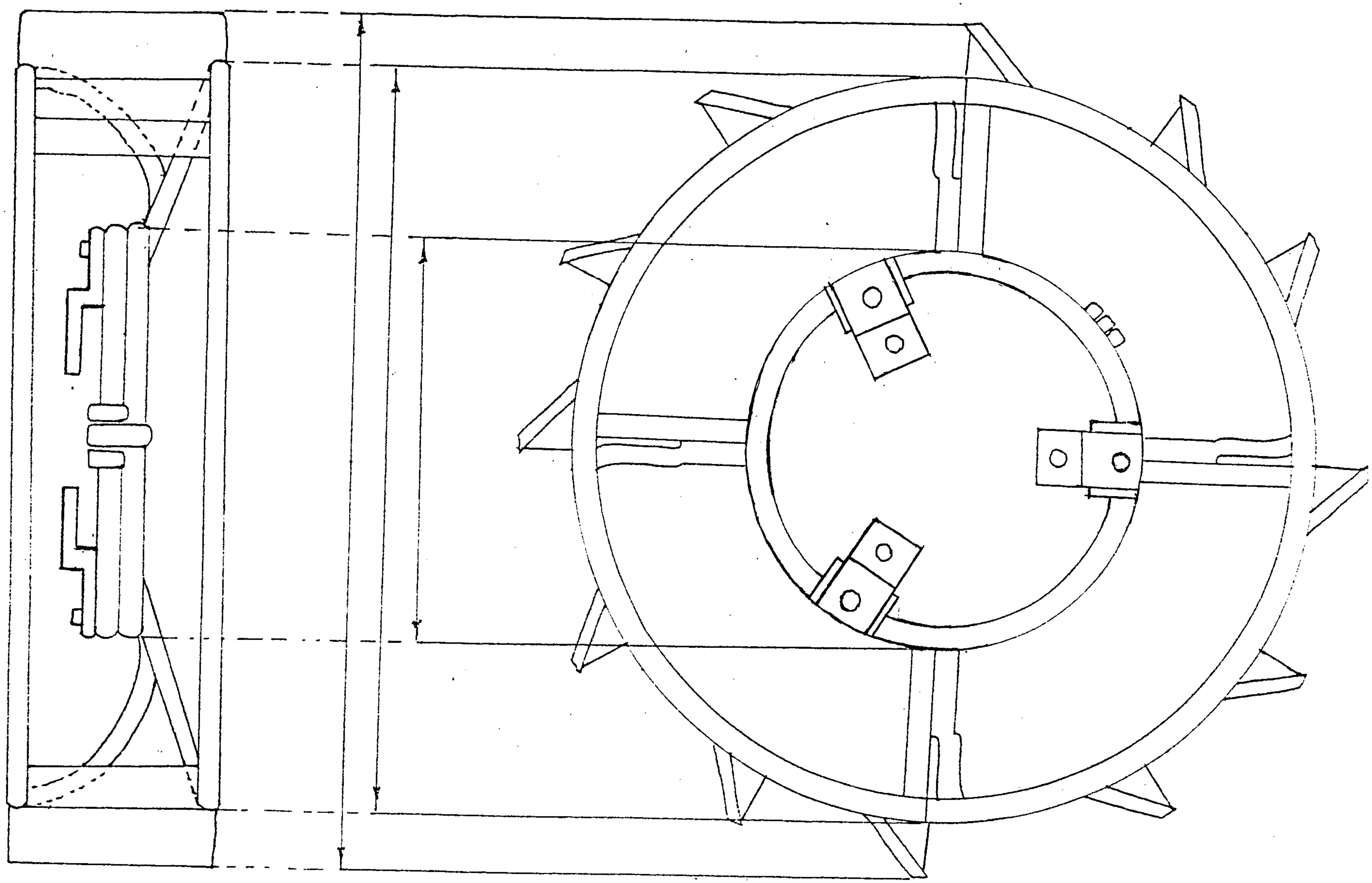
Traction cage

Photo 07: Multipurpose Cage Wheel for Two wheel Tractor



mounting ring

Figure 34.1 : Multipurpose Cage Wheel for Two wheel Tractor



Traction cage

Figure 34.2 Multipurpose Cage Wheel for Two wheel Tractor

4. CONCLUSION

Performances of design cage wheel were significantly differences with conventional cage wheel according to the considered criteria in the field test. The performance of developed retractable lugged cage wheel for two wheel tractor was high compared to other two traction aids. It was proved by Duncan's Multiple range Test. The relative performance of designed cage wheel, over conventional cage wheel was about 1:3 for pull in location 01 and 1:7 for location 02.

The performance of the swinging flat lug retractable cage mechanism ideal in road as well as field ~~capacity were found to be satisfactory~~.

Effective field capacity and travelling speed of four-wheel tractor with designed cage wheel were 0.36 ha/hr and 2.05 m/s respectively. Above observations with conventional cage wheel were 0.23 ha /hr and 1.6 m/s respectively.

Therefore effective field capacity and travelling speed of four wheel tractor equipped with designed cage wheel were greater by 60.8 % and 28.08 % respectively.

Time require to plough with the tine tiller per ha of designed cage wheel and conventional cage wheel were 2.75 and 4.71 hr/ha respectively. Therefore time per ha has decreased by 41.68 % in the using of designed cage wheel.

It was estimated that the travel reduction of designed cage wheel was significantly different from conventional cage wheel. Mean travel reduction of designed cage wheel and conventional cage wheel were 9.72 and 24.10 % respectively in with ploughing and this values of without ploughing situation were 5.6 and 12.3. respectively. Hence in these both situations travel reduction of four-wheel tractor with designed cage wheel has decreased by 59.69 (in with ploughing) and by 54.09 % (in without ploughing) than the conventional cage wheel.

When consider only designed cage wheel, mean values of the travel reduction in with ploughing and without ploughing were 9.7 and 5.6 respectively. That was travel reduction of with ploughing has increase by 71.89 % than without ploughing. This value of conventional cage wheel was 95.76 %.Thus, increased value of travel reduction in designed cage wheel was lower than conventional cage wheel.

Therefore when consider the above matters, We can conclude that traction power of the tractor with designed cage wheel was higher than conventional cage wheel. When consider the Duncan multiple range test, The travel reduction of first high gear has different frŏm travel reduction of other gears in both situations which were with and without ploughing.

Cost of production of conventional cage wheel and designed cage wheel of the two wheel tractors were 3496 Rs and 4009.50 Rs respectively. Difference between Cost of production of conventional cage wheel and designed cage wheel is 513.50 Rs. This values for four wheel tractors were 5846 Rs and 6020 Rs respectively. Difference between Cost of production of conventional cage wheel and designed cage wheel for four wheel tractor is 176 Rs. Consider the benefit of designed cage wheels this difference is negligible.

The developed folding type Cage wheel was tested in the field , obtaining efficient performances comparing with the conventional cage wheel. But it should be still further developed to improve its performance in order to find the possibility of adapting in more difficult soil condition. It is evident from the farmer survey that the key requirements of the modification or redesign of new cage wheels are:

1 Low cost and simplicity

2.Quick mounting and dismounting system to facilitate road transportation

3. High Floating ability.

To achieve the above requirement, First model of **Multipurpose Cage Wheel** was designed and tested in a field. The test was successfully finished and smooth operations were obtained.

RECOMMENDATIONS FOR IMPLEMENTATION

It can be recommended that the "**Multipurpose Cage Wheel**" is a new suitable traction aid for small and medium power tractors which is used in the high and wet land conditions. The cage wheel has simple construction , good serviceability, high field performance in different soil condition, and low cost.

2. REVIEW OF LITERATURE.

2.1Traction

Traction is the term applied to the driving force developed by a wheel, track or other traction device. It is developed by the interaction of mechanical devices with soil. Theory, experimental studies, and field tests provide the general nature of these interactions for analysis and design of tractive systems.

Dwyer (1984) provides a good over view in the development of analytical and empirical relationships for tractive performance of wheeled vehicles. The mobility number concept was first derived by Freitag (1965) and further developed by Ternage (1972) using dimensional analysis and a series of performance measurements over wide range of tire size and shape. Wismer and Luth (1974) further developed the utility of this approach for predicting tractive performance.

2.2 Soil mechanics to traction

2.2.1Soil mechanics

Because of the complex and variable nature of soil, its properties have not been classified with the degree of precision normally associated with most engineering materials as a results the experimental other than the analytical approach as generally been used in the design of traction members for tractors and other off high way vehicles.

In recent years however some progress as been made in a seem empirical method of designing traction members. This has been possible because of an increased interest in this area by several investigations. Bekker has been largely responsible for the analysis certain physical properties

(Parameters) of soil in such away that these properties could be used in marking reasonable predictions of the performance of traction device.

Soil mechanics as an art and science as almost exclusively been developed for and applied to the problems of designing dams, bridge, buildings, etc. For the science of soil mechanics to be of value in predicting the traction and floatation of a tractor, it has been necessary to make modifications of the science as it has normally been used by civil engineers.

2.2.2The reactions of soils to forces applied by tool and the soil condition.

The reaction of soil to forces applied by tillage are affected by the resistance of soil compression, the resistance to shear, adhesion (attractive forces between the soil and some other materiel) and frictional resistance. These are all dynamic properties in that they made manifest.

Only through movement of soil Nichols (1968) has shown that reactive forces of all classes of soil are dominated by the film moisture on the colloidal particles and are thus directly related to the soil moisture and colloidal content. Soil may be classed as plastic and non plastic. The term plastic implying that the soil moldable within a certain range of moisture contents and that it will retain its molded shape after drying.

Sands or other soil containing less than 15 to20 percent colloidal or clay generally considered to be non plastic. If a plastic soil is saturated with water and then allowed to dry it passes through the following stages in order: sticky plastic, friable (crumbly), and hard (cement).

The friable stage represents optimum condition for tillage. Soil compaction by tillage implements is promoted by working the soil when too wet.

2.2.3 Shearing Action

As the tool advances as the soil in its path is subjected to compressive stress which in a friable (uncemented) soil resulting in a shearing action. The shearing of most solids in that the reaction may extended for a considerable distance on either sides of shear plane because of internal friction and the cohesive action of moisture films.

Cohesive may be defined as the force that holds two particles of same kind together. Internal friction results from inter -locking of particles within the soil mass cohesion and internal frictions are sometimes refereed to as real physical properties of the soil. The reality they are only parameters of shear as indicated in the following equation.

$$T = C + \sigma \tan \phi$$

Where T = Shearing stress at soil failure

C = cohesion

σ = Stress normal to plane of shear failure

ϕ = Angle of internal friction.

Based on above equation, cohesion might be rationalised as the shear stress with the zero normal lords. Values for C and may be determined by measuring the shear stress fore several values of normal stress. Shear strength has an important influence on the draft of tillage tool.

Failure of soil by compression is generally associated with a reduction in volume. Failure by shear and failure by compression are not independent phenomena but occur as some combined action.

2.2.4 Friction and adhesion.

All tillage operations involve the two types of friction.

1. Soil on soil friction.
2. Soil on steel friction

2.2.4.1 Soil on soil friction.

Soil on soil friction is usually assumed to follow the law for simple friction, in which,

$$\lambda = F/N = \tan \psi$$

where ,

λ - Co-efficient of friction (soil on soil)

F - Frictional force tangent to the surface

N - Normal force

ψ - Friction angle

In this idealised relation is independent of the normal loaded the contact area and the speed of slipping .

2.2.4.2 Soil on steel friction

Friction of soil on a tillage tool is usually soil on steel friction when soil slides on metal adhesive forces between the soil and the metal have a marked influence on the friction force. The adhesive forces are primarily due to the moisture films and their magnitude varies with the moisture content. The adhesive force has the effect of increasing normal load on the surface, thus increasing the tangial friction force.

Since it is impractical to separate the two components the usual practice in laboratory testing is represent their combined effect by an " apparent co-efficient of friction" which is identified as 'λ'

Apparent co-efficient of friction depends on following factors.

a. Moisture content of the soil, reported that Nichols (1931)

b. Types of soil

c. The type and smoothness of the material, that Fox, Bockhop (1965)

a. Moisture content of the soil

Nichols described the following three phases

i. Friction phase

ii. Adhesion phase

iii. Lubrication phase

In the friction phase adhesive forces are small and the co-efficient of friction is essentially independent of moisture content of soil in a friable condition usually have moisture content in this range.

In the adhesion phase, moisture films develop between the soil particles and the metal, thus creating adhesive forces that cause the apparent co-efficient of friction to increase rapidly with moisture content. When the soil has enough moisture to act as lubricant, the apparent co-efficient of friction decreases as more water is added.

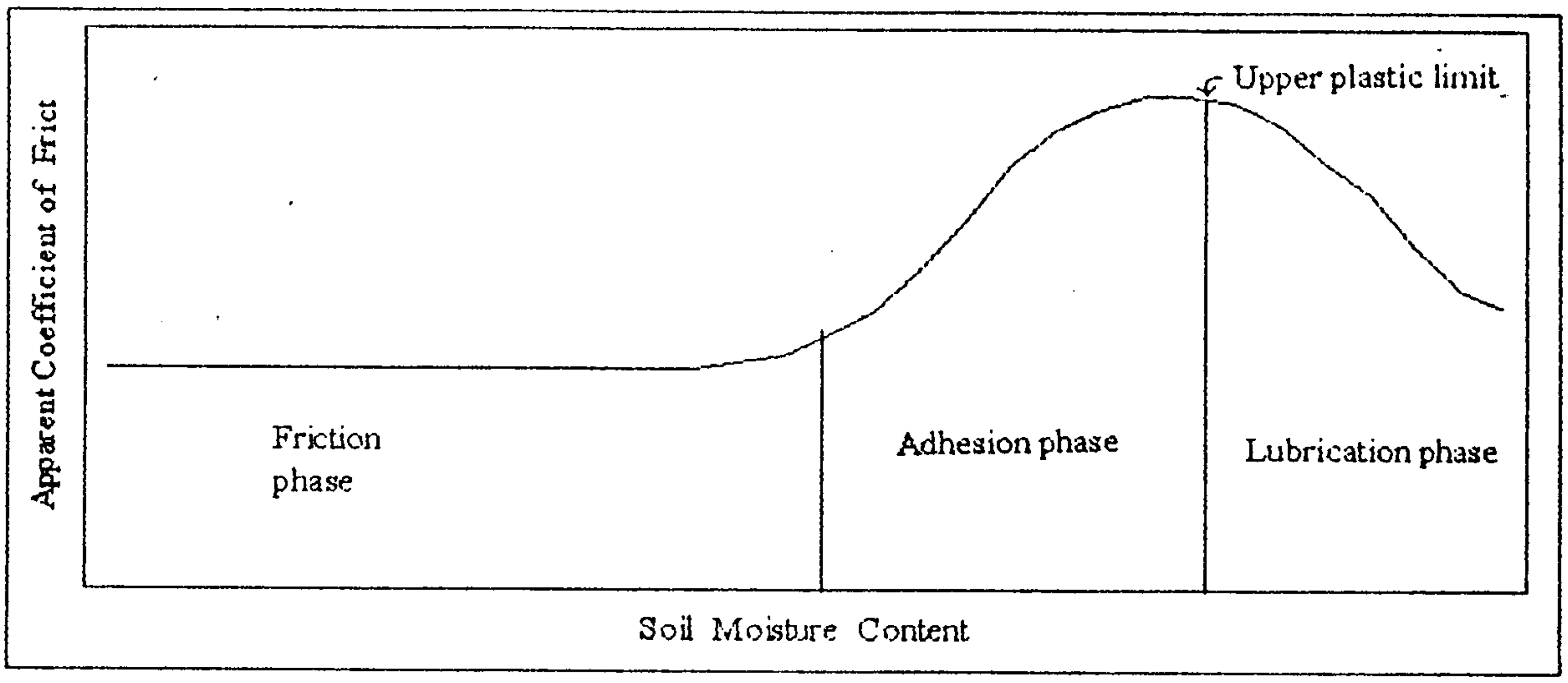


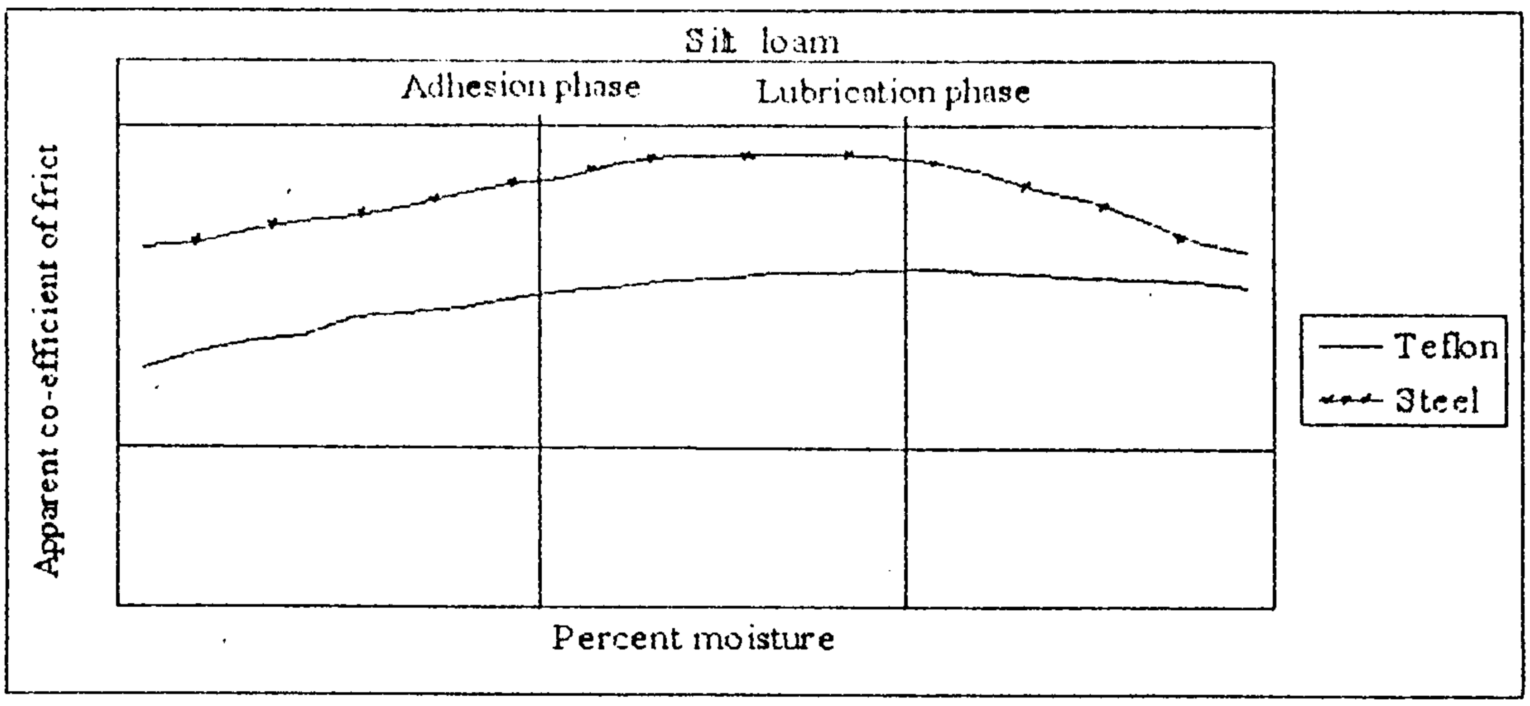
Figure 01: Characteristics curve showing the effect of moisture content upon the Apparent co-efficient of friction between soil and steel.

b. Types of soil

Apparent co-efficient of friction is higher for clays than the sandy soils. Typical ranges for soil on smooth steel having an ordinary polish as reported by various investigators are 0.2 to 0.5 sand, 0.3 to 0.65 for loans and 0.35 to 0.8 for clay soils. The lower portion of each range represents values in the friction phase.

c. The type and smoothness of the material.

The type and smoothness of the material on which the soil slides affects the apparent co-efficient of friction. Material such as Telfon. Which resist wetting do not develop large adhesive forces with the soil and therefore have substantially lower apparent co-efficient of friction.



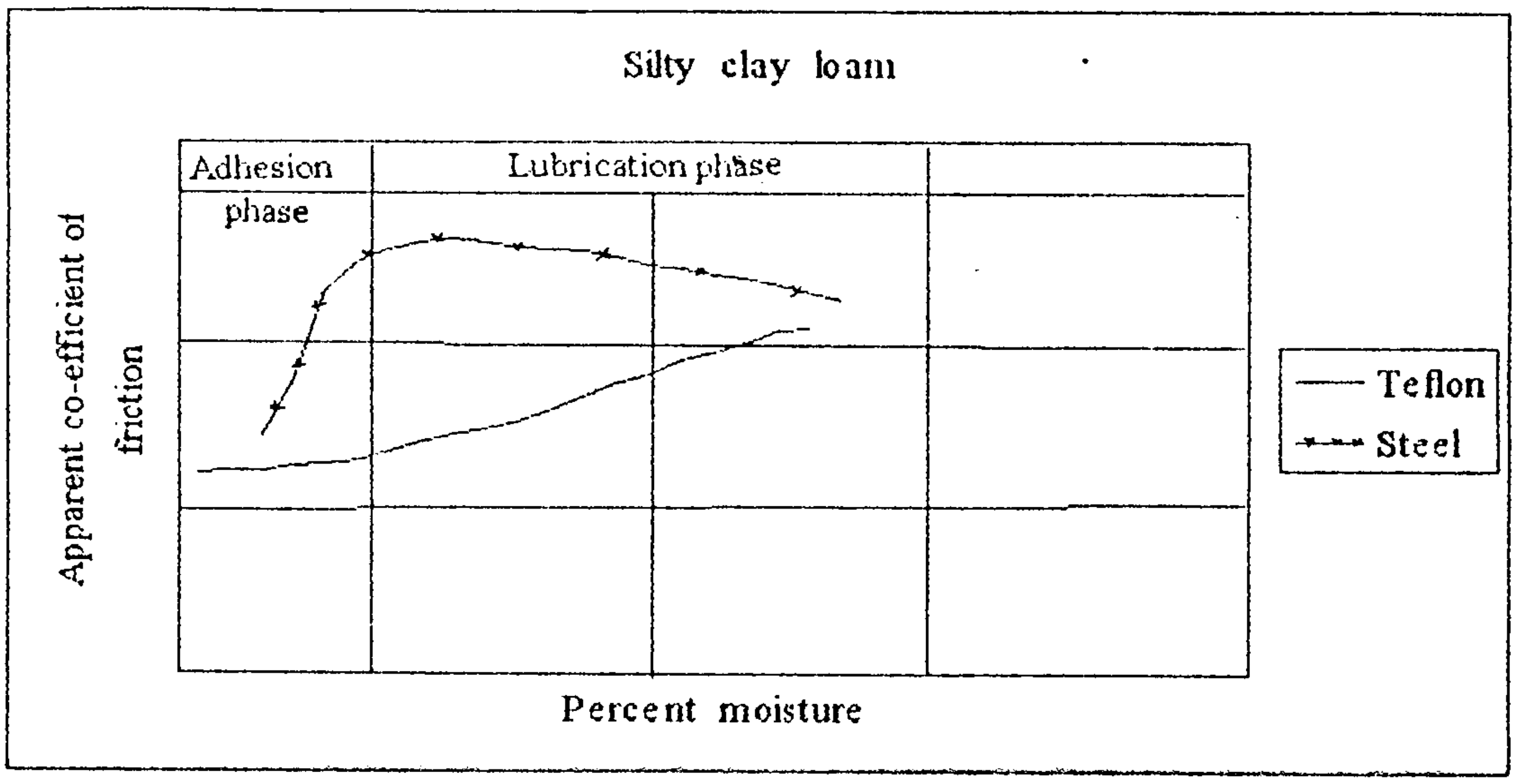


Figure 02 : Variation of the apparent co-efficient of friction in different materials and soil.

2.3 traction device

Transmitting engine power to the drawbar in agricultural and other off highway vehicles is achieved through traction device, namely wheels and tracks. Off the three principle ways of transmitting tractor -engine power in to useful work-power take off, hydraulic, and draw bar- the least efficient and most used method is the drawbar. Basic configurations of wheels and tracks are modified to meet special operating conditions in various parts of the world. The predominate traction device is the pneumatic tire.

2.3.1 Traction Devices for Paddy Fields

The mechanisation of rice production in some Asian countries has reached a high level of accomplishment (Tanaka 1984). In Japan approximately 95 percent of the operations are mechanised. The moisture content of paddy field soil is usually very high, and in many cases farm vehicles must operate in fields that are saturated of flooded. Trafficability of the surface soil layer is very poor, being extremely soft with low load-bearing capacity. Cone indices will typically be less than 50 N/cm^2. Performance of regular rubber tired wheels is not acceptable because of high slippage and adhesion of sticky soil. Specially designed high-lug rubber tires are commonly used in paddy fields.

Farm tractors and other farm vehicles that are operated in these conditions often require special devices used with tires or in place of tires. As an example of some typical devices, lug wheel are considerd. The lug plates are welded to a circular rim. Many types and shapes of lug plates are in use for paddy fields operations. The lug wheel used as an auxiliary device with a tractor tire. Float type lugs are connected to the circular ring plate and the lugs can be folded towards the centre of the wheel when the tractor operates on a hard surface or paved road.

Development of traction and transport performance prediction equations for paddy fields conditions is extremely challenging Tanaka (1984) provides a state of the art overview of analytical work and an extensive bibliography.

2.4 Various research works carried out for improving trafficabilty of four-wheel tractor in faddy field

Balley P.H. (1956) Compared the performance of wheels, starches and the use of ballesting in 13 different soils (generally sandy, sandy loam, sandy clay and clay) and concluded that ballasting was better for sandy soils and strakes were more effective in clay soils.

South Well P.H. (1964) Compared the performance of different traction aids in five different soil condition his experiments considered single pneumatic tyres, dual pneumatic tyres, ballested (water filled) tyres, tyres with chains, tyres with strakes and tyres with half tracks. He concluded from the result that the use of retractable staves were suitable for agricultural Purposes compare to the other methods.However this finding interferes with that obtained by BALLEY (1956). Who found that the ballasted wheels were more suitable for sandy soils and the stare were effective for clay soils .

Kisum, (1966) carried out an experiment with a pair of cage wheels having a diameter of 1100mm, and with 16 lugs per wheel, he found a relationship between drawbar pull, sinkage coefficient, rolling resistance and slip per different lug and lug heights.

His results showed that a 34 Kw 4-wheel tractor achieved its optimum trafficability with 30-40 degree lug angle and 100m-lug height. But his experiments did not determine optimum by spacing and also latched theoretical analysis.

Datt P and Ojha T.P (1970) studied optimum wheel parameters and concluded that when working on paddy soils, the upward thrust acting on the wheel could be reduced by cage wheels was smaller than that of pneumatic wheels. They develop and expression for the optimum lug angle with minimum shear spacing (the minimum distance left between the tranches cut by successive lug)

Chang C.S. and Taylor G.H. (1991) Conducted soil bin experiments for 6 types of open lugged wheels commercially available at that time. They measured simultaneously the torque pull, dynamic weight, angular velocity, forward speed and slip of the wheels as they were driven through the soil bin. They concluded that the tractive performance of a wheel was mainly dependent on the lug engagement with soil hard pan.

Taylor J.H. And Burt E.C. (1973) carried out experiment to compare a pneumatic tyre, a pneumatic track and a steel wheel for tractor performance under the same field conditions and found that the steel wheel and pneumatic track were better in traction performance than the pneumatic tyre.

An explanation for this is that with the pneumatic track, higher thrust can be provided with little slip due to the relatively large contact area covered by the track compared to an ordinary wheel. Because of their reduced contact pressure, track can be used for soft soil conditions and this also results in minimum soil compaction.However there are disadvantages with tracks the difficult in steering and limited forward speeds especially for road transportation needs to be considered. As a result, tracks have limited applications to field operations.

Pandey K.P. and Ojha T.P. (1973) carried out an experiment using a power tiller with three types of steel lugged wheels each having different lug heights (25-44cm) the objective of their study was to find the effect of lug height on tractive performance for the three types of wheels.
The outer diameters of the wheels are maintained so that they could be used for road transportation (the outer diameter of the lugged wheel was smaller than that of the tyre). They showed an increase in slip value at lower normal loads.
In this case, when the tyre diameter becomes larger than that of lugged wheel the tyre always firstly touches the hard pan so an increase in lug height under such conditions causes an increase in rolling resistance in tractive performance

Ojhar T.N and Pandey K. P. (1974) carried out an experiment to design a wheel capable of converting tractor engine power to draw bar power with maximum efficiency . They tested 6 wheels of which 3 were pneumatic wheels and the other 3 were steel wheels, in varying moisture conditions in soil.For 10% and 14% moisture soils, pneumatic wheels performed better but under puddled soil conditions better performance was given by the steel wheels.

Seng Ooi Ho (1975) studied the importance of considering traction and sinkage capacities when designing wheel parameters for soft soils. Also he studied the relation between tracfficability soil properties and wheel parameters. He compared experimental and theoretical results and obtained a good correlation for the wheel having dimensions of 762mm diameter and 305mm lug spacing.

Ossain M.M.D. (1981) tested the field performance of a Thai power tiller with a chisel plough in differently moistured plough soils. He compared rubber tyre and cage wheel was better for all the soil conditions he tested. He found that the transmitted power, tractive efficiency, coefficient of traction all were low while the slip was very high.

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Appendices - A

Design details of Wheel Parts

a) Design of lug frame

The average Weight of medium power tractors	= 8.8 kN (895 kg)
Approximated vertical load on drive wheels	= 6.6 kN (675 kg)
Approximated draft force	= 8.8 kN

For worst conditions, assuming only lugs touch the ground). one lug in each wheel touches the ground (depend on the sinkage, but normally 3-4)

Approximated vertical load on one lug	= 3.3 kN
Approximated horizontal load on one lug	= 4.4 kN

The lug frame acts as a simply supported beam having one downward load. According to Figures (a), (b) and (c), the maximum bending moment is occurred in lug frame at cross bar.

Total load perpendicular to lug frame $P_i = 3.3 \text{ Sin } 60 + 4.4 \text{ Cos } 60$

$= 5.05$ kN

Maximum bending moment $M_b = P_i * 0.12$

$= 0.607$ kNm

Since each lug frame has two bars in both edges,

Bending moment carried by one bar = 0.304 kNm

The cross section of the bar selected was a rectangular section having height h and breadth b,

Bending stress carried $S_b = 6 * M_b / b * h^2$ ----------(a.1)

Cross section of the selected bar was 25.4 * 12.5 millimeters,

$$S_b = (6 * 0.304) / (0.0125 * (0.0254)^2)$$

$$S_b = 226 \text{ MN} / \text{m}^2$$

Flat bars made of rolled steel can carry 300 MN / m^2 of yield stress. Therefore the selected section is safe in bending.

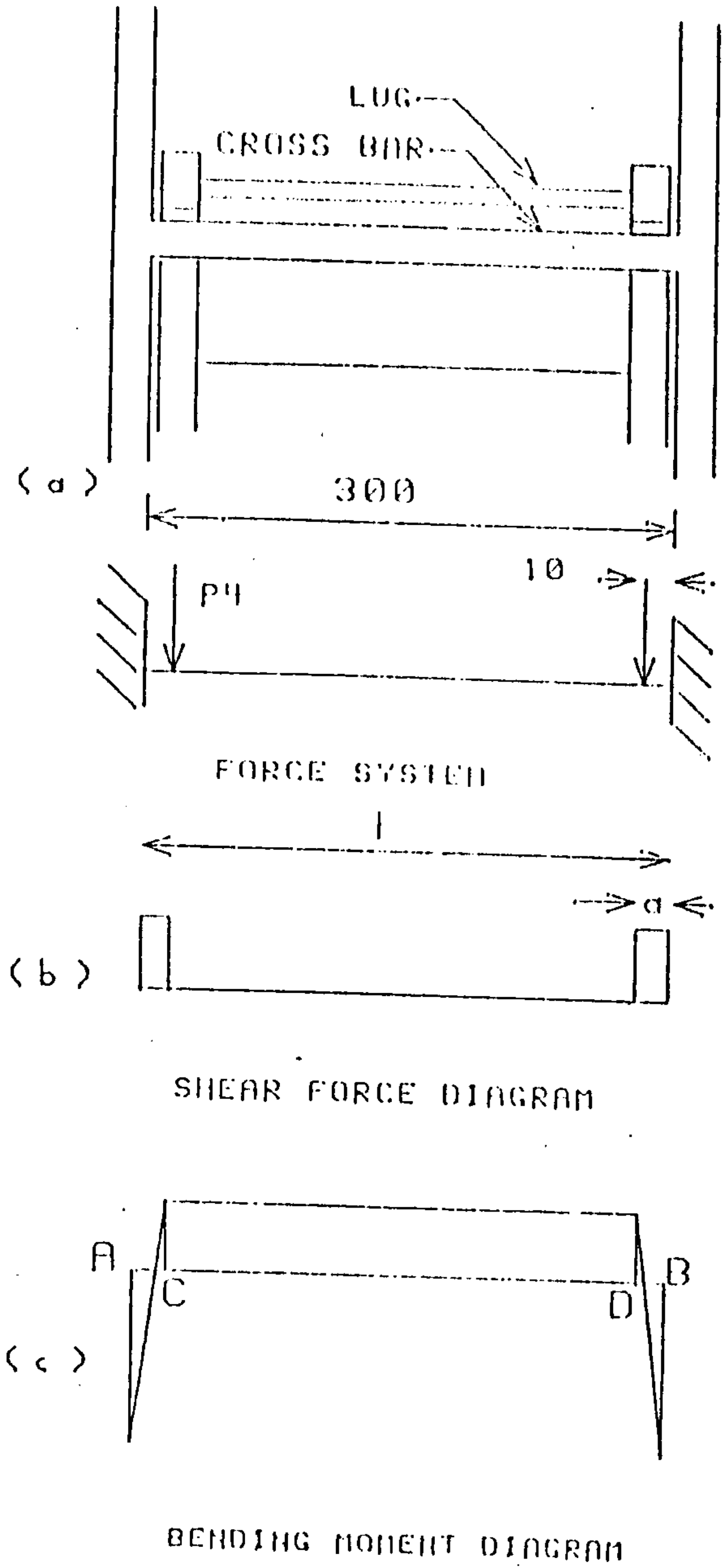

Figure. 1. Cross bar structure, shear force and bending moment diagram.

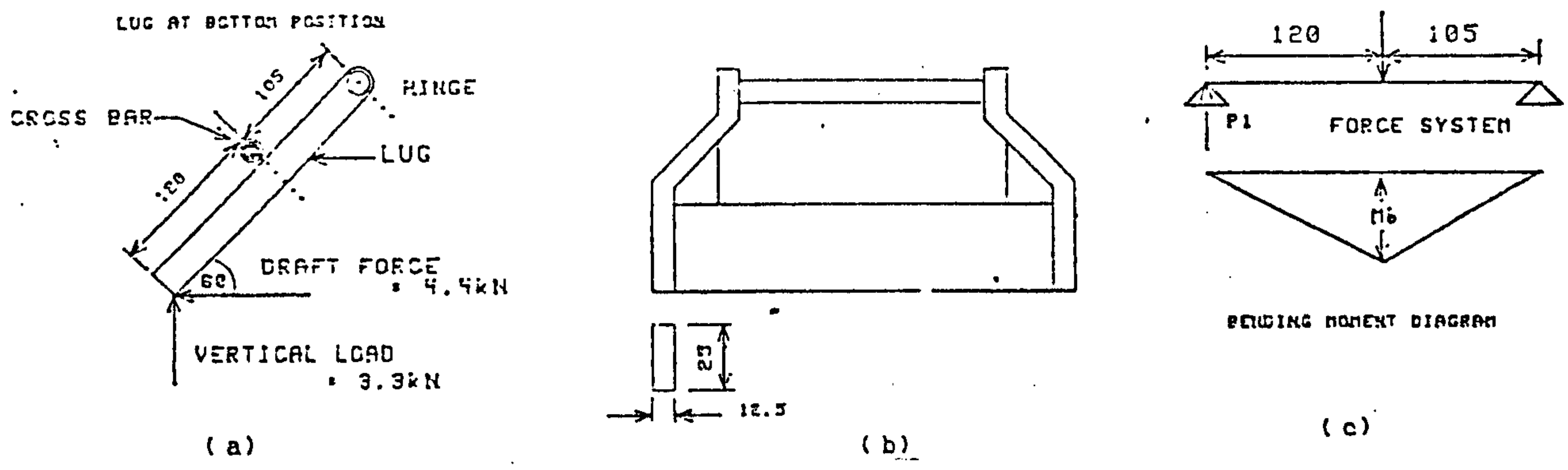

Figure. 2. Structure of lug frame and bending moment diagram.

b. Design of lug hinge

Main critical part in the lug hinge mechanism is the hinge clamping bolts. Brackets were made by forging 6 millimeter steel plate. From Figures 2 (a), (b) load at hinge perpendicular to lug frame P_2.

$$P_2 = P_i * 0.12 / 0.105$$

$$= 5.78 \text{ kN}$$

Force radial inward to the cage ring per one hinge P_3,

$$P_3 = P_2 * \text{Sin } 60 / 2$$

$$= 2.5 \text{ kN}$$

This load is carried by two bolts having 6 millimeter diameter in lug hinge bracket (part drawing Fig-)

The tensile stress S_t on each bolt,

$$S_t = 2 * P_3 / (\pi * d_b^2) \text{ ----------------(a.2)}$$

Where, d_b = bolt diameter, 6 millimeters,

$$S_t = 44.2 \text{ MN} / \text{m}^2$$

The yield stress of mild steel is around 225 MN / m^2, therefore the selected bolt can carry the available load with 5 safety factor.

Appendices -B

DEPTH TO THE HARD PAN (cm)

PC1	PR1	PH1	PC2	PR2	PH2	PC3	PR3	PH3
24	23	22	28	27	25	26	23	22
24	23	22	28	28	25	26	23	25
23	26	23	23	27	23	27	23	22
24	24	23	28	20	23	24	19	18
25	25	22	28	26	21	24	19	18
24	22	20	28	26	23	26	24	24
23	23	24	26	25	20	27	24	24
22	23	23	23	24	21	26	24	24
22	23	23	26	25	23	26	23	23
22	22	20	26	26	23	23	23	17
22	22	21	27	22	24	25	23	22
23	23	23	25	27	18	24	23	22
23	22	22	28	27	25	24	24	23
22	24	24	22	28	23	24	24	22
19	25	24	28	25	21	22	23	23
19	24	25	24	24	21	27	23	22
18	26	26	25	25	20	24	23	20
17	23	26	28	25	20	23	23	20
22	22	26	28	27	22	28	14	16
22	22	24	27	28	21	27	20	25
22	23	24	27	28	21	25	23	21
19	24	23	23	28	18	22	23	20
21	23	24	28	27	14	22	23	14
21	24	24	28	27	20	24	23	25
21	25	22	28	27	18	25	23	20
21	25	23	16	28	19	25	22	20
19	25	24	16	26	20	25	23	18
19	24	24	23	26	17	23	22	24
18	23	24	24	26	13	22	23	12
19	22	21	25	26	20	22	23	20
21	22	20	28	27	17	23	23	23
18	24	20	25	26	21	23	22	20
22	23	21	26	27	19	23	22	23
20	26	18	21	28	21	24	21	16
19	25	20	21	28	21	24	21	23
21	26	20	25	27	20	25	22	19
21	26	23	28	27	20	22	22	20
22	23	23	11	28	18	22	22	23
22	23	24	17	26	18	22	21	19
21	22	25	27	24	18	24	21	17
21	24	25	25	24	21	23	24	17
20	24	25	26	23	21	24	21	8

19	25	22	27	24	20	24	22	20
22	25	20	25	27	20	24	21	19
22	25	18	16	27	22	23	21	18
22	22	18	24	25	22	27	22	22
22	22	18	23	25	17	23	22	18
23	22	23	18	24	18	21	21	19
23	23	18	27	26	18	23	21	19
25	22	25	19	26	16	26	23	22
24	23	20	22	26	18	23	23	22
24	23	20	26	26	18	25	23	21
25	23	24	27	26	18	25	23	20
22	24	24	27	27	18	26	22	22
21	20	24	27	27	18	24	23	23
20	21	23	27	28	21	23	23	24
20	24	21	25	28	26	23	23	17
23	24	21	24	28	26	24	23	19
24	26	23	21	28	26	25	23	23
21	24	22	22	27	26	25	23	26
23	22	24	27	27	27	26	23	22
25	23	18	20	26	27	24	22	23
25	23	18	22	28	25	24	22	24
28	24	20	26	28	25	25	22	14
22	25	22	27	27	25	22	22	16
21	26	22	27	27	26	23	23	22
21	26	23	27	26	22	22	23	16
22	23	28	27	26	22	22	23	16
22	22	26	25	25	23	22	24	22
22	24	26	24	25	23	24	24	24
23	23	23	21	25	26	23	23	26
23	22	24	22	25	25	25	23	25
25	25	20	26	28	24	22	23	25
26	25	25	26	27	18	22	22	23
26	25	25	23	27	25	27	23	25
24	24	18	26	26	21	27	23	24
22	23	18	26	26	21	27	23	25
23	22	18	24	26	26	16	23	25
23	24	18	25	27	23	26	24	22
22	24	20	21	27	26	26	24	20
23	22	23	21	27	23	19	23	27
24	26	24	22	28	23	24	23	22
24	26	25	26	28	22	28	23	26
20	24	22	26	25	25	25	23	26
20	24	21	26	25	25	25	23	25
20	24	20	26	26	21	25	22	27
24	23	20	26	27	25	28	22	27
24	24	18	25	26	26	29	22	27
24	23	18	25	27	24	26	23	27
23	22	17	25	28	25	26	21	27
23	23	17	24	27	25	26	19	27
24	25	18	26	26	25	25	19	28
24	24	20	26	27	26	27	20	24
23	25	23	26	27	27	27	22	23

(21.3)

23	23	24	23	26	27	29	22	27
22	22	25	25	28	27	30	22	27
22	24	22	24	27	25	30	23	26
22	22	21	25	28	23	29	22	26
24	23	20	20	27	26	29	21	18
25	22	20	24	26	23	30	20	27
23	21	18	25	27	23	30	20	27
22.84653	23.54455	21.92079	24.54455	26.34653	21.9901	24.68317	22.28713	21.86139

Appendices - C

Program for "SAS" of travel reduction in Faculty farm experiment (With ploughing)

```
DATA;
INPUT GEAR $ AIDS $ BLOC $   TRAVEL;
CARDS;
   1H   C   1   12.28
   1H   C   2   22.03
   1H   C   3   19.03
   1H   R   1    8.47
   1H   R   2    8.47
   1H   R   3   12.28
   2H   C   1   22.03
   2H   C   2   34.21
   2H   C   3   27.4
   2H   R   1   12.28
   2H   R   2   12.28
   2H   R   3    8.47
   1L   C   1   24.81
   1L   C   2   22.03
   1L   C   3   19.03
   1L   R   1   12.28
   1L   R   2    8.47
   1L   R   3   12.28
   2L   C   1   22.03
   2L   C   2   27.4
   2L   C   3   24.81
   2L   R   1    8.47
   2L   R   2    8.47
   2L   R   3    8.47
   3L   C   1   29.82
   3L   C   2   29.82
   3L   C   3   24.81
   3L   R   1    4.31
   3L   R   2    8.47
   3L   R   3   12.28
;
PROC ANOVA;
CLASS GEAR AIDS BLOC;
MODEL TRAVEL=GEAR AIDS BLOC GEAR*AIDS;
RUN;
MEANS GEAR AIDS GEAR*AIDS/DUNCAN;
RUN;
```

B.

SUMMARY

Title of Project : Development of swinging Lugs reversible Cage wheels for small and medium power Tractors

Institute where Research is being carried out :

Dept. of Agric. Engineering

Faculty of Agriculture , University of Ruhuna .

Chief Scientific Investigator : Dr. P. L. A. G. Alwis

Period of Contract

Date of award of the grant : 15th January 1997

Date of completion : 15th January 1999

Objectives :

Design and develop a suitable mechanism for a folding type cage wheels for small and medium power tractors.

Experimental Method

A folding type cage wheel for small and medium power Tractors were designed and developed to provide facility for road transportation and to improve performance in Wet land operations. Two pair of Cage wheels were constructed for small and medium power tractor after testing first wheel and implementing necessary modifications.

The main advantage of this cage wheels were its capability of road transportation since the cage wheel diameter was smaller than the tire in the retracted situation and an improved traction while puddling as the cage wheel diameter was greater than the tire in and expanded situation, so that the lugs can touch the hard pan before the tire.

Two experiments were conducted in two location (On station Trial under controlled field condition and farmer trial under practical field conditions) to compare the performance of above designed cage wheels with conventional cage wheels. Effective field capacity, Time per hectare, Travelling speed and travel reduction were considered as criteria for the evaluation of Cage wheels. In additionally Cost analysis also was affected.

Results obtained :

The results of farmer trial shows that the effective field capacity and Travelling speed of designed cage wheel were 0.36 ha/hr and 2.05 m/s respectively. Above observations of the conventional cage wheel were 0.23 ha/hr and 1.6 m/s respectively. Therefor the effective field capacity and Travelling speed of Four wheel tractor equipped with designed cage wheel were greater by 60.8 % and 28.08 % respectively.

Time per hectare of designed cage wheel and conventional cage wheel were 2.74 hours and 4.72 hours respectively. So , time per hectare to plough the field with design cage wheel has decreased by 41.68% .

According to the test results of on station trail it was observed that the travel reduction of designed cage wheel was significantly different from conventional cage wheel. Mean travel reduction of designed cage wheel was 9.7 % and that of conventional cage wheel was 24% . Hence travel reduction of designed cage wheel was lower than conventional cage wheel.

Cost of production of conventional cage wheel and designed cage wheel was 5846 Rs. and 6020 Rs .for two wheel tractor and 5846 Rs. and 6020 Rs .for four wheel tractor respectively. Considers the benefits of designed cage wheel, this difference is not concerned. By considering about test results It can conclude that the performances of the designed cage wheels were significantly higher than conventional cage wheel.

Conclusions :

The developed folding type Cage wheel was tested in the field , obtaining efficient performances comparing with the conventional cage wheel. But it should be still further developed to improve its performance in order to find the possibility of adapting in more difficult soil condition. It is evident from the farmer survey that the key requirements of the modification or redesign of new cage wheels are:

1 Low cost and simplicity

2.Quick mounting and dismounting system to facilitate road transportation

3. High Floating ability.

To achieve the above requirement, First model of **Multipurpose Cage Wheel** was designed and tested in a field. The test was successfully finished and smooth operations were obtained. Therefor it can be recommended that the **"Multipurpose Cage Wheel"** is a new suitable traction aid for small and medium power tractors which is used in the high and wet land conditions. The cage wheel has simple construction , good serviceability, high field performance in different soil condition , and low cost.

C.

Title of submitted papers	Name of journal or Scientific gathering

* Development and testing of Folding type Cage Wheels for Four wheel Tractor. -SLAAS 55th sessions

* A Multipurpose Cage Wheel for Two wheel Tractor -SLAAS 55th sessions

* Development and testing of single ring retractable lugged cage wheels for Two wheel Tractor- Journal of the AESSL

"SAS" of travel reduction data in Faculty farm experiment (With ploughing)

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
GEAR	5	1H 1L 2H 2L 3L
AIDS	2	C R
BLOC	3	1 2 3

Number of observations in data set = 30

Dependent Variable: TRAVEL REDUCTION

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1830.324143	166.393104	14.82	0.0001
Error	18	202.145753	11.230320		
Corrected Total	29	2032.469897			

R-Square	C.V.	Root MSE	DIST Mean
0.900542	19.81805	3.351167	16.9096667

Dependent Variable: TRAVEL REDUCTION

Source	DF	Anova SS	Mean Square	F Value	Pr > F
GEAR	4	110.531047	27.632762	2.46	0.0825
AIDS	1	1552.177470	1552.177470	138.21	0.0001
BLOC	2	30.934247	15.467123	1.38	0.2776
GEAR*AIDS	4	136.681380	34.170345	3.04	0.0443

Duncan's Multiple Range Test for variable: TRAVEL REDUCTION

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 18 MSE= 11.23032

Number of Means	2	3	4	5
Critical Range	4.059	4.261	4.401	4.480

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	GEAR
	A	19.445	6	2H
	A	18.252	6	3L
B	A	16.608	6	2L
B	A	16.483	6	1L
B		13.760	6	1H

Duncan's Multiple Range Test for variable: TRAVEL REDUCTION

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 18 MSE= 11.23032

Number of Means	2
Critical Range	2.567

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	AIDS
A	24.103	15	C
B	9.717	15	R

Level of GEAR	Level of AIDS	N	-------------TRAVEL ------------ Mean	SD
1H	C	3	17.7800000	4.99374609
1H	R	3	9.7400000	2.19970453
1L	C	3	21.9566667	2.89069772
1L	R	3	11.0100000	2.19970453
2H	C	3	27.8800000	6.10417071
2H	R	3	11.0100000	2.19970453
2L	C	3	24.7466667	2.68556015
2L	R	3	8.4700000	0.00000000
3L	C	3	28.1500000	2.89252485
3L	R	3	8.3533333	3.98628064

Programm for "SAS" of travel reduction data in Faculty farm experiment

(Without ploughing)

```
DATA;
INPUT GEAR $ AIDS $ BLOC $    TRAVEL;
CARDS;

    1H    C    1    8.47
    1H    C    2    8.47
    1H    C    3    8.47
    1H    R    1    0.001
    1H    R    2    8.47
    1H    R    3    8.47
    2H    C    1    4.31
    2H    C    2    12.28
    2H    C    3    12.28
    2H    R    1    4.31
    2H    R    2    12.28
    2H    R    3    8.47
    1L    C    1    8.47
    1L    C    2    8.47
    1L    C    3    8.47
    1L    R    1    8.47
    1L    R    2    4.31
    1L    R    3    8.47
    2L    C    1    15.79
    2L    C    2    15.79
    2L    C    3    12.28
    2L    R    1    4.31
    2L    R    2    4.31
    2L    R    3    0.001
    3L    C    1    12.28
    3L    C    2    29.82
    3L    C    3    19.03
    3L    R    1    4.31
    3L    R    2    4.31
    3L    R    3    4.31
;
PROC ANOVA;
CLASS GEAR AIDS BLOC;
MODEL TRAVEL=GEAR AIDS BLOC GEAR*AIDS;
RUN;
MEANS GEAR AIDS BLOC GEAR*AIDS/DUNCAN;
RUN;
```

"SAS" of travel reduction data in Faculty farm experiment (Without ploughing)

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
GEAR	5	1H 1L 2H 2L 3L
AIDS	2	C R
BLOC	3	1 2 3

Number of observations in data set = 30

Dependent Variable: TRAVEL REDUCTION

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	781.8956466	71.0814224	5.35	0.0009
Error	18	239.1916113	13.2884228		
Corrected Total	29	1021.0872579			

R-Square	C.V.	Root MSE	DIST Mean
0.765748	40.58151	3.645329	8.98273333

Dependent Variable: TRAVEL REDUCTION

Source	DF	Anova SS	Mean Square	F Value	Pr > F
GEAR	4	99.0394995	24.7598749	1.86	0.1608
AIDS	1	332.5204961	332.5204961	25.02	0.0001
BLOC	2	71.4273501	35.7136750	2.69	0.0952
GEAR*AIDS	4	278.9083009	69.7270752	5.25	0.0056

Duncan's Multiple Range Test for variable: TRAVEL REDUCTION

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 18 MSE= 13.28842

Number of Means	2	3	4	5
Critical Range	4.415	4.635	4.787	4.874

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	GEAR
	A	12.343	6	3L
B		8.988	6	2H
B	A	8.747	6	2L
B	A	7.777	6	1L
B		7.059	6	1H

Duncan's Multiple Range Test for variable: TRAVEL REDUCTION

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 18 MSE= 13.28842

Number of Means	2
Critical Range	2.792

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	AIDS
A	12.312	15	C
B	5.653	15	R

Duncan's Multiple Range Test for variable: TRAVEL REDUCTION

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 18 MSE= 13.28842

Number of Means 2 3

Critical Range 3.420 3.590

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	BLOC
	A	10.851	10	2
B	A	9.025	10	3
B		7.072	10	1

Level of GEAR	Level of AIDS	N	-------------TRAVEL Mean	------------ SD
1H	C	3	8.4700000	0.00000000
1H	R	3	5.6470000	4.88957943
1L	C	3	8.4700000	0.00000000
1L	R	3	7.0833333	2.40177712
2H	C	3	9.6233333	4.60148165
2H	R	3	8.3533333	3.98628064
2L	C	3	14.6200000	2.02649944
2L	R	3	2.8736667	2.48780231
3L	C	3	20.3766667	8.84720483
3L	R	3	4.3100000	0.00000000

Appendix _B

Program of SAS for Farmer field observation

```
DATA;

INPUT AIDS $ BLOC $ Ttime Ctime Ecapa Tspeed;

CARDS;

    C  1  20.20 6.73  0.15  1.44
    C  2  11.63 3.88  0.26  1.52
    C  3  10.04 3.35  0.30  1.64
    C  4  12.47 4.16  0.24  1.72
    C  5  18.32 5.44  0.18  1.69
    R  1   8.24 2.75  0.36  1.82
    R  2   8.07 2.69  0.37  2.00
    R  3   8.29 2.76  0.36  2.00
    R  4   8.40 2.80  0.36  2.22
    R  5   8.23 2.74  0.36  2.22

;

PROC ANOVA;

CLASS AIDS BLOC;

MODEL Ctime Ecapa Tspeed Ttime=AIDS BLOC;

RUN;

MEANS AIDS BLOC/duncan;

RUN;
```

SAS for Farmer field observation

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
AIDS	2	C R
BLOC	5	1 2 3 4 5

Number of observations in data set = 10

Dependent Variable: TIME PER HECTARE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	13.37494000	2.67498800	2.87	0.1645
Error	4	3.72886000	0.93221500		
Corrected Total	9	17.10380000			

R-Square	C.V.	Root MSE	CTIME Mean
0.781986	25.88506	0.965513	3.73000000

Dependent Variable: TIME PER HECTARE

Source	DF	Anova SS	Mean Square	F Value	Pr > F
AIDS	1	9.64324000	9.64324000	10.34	0.0324
BLOC	4	3.73170000	0.93292500	1.00	0.4997

Dependent Variable:EFFECTIVE FIELD CAPASITY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.05398000	0.01079600	6.12	0.0519
Error	4	0.00706000	0.00176500		
Corrected Total	9	0.06104000			

R-Square	C.V.	Root MSE	ECAPA Mean
0.884338	14.28976	0.042012	0.29400000

Dependent Variable: EFFECTIVE FIELD CAPASITY

Source	DF	Anova SS	Mean Square	F Value	Pr > F
AIDS	1	0.04624000	0.04624000	26.20	0.0069
BLOC	4	0.00774000	0.00193500	1.10	0.4656

Dependent Variable: TRAVELING SPEED

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.66661000	0.13332200	46.78	0.0012
Error	4	0.01140000	0.00285000		
Corrected Total	9	0.67801000			

R-Square	C.V.	Root MSE	TSPEED Mean
0.983186	2.922025	0.053385	1.82700000

Dependent Variable: TRAVELING SPEED

Source	DF	Anova SS	Mean Square	F Value	Pr > F
AIDS	1	0.50625000	0.50625000	177.63	0.0002
BLOC	4	0.16036000	0.04009000	14.07	0.0126

Dependent Variable: TOTAL TIME

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	138.3772300	27.6754460	2.78	0.1716
Error	4	39.7908600	9.9477150		
Corrected Total	9	178.1680900			

R-Square	C.V.	Root MSE	TTIME Mean
0.776667	27.69339	3.154000	11.3890000

Dependent Variable: TOTAL TIME

Source	DF	Anova SS	Mean Square	F Value	Pr > F
AIDS	1	98.78449000	98.78449000	9.93	0.0345
BLOC	4	39.59274000	9.89818500	1.00	0.5019

Duncan's Multiple Range Test for variable: TIME PER HECTARE

NOTE: This test controls the type I comparisonwise error rate, not
the experimentwise error rate

Alpha= 0.05 df= 4 MSE= 0.932215

Number of Means 2

Critical Range 1.699

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	AIDS
A	4.712	5	C
B	2.748	5	R

Duncan's Multiple Range Test for variable: EFFECTIVE FIELD CAPASITY

NOTE: This test controls the type I comparisonwise error rate, not
the experimentwise error rate

Alpha= 0.05 df= 4 MSE= 0.001765

Number of Means 2

Critical Range .0739

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	AIDS
A	0.3620	5	R
B	0.2260	5	C

Duncan's Multiple Range Test for variable: TRAVELING SPEED

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 4 MSE= 0.00285

Number of Means 2

Critical Range .0939

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	AIDS
A	2.0520	5	R
B	1.6020	5	C

Duncan's Multiple Range Test for variable: TOTAL TIME

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 4 MSE= 9.947715

Number of Means 2

Critical Range 5.548

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	AIDS
A	14.532	5	C
B	8.246	5	R

Duncan's Multiple Range Test for variable: TIME PER 1ha

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 4 MSE= 0.932215

Number of Means	2	3	4	5
Critical Range	2.686	2.742	2.753	2.758

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	BLOC
A	4.740	2	1
A	4.090	2	5
A	3.480	2	4
A	3.285	2	2
A	3.055	2	3

Duncan's Multiple Range Test for variable: EFFECTIVE FIELD CAPASITY

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 4 MSE= 0.001765

Number of Means	2	3	4	5
Critical Range	0.117	0.119	0.120	0.120

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	BLOC
A	0.3300	2	3
A	0.3150	2	2
A	0.3000	2	4
A	0.2700	2	5
A	0.2550	2	1

Duncan's Multiple Range Test for variable: TRAVELING SPEED

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 4 MSE= 0.00285

Number of Means	2	3	4	5
Critical Range	0.148	0.152	0.152	0.152

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	BLOC
A		1.9700	2	4
A		1.9550	2	5
B	A	1.8200	2	3
B	C	1.7600	2	2
	C	1.6300	2	1

Duncan's Multiple Range Test for variable: TOTAL TIME

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 4 MSE= 9.947715

Number of Means	2	3	4	5
Critical Range	8.773	8.959	8.992	9.009

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	BLOC
A	14.220	2	1
A	13.275	2	5
A	10.435	2	4
A	9.850	2	2
A	9.165	2	3