ANALYSES AND IMPROVEMENT OF A "LOCAL PLOW"

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LOCAL PLOW STUDIES

SIDDIQUI

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AN ABSTRACT OF THE THESIS OF

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Experiments were conducted at the Agricultural Research and Education Center of the American University of Beirut to evaluate the performance of a locally manufactured plow. An attempt was made to solve the problem of the plow beam distortion and breakage, and to increase the efficiency of the plow. A new design was made to make the plow compact by bringing the plow bottoms nearer to the main frame, and also nearer to the centre of draft, and to have an even distribution of the weight and the draft of the plow.

The comparative study of the plows consisted of functional testing, power requirement, structural strength, accuracy of the design, and materials of construction.

The newly designed plow weighed less and the draft and power requirements were considerably less than that of the local plow. The depth of plowing of the new design was greater and the widths of the ridges were less compared to the old design. Maximum draft, wheel slippage, and bogdowns were more frequent with the old design.

Because of less turning radius, compact design, less weight, and equal distribution of weight and draft, the new design showed better maneuverability and increased efficiency in operation.

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I. INTRODUCTION

The plow of this study was first manufactured in the year 1949 in Hobeyka Brothers' Workshop, Zahle, Lebanon. The first machine contained only three bottoms, but gradually it was increased in size to five bottoms, a size which is by far the most extensively used today. Its price in the years 1950-54 was 650.00 L.L. but because of its wide use and subsequent large production the price today is only 250.00 to 300.00 L.L.

Animal power and implements which the Lebanese farmers had developed over the years were found inadequate for the new system of higher production, thus making it necessary to adopt tractors and develop bigger machines for various agricultural jobs. Therefore, the first such step evolved in the form of this plow, which though tractor mounted is very similar to a horse drawn plow (Figures 1 and 2). The major difference between this plow and the horse drawn plow is that it has five bottoms and is made of iron and steel only, whereas the horse drawn plow is made, mainly, of wood with a steel plow bottom. Relatively the latter is smaller in size and lighter in weight compared to the plow bottoms of the tractor mounted plow.

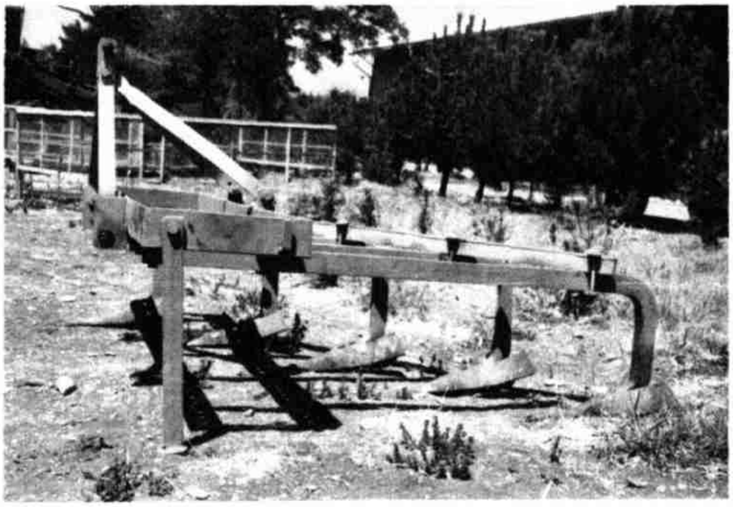

Figure 1. A "local plow", side view from left.

Figure 2. A "local plow", side view from right.

Historical

Reasons for the Origin of this Plow

Some of the known factors that gave impetus to the evolution of this plow were:

1. Scarcity of animal power.
2. Limitation of the animal power for doing agricultural operations.
3. High cost and scarcity of labor.
4. Unsatisfactory performance of the animal power and the horse drawn plow in the field.
5. Uncertainty of completing field work on time with animal power.
6. High degree of economic development and positive attitude of the farmers to introduce labor saving, efficient and fast working farm machinery to make the costly and scarce labor to work at greater efficiency.

Therefore, animal power was replaced with tractor power. There was need for a suitable matching plow for a tractor, but the foreign-made moldboard or disc plows were found to be costly and quite highly specialized. The former horse drawn plow was general purpose and hence the idea evolved to assemble more than one horse drawn plow bottoms and fix them rigidly to one frame. To withstand the heavy load this plow arrangement was made out of iron and steel. Although the change in power from animal to tractor was a great one, the change from horse drawn plow to the tractor driven plow was not extensive so the farmers got acquainted with it very quickly. Each bottom of the tractor driven "local plow" is very similar in shape and action to the horse drawn plow bottom. The name of the plow, given by the manufacturer, is "Arab plow" and is so used in the text.

Uses

In conventional agriculture a machine is accepted more for general than for specialized purposes irrespective of the efficiency of the plow and quality of the job done. The "Arab plow" fulfills this condition of conventional agriculture by being a general purpose plow. It is used for:

1. Primary tillage.
2. Secondary tillage.
3. Covering broadcast seeds.
4. Mixing broadcast fertilizers.
5. Cultivating for weed control in orchards and vineyards.
6. Digging potatoes.
7. Plowing very stony ground.

It is used extensively in the Beqa'a plain of Lebanon and in Syria. It is made of iron and steel and is pulled by a tractor with the help of a three point hitch. The reasons for its wide uses are:

1. It is a general purpose machine.
2. It costs much less compared to foreign made plows.
3. It is easily available.
4. Simplicity of design and ease of repairing and maintenance.
5. Similarity of this plow with the horse drawn plows.
6. Lack of animal power and high cost of labor.
7. A positive attitude of the farmers to improve their degree of mechanization.

Reasons for Study

Although the work of this plow was popular with the farmers the structural strength of the plow was found highly questionable. It was found that the beams of the plow break and twist at the elbow. This breakage was observed to occur most often with the longest beam and then with the shorter beams. In a few cases, only the longest beam was broken or twisted while the other beams remained in good condition. Under these circumstances it was thought worthwhile to study the working ability of this plow and advocate some improvements.

An attempt has been made to solve the problem of breakage and to increase the efficiency of the "Arab plow". A new design was made at the American University of Beirut (AUB) Agricultural Research and Education Center (AREC) workshop in the Bekaa plain, Lebanon. The intent was to make the plow compact by bringing all the bottoms nearer to the main frame and also nearer to the centre of pull and to have an even distribution of the weight and the draft of the plow.

Another aspect of the study was to investigate through functional testing the overall efficiency and performance of the original plow compared with that of the new design. At the same time few changes were recommended in the design of the original plow to increase its efficiency.

Another important objective of the study was to recommend changes in the cultural practices to make better use of the existing plow.

Accuracy of the parts of the plow, its finish, and the strength of the materials were other topics utilized in the investigation to determine the quality of material, strength, design, and the engineering.

Although the "Arab plow" is a simple one and similar to a horse drawn plow, the word simple is not synonymous with primitive. Remaining basically the same as the horse drawn plow, this plow can be perfected in design and performance, yet retain its simplicity. An evaluation which takes this into account will reveal many cases where improved locally produced plows were the best means to development for small farmers, many of whom were not in a position to benefit directly from highly specialized machines or were not in a position to undergo the costs incurred in buying such machines.

In Lebanon where the technical know how of the farmers is still low, it would seem that significant improvement of production can be accomplished by improving the locally made plows. With small investments a development may be initiated which will strengthen the economy of the farmers, small and large alike. It is expected that progress at the level where all farms and the entire agricultural labor force can participate will prepare the way for the creation of capital so much needed for larger investments in highly specialized machines.

In introducing the improvements in the design of the plow it was kept in mind that readily-obtained raw materials, skill of local craftsman, and traditions of the methods of the area were the main factors that governed the design and construction of this plow; therefore, no drastic change in design is introduced, but recommendations are made for future alterations in construction.

Description of the "Arab plow"

Main Frame

The main frame is made of angle iron, welded in the form of a rectangle (Figure 3). There are holes on the long sides of the rectangle for adjusting the distance between the plow bottoms. The beams of the plow are rigidly fixed to this frame with the help of nuts and bolts. Three point hitch arrangements are fitted to this frame and make a part of the body of the frame.

On the left[1] side of this frame a folding stand is provided to support the plow while it is resting in the garage. This stand can be folded while the plow is working in the field (Figure 4).

The depth control arrangement which is a part of the three point hitch is also fitted to this main frame.

Plow Beams[2]

These are made of hard grade steel and are one of the most important members of the whole set up. One end of the beam is fitted to the main frame while at the other end the plow bottom is fitted to it. This end of the beam has a built-in angle with the horizontal plane, and this characteristic helps the plow bottom to sink or bite into the soil (Figure 5).

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1 Left being the left of the tractor driver while looking in the direction of travel.

2 See Appendix A.

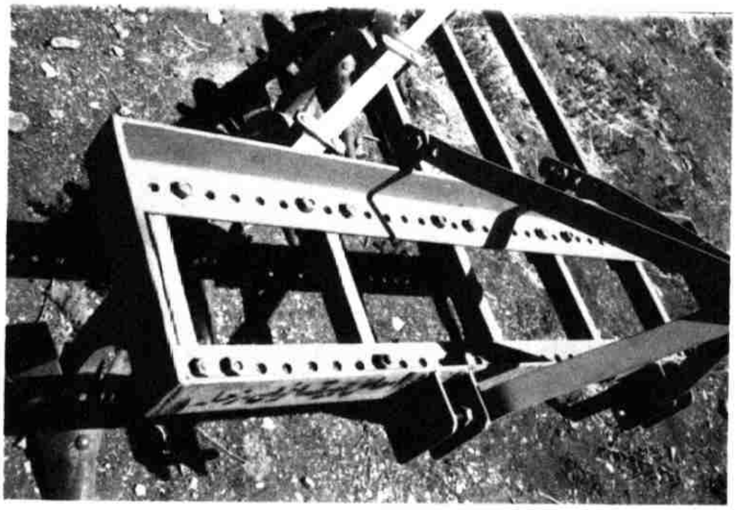


Figure 3. Main frame with depth control arrangement.

Figure 4. Front view of the plow showing folding support.

There are five different sizes (in length only) of beams in the original design. The one on the right is the smallest and the one on the left is the longest. The rest gradually increase in size from the right to the left.

The Plow Bottom

The plow bottoms are made of steel (of 0.9% carbon) and are similar in shape and action to the plow bottoms of the local horse drawn plows, but are relatively bigger in size (Figure 6). The plow bottom has two moldboards for inverting the soil and an elongated share, built very rigid and strong to break the soil by wedge action. The width of each bottom is 11.81 in (30.00 cm) from one tip of the moldboard to the opposite tip. Each plow bottom makes a 13^{0} angle with the horizontal, and this fixed angle keeps it in the ground.

This is a symmetric breaking type plow bottom which can be more correctly designated by its ancient name "ard" (Swedish: ard; German: arl; French: araire; Latin: aratrum; Armenian: araur). It throws soil to both sides. Its draft line lies in a vertical plane with the beam and share point dividing the plow bottom into two symmetric halves.

Beam Reinforcement

Two angle irons welded together are fitted to the upper side of the beams, to prevent side thrust of the

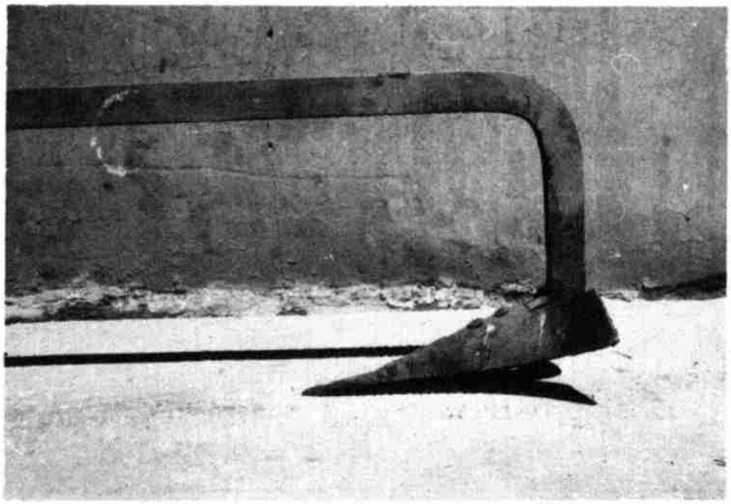


Figure 5. Plow beam and plow bottom.

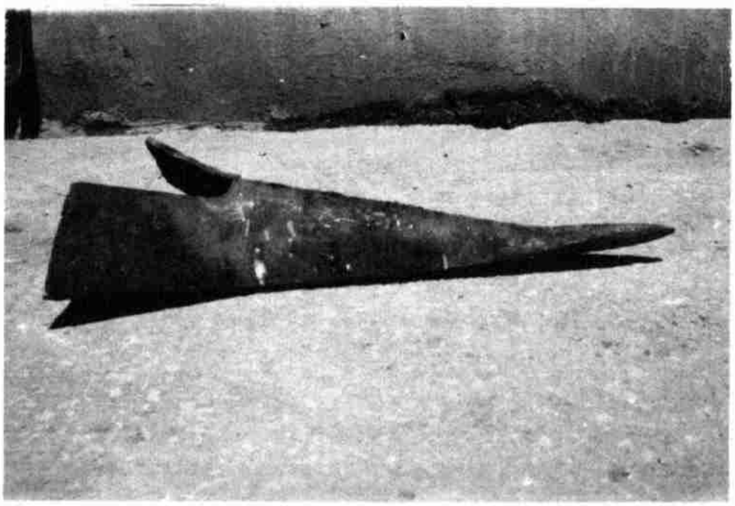


Figure 6. Plow bottom.

beams and to give more rigidity to the entire machine (Figure 7).

<u>Weight of the Plow</u>

Total weight of the old design = 550.00 lb (250.00 kg).

Figure 7. Beam reinforcement.

II. REVIEW OF LITERATURE

Investigations made in the USA regarding the farmer's attitude towards the machine he gets and the relation of research to machinery improvements have revealed two general facts. One is that more fundamental research is needed in the field of farm machinery so that research organizations can find out basic information which can be of great value to the engineer working in product improvement in a company. The second fact is that in many cases there is too wide a gap between the agricultural engineer and the farmer. It is not surprising to learn how few people in the farm machinery industry have actually tried to find out what the farmer wants and what he will need in the future (Johnson, 1954).

The situation in Lebanon is more dismal because very little or no fundamental research has so far been conducted in farm machinery. Here, until very recently, the farm implement industries were probably the main centre of machinery production and development, but indications are that the efforts to improve the implement by the industries were meager.

Draft Measurements

The non-uniformity of soil and the fact that the control of soil properties in the field is almost impossible have made field draft tests for tillage implements difficult.

Telischi <u>et al</u>. (1956) found that the variables that exist in the tillage operation can be divided into three sections: (A) Soil, (B) implement, and (C) others.

(A) Soil variables include:

1. Particle size distribution, including the type of colloidal material.
2. Chemical composition, including the effect of organic matter.
3. Moisture percentage.
4. State of compaction or bulk density.
5. Soil structure, including soil cementation effects.
6. Effect of vegetation and crop residues.
7. Effect of slope of soil.

(B) Implement variables include:

1. Kind of implement.
2. Kind of metal.
3. Surface condition and sharpness of the implement.
4. Bearing area against the soil.
5. Curvature and the shape of surface applying force.

(C) Other variables include

1. Speed.
2. Width.
3. Depth of furrow.

Telischi _et_ _al_. (1956) found from field tests that the draft requirement of tillage tools increased with the increase in speed. It was also found that increase in moisture content increased the draft and this draft increase became constant at a moisture content above the wilting point in a soil low in clay percent (16.7% clay), but in a soil high in clay content (22.5% clay or more) the increase in moisture caused increased draft. Payne (1956), who conducted experiments in the field with a rectangular flat plate tine, found that for the range 1/2 to 6 mph there was approximately 20 to 30% increase in draft. He also observed that the soil adjacent to the tine seemed more broken up at higher speeds.

Rate of Work

Although the prime requirement of a machine is that it should be able to satisfactorily perform its intended function, the economic aspects of the machine application are of great importance in machine design. To work out a most effective design, a thorough understanding of the field capacities and factors affecting it is necessary. In this connection a knowledge of the meaning of the terms related to field performance of machines is necessary.

The effective field capacity of a machine is a function of the rated width of the machine, the percentage of rated width actually utilized, the speed of travel, and the amount of field time lost during the operation.

Field efficiency is the ratio of effective field capacity to theoretical field capacity expressed as percent. It includes the effects of time lost in the field and of failure to utilize the full width of the machine.

Theoretical field capacity of an implement is the rate of field coverage that would be obtained if the machine was performing its function 100% of the time at the rated forward speed and always covering 100% of its rated width.

Effective Field Capacity

The effective field capacity of a plow is a function of its rated width, the percentage of rated width actually utilized, the speed of travel, and the amount of field time lost during the operation. With a cultivator type plow it is practically impossible to utilize its full width. The required amount of overlap is largely a function of speed, ground condition, and the skill of the operator. The rated width of implements with spaced functional units such as cultivators can be found as follows:

<u>Rated</u> <u>width</u> = number of units x spacing of the units. Here the rated width is assumed to include one-half space beyond each outside unit.

The effective field capacity of a machine can be calculated as follows (McKibben, 1942):

$$C = \frac{5280 \times S \times W \times E_f}{43560 \times 100}$$

$$= \frac{SW\ E_f}{825} \text{ ------------ (i)}$$

Where:

C = effective field capacity, in acres per hour

S = speed of travel, in miles per hour

W = rated width of implements, in feet

E_f = field efficiency, in percent.

The field efficiency can be calculated as follows:

$$E_f = K \frac{To}{To + Tw + Ta} \text{ ----------- (ii)}$$

Where:

K = percentage of implement width actually utilized

To = theoretical time required for one acre (at the theoretical field capacity)

Tw = time lost per acre due to interruptions that are not proportional to area (Tw usually tends to be proportional to To)

Ta = time lost per acre due to interruptions that tend to be proportional to area.

Tw includes time lost in turning, idle travel across ends, and adjustment of the machine which usually tends to be proportional to the effective operating time, within reasonable limits of width or speed of the implement.

Ta includes time lost by field obstructions, clogging, bogdowns, etc.

Field efficiency (and lost time) is the most difficult variable to evaluate in relation to field capacity. Extensive time studies and field surveys are needed to determine the field efficiency. McKibben (1930) found that if a field efficiency of 82.5% (i.e. 17.5% lost time) is assumed (which is assumed to be a reasonable value for many operations) it will be shown from equation (i) that the capacity of a field machine in acres per hour (in a ten hours day) will be as follows:

$$\text{Acres per hour} = \frac{SW\ 82.5}{825} = \frac{SW}{10}$$

$$= 1/10\ (\text{speed, mph})\ (\text{rated width of machine in ft})$$

Barker (1962), while studying the variability of individual drivers on measures of tractor performance, found that the rate of working was very dependent on the driver who may have a greater influence on output than the machine being used. He also warned that when testing machines it is essential to ensure that the variations due to the skill of the operators do not confuse the comparison between the machines.

Impact Loads and Safety Devices

Impact Loads

Failure of plow beams requires a study of the impact loads to which they are subjected and of the possibilities of devising mechanisms on the plow and tractor to reduce impact loads which are the most probable cause of breakage of the beams.

An analysis of the theory of impact loads by Hanavan and Reece (1963) showed that basically the process consists of a transformation of the kinetic energy of the tractor and implement into strain energy of the implements and its connections to the tractor. From this simple analysis, ignoring the effect of traction and rolling resistance during the impact, it emerges that the impact load L_{max} is given by:

$$L_{max} = V\sqrt{\frac{Wr}{g}} \qquad \text{------------ (i)}$$

The theoretical analysis went on to consider the effect of the tractive effect of the tractor wheels during the impact. It was shown that this can have a surprisingly large effect due to the very great on-loading of the driving wheels from load transfer resulting from the impact load. This load transfer is to some extent offset by that due to the inertia force acting through the centre of gravity of the tractor. Therefore, if the load transfer through the linkage is large, a considerable extra force can be developed due to traction, but if it is small, the additional impact load is correspondingly small. It was shown that, taking into account traction, the impact load is given by:

$$L_{max} = V\sqrt{\frac{\left(1-\mu\frac{f}{w}\right)W_T}{\left[1-\mu\tan\theta\left(1+\frac{e}{w}\right)\right]g} + \frac{\mu W_T\left(1+\frac{O}{w}\right)-R}{1-\mu\tan\theta\left(1+\frac{e}{w}\right)}} \quad \text{(ii)}$$

Where:

- W = weight of tractor and implement, lb
- W_T = weight of tractor only, lb
- R = rolling resistance, lb
- w = wheel base, in
- O = distance of centre of gravity of tractor in front of rear axle, in
- f = height of centre of gravity of tractor and implements, in
- θ = angle draft, deg
- e = horizontal distance between point of implement and back axle, in
- r = stiffness of tractor - implement combination, lb/in
- g = gravitational constant, 12 x 32 in/S^2
- V = velocity of tractor at the beginning of impact, in/S

T = impact time: the time from the beginning of impact to the development of maximum force, S

μ = coefficient of friction between ground and tire

I = moment of inertia of component, lb ft/S^2

G = gear ratio between components and back axle in first gear.

In both equations (i) and (ii), L_{max} increases linearly with speed.

The impact time T was shown to be quite independent of the speed and magnitude of the impact force and is given by:

$$T = \frac{\pi}{2} \sqrt{\frac{W}{rg}} \quad \text{-------} \; (iii)$$

For commercial tractors and implements such as plows and subsoilers the impact time was found to range from 0.05 seconds for linkages and implements of very stiff construction to 0.07 seconds for more flexible arrangements.

Reduction of Impact Load

Many attempts have been made by the tractor and implement industry to reduce the magnitude of impact loads which act on tillage implements, the main aim was to prevent damage to the implement frame and destruction of the soil working tools. As tractor speeds increase and as cultivation is extended into more and more difficult terrain, the effect of impact loads become increasingly important. Investigations have been carried out to find the nature and causes of impact loads and the various possible types of safety devices. The ultimate object was to develop improved types capable of allowing high speed cultivation in the presence of rocks and roots. Kilgour and Reece (1962) suggest four basic principles which can be used to minimize impact loads:

1. To reduce the weight of the tractor and implement and decrease the stiffness of the implement and its connection to the tractor.
2. To reduce that part of the impact load that is contributed by traction during the impact.
3. To provide some energy absorbing capacity in the system so that only a proportion of the kinetic energy is turned into strain energy.
4. To provide "impact-avoiding" devices whereby the tillage tool is able to ride over obstructions. These involve some energy storing capacity so that the tool can be driven back into its working position.

The investigation by Kilgour and Reece (1962) was limited to consideration of devices falling into group (2) of the above classification. He found that two methods can be used; the first is to throw out the tractor clutch during the impact; this reduces traction by removing the source of energy for driving the wheels. The second is to reduce the load transfer from the implement to a low level at the beginning of the impact so that the driving wheels are unloaded and slip without much traction. This proposal applies to draft or position control systems in which the high degree of load transfer developed in normal work is obtained through the tractor hydraulic system. It is therefore, necessary to put the control valve into the lower or drop position at the beginning of impact. It seemed possible for a draft-controlled implement to be subjected to exceptionally large impact forces due to high traction during the impact.

Kilgour and Reece (1962) experimentally demonstrated that many of the traction-reducing devices that are in use are not capable of making the theoretically possible reduction in load due to their slowness of operation. It was found that ideally these devices can only cause minor reductions in the impact load and that in practice even this is not achieved, chiefly because the devices do not respond quickly enough.

III. MATERIALS AND METHODS

The experiments were conducted at the AREC. The soil on the experimental site of the research was calcareous clay and contained an appreciable number of rocks of varying sizes.

A new design of the "Arab plow" was made at the AREC workshop. The old design and the new design of the "Arab plow" was tested in the "students plot" of the AREC. The results were recorded in the form of numerical data, photographs, and visual observations. Before starting the final field tests, numerous trials were conducted to get acquainted with the proper use of the plows and the experimental set up in general.

Construction of New Design

The two longest beams of the old design, numbered 1 and 2 (Figure 13) were cut to the size of the 3rd and 4th beams of the same design. In other words the 5th beam and two sets of each of the 3rd and 4th beams of the old design were used to form the total of five beams for the new design.

The reinforcement (Figure 7) which was meant to strengthen the beams and to prevent their sideway movement was found unnecessary and was removed.

The folding stand attached to the left side of the old design (Figure 4) which was provided to support the plow while resting in the garage was found unnecessary for the new design, because of equal weight distribution, and was removed.

The newly designed plow bottoms were arranged in the (inverted V) shape (Figures 8 and 13).

In the new design the length of the longest beam was equal to the length of the 3rd beam with the old design. Therefore, the plow bottoms with the new design were brought 27.56 in (70.00 cm) nearer to the main frame (Figure 13). The shortest plow beam in the new design was put in the middle,and one of the longest two beams was put at the far left and the other at the far right. The middle sized beams were put in the centre between the shortest and the longest beams. In other words the middle sized and the longest beams were used in sets of two-one on each side of the shortest central beam (Figure 8).

In the old design the shortest beam was on the far right and the longest on the far left and the rest were fitted from right to left in increasing length (Figures 9 and 13).

Field Design

Thirty two test plots of 6 x 75 ft were marked with

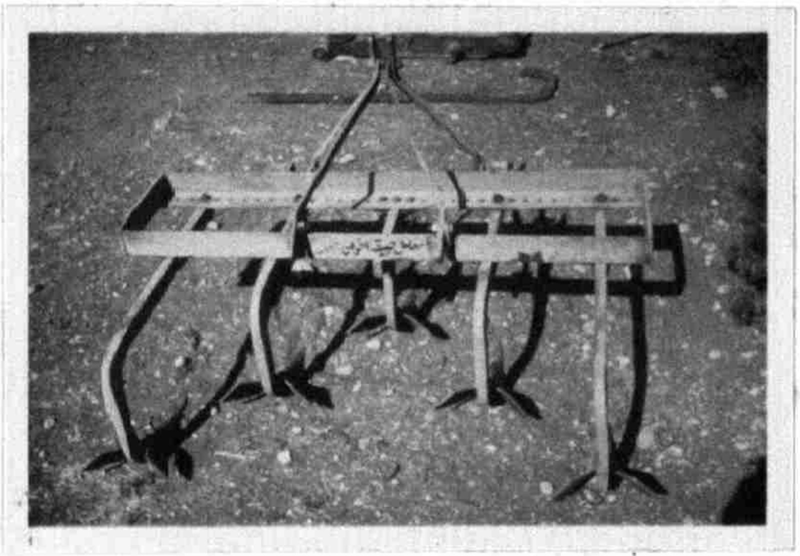


Figure 8. The new design.

Figure 9. The old design.

stakes in the field.

Extreme care was taken, in the selection of the plots, to keep the variability of degrees of slope, and the hardiness, roughness, and stoniness of the soils to a minimum. This was done primarily with visual observations, but if any run of the experiment encountered exceptionally hard and rocky soil, then either the test was repeated in a new plot or the length of run of the same plot was increased. Only 75 ft of representative test run were taken into consideration and the remainder was rejected. Any test that gave abnormal results due to extreme rockiness or hardiness of the soil was repeated in a different plot.

Experimental Design

Two tractors, one International Harvester 504 (I.H.) of 41 drawbar horse power and one Massey Ferguson 135 (M.F.) of 35 drawbar horse power, were used for conducting the experiment.

The plow was mounted on the M.F. tractor with a three point floating hitch. The M.F. tractor in turn was pulled by the I.H. tractor with the help of a 20 foot heavy duty chain (Figure 10). A direct reading spring dynamometer was hooked to the drawbar of the I.H. tractor and to its other hook the chain coming from the front of the M.F. tractor was attached (Figure 11). The engine of the M.F. tractor was kept running but the gear shift was in neutral. In short the M.F. tractor served as an idler

Figure 10. Experimental set up for field test.

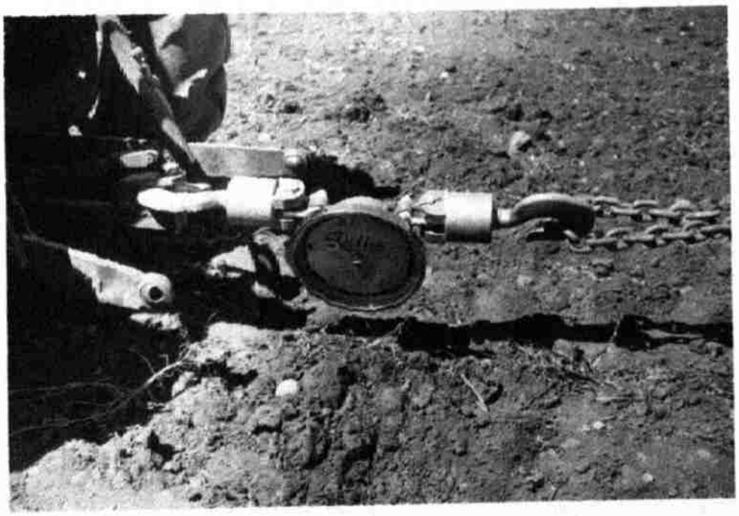


Figure 11. Dynamometer arrangement.

and was used to raise or lower the plow and for turning at the ends and for achieving the proper alignment with the front tractor. The front tractor was used to pull the M.F. tractor and the plow.

The stabilizers were not used with either of the two designs except while testing the plows on sloping land, which is so specified in the text.

Tractor Operation

Two experienced tractor operators were used for the job. Both the tractor operators had some knowledge of the "Arab plow" and were familiar with the proper use of the plows.

Each operator was assigned a tractor and he stayed with the assigned tractor throughout the experiment.

The operator who drove the lead tractor (which pulled the combination of tractor and plow) had a fair knowledge of English and knew very well how to read the tachometer and how to select a particular speed. The speeds were always selected and checked by the experimentor before the beginning of each test.

Tractor Speed

The speed of the tractor was regulated with the help of the tachometer on the tractor. The speeds selected for the tests were 1.00, 1.25, 1.50, 1.75, 2.00, 2.25, 2.50, 2.75, 3.00, 3.50, and 4.00 mph. The lead tractor which pulled the combination of tractor and plow was always driven in the second gear.

Previous Crop and Cultural Practices

The field was disk-plowed and harrowed once with an offset disk harrow, cultivated once for weeding and again harrowed, this time with a spike tooth harrow. It was planted with barley in the fall of 1967 with a grain drill.

At the time of the field test with the new design the average height of the barley was 10 to 12 in. Due to dynamometer breakdown the field test of the old design was delayed and the height of barley at the time of old design test was found to be more than 10 to 12 in. Therefore, the field was mowed with a rotary field mower which brought the height of the barley down to 8 in.

Moisture Content

Moisture content of the soil was determined, on the day of the field test, for both the old and the new design.

Three soil samples, one each from two, four and six inches depth of the experimental plots were taken. The moisture percent on dry weight basis of the soil samples were determined by the oven drying method in the soil science laboratory of the School of Agriculture at AUB.

Depth Setting

Provisions for depth control were provided with the top link of the tractor three point link arrangement and the hitch arrangement on the plow.

Since the experiment was designed to give the toughest test to the plow, in a very dry soil, only one depth setting was used and that was the maximum depth. The maximum depth setting was achieved by shortening the top link on the tractor and using the top hole of the depth control arrangement on the plow. This one maximum depth setting was used for each speed tested with both the old and the new designs.

Dynamometer Control

A simple direct reading spring type dynamometer was used for draft tests. The maximum reading that could be obtained from the dynamometer was 11000.00 lb (5000.00 kg).

During the trial tests the dynamometer face or dial used to flip downward. Therefore, for taking readings during the run, it had to be turned upwards each time a reading was to be taken. Under these circumstances it was found necessary to attach a wire at one side of the dynamometer with the help of a screw on the dynamometer. The other end of the wire was bent in the form of a hook which could be attached to the waist belt of the experimentor. This way the face of the dynamometer always remained upward and left both hands of the experimentor free for taking down the instantaneous readings of the dynamometer. While using the wire on the dynamometer extreme care was taken so that no side force was applied to the instrument.

Before starting the field tests, the dynamometer was tested for its proper function in the workshop by lifting a heavy machine of known weight and reading the dynamometer for correct measurement. It was found difficult to dampen the vibrations of the needle enough to permit accurate readings. Therefore, the dynamometer readings for average draft were approximate. An exception to this rule was the maximum draft readings which were accurately recorded by a special pointer.

Total Weight of the Plows

Total weight of both the designs were measured and the reduction of weight in the new design was determined.

Draft Measurements

Several tests were carried out in the field to determine the force required to pull the M.F. tractor with the plow in the lifted condition. In the subsequent tests the force needed to pull the tractor and the plow in the engaged condition was read from the dynamometer. The difference between the two readings gave the draft requirement of the plow at that particular speed.

Plow draft = pull of combination - rolling resistance of the plow and tractor.

Fifty readings were taken from the dynamometer for each run, and after deducting the pull of tractor and plow in the lifted condition, average draft was found for each speed tested. Maximum drafts encountered at all speeds were also recorded.

Draft measurements were taken at 1.00, 1.25, 1.50, 1.75, 2.00, 2.25, 2.50, 2.75, 3.00, 3.50, and 4.00 miles per hour. This was done both with the old and the new designs.

Depth and Ridge Widths

The depths of plowing at each speed and the top widths of the ridges (that formed between two furrows or two plow bottoms) were measured on the same day the test was made. Twenty five readings for depth and 25 readings for ridge widths were taken. The readings were taken at 3-feet intervals along the length of each plot. Starting from the left row, where the 1st reading was taken, the 2nd reading was taken after 3 ft in the second row from the left, and the 3rd reading was taken in the 3rd row from the left after 9 ft from the starting point. The process was repeated through the 5th row and then moved to the left to the 4th, 3rd, 2nd, and 1st rows along the distance as before. The same sequence of measurements was continued to the end of the run. The same procedure was used for each test and with both the plow designs.

The depth was measured with the help of two scales. All the loose soil from the furrows was removed down to the hard unplowed bottom of the furrow. The soil on the surface of the ridges was carefully removed to the point of unplowed ground. One of the scales was then placed across the furrows as a bridge between two ridges and the other scale was held vertically at the bottom of the furrow, and the depth reading was taken at a point on the vertical scale where the bottom of the horizontal scale touched it.

For measuring the top width of the ridge, all the loose soil was removed to the point of unplowed surface, a scale was placed across it, and the reading was taken from the top.

Clod Size

Clod sizes were measured to determine the effect of speed and depth of plowing on the clods. All the clods, having a side dimension of 4 in or more, were measured and the number of clods of each particular size was counted in each run. This was done with both the old and the new designs. The three greatest dimensions (one of which was always 4 in or more) of all the clods were measured and their mean diameter was calculated to show the degree of clodiness and the amount of pulverizing effect the plow had on the soil. Topography of the land was the biggest factor that determined the size of the clods.

From the mean diameters of the clods, the seven biggest clod sizes were selected and the number of clods for each size was calculated for each speed tested with the old and the new designs.

Measurements of clod size was very difficult, because they were dry and broke very easily. Readings were taken to the tenth of an inch. The clod size varied from place to place in each test plot, with bigger clods at one spot and relatively smaller clods at another spot at the same speed and depth setting. For this reason, the method of comparing seven biggest clod sizes at each speed was adopted and the clod size was measured along the whole length of each test plot.

Draft and Performance of Reduced Plow Bottoms

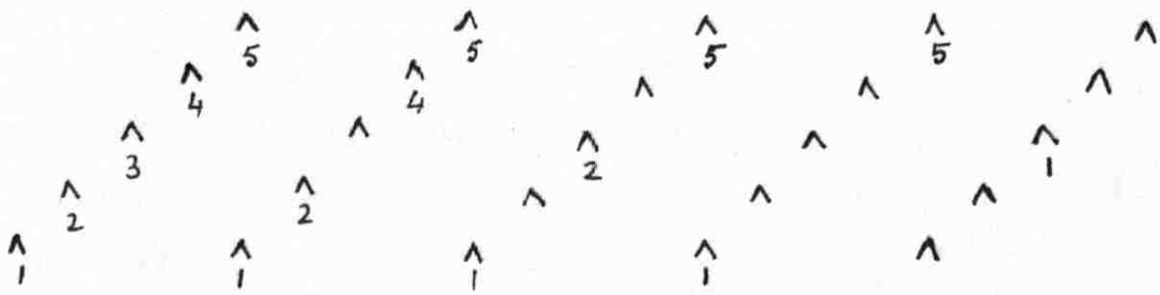
An attempt was made to measure the draft of individual plow bottoms to ascertain any variation in their requirement. Observations of experienced users of the plow disclosed the fact that maximum breakage or failures of the member occurred in the longest beams.

With the old design this test was made by removing one plow bottom at a time. The idea was to find the draft of four, three, two, and one bottoms at a time and then by subtraction find out the individual draft; the first and 5th bottoms each were tested alone for their individual draft.

With both the designs the bottoms were numbered one, two, three, four, and five from left to right (left being the left of the tractor driver while looking in the direction of travel) (Figure 13).

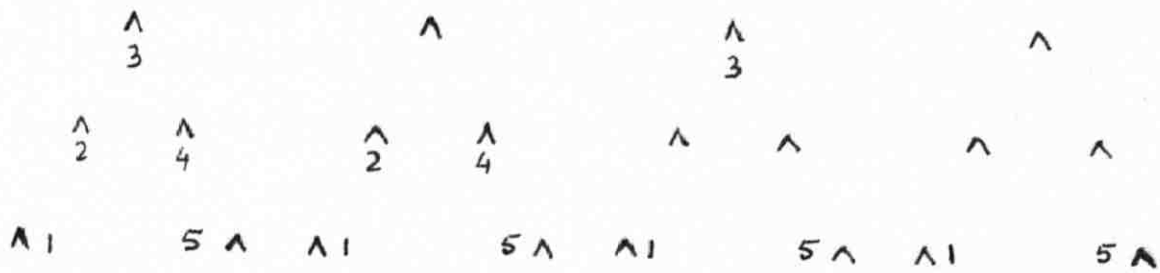
For conducting this test with the decreasing number of plow bottoms, the original position of the plow bottoms was changed and the remaining bottoms on the main frame were rearranged in such a way that they did not create any apparent unbalance in the plow set up.

The test arrangements with the old design were as follows:



As shown above the 1st test included all the five bottoms; the 2nd test included 1st, 2nd, 4th, and 5th bottoms, and the 3rd bottom was removed with the intention that the difference between the draft of these two tests would give the draft requirement of the 3rd bottom. The 3rd test included the 1st, 2nd, and 5th bottoms, but the 2nd bottom was bolted at the place of the 3rd bottom to prevent the apparent non-balance. The 4th test included only 1st and 5th bottoms in their original position. The 5th test included only the 1st bottom, but it was placed at the centre of the main frame at the place of the 3rd bottom. The 5th bottom was also tested for its individual draft by putting it at the centre of the main frame.

Similar tests were carried out with the new design in the following way:



With the new design the 1st test included five bottoms; the 2nd test included 1st, 2nd, 4th, and 5th bottoms and the 3rd bottom was removed. It was thought that the difference in the draft requirement of two tests would give the draft requirement of the 3rd bottom.

In the case of the new design the plow bottoms were not rearranged and unlike the old design they remained in their original position throughout the test. This was because of the symmetrical design of the plow, with the 1st and 5th bottoms; and the 2nd and the 4th bottoms being of the same size.

The 3rd test included 1st, 3rd, and the 5th bottoms; 2nd and 4th bottoms were removed. The 3rd bottom was again attached in order to cross check the results. The 4th test included the 1st and the 5th bottoms only, with the intention that the dividing of the total draft of the 1st and 5th bottoms by two would give the individual draft of the 1st or

5th bottom. As stated above, this was possible because the beams of the 1st and 5th bottoms were of the same size and both the plow bottoms were similar in function by virtue of their symmetrical position on the main frame. The 1st and 3rd bottoms were also tested for their individual draft.

Throughout this test the depth setting was at the maximum, the same as for the previous tests. The speed was 2.50 mph for tests with both the designs.

Analysis of the Capacity of Machines

Lost time was the most difficult variable to evaluate in relation to field capacity. Specific study is needed to evaluate the lost time for any particular equipment, but since no such study was made, certain assumptions were made regarding the field efficiency. It was found that if a field efficiency of 82.5% (i.e. 17.5% lost time) was assumed (which is a reasonable value for many operations) then the capacity of field machine in acres per hour (in ten hours day) would be as follows:

$$C = \frac{5280 \times S \times W \times E_f}{43560 \times 100}$$

$$= \frac{SW\ E_f}{825}$$

$$= \frac{SW\ 82.5}{825}$$

$$= \frac{SW}{10}$$

= 1/10 (speed, mph) (rated width of machine in feet).

Rated width of machine = number of units x spacing of units.

Here the rated width is assumed to include one half space beyond each outside unit. If this formula is used, then the rated width will be nearly 1.97 in greater. Therefore, rated width of both the designs were calculated as follows:

Rated width = 4 (spacing of units) + 2(one half size of each outside unit)

= 4 x 13.78 in + 2 x 5.905 in

= 55.12 + 11.81

= 66.93 in

= 5.58 ft

Where:

Spacing between two units = 13.78 in (35.00 cm) and the size of each unit = 11.81 in (30.00 cm).

Normally the spacing of the functional units of cultivators are such that the units overlap each other, but in the case of the "Arab plow" there was a gap of 1.97 in (5.00 cm) between two units (Figure 13). Therefore, the rated width was found by finding the distance from centre to centre of the outer units and one half size of one unit beyond each outside unit was added to that.

Maximum Draft, Wheel Slippage and Bogdowns

A chalk mark was made on the inside of the rear tractor wheel in such a way that the chalk mark and the dynamometer both could be seen by the experimentor from one place. The numbers of wheel turns without forward movements were recorded for that particular run.

It was easy to determine the wheel slippage in the case of the new design but with the old design, the wheel slippage invariably led to complete tractor bogdown and the plow had to be lifted from the ground to get out of the bogdown. As a result, wheel slippage was recorded for the new design and numbers of bogdowns for the old design for each speed tested.

Maximum draft encountered at all the speeds tested was also recorded.

Miscellaneous Tests

Several preliminary trial tests, other than those mentioned above, were conducted to determine and compare the performance of the two machines under a wide range of expected operating conditions in the field. While carrying out the miscellaneous tests the tractor was driven and the plow was operated by the experimentor himself.

Gage Wheel Attachment

The first attempt to improve the old design was the gage wheel attachment. A small gage wheel was fitted to the left side of the main frame of the old design (Figure 12) for giving support to the unusually heavy left side of the plow and for providing a depth control

Figure 12. Gage wheel attachment.

arrangement. The left two plow bottoms were suspected to dig deeper than the bottoms on the right with the smaller beams. This wheel was found in the junk and was repaired and bolted to the plow. To do this two holes were drilled on the main frame of the plow.

The gage wheel test was done with the old design only. The new design by virtue of its plow bottom arrangement did not need such a member in the plow set up.

Field trials were carried out with the gage wheel on the plow, but no data were taken, because the visual observations gave enough indication as to the value of the gage wheel.

Stubble Mulch Tillage and Weed Control

Both designs were used in stubble mulch of wheat of 6 to 12 inch size and a field full of heavy brush like weeds of 15 to 20 inch size and their performance was recorded and photographs were taken. Also, the two plow designs were tested for cultivating a weedy field of loose soil and the visual observations of their performance were noted.

Plowing Sloping Lands

This experiment was carried out on the "Tel" at the AREC and the visual observations of the individual plow performance were noted.

Accuracy of Design-Material Testing and Finish

Considering the plow bottoms as the most vital part of the machine, and the part of the machine that most needed the use of engineering technique, it was thought advisable to study the dimensions of each part of the plow bottom to check the consistency and the accuracy in design. The difference in the dimensions of each member of the plow bottom with respect to another plow bottom was expected to have considerable effect on the working ability of each plow bottom and altogether on the efficiency of the entire plow. The same five bottoms were used with both the designs.

Visual observations were made regarding the finish of the plow bottoms in particular and the machine in general.

Finish and design of the plow bottom were considered to be one of the most important factors that determined the extent of useful forces acting on the plow bottoms. Visual observations were made regarding the finish and quality of nuts and other materials used for binding different members together.

Since the plow beams were the only part whose strength was found questionable, it was thought essential to ascertain its tensile strength in order to determine whether the strength of the beam will be enough to sustain the forces acting on it under normal conditions. It was also considered important to have an idea as to the maximum load that it could bear. The tensile strength for the beam was determined by the School of Engineering at AUB.

Maneuverability and Efficiency of Operation

Visual observations were made to determine the quality of work done, efficient use of power and efficient use of human labor. Observations also were made regarding the amount of lost time, which was reflected by the amount of control and adjustment of machine, amount of clogging, and the ease and quickness in hitching the machine. Turning radius of the machine which also had an effect on the amount of lost time was also determined. Ease of steering and comfort of ride were also observed to determine the extent of fatigue the operator had to undergo while working with the plows. Chances of accidents were also observed with both the designs. Stability and weight of the machine were considered from the maneuverability point of view.

Quality of Work Done

A comparative study was made regarding the smoothness of the plowed surface, size of the clods, turning under of the residue, and the uniformity of the depth of plowing. Visual observations were made and photographs were taken to show the comparative performance. In certain cases, for example, the clod size, data were taken to show the biggest size clods as mentioned before.

Repair and Maintenance

Observations were made regarding the probable parts that might need repairing during their life time. The study in particular investigated the possibility of adjustments to compensate for wear, easy replacement of worn out or broken parts, and the simplicity of construction of the machine.

IV. RESULTS AND DISCUSSION

Total Weights of the Plows

It was found that the weight of the original design was 550.00 lb (250.00 kg) compared to 457.60 lb (208.00 kg) weight of the new design. Therefore, a reduction of 92.40 lb (42.00 kg) was observed with the new design which considerably reduced the draft requirement of the new design. It is expected that the low weight of the new plow will reduce its price because the steel is sold by weight. The power requirement should also be reduced.

Draft Requirements

Each bottom of the "Arab plow" is similar to a double moldboard plow bottom with the moldboard placed back to back and the soil being thrown to both sides. The side components of the useful soil forces balance each other so that the resultant useful force lies in a vertical plane in the direction of travel.

The centre of draft of the whole set up, in the case of the old design, was approximately at the centre of the 3rd plow bottom in a vertical plane in the direction opposite of travel (Figure 13). The centre of draft,in the case of new design, was approximately in the middle

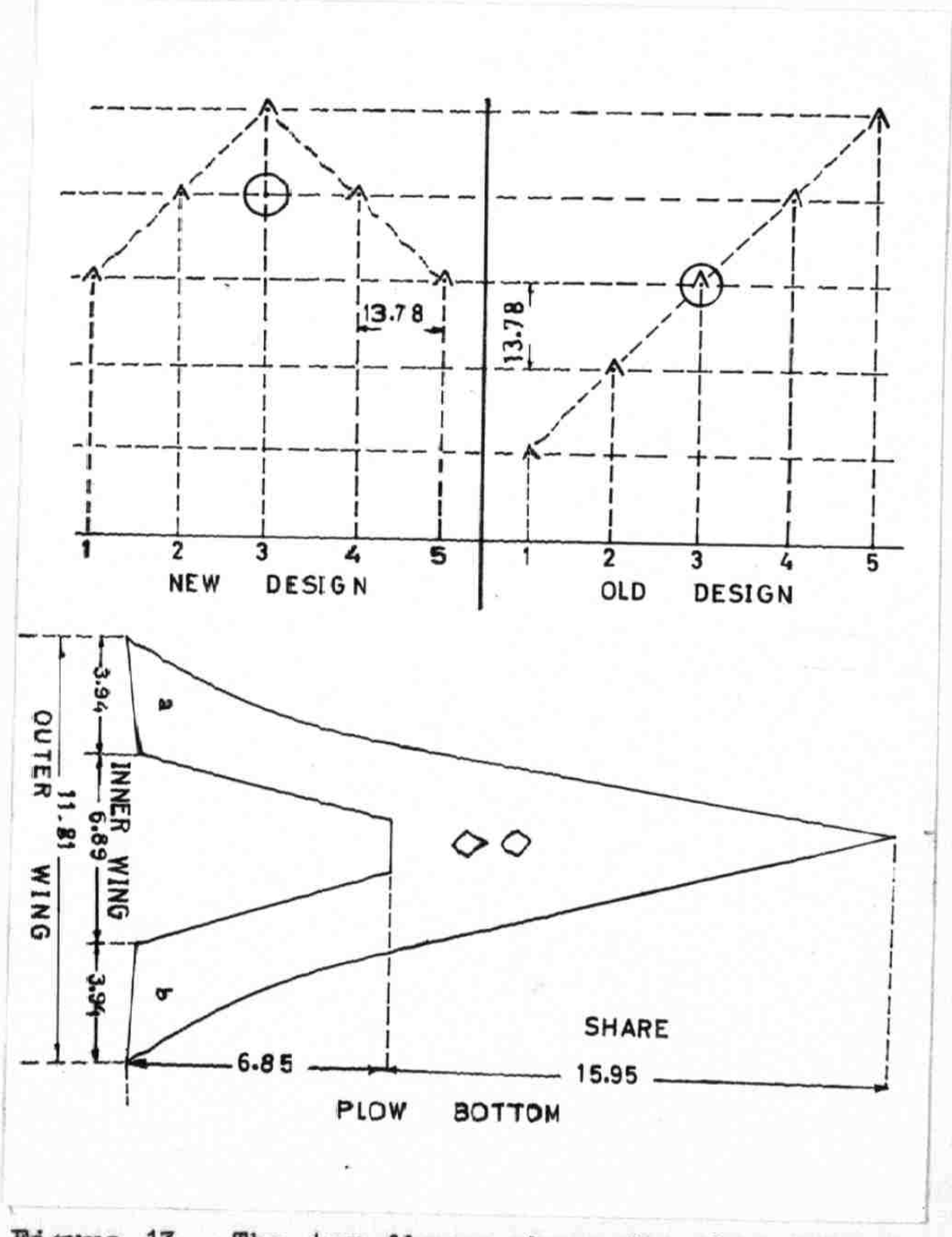


Figure 13. The top figure shows the plow bottom arrangement and the centre of draft (encircled) of the old and the new designs. The figure at the bottom shows the standard design of the plow bottom.

Note - The theoretical centre of draft in the new design is located 2.76 in behind the centre of the circle, in the old design at the exact centre of the circle.

between the middle two bottoms (2nd and 4th) right behind the centre bottom approximately 13.78 in from the centre bottom, and 13.78 in away from 2nd and 4th bottoms in a vertical plane in the direction opposite of travel. When used alone, the plow bottom with the longest beam (1st bottom with the old design) had more draft requirement than the rest of the bottoms, but the entire plow did not show any side draft during the experiment. Since a simple spring dynamometer could not give any indication of any side draft, it has been assumed that the centre of draft of the old design lies at the centre of the 3rd plow bottom in a vertical plane in the direction opposite of travel. It is possible that the tendency of the 1st bottom to plow deeper (due to its position being 27.56 in behind the centre of draft) was offset by the 5th bottom (its position being 27.56 in ahead of centre of draft) which tended to plow shallower. This phenomena was more evident when reduced numbers of bottoms were used to determine individual draft in later experiments.

The results from this experiment indicated that the average draft requirement was more for the old design at every speed tested (Table 1 and Figure 14). The draft requirements always increased with increase in speed of travel. This phenomena was observed with both the designs, but in the case of the new design the draft requirement dropped sharply at high speed. Telischi _et al_. (1956) found

Table 1. Average draft, horse power requirement and the capacity of machines at different speeds (maximum depth setting. Draft in pounds, capacity in acres per hour, and speed in miles per hour).

Speed	New design			Old design		
	Draft	Horse power	Capacity	Draft	Horse power	Capacity
1.00	1672	4.44	0.56	1903	5.08	0.56
1.25	1718	5.73	0.70	1984	6.62	0.70
1.50	1760	7.05	0.84	2048	8.23	0.84
1.75	1775	8.28	0.98	2130	9.98	0.98
2.00	1797	9.60	1.12	2160	11.54	1.12
2.25	1808	10.86	1.26	2196	13.15	1.26
2.50	1870	12.51	1.40	2253	15.02	1.40
2.75	1936	1424	1.53	2356	17.26	1.53
3.00	2066	16.56	1.67	2376	18.99	1.67
3.50	1960	18.34	1.95	2402	22.44	1.95
4.00	1881	20.05	2.23	2451	26.18	2.23

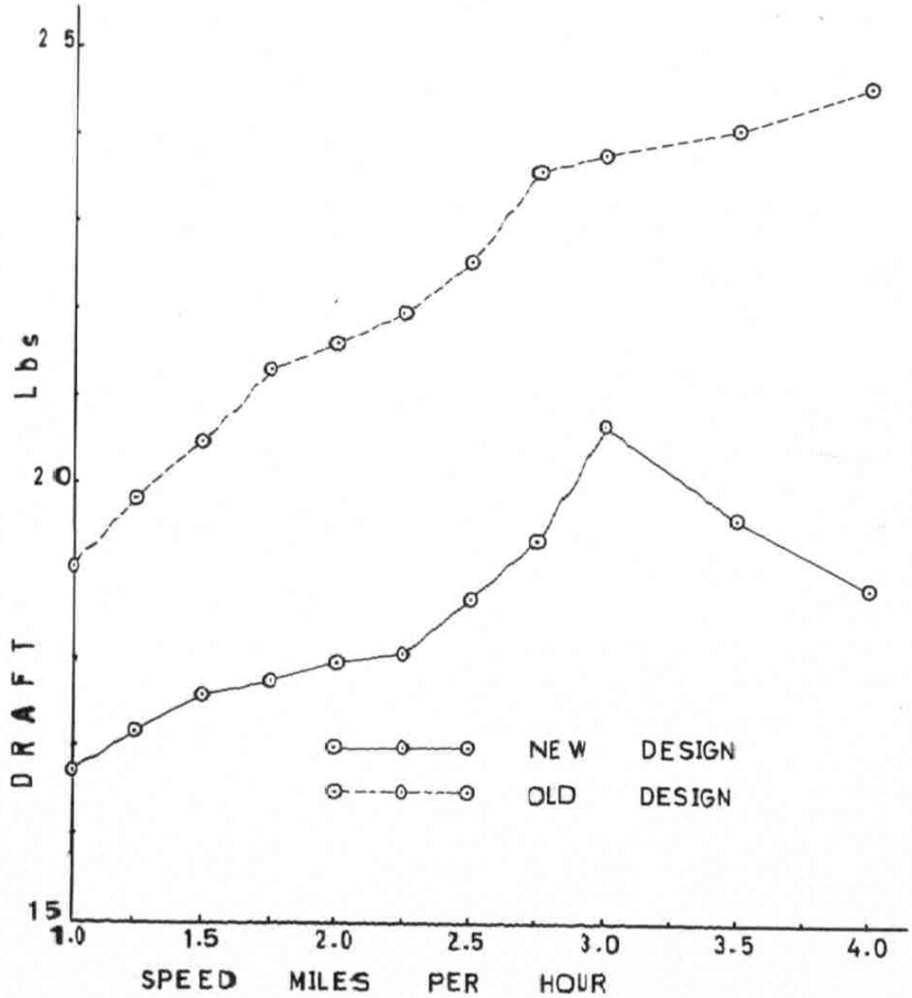


Figure 14. Draft in x100 lb at different speeds.

from field experiment that draft requirements increase with speed which agrees with the present findings, but they did not observe any decrease in draft at high speed.

In the case of the old design there was sharp increase of draft up to 2.75 mph, but after that the increase was steady and not so magnified. With the new design there was a sharp increase in draft from 2.25 mph to a maximum draft requirement at 3.00 mph after that a sudden drop took place in the draft requirement.

The reason for sudden drop in draft requirement with the new design was due to the inability of the plow bottoms to maintain the same depth at high speed; therefore, a decrease in draft requirement was accompanied with less depth of plowing. At these speeds (in excess of 3.00 mph) there was considerable working of the soil by the new design. The clods were found to be smaller than at any speed tested from 1.00 to 3.00 mph (Table 3).

With the old design, a decrease in the depth of plowing was observed after 2.75 mph speed, but no decrease in draft was observed, though the draft increase after 2.75 mph speed was low and increased steadily. There was no indication of smaller clod size at high speed.

More weight of the old design, compared to new design, was thought to be the major reason for its high draft requirement. The fact that the longest beam in the old design was relatively farther away from the centre of draft, with a tendency to dig deeper, could be another reason for its high draft requirement, but the shortest beam in the old design was relatively farther away from the centre of draft with a tendency to plow shallower. Therefore, the effect of longest beam plow bottom to go deeper was counteracted by the shortest beam plow bottom. The overall depth of plowing with the old design did not exceed the new design, but it seemed that extra energy was consumed by the unequal weight and draft distribution in the old design.

The maximum distance between the centre of draft and the plow bottoms was with the 1st and 5th bottoms and was 27.56 in (70.00 cm) in the old design, compared to 13.78 in (35.00 cm) with the new design. Therefore, relatively lower weight and even distribution of weight and draft were the main reasons for the lower draft requirement with the new design.

Relatively drier soil on the day of test of the old design was another probable reason for high draft requirement of the old design, but the difference in moisture content of the soil, between the old and new design test which took place on two different dates due to dynamometer breakdown was very little (17.07% for new design and 16.22% for old) and though it may have contributed to the higher draft of the old design it was apparently not a major factor for such increase. It is uncertain as to how much the drier soil contributed to a higher draft of the old design. Telischi *et al*. (1956) found that increase in moisture content increases the draft and this draft increase becomes constant at a moisture content above wilting point in a soil low in clay content, but in a soil high in clay content (22.50% or more) the increase in moisture caused increased draft.

Unlike the deductions made by the above experimentor, it is suspected that the soil of the test plots, which is calcareous and high in clay percent, with less moisture content might have caused added draft to the old design. This could have been possible due to the baking and drying of the soil. Because of many variables involved it was difficult to ascertain the theoretically possible increase in draft with a 0.85% decrease in soil moisture, but whatever the increase in draft it was certainly very little compared to the total average draft of both the designs.

Depth and Ridge Widths

The plow bottoms were found to act as a wedge splitting the surrounding soil in half and pushing it sideways and upwards to form a passage for itself. The soil so treated was isolated from the bulk of the land along an inclined surface of slip which rose from the bottom of the wedge and emerged at ground level to form a V shaped crack surrounding the plow bottom. In the test plots the soils showed a V shaped upheaval on the surface and the two halves appeared to move in opposite directions, but the cracks and exact delineation of the zone were masked by the clods and pulverized soil which had to be removed for measuring depth of plowing and width of ridges.

The results(Table 2 and Figure 15) indicated that there was a slight increase in depth of plowing from 1.00 to 1.50 mph speed with both the designs but the increase was more pronounced with the old design. From 1.50 mph to 3.00 mph speed of travel there was no definite trend of increase or decrease in depth of plowing of the new design (with one maximum depth setting) but above 3.00 mph the depth of plowing decreased greatly. With the old design there was no definite trend of increase or decrease in the depth of plowing from 1.50 to 2.75 mph and then a sudden drop in the depth from 2.75 to 3.00 mph after which the trend was indefinite.

The decrease in the depth of plowing of the new design was due to the inability of the plow bottoms to penetrate the ground at high speed. Similar phenomena was shown with the old design but it was not so distinct. It appears that the relatively longer beams of the 1st and 2nd bottoms of the old design were able to penetrate the ground even at high speed when the new design showed less ability to do so. It is expected that at even higher speeds the old design also might show a distinct drop in the depth of plowing. The weight of the old design was another factor that kept the depth of plowing at high speed, greater than

Table 2. Average depth of plowing and top width of ridges at different speeds (maximum depth setting. Depth and ridge width in inches and speed in miles per hour).

Speed	New design		Old design	
	Depth	Ridge	Depth	Ridge
1.00	4.13	6.26	3.76	6.93
1.25	4.16	6.20	3.84	6.85
1.50	4.18	6.17	4.05	6.42
1.75	4.15	6.22	4.06	6.39
2.00	4.13	6.26	4.04	6.43
2.25	4.19	6.15	4.04	6.43
2.50	4.18	6.16	4.06	6.40
2.75	4.07	6.36	4.02	6.47
3.00	4.02	6.48	3.73	6.99
3.50	3.44	7.52	3.69	7.06
4.00	3.21	7.94	3.73	6.99

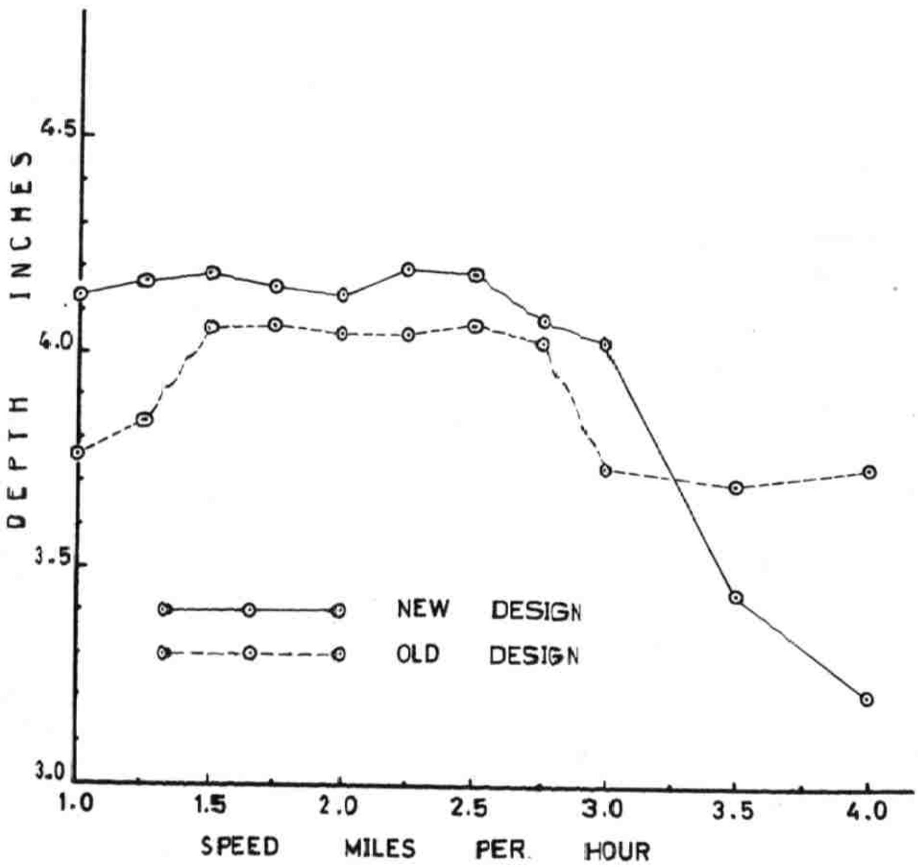


Figure 15. Depth of plowing at different speeds.

the new design. This indicates that weight was an important factor for achieving a certain depth with such machines.

With the new design, decrease in depth of plowing was accompanied with extreme working of soil, but such extreme working of soil was not observed with the old design.

At very high speed of 3.50 and 4.00 mph no wheel slippage of the tractor occurred while pulling the new design, but with the old design the wheel slippage and tractor bogdowns were frequent (Table 5).

As shown in Figure 16, it was found that the top width of ridges was inversely proportional to the depth of plowing. There was no definite trend in the increase or decrease of the width of the ridges, but in the case of the new design the ridge width increased greatly at high speed. This was due to the sharp decrease in the depth of plowing of the new design at high speeds and the increased pulverization of the soil. Several days after the test it was found that the plants were still growing on the ridges of the test plots of both the designs, but this effect was more prominent on the test plots of the old design than of those when the new design was tested.

It is suspected that besides the greater depth of plowing with the new design its symmetrical arrangements of plow bottoms could be another reason for less ridge width.

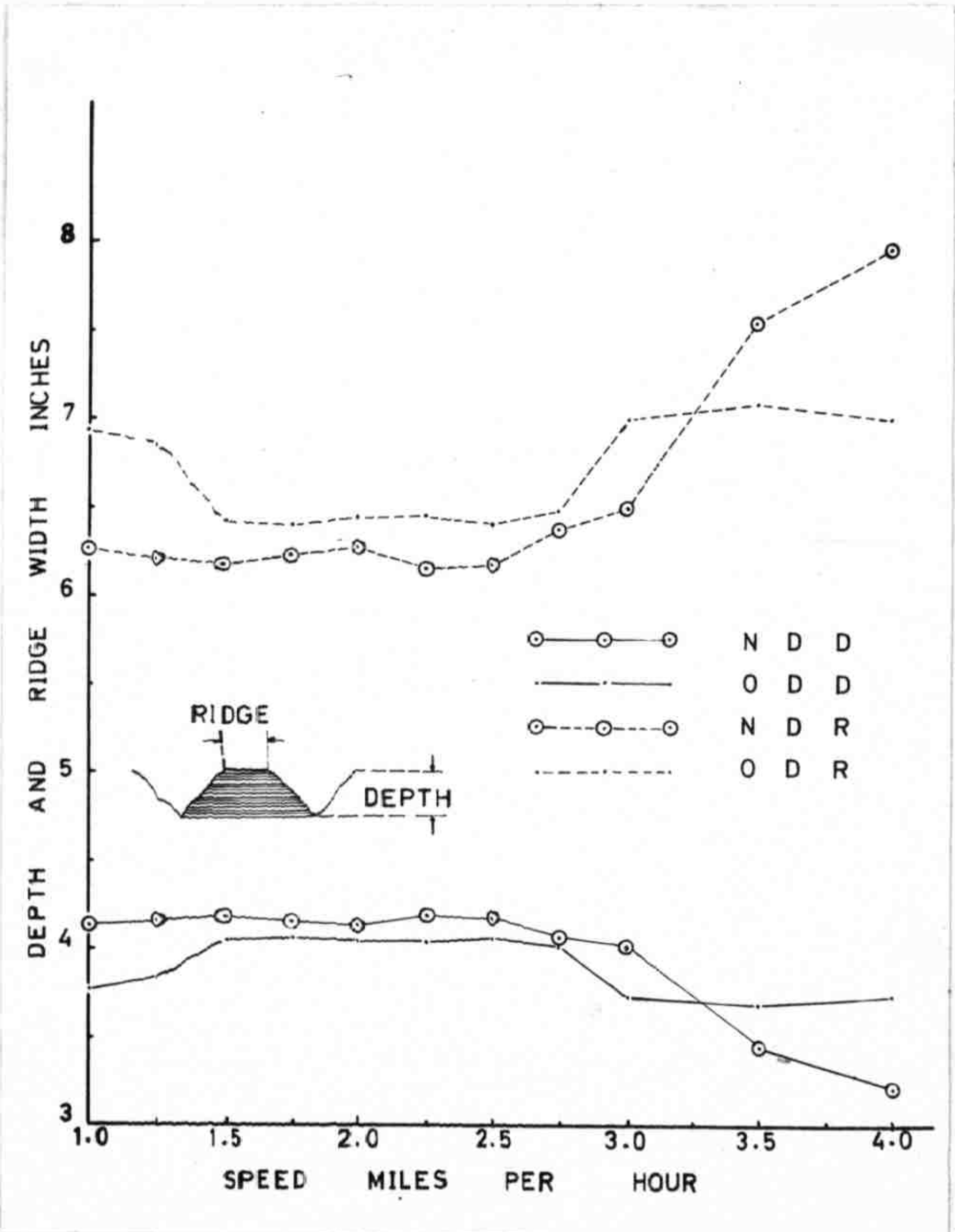


Figure 16. Depth of plowing and the ridge width at different speeds. (N D D = new design depth; O D D = old design depth; N D R = new design ridge width; and O D R = old design ridge width. Inset shows the depth of plowing and the top width of the ridges).

It is expected that with deeper plowing depth the ridge effect will be reduced to very narrow and small ridges, but whatever the depth of plowing the ridges always will be formed, and it is mainly for this effect that more than one plowing and cross-plowing would be necessary to do a satisfactory job of seedbed preparation with either design.

The general custom in the Bekaa valley is to have three to four plowings and cross-plowings for spring seedbed preparation. In the fall the soil is hard and dry and in the spring the soil is moist and wet. Therefore, pre-irrigation on hard and dry soil or plowing the land when it is neither sticky nor cemented will greatly reduce the need for additional plowings. In a plastic soil the friable stage is the optimum condition for tillage with the "Arab plows". While working in friable soil condition, in the same test plot a few days after a heavy shower, the depth of plowing was found to be 6 to 7 in, both with the old and the new designs and the ridge effect was extremely reduced. This test was conducted outside the scope of the main experiments to observe the action of the plows in moist friable soil.

Clod Size

The land plowed with the "Arab plow" was left in a very rough and furrowed condition full of clods of varying sizes because the soil upheaval took place due to the wedge action of the plow bottoms which cracked and pulled the soil upwards.

Since the plow bottoms were the only member of the plow which were were directly responsible for soil upheaval, and since the same plow bottoms were used with both the designs, not much difference in the cloddiness of the test plots of the two designs was expected. Still the clod sizes were measured at all the speed tested with both the designs to determine the cloddiness of the field and the effect of speed and depth on the clod size.

A very careful observation in the field indicated that the longest side of the clods was always parallel to the direction of travel of the plow bottom. At those plots where relatively bigger clods were pulled out the ridge effect was greatly reduced. The mean diameter shown in Table 3 is an average of the three sides of the clods, one side of which could be more than 1 ft but the other two sides in most cases were relatively small enough to bring the mean diameter to a small value. It was for this reason that the numbers of clods were not always in the increasing order with the decrease in their mean diameter.

The results from this test indicates that the mean diameter of clod size and their total number reduced greatly at high speed with the new design (Table 3). This was due to the extreme working of the soil by the new design at high speed. No such effect was observed with the old design.

Table 3. Seven biggest clod sizes at different speeds (clod mean diameter in inches and speed in miles per hour. N = number of clods; D = mean diameter of clods).

New design					
1.00 mph		1.25 mph		1.50 mph	
N	D	N	D	N	D
2	6.11	1	8.74	6	7.69
10	5.18	4	8.08	8	7.17
2	4.79	6	7.95	9	6.10
20	4.13	9	7.29	15	4.28
12	3.74	2	5.98	8	4.14
20	3.70	14	4.80	18	3.74
25	3.48	15	4.14	30	2.97
1.75 mph		2.00 mph		2.25 mph	
N	D	N	D	N	D
1	8.34	1	9.78	3	6.12
2	7.81	2	9.25	5	5.20
1	7.68	1	7.81	4	4.81
1	5.58	1	7.55	8	4.77
1	5.45	2	7.02	10	4.15
5	4.93	6	6.76	10	4.02
8	4.40	4	6.23	15	3.50
2.50 mph		2.75 mph		3.00 mph	
N	D	N	D	N	D
10	7.30	2	7.92	6	6.33
5	7.17	3	7.53	6	5.67
3	5.99	1	7.26	8	5.01
8	5.72	2	6.48	9	4.88
6	5.20	5	6.21	10	4.09
5	4.68	4	5.56	15	3.70
10	3.89	5	4.64	19	3.44
3.50 mph		4.00 mph			
N	D	N	D		
2	5.35	4	4.74		
1	5.48	5	4.61		
2	5.22	8	3.83		
5	5.08	10	3.69		
1	4.69	7	3.56		
7	4.16	15	3.43		
10	3.51	19	3.39		

Table 3 (Continued).

Old design					
1.00 mph		1.25 mph		1.50 mph	
N	D	N	D	N	D
1	8.08	2	7.06	1	8.96
3	5.98	4	6.27	1	8.44
3	5.72	10	5.22	2	7.52
3	5.19	5	5.09	4	7.26
4	4.80	15	4.17	5	5.81
4	4.67	25	3.78	8	5.15
6	3.75	20	3.64	10	4.24
1.75 mph		2.00 mph		2.25 mph	
N	D	N	D	N	D
1	9.62	1	10.00	1	8.30
3	7.00	5	7.25	2	7.65
3	6.47	10	5.68	2	6.99
5	6.34	10	4.63	2	6.46
6	6.08	10	4.37	5	5.80
8	5.42	15	4.23	7	5.15
6	4.90	21	3.84	7	4.76
2.50 mph		2.75 mph		3.00 mph	
N	D	N	D	N	D
1	8.44	2	9.48	1	10.43
3	7.52	2	8.43	2	7.94
3	6.07	2	7.90	3	7.15
5	5.42	5	5.67	9	6.62
10	5.03	5	5.40	3	6.36
20	4.76	3	4.75	5	6.10
8	4.37	10	4.62	13	5.05
3.50 mph		4.00 mph			
N	D	N	D		
5	7.53	1	9.64		
7	7.27	1	9.38		
4	6.61	4	8.47		
6	6.22	2	8.33		
8	6.09	3	7.67		
11	5.56	1	7.41		
12	5.43	3	6.36		

Instead tractor bogdowns were very frequent even at high speed, a factor which resulted in extremely big clods at the place of bogdowns.

Payne (1956), while working with a rectangular flat plate tine, also observed that the soil adjacent to the tine was more broken up at higher speeds. This observation agrees with the action of the new design of the "Arab plow" at higher speeds.

It was observed that the clod size was very much affected by the topography of the land. Wherever the plow bottoms could catch the soil, they pulled bigger clods at any speed with both the designs except with the new designs at very high speeds. It was frequently observed that while few bottoms of the plows were digging deeper and bringing up large clods the remaining bottoms at the same spot were found barely scraping the ground. This was more evident with the old design because of its longest and shortest plow bottoms being located much farther away from each other. Unlike the old design the new design was more compact. A very distinct effect of this compactness was its increased response to tractor's speed of travel with a result that at high speeds it did not get the opportunity to dig deep and encounter any bogdowns which would have put the plow beams under extreme load. Such load may cause the breakage and twisting of the beams. The beams of the old design were found to have undergone heavier loads than the beams of the new design (Table 5). Higher weight of the old design was the main reason for its occasional deep penetration and bogdowns. Also a quick response to tractor steering was not observed at very high speed because of its higher weight and its 1st and 2nd bottoms being located too far behind the main frame to respond quickly. Probably it was at very high speed that the bottoms with longer beams played a very distinct role of catching the ground with the result that the entire plow kept nearer to the normal depth of plowing and underwent the usual bogdowns (as at lower speeds) depending on the topography. No distortion or breakage of the beams were observed with either design throughout the test.

The soil moisture content was less on the test day of the old design, a factor which resulted in relatively less average depth of plowing, but it is suspected that with a little more soil moisture (as on the day of the new design test) the plow would have dug even deeper which would have resulted in the same or more frequent bogdowns.

On many occasions it was observed that clods were extracted from a deeper depth than the depth at which the plow bottom was working. For example, if the plow bottom was working 4 in deep, the clods occasionally were pulled from a 6 in depth. This phenomena was easily observed, because the mark of plow share could be seen distinctly on the side of the clods at 4 in depth. This happened especially at the places of bogdowns and was more frequent with the old design.

Draft and Performance of Reduced Numbers of Plow Bottoms

The results from the draft test indicated that as the number of bottoms were decreased the depth of plowing and clod size increased as did the unit drafts. In the case of the old design (Table 4) the draft requirement of four bottoms (1st, 2nd, 4th, and 5th) was found to be 1650.00 lb compared to 1903.00 lb draft of the plow with five bottoms giving a very low value of draft for the 3rd bottom. The draft of three bottoms (1st, 2nd, and 5th) was a little less than the previously tested four bottoms showing an extremely low draft for 5th bottom as 84.00 lb. The draft of the 1st and 5th bottoms was more than the previously tested three and four bottoms; and the draft of the 1st bottom was more than the draft of three bottoms (1st, 2nd, and 5th) and two bottoms (1st and 5th). The draft of the 5th bottom was found to be 1008.00 lb when tested alone.

In the case of the new design similar results of increased draft and clod size were observed with the reduced number of plow bottoms.

It is evident that the method of evaluating individual drafts by removing plow bottoms was a failure, because with the reduced number of bottoms the draft increased. The result was that the draft value of that particular plow

Table 4. Draft of reduced bottoms at maximum depth setting and 2.50 mph speed.

Number of bottoms	Draft, lb
New design	
Five bottoms (1st, 2nd, 3rd, 4th, and 5th)	1672
Four bottoms (1st, 2nd, 4th, and 5th)	1467
Three bottoms (1st, 3rd, and 5th)	1632
Two bottoms (1st and 5th)	1364
One bottom (1st alone)	1188
One bottom (3rd alone)	836
Old design	
Five bottoms (1st, 2nd, 3rd, 4th, and 5th)	1903
Four bottoms (1st, 2nd, 4th, and 5th)	1650
Three bottoms (1st, 2nd, and 5th)	1566
Two bottoms (1st and 5th)	1716
One bottom (1st alone)	1771
One bottom (5th alone)	1008

bottom in question (which can be obtained by reducing draft of four, three, two, or one bottom from the preceding one) was found either extremely low or below zero. It was expected that the draft of each bottom would be approximately one fifth of the total draft; but the data indicated sharply different values.

In the case of the old design it was found that the draft requirement of the 1st bottom (with longest beam) was much more than the 5th bottom (with shortest beam). The results showed an average draft for the 1st bottom to be 1771.00 lb compared to 1008.00 lb for the 5th bottom. The depth of plowing and clod sizes with the 1st bottom were more than the 5th bottom. When the 1st and 5th bottoms were tested together, the 1st bottom plowed 1 in deeper than the 5th bottom and the clods were proportionately larger, but the average depth of plowing of the two bottoms and the average clod sizes were smaller than those observed with the 1st bottom alone. Another observation made with this test was that bogdowns and wheel slippage were found common with five bottoms together, then this feature reduced gradually with the decrease in plow bottom up to the point where three bottoms were used, but with two bottoms (1st and 5th) and one bottom (either 1st or 5th) no bogdown or wheel slippage was observed although the draft of 1st and 5th bottoms were more than four or three bottoms used together. It was also observed that the depth of clods was very frequently more than the depth at which the plow bottom was working. This phenomena could be explained from the fact that the soil was very dry and the wedge action of the plow bottoms dug the clods from a deeper region than the real depth at which they were working. It was observed that with fewer bottoms the depth of plowing was much more uniform compared to five bottoms together. This phenomena was more pronounced when 1st or 5th bottom worked alone; and the combination of 1st and 5th bottoms was not as good as each of them alone, but still the uniformity was more than the five bottoms together. The five bottoms together did not work at uniform depth.

It is suspected that greater leverage provided by the longer beams (their bolted point being farther away from the plow bottom) could be a big reason for their distortion and breakage after the impact with a buried rock or other obstruction in the soil. One of the main advantages of the new design is that the beams were reduced in length and the longest beam of the new design was found to be 27.56 in (70.00 cm) shorter than the longest beam of the old design. Another apparent effect of this reduction in beam length was that the difference between the drafts of the longest and the shortest beam plow bottom was narrowed in the new design (Table 4). No apparent side draft was observed (the attempt to find the side draft failed because of the inability of evaluating the draft of individual bottom while all the five bottoms worked together). It is suspected that, if any side draft did exist with the old design, it certainly was reduced to a minimum in the new design with its shorter beams, symmetrical design, and the equal distribution of weight and draft.

Maximum Draft, Wheel Slippage and Bogdowns

The results (Table 5) indicate that the maximum draft encountered by the old design was more than new design at all speeds tested. In the case of the new design there was no definite correlation between the requirement of maximum draft and speed. In the case of the old design, though not very pronounced, there was a relationship between maximum draft encountered by the plow and speed. The topography of the field and variation of soil characteristic from place to place may have accounted for other inconsistencies. The occurrence of wheel slippage was irregular but unlike the old design at speeds of 3.50 mph and 4.00 mph there was no wheel slippage with the new design. There were no bogdowns with the new design.

In the case of the old design, wheel slippage was always followed by bogdowns, but there was no definite trend in the increase or decrease of bogdowns with increase in speed. The reasons for the indefinite wheel slippage and bogdowns were the same as those that governed the maximum draft requirements (Figure 17).

Table 5. Maximum draft, bogdowns, and wheel slippage at different speeds* (maximum depth setting).

Speed (mph)	New design			Old design	
	Maximum draft (lb)	Drive wheel slippage		Maximum draft (lb)	No. of bog-downs
		No. of wheel turns	% Slip		
1.00	2600	0	0	3300	0
1.25	3300	4	40.94	3960	4
1.50	3300	0	0	5500	4
1.75	3080	2	20.47	5060	5
2.00	2860	1	10.24	5940	3
2.25	2860	0	0	5500	4
2.50	3300	1	10.24	6600	3
2.75	3520	2	20.47	5720	2
3.00	3300	1	10.24	6600	2
3.50	3300	0	0	6160	3
4.00	2860	0	0	6600	4

* See Appendix B.

Figure 17. A spot where bogdown took place with the old design.

Rate of Work, Draft, Power, and Speed Relationship

It was found that the horse power requirement for the old design was greater at all speed tested (Figure 18). This was because of the fact that horse power is directly proportional to draft requirement which was more for the old design at all speeds tested. The increase in the horse power requirements was fairly constant with both the designs. Although the draft requirement with the new design decreased at high speed (after 3.00 mph), the horse power requirement still increased but the slope of the curve was gentler than the slope of the curve up to 3.00 mph.

The tests indicated that the rate of work for the new design in acres per hour was more than the old design at any particular horse power requirement (Figure 19). At speeds above 3.00 mph, the increase in the rate of work of the new design, with a unit increase in the horse power, was more than the old design.

It was found that the draft requirement at any particular rate of work was more for the old design (Figure 20). Although at high speed the draft requirement of the new design dropped, the rate of work per hour still kept increasing. Higher draft and power requirements for any rate of work with the old design were caused by its greater weight, uneven distribution of weight and draft, and relatively drier soil.

It is thought that more work can be performed per day by the new design. Rate of work of the new design was found to be increasing with the increase in speed (Figure 21). The same rate of work with increasing speed was assumed for the old design also, but it is highly probable that the percentage of lost time for the old design will be more than the new design because of its greater weight, bigger turning radius, and more wheel slippage and bogdowns. The relative increased response of the new design to tractor steering, was another factor which might reduce its percent of lost time. Because of the variety of problems involved, no accurate attempt was made, but some visual observations

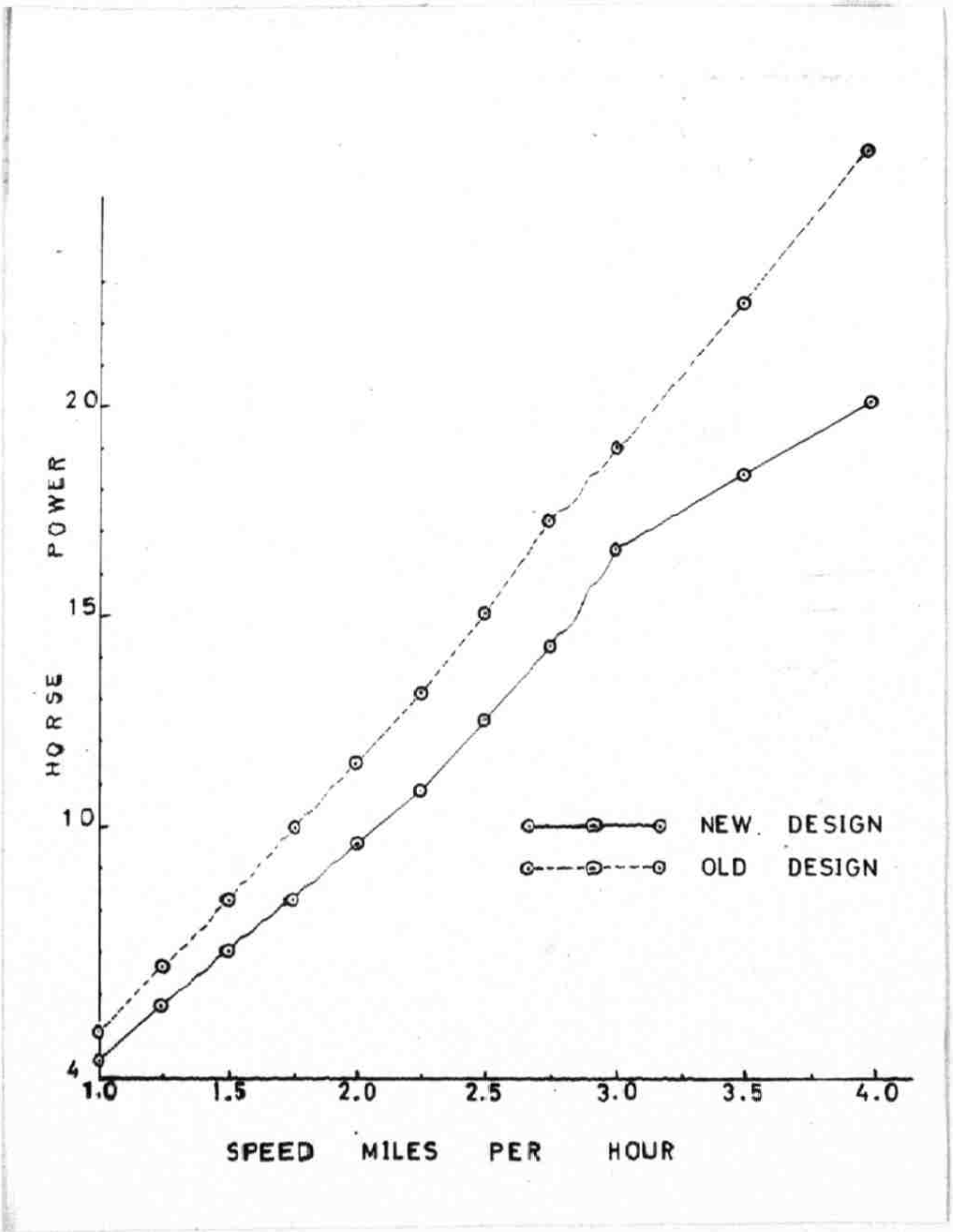


Figure 18. Horse power requirement at different speeds.

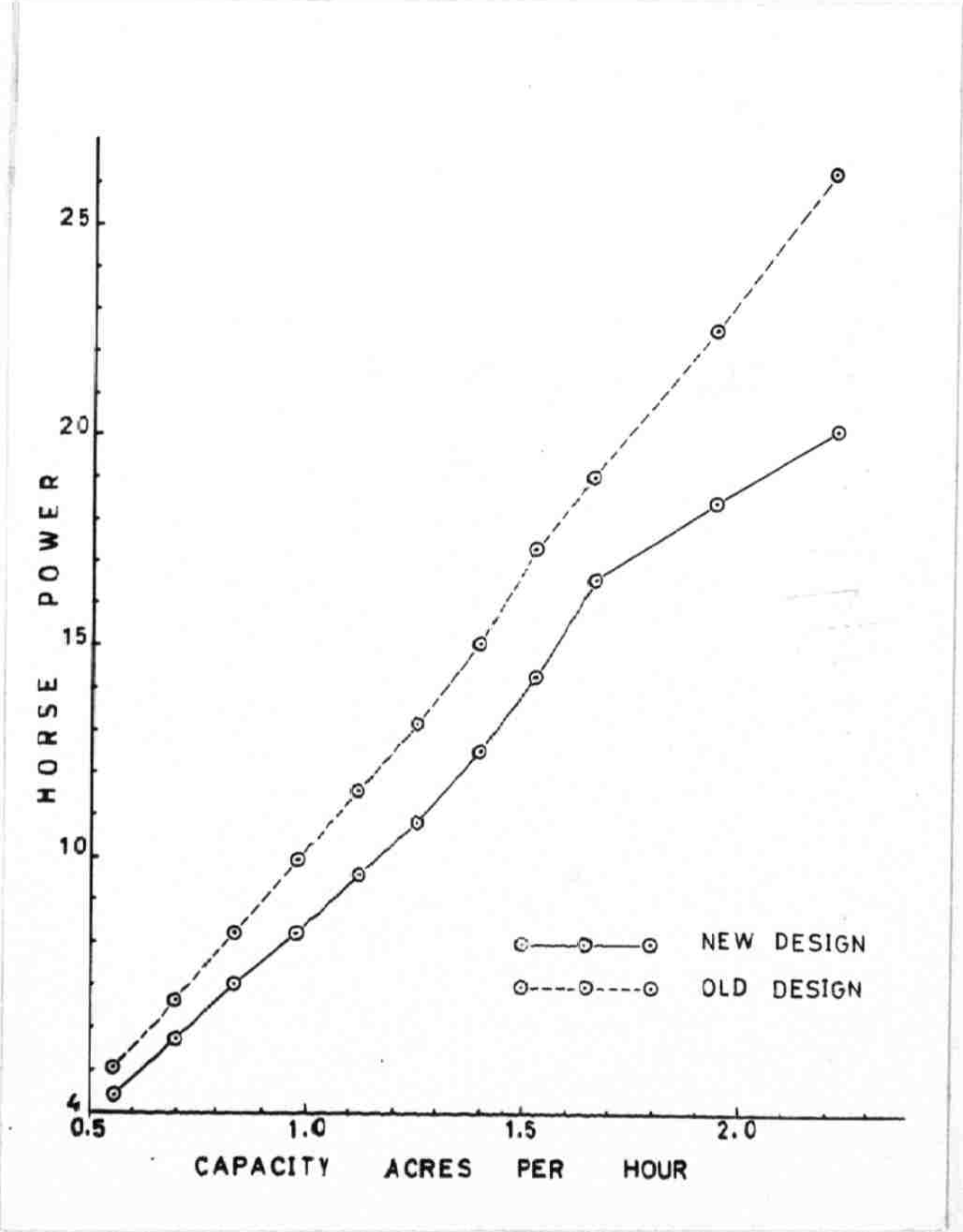


Figure 19. Horse power requirement and the capacity of the machines.

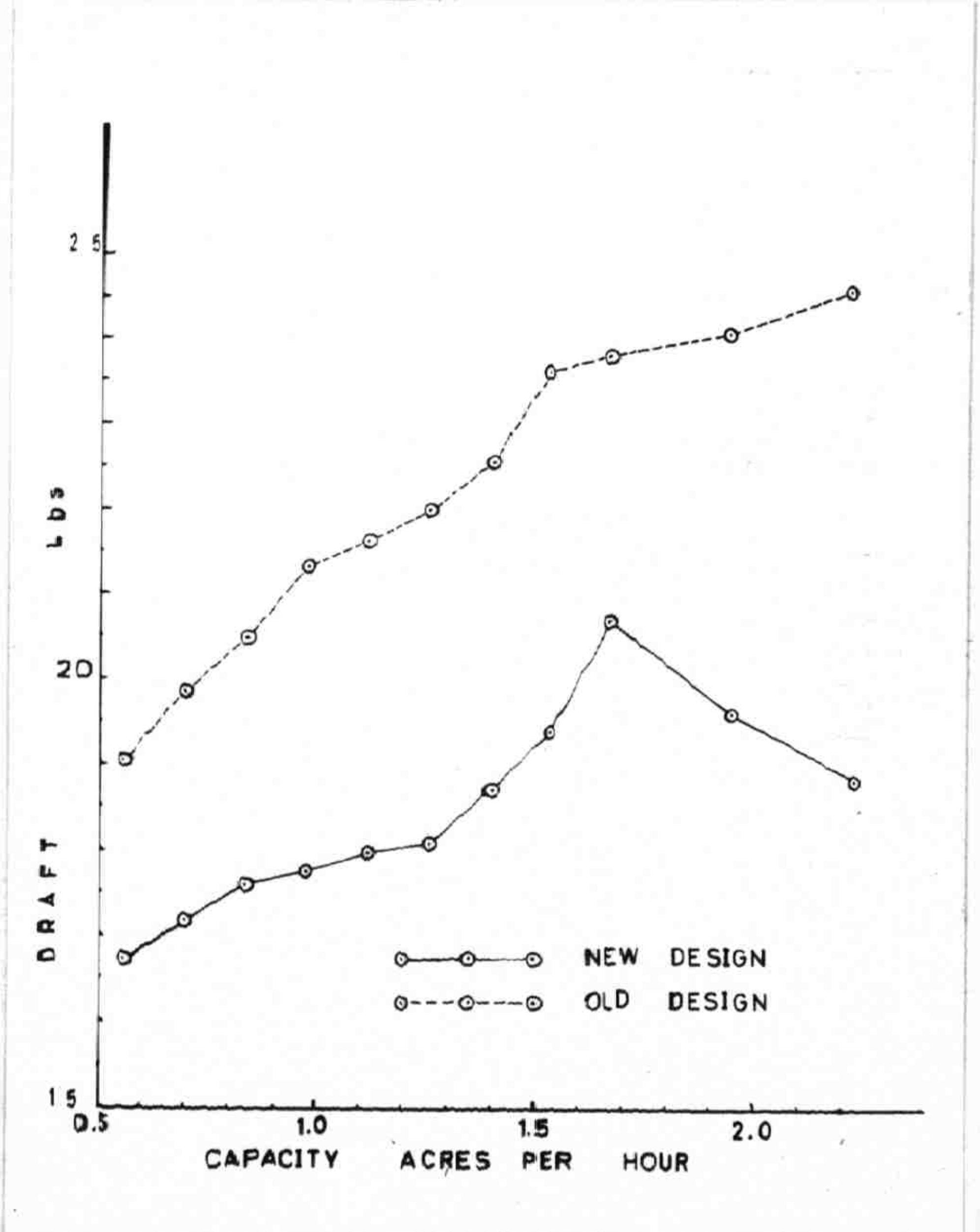


Figure 20. Draft requirement and the capacity of the machines (draft in 100 lb).

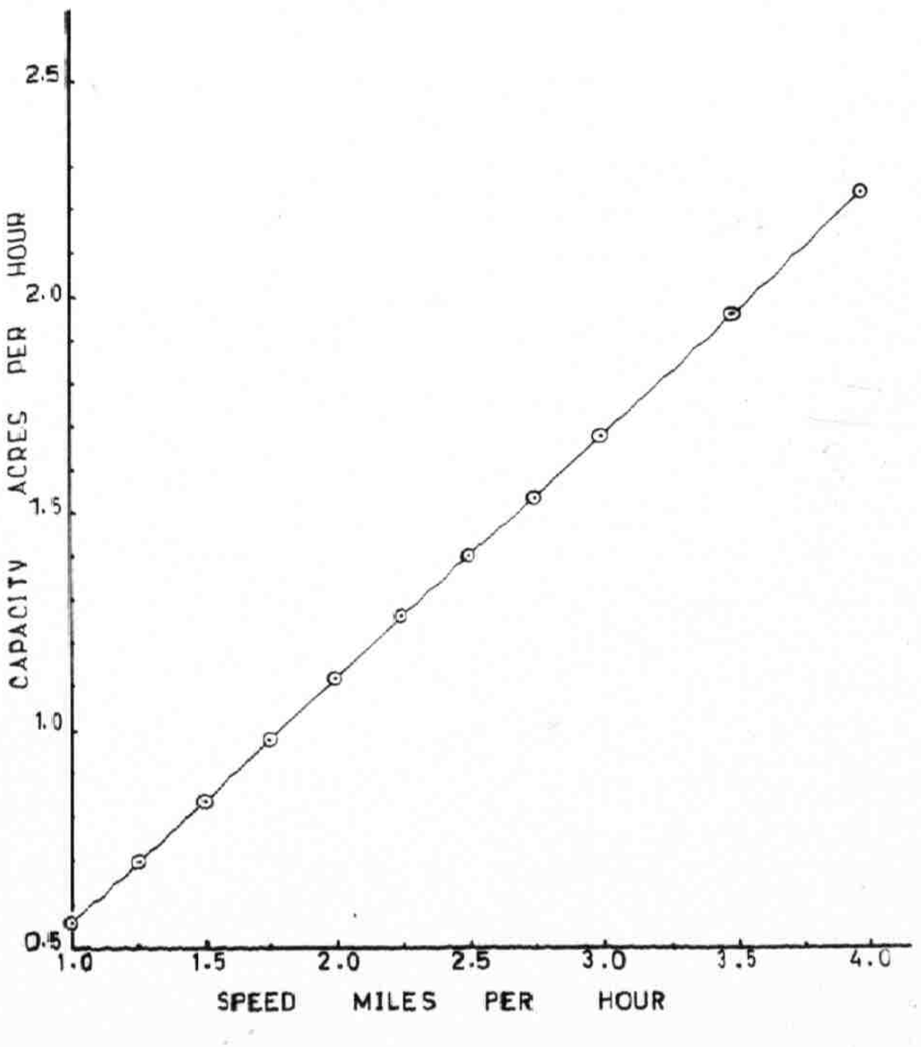


Figure 21. Capacity of machine at different speeds.

were made regarding a few factors which could affect the percent of lost time.

For the sake of comparison and in the absence of any definite evaluation of percentage of lost time for either of the designs, it was found necessary to assume that the rate of work of both the designs was the same. Therefore, the figure showing capacity of machine at different speeds should be taken for both the designs until further investigations are done in this line.

Miscellaneous Tests

Gage Wheel Test

The gage wheel attachment to the old design did not give any positive results. It was found that whenever an attempt was made to control the depth of plowing, the 1st and 2nd bottoms were either floating or barely scraping the ground. When the gage wheel was adjusted to let the 1st and 2nd bottoms plow at proper depth, it was found to be hanging above the ground. It is suspected that the effect of the uneveness of ground on the action of plow bottoms was magnified in the presence of gage wheel. It is very difficult to understand the exact role of gage wheel with the old design, unless specific study is done on this aspect. It is suspected that the location of the gage wheel, in the middle of the left side of the main frame (Figure 12), was not the proper place for it.

Stubble Mulch and Weed Control

While working in a field of wheat stubble of 6 to 12 inch length, it was found that the depth of plowing went on decreasing slowly as the stubble kept collecting under the plow beams and above the plow bottoms, until the extreme wheel slippage occurred and ultimately the tractor bogged down. The depth of plowing decreased from 6 in in the beginning of the field to 2 in after around 100 ft of run. This phenomena was observed with both the designs. In the case of the old design the 1st bottom collected the least and the 5th bottom the most straw (Figure 22). In the new design the outer bottoms collected less straw than the rest. Intercultivation of orchard, where heavy brush like weeds of 15 to 20 inch size were growing, showed similar results as observed in stubble mulch plowing with both the designs (Figure 23).

Another test was carried out in a field of loose and moist soil full of Johnson grass of 8 to 10 in average height. Both the designs gave a satisfactory performance of weed control, but a very significant phenomenon was observed with the new design. The new design was found to form a mound in the middle over the furrow opened by the middle bottom. This mound was formed because unlike the old design there were two bottoms in the new design which threw soil towards the centre bottom. The 2nd and 4th bottoms following the 3rd bottom threw soils in the furrow opened by

Figure 22. Old design plowing a field with wheat stubble mulch.

Figure 23. Intercultivation of orchard with the new design.

the 3rd bottom and formed a mound. In the case of old design no two bottoms threw soil in one single furrow and so no such effect was observed.

Plowing Sloping Land

On a grade of about 15° to 20° it was found that both the designs were swung towards down the slope in lifted condition. In lowered condition the old design was still found to be swung towards down slope but not as much as it was in lifted condition. This effect was more pronounced when the left side (the heavier side) of the old design was towards the down slope. The apparent result was that it was difficult to start straight furrows or follow the already opened furrow especially in the beginning of the field, but after a few feet of travel from the beginning of the field this defect used to disappear with the new design and greatly minimized with the old design. Because of the more weight on the left of the old design even on horizontal ground a left swing in the lifted condition was evident. The use of stabilizers gave very favorable results with no more swings on the slope and it was possible to start or follow straight furrows. The left swing of the old design also disappeared by the use of stabilizers.

Accuracy of Design, Finish, and Strength of Material

Analysis of individual plow bottom dimensions showed that there was much variation in the dimension of similar members of the five bottoms (Figure 13 and Table 6). The distance between the inner and outer wings determined the curvature of the plow wings or moldboards of the plow bottoms. Theoretically, a difference in curvature should make a difference in the resistance of the soil passing over the moldboard, but no visible difference was observed due to difference in wing curvature. Much more specific studies under ideal conditions will have to be made to find the effect of difference in curvature. The "a" and "b" wing widths varied with each bottom and from bottom to bottom. Share lengths were also found to be different. No apparent effects of these variations were observed, but it is essential that the dimensions should be consistent in order to get uniform action on the soil and increased efficiency of the plow. The finish of the plow bottom was very crude and unsatisfactory. One of the short wings of a plow bottom was made to the approximate size of the other wings by welding an extra piece of metal to the bottom. The welding was crude and was rough enough to cause extra resistance to the soil. The plow bolts and nuts were made of relatively soft metal with the result that the threads of some of the bolts and nuts were broken after five or six times of loosening and tightening. The heads of the plow bolts were found sticking above the surface of the plow bottom thus causing extra resistance to the soil (Figure 24). The normal practice of making a countersink on the bottoms, so

Table 6. Accuracy in design dimensions of plow bottoms compared* (in inches).

Items	1st bottom	2nd bottom	3rd bottom	4th bottom	5th bottom	Standard design
Outer wings size	12.01	12.20	11.93	11.73	11.30	11.81
Inner wings size	6.89	7.09	6.69	7.09	6.30	6.89
Wing width	a 3.98 b 3.58	a 4.06 b 3.94	a 3.74 b 3.94	a 3.39 b 3.86	a 3.78 b 4.06	3.94
Share length	15.91	16.14	16.06	16.14	16.06	15.95

* See Figure 13 on page 46.

Figure 24. Plow bottom showing plow bolt fitting without countersink

that the bolt head is flush with the bottom surface, was not followed. Because of the roughness of the plow bottom surface it did not scour well. It is suspected that the crude finish of the plow bottom must have increased the amount of useful forces acting on them. The clamps used for fitting the beams with the main frame were not accurately made and consequently only few of those were fitting properly, and the bolts going through some of them were curved causing an unnecessary load on its threads, a factor which will reduce the life of the bolts.

Beam Strength and Safe Load

The tensile strength test of the beam metal gave the following results:

Yield point	=	49882.00 psi
Breaking point	=	113028.00 psi
Ultimate point	=	115375.00 psi
Elongation	=	17.9%

According to "ASTM" a metal of the above tensile strength is called a "Hard Grade Steel" or carbon steel which has 0.6 to 0.7% of carbon. It is a very brittle steel because of the fact that it has a high "yield point" value and that there is little difference between the breaking and ultimate point values.

The strength of the beam of the "Arab plow" whose cross-section is 3.086 sq in will be:

Yield point	=	153,936.00 lb load
Breaking point	=	348,804.00 lb load
Ultimate point	=	356,047.00 lb load

For machinery design purpose the load at the yield point is considered to be the maximum limit of the safe load, because after the yield point there is elongation of the metal and a reduction in the cross-section. If the stress and elongation are plotted on a graph, it will be found that elongation increases slowly with the increase in stress up to the yield point and then there is a sharp increase in the elongation with the increase in stress. The metal can come back to its former shape after elongation up to the yield point, but after that it cannot because it is strained beyond elastic limit. Therefore, yield point load is taken to be the maximum load capacity of the beam.

From the high tensile strength of the beams it appears that the maximum draft encountered by either design was much lower than the load capacity of the beams. Probably the load created at the time of impact of the bottom with a rock or other obstruction in the soil is the place where the beams break. An investigation of that point of breakage and the amount of impact load needed to do that is beyond the scope of this work but a possible method for calculating the impact load has been mentioned in the review. Even then special investigation will be needed to predict the possible impacts that might be expected to occur in the field. It seems certain that a careful use of the plow (avoiding buried rocks and other obstructions) should completely prevent the breakage.

It is also suspected that an "Arab plow" during its life may go through several bending and straightening of the beams which might reduce their strength. The result would be that even a smaller impact load (smaller than the load needed to break the new beam) will be enough to break the beams. It is also possible that the beams, which were reported by farmers to have broken, were of low quality material and did not have high tensile strength.

The breakage and twisting of longer beams draw special attention. The longer beams because of their length and with the plow bottom situated far away from the hinge or bolted point on the main frame, provide extra long leverage at the time of impact and make the beams susceptible to breakage.

The average draft of the longest beam (Table 4) in the old design is much below the amount of load it can sustain. In the test plots in the absence of any buried stone or hard material no high impact was caused. Therefore, in those field conditions it is unprobable that the beams would break even if they are subjected to a much higher load than what was encountered during the experiment.

Bending stress for one beam can be calculated as follows:

Load = average draft load x three to four safety factors.

The attempt to determine the average draft of individual bottoms failed, but it is true that plow bottoms do not have equal draft (if each one is tested alone) because of unequal beam length. It is very difficult to say whether dividing the average draft of the five plow bottoms used together will be really indicative of the average draft of each bottom. Under these circumstances and to be on the safe side the average draft of the longest beam of the old design may be considered to be the same for each bottom. Therefore, the bending stress for one beam of "Arab plow" will be as follows:

Load = average draft of the bottom with the longest beam x safety factor

= 1771.00 lb x 4

= 7084.00 lb

This load is much lower than the tensile strength of the beam. Therefore, under normal conditions the beams can easily withstand a load more than 7084.00 lb, but it is difficult to say what will be the result of a sudden "impact load" on the beams.

Maneuverability and Efficiency of Operation

The new design because of its light weight is much more easily hitched to the tractor and its response to tractor steering is faster than the old design. The old design needed a greater turning radius, approximately 27.56 in more than the new design, with the result that sharp turns near the fence are easier with the new design. Because of the offset arrangement of the plow bottoms with the old design, there was always a danger of catching a tree or fence by the longest beam of the plow. In one instance during the experiments, a small tree was pulled out by the bottom of the longest beam. Compact design and equal distribution of weight and draft of the new design permitted better control and operation. Frequency of bogdowns with the old design exerted extra load on the tractor and was also a cause of fatigue to the operator. It is expected that with less wheel slippage and no bogdowns and better control of the plow the efficiency of the plow and the operator should be more with the new design than with the old design.

Quality of Work Done

Since the design of the plow bottoms was the same with the two designs, their effect on the soil was expected to be the same. In general the field after one plowing with either of the designs was very rough and furrowed and full of clods of varying sizes (Figure 25). In the case of the old design humps of big clods were frequently found at the place of bogdowns. In the case of the new design there was a continuous mound formation around the furrow made by the 3rd bottom. This effect was not very significant on first plowings and on very hard soil, but in loose ground the effect was much more pronounced. At the high speed of 3.50 mph and 4.00 mph the mound formation in hard soil was negligible because the soil was well worked and thrown farther away.

It was found that for a complete job of seedbed preparation two to three plowings would be necessary with both the designs. Otherwise, wide unplowed ridges remain.

It is expected that if a spike tooth harrow, heavy metal bar, or a pipe filled with concrete is dragged behind both the designs, it will help greatly in smoothing the

Figure 25. General field condition after plowing with the new design.

plowed field. This treatment should be applied with the last plowing only.

Repair and Maintenance

Because of the simplicity of the two designs, their repair and maintenance are very easy. In the first place, they need very little maintenance, but if the beam is sprung it can be straightened easily. Normally, daily maintenance will consist only of checking for loose nuts and bolts and the plow bottom, all of which can be tightened easily with simple shop tools.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Experiments were conducted at the AREC of the AUB to evaluate the performance of a locally manufactured plow. An attempt was made to solve the problem of the beam breakage, which quite often took place with the longer beams of the old design, and to increase the efficiency of the plow. A new design was made at the AREC workshop in order to make the plow compact by bringing all the bottoms nearer to the main frame. Other objectives were to bring the centre of draft nearer to the centre of the plow and to obtain an even distribution of draft and weight. The study of the plows consisted primarily of functional testing, but determination of power requirements, structural strength, accuracy of design, and materials of construction were also included.

The results indicated that the newly designed plow weighed less than the old one, and the draft and power requirements were considerably lower for the newer one. The depth of plowing of the new design was greater and the widths of ridges were less compared to the old design. An exception to this fact was found at high speeds at which point the depth of plowing decreased sharply and the ridge width increased with the new design. With both the designs there was an inverse relationship between the depth of plowing and the ridge width. Maximum draft, wheel slippage, and bogdowns were encountered with the old design much more frequently than with the new one.

At any speed, for an equal rate of work per hour, the draft and power requirements of the old design were greater.

It was found that there were quite significant variations in the dimensions of members of the machine.

In loose and moist soil the new design formed a mound in the middle, whereas the old design did not. Both the designs showed a very poor performance of plowing a land full of long wheat stubble and a land full of heavy brush like weeds. Because of less turning radius, compact design, less weight, and equal distribution of weight and draft, the new design showed better maneuverability and increased efficiency in operation.

It was found that plow bottoms did not scour well with either design, because of their surface roughness and crude finish.

From the tensile strength test of the beams and the maximum draft encountered by the plow, it is concluded that the beams will not break in a soil similar to the test plots where there were no buried rocks or other obstructions.

Conclusions

1. The new design weighed 92.40 lb less than the old design.

2. Average draft needed was more for the old design at every speed. The draft increased with the increase in speed, but there was a sharp drop in the draft of the new design at high speed.

3. There was no definite trend of increase or decrease in the depth of plowing (with maximum depth setting) of the old design, but in the case of new design the depth decreased greatly at high speed.

4. Horse power requirement was greater for old design at all speed tested. In general horse power requirement increased with the increase in speed.

5. Top width of ridges was found to be inversely proportional to the depth of plowing. There was no definite trend in the increase or decrease of the width of the ridges, but in the case of new design the ridge top width increased greatly at high speeds.

6. There was no definite trend in the increase or decrease of the mean clod size diameters, but there was a marked decrease in the mean diameters of clods with the new design at high speeds.

7. In loose and moist soil the new design formed a mound in the middle whereas the old design did not.

8. Both the designs were found extremely incapable of plowing a land with wheat stubble of 6 to 12 inch size and a land full of heavy brush like weeds of 15 to 20 inch size.

9. There were less wheel slippage and bogdowns with the new design.

10. Maximum draft encountered by the new design was less than the old design at all speeds tested.

11. With fewer bottoms the relative depth of plowing and eventually the unit draft requirement increased with both the designs.

12. The new design responded better to tractor steering than the old design.

13. Smaller turning radius was needed for the new design.

14. On sloping land the use of stabilizers was a must for both the designs; side swing was more evident in the case of the old design due to unequal weight distribution.

15. Two to three plowings and cross-plowings were found to be necessary for a good seedbed preparation with both the designs.

16. Both the designs responded very much to the topography of land as to the depth of plowing.

17. Both designs were incapable of turning under the residue.

18. At speeds exceeding 3.00 mph, extreme pulverizing of the soil was observed with the new design, but no such effect was observed with the old design at any speed tested.

19. Both the designs left the plowed field in a very rough, cloddy, and furrowed condition.

20. To break the clods and smoothen the surface, an extra item (e.g. a spike tooth harrow or a simple heavy metal bar or a pipe filled with concrete) is necessary with both the designs. This item is more essential after the use of the new design which forms a mound in the middle. To remedy this, a spike tooth harrow or a metal bar or pipe filled with concrete can be dragged behind the plow in the last plowing operation.

21. The new design will be more economical from the point of purchase cost and cost of operation compared to the old design.

22. The beams will not break in a soil similar to test plots, where there was no buried rock or other obstructions.

Recommendations

1. A set of functional requirements or specifications should be established for the "Arab plow". In other words, what must the machine do? Under what conditions is it expected to operate satisfactorily? The answer to the first question includes the consideration of the desired effect

of the "Arab plow" upon the soil. General experience, field investigations, and surveys should be involved in answering the second question.

2. One of the problems in the fabrication of the "Arab plow" is that the size, shape, and weight of parts are not strictly according to any specific standard. Therefore, the first step in the improvement of the "Arab plows" should be the standardization of parts to definite measurements.

3. Standard specifications of the materials to be used and proper heat-treatment processes for the various working and static parts should be made.

4. A committee should be set up in the country which will recommend and supervise the standard size and materials of construction. It will help produce standardized and economical machines on a mass production basis and will also regulate the import of proper materials of construction on a wholesale basis.

5. More specific research work is needed for the improvement of the "Arab plow".

6. For more accurate draft measurements, a three point strain gage or hydraulic dynamometer should be used for future experiments.

7. A spike tooth harrow, or a heavy metal bar, or a pipe filled with concrete should be used behind the "Arab plow" in the last plowing operation to break clods and

smooth the surface.

8. On harder soil the spacing between the plow bottoms should be reduced to reduce the ridge effect.

9. Possibility of spring trip arrangement should be investigated for protecting the plow bottoms and plow beams against breakage.

10. Other possibilities of devicing mechanisms on the plow and tractor, to reduce impact loads, which are the cause of failure of the beams should be investigated.

11. Investigations should be made to improve the scouring action of the plow bottoms. Probably better finish and smoother surface of the plow bottoms will help improve scouring.

12. Increasing the width of the beam metal (8 to 10 in before the start of the bend) gradually to a maximum at the centre of bend and then reducing the width gradually up to the original width (8 to 10 in after the end of the curve) will highly increase the strength of the beam at the curve. At the same time the beams should have a milder angle of bend (here the curve or bend in question is the 90° bend of the beam).

13. Field testing only can bring good results if further extensive experiments are done to draw reliable conclusions. This is essential because of the variability of soil conditions and the inability to control these variables.

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A P P E N D I C E S

Appendix A

Design of the Plows

Old design. Pages 101 to 105 contain design plates numbered one to five. The dimensions given on the design plates are in millimeters (25.40 mm = 1.00 in). These design plates are photographs of the original design and are reduced in size. The scale for the photographs and the original designs is 1:2.25. Therefore, any measurements on the photograph should first be multiplied with the factor 2.25 and then by the scale factors provided on the photographs of the design plates.

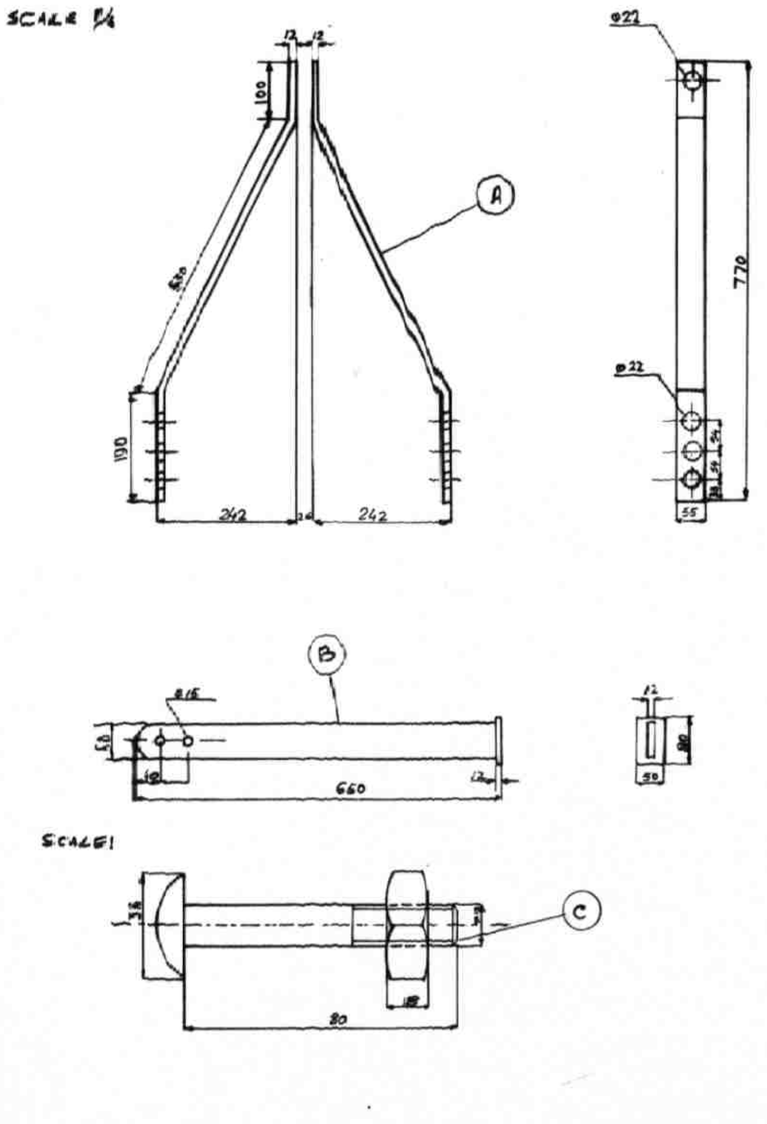
Items on the design plates have been described in the text of this thesis as follows:

Design plate No. 1:

- Item A: Member of the three point hitch arrangement with lower three drilled holes for depth adjustment.
- Item B: Folding support of the plow.
- Item C: Plow bolts and nuts.

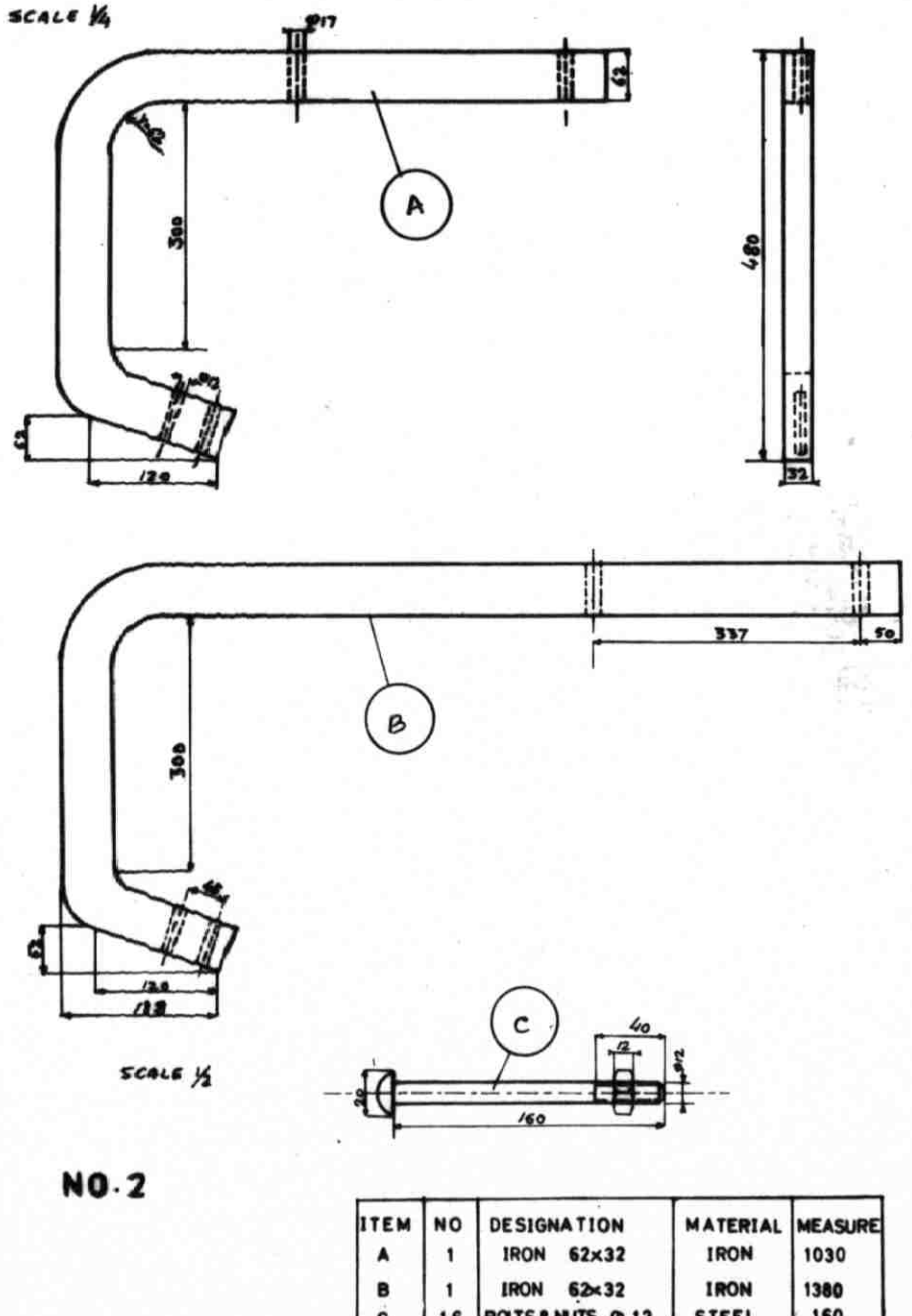
Design plate No. 2:

- Item A: Fourth plow beam.
- Item B: Third plow beam.
- Item C: Nuts and bolts for reinforcement.



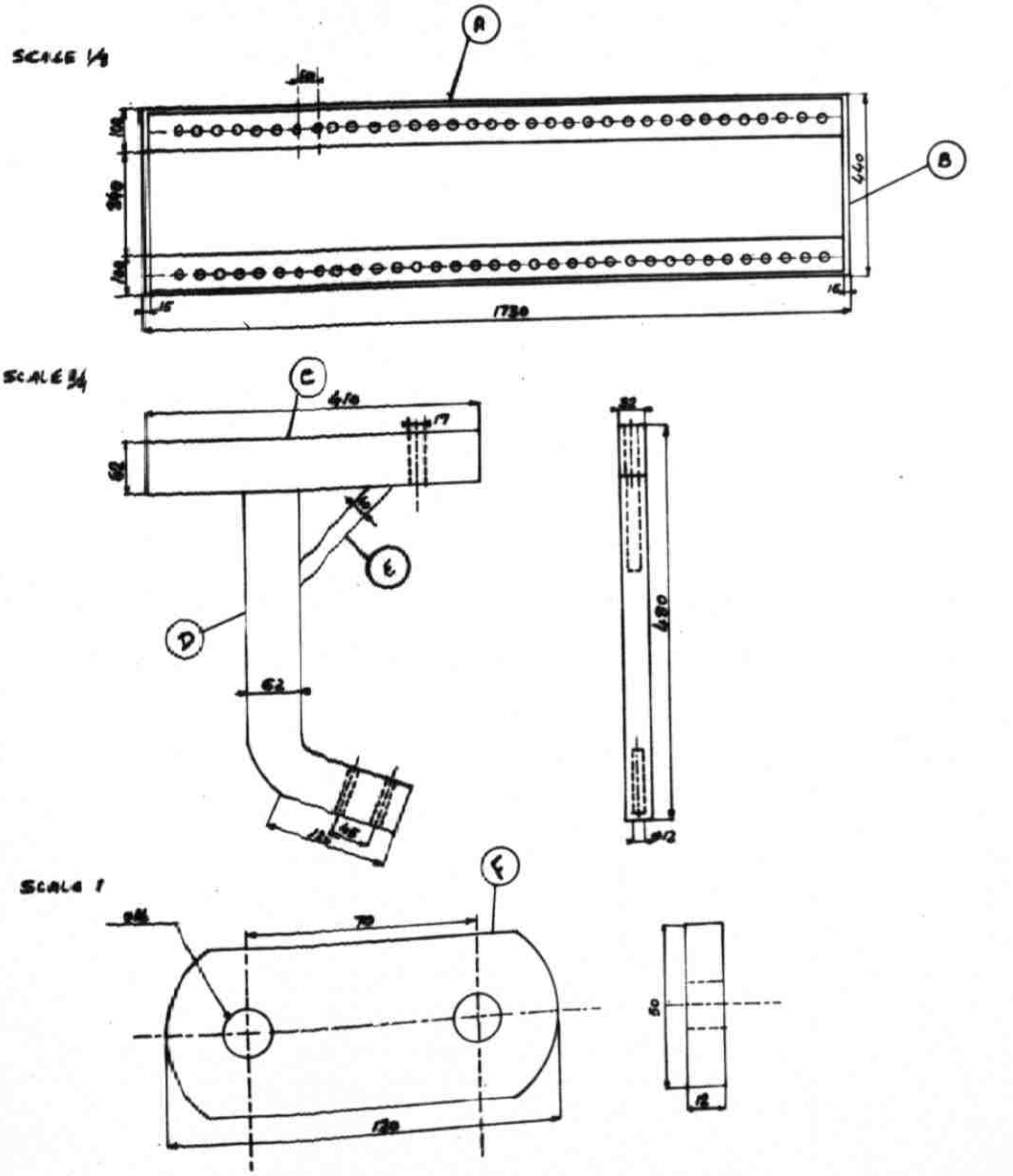
NO.1

ITEM	NO	DESIGNATION	MATERIAL	MEASURE
A	2	FLAT IRON 55 X12	IRON	820
B	1	FLAT IRON 50X12	IRON	636
C	10	BOLTS& NUTS Ø12	STEEL	80



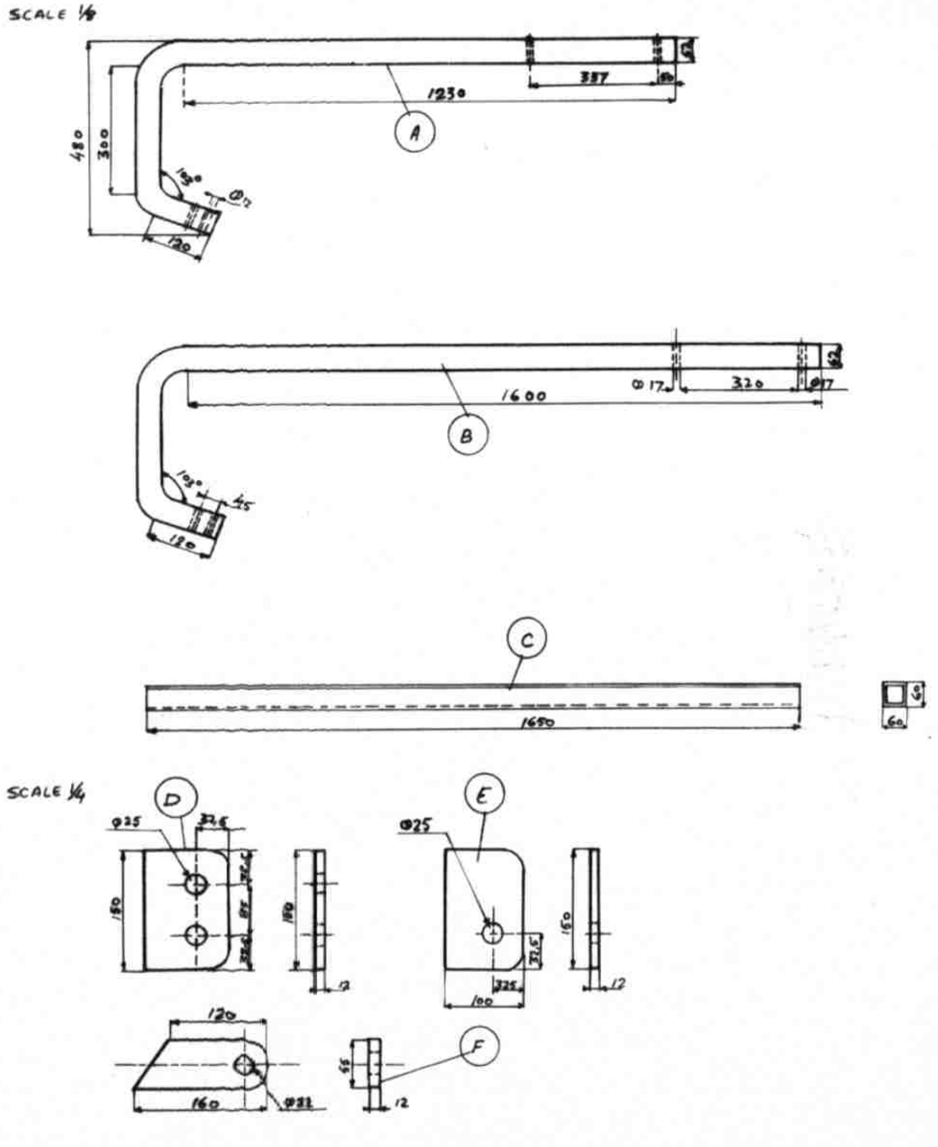
NO. 2

ITEM	NO	DESIGNATION	MATERIAL	MEASURE
A	1	IRON 62x32	IRON	1030
B	1	IRON 62x32	IRON	1380
C	16	BOLTS & NUTS Φ 12	STEEL	160



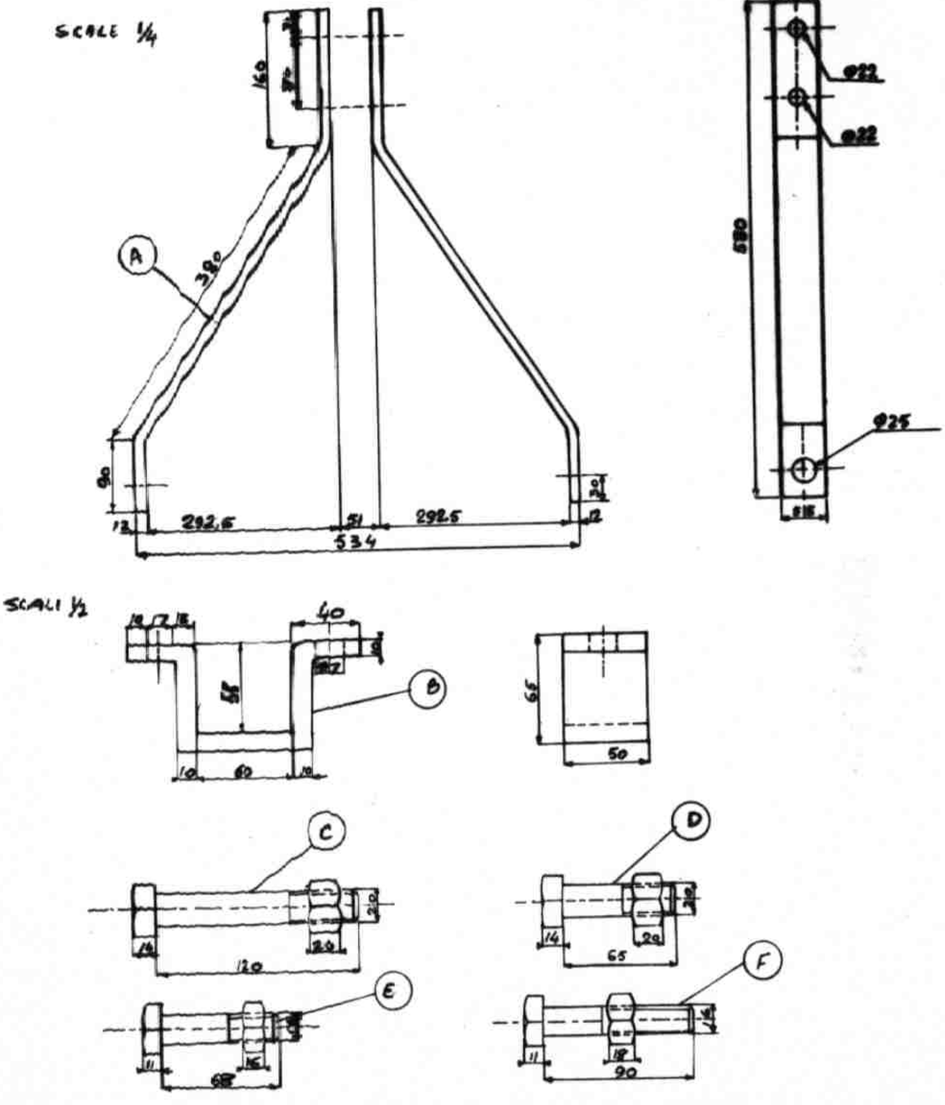
NO.3

ITEM	NO.	DESIGNATION	MATERIAL	MEASURE
A	2	ANGLE IRON 100X60	IRON	1700
B	2	FLAT IRON 100X15	IRON	440
C	1	IRON 62X32	IRON	410
D	1	IRON 62X32	IRON	440
E	1	FLAT IRON 40X16	IRON	160
F	8	FLAT IRON 50X12	IRON	120



NO. 4

ITEM	NO	DESIGNATION	MATERIAL	MEASURE
A	1	IRON 62x32	IRON	1730
B	1	IRON 62x32	IRON	2100
C	2	ANGLE IRON 50x50	IRON	1650
D	2	FLAT IRON 100x12	IRON	150
E	2	FLAT IRON 100x12	IRON	150
F	2	FLAT IRON 55x12	IRON	160



NO. 5

ITEM	NO.	DESIGNATION	MATERIAL	MEASURE
A	2	FLAT IRON 55 X 12	IRON	620
B	10	FLAT IRON 50 X 10	IRON	255
C	1	BOLT & NUT Ø 20	STEEL	120
D	4	BOLT & NUT Ø 20	STEEL	65
E	12	BOLT & NUT Ø 16	STEEL	68
F	5	BOLT & NUT Ø 16	STEEL	90

Design plate No. 3:

Items A and B: Main frame with drilled holes for spacing plow units.

Items C, D, and E: First plow beam.

Item F: Clamp for the reinforcement with drilled holes for two bolts.

Design plate No. 4:

Item A: Second plow beam.

Item B: First plow beam.

Item C: Reinforcement bar.

Items D and E: Three point hitch arrangement for lower links.

Item F: Arrangement for bolting item A (with depth control arrangement) of design plate No. 1.

Design plate No. 5:

Item A: Members of the three point hitch arrangement.

Item B: Clamps for fixing plow beams on the main frame.

Item C: Bolt for the three point hitch arrangement fitted near the point of top link.

Item D: Bolts for the three point hitch and depth control arrangement. Two at the lower link points and two at the point of depth adjusting arrangement.

Items E and F: Bolts on the main frame for the plow beam attachment.

New design. The design plates one to five for the old design should be considered for the new design also, but with the following modifications:

Design plate No. 1:

Item B is eliminated.

Design plate No. 2:

Two numbers of item A and two numbers of item B are needed; item C is eliminated.

Design plate No. 3:

Item F is eliminated.

Design plate No. 4:

Items A, B, and C are eliminated.

Design plate No. 5:

No change.

Appendix B

Abbreviation, Definitions and Formulas

Abbreviation

Agricultural Research and Education Center	AREC
American Society for Testing Materials	ASTM
American University of Beirut	AUB
and others	*et al.*
Centimeter(s)	cm
Foot (feet)	ft
Foot pound per minute	
Horse power	HP
Inch (inches)	in
International Harvester	I.H.
Kilogram (s)	kg
Massey Ferguson	M.F.
Miles per hour	mph
Millimeter (s)	mm
Pound (s)	lb
Pounds per square inch	psi
Second (s)	S

Definition

Bogdown. Sinking of the plow into the ground with continuous drive wheel slippage, with the result that the tractor could not move forward without lifting the plow from the ground.

Design. Design is the arrangement of the parts to show the difference of make-up in machines of the same type.

Draft. Draft is the horizontal component of pull, parallel to the line of motion.

Mounted implement. Mounted implement is one that is attached to the tractor in such a manner that it is steered directly by the tractor and, at least for the raised position of the implements, is completely supported by the tractor.

<u>Formulas</u>

1. $$HP = \frac{\text{(force, lb) (velocity, fpm)}}{33{,}000}$$

2. Drive wheel slippage

   $$\text{Percent slip} = 100 \ \frac{(R - r)}{R}$$

   R = total drive wheel revolution count to traverse the drawbar runway under load.

   r = total drive wheel revolution count to traverse the drawbar test runway under no load.

   Tractors equipped with pneumatic tires, the wheel slippage should not exceed more than 15%.