THE DESIGN OF A TRACTOR-MOUNTED YAM LIFTER.

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D.T.A. Report

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Report submitted in part fulfilment for the Diploma of Tropical Agriculture of the Imperial College of Tropical Agriculture, Trinidad, British West Indies.
Yams were studied in the field to determine the position of the tubers relative to the banks. The results were used in the design and development of a tractor-mounted yam lifter. After considerable testing and modification a model was produced which operated with reasonable success in the limited trials which it was possible to undertake.
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ACKNOWLEDGEMENTS

I wish to express my very sincere thanks to Mr. P. F. Rosher for patiently supervising the whole project. Mr. Rosher suggested the problem, and throughout offered much valuable advice and information, but allowed me to make all the decisions about the machine's development.

My thanks are also due to:

Mr. G. E. Hodnett for suggesting the method of analysing the results of the excavation study;

Dr. A. L. Jolly for providing information collected on his Peasant Holding Investigation;

Messrs. G. Bally and Jaggai of the Old Farm staff for their patience and interest in the lifter. Their helpful enthusiasm did much to offset disappointment during the developmental work;

The Works Department for their patience and skill in making and un-making the various models.
INTRODUCTION

Yams are widely cultivated throughout the humid tropics. They are capable of giving very high yields per acre; are relatively free from pests and diseases; and store well.

At the present time, however, they are mainly cultivated as a peasant crop and are not grown on a large scale. In the past this has been for two reasons: the markets have not existed for large quantities of yams, and the labour requirement for their cultivation is very high when grown in the traditional manner.

Now that the former reason is no longer true, some answer must be found to the latter.

Urban populations in the tropics are increasing, and the problem of providing food supplies is recognised in many territories. The qualities of the yam crop commend it for large scale food supply, provided that it can be grown economically. If this is to be done the labour requirement must be reduced.

The yam crop also has great possibilities as a cash crop, providing, as it does, the raw material for starch extraction and alcohol production.

These facts have been recognised at the Imperial College of Tropical Agriculture for several years, and a programme of investigation is being carried out.

The cultivation of yams may be divided into the following operations:

1. Bed preparation
2. Planting
3. Staking
4. Weed control
5. Harvesting

All operations are, at present, done using hand implements; but each could be mechanised.

It should be noted that efficient mechanisation may
necessitate considerable modification to the present system of cultivation.

1. **Bed preparation**

   This operation, including the formation of the banks, can readily be achieved with tractor-drawn or mounted implements. (N.B. The ridges on which the yam plants grow are called banks in Trinidad. This term is therefore used throughout the report).

2. **Planting**

   Yams are propagated by planting 'sets', portions (usually the crown) of old tubers. This could probably be done using a potato planter, which need only be of the simplest type.

   James (1953) has developed a system for combining the mechanical bed preparation with planting. He has shown that, although the yield is not affected, the labour requirement is very considerably reduced.

3. **Staking**

   This, at present, probably takes up more labour than the other operations. Work has been done at I.C.T.A. in an effort to reduce it. Already with the College crops fewer stakes per row are used.

   The problem can next be approached either by:

   (i) mechanising staking, for example by the use of a post hole digger or

   (ii) replacing staking by another method of supporting the dense vine growth.

   Living maize stalks have been tried, but not very successfully.

   The way in which this problem is finally to be overcome is important in the effects which it will have on the mechanisation of the harvesting operation.

4. **Weed Control**

   This is, at present, almost as expensive as staking, but contemporary work on chemical control suggests that this may prove to be a practicable method.
It should be noted that, the healthier the vine growth, the less is weed competition a problem.

5. **Harvesting**

This forms the scope of the present investigation. As yet, no successful aid to yam harvesting has been recorded, although harvesting accounts for about 20% of the total labour requirement (Economics Rept. Peasant Investigation records 1956-57 crop). The decision was taken, therefore, that the object of this project was to design, construct and test an implement, which would appreciably reduce the overall cost and time involved in harvesting the yam crop. At the same time the machine should not lower the value of the product by damaging the tubers.

It is realised, of course, that before a new machine is developed, any existing machines which might do the job should be considered, and, if possible, tested. This was done, and is discussed in the section on investigation ("Study of machines doing comparable operations"). In this case, no such machines were available for testing, and the cost of obtaining them would have been prohibitive. It was, in fact, cheaper to make a new one.

The development of a new machine should fall into two distinct parts: (a) Research

(b) Design

construction and testing.

Ideally all research should be completed before the design commences. In the present project this was not possible for two reasons:

1. Time was short and the overall development of the project depended on the availability both of equipment and of yams to be harvested.

2. The necessity for some information did not become apparent until after the prototype had been tested.

Therefore, after the preliminary field investigation, developmental work on the machine, and field studies proceeded concurrently.
For the sake of clarity, however, research and machine development are reported in separate sections.

Because of its intrinsic importance a discussion of the final model and an appraisal of its capabilities have been placed in a distinct and final section.

The measurements made in the field profile study are bulky and are therefore recorded in an appendix.

A summary of the whole project is formed by the Illustrations, which are placed in a separate section.
INVESTIGATION

I. STUDIES MADE BEFORE DESIGN OF PROTOTYPE

(1) Examination of College Farm Yam Crops.

The first step was to achieve some degree of familiarity with the Yam crop. To this end, the yams growing on the College New and Old Farms were examined, along with the corresponding Crop Records. At the Old Farm ½ acre was being grown on Field 9 and at the New Farm ½ acre on Field 5. In addition to general observations of the crop, the following measurements were made:

(1) Bank spacing (i.e. width between rows),
(2) Height of bank (above furrow base),
(3) Overall width ('spread') of tubers in single plant.
(4) Depth of deepest tuber of plant (from top of bank).

Results

<table>
<thead>
<tr>
<th>Remarks</th>
<th>Width between adjacent furrows</th>
<th>Height from top of bank to base of furrow</th>
<th>Overall width of tubers in single plant</th>
<th>Depth of base of tuber from top of bank</th>
</tr>
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<tbody>
<tr>
<td>Old Farm Field 9</td>
<td>Ins.</td>
<td>Ins.</td>
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<tr>
<td>½ acre. Unrotted trash still present beneath tubers. Tuber usually in a tight cluster 1 - 3 per plant. Weed growth was rank. The soil is a sandy loam.</td>
<td>48</td>
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<td>54</td>
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<td>6</td>
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Average = 52 7 5 9

<table>
<thead>
<tr>
<th>New Farm - Field 5</th>
<th>Ins.</th>
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<tr>
<td>½ Acre well weeded. Apparently poorer vine growth than on Old Farm Soil: sandy loam</td>
<td>36</td>
<td>6</td>
<td>3</td>
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<td>35</td>
<td>6</td>
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<td>4</td>
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</table>

Average = 36 8 5 6
In places a layer of very hard soil was noted about 6" below the top of the ridge. Tuber development always stopped at this layer.

Conclusions and Observations.

From this the following points were noted:

1. The spacing of the banks was very variable, even between adjacent banks, but 4' would seem to be a working width.

2. The banks were considerably flattened by this time, and on both Farms were only 6"-9" high. This means that the deeper tubers extend below the level of the furrow bases.

3. The widest spread of tubers observed in any one plant was 7".

4. The deepest tuber measured was 12" from the top of the bank to the base of the tuber.

5. The mass of dead leaves and weed growth will probably be a problem in harvesting.

6. At the time of the investigation, the skin of the tuber was very delicate and the flesh was soft.

The yam beds were prepared and planted thus: (from Crop Records).

On both College Farms the operations were similar. (Area previously in cane).

Disc ploughed - (tractor mounted)
Disc harrowed.
Cane stumps dug out and removed.
Ploughed - tractor and bull.
Yam trenches were opened by tractor-mounted disc.
Trenches filled with trash for planting.

Ridges split back over the trash, to form banks in which:

Yam sets were planted, using a cutlass i.e. the method suggested by James (1953), had not been adopted. Subsequent observations showed that the 1957-58 crop was ploughed in the same way.

Subsequently weeded by cutlassing.
No other yam crops were examined because, as far as could be ascertained, at no other place in Trinidad were yams grown on the same scale as on the College Farms. All others grown were on a very small scale in peasant gardens, and frequently mixed with other crops. Mechanisation of their cultivation could hardly prove economic, and therefore their study should not influence the design of a mechanical lifter.

(2) Study of Reports on previous work

This was intended to widen the background knowledge of yams, and in particular their cultivation. James' (1953) work on bed preparation has been referred to in the Introduction. The improvements which he suggests may affect the mechanisation of harvesting.

(3) Possibility of adapting other machines

This stage has already been mentioned in the Introduction. The operation to be performed is that of lifting a bulky root crop which is planted in ridges. Comparable crops whose harvesting is already aided by machines are Irish and sweet potatoes and beet (fodder and sugar).

Both differ from yams in several important respects, which affect the mechanisation of harvesting (Park et al. 1953).

Both Irish and sweet potatoes have several small tubers per plant, scattered within the ridge. Yams have only two or three large (and elongated) tubers per plant, and these usually in a tight cluster in the centre of the ridge (bank).

Yams, because of their relatively large tuber size and because of the softness of their flesh are far more prone to damage than are either Irish or Sweet potatoes. Furthermore a comparatively small degree of damage greatly reduces their market value. Yams which were unavoidably damaged in the investigation described in the next section had to be sold at a half the normal market price.
This characteristic rules out the possibility of using several well established Irish potato and beet diggers, such as the spinner and elevator digger types. These would inflict damage by the elevator chain and by dropping the tubers back on the ground. (Bainer et al. 1955, p. 24).

Also any type of middle buster plough is out of the question as the central beam would crush most of the tubers.

Yam banks are wider and higher than the ridges in which potatoes and beet are grown; the yam tubers grow to a greater depth and are spread over a greater width than potatoes or beet. These factors mean that a yam lifter has to be on an altogether larger scale than one required for potatoes or beet.

To sum up, one may say that machines performing comparable operations on other root crops would not be expected to work without extensive modifications. However, a study of these machines did suggest possible approaches to the problem.

(4) **Enumeration of principles to follow in designing prototype.**

(1) Great care must be taken not to damage the tubers.

(2) Provision must be made for clearing vines and trash from the path of the lifter.

(3) For economy of power requirements as little soil as possible should be lifted in as short a distance as possible. However, limitations to the application of this are imposed by the necessity to move adequate soil to avoid damaging the tubers.

(4) The machine must be designed to cope with the soil conditions which exist at harvest time.

(5) Any part of the implement which operates below ground level must be designed so as to reduce draft to a minimum.

By this stage it seemed probable that the projected machine would include some kind of share body to undercut the tubers. Also discs may be required, if only to cut trash. Therefore, the factors affecting forces on tillage implements were studied (Bainer et al. 1955). Specific references will be made during the discussion of
the design of the prototype.

In the present case, the characteristics of the initial studies were confined. They assumed that the soil was uniform, and subsequently based on a uniform initial water table. This meant that the initial investigation was based on uniform support, which was not realistic for the conditions of the area. It was assumed that the soil conditions were uniform throughout the area. However, the soil conditions were not uniform, as the soils varied widely in the vicinity of the land. This meant that the methods were still not fully developed at the time of the initial investigation.

It was actually concluded that more work was required. This should probably revolve around the more general requirements for the future development of the site. It was thought quite probable that the development of the later years is continued by another worker, who could improve the results of an ongoing study.

An investigation has therefore been designed to measure the following characteristics of the College farm crops from these samples:

1. The total width of tubers of an individual yam plant (as in the initial study but taking a much larger sample).
2. The maximum distance to which tubers developed away from the central point along the row of the bank, measured within a sample strip of bank.
3. The depth to which tubers developed, measured from the top of the bank (as in the initial study but taking a much larger sample).
4. An accurate profile of the bank and furrow system in cross section.
5. The weight of tubers and those not visible in the crop.

This was necessary to give a standard the characteristics of the soil on which development work was done, with the characteristics.
II. STUDIES MADE DURING SUBSEQUENT DEVELOPMENT

As the machine was tested, the shortcomings of the initial studies were realised. They assumed that the yams were planted, and subsequently developed, in a straight line along the centre of the bank. When the initial investigation was made the bamboo supports were in position, and vine growth was dense. Later, when the vines had died and had been cleared from the top of the banks, it was apparent that the yam plants were certainly neither in a straight line nor even roughly in the centre of the bank. A further point was that the tubers were still not fully developed at the time of the initial investigation.

It was clearly indicated that a much more comprehensive and thorough investigation was required. This should provide information and data which were essential for the future development of the machine. It was thought quite probable that the development of the lifter would be continued by another worker, who would require the results of an objective study.

An investigation was therefore designed to measure the following characteristics of the College yam crops from random samples.

1. The total width of tubers of an individual yam plant (as in the initial study but taking a much larger sample).
2. The maximum distance to which tubers developed away from a straight line along the top of the bank, measured within a sample strip of bank.
3. The depth to which tubers developed, measured from the top of the bank (as in the initial study but taking a much larger sample).
4. An accurate profile of the bank and furrow system as seen in cross section.
5. The weight of tubers - and thence an estimate of the yield. This was necessary to give a standard for comparison of the crop on which developmental work was done with other yam crops.
(6) Any additional information such as the position of trash and manure in the bank.

The method of investigation will be described in detail both to justify the results and to give a guide should it be necessary to repeat the work on other yam crops.

It was decided to carry out the investigation by selecting at random five yard lengths of bank.

In order to obtain the above data the entire five yards was to be excavated in a manner comparable with an archaeological investigation.

Procedure

The Illustrations (diagrams 1 & 2, Plates 1 - 6) should be referred to, to clarify the text.

(1) First a base line was laid down by stretching a line (between two pegs) along the furrow roughly half-way between two banks.

(2) A trench was dug at right angles to the banks, so that it joined three furrows and cut through two banks. The depth of the trench was such that its floor was three or four inches below the base of the deepest furrow. Bank A was the one to be examined but the profile of bank B was also measured, to show the relative position of two adjacent banks.

The profile was measured by placing a piece of angle iron supported by vertical pegs against the side of the dug trench. The angle iron was marked off at 6" intervals. The zero mark was placed against the base line, at any convenient distance below the bottom of the furrow. It was set horizontal using a spirit level. The vertical distance from angle iron to ground level was measured at six inch interval-marks \( h_1, h_2, \ldots, h_6 \). The measurements were recorded as in the appendix and later corrected to give the height above the bottom of the furrow. (not the base line because this could not be kept horizontal; it sagged). At the same time the position of any unrotted trash, etc. (see in the cross section) was noted.
The first yam plant in the sample strip was excavated. This was done by removing the soil from around the tubers, which were left undisturbed. It was then possible to measure:

(a) The distance from the base line of the nearest portion of the nearest tuber (recorded in the results as \( X \)).

(b) The total width of the tubers (recorded as \( x \)). \((X + x)\) therefore, is the distance from the base line of the furthest point of the furthest tuber. The yam was then removed and the following measured:

(c) The depth of the deepest tuber below the top of the bank (recorded as \( y \)).

(d) The total weight of the tubers of one plant.

The second, and all subsequent plants were excavated in the same way.

At a distance of one yard from the first cross-section profile trench, another trench was dug and the profile recorded in the same way as the first. This time, however, the profile of only the bank being excavated (Bank A) was measured and not the adjacent one. This was repeated every yard along the bank, up to and including the end of the five yard sample. Thus six profile trenches were dug for each five yard sample; only the first of these six being extended to pass through the adjacent bank.

Nine sample strips were excavated on the New Farm yam area. This constituted a thorough survey. Only three samples were taken on the Old Farm. The number of excavations which could be made there was restricted by time and by the fact that if numerous sample strips were excavated all over the field, subsequent trials of the lifter would be affected. Some investigation was necessary, however, to compare the Old Farm crop, on which the machine tests were carried out with the New Farm crop, where the major part of the study was made.
Observations and Conclusions.

(1) **Width of Scoop.**

Analysis of the data giving the lateral disposition of the tubers indicates minimum widths for the scoop. Assuming that the lifter can be driven in a straight line along the crop row then:

At the Old Farm, a scoop width of 11.4" will cut approx. 5% of plants and 13.6" will cut 2% of plants.

and at the New Farm, 19.4" will cut 5% of plants and 23.5" will cut 2% of plants.

The percentage of plants which it is permissible to damage can only be decided after weighing the financial loss through damage (which could be 'nil') against the greatly increased operating costs of a wider scoop. (due to increased power requirement). This can only be done after very extensive testing on a field scale. Also, the machine rarely can be operated under optimum conditions, and therefore a generous margin must be allowed for operating error.

(2) **Depth of operating.**

This is not so critical as the width of the scoop, as the depth of the implement can easily be altered when in use. The figures recorded for the depth of the tubers cannot be analysed, because the datum line - the top of the bank - is not constant. However, there are very few tubers that descend more than 12" from the top of the bank, so if the implement is initially operated an inch or two beneath this point, tuber damage by horizontal cutting should be negligible. Final adjustment must be by trial and error in the field.
(3) **Average weight of tubers per plant.**

This is 4.6 lbs. at the New Farm and 2.8 lbs. at the Old Farm. The yield per acre of these crops (from farm records) are 19400 lbs./acre at the New Farm and 16500 lbs./acre at the Old Farm. These figures indicate the nature of the crop on which the machine was tested during the development.

(4) **The bank profile.**

These were plotted on transparent (tracing) graph paper. The six profiles for each sample plot were plotted on common axes. The extremities (side and base) of the largest tubers in the sample were included on the profile. An example of this is shown in diagram 2. Transparent paper was used so that the profiles of several plots could be examined simultaneously. The profiles were used when considering:

(a) depth of share beneath top of bank,
(b) depth that side-plates are in soil.
(c) adjustment of discs (and later, of skids).

To do this a cross-section of the scoop was drawn to the same scale as the profile and cut out. This was used as a gauge, laid on the profile, and the necessary measurements read off.

(5) It was noted that the rows of plants were frequently well to one side of the centre of the bank. This is thought to be caused by inefficient planting and/or subsequent earthing up.

(6) It was apparent that a large number of the tubers had had their downward growth checked by an obstruction at some point. The position of this obstruction varied from 4" to 9" below the top of the bank. The soil below this level was very much harder than that above it. On meeting it the tuber developed, laterally; the growing point often dividing into a number of finger-like projections. This feature was more marked on the New Farm than on the Old Farm. Commonly a layer of unrotted pen manure and/or trash rested on top of this hard layer.
It was considered that this effect was caused by inadequate preliminary cultivation. Cultivation for yams should be deep, otherwise this plough 'sole' (pan) effect is liable to impede their subsequent development. The same suggestion is made by James (1953).

(7). Much unrotted trash and pen manure was still apparent in the sections of the banks. This was usually in a solid block, sometimes two or three inches thick, and rarely mixed with the soil. The deposit was usually elliptical in section. Very frequently it was not centrally placed in the bank. Sometimes there was trash only in one half of the bank. If the yam plants tended to be on one side of the bank then commonly the trash was on the same side. This indicates that when the final banks were formed the ridges were not split evenly, and the trash and manure were displaced to one side (see plate 4).

(N.B. This could not apply at the Old Farm, where the banks were made before planting. The sets were planted with a cutlass).

(2) simulated the operating conditions of the scoop
by being inverted mounted.

(3) only gave information about the scoop width.

It was envisaged that this approach might be used in
1

determine the optimum share width for yam crops differing from the
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College Farm crops by nature of variety, or environment. This
1

method was used on the same crop which was studied by excavation
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(Cole Farm). Thus it was possible to compare the two methods.

Procedure
The vertical knife blades were constructed (from 3/16" mild
1

steel plate) and mounted on the Ferguson tool bar. The distance
1

between the blades could readily be adjusted by moving them along
1

the toolbar. (See plates 7 & 8).

In practice the scheme did not work well, mainly because
1

the knives were not strong enough, and bent. Hence, this was
1

sufficiently by using them on sets on the bank parallel lines of given
The excavation and profile investigation yielded much objective basic information necessary for the design for a mechanical harvester. At this point in the machine development, however, the most controversial question was that regarding the optimum width of the scoop. It had to be wide enough not to damage any tubers, but not so wide that the power required was impossibly high. The range between these two limits appeared to be very small. The excavation study determines the minimum width as varying from 11" to 23½", depending on the crop and the percentage which it is permissible to damage. But this assumes that it is possible to operate the machine in a straight line along the crop row. Also the excavations were very tedious and time-consuming.

A method of investigation was therefore devised, of which the principal features were that it:

1) was simple and rapid to use.
2) simulated the operating conditions of the scoop by being tractor mounted.
3) only gave information about the scoop width.

It was envisaged that this approach might be used to determine the optimum share width for yam crops differing from the College Farm crops by nature of variety, or environment. This method was used on the same crop which was studied by excavation (New Farm). Thus it was possible to compare the two methods.

Procedure

Two vertical knife blades were constructed (from 3/16" mild steel plate) and mounted on the Ferguson tool bar. The distance between the blades could readily be adjusted by moving them along the toolbar. (See plates 7 & 8).

In practice the scheme did not work well, mainly because the knives were not strong enough, and bent. However, this was overcome by using them to mark on the bank parallel lines of given
distance apart. Vertical cuts were then made along these lines with a cutlass. The tubers in the sample strip were dug by hand and the following data recorded:

1. Total number of yam plants in sample.
2. Number of yam plants cut.
3. Total weight of tubers in sample.
4. Weight of tubers cut
   (a) Main portion.
   (b) Distal portion - i.e., the small pieces cut off from the main portion by the cutlass.

Runs were made with the knives set at 12", 16", 20" and 24" apart. Three runs were made at each. The length of bank dug was five yards. Thus twelve plots each five yards long and one bank wide were dug.

These were selected at random over the field.

Results (Of Knife Gauge Investigation)

<table>
<thead>
<tr>
<th>Width between knives (in plot)</th>
<th>Total no. of plants in plot</th>
<th>Total no. of plants cut by knife</th>
<th>Total wt. tubers cut in plot</th>
<th>Wt. of tubers cut (main portion)</th>
<th>Wt. of tubers cut (distal portion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12&quot;</td>
<td>7</td>
<td>2</td>
<td>35 1/2</td>
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<td>10</td>
<td>0</td>
<td>46 1/4</td>
<td>0</td>
<td>46 1/4</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1</td>
<td>43</td>
<td>10</td>
<td>32 1/4</td>
</tr>
</tbody>
</table>

Percentage cut at 12" = 26%
" " " " 16" = 0%
" " " " 20" = 0%
" " " " 24" = 4%
The results were not analysed statistically because the experimental error was considered to be too high to warrant it.

Conclusions

The results indicate that a scoop width of 16" would be adequate to ensure negligible tuber damage. The excavation studies show that if the width of the scoop were 19.4" then 5% of the plants would be damaged. The poor correlation between these figures is probably due to an inadequate sample being taken in the knife-gauge investigation, compared with that in the excavation investigation.

The principle of the method is sound; its application was poor. It is believed that the method could give useful results if:

(a) The knife gauge worked efficiently,
(b) A very large sample was taken.

The method has been successfully used in comparable work with sweet potatoes (Park et al. 1963). Here two deep digger plough bodies, one a mirror image of the other, were used. However, the difference in size between sweet potato and yam tubers would probably make it impossible to apply exactly the same procedure to yams.
In developing the final model, four distinct models were constructed and tested. Each is described under a separate heading. Each model is designated by a Roman Numeral (i.e., Models I - IV). The latter two models each had several minor modifications, each of which was tested separately. These tests were designated A, B, C etc. The development of each model is described in the same way:

1. Its field test is described, observations made during this test are reported. These usually fell into the following categories:
   - Ease of soil flow over the implement.
   - Damage inflicted on the tubers - its nature and severity.
   - Effect of use on the machine - structural weaknesses.

(It is interesting to note that each was a limiting factor to the successful operation of the machine at different stages).

2. Modifications which were made as a result of these observations.

3. A discussion of modifications and future lines of development which were considered but not immediately adopted.

The Section on Model I includes a description of its design and construction in addition to the above headings.

It is very important to note that throughout, the actual machine built was considered as a test rig, to find the optimum position, both in relation to the yam bank and to each other of the various functional parts of the machine. The actual manner in which these parts were supported is of much lesser importance, although in practice these often proved the most difficult problems to solve. For example, if discs were fitted, their "disc" and "tilt" angles were more important than their means of support.
MODEL I (The prototype)

The principles enumerated at the end of "Investigations", Part I, were noted. In addition certain other principles were followed, because the machine was an experimental one:—

(1) the machine was to be as simple as possible so that it could be built with readily obtainable materials and resources.

(2) all parts had to be readily adjustable and if necessary, readily modified.

To organise the development, the operation was considered, and in fact designed, in two stages:—

I. The elevation of the tubers and surrounding soil to a level at which stage II could be carried out. This part of the machine was termed the digger unit.

II. Separating the soil from the tubers. This unit was termed the lifter unit.

The Digger Unit

Stage I, then, necessitates elevating a section of the yam bank which includes the tubers. This was to be achieved by a machine designed in the following way (See diagram 3, plates 9 & 10).

(1) The section is undercut by a horizontal blade, hereafter referred to as the share. In plan the share point is V-shaped to improve soil penetration.

(2) This share is supported on each side by a vertical steel plate. The leading edge of this plate is sharpened (levelled) and angled, also to improve soil penetration.

Share and side-plates were both made from 3/16" mild steel plate.

(3) Elevation of the section soil thus cut is to be achieved in two stages:—

(a) curving the near portion of the share to start the soil moving in an upward direction (comparable to the control area of the mouldboard of a plough). The curvature must not be excessive (Bainer et al. 1955, ch.7).
(b) continuing this upward motion along a sloping tray formed of \(\frac{1}{2}\)" diameter mild steel bars. It was hoped that these bars would allow a certain amount of soil to fall through, thereby decreasing the amount of soil to be elevated the full distance.

The structure so formed may be regarded as a scoop, with sides formed by the side support plates, and the sloping base by the share and bars. It is referred to as the scoop throughout the report.

The whole scoop was to be mounted on a Ferguson toolbar frame as this was strong, very convenient and should be readily available when required. A length of 2" angle iron (mild steel) was bolted along the top of each side plate. To these bars the toolbar was bolted. These are referred to as the support bars.

The Sifter Unit - Stage II.

This was designed at the same time as the Digger Unit, but was not to be built until the latter had been constructed and made to work efficiently. In fact, the Sifter Unit never got beyond the drawing board stage, and subsequent development of the Digger Unit indicated that a separate Sifter might not be necessary. In any case it was realised that it would be extremely difficult to design one which did not damage yams.

Therefore, since interest in it is purely academic, the Sifter Unit will only be described very briefly. The soil and tubers elevated by the Digger Unit would be delivered on to the front of the tray. This tray, formed of rubber covered slats, would be attached at its front end to the rear of the digger unit, in such a way that it was free to oscillate in a vertical plane. (It's point of attachment forming a pivot for such movement). It's rear end would be supported by an eccentrically mounted wheel. This would supply the necessary oscillatory motion which, it was hoped, would sift soil from the tubers. The tubers would be deposited back on the ground.
When the design was completed, cardboard models of both units were constructed, and the design was critically reconsidered with specific reference to the following points:
(No further reference to the Sifter Unit will be made as its development ceased at this point).

1. **Heel of Sideplates** (see diag. 3).

   It was felt that if the side plates were left as shown in the plan the lower portion (the heel) might cause unnecessary soil/metal friction. This was important since the power required to operate the machine might well prove a limiting factor to its development. However, it was considered that the heel, if left on, would provide lateral stability to the machine, helping it to run in a straight line. Therefore, it was decided to keep the plate as it was until shown by testing to be undesirable. The question arose later in consideration of Model IV.

2. The possibility of attaching runners to the base of the side plates was considered. It was suggested that these might be necessary to counteract the downward force which would be exerted by the soil on the share. However, it was thought that this force could be usefully applied in two ways.

   (a) to aid penetration of the discs.
   (b) to increase the load on the rear wheels of the tractor (via the mounting linkage) thus improving traction.

   Therefore runners were not added.

3. **Discs.**

   The mounting of these was to be discussed after the scoop had been tested without them. The support bars of the scoop were to be projected forward in order to provide a possible point for attachment of the disc-supporting brackets. This modification to the design was executed.
4. Serious doubts were expressed at this stage concerning the width of the scoop, with relation to the damaging of tubers. However, the study of yams made (described in Investigations Part I) indicated that the width of 12 inches as designed, was sufficient. Only field testing could finally give the answer. Therefore, the width was left at 12 inches but the dimension caused considerable controversy throughout the development.

When these preliminaries were completed, the materials were obtained and the Prototype (Model I) was constructed according to the plan.

1. FIELD TEST - 18/12/56

The tractor was driven by one of the regular farm drivers. An attempt was made to scour the surface of the machine (to reduce the soil/metal friction) by operating it in a field which had recently been ploughed. (previously it was in grass). In fact, very little soil flowed through the scoop, which almost immediately became choked. This was repeated once or twice, and invariably the scoop became filled with hard-packed earth within a few yards. The scoop was cleared of soil, and tried on a yam bank which had been cleared of vines and trash. The same thing happened again. The scoop was run for a few yards at a depth of about 6". All the tubers in its path were cut horizontally but not vertically. To run in a straight line over the yam plants, the driver had to place sighting poles along the bank. The reasons for the scoop choking were considered to be:

(1) The angle of soil elevation (i.e., of the elevator bars) was too steep. No earth appeared to fall between these bars, so that their sifting effect was nil.

(2) Soil was piling up against the cross-members of the toolbar, which pass across the top of the scoop.

(3) Large clods of earth (and roots) wedged across the mouth of the scoop.
The following modifications were made to overcome this:

(For details see diag. 4 and plates 11 & 12).

1. The elevator bars were supported at the end away from the share by a cross-bar, itself bolted at each end to the side of the scoop. This cross-bar was lowered until the bars were nearly horizontal. Provision was made for rapid adjustment of this angle, in the field by drilling a series of holes for different positions of the cross bar. (See plates 9 & 10).

2. The top of the scoop was to be widened, making the upper part of the scoop V-shaped. It was thought that, as soil was pushed up to this level, it would no longer press against the sides. Also, because it would be spread laterally, the soil would not reach so high up in the scoop and would therefore not touch the toolbar.

3. Discs were to be fitted. These would remove that portion of soil which clogged against the side of the scoop when the sides were straight, and would help to break up hard clods.

The fitting of these discs proved very difficult. Two discs were available, which had a diameter of 18" and a disc concavity of \( \frac{\sqrt{3}}{2} \). The depth control wheels and supports for a Ransomes M65 Cultivator were available. The wheels were removed and replaced by the discs. By using these supports the height of the discs could readily be adjusted. The discs had holes cut (by oxy-acetylene flame as the steel was too hard to drill) so that they could be bolted to the wheel hubs. These revolved on the support arm on roller bearings. Part of the hub and axle protruded through the centre of the disc, and a cap was fitted over this to protect the bearing, which was subsequently packed with grease. (Plates 20-24 will clarify these details).

At its upper end the disc support was bolted to a special bracket fabricated for the purpose from 3/16" mild steel plate.
This was bolted to the support bars of the scoop. The axle was additionally supported by a horizontal bar bolted to the inner side of the scoop side-plate.

It was known that for an average disc plough the disc angle should be about 40°-45° to minimize draft (Bainer et al., 1955). Also for minimum draft and maximum penetration the tilt angle should be fairly small - 15° or less.

In practice these angles were limited by the difficulty of mounting the discs, but an attempt was made to set the discs at these angles. The final disc angle was about 45° and the tilt angle about 0°. The discs were set so that their leading edges were approximately \( \frac{1}{2} \) inside the line of the side plate (at the lower part of the scoop). This meant that the two discs were 12" - (2 x \( \frac{1}{2} \)) = 11" apart at their nearest parts (i.e., the two leading edges of the discs.

The modifications were duly completed and the machine, now Model II was ready for field testing.
Various modifications were required and made in the field during the test. They are therefore described in the test report.

1. TEST I. (12.3.57)

This took place in mid-March. It should be noted that this is at least two months after the normal harvesting time, and as the dry season was well advanced, the soil was extremely dry and hard. It was broken with great difficulty to large clods.

Again the implement was first tried on ploughed land. As with model I, the scoop almost immediately became choked, although this time the elevator bars were nearly horizontal. They were therefore removed altogether, and for the rest of the test no further trouble of this nature occurred.

The banks on which the machine was tested were previously cleared of all trash and weed growth using a brushing cutlass.

At the first trial run on a yam bank the whole unit crabbed very badly and ran right off the bank. At the time the discs were as far down as the adjustment would permit - penetration about 9" into the soil. The crabbing was explained thus: On each disc a considerable force is exerted in a sideways (and inwards) direction. The size of this force depends mainly on the size of furrow slice being cut (i.e. on the volume of soil being moved). If both discs are cutting a similar sized furrow these forces will be equal. If one slice is larger than the other, as would happen if the unit made only a very slight deviation from the centre of the bank, then the machine would be forced sideways. The deeper the discs the larger the furrow slice cut, and hence the greater this effect. Therefore, the discs were raised until they only penetrated 5" into the soil. In this position they fouled the tractor lift arm when they were in the raised position but ran freely when lowered for work. This appeared to have corrected the tendency to crab.
The next difficulty was that the scoop would not penetrate to the required working depth. Therefore a weight - one man - was placed on the top of the scoop and no trouble was then met in achieving the required depth. The implement worked very well like this for two or three yards, the tractor nearly failed (apparently for lack of power) before being brought to a halt by wheelspin. (The wheels were fitted with pneumatic tyres with badly worn threads).

In the two or three yards that the unit was working, soil flow through the scoop was good, the discs were working effectively and tuber damage was negligible. The limiting factor appeared to be simply the power and wheel grip of the tractor, aggravated by adverse soil conditions.

The machine was also tried on a piece of uncleared bank where there was much trash and weed growth. The discs, which kept revolving, appeared to have no trouble in cutting and clearing this trash.

It was decided that the trial was not a representative one owing to the adverse soil conditions. Therefore it would be repeated after irrigating the area to soften the soil, but without altering the machine in any way.

About 2" of water was applied to the area the day before the test. On the day of the test, the soil was in excellent condition, friable but not too wet. The tractor wheels were fitted with steel girdles to improve wheel grip. No wheel spin occurred throughout the test.

The discs were set to penetrate about 5" and throughout the test cut trash and furrows very effectively. The scoop only clogged once, when coarse weeds and trash fouled the toolbar frame at the top of the scoop. Such weeds should not be present at the normal harvest time, but coarse vine growth would. The banks were not cleared in any way before the test. About 30 yards of bank
were lifted. The tubers were loose in the soil and could easily be lifted out by hand. A few tubers were cut vertically and horizontally, and where this occurred it was necessary to use a fork to extricate the broken pieces.

2. Modifications. (See diag. 5, plates 13 & 14).

(a) The scoop had to be widened. The necessity for this proved in practice by tuber damage, and in theory by the excavation and profile studies described under "Investigations" Part II. While the hand lifting of the tubers was greatly facilitated, it was felt that the degree of tuber damage did not justify using the machine on a field scale.

The share was therefore cut out and replaced by one of similar curvature (i.e. cross-section) but 24" wide. The width of the scoop was thereby increased from 12" to 24". This was greater than the safe minimum width indicated by the profile study, but it was done in an attempt to 'bracket' the optimum width. (It was originally intended to bolt the new wide share to brackets inside the scoop. This would have made it readily interchangeable with shares of other widths; but the welder considered it easier and better to weld in a new share, then, should one of a different width be required, to cut out the old share and replace it with a new one. This he did).

(b) Penetration had to be improved. It should not be necessary to weight the toolbar to achieve adequate penetration. It was hoped that the relatively larger surface area of the new share would help. Also its point was to be made to point downwards slightly more than the old one.

The discs were now too far apart to place between the tractor wheels. They were, therefore, positioned roughly, underneath the toolbar with the scoop behind (See Diag. 5).

3. Future lines of development.

Penetration may be opposed by pressure on the bottom of the side plates of the scoop. Therefore if the share modifications made, do not correct this, a strip will have to be cut from the
bottom of the side. It may even be necessary to remove the whole of the side other than that needed for support of the share. This would greatly reduce soil/metal friction, if the discs are not working efficiently - but they should be working efficiently. 

Next towards. It had already been proved that the discs work efficiently even in thick brush. The main object of this test was to determine the effect of widening the scoop. Therefore the discs were removed and fresh cleared by hand. The machine was returned to the field four.

Again the machine's operation was halted almost immediately by a structural failure. The scoop support bar bent (see Plate 10). This was not entirely unexpected since they were subjected to a very considerable bending moment. Also as they worked the scoop dug deeper greatly increasing this moment.

The lifter was returned to the workshop and the bent support bar was removed and shortened. The scoop was then repositioned directly beneath the toolbar frame (Plate 16). This had not been possible before due to the position of the discs.

On Sept. 26th.

The first run was with the scoop so shallow (about 6" from the top of the bank) that it cut most of the turf. During the second run it was as deep as it could go, about 30". The test was concluded when the bolts holding the scoop support bar to the toolbar frame sheared.

Malfunction

Apparently depth control was now extremely difficult. The operation could not hold the scoop at the required depth. Probably this was because the draft was near the maximum for the hydraulic lift system. At any rate, lack of adequate penetration was no longer a problem - rather the reverse.

This problem was to be provisionally solved by-

The soil was not irrigated before the test and was therefore extremely hard. At the first run the disc supports bent inwards. It had already been proved that the discs work efficiently even in thick trash. The main object of this test was to determine the effect of widening the scoop. Therefore the discs were removed and trash cleared by hand. The machine was returned to the field for:

**TEST B (same day)**

Again the machine's operation was halted almost immediately by a structural failure. The scoop support bars bent (see plate 13). This was not wholly unexpected since they were subjected to a very considerable bending moment. Also as they bent, the scoop dug deeper greatly increasing this moment.

The lifter was returned to the workshop and the bent support bar was removed and shortened. The scoop was then repositioned directly beneath the toolbar frame (plate 14). This had not been possible before due to the position of the discs.

**TEST C. 26.3.57**

The first run was with the scoop so shallow (about 6" from the top of the bank) that it cut most of the tubers. During the second run it was as deep as it would go, about 23". The test was concluded when the bolts holding the scoop support bars to the toolbar frame sheered.

**2. Modifications**

Apparently depth control was now extremely difficult. The operator could not hold the scoop at the required depth. Probably this was because the draught was near the maximum for the hydraulic lift system. At any rate, lack of adequate penetration was no longer a problem - rather the reverse.

This problem was to be provisionally tackled by:
1. Fitting depth controlling on the outside of the scoop. (Their exact position could be obtained by studying the results of the bank profile study). (See plate 14).

2. Lengthening the top link of the hydraulic lift system.

3. Future lines of development.

If the skids appear to be successful a depth control wheel might be fitted.

TEST D. 27-3-57

The trial area was first irrigated (about an inch of water was applied), then cutlassed clear of trash. The skids were positioned so that they ran on the soil surface when the share was running about 10" below the top of the bank. A trial run was made. The tractor had difficulty in pulling the lifter and would have developed wheel spin if steel girdles had not been fitted to the wheels. The downward force exerted on the share was obviously very considerable because the skids were pressed into the ground and soil/metal friction must have been very great. However, the yams were loosened well enough to make some observations. Two banks were excavated, making a total length of 28 yds. For a total distance of seven yards the scoop was not operated at the correct depth. Some measurements were made.

Length of bank excavated at correct working depth = 19 yds.

No. of yam plants in this portion = 51
No. " " cut vertically = 0
No. " " horizontally = 0

Length of bank excavated at less than working depth = 9 yds.

No. of yam plants in this portion = 29
" " " cut vertically = 0
" " " horizontally = 15
The scoop was not at the correct working depth at the beginning and end of each bank, and on two occasions when the scoop was lifted to decrease the draught because the tractor wheels were slipping. These figures suggest that the scoop is now at least wide enough. When it can be held at the correct working depth it operates successfully, but with this tractor it is very difficult to hold it at this depth.

2. Modifications (See diag. 6, plates 15-21)

Little more could be done with the machine in its present form because it was apparent that the structure was not strong enough to withstand the stresses involved.

The profile study indicated that the share need not be as wide as 24". This would therefore be reduced to 22". Now that the scoop was wider it was not necessary to have the side plates angled. These would therefore be replaced by straight sides, which should be stronger.

At times earth has reached the top of the scoop, fouling the toolbar cross frames. The new scoop therefore would be 4" deeper.

Discs were again to be fitted to the machine. Adequate penetration is not a problem. Therefore the bottom of the side plates would not be cut away, as suggested in the modifications considered, after Test 2 of Model II. The overall downward force on the machine (which controls its penetration) would be reduced by re-fitting discs. Ekids, therefore, would not be fitted until shown to be necessary.
MODEL IV

1. **TEST A. (2.4.57)**

The banks were first irrigated (about 1" of water applied the previous day) but not cleared of trash. The Old Farm Ferguson tractor was used fitted with steel wheel girdles.

For ten or twelve yards the lifter worked very well. Then it was noticed that the disc supports were beginning to bend causing the discs to converge. The test was therefore suspended.

When the tractor stopped, measurements were taken of the excavated bank in and around the scoop, with the latter still in position. These measurements are noted on diag. 7.

The two discs were probably working closer together than is either necessary or desirable. The above measurements show that they are cutting about 4" inside the side of the scoop, reducing its effective width.

2. **Modifications** (see sketches & photographs).

   (a) Extra supports to be fitted to disc arms - in form of cross braces.

   (b) Disc angle to be decreased so that discs cut about 2" inside scoop. The minimum distance between discs would now be 18". These modifications were effected (the method of disc adjustment is shown in plate 21). It was also decided that for the next test the new Ferguson 35 would be used. This had more power, better wheel traction, and much improved depth control.

1. **FIELD TEST B (8-9.5.57)**

The field was not previously irrigated, and was very hard. The tractor used was the new Ferguson 35.

A trial run was made and it was immediately apparent that although the discs were operating efficiently, trash was not cleared from the centre of the bank and this was piling up against the new disc iron braces. Since these were merely a temporary remedy to strengthen the disc supports and did not affect the principles of the machine's operation, it was considered that
raking the banks clear of trash would be justified. This was done and there was no further trash accumulation. However, the cross bars did limit the depth to which the scoop could be allowed to penetrate. Mainly for this reason the tips of several deep tubers were broken, although not actually cut.

The tractor was being driven slowly (in 2nd gear low range). Unfortunately no meter was fitted to indicate the actual speed. Several runs were made in this fashion. Fracture of the soil and therefore tuber exposure was good. The tubers could easily be lifted out by hand but it was found that even better results were obtained by using a miniature hand fork (3" prongs) to move aside the larger clods.

Several times the tractor wheels started to slip, but the new hydraulic system immediately eased the draught by lifting the scoop a mere two or three inches. No particular tuber damage was noted as a result. The scoop drops again as soon as the tractor is moving. Some 26 cwt. of yams were lifted in this way with very little tuber damage.

It was then found that if the tractor was operated at higher speed (3rd gear low range) - equivalent to a fast walking speed, there were no stoppages due to wheel spin. Presumably the momentum of the tractor and implement carried it past obstacles. Two runs were made like this. Exposure was considerably better; the whole bank was shaken up more thoroughly and the tubers tended to come to the surface. Tuber damage was less than at the slower speed.

Unfortunately the machine could not withstand the greater stress resulting from the increased speed. First the share bent (plates 16 & 17). It had been curved as a section of a cylinder with the axis of curvature running horizontally and at right angles to the path of travel. It was now bent; still as a section of a cylinder but with its axis running parallel to the direction of
travel but inclined downwards.

This new shape of the share increased the draught still further, and, as a result, the bolts holding the scoop support bar to the forward toolbar frame bar sheered. The fracture occurred in the shank, which was 7/16" in diameter, and made of mild steel.

These were replaced, and the draught was decreased by tilting the scoop backwards. This was achieved by lengthening the top link of the tractor hydraulic lift to its full extent.

A further run was made, again at high speed. Exposure was even better. Some forty yards of bank were excavated at this speed before and after the share bent but not a single tuber was damaged. The new angle of the share meant that the scoop dug much more deeply than before, so it was raised slightly.

The test was concluded when the toolbar bolts broke a second time.

It was noted that at all operating speeds tested the clods were as large or larger than the yam tubers. This means that separation of the tubers by size sifting would not be possible. (See plates 25 & 26).

2. Modifications (See Plates 18 - 20).

Time was now short. Therefore no attempt was to be made to straighten the bent share, but a piece is to be cut from the front of the share, making the point more obtuse when viewed in plan. (See plates 18 & 19).

This will considerably reduce the timing force (moment) exerted on the toolbar by the downward soil force on the share. It was this moment that caused the toolbar bolts to sheer.

1. TEST C. 27.5.57

This test was not a satisfactory one. It was not possible to wait for rain, as had been hoped, so the ground was still very hard. The only yams left to lift were those laid out for a timed trial of the final model, plus two short disced rows. Uniform irrigation of the whole trial area was impracticable. The two
discard rows were lifted first. Apparently it was difficult to achieve adequate penetration. Shortening the top link of the lift system as far as possible did not correct the situation, although it did improve it. The yams of the trial area were next lifted. Full results are reported in the next section. Only towards the end of the trial was it possible to achieve adequate working depth. It was then realised that the hydraulic lift controls had not been operated properly (the 'draught control' lever had been pushed down as far as it would go. This appeared to render the automatic draught release systems inoperative). It would probably have helped if the discs could have been raised, but they were already as high as they would go. Further upward adjustment was limited by the screw of the adjustor and the hydraulic lift arms.

The machine showed a tendency to crab, always to the off-side. This tendency and its correction has been discussed in test (1) report of Model II. Unfortunately the fault, and the raising of the near side disc to correct it, did not occur until near the end of the last row. It was therefore not possible to test the results of the correction properly.

Exposure of the tubers was good, comparable with that in test B of Model IV. Unfortunately a large percentage were damaged — nearly all of these were cut horizontally because the scoop was not deep enough. A few were cut vertically when the lifter crabbed.

No structural weaknesses were recorded.

The test was concluded when there were no more yams to lift.

This final model is drawn in detail in the section on Illustrations.
THE FINAL MODEL

Field Trial

The field test (C) of the final model, Model IV, showed that it was capable of loosening and exposing the yam tubers, inflicting negligible damage on the tubers as it did so.

It remained to prove that this in fact saved an appreciable amount of labour at harvesting. Therefore a trial was laid out to compare hand lifting with machine lifting.

Layout

Sixteen adjacent rows, all of reasonable uniformity were selected. Each was 80' long. The area formed a square block. The average spacing of the banks therefore was 44" (centre to centre). The area was divided into four plots, each of four adjacent rows. The first plot was machine lifted, the next hand lifted, the next by machine and the last by hand.

Procedure

The plots machine lifted had the lifter driven along. This operation was timed. The tubers were then lifted from the soil by hand (using the miniature hand fork) cleaned and placed in heaps in the furrow. This operation was also timed.

The hand lifted plots were dug with a digging fork in the traditional manner, and the yams lifted, cleaned and placed in the furrows as with the machine lifted ones. The time taken to complete the whole operation was recorded.

The time taken to transport the yams was not recorded as this operation was not aided by the lifter.

A gang of the same three men harvested each plot. In addition the yams from each plot were divided into damaged and undamaged, and each lot was weighed separately.
Results.

<table>
<thead>
<tr>
<th>Plot</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
</table>

Time taken in minutes:

(a) in Plots 1 & 3, to lift tubers clean and lay them in furrow.

(b) in Plots 2 & 4, to dig, lift, clean and lay tubers in furrow.

<table>
<thead>
<tr>
<th>Number of tubers damaged</th>
<th>263</th>
<th>26</th>
<th>171</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of tubers damaged (in lbs.)</td>
<td>520</td>
<td>35</td>
<td>330</td>
<td>59</td>
</tr>
<tr>
<td>Weight of undamaged tubers (in lbs.)</td>
<td>476</td>
<td>889</td>
<td>319</td>
<td>977</td>
</tr>
<tr>
<td>Total weight of tubers (in lbs.)</td>
<td>996</td>
<td>924</td>
<td>649</td>
<td>1036</td>
</tr>
</tbody>
</table>

In addition tuber damage was so high that the machine dug plots had to be dug over again by hand to retrieve the broken pieces. This took 15 minutes on Plot 1 and 20 minutes on Plot 3. It took 14 minutes to operate the lifter on the two plots (average 7 men per plot).

Discussion

This trial was unsatisfactory for several reasons, all resulting from a chronic lack of time.

1. The tractor operator and experimental staff did not have time to acquaint themselves fully with the operation of the machine. The direct result of this was the very high degree of damage inflicted on the tubers. This was excessive and disappointing.

2. The trial had to be carried out under very adverse soil conditions as it was not possible to wait for the necessary rain. Neither was it possible to irrigate the whole experimental area uniformly. This increased the tuber damage both in machine and hand dug plots.

3. After the machine had been used, the supervision of the trial and the recording of results had to be left to the farm staff. The accuracy of the results cannot, therefore, be vouched
for personally. Plot 3 would appear to have an unaccountably low yield.

The writer considers that the trial is of value in giving an indication of:-

(a) the possible time saving (hand digging took nearly three times as long to produce the same result),
(b) the degree of tuber damage which can result if the lifter is not used properly.

It should be stressed that in test B of Model IV the lifter caused absolutely negligible tuber damage.

**ASSESSMENT OF THE MACHINE'S VALUE AND SOME SUGGESTIONS FOR FUTURE WORK.**

It has been demonstrated that the final Model (Model IV) will loosen tubers in the bank so that they can easily be lifted straight from the soil. When the lifter has passed a section of bank, the appearance of the bank is as if a large fork had been thrust into the bank beneath a yam plant and forced upwards. The bank is burst open and the tubers exposed and moved towards the surface.

The original intention was to elevate soil and tubers, sift off most of the soil, and replace the tubers on the ground. It is considered that the action which has actually been achieved is far more satisfactory. Tubers and soil are moved a minimum distance. This reduces the power required to a minimum. If soil was lifted and dropped again power would be wasted.

Furthermore tuber damage is kept to a minimum. This is essential. Any tuber damage which does occur at the present is due not to bruising by the action of the machine, but by cutting by parts of the machine which are not in an optimum position in relation to the plants.

This may be caused by:-

1. Incorrect width of scoop.
2. incorrectly set discs.
3. incorrect working depth.
4. failure to keep to a straight line along the centre of the bank when working.

Incorrect scoop width would be a fault inherent in the design, and it is believed that testing has shown that this is not the case. The other faults can be corrected by a process of trial and error in the field. This emphasizes the necessity in the future for adequate use on a field scale for operators to become familiar with the machine; to learn what faults can occur and how these can be corrected. This, of course, is necessary with any implement; even, or particularly, the basic cultivation implement, the plough. But at worst the work done by an incorrectly adjusted plough can be ploughed over again. With the yam lifter incorrect adjustment causes irreparable damage.

This leads to another point which must be considered with reference to the existing yam lifter. Throughout, it has been recognized that it was a prototype, and if it was strong enough to be tested in the field for just long enough to show that it worked, then that was satisfactory. If it broke it could be repaired and made a little stronger. But a machine for field use must be much stronger, capable of withstanding continued hard work and occasional bad usage without permanent distortion. Therefore it is suggested that, although the present machine be tested, preferably to destruction under what would be its normal working conditions, a new machine should be constructed if it is to join the normal complement of farm machinery.

Some specific suggestions may be made here for consideration before the construction of a new machine.

1. **Scoop width.** This appears to be perfectly satisfactory, but more extensive testing is necessary.
2. **Depth of scoop.** This also appears to be satisfactory at the moment, but it is just possible that it may need to be
still deeper when dealing with dense vine growth. The difficulty which would then be encountered would be that the tip of the share would have a very small ground clearance when raised for transport.

3. The scoop to be built of much stronger (i.e. heavier gauge) steel.

4. It would be advantageous to remove the necessity for a toolbar by mounting the three point linkage pins directly and permanently on the scoop; this might also remove any necessity for deepening the scoop.

5. The Discs. These may need to be serrated to cope more efficiently with trash. They may also need to be of smaller diameter so that they can be raised higher without fouling the tractor lift arms.

6. Disc support. The existing ones must certainly be replaced by something more permanent. The following arrangement has been suggested:

   (a) Mount disc on roller bearing on axle (as at present).

   (b) Support axle at right angles on a straight steel tube (or circular bar), say 2"-3" in diameter. Mount this in a concentric tube, within which it is a sliding fit. Weld the outer tube solid to the scoop. The inner disc supporting tube would be free to rotate and to move up and down in the outer fixed tube. It could be held in any desired position by a pin passed through both tubes. The disc angle on the existing machine appears to be satisfactory. In fact it is 0°, i.e. the disc is vertical. The lateral position of the disc axes are also satisfactory, but it would be advantageous to allow for adjustment of the disc angle. This could be done by rotating the supporting tube in the fixed tube. It should also be possible to adjust the working depth of the discs. At present, they are used in the highest position possible. It is impossible to raise them any further with the screw adjustment and
if it were, they would foul the tractor hydraulic lift arm. This situation must be remedied.

These are a few practical suggestions towards the construction of a field model.

Once a successful field model has been constructed and proved, a system of field management must be worked out. This work could, of course, be started with the existing machine. Time and motion studies are necessary to find the optimum labour force necessary to make efficient use of the machine. Only then will it be possible to give a true picture of the economies which the machine can effect. No attempt has been made to give an estimate of the cost of the existing machine, as this would be quite unrealistic even were it possible.

To sum up, one may say that the original object of the project has been successfully achieved. A machine has been produced which can efficiently replace hand labour in harvesting yams. It remains to incorporate the machine into regular farm practice.
Diagram 1. Measurements taken during excavations and profile investigation

(a) As seen in Section (i.e. profile)

Profile 6

Profile 5

Profile 4

Profile 3

Profile 2

Profile 1

Profile 1A

Bank under investigation

Baseline along base of furrow

Adjacent bank

b) Plan of Excavation
Diagram 2 - Example of Profile drawn from results of excavation study.

Old Farm - Plot I (See Appendix)

Outer limits of largest tubers - all others are within these limits

Profile IA (i.e. adjacent bark)
Plate 1

The first profile trench of a plot (See p.11). The square rule is in position to measure the height of the bank at the 2'6" mark. (The square is against the bank which forms the plot, but the trench is extended so that the profile of the adjacent bank can be recorded. The base line is in position in the right hand furrow. To the right of it is a spirit level used to ensure that the angle iron 'horizon' is truly horizontal. This latter is seen at the bottom of the trench, and is marked off at six-inch intervals.

Plate 2.

The measurement 'X' is being taken (see p.12). Soil has been removed from around the tubers, leaving them undisturbed. Subsequently, 'x' will be measured without moving the tubers. They will then be lifted and 'y' measured.

Plate 3

Sometimes manure and trash were seen when the profile trench was dug, (p.12). Here a particularly heavy deposit is shown.

Plate 4

Another deposit of manure, this time well rotted but very badly placed. It is all to one side of the centre of the bank.
Plate 5
Sometimes a trench had to be cut through the middle of a yam plant. This example is recorded because it gives a good idea of the typical shape and position of the tubers. It will be observed that both larger tubers seem to terminate their downward growth at the same level. Below this level the soil was very much harder than above it. (See p. 14).

Plate 6
The fourth profile trench of the plot has just been dug. It took three to four hours to complete one plot.
Plate 7

The two knife blades which together form the knife-gauge. The longitudinal bars and the tractor tool bar to which they are attached are just out of this picture, but can be seen in Plate 8. (see p.16)

Plate 8

The knife-gauge in use (N.B. the knives are set wider apart than in Plate 7). The line marked by the knives can be seen. Subsequently, a deep vertical cut was made along this line with a cutlass. If the knives were pushed any deeper they bent.
MODEL I (LIFTER UNIT)

a) SIDE ELEVATION

- Ferguson toolbar
- "support bars" forming floor of scoop
- "share" (edge ground)

b) PLAN

- Support bars forming base of scoop

b) PLAN

- Side plate

- Share 10" (measured at rear end of scoop)

- Scale - 1:10
Photographs of Model I taken after the test on 18/12/56 (see p. 23). The nearer support bar has been removed for the sake of clarity. The holes which allow for adjustment of the bars forming the base of the scoop have already been made. The horizontal chalk line on the side plate indicates where it is to be bent outwards to make the scoop wider. The bolts on the remaining support bar are for attachment to the toolbar.
MODEL II (Support bars not shown)

approx. position of disc and its support

a) SIDE ELEVATION

b) END ELEVATION

c) PLAN

disc angle = c. 30°

c. 12°

SCALE 1:10
Model II as tested on 12/3/57 and 16/3/57 (see p.26). Plate 11 shows the lifter mounted on the tractor as tested on 16/3/57. The wheel girdles were fitted to the tractor wheels for that test. The bars in the base of the scoop have been removed. On plate 11 horizontal white lines on the side scoop show where it is bent. (These lines are welding seams). The method of mounting the discs can be seen, and also the means of adjusting their length. This is shown more clearly on plates 21 & 22. (These show that some brackets, slightly modified, in use on another model). In plate 12 the extra support for the disc arm can be seen bolted to the inner side of the left hand side-plate.
**Diagram 5**  
**MODEL III (Support bars not shown)**

![Diagram showing relative positions of scoop, discs, and tractor](image)

---

a) Sketch (not to scale) showing relative positions of scoop, discs, and tractor (see plate 13) as in Test A

---

b) Section of front of scoop (discs not shown)

---

c) Same section as in b), but now as for Test D  
- N.B. skids (see plate 14)
Model III after test B. (see p.30). The support bars, obviously a weak point in the design, have bent. At the beginning of test A both discs were in position. The supports bent inwards. Both were removed for test B, but one was replaced before the photograph was taken in order to show their position. (N.B. the support bars are now fixed on the inner side of the side-plates). After this photograph was taken the support bars were cut at the bend (marked in chalk) and the toolbar bolted immediately over the scoop - as in plate 14.

With no other modifications test C was carried out but depth control was a problem. Therefore, the skids seen in plate 14 were bolted to the outside of the side plates, and this modification was tested in test D. This machine was moderately successful.
Diagram 6
Scoop Details of Model IV (see also Plan)

Diagram 7
Sketch of Cross-section of Bank as Lifter Passes
(from rear)

Toolbar across top of scoop

Side plate

Furrow cut by disc

Spoil from disc

Top of bank much broken and fissured

Measurements taken when scoop was stopped while lifting a bank in Test A
A view from above of Model IV as for test B. (see pp. 32, 33). The only modification made after test A was the fitting of extra cross braces for the disc supports. These are seen between the share and the toolbar. They are seen in more detail in plates 22, 23 and 24. The scoop is now directly beneath the toolbar, and the discs and front of the scoop fit between the tractor rear wheels. (The tractor is a new Ferguson 35). Long point of the share can be seen. Plate 20 will give a good idea of the side view, except that there the share has been shortened.
Indicate the extent of the bending of the share. (See p. 35). Diagram 6 shows its original shape. Plate 16 shows how it is bent laterally. Plate 17 shows how much it has bent longitudinally. Time was short, so that all that could be done was to shorten the share points.

Plate 16.
Shows the share before it was shortened.

Plate 19.
Shows the share after shortening, with the piece cut off. In this way the point was shortened by 7".
N.B. This should be studied in conjunction with Plates 15–23.

1. **SIDE VIEW**
   - Showing position of discs relative to scoop
   - Method of disc mounting and adjustment not shown
   - See photographs

2. **SECTION AB**
   - OF LIFTER (see Side View)
   - With position of discs superimposed

3. **PLAN OF LIFTER**
   - Showing relative position of scoop and discs

---

**Disc**

- Limits of vertical adjustment ± 30°
- Shown with existing supports
- Approx. position of section of scoop

**Side plate**

- Sharpened portion of side plate
- Plate for fixing lifting bracket

**Support bars**

- Support bars omitted
- 17°
- 10°
- 4°

**Scale 1:5**

---
The Final Model (Model IVC) as used in the Field trial (see p. 35)

Plate 20
Side view. The point of the share still projects below the base of the side plates, therefore the rear of the scoop is supported by a piece of timber.

Plate 21
A close up of the disc supporting bracket. A piece of 2" angle iron is bolted to the side plate. To this the base plate of the support bracket is fixed with two bolts. The rear one (seen in the photograph) passes through a slot in the base plate. By slackening the bolts, therefore, it is possible to rotate the whole disc support in a horizontal plane. The centre of rotation is the forward bolt, which cannot be seen, as it is within the base-portion of the bracket.
The camera is moved to the right from the position in which it recorded plate 20. Therefore it shows the inner side of the near (i.e. left hand) side of the scoop. It will be seen that the disc is fully raised. Further upward movement must be by repositioning the disc support bracket higher up the side plate.

Taken from in front and above the lifter. The cross braces are shown. These are purely a temporary expedient to stop the disc supports from bending inwards. Unfortunately they nearly touch the soil surface and tend to collect trash. They would render the machine inoperative under normal harvesting conditions.

The front of the scoop from near ground level.
Plates 25 & 26

Some of the work done in test B. (See pp. 33-35)
The lines on each side of the plate indicate the path of travel of the discs. In places, a clearly defined furrow is seen. In the upper half of plate 25 one has been thrown away from the camera by the further disc. The bursting effect of the lifter on the bank is shown. In plate 25, a tuber is particularly well exposed. In plate 26 just the neck of the tubers appear. This was the common appearance of tubers after the machine had passed. Usually it was possible simply to grasp the neck of the tuber and lift it out of the soil. Sometimes it was necessary to move large clods aside with a small hand fork.
APPENDIX

Records of
Excavation and Profile Investigation.

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S.E. = ± 3.8

S.E. = ± 3.7

Plot 2 - New Farm

Sum of squares (S.S.) = 3977
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S.E. = ± 3.8

S.E. = ± 3.7

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| 5             | 0  | 1½ | 4½ | 6½ | 7  | 7½ | ½  | -½ |    | 6               | 19 | 7  |      | 26  | 8          | 7                     | 2
| 6             | 0  | 0  | 4½ | 7½ | 7½ | 5½ | 3  | ½  | 3  | 7               | 16 | 7  |      | 23  | 5          | 3½                    | 2

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S.S. 6948
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S.S. 9916 14270
T² 16.100 2420.64
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Pooled Standard Errors were calculated for $X$ and for $(X + x)$. From these Confidence limits for $X$ and for $(X + x)$ were calculated.

The mean of $x$ values was calculated.

Therefore the width of a scoop which will cut a given percentage of tubers, given optimum operating conditions (see p. 13) will be equal to the mean of $x$ plus the respective Confidence Limits of $X$ and $(X + x)$. 

**Analysis of Results**

This is represented diagrammatically thus:---
NEW FARM

Mean of all values of \( x = \frac{541}{75} = 7.2 \)

Pooled variance of \( X = \frac{(\text{Sums of squares} - \text{Correction Factor})}{\text{degrees of freedom}} \)

\[
\frac{31329 - 10}{9} + \frac{3977 - 7}{6} + 2242 - \frac{12100}{6} \]

\[= \frac{672.1}{66} = 10.18 \]

\[\therefore \text{Pooled Standard Error of } X = 3.19 \]

95% Confidence Limits for \( X = \pm t \times \text{S.E.} \)

\[= \pm 2.0 \times 3.19 \]

(66 degrees of freedom)

\[= \pm 6.38 \]

98% Confidence Limits for \( X = \pm 2.66 \times 3.19 \)

\[= 8.49 \]

Pooled Variance of \((X + x)\):

\[
\frac{5617 - 10}{9} + \frac{7189 - 7}{6} + 4180 - \frac{24964}{6} \]

\[= \frac{568.6}{66} = 8.61 \]

\[\therefore \text{Pooled Standard Error of } (X + x) = \pm 2.93 \]

95% Confidence Limit for \((X + x) = \pm 2.0 \times 2.93 = \pm 5.86 \)

98% Confidence Limit for \((X + x) = \pm 2.66 \times 2.93 = \pm 7.79 \)

\[\therefore \text{Scoop width which will cut 5\% of plants} \]

\[= 6.38 + 7.2 + 5.86 = 19.44 \text{ (inches)} \]

and Scoop width which will cut 2\% of plants

\[= 8.49 + 7.2 + 7.79 = 23.48 \text{ (inches)} \]
OLD FARM

Mean of all values of $x = \frac{210}{42} = 5.0$

Pooled Variance of $X = \frac{78.6}{39} = 2.02$

Pooled Standard Error of $X = \pm 1.42$

95% Confidence Limits of $X = \pm 2.02 \times 1.42 = \pm 2.87$

98% Confidence Limits of $X = \pm 2.70 \times 1.42 = \pm 3.83$

Pooled Variance of $(X + x) = \frac{121.8}{39} = 3.12$

Pooled Standard Error of $(X + x) = \pm 1.77$

95% Confidence Limits for $(X + x) = \pm 2.02 \times 1.77 = \pm 3.57$

(39 degrees of freedom)

98% Confidence Limits for $(X + x) = \pm 2.70 \times 1.77 = \pm 4.78$

Scoop width which will cut 5% of plants

$= 2.87 + 5 + 3.57 = 11.4$ (inches)

and Scoop width which will cut 2% of plants

$= 3.83 + 5 + 4.78 = 13.6$ (inches)
BIBLIOGRAPHY


