FURTHER WORK ON THE DEVELOPMENT OF
A SIMPLE TRACTOR-MOUNTED YAM HARVESTER

by

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1958
D.T.A. Report

Submitted in part fulfilment for the
Diploma in Tropical Agriculture of the
Imperial College of Tropical Agriculture,
Trinidad, The West Indies.
ACKNOWLEDGEMENTS

I wish to express my thanks to the many people who have helped me in this project. Particularly my supervisor, Mr. P.H. Rosher, for his guidance, Messrs. Cook and de Peza of the Works Department, and Mr. Bally and his staff at Old Farm for their work and enthusiasm in making and testing the machine.
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INTRODUCTION

In Europe and North America the potato (Solanum tuberosum) is an important bulky carbohydrate food for industrial populations. Yams (Dioscorea spp.) have potentially a similar importance to the growing urban populations of the wet tropics. Unlike cereals (the alternative carbohydrate foodstuff) yams do not need a markedly dry season for ripening and harvest, and so are well suited to humid areas. They are quite easily stored but have the disadvantage not shared by cereals, of being too bulky and too fragile for easy transportation.

Because of the belief that yams could, in the future, play a large part in feeding industrial populations in the tropics, a programme of research has been undertaken at the Imperial College of Tropical Agriculture. Various aspects of their culture have been investigated; James (1953) studied the growth and development of yams, and devised a method of mechanically preparing the beds, and planting, which reduced manual labour considerably. Work is at present in hand (Falode, private communication) to achieve weed control by spraying, and is showing promise. The possibility of avoiding staking with bamboo by interplanting with maize to support the dense growth of vines has been investigated, and found to be impracticable. Teriba (private communication) has worked on the use of plant growth substances. One hormone which reduces sprouting has been used to lengthen the storage period. Another which breaks the dormancy period has been investigated so that out-of-season crops can be grown with the aid of irrigation. As this work is giving some success it may be possible to supply yams throughout the year. One of the biggest expenses incurred with the yam crop is that of hand harvesting. Warren (1957) published his D.T.A. report on work done to develop a simple tractor-mounted yam harvester. It is from his work that this investigation is a continuation.

The object of this project is, by making structural modifications and by estimating the extent of damage, to make an effective machine, to evolve an efficient system of field organisation, and to assess the resultant saving of labour.

By the time Warren drew his work to a close after several major modifications, he had made a machine which would satisfactorily loosen and partially lift yams. This machine, which was not tested adequately due to lack of time, was made up of several components: the scoop, a pair of discs, and a pair of beams (called "support bars" by Warren).
The scoop consisted of a share which actually lifted the yams, and a pair of side plates which carried the share. The beams connected the scoop to the tractor draw bar and also had the discs attached to them. A pair of discs was fitted to ease the passage of the scoop sides through the soil and to deal with trash which would otherwise block the scoop.

Warren suggested that as his scoop was bending, thicker metal should be used. In accordance, an identical scoop was made from \( \frac{1}{2} \) inch instead of \( \frac{3}{16} \) inch thick steel sheet. Also in accordance with his recommendation, the concave discs were mounted on sliding concentric tubes (stem and sleeve) so that their depth could be easily adjusted. This was to do away with the original unsatisfactory mounting and cross-braces which led to frequent blockage.

No fixed plan of tests could be made at the outset, but because of the nature of the problem of developing a machine, each test had to be made in the light of findings from preceding tests. Throughout the practical necessity of harvesting the crop quickly to avoid larceny had to be observed. There was no intention to use statistical methods since the saving made by the machine should be so outstanding as not to demand the use of such fine techniques. However, the damage percentages in Test 7 were found to be analysable, and an analysis was done.
PRE-HARVEST TESTS

Test I - First trial of Strengthened Machine
21.11.57.

The new scoop made of heavier sheet steel was tried without discs, using a Ferguson model T 20 tractor, which was expected to have inadequate power. The original 2-inch angle iron beams from Warren's machine were used.

With the scoop positioned almost directly under the tool frame (see diagram 'a' below) the tractor was driven on to a recently ploughed maize stubble. The share failed to penetrate, the scoop rapidly blocked with grass and tough dead stems and the tractor wheels spun easily in the soft wet soil. It was tried again on some land thickly covered with rhizomatous Bamboo grass (*Paspalum fasciculatum*). Here it penetrated about six inches and cut clearly through the sticky soil and grass until it was eventually blocked by the accumulation of rhizomes.

This was encouraging but it was thought that discs would have to be used to deal with the trash of weeds and yam vines. To make room for discs to be fitted the scoop was moved further back on the beams (see diagram 'b'), and the machine tried again in the field.

Again the scoop cut well, the share running about six inches below the surface. Though most of the Bamboo grass was severed easily, rhizomes gradually accumulated in front of the leading edge of the scoop sides. This caused a blockage and the angle-iron beams bent. (Warren had similar trouble, see p. 30 of his report).
Modifications Resulting from Test I

From the test it was apparent that stronger beams would be necessary to allow the scoop to be moved back to make room for discs. No heavier angle-iron or suitable channel girder could be obtained. Instead, 3 x 3 x \(\frac{1}{2}\) inch angle-iron was used, and welded to make two box girders of square cross-section (see photographs 1 - 9).

Three types of disc were chosen:

i) Concave discs, the original ones but mounted in an improved way. (See photographs 8 & 9)

ii) Plain discs, the coulters from a Ferguson mouldboard plough, 14 inches in diameter, to cut trash and make vertical slits just ahead of the scoop sides to reduce draught. (See photographs 4, 5 & 6).

iii) Scalloped discs, 20 inches in diameter, similar to the plain discs but of larger diameter, and scalloped to deal with trash more effectively. (See photographs 1, 2, 3)

Ferguson disc coulters were chosen as a set was available on the College Farm, and because they are likely to be already present on mechanised farms. The scalloped discs were to be made up in the workshop and used with the bearing from another pair of Ferguson coulters. Both they and the plain discs were mounted using the cranked stem and clamp from a Ferguson plough. To do this a short bar of steal (The beam extension) of similar dimensions to the front end of the plough beams, and similarly drilled, was welded to the front of each box girder (see drawings & photograph 3).
Each concave disc already had a stem one foot long, of one inch square mild steel bar. Seamless steel brine piping was fitted closely over these and welded securely at each end. This gave the discs stems circular in cross-section, and about 1 5/8 inches in diameter. The outer concentric tubes, or sleeves, were one foot lengths of seamless boiler tubing into which the stems fitted easily, but closely.

The box girder beams were bolted inside the top of the scoop as it was thought that if the sleeves were welded vertically on the outside of these (see diagram below) the position of the discs would approximate closely to that in Warren's machine.

The positioning of these disc mountings was investigated using scaled-down paper cut-outs of the discs which could be moved about on a drawing of the harvester.

The stems and sleeves were drilled so that a pin could be passed through and the discs would be at 30° to the line of travel, as they were in Warren's harvester. A series of holes in the stems gave a means of adjusting the depth of the discs.

The heels (see diagram below) of the scoop were cut off, because they added little strength to the scoop sides, and could only increase the draught.
Not only would draught be increased simply by soil-metal friction, but if the machine worked in such a way that the beams were not horizontal (see diagram) and dipped towards the rear, the heels would be running below the level of the share. When in work in the crop the harvester actually ran in this manner. By cutting through undisturbed soil below the level of the share the heels would increase draught to no purpose.

Finally a set of three holes at one-inch intervals was made at the back of each scoop side to act as a pitch adjustment to the share (see drawings, and photographs 1 - 6).

Test 2 - Test of new scoop and beams on trial banks 23.12.57

Three banks each ten yards long had been made up on the Bamboo grass area so that a realistic trial of the machine could be made. It had been hoped that the soil would consolidate and the rhizomes flourish to give realistic conditions of work. There was little rain after the banks were made, and at the time of the test the soil was knobly and loose, so conditions did not resemble those in the crop.

Before the machine was tested it was obvious that the concave disc mountings were too close, and that if the harvester was used like this, serious damage would be done to the crop.

The scoop was used without discs on the mock banks; it did not penetrate well, and merely scattered the loose soil. However, penetration was good on flat undisturbed land, and a clean cut 6 - 8 inches deep was made in wet sticky soil thick with Bamboo grass. The scoop was run through the ground for some time to polish the metal, and to match maximum working depth with tractor power.

The plain discs were fitted, and found to work well cutting the soil and rhizomes to make slits ahead of the scoop sides.

From the apparent ease with which the tractor worked it was concluded that the removal of the heels of the scoop had effectively reduced draught. The beams proved to be of ample strength, and contrary to expectations, there was no sign that the bolts which joined the scoop to the beams would shear.
Modifications resulting from Test 2

No alterations were made as a result of the test, but new sleeves were fitted to mount the concave discs further apart. Holes were cut through the box girders a short way behind the original sleeves (to avoid fouling the tool bar connection to the top linkage.) The sleeves were drilled to take the pin which fixed the stem, and were welded through the holes cut in the beams.

As the plain discs worked so well the manufacture of the scalloped discs was pressed forward. The bearings and cranked stems from another pair of Ferguson disc coulters were used. Because these new discs had a greater diameter, the component which holds the two ends of the disc axle and articulates with the cranked stem had to be remade with longer arms (see diagram page 4).

HARVESTS TESTS

DESCRIPTION OF AREA

All the tests except the last (test 7) were done on a crop of Lisbon Yams (Dioscorea alata) growing in Field 25 of Old Farm, I.C.T.A., on a soil classified by Chenery (1954) as St. Augustine loam. The field measured 150 - 28 yards, and had an area of 0.86 acres. It had been prepared by disc ploughing and had been opened with a mould-board plough to make trenches which were filled with trash by hand during March. The trenches were closed using tractor-mounted ridging bodies, and the banks thus formed were shaped by hand. The field was in two cambered beds both having ten banks, each 150 yards long. At planting time in June the banks had a height of about one foot between crest and furrow bottom, but by harvest time in mid-January had consolidated to between six and nine inches.

Test 7 was performed on part of Field 28 in an area 124 x 12 sq. yards which was made up into two beds of four banks each. This field too, was on St. Augustine loam according to Chenery.

The bamboos used for trailing the yam vines were removed by farm staff because in normal practice, outsiders wanting firewood come with carts and take them away. In normal years the rains stop earlier than they did this year and the vines wither up. This year at harvest time the trash was still green and extremely tough, which made harvesting more difficult (see photographs 10 & 11).

When work started in mid-January the soil was damp enough to adhere to the tubers and necessitate hand cleaning, but not sticky and difficult to drive and work on. In the two weeks over which harvesting was spread, considerable drying occurred, the soil hardened making hand digging difficult.
Due to the relatively dry rainy season the yams were poorly developed, so the incidence of damage was probably less than in normal years.

Test 1 - A Simple Test of the Capabilities of machine on trash-free banks.
14.1.58

This was a simple trial of the harvester to assess its general performance on yam banks from which the trash of vines and weeds had been removed to make working conditions as easy as possible. Two banks had been completely cleared of trash, but only about ninety yards of one of them was used in this test.

First, the machine was used without discs of any sort and with the share at minimum pitch. After a short run of about twenty yards the plain discs were fitted, and after another short run the share pitch was varied.

When no discs were used the scoop ran through the soil at a depth of 4 - 6 inches. Even at this depth which was not the maximum allowed by the tractor hydraulics, the tractor (Ferguson 35) was at the limit of its power. Few yams were cut, those that were were cut vertically by the scoop sides due to the yams not growing centrally in the bank.

The plain discs appeared to reduce draught considerably, and as a result the working depth could be increased to 6 - 8 inches. Although the scoop ran through the soil cleanly and easily it did not disrupt the bank nearly enough. The disturbance consisted merely of two parallel cuts made by the scoop sides, and a few transverse cracks. The pitch of the share was increased first by one hole, and later by two, without impairing its running qualities, but with only a slight increase in the disturbance caused to the bank.

When the plain discs were fitted the harvester could be run satisfactorily with the share 6 - 8 inches below the bank when the tractor was in low third gear. This depth seemed adequate since few yams were cut; though no measure was taken of the extent of damage. Even with the share set at maximum pitch the soil of the bank was not disrupted enough. Consequently the yams had to be dug out by hand using forks and it seemed that little saving in labour was achieved.
Modifications resulting from Test 1

No structural modifications were made to the harvester, but in all subsequent tests it was worked with the share set at maximum pitch.

A scale of inches was painted in white on each of the scoop sides, to give some indication of the depth at which the harvester was working.

As can be seen from the diagram the two scales will read differently according to the symmetry of the bank, and will always give readings lower than the true depth of the share below the crest of the bank.

The suggestion was made that fines or bars fitted to the back of the share would lift the soil higher and break it more. Probably some soil would fall between the bars to expose the yams more. This modification was deferred until more tests had been made with the existing machine.

Test 2 - A simple test to assess the incidence of damage.  
21.1.58

The primary object of this test was to make an estimate of the extent of damage done to the yams in the course of harvesting.

The remainder of the two banks cleared for the previous test were used. Though only a week later, the soil had dried noticeably since the first test. The banks were divided into ten-yard lengths and the tractor and harvester drive through, using the plain discs.

Two men were set to dig these ten-yard sections, and the tubers from each section were collected into a sack and labelled. There was insufficient time to dig all the loosened yams, the remaining ones were dug next day by the farm staff who collected & labelled the several sections.

The bags of yams were sorted into damaged and undamaged, and the numbers and weights of yams involved, recorded. The percentage of damaged yams to the total was calculated for each sample, the mean and range of these percentages are given in Table I.
TABLE I

<table>
<thead>
<tr>
<th></th>
<th>MEAN</th>
<th>RANGE</th>
<th>No. of SAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Damage by weight</td>
<td>13.1</td>
<td>0.6 - 35.2</td>
<td>14</td>
</tr>
<tr>
<td>% Damage by numbers</td>
<td>10.7</td>
<td>2.0 - 28.4</td>
<td>13</td>
</tr>
</tbody>
</table>

Fuller details are given in Appendix I

From the nature of the damage - the preponderance of rough fractures and prong marks, and the rareness of clean cuts - it was apparent that much of the damage was done by the men digging, and little by the harvester.

The assessment of damage by weight and by numbers, are both imperfect measures. By weight because larger yams are more prone to damage and because fragments are unavoidably left in the soil, and by numbers because cut fragments of one yam tuber may be counted as several damaged yams. In larger tests made subsequently yams were too numerous to be counted, so damage was assessed by weight alone.

From this test it was concluded that the percentage of damage was not excessive and that little of the damage was attributable to the machine. The scoop ran through the cleared banks without difficulty, but the soil was not disrupted enough and digging was still very laborious.

Test 3 - To test the different types of disc. 22.1.58

From the previous tests on trash-free banks it was obvious that the harvester worked fairly well. In this test it was intended to try the effect of the different types of discs with the harvester on working on banks which the trash still lay (Photographs 11 & 12).

The bamboos had been taken from the area, but the vines still lay on the banks. Though the dry season had advanced far enough for the soil to be noticeably harder, the vines were still green and tough.

An attempt was made to run the entire length of banks using the harvester first without discs, and then with the three different types of discs; using four banks in all.
Without discs the harvester blocked seven times in a distance of about eighty yards which took six minutes. At each blockage the harvester was raised on the tractor hydraulics and extensive damage done to the yams. Thus performance was so poor that the bank was not finished. Digging this stretch took six men twenty-four minutes. The yams were collected, taken to the farm, sorted into damaged and undamaged and crudely weighed on the weigh-bridge. The results were:

<table>
<thead>
<tr>
<th>DAMAGED</th>
<th>UNDAMAGED</th>
<th>TOTAL</th>
<th>% DAMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 lbs</td>
<td>265 lbs.</td>
<td>385 lbs.</td>
<td>31</td>
</tr>
</tbody>
</table>

When the plain discs were used a whole bank was lifted in spite of frequent blockages, but took the excessively long time of fifteen minutes. Five men were set to dig; they were idle, and took an hour to dig the bank. As with the previous bank the yams were collected, sorted and crudely weighed, with the result:

<table>
<thead>
<tr>
<th>DAMAGED</th>
<th>UNDAMAGED</th>
<th>TOTAL</th>
<th>% DAMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>140 lbs</td>
<td>535 lbs.</td>
<td>675 lbs.</td>
<td>21</td>
</tr>
</tbody>
</table>

The scalloped discs were used on the next bank; it was thought they might deal with the trash more easily. A whole bank was loosened in ten minutes, and there were six blockages in the 150 yds. Five men took fifty minutes to dig the yams. Sorting and crude weighing gave the values:

<table>
<thead>
<tr>
<th>DAMAGED</th>
<th>UNDAMAGED</th>
<th>TOTAL</th>
<th>% DAMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>145 lbs</td>
<td>590 lbs.</td>
<td>735 lbs.</td>
<td>20</td>
</tr>
</tbody>
</table>

A fourth bank was started using the concave discs but was not completed because of frequent blockages and obviously excessive damage. Although the discs were set at minimal depth nearly all the yams were cut. Since damage was so obviously excessive no measure was taken of it.

None of the discs tried would deal with the trash well enough to prevent blockages and the machine would not work in these conditions without discs. The scalloped discs were least unsuccessful, and the concave discs were completely unsuitable. The concave discs effectively threw the soil out sideways and the scoop broke up the soil much more than when the other discs were used. The minimum depth at which the could be set was limited by the beams, so cutting could not be reduced at all.
Only by first clearing away the trash by hand using brushing cutlasses could the machine be used to harvest a crop. With this done it could be used with the plain discs to cut any remaining scraps of trash and to reduce draught.

Test 4 – Trial of a method of field organisation
24.1.58

It was known that if the trash was cleared away the harvester with plain discs would loosen the banks without causing much damage to the crop. The object was to test a method of organising labour and machine in the field to find what rate of working could be achieved, and to assess percentage damage when working on a fairly large scale.

An area containing six banks each 150 yards long was cleared of trash by cutlassing before the test was started. It was divided transversely into ten equal sections and marked with stakes, so that each of ten men had six fifteen-yard sections to dig.

Work was done bank by bank; the harvester was taken down the first bank and as it passed him each man began digging in his section. When work was finished on the first bank the tractor was driven down the second bank, and again the men started digging. So work proceeded.

Out of the ten sections in each bank two were chosen at random, and the yams from them bagged and labelled as samples for an estimation of damage. For each bank two men were chosen, also at random and timed while digging. To begin with the two men timed were not the same as those from whom damage samples were taken. It proved difficult to watch and sample four different men, so after the first two rows the same two men were timed and sampled for each bank.

Since this and the next test were so similar the results are treated together under Test 5.

Test 5 – To test another method of field organisation
24.1.58

This trial of labour and machine organisation was a continuation of the previous test, number 4, and was done on the same day on an adjacent area containing five banks each 150 yards long.

In this case the trash had not been cleared. The ten diggers had to clear their sections of each bank before the harvester was driven through, and they could start digging. Work was done row by row as in the previous test (See photographs 12 & 13).
For each bank two of the men were chosen at random, timed while they cutlassed the trash and moved it a few feet on to already harvested land, and while they dug the yams (which were taken as damage samples), again the tractor was timed as it drove with the harvester down each bank.

Plain discs were used throughout tests 4 & 5 as the amount of trash remaining was slight. On the last row lifted in Test 5, however, the scalloped discs were tried but made no difference. There was slight accumulation of scraps of trash by the time the harvester reached the end of a bank, but this was not serious. The machine worked satisfactorily throughout, the share running 6 to 8 inches down according to the scale or the scoop side, and actually deep enough not to damage yams a foot long.

As tests 4 & 5 were almost identical the results from both were treated together. The means and standard errors (5% significance) of the times, and the mean and the range of the damage percentage were calculated and are given in Table 2.

| TABLE 2 |
|------------------|--------|----------|
|                  | MEAN   | S.E. OF MEAN | NO. OF READINGS |
| Tractor time     | 2m 27s | ± 8s      | 10 |
| Digging time     | 11m 52s| ± 1m 11s  | 18 |
| Clearing time    | 3m 38s | ± 29s     | 8  |
| % Damage         | 13.8   | 0.9 - 46.4 | 19 |

After working for about 2½ minutes lifting one bank the tractor stood idle for about twelve minutes (or about a quarter of an hour in test 5 when the men had to cutlass the banks) while the men were digging, before being able to lift the next row. To reduce this waste of tractor time by increasing the number of men digging would be impracticable because about six times as many men would be needed to keep pace with the tractor.

With the cost of the tractor and operator at $1.60 (about six shillings and sixpence) an hour the time spent standing idle would have to be minimised. A new method of organising the field work was devised in which the area would be cutlassed first, the harvester would work for a short time to loosen the banks, and then go away to do other work while the men continued to dig the loosened tubers.
Test 6 - A Confirmatory test 25.1.58

Three banks of yams not enough for a full test remained in the field. By now the soil was drying rapidly, about two-thirds of the way from the western end of the field an exceptionally hard dry area of gravel was met with, where the machine ran shallow at about 4 inches according to the scale. This had been noticed the previous day in Test 5. The last of the three banks was partly overgrown by the field of cane which was adjacent on the north side.

Because the area was so small only six men were used to dig, which caused even more tractor time to be wasted by standing idle. The banks were marked off into six equal sections. The work was done row by row; the men first cutlassing off the trash, and then digging the yams after they had been loosened by the harvester.

The machine was tried on the first bank using the concave discs but after about twenty yards they were abandoned and replaced with the scalloped discs, which it was thought would be best on the overgrown banks next to the sugar cane. In an attempt to disturb the banks more the tractor was driven faster, at full throttle in high first gear, (as opposed to low third in the previous tests,) except in the overgrown row when the lower gear was used.

One section from each bank was taken at random as a damaged sample. While working on banks 2 & 3 one man, chosen randomly was timed as he did his various jobs.

The extent of damage was much higher; the mean of the three samples being 35.8% the range 29.3 - 46.8%. This was thought to be due to the higher tractor speed and resultant shallower working.

The times recorded were:

<table>
<thead>
<tr>
<th>BANK</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutlassing time</td>
<td>6m 0s</td>
<td>8m 45s</td>
</tr>
<tr>
<td>Waiting</td>
<td>5 30</td>
<td>5 45</td>
</tr>
<tr>
<td>Digging</td>
<td>17 30</td>
<td>17 15</td>
</tr>
<tr>
<td>Waiting</td>
<td>3 0</td>
<td></td>
</tr>
<tr>
<td>Tractor time</td>
<td>1 45</td>
<td>3 15</td>
</tr>
</tbody>
</table>

In the case of bank 3 the cutlassing time and the time taken for the tractor and harvester to pass down the row (it blocked twice) were unrealistic as the bank was smothered by the cane.

So much time was spent waiting presumably because the man worked more quickly than the others. The digging time of 17m 30s for a 25yd section is better than the average of about 12m for 10yd sections in the previous test, which is surprising since the men were not on piece work as in tests 4 & 5.
The concave discs were abandoned as useless because they "crabbed" badly, they cut unevenly into the sides of the bank, slewed the tractor & harvester round, making it impossible to steer. Determined holding on to the steering wheel was completely ineffective. Excessive damage was done to the yams. Several fresh starts were made after straightening the tractor, but crabbing occurred repeatedly.

Modifications

i) The concave discs were rejected as they made the tractor and harvester unmanageable and did so much damage. The outer sleeves were later cut off flush with the box girder beam as they tended to collect trash. Though the scalloped discs worked no better than the plain, and were less desirable because they were more expensive, they were retained in case more difficult conditions occurred elsewhere.

ii) It had been apparent since the earliest tests that the banks were not disrupted near enough, and that as a result digging out the yams was still very laborious. It was thought that if several steel bars were fixed to the back of the share they would continue the upward movement of the soil passing over the share.

The bars which were fitted caused an extra drop of about four inches off the back of the share, which should break the soil more and expose the tubers. It was hoped that some soil would fall between the bars exposing the yams even more. Warren tried a set of bars to sieve off the soil in his original machine, Model I, but found that the resultant resistance to soil passing through the scoop caused immediate blockage.
Whereas in his machine Warren had four bars fixed in a scoop twelve inches wide, in this case four bars were spaced across a scoop twenty-two inches wide. There was thus a space of about four and a quarter inches between the bars, as against two and a quarter originally. The bars which Warren called "elevator bars" were about twenty inches long, and attempted to raise the soil by about eight inches. The new ones had one foot of exposed length (another four inches was welded under the share) and were planned to raise the soil by about only 4 inches. These new bars, which were of half-inch mild steel rod, were bent downwards at the back so that no sharp edges projected to damage the tubers as they fell off the back. (See photographs 2, 5, 6, 7, 8 and drawings).

Test 7 - To test a new method of field organisation.
28.1.58

Since so much tractor time was wasted when the banks were cutlassed, loosened, and dug one by one, another method in which the tractor could work for a short while loosening the yams, and then go away to do other work, was devised.

A small area of yams 124 yards by 12, was situated in Field 28 where the soil was classified as St. Augustine loam by Cheney(1954). It was made up into two beds each containing four banks. The planting practice, and condition of the crop was similar to that in Field 25. Before work began the whole area was cleared of bamboos and of trash by cutlassing.

So that a comparison could be made between the damage done and the time taken in hand and machine-assisted harvesting, the field which was 124 yards long was divided into 100 yards (made up of ten 10 yd sections) which were loosened with the machine, a four-yard discard (marked with lime for the tractor driver to raise and lower the harvester out and into work), a ten-yard section dug by hand, and a discard of about ten yards where the tractor was turned, as the boundary at this end of the field was a deep ditch. Both the discard end and the turning area were dug by hand as the men worked along the banks, but these were not part of the experiment.

Four workers were set to dig the loosened banks, each dug two whole banks (the entire 124 yds of each) by early afternoon. They were timed while they were digging the 100 yard loosened part of each bank, and two of the ten 10-yard sections were chosen at random and the yams collected as damage samples.
All the eight hand dug sections were taken as damage samples and the workers timed while they were digging them. Thus for each bank there were three samples for damage estimation; one, the yams from the hand-dug section, and two chosen at random from the ten machine-loosened sections.

The harvester was used with the plain discs and worked throughout without blocking but accumulated a slight amount of trash by the end of each bank. The effect of the bars was to raise and shatter the soil much more, but no soil fell between them. After six rows had been loosened the machine was sent away and the two outer bars removed, leaving only the two centre ones. It was hoped that soil would fall down these wider spaces and that the soil passing over the two remaining bars would break longitudinally to expose the yams more. This did not happen, though the soil did seem to be shattered slightly more.

The tractor was timed only over the first four banks which it lifted in seven and a half minutes. It seems reasonable to suppose that if it had continued to work through the whole eight banks it would have done so in a quarter of an hour, i.e. 8 - 100-yd stretches, or 1200 sq yds in 15 minutes.

The actual time spent by each man digging on the machine-loosened and the undisturbed sections were recorded. From these times and the weights of yams dug the rates of digging was calculated and are given Table 3.

**TABLE 3**

a) Digging two 100-yd lengths of loosened bank

<table>
<thead>
<tr>
<th>MAN</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Mean 2 hr. 50m</th>
<th>Rate Per Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME (hrs)</td>
<td>2.34</td>
<td>2.46</td>
<td>3.10</td>
<td>2.47</td>
<td>1106</td>
<td>400</td>
</tr>
<tr>
<td>WEIGHT OF YAMS (Lbs)</td>
<td>1182</td>
<td>1054</td>
<td>1232</td>
<td>950</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) Digging two 10-yd lengths of undisturbed bank

<table>
<thead>
<tr>
<th>MAN</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Mean 34m 0s</th>
<th>Rate Per Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME (Mins &amp; secs)</td>
<td>36.30</td>
<td>31.50</td>
<td>34.00</td>
<td>34.20</td>
<td>125</td>
<td>220</td>
</tr>
<tr>
<td>WEIGHT OF YAMS (Lbs)</td>
<td>127</td>
<td>117</td>
<td>136</td>
<td>120</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fuller details given in Appendix 3.
The tractor was driven in low third gear at full throttle, at which speed the share ran 6 - 8 inches deep according to the scale. Damage was more serious in the case of hand digging; see Table 4.

<table>
<thead>
<tr>
<th></th>
<th>MEAN</th>
<th>RANGE</th>
<th>No. of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand digging</td>
<td>19.1</td>
<td>7.6 – 40.3</td>
<td>8</td>
</tr>
<tr>
<td>Machine assisted</td>
<td>9.3</td>
<td>0.0 – 25.5</td>
<td>16</td>
</tr>
</tbody>
</table>

On conversion to radians and paired analysis, the damage done in hand harvesting was found to be significantly greater than that done in machine-assisted harvesting. (Details are given in Appendix 4.)

Hand digging was very difficult, and, consequently, the extent of damage was much higher. The incidence of damage on the hand harvested sections was about the same as that recorded in previous tests after machine lifting, while the machine damage in this case was reduced to about half. One man dug with his hands all day, while the others used their forks much less than in previous tests. (See photographs 14 & 15)

INVESTIGATION OF EQUIPMENT FOR CLEARING TRASH

It had been felt from the outset that the presence of a dense growth of vines would be a serious hindrance to the working of the harvester even though it was equipped with discs. The vines of a yam crop are not only abundant but extremely tough and resistant to breaking or cutting. Normally a major problem, it was worse this season as the dry season was late starting so the vines were still green. Two pieces of equipment were tried:

- Towner Disc Ridging and Bordering Assembly-

This tractor-mounted gang of heavy discs made up of two opposed sets was tried on level land. The sets of discs had vertical and horizontal adjustment but difficulty was encountered in setting them close enough to straddle the yam banks. They cut deeply on the flat land and were not difficult to steer but were abandoned as they could not be set closely enough.

- Brush Cutter -

This tractor-mounted equipment commonly used for dealing with weeds and bush in orchards and plantations in the tropics.
In normal practice it is used on flat land, and is very effective. Taken over yam banks with the tractor astride the bank the brush cutter cleared a wide strip along the ridge. It cut up quite dense masses of vines without damaging the tubers. Blockages did occur, not in the blades as expected, but at the universal joint of the power-take-off shaft where a projecting pin tended to wind on vines.

When this had been done the harvester fitted with the scalloped discs was driven along the banks. It quickly accumulated a mass of rhizomes of bamboo grass which infested parts of the area. These caught on the downward projecting sleeves for mounting the concave discs (these were later removed) and a mass of soil and rhizomes formed a congestion inside the scoop building up against the box girder beams.

The resultant increase in draught caused the harvester to be raised by the tractor hydraulic system, which caused many of the yams to be cut horizontally by the share.

Now that the concave discs had been rejected the outer sleeve mountings could be cut off. This was done later. But because of the construction of the tractor tool bar the beams could not be fixed outside the scoop sides instead of inside.

Modifications.

1) The sleeves for mounting the concave discs were cut off.
2) It is suggested that a special tool frame be made up to mount the harvester on the Ferguson 3-point linkage so that the beams could be fitted outside the top of the scoop sides, there being no longer any reason for having them inside when the concave discs are not being used.
DISCUSSION & CONCLUSION

In some ways the yam crop is an easier one to harvest than the potato crop. Each potato plant has several small tubers which are distributed throughout the bank, and are virtually unconnected to one another. To harvest them a machine must expose every tuber so they can be picked up by hand. This means that a great deal of earth has to be moved. Because yam plants have only one, or a few large tubers which are joined at the crown, and which do not spread widely or grow deep, they are more easily lifted by machine. The present harvester has the effect of a wedge pushed along under the bank which raises the tubers slightly exposing them to view and disrupts the bank making it easy to pull the yams out.

The two pre-harvest tests and the first three harvest tests served to show how the harvester would behave when in work, what modifications needed to be made to make it work efficiently, and what were its limitations. In subsequent harvest tests a system of field organisation was evolved and proven.

The two pre-harvest tests were done on fallow land. The first showed that if the concave discs were to be mounted in an improved way and if other sorts of discs were to be tried, the scoop would have to be positioned behind the tool bar instead of directly below it. To do this stronger beams would be necessary to withstand the turning moment which otherwise would be taken by the tool bar.

The second of these tests demonstrated that the new box-girder beams were of ample strength, and that the disc coulters from a Ferguson mould board plough effectively eased the passage of the scoop through the soil. The machine behaved well when in work; this was thought to be due to the removal of the heels of the scoop sides which effectively reduced draught.

It was thought that the presence of a dense mass of yam vines would be a severe hindrance to the harvester. To deal with this, three types of discs were available and could be quickly fitted to the harvester.

Throughout the harvest tests samples were taken to assess the extent of damage done to the crop. In a test done by Warren (p. 38) about 50% of the yams on machine-loosened plots were damaged, compared with about 5% on hand-dug plots.
The first harvest test showed that the harvester worked promisingly on trash-cleared banks, but that without discs to reduce the draught the Ferguson 35 Tractor was at the limit of its power when in low third gear. The pitch of the share was increased in an effort to increase the disruption of the bank. Even at maximum pitch the soil was not disturbed enough to make much reduction in the manual labour required to dig out the yams. It was suggested that some bars fitted to the share might help loosen the soil, but this modification was deferred till more tests had been done.

In the second test greater attention was paid to the incidence of damage. It was expected that the percentage of damaged tubers would be high and that this would preclude the use of the machine. With the tractor in low third gear and at full throttle the harvester could be run with the share 6 - 8 inches down according to the scale (which would mean about 10 - 12 inches below the crest of the bank). Working at this depth there was very little damage. About 13% by weight were damaged. It was apparent from its nature that little of the damage was inflicted by the machine.

If the bank could be disrupted more without damaging the crop in the process, less damage might be done in pulling out the loosened yams.

It was concluded from these tests that when the trash was removed from the banks to make working conditions as easy as possible the harvester behaved quite well in the soil, and did little damage.

For the third test the bamboos were removed, the vines were left lying on the ground. When tried without discs blockages were so frequent that it was clearly impracticable. Neither in this case nor when the concave discs were used was a complete bank loosened. The concave discs although set at minimum depth severely cut nearly every yam. They effectively threw the soil out sideways and the bank was well broken up. However, the machine blocked when ever it reached a thick mat of vines. The Plain and Scalloped discs were more effective and a whole length of bank was loosened with each. However, blocking was frequent, it took ten minutes with the scalloped, and fifteen minutes with the plain discs for the harvester to complete a bank. This, and the hour for five men to dig a loosened bank were clearly excessive. Only about twenty percent of the yams were cut according to the crude weighings made.

From this test it was concluded that none of the discs would enable the harvester to work on trash covered banks. It had been hoped that it would be possible to deal with the trash mechanically either by discs attached to the harvester or by some preliminary operation. The set of Towner discs was found to be unsuitable, and the Brush-cutter was not very successful though it did show promise.
These tests had demonstrated that if the vines were cleared away, the harvester fitted with either the Plain or Scalloped discs would work well without blocking and without doing much damage.

Subsequent tests to find an efficient system of field organisation were done using the Plain discs. These were as effective as the Scalloped in reducing draught, were cheap, and might be more readily available. Throughout these tests in which about an acre was harvested the machine worked well, and showed no signs of bending, and few of abrasion.

It became apparent that working row by row (a system used in England for harvesting potatoes) was inefficient because of the waste of tractor time. The time taken to dig out the yams was so great compared with the time for the harvester to loosen the banks that even a big gang of men would be unable to keep up with the tractor. When the banks were cleared one by one (Test 5) even more tractor time was wasted. There was further waste of time when the faster workers had to wait for the slower men to finish digging before the harvester could loosen the next bank.

In the final test (Test 7) an efficient method of working was proven. An area 100 yds by 12 yds (1200 sq. yds – nearly one quarter acre) containing eight banks, previously cleared of trash, was loosened in fifteen minutes, i.e. a rate of working of about an acre an hour.

The bars fitted to the scoop were effective in disrupting the bank because they raised the soil more and dropped it further back on to the ground. As a result it was easier for the men to dig out the yams, and less damage was done by their forks. The percentage of damage was just under 10% compared with about 20% for hand harvesting in the same test, and means of 13 to 36% in previous tests with the machine.

Machine harvesting caused significantly less damage than hand digging. In this case the soil had dried sufficiently to be really hard, which made hand digging difficult and very damaging to the crop. The season had been dry and, by all accounts, yields and tuber size were lower than usual. After a normal rainy season when yams were bigger it would be expected that more damage would be done by the harvester.

In a normal season the rains would have been less protracted and by harvest time in January the vines would have withered. In their green state they were difficult to deal with, the only possible course was to remove them, using cutlasses.
For the last test, clearing the trash off a quarter acre took twenty man hours and cost about seven dollars (B.W.I.) However, this would have been necessary in the circumstances, for hand digging, and was not an extra expense incurred because of the machine.

Cost of Harvester

Since the machine was under development many modifications had to be made, and much unnecessary work (e.g. the concave discs and their mountings) was done. The quantity of steel bought was excessive; twice as much angle iron and mild steel plates as was needed were obtained for the box girders and scoop, because only standard-sized pieces of material were available. Where this has happened an estimate is given of the actual value of material used.

The cost was:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>$ 39.65</td>
</tr>
<tr>
<td>Welding rods, gas electricity and tools</td>
<td>8.32</td>
</tr>
<tr>
<td>Materials:</td>
<td></td>
</tr>
<tr>
<td>½ inch plate (estimate)</td>
<td>24.00</td>
</tr>
<tr>
<td>3 &quot; angle iron (estimate)</td>
<td>15.00</td>
</tr>
<tr>
<td>2¼ x 1 inch bar</td>
<td>4.97</td>
</tr>
<tr>
<td>Bolts</td>
<td>2.48</td>
</tr>
<tr>
<td>Tubing for sleeves</td>
<td>6.72</td>
</tr>
<tr>
<td>Plain discs, stems &amp; clamps</td>
<td>58.00</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$159.14</td>
</tr>
</tbody>
</table>

This particular machine cost about One hundred and sixty dollars (£32) to make. Much of this was made up of labour costs which in the case of normal manufacture would be greatly reduced. The price of the plain disc assembly is derived from the cost of the component parts in a current Ferguson spares list.

After harvesting just over an acre (1.2 acres), the machine showed few signs of wear. It would be possible to fit a special hardened share to resist abrasion, but an ordinary mild steel one would be easily cut out and renewed when it became worn.
Saving of Labour Costs

From the rates of working found in Test 7:-

Hand harvesting 220 lbs/hr. or 1000 lb/day
Machine-assisted harvesting 400 lbs/hr or 1800 lbs/day

On average a man earns about $3. a day, which in the case of hand harvesting means a piece work rate of 30 cents per 100 pounds of yams. After loosening with the harvester the men should be able to dig 1800 pounds of yams in a day, and would earn $3. if they were paid at the rate of 17 cents per 100 pounds.

If the crop yielded 20,000 lbs per acre, which is good for Trinidad (though yields of 30,000 lbs are known) hand digging would take 20 days, and machine-assisted harvesting about 11 days. This saving of nine days in harvesting an acre of yams would result in the saving of $27. in wages.

The only extra cost incurred would be that of the tractor and operator, $1.60 per hour. Since machine will loosen one acre an hour, a saving of $25. per acre is made. At this saving the harvester would repay its capital cost by harvesting seven acres of yams.

It can be concluded that a machine has been developed which will considerably reduce the manual labour needed to harvest yams. The saving is such that it will repay its capital cost by harvesting about seven acres of the crop. After which there is a net saving of twenty-five dollars per acre.
# APPENDIX I

## Incidence of damage in Test 2

<table>
<thead>
<tr>
<th>Sample</th>
<th>Damaged No. Weight</th>
<th>Undamaged No. Weight</th>
<th>Total No. Weight</th>
<th>% Damage No. Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs. oz.</td>
<td>lbs. oz.</td>
<td>lbs. oz.</td>
<td>lbs. oz.</td>
</tr>
<tr>
<td>1</td>
<td>3 0 18</td>
<td>31 9 4</td>
<td>34 9 12</td>
<td>8.8 5.1</td>
</tr>
<tr>
<td>2</td>
<td>4 1 10</td>
<td>25 15 5</td>
<td>29 16 15</td>
<td>13.8 9.6</td>
</tr>
<tr>
<td>3</td>
<td>3 0 9</td>
<td>26 7 11</td>
<td>29 8 4</td>
<td>10.3 6.8</td>
</tr>
<tr>
<td>4</td>
<td>- 1 4</td>
<td>- 10 4</td>
<td>- 11 8</td>
<td>- 10.9</td>
</tr>
<tr>
<td>5</td>
<td>21 13 6</td>
<td>53 29 8</td>
<td>74 42 14</td>
<td>28.4 31.2</td>
</tr>
<tr>
<td>6</td>
<td>8 3 13</td>
<td>54 28 8</td>
<td>62 32 5</td>
<td>12.9 11.8</td>
</tr>
<tr>
<td>7</td>
<td>5 7 5</td>
<td>53 38 8</td>
<td>58 45 13</td>
<td>8.6 15.9</td>
</tr>
<tr>
<td>8</td>
<td>10 9 8</td>
<td>50 49 6</td>
<td>60 58 14</td>
<td>16.6 16.1</td>
</tr>
<tr>
<td>9</td>
<td>1 0 2</td>
<td>48 22 0</td>
<td>49 22 2</td>
<td>2.0 0.6</td>
</tr>
<tr>
<td>10</td>
<td>2 2 14</td>
<td>52 36 3</td>
<td>54 39 1</td>
<td>3.7 7.4</td>
</tr>
<tr>
<td>11</td>
<td>2 2 0</td>
<td>63 44 4</td>
<td>65 46 4</td>
<td>3.1 4.3</td>
</tr>
<tr>
<td>12</td>
<td>13 9 6</td>
<td>67 48 10</td>
<td>80 58 0</td>
<td>16.2 16.2</td>
</tr>
<tr>
<td>13</td>
<td>15 17 0</td>
<td>53 31 5</td>
<td>68 48 5</td>
<td>22.0 35.2</td>
</tr>
<tr>
<td>14</td>
<td>11 7 8</td>
<td>64 52 0</td>
<td>75 59 8</td>
<td>14.6 13.6</td>
</tr>
</tbody>
</table>

Total 139.4 183.7

n 13 14

Mean 10.7 13.1

Lowest Reading 2.0 0.6

Highest " 28.4 35.2
APPENDIX II

Results of Tests 4 & 5

a) Tractor time

155 seconds

<table>
<thead>
<tr>
<th>Unc. SS</th>
<th>C.F.</th>
<th>Con. SS</th>
<th>Variance</th>
<th>S.D.</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>217400</td>
<td>216090</td>
<td>1310</td>
<td>1330</td>
<td>145.5</td>
<td>t(\frac{S.D.}{n}) at n-1 d.f.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\frac{10-1}{3.3}$</td>
<td>12.07</td>
<td>$\frac{12.07}{3.3}$</td>
</tr>
</tbody>
</table>

Total = 1470

n = 10

Mean ($x$) = 147 secs. = 2m. 27 secs.

Mean = 2 minutes 27 seconds, Standard Error = 8.2 seconds.

b) Digging time

600 seconds

<table>
<thead>
<tr>
<th>Unc. SS</th>
<th>C.F.</th>
<th>Con. SS</th>
<th>Variance</th>
<th>S.D.</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>9473125</td>
<td>9123568</td>
<td>349557</td>
<td>349557</td>
<td>20562</td>
<td>$\frac{18 - 1}{20562}$</td>
</tr>
</tbody>
</table>

Total = 12815

n = 18

Mean ($x$) = 712 secs. = 11 m. 52 secs.

Mean = 11 minutes 52 seconds, Standard Error 1 minute 11 seconds
c) Clearing time

150 seconds

180   Unc. SS = 388975
240   C.F.  = 380628
245   Con. SS = 8347
240   Variance = 1192
225   S.D. = 34.5
240   S.E. = 28.7 = 29

Total = 1745
n = 8
Mean 218 = 3 m. 38 s.

Mean = 3 minutes 38 seconds. Standard Error. 29 seconds.

d) Damage percentage

46.4
7.7  8.6
29.6 9.6
29.1 8.7
15.6 5.2
2.7  14.4
5.5  12.8
11.7 12.5
7.7  0.9
26.0

Total = 263.7
n = 19
Mean = 13.9%

Highest value 46.4%
Lowest 0.9%
APPENDIX 3

Results of Test 7

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Whole lbs.</th>
<th>Cut lbs.</th>
<th>Total lbs.</th>
<th>% Damage</th>
<th>% Damage in Radians</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8</td>
<td>44.0</td>
<td>0.0</td>
<td>44.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>1.10</td>
<td>39.8</td>
<td>1.2</td>
<td>41.0</td>
<td>2.9</td>
<td>10.0</td>
</tr>
<tr>
<td>1.9</td>
<td>45.0</td>
<td>11.6</td>
<td>56.6</td>
<td>20.4</td>
<td>26.6</td>
</tr>
<tr>
<td>2.2</td>
<td>57.2</td>
<td>3.2</td>
<td>60.4</td>
<td>5.3</td>
<td>12.9</td>
</tr>
<tr>
<td>2.5</td>
<td>50.6</td>
<td>5.0</td>
<td>55.6</td>
<td>8.2</td>
<td>17.5</td>
</tr>
<tr>
<td>2.10</td>
<td>61.6</td>
<td>10.4</td>
<td>72.0</td>
<td>14.4</td>
<td>22.0</td>
</tr>
<tr>
<td>3.1</td>
<td>44.4</td>
<td>15.2</td>
<td>59.6</td>
<td>25.5</td>
<td>30.7</td>
</tr>
<tr>
<td>3.5</td>
<td>52.6</td>
<td>17.4</td>
<td>70.0</td>
<td>24.8</td>
<td>30.0</td>
</tr>
<tr>
<td>3.9</td>
<td>67.6</td>
<td>18.4</td>
<td>86.0</td>
<td>21.4</td>
<td>27.3</td>
</tr>
<tr>
<td>4.1</td>
<td>31.4</td>
<td>6.0</td>
<td>37.4</td>
<td>16.0</td>
<td>23.6</td>
</tr>
<tr>
<td>4.2</td>
<td>29.2</td>
<td>3.4</td>
<td>32.6</td>
<td>10.4</td>
<td>18.4</td>
</tr>
<tr>
<td>4.9</td>
<td>45.4</td>
<td>7.6</td>
<td>53.0</td>
<td>14.3</td>
<td>22.0</td>
</tr>
<tr>
<td>5.3</td>
<td>49.0</td>
<td>5.8</td>
<td>54.8</td>
<td>10.6</td>
<td>19.4</td>
</tr>
<tr>
<td>5.9</td>
<td>39.0</td>
<td>0.6</td>
<td>39.6</td>
<td>1.5</td>
<td>8.1</td>
</tr>
<tr>
<td>5.10</td>
<td>41.0</td>
<td>3.8</td>
<td>44.8</td>
<td>8.5</td>
<td>17.5</td>
</tr>
<tr>
<td>6.5</td>
<td>53.0</td>
<td>0.0</td>
<td>53.0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>6.6</td>
<td>57.2</td>
<td>2.4</td>
<td>59.6</td>
<td>14.1</td>
<td>22.0</td>
</tr>
<tr>
<td>6.9</td>
<td>51.8</td>
<td>18.6</td>
<td>70.4</td>
<td>26.4</td>
<td>30.7</td>
</tr>
<tr>
<td>7.7</td>
<td>44.0</td>
<td>2.6</td>
<td>46.6</td>
<td>5.6</td>
<td>14.2</td>
</tr>
<tr>
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<td>7.6</td>
<td>16.4</td>
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<td>Row (Bank)</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
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<tr>
<td>Machine</td>
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<td>12.9</td>
<td>30.7</td>
<td>23.6</td>
<td>19.4</td>
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<td>18.4</td>
<td>8.1</td>
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<tr>
<td>Hand (H)</td>
<td>26.6</td>
<td>22.2</td>
<td>27.3</td>
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<tr>
<td>Row Totals</td>
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<td>Machine</td>
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<tr>
<td>Mean (M)</td>
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<td>30.4</td>
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<td>H - M</td>
<td>21.6</td>
<td>6.8</td>
<td>-3.1</td>
<td>1.0</td>
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</table>

Between rows

C.F. = \( (\frac{455.4}{4^2}) \frac{24}{24} = 8641.2 \)

Crude SS = 9284.9

Conr. SS = 642.8

Total SS = 10707.1 - 8641.2 = 2065.9

Analysis of Variance
d.f.    S.S.    M.S.    t
Between rows 7   642.8   91.8    1.03   NS
Within rows (by difference) 16   1423.1   88.9
Total 23   2065.9

Analysis of H - M

C.F. = 701.25

Crude SS = 1476.39

Conr. SS = 775.0

Variance = \( \frac{775.0}{7} = 110.7 \)

S.E. = \( \sqrt{\frac{110.7}{8}} = 3.72 \)

\[ t = \frac{\bar{x}}{S.E.} = \frac{9.36}{3.72} = 2.52^* \]

\( t \) significant at 5% (2.36)
1. Side view: the four concave disc sleeves can be seen clearly. In this case the scoop has been moved back four inches on the beams, but it was never worked like this.

2. The four curved elevator bars are visible; the outer two were later removed.

3. The harvester detached from tractor and tool bar. The beam extension and clamp for the disc stems can be seen.
4. Side view of the harvester in the field, showing concave disc sleeves, and the holes giving share pitch adjustment.

5. Harvester in the field, showing depth of soil passing over share and bars. Two of the four bars originally fitted have been removed.

6. The harvester taken off the tractor, the relative position of toolbar, discs and scoop can readily be seen. The two remaining elevator bars can be seen.
7. The harvester in the field showing the two remaining elevator bars, and the mass of soil passing through the scoop with very little falling between the bars.

8. Showing relative position of concave discs and two elevator bars.

9. Showing disc, and stem and sleeve mounting.
10. The mass of yam vines, 6-7 ft. tall supported by bamboo stakes.

11. A thick trash of weeds and vines lying over the banks after the bamboos had been removed.
DIGGING IN THE FIELD DURING TEST 5 WHEN WORK WAS DONE BANK BY BANK WITH A GANG OF TEN MEN

12. Trash moved over, one row at a time can be seen. There are women cleaning the yams, and other men weighing

13. One man digging during Test 5. He is working towards the camera; in the foreground the disruption caused to the bank is seen. Just beyond the man is the part of the bank he has dug.
DIGGING IN THE FIELD DURING TEST 7 WHEN EACH MAN WORKED THE ENTIRE LENGTH OF A BANK.

14. The gang of four men digging, they are working away from the camera. Two of them are digging with their hands.

15. One of the four men working away from the camera. The state of disruption of the soil can be seen, and that he is working with his hands.