A MECHANICAL HARVESTER FOR DIOSGENIN-PRODUCING YAMS

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SUMMARY

It is possible to harvest yams which are distributed through large volumes of soil by lifting the entire soil volume with the kinds of machines usually used for digging and grading road-building materials and employing screens which can separate out the yam from the main body of the soil.

RESUME

Il est possible de récolter 1'igname semée sur une large surface de sol en soulevant toute la surface du sol à l'aide d'engins ordinairement utilisés pour creuser ou d'équipements de construction routière, et en utilisant des cribles pouvant débarrasser 1'igname de la motte de terre.

RESUMEN

El ñame que se encuentra distribuído a través de grandes volúmenes de suelo, se puede cosechar volteando el volúmen completo con máquinas de las usadas para la excavación y nivelación de los materiales de construcción de caminos y utilizando cribas que pueden separar el ñame del suelo en sí.

INTRODUCTION

There has been considerable interest for about twenty years in developing commercial production of *Dioscorea* spp. containing diosgenin as a starting material for the production of steroidal compounds. Several projects directed towards the development of the necessary technology for commercial production are, or have been, in progress in Puerto Rico, Mexico, Guatemala, Costa Rica, Kenya and India[1]. Considerable work on the diosgenin-rich *Dioscorea* spp. has been carried out at Federal Experiment Stations in Puerto Rico and in Florida, U.S.A.[1,4,5].

Of the diosgenin-bearing species[2], *D. composita* Hems[1]. and *D. Floribunda* Mart. and Gal., having been most seriously considered for commercial production because of their yield potential and their high diosgenin content and purity[4,5]. Of the two, significantly greater root and diosgenin yields per unit of land area are obtained from *D. composita* in Guatemala, making it the better prospect for commercial production. The vines of *D. composita* also grow more vigorously and the shade provided by the thick foliage helps control weeds. The white-fleshed roots are firm but brittle, and at harvest, range in thickness from 2 to about 15 centimeters.

One of the problems of the large scale, commercial production of *D. composita* is the irregular, deep position in the soil of the tuberous roots. They may occur as far as 30 centimeters to the side of the planting row, and, depending on soil conditions, may occur to a depth of over 90 centimeters during a three-year crop cycle. The major portion of the root yield is located at less than 76 centimeter depth. No common harvesting implement can dig roots from this depth, so that it was necessary to develop one. The aim was to reduce the cost of harvesting below that of hand harvesting at prevailing labour rates.

PREVIOUS ROOT AND TUBER HARVESTERS

Most authors suggest a simple, soil-loosening tuber-lifting implement for the harvest of *Dioscorea species. Martin and Gaskins*[5] suggest a large moldboard plough and Martin *et al.*[4] mention a lister-bottom plough as possibilities for turning up the tubers for subsequent collections by hand. An early cultivation project conducted by Merk & Company in Guatemala developed a soil-loosening implement for harvesting *Dioscorea* species based on the model of a seedling tree lifter. Coursey[2] describes the construction and operation of a tuber-lifting plough for edible *Dioscorea* species after the use of which the tubers were raked by hand from the loosened soil. It was designed to harvest the tubers from ridges of soil which is the common method of growing edible *Dioscorea* species. Efforts to select cultivars with regularly shaped roots for easier, mechanical harvesting were being made.

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Martin and Gaskins[5] discussed the development of a harvester for medicinal *Dioscorea* species based on the principles of a potato harvester. A machine of this type was designed and constructed for a project in Puerto Rico but results are not known.[3] In our work such a design was considered for *D. composita* but rejected on engineering criteria. As an alternative, an existing machine was sought which could be adapted to the particular requirements of harvesting *D. composita.*

DESCRIPTION OF THE NEW MECHANICAL HARVESTER

The basic machine

The problem of mechanically harvesting a closely planted crop of *D. composita* is one of removing and sifting 7620 m^3 of soil per ha. Therefore an elevating grader of the type normally used to load trucks with gravel and stones fot road making, was selected as the basic component for a harvester. The standard, Model K-12, Ulrich BoMor machine acquired for this purpose, according to specifications, could dig to a depth of 61 centimeters and elevate up to 688.5 cubic meters of earth per hour. Models of greater capacity were also available.

The elevating grader is mounted on a Model 12 or 14 Caterpillar motor grader in place of the usual grader blade. Its main components are a heavy concave, disc-plough blade and a wide belt conveyor. The standard, disc-plough blade for this model is 76.2 centimeters in diameter. It is mounted on a heavy beam which can be adjusted for depth of cut. The standard belt conveyor is 1.067 m wide and 5.795 m long, and is mounted at right angles to the disc-plough blade, and can deliver earth to a height of about 2 m. The lower end is hinged to a frame, and the upper end is raised or lowered by cables and a winch. The conveyor belt is driven by a system of V-belt pulleys, shafts and gear boxes from the crankshaft of the grader engine.

The belt speed is 137.25 m per minute. As the motor grader moves forward on the bottom of the trench, the disc-plough blade shears off a strip of earth 25 – 30 centimeters wide from the face of the cut on the left and, acting as a moldboard, guides the ribbon of soil onto the lower end of the belt conveyor which delivers it upward to the right, across the direction of travel.

Modifications to the basic machine

The basic machine was modified for root harvesting by replacing the standard, disc-plough blade with one 91.5 centimeters in diameter to increase the depth of cut to 76.2 centimeters. The difference between the blade diameter and the depth of cut allows for trash and expansion of the soil as it is loosened. Other modifications were shortening of the belt conveyor to 3.66 meters and later to 3.05 meters to reduce soil displacement, and increasing the belt speed to 183 meters per minute in order to carry the increased volume of soil from the larger blade.

Separating screen-conveyor

To separate the roots from soil, a draper chain screen-conveyor was mounted on the discharge end of the belt conveyor. Draper chain conveyors are commonly used in sugar beet and potato harvesters and are made of links of steel rod with formed ends which hook together to make an endless belt. The pitch and thickness of the links can be selected to obtain the desired opening. The teeth of the driving sprockets on the head shaft mesh with the openings between the rods and pull the chain over supporting idlers.

In Models I and II of the screen-conveyor, a single, rigid frame supported two, adjacent aprons of draper chain, each 53.66 centimeters wide. The total width of the screen bed was 1.13 meters. The rod diameter was 1.11 centimeters and the straight portion of the links was coated with bonded rubber to reduce the opening to 1.9 centimeters. The aprons were supported in the area of impact by a grate of iron bars. Sets of eccentric, sprocket idlers, evenly spaced form the grate to the head shaft, supported and shook the chain.

Both models were shaft driven by a 30 h.p. gasoline engine with a 2.67 to 1 clutch reduction assembly. The final drive, mounted on the head-shaft, further reduced the shaft speed by 4.11 to 1.

The lower end of the screen-conveyor frame was hinged to the upper end of the belt conveyor and the angle of incline was adjusted for efficient screening by cables and a winch mounted on the grader frame. The incline could be varied from 25 – 35 degrees, depending on soil conditions.

Major changes in the Model II from the Model I screen were:

1. Increasing the length from 2.44 meters to 3.68 meters to provide more screening area.
2. Mounting a gear box in the drive train to reduce the screen speed.
3. Welding flights on four links of each draper chain apron to prevent round stones from tumbling.
4. Installing curtains of heavy belting over the draper chains to break clods.

Various minor changes in components or adjustments in their position were also made to improve mechanical operation or increase screening efficiency.

HARVESTING

The vines were chopped and burned to eliminate surface trash. A border, 9 m wide, was hand harvested to allow for soil displacement by the harvester. Next, a smooth incline was graded with a bulldozer or the motor grader along the harvested border to the depth of harvest. Then, with the harvester attachments mounted, succeeding cuts were made from the unharvested bank. Workers, stationed at intervals on the discharge bank, collected and put the root into sacks which were removed on a tractor-drawn wagon.

Soil displacement by the harvester left a trench in the centre of the fields about twice as wide as the belt conveyor length. Since refilling this trench would have been costly, it was left open and its sides were graded to allow further field operations. Plans are to harvest the succeeding crop of *D. composita* from the centre.

FIELD TESTS AND RESULTS

The first test in February-March, 1969, was of the modified, basic machine i.e. without the separating screen-conveyor. The root was raked out by hand from the entire discharge from the belt conveyor. A Model 12/ Caterpillar, ca. 90 h.p. motor grader was used. The rectangular field was harvested from both sides leaving a ditch 7.3 meters wide in the centre.

The modified, basic machine together with the first kind (Model I) of the screen-conveyor was mounted on a Model 12F, Caterpillar, 125 h.p. motor grader and tried in the second test in March-April, 1969. The root was hand picked from the surface of the bank of screened soil. A rectangular field was harvested from both sides and the centre ditch was 6.0 meters wide at the bottom.

The third test in March-April 1971, used the modified, basic machine combined with the Model II screen-conveyor, mounted on a Model 14E Caterpillar, 150 h.p. motor grader. The root was picked from the surface as in Test 2. The field was roughly square and was harvested from the four sides. Results on performance are presented in Table 1.

When Models I and II screens were attached the harvest time was increased by 8.5 and 9.0 hours per hectare respectively. The Model I screen reduced the percent of yield dug but not recovered from 16.6 – 11.9. The Model II screen further reduced the percent unrecovered to 4.1. The deeper harvest in Test 3 resulted in little root being left below harvest depth.

Results on the economic aspects of harvesting are presented in Table 2.

When the Models I and II screen-conveyors were attached (Tests 2 and 3) the total harvester cost increased by about 150 percent, but total gathering cost per ton harvested decreased by an average of 37.5 percent compared with the non-screening machine. The efficiency of yield recovery increased with the screen-conveyors attached as indicated by the reduction of the value of root left in the field per metric ton of root recovered. The net result was a reduction in the total cost of harvest to $20.38 per metric ton. Estimated harvesting costs for greater yields than those of the test harvests showed that harvester costs, which are a function of land area or time, would be reduced by the increased yield. The net result would be a significant reduction in the total cost of harvesting.

In Table 3 the costs of hand harvesting are presented for comparison. Payment on the basis of the weight of root harvested decreased the efficiency of yield recovery but also decreased the total cost of harvest by $16.14 to $24.67 per metric ton recovered. The difference in harvest cost between Harvest Analyses 2 and 3, which were roughly equal in yield, was due to different rates of harvest because of soil condition or different groups of worker. Although the payment per unit of weight was the same for both groups, the difference in dilution of the constant overhead by the yield harvested per day changed the total cost of harvest.

When yield per hectare increased in Harvest Analysis 4, the harvest cost decreased significantly. However, total harvest cost is influenced by the yield unrecovered and data from commercial, hand harvests, other than those presented in Table 3, indicate that the unrecovered yield can vary up to 25 percent of the total yield.

DISCUSSIONS AND CONCLUSIONS

The results showed that *D. composita* was machine harvested for $1.76 per metric ton less ($20.38 compared with $22.14) than by hand when yields were about 40 metric tons per hectare. This cost advantage was due to more efficient root recovery. Our analysis of costs shows that there will be a relatively greater cost advantage for machine harvesting at higher gross yields and that harvester costs per metric ton of root harvested decrease proportionately as yield increases whereas hand harvest costs are relatively inelastic. Other advantages of mechanized harvesting are better control of the rate of harvest and lesser dependence on a seasonal supply of temporary labour.

A disadvantage of this harvester is that it completely mixes the soil to the harvest depth. Harvesting by hand also churns the soil, but to a somewhat lesser degree. This is presently being evaluated by collecting yield data on subsequent crops of *D. composita*. Another disadvantage is the depression left in the centre of the field. The best solution yet found is to harvest around large, square fields so that the depression occupies the smallest percentage of field area.

Buried rocks and boulders caused delay and damaged the belt, but did not affect the screen-conveyor. Other components of the elevating grader attachment failed mechanically on several occasions due to inexperienced operators or overloading. It was concluded that an elevating grader with a wider belt conveyor was indicated.

This machine is best suited for large-scale, commercial production and its efficient use is restricted by certain conditions. Fields should be large and fairly level. The soil should be deep, friable and free of large rocks. Experience indicates that dry soil is preferable but this would depend somewhat on its physical structure. Hard, cloddy soil reduced screening efficiency but this could be overcome by further modifications.

Further development of the harvester would include repositioning the screen-conveyor to deliver to the rear and adding a narrow, long conveyor to transfer the root to a self-unloading hopper or cart attached to the rear of the motor grader. With such an arrangement, the hand labour of gathering the root would be eliminated and the machine would be a complete harvester.

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TABLE 1

Yields and efficiency of harvesting *D. composita* with the modified, basic machine (Test 1), with Model I screen (Test 2), and with Model II screen (Test 3)

Test	Harvest area (ha)	Harvest time (hrs/ha)	Harvest depth (cm)	Total yield harvested (M.T./ha)	Yield not recovered M.T./ha.	Yield not recovered % of yield harvested	Yield*below depth of harvest (M.T./ha)
1.	3.92	23.4	76.2	41.5	6.9	16.6	13.3
2.	4.17	31.9	76.2	33.6	4.0	11.9	6.4
3.	4.98	32.4	83.8	41.7	1.7	4.1	0.2

*Yield occurring below 76.2 centimeters is variable depending on soil structure, growth time and the efficiency of previous harvests. Previous harvests of all areas reported in Table 1 were by hand and the yield below machine harvest depth was mostly due to the growth of volunteer plants.

TABLE 2

Yield recovered and cost of harvesting *D. composita* by machine

Test	Yield recovered by machine (M.T./ha)	Total harvester cost $/M.T.	Total gathering cost $/M.T. harvested	Extra*cost of border harvest $/M.T. harvested	Value** of root not harvested $/M.T.	Total cost $/M.T. harvested
1 mod. basic machine	34.6	5.34	7.34	0.33	27.87	40.88
2 with Model 1 screen	29.6	13.16	4.98	0.33	16.77	25.24
3 with Model II screen	40.0	13.82	4.20	0.33	2.03	20.38
Estimates***	71.0	7.47	4.20	0.33	2.29	14.29

* The total extra cost of hand harvesting the borders, i.e. the cost above that of machine harvest, divided by the total field production harvested by the machine. The cost shown assumed equal field sizes and yields and is based on Table 3 data.

** $\frac{\$47.73/\text{M.T.} \times \text{total M.T./ha left in field}}{\text{M.T./ha harvested by machine}}$ = Value/M.T. harvested

***The estimates of costs at the yield recovered of 71.0 M.T./ha are included to show the yield-cost relationship of mechanized harvest. They are based on Test 3 data.

TABLE 3

Wage basis, yield and cost of harvesting *D. composita* by the hand method

Harvest analysis	Wage basis	Total yield M.T./ha	Yield unrecovered M.T./ha	Yield unrecovered % of total yield	Harvest cost $/M.T. harvested	Value* unrecovered root $/M.T. harvested	Total cost $/M.T. harvested
1.	Daily wage	41.5	1.45	3.45	43.22	1.70	44.92
2.	Unit of weight	41.5	4.36	10.5	23.18	5.60	28.78
3.	Unit of weight	39.5	4.15	10.5	16.54	5.60	22.14
4.	Unit of weight	74.4	8.41	11.3	14.17	6.08	20.25

* $\frac{\$47.73/\text{M.T.} \times \text{M.T./ha unrecovered}}{\text{Total M.T./ha} - \text{M.T./ha unrecovered}}$ = Value per M.T. harvested