Pickup Mechanism for Harvesting Wetland Taro

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TARO, one of the edible aroids(*Colocasia esculenta (L.) Schott*), is grown throughout the tropics and subtropics as a subsistence food crop. It is one of man's oldest cultivated crops, dating back to 100 B.C. (Bowers, 1967). In Hawaii, taro considerable commerical importance. It is raised chiefly for use as a vegetable and for making the traditional Hawaiian "poi". Recent efforts have also been made in developing new products for further market expansion such as taro chips and a special dietary "cereal".

Flooded culture is the primary means of production for Hawaiian taro with about 99 percent of the total acreage planted in paddies similar to those used for rice (Doue, 1967). Fields are usually divided into one-half acre plots with dikes used for retaining irrigation water. Highest yields have been obtained from plats spaced at 12 in. in 20-in. rows. Common yields are around 15 tons per acre with corm sizes ranging from 1/2 to 4 lb. The plants are highly variable in size and shape with young corms or cormels arising from the side of the main corm in a satellite structure amidst a heavily fibrous root system. This characteristic growth presents some especially difficult problems in connection with harvest of the crop from the flooded fields.

Taro is harvested almost entirely by hand through digging or pulling of the mature corms from the paddy soil. A digger bar is first used to break or sever the roots and to pry the corms apart within each plant. Typically, one man is involved in digging, followed by two to four people bending down in the field to pick up the loosened corms, break off stems, remove roots and wash away loose mud. A wooden boat pulled by a horse is then used for transport of the bagged taro from the paddy.

During the past 10 years the taro acreage in Hawaii has gradually decreased, primarily due to the large amount of labor involved in production, Hand labor for harvesting is especially high and severe, requiring much stooping work and long hours in the flooded fields. A shortage of labor and resulting inability to meet market quotas by growers has led to increased interest in mechanization of the harvest and field handling operations.

Problems of hand labor in the flooded growth areas are being approachcd using small walking type rice tractors. At least one company has developed a tool for use with thesetractors for harvesting taro in the paddy, An 8-in. diameter mud auger driven laterally from the tractor power shaft has been shown to effectively break up

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the buried taro corms, leaving them in a row orientation. Reduction in working time between the conventional hand digger bar and the auger type digger is about 10 to 1. However, pickup of taro after machine digging is still done by hand even though it becomes very difficult to hand separate the corms from the thick mud layer. Needed is an effective mechanical pickup device and transfer conveyor to eliminate the remaining hand operations and to further increase the field harvest capacity.

The objectives of the research reported in this paper were to determine the important functional requirements for a practical taro pickup machine that could directly follow the auger operation; and from this data, to design and develop an experimental machine for field evaluation.

Desigh Considerations

The general requirement for harvester opcration in the paddy for pickup from augered windrows directed the design specifications for development of machine components. Therefore, the selected machine coneept must contend with the characteristics of wetland culture, as well as the highly variable physical propertics of taro. It was projected that a successful harvester would have to:

1 pick up both with and without stems and leaves;

2 completely sparate taro corms from mud;

3 provide adequate transfer of both corms and stems to a conveyor;

4 hold taro damage to a minimum;

5 not require an undue amount of tractive efrort during paddy operation.

Of several design concepts considered for the pickup function, a tined rotor device was selected as best fulfilling the above conditions. This device consists of a rotor placed perpendicular and immediately over a taro windrow. Several rows of curved rotor tines are used for lifting the corms from the paddy and transferring them to a rearward moving conveyor. The device is illustrated schematically in Fig. 1.

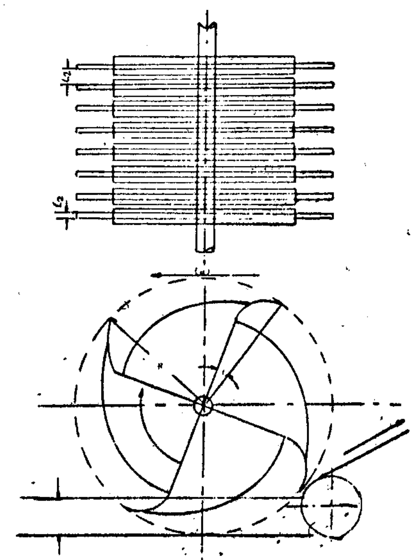


FIG. 1 Diagram of rotary pickup device.
(a) top view (b) siew.

Experimental Procedure

For the development of the proposed pickup machine, an experimental laboratory test device was used to predict performance and to study variable relations useful in the design of the prototype machine. Effects of machine configuration and operating speeds on machine performance in terms of pickup efficiency and transter of material to the conveyor were of primary interest. From an analysis of the pickup and transfer motions of the test device, the following funetional relation of design and operating variables was consiered for the definition of performance:

$$E_p = f\ (R, L_1, L_2, C, N, m, \lambda_1, D, \omega, F_s, C_s) \quad \cdots\cdots (1)$$

where

E_p = machine pickup efficiency,percent
R = tine length, in. (rolling radius)
L_1 = tine spacing, in.
L_2 = tine width, in.
C = tine curvature, deg per in.
N = number of tine rows
m = number of tines per row
λ_1 = geometric variables describing rotor and conveyor shape; relative position of rotor to conveyor
D = depth of operation in soil, in.
ω = rotor angular velocity, rad per sec
F_s = machine forward speed, mph
C_s = conveyor speed, fps

Variable dimensions and speeds are indicated on the diagram of Fig. 1.

A dimensional analysis of the variables in equation (1) gives the following expression of dimensionless terms:

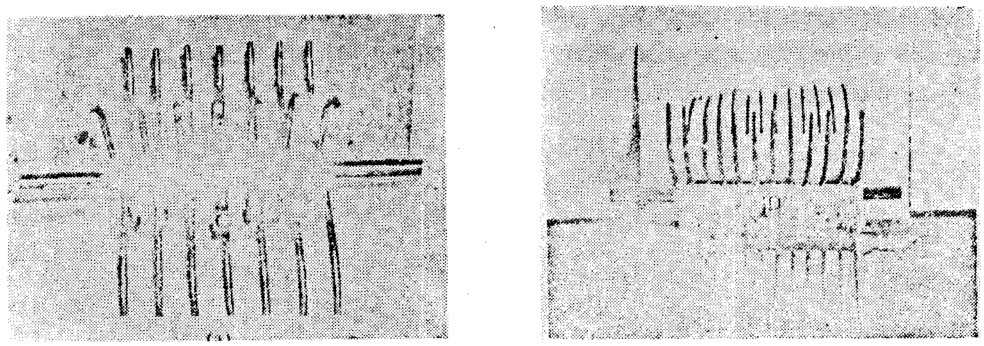
$$E_p = F\left(\frac{L_1}{R}, \frac{L_2}{R}, CR, N, m, \frac{\lambda_1}{R}, \frac{D}{R}, \frac{F_s}{\omega D}, \frac{F_s}{C_s}\right) \quad \cdots\cdots (2)$$

In equation [2]. the first six dimensionless variables represent geometric or design configuration conditions for the test machise, and take on constant values for any given set of rotor design specifications. Five different rotor types were tested to investigate the functional configuration. Table 1 gives descriptive information on the five rotors. Rotor types C and D are further demonstrated in Fig. 2.

Table 1. Experimental Pickup Rotors and Their Specifications

Rotor type Number of tine rows	A 4	B 4	C 4	D 4	E 4
Number of tines per row	5	7	7	12	9
Tine material	1-in. pipe	½-in. rod	½-in. rod	3/8-in. rod	3/8-in. rod
Tine length (radius)	8 in.	10 in.	10½ in.	12 in.	13 in.
Tine spacing	2 in.	2 in.	2 in.	1 in.	1½ in.
Tine curvature	Straight	Straight	Curved 15 deg	Curved 20 deg	Curved 25 deg

Transfer guides	Bars above rotor shaft	Bars below soil to conveyor	None	None	None
Rotor direction	CW and CCW	CW and CCW	CW and CCW	CW only	CW only
Rotor shape	Pipe tines on rotor shaft	Straight rods on rotor shaft	Curved rods on rotor shaft	Curved rods through center drum	Curved rods through eccentric drum



(a) (b)

FIG. 2 (a) Test rotor C. curved rods on rotor shaft; (b) Test rotor D, curved rods through center drum.

The last three variables of equation [2] define the operating conditions for study of the machine function. The ratio, D/R relates operating depth to rotor size and the product, $F_s/\omega D$ specifies the influence of the machine forward and rotational speeds.

Forward movement of a single row of rotor tines may be represented in terms of rotor and machine uelocities by considering the horizontal displacement per tine row, or rotor lead. The lead is defined by the equation:

$$L = \theta V_f/\omega \quad (3)$$

where

θ = angular displacement between two tine rows

V_f = forward rotor velocity

ω = angular velocity of rotor

The length of lead for consecutive rotor tines determines the maximum amount of soil and taro that can be moved during each tine traverse, without pushing material away. Thus, it should be an important indicator of effective pickup motion. Rotor lead should at least be equal to the maximum taro size plus the difference between the effective pickup point and the point of tine exit from the soil surface, with respect to the rotor center. The expression for this criterion is given by:

$$L \geqq Z + (G-P) \quad (4)$$

where

Z = maximum taro size

G = distance from rotor center to tine exit point on soil surface

P = effective pickup position with respect to rotor center

Rotor lead per tine row may be expressed in the form of the previous dimensionless velocity ratio. Forming a new dimensionless product by combining N and $F_s/\omega D$ from equation (2) givcs a useful design, parameter, the coefficient of lead, $V_r/\omega ND$.

Evaluation of Performance

An experimental laboratory mechanism was used to predict the variable relationships for a tentative prototype pickup machine. The device as developed for laboratory tests is shown in Fig. 3. Important test components included the pickup rotor assembly, transfer conveyor, and movable taro and soil bin. Individual test rotors were driven by a reversible hydraulic motor to permit study of rotor-turning direction as well as design configuration.

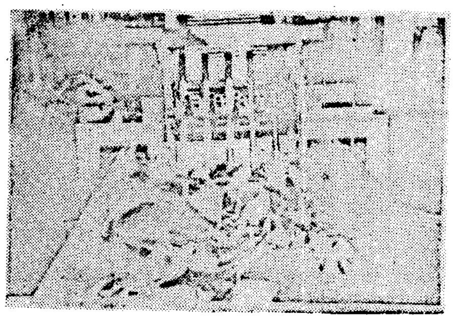


FIG. 3 Laboratory pickup device.

Experimental tests were conducted in an 8 ft long, 2 1/2 ft wide, and 1 1/2 ft deep bin filled with soil and water in a simulated paddy condition. Taro was placed on the surface at random to represent field condition. The bin was pulled on a track by a 1/2 hp electric motor drive permitting variation of ground speed.

Physical and geometrical properties data were obtained on a representative sample of harvested taro. The extent of size variation of the available taro is shown in Fig. 4. For test purposes, three taro size groups were selected and average size dimensions used for design considerations. The size groups obtained were:

	Average Dimensions (in.)	Average Weight (lb)
A (Large)	5-3/8×9-5/8	3-5/8
B (Medium)	3-3/4×5-1/2	1-1/8
C (Small)	2-3/4×3-1/4	5/16

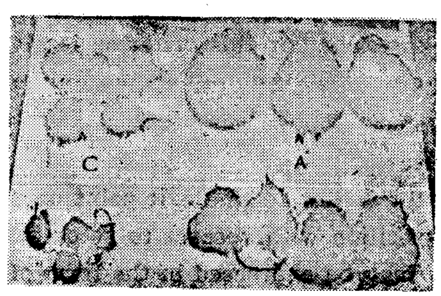


FIG. 4 Size variation of harvested taro.

Specific objectives of the experiments were to determine

1 effect of pickup motion on test material as determined by taro size, operating depth, and rotor lead (horizontal displacement per tine row);

2 effect of transfer motion as determined by rotor turning direction, rotor shape, curvature of rotor tines, and angular velocity;

3 influence of machine operating conditions, as specified by rotor lead, on pickup percentage.

Pickup motion was related to the horizontal displacement of each rotor tine row with respcct to machine forward motion through use of equation (4), which gives the expression for effective lead. The average effective pickup position was found for each taro size group at various operating depths of the rotor. Results of the evaluation of the rotor. Results of the evaluation of equation (4), expressed in terms of the previously developed coefficient of lead and a dimensionless taro size ratio, Z/R, are given in Fig. 5 for three values of D/R. These experimental relations give the direct variation of required rotor lead for given sizes of taro with respect to a specified rotor size and depth of operation. Within the ranges of test data, Fig. 5 indicates the desirable design operating speed ratio for a given rotor radius.

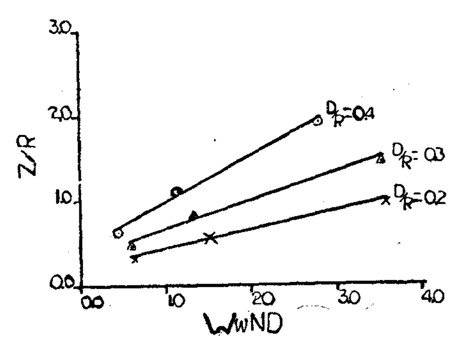


FIG. 5 Taro size ratio versus effective coefficient of lead.

Evaluation of rotor configuration in terms of effective transfer of taro to the conveyor indicated that the most important geometric variables were tine spacing and curvature, rotor direction and velocity, and shape of the rotor. Tine spacing is related to transfer through interaction with taro size and stem condition. If tine spacing is too small, the corms are jammed between individual tines. Also, stems tend to wind around the rotor with resulting clogging. Of the spacings studied, the largest of 2 in. gave minimum damage for transfer to the conveyor. A large curvature of the tines is valuable in improving pickup action. But in motion, the force due to rotor tine curvature maintains the corms in a circular motion and makes it more difficult to transfer to the conveyer. As a compromise, a curvature of approximately 15 deg was shown to be effective.

A clockwise turning direction of the rotor, that produces an upward movement of the tines through the taro for throwing over the rotor onto the conveyor, was much superior to the counterclockwise direction. Downward movement of the tines in the counterclockwise direction pushing the taro through the mud onto the conveyor results in severe clogging and a very high loading of the rotor. Clockwise turning direction also assists in separating the taro corms from the mud. Rotor angular velocity in the clockwise direction influences both pickup and transfer. However, as this velocity is lowered, lead is increased for a given machine speed which greatly assists pickup from the mud. From the tests, the best rotor angular velocity range satisfying both of these conditions is from 30 to 60 rpm.

Evaluation of the performance of the five experimental rotors indicated that a shape providing tines protruding from a central drum or cylinder gives improved transfer action over a straight tined shaft. The drum prevents taro from dropping into the center zone of the rotor, thus eliminating some clogging and improving centrifugal transfer. In addition, winding of the stems around the rotor is diminished. An eccentric rotor shape or retracting tine mechanism would permit closer positioning of the rotor to the conveyor.

The tests of experimental rotors demonstrated that the ratio of machine forward speed to angular velocity, or effective rotor lead, is an important factor influencing taro pickup percentage. Fig. 6 shows the relation obtained for pickup percentage as a function of the coefficient of lead. $V_t/\omega ND$. Within the range of data, pickup is directly proportional to the length of lead. This indicates that the highest practicable lead should be incorporated in the design operating conditions for the prototype machine. However, this value will be limited by the restricted machine speed in the paddy and the required level of rotor speed to provide adequate pichup and transfer motion.

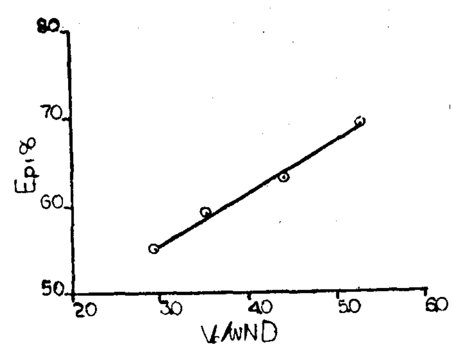


FIG. 6 Taro pickup percentage as a function of coefficient of lead.

Development of Field Pickupmachine

Results of the experimental tests, in terms of design parameters and their relationships, were evaluated to determine design recommendations for a prototype ield machine. Fig. 7 shows the completed version of the experimental harvester. General design specifications formulated for construction of the machine components were as follows:

Rotor Size

Since the field machine is intended for pickup of one augered row of taro approximately 18 in. in width with 18 in. interior row spacing, a rotor Width of 26 in. was used. Effective rolling radius of the tines during pickup was increased to 16 in.

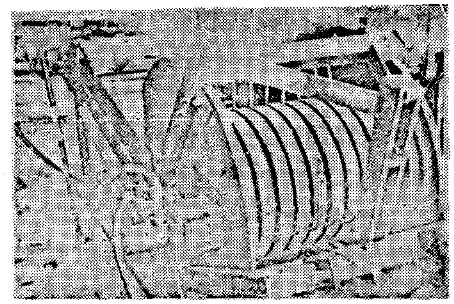


FIG. 7 Prototype machine-rotor housing cover removed.

Rotor Tines

Three rows of tines were used, rather than four as on the test rotors, to increase the value of coefficient of lead at lower levels of operating velocity ratio. Eight tines were located on each row. Tines were made of 1/2 in. diameter rod, with 25 deg of curvature.

Rotor Configuration and Shape

A cam controlled mechanism was designed to provide retraction of tines within a drum type rotor during a portion of the rotational cycle The tine retracting movement occurring just previous to the conveyor transfer point is demonstrated in Fig. 8. Three planetary tine mounting shafts spaced 120 deg apart were located at a radial distance of 7 in. from the central rotor drive shaft. A roller cam follower, attached to the end of each tine shaft, turns within the cam mounted on one end of the rotor housing. As a follower passes through 20 deg of rotation with respect to the top position, moving rearward, the tines are retracted into the drum. Likewise, as each follower returns to the point 30 deg ahead of the lowest position, the immediate row of tines is accelerated outward and forward through the mud for taro pickup. This retracting motion produced by the cam mechanism is shown in Fig. 9.

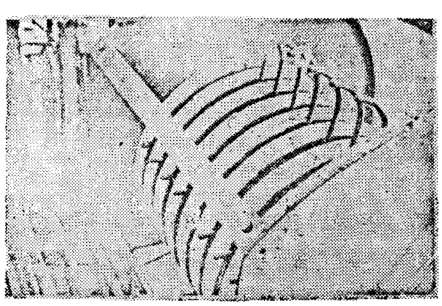


FIG. 8 Retractable rotor tines mechanism (A-tines fully extended; B-tines retracted; C-rotor drum assembly.

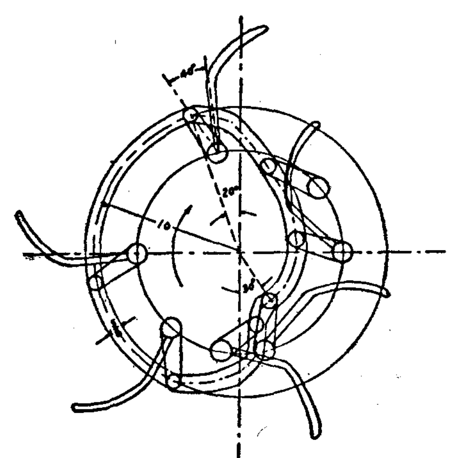


FIG. 9 Motion of cam controlled tines.

Conveyor

A 6-ft length rod and chain conveyor 24 in. in width was used to transfer taro from the pickup rotor. Conveyor inclination angle was adjustable from 15 to 30 deg and the attachment point at the rotor variable. No provision was made for collection of material at the conveyor exit on this experimental machine.

Drive

Separate hydraulic motors were used to power the rotor mechanism and conveyor, with the machine hydraulic system driven by the tractor PTO shaft.

Frame and Hitch

The main frame design provided base skids, made of enclosed 6-in. channel sections, to support the machine in the paddy and act as runners, A category 13-point free-link hitch was used for attachment to the tractor. The draft links permitted adjustment of operating depth during field work.

Field evaluation

The prototype pickup machine was pulled by a 32 hp tractor in the test plot as shown in Fig. 10. Tractor forward speeds ranged from 0.5 to 1 mph, with rotor angular velocities of 15 to 30 rpm. Within the experimental field, taro plants were hand placed in windrows similar to augered conditions.

Taro stems combined with the muddy conditions tended to help taro pickup, since, the stem material and heavy soil kept the plants in the windrows and prevented corms from being pushed forward. Taro pickup percentage in the test padby was approximately 70 to 90 percent. Also, as shown in Fig. 11, the retracting motion of tines assisted in separating mud from taro and preventina rotor clogging, as well as cleaning the rotor.

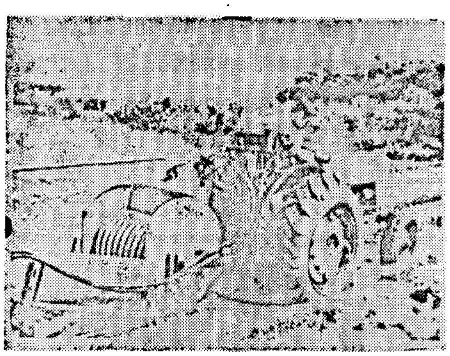


FIG. 10 Prototype machine in field trial.

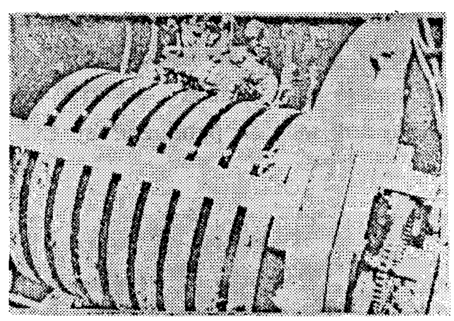


FIG. 11 Retracting tines during field operation.

Transfer motion was adequate for work in the muddy field conditions. Maintaining the clearance between retracted tines and the conveyor at 1 in. prevented taro from dropping through the machine. The backward motion of tines just before transfer of material also eliminated the problem encountered in laboratory tests of the centrifugal force of taro, turning along with the curved tines, carrying the material away from the conveyor. Elimination of rotor clogging also greatly assisted effective transfer to the conveyor.

The conveyor speed was maintained at a level about twice that of the peripheral, velocty of rotor tines. At this ratio as soon as taro dropped onto the conveyor, the conveyor rods would effectively pull the material backward away from the rotor assembly.

Tractive effort required to pull the machine was small in comparison to rotor loads. The skids provided a good machine base and adequate sliding motion. Since this machine was constructed for preliminary testing, it is probably excessive in weight for commercial use. In future machines, it should be possible to decrease the weight at least one-third to provide greater stability in transport and reduce the pulling load during operation in the taro paddy.

Summary and Conclusions

1 Machine components were developed, evaluated, and incorporated in an experimental taro pickup machine. Results from preliminary field tests indicate that the harvester will provide: (a) Pickup of taro-corms, including stem material, from a windrow of plants in the paddy; (b) Effective transfer of the corms to a rearward moving conveyor that could be used in field loading and (c) Separation of mud from the corms by the action of the retractable tines mechanism.

2 Design configuration for a pickup rotor mechanism was studied using a laboratory device and movable "taro paddy". Final design and operating conditions were determined for effective machine performance.

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