# Technology and Product Reports

## Modified Paddock Vacuum Reduces Labor Input for Chinese Chestnut Harvest

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Additional index words. *Castanea mollissima*, economics, harvest costs, labor efficiency, nut production

Summary. **The time required to harvest and field sort chinese chestnuts (*Castanea mollissima*) with two types of paddock vacuums and with a manual nut-harvesting tool was compared. Pickup time for harvesting chinese chestnuts was faster with a small paddock vacuum (Paddock Vac) than with a manual nut-harvesting tool (Nut Wizard), but field sorting plant material and soil, as well as movement of the small vacuum, was time-consuming. With minor equipment modifications to facilitate sorting, harvest time for a larger paddock vacuum (Maxi Vac) was 2 seconds faster per nut than that for the manual nut-harvesting tool. Economic analyses revealed that the larger modified vacuum also reduced labor costs by $237 when the wage rate was low ($8 per hour) and with total production at 1000 kg. However, with the lower equipment cost, the manual nut-harvesting tool was more economical to use than the modified paddock vacuum, with $8 per hour labor costs and <6370 kg of harvested chestnuts. As labor costs and nut production increased, it was more economically efficient to use the modified paddock vacuum as compared with a manual nut-harvesting tool. At $10, $12, and $15 per hour labor, the modified pasture vacuum was the lowest cost method of harvesting chestnuts at yields >4555, 3466, and 2510 kg, respectively. Thus, the modified pasture vacuum may provide a relatively inexpensive method for new, small producers to mechanize chestnut harvest.**

Chinese chestnut is an attractive niche crop in the United States because of its potential for high yields and ease of production, resulting in substantial economic returns (Gold et al., 2006; Warmund, 2011). In a survey conducted in 2006, most chestnut growers in the United States (64%) had small orchards (<10 acres) and had been producing this crop for less than 10 years (Gold et al., 2006). Presently, fewer than five growers with more than 10 acres use large harvest equipment. In the western United States, mechanized hazelnut sweeper-type harvesters (Weis McNair, Chico, CA) are used in orchards with a bare soil surface. However, this equipment is not an effective harvester in the midwestern or eastern United States where groundcovers are needed in chestnut orchards to minimize soil erosion. A mechanized pecan harvester (Savage, Madill, OK) has also been tested, but was ineffective because it fails to pick up many of the flat-sided chestnuts (K.L. Hunt, unpublished data). Large-scale self-propelled chestnut harvesters that pick up the crop and separate nuts from burs are available in Europe, but the equipment and shipping are cost-prohibitive for most new growers in the United States.

Thus, for small-scale (<10 acres) chinese chestnut producers, harvest is problematic. Up to 50% of the cost of production in a bearing chestnut orchard is for harvest labor (L.D. Godsey, unpublished data). Chinese chestnuts are generally harvested from the ground every other day to prevent nut decay and depredation from wildlife. Often the only affordable manual harvesting tool is a Nut Wizard (Holt's Nut Wizard, Douglas, GA) or hand harvest with a pair of leather gloves to avoid skin punctures from spiny burs. Part-time seasonal labor is often scarce due to the physical nature of the work, and it is difficult to hire employees who may be available only after school or weekends during the September and October harvest season. Because of the high labor requirements for harvest, alternative low-cost equipment that hastens the pickup time for chestnuts would be useful.

Relatively inexpensive pasture vacuum systems, developed to collect horse manure, are commercially available and may provide an efficient method to pick up chestnuts and burs. Thus, this study was conducted to compare the time required to harvest chestnuts with paddock vacuums and with a Nut Wizard, as well as evaluate the economic feasibility of using this equipment.

### Materials and methods

In 2009, a Paddock Vac [Greystone Vacuums, Monroe, WA (Fig. 1A)] and a medium-sized Nut Wizard (Fig. 1C) were used to harvest chinese chestnuts. The Paddock Vac was equipped with a 105-gal collection tank, a 5-inch-diameter, 12-ft-long reinforced

**Units**

| To convert U.S. to SI, multiply by | U.S. unit | SI unit | To convert SI to U.S., multiply by |
|---|---|---|---|
| 0.4047 | acre(s) | ha | 2.4711 |
| 0.3048 | ft | m | 3.2808 |
| 3.7854 | gal | L | 0.2642 |
| 2.54 | inch(es) | cm | 0.3937 |
| 0.4536 | lb | kg | 2.2046 |
| 1.1209 | lb/acre | kg·ha$^{-1}$ | 0.8922 |
| 28.3495 | oz | g | 0.0353 |

hose, and a small gas-fueled engine and was towed with a utility vehicle (Polaris Ranger; Polaris Industries, Medina, MN). A second hose was attached to the original one to increase the harvestable area without moving the equipment.

Twelve, 14-year-old 'Qing' chinese chestnut trees growing in a deep, upland Menfro silt loam soil (fine-silty, mixed, superactive, mesic Typic Hapludalfs) at the Horticulture and Agroforestry Research Center (HARC) near New Franklin, MO, were used for this study. Cultivars had been grafted onto Miller 72–138 seedling rootstock and were spaced 4 × 8 m apart. Trees were pruned and fertilized annually following local recommendations (Hunt et al., 2009). Pelletized ammonium nitrate (34N-0P-0K) was applied underneath the trees to the dripline of the canopy annually on 27 Mar., 23 May, and 26 Oct. at 75, 30, and 45 kg·ha$^{-1}$, respectively. A cross-over split plot experimental design was used in which two rows of six trees were divided into 24 plots with 12 replications of each harvest method. The 4 × 8 m-area below the tree canopy was divided in half and designated as either the east or west sector. Harvest equipment used on each tree sector was randomly assigned, and the same sectors were harvested on 15, 16, 22, and 25 Sept. 2009. All chestnuts that had naturally fallen to the ground were harvested at each date. For the Nut Wizard, the time to pick up the chestnuts, empty them into a container, and then pick up burs and dump them into another bin for disposal was recorded. For the Paddock Vac, the time to pick up chestnuts and burs, sort them, move the equipment, and dump the burs and other debris was recorded. Nut numbers and their fresh weights were also recorded to calculate the time to harvest chestnuts on a per kilogram


**Fig. 1. Harvest equipment evaluated for harvesting chinese chestnuts: (A) pasture vacuum (Paddock Vac; Greystone Vacuums, Monroe, WA), (B) modified pasture vacuum (Maxi Vac, Greystone Vacuums) with raised collection tank and open-weave metal shelf, and (C) manual nut-harvesting tool (Nut Wizard, Holt's Nut Wizard, Douglas, GA).**

We gratefully acknowledge Ken Hunt for maintaining the chestnut trees.

Contribution from the Missouri Agricultural Experiment Station project 322. This work was partially supported by the University of Missouri's Center for Agroforestry under cooperative agreements 58-6227-1-004, 58-6227-2-008, and 58-6227-5-029 with the USDA-ARS Dale Bumpers Small Farms Research Center, Booneville, AR. The Missouri Department of Agriculture, Agricultural Consultation, and Training also funded a portion of this project, using Specialty Crop Block Grant funds provided by USDA Agricultural Marketing Service.

Any opinions, findings, conclusions, or recommendations expressed in this article are those of the authors and do not necessarily reflect the view of the USDA. Mention of trade names or commercial products in the article does not imply recommendation or endorsement by the University of Missouri or the USDA.

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basis. Total pickup times, harvest times (which included sorting nuts and collecting and disposing of burs), nut weight, and harvest efficiency (harvest time/kg of chestnuts) data were subjected to an analysis of variance (ANOVA) using the PROC MIXED procedure of SAS (version 9.1; SAS Institute, Cary, NC), and means were separated by Fisher's least significant difference test, $P \leq 0.05$.

After using the harvest equipment in 2009, a larger Maxi Vac (Greystone Vacuums) with similar features as the Paddock Vac, except for a 211-gal collection tank, was purchased. In an attempt to improve harvest efficiency, this vacuum was modified for the 2010 harvest. The collection tank was raised to a 3-ft height, and a 4 × 5-ft open-weave expanded metal shelf (Expanded Solutions, OK City, OK) was mounted near the end of the compartment to facilitate chestnut removal and sorting (Fig. 1B). Open spaces in the woven wire of the shelf were 0.375 × 0.937 inch. For the 2010 study, 18 'Qing' trees in the planting described earlier were used in a cross-over experimental design. The area below the canopy of two adjacent trees in a row was divided in half, resulting in nine replications of each 8 × 8-m plot. Experimental methods, data collection, and analyses were similar to those used in 2009, with independent variables of tree, side, treatment, date, and treatment within date. Harvest time per nut was also calculated. Harvest dates were 21, 23, 27, and 30 Sept. and 4 Oct. 2010. To compare the harvest efficiency of the Maxi Vac and the Nut Wizard, time required to harvest chestnuts at typical production levels for small-scale operations was calculated. Next, the difference in harvest time for the Maxi Vac and the Nut Wizard was obtained. Then potential wages saved using the Maxi Vac vs. the Nut Wizard were calculated. The difference in harvest time (seconds per kilogram) at varying production levels was multiplied by varying wage rates (dollars per hour) to obtain a labor cost per kilogram. Wages ($8 to $15 per hour) were based on published agricultural labor rates (U.S. Department of Agriculture, 2011).

Equipment costs were based on the sum of the purchase price and the shipping cost for the Nut Wizard ($65) and the Maxi Vac ($4700). Modifications to the Maxi Vac were $405. Total rental cost of towing equipment was $50 annually for all production levels, which was based on 5 h of actual engine hours of work at $10 per hour (Plain et al., 2009). The cost of the Maxi Vac was depreciated using a straight-line method over a 7-year period with no salvage value (Eidman et al., 2000; Lazarus and Smale, 2010; U.S. Internal Revenue Service, 2011). Thus, annual fixed cost of depreciation was $729 per year. Nut Wizard equipment cost was spread over a 5-year useful life. Fuel, oil, and lubricant costs for the Maxi Vac were $2.66 per hour, with $0.10 per hour annual maintenance cost. No fuel cost was calculated for the Nut Wizard.

## Results and discussion

Pickup and harvest times, nut weights, and harvest efficiency for trees and side (east vs. west) of the tree canopy were similar for each type of equipment in 2009 (Table 1). The Paddock Vac pickup time was faster than the Nut Wizard across all harvest dates. However, total harvest time was faster using the Nut Wizard as compared with the Paddock Vac. Sorting chestnuts from burs, soil particles, and other plant debris (grass clippings, twigs, etc.), as well as moving the equipment to adjacent trees, were time-consuming with the Paddock Vac. Additionally, sorting and emptying the material from the Paddock Vac required considerable operator bending, which was uncomfortable. Nut weights harvested with each type of equipment were similar, but the Paddock Vac was less efficient than the Nut Wizard across all dates.

Climatic conditions during the harvest period affected the performance of the equipment in 2009 (Table 1). Pickup and harvest times for both types of equipment were longer on 22 Sept. than on all other dates. The only rainfall that occurred in September before the first two harvest dates (15 and 16 Sept.) was 14 mm on 5 Sept., so soil conditions were relative dry. However, 42 mm of precipitation occurred during a 53-h period before the third harvest, and an additional 25 mm of rainfall was recorded about 8 h

**Table 1. Average time to harvest and sort chinese chestnuts from burs with a paddock vacuum (Paddock Vac) or a manual nut-harvesting tool (Nut Wizard) in 2009.**

| Date | Harvest method | Pickup time (s/tree) | Total harvest time (s/tree)[z] | Nut wt (g/tree)[y] | Harvest efficiency (s·kg$^{-1}$)[x] |
|---|---|---|---|---|---|
| 15 Sept. | Paddock Vac | 68 | 144 | 559 | 257 |
| | Nut Wizard | 99 | 99 | 567 | 175 |
| 16 Sept. | Paddock Vac | 79 | 167 | 894 | 186 |
| | Nut Wizard | 140 | 140 | 1137 | 123 |
| 22 Sept. | Paddock Vac | 236 | 653 | 3001 | 218 |
| | Nut Wizard | 475 | 475 | 2757 | 172 |
| 25 Sept. | Paddock Vac | 52 | 105 | 250 | 419 |
| | Nut Wizard | 140 | 140 | 406 | 344 |
| Significance[w] | | | | | |
| Harvest method | | *** | ** | NS | * |
| Date | | *** | *** | *** | *** |
| Tree | | NS | NS | NS | NS |
| Side of tree | | NS | NS | NS | NS |
| Date × harvest method | | NS | NS | NS | NS |

[z]Total harvest time for the Paddock Vac (Greystone Vacuums, Monroe, WA) is the sum of the time for picking up chestnuts and burs, sorting nuts from burs, movement of equipment, and dumping burs. Total harvest time for the Nut Wizard (Holt's Nut Wizard, Douglas, GA) is the sum of the time for picking up and dumping chinese chestnuts, then picking up burs, and dumping burs.
[y]1 g = 0.0353 oz.
[x]Harvest efficiency is the total time divided by the weight of the harvested chinese chestnuts; 1 s·kg$^{-1}$ = 0.4536 s/lb.
[w]ANOVA included side of tree (east vs. west), tree, harvest method, and date of harvest; NS, *, **, *** nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

before the final harvest. On 22 Sept., wet soil clods were picked up with the Paddock Vac along with plant material. However, clods did not always fall through the open-weave shelf, resulting in long harvest times. Also, most chestnuts were harvested on 22 Sept., followed by those on 16 Sept., and the fewest nuts were collected on 15 and 25 Sept. Harvest efficiency for both types of equipment was the lowest on 25 Sept., due to the time required to locate the few nuts in plots and sort out soil clods.

In 2010, climatic conditions did not affect harvesting chestnuts. By replacing the Paddock Vac with the larger Maxi Vac, nuts from two trees were harvested before moving the equipment. With the addition of the raised shelf on the Maxi Vac, soil particles easily sifted through the open-weave material, which facilitated sorting and reduced the harvest times per nut by about 2 s as compared with the Nut Wizard (Table 2). Also, the modified Maxi Vac had greater harvest efficiency than the Nut Wizard and eliminated operator fatigue associated with bending over to remove chestnuts from the vacuum tank.

The amount of time saved using the Maxi Vac rather than the Nut Wizard when harvesting 1000 to 8000 kg of chestnuts ranged from nearly 30 to 238 h (Table 3). This represents a considerable savings in labor costs. For example, when wages range from $8 to $15 per hour, $238 to $445 are saved when harvesting 1000 kg of chestnuts (Table 4). When 8000 kg of nuts are harvested at $8 to $15 per hour wages, the Maxi Vac reduced labor costs by $1901 to $3564, respectively. Equipment costs for the Maxi Vac ranged from $896 to $1718 when harvesting 1000 to 8000 kg of chestnuts due to the variable costs (Table 5). Equipment cost for the Nut Wizard remained constant ($13) at varying production levels.

When the total cost of labor and equipment at varying yields were calculated, the Nut Wizard was more economical for harvesting chestnuts than the Maxi Vac at low production levels (Fig. 2). However, at higher levels of production and higher wage rates, the Maxi Vac was the more economically efficient harvest method. At $8, $10, $12, and $15 per hour wages, the Maxi Vac was the lowest cost method when total chestnut production levels were >6370, 4555, 3466, and 2510 kg, respectively.

Typical production for 12- to 15-year-old commercial orchards at standard 30 × 30-ft spacing is 2000 lb/acre (Hunt et al., 2009). Based on the equipment costs used in this study and an $8 per hour wage for harvest

**Table 2. Average time to harvest and sort chinese chestnuts with a modified pasture vacuum (Maxi Vac) or a manual nut-harvesting tool (Nut Wizard) in 2010.[z]**

| Harvest method | Harvest time (s/plot) | Nut wt (kg/plot)[y] | Nuts (no.) | Harvest time (s/nut)[y] | Harvest efficiency ($s \cdot kg^{-1}$)[x] |
|---|---|---|---|---|---|
| Maxi Vac | 973 | 6.4 | 350 | 2.78 a | 153.06 a |
| Nut Wizard | 1209 | 4.7 | 254 | 4.76 b | 259.97 b |

[z]Values represent means of nine replications of two-tree plots [8 × 8 m (26.2 ft)] for each type of equipment. Harvest time for the Maxi Vac (Greystone Vacuums, Monroe, WA) is the sum of the time for picking up chinese chestnuts and burs, sorting nuts from burs, movement of equipment, and dumping burs. Harvest time for the Nut Wizard (Holt's Nut Wizard, Douglas, GA) is the sum of the time for picking up and dumping chinese chestnuts, then picking up burs, and dumping burs.
[y]1 kg = 2.2046 lb.
[x]Means within each column followed by different letters are significantly different ($P \leq 0.05$); 1 $s \cdot kg^{-1}$ = 0.4536 s/lb.

**Table 3. Harvest time for a modified pasture vacuum (Maxi Vac) and a manual nut-harvesting tool (Nut Wizard) calculated at several levels of chinese chestnut yields using data collected in 2010.**

| Yield (kg)[z] | Harvest time (h) | | Difference (h)[y] |
|---|---|---|---|
| | Maxi Vac | Nut Wizard | |
| 1000 | 42.51 | 72.21 | 29.70 |
| 2000 | 85.03 | 144.43 | 59.40 |
| 3000 | 127.54 | 216.64 | 89.01 |
| 4000 | 170.06 | 288.86 | 118.80 |
| 5000 | 212.57 | 361.07 | 148.50 |
| 6000 | 255.08 | 433.28 | 178.20 |
| 7000 | 297.60 | 505.50 | 207.90 |
| 8000 | 340.11 | 577.71 | 237.60 |

[z]1 kg = 2.2046 lb.
[y]Difference represents the time saved by using the Maxi Vac (Greystone Vacuums, Monroe, WA) vs. the Nut Wizard (Holt's Nut Wizard, Douglas, GA) to harvest chestnuts.

**Table 4. Total labor costs and labor cost difference using a modified pasture vacuum (Maxi Vac) vs. a manual nut-harvesting tool (Nut Wizard) at varying wage rates and chinese chestnut yields calculated from 2010 data.**

| Wage rate ($/h) | Harvest method[z] | Yield (kg)[y] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 | 8000 |
| | | $ | | | | | | | |
| 8 | Maxi Vac | 340 | 680 | 1020 | 1360 | 1701 | 2041 | 2381 | 2721 |
| 8 | Nut Wizard | 578 | 1155 | 1733 | 2311 | 2889 | 3466 | 4044 | 4622 |
| Labor cost difference | | 238 | 475 | 713 | 950 | 1188 | 1426 | 1663 | 1901 |
| 10 | Maxi Vac | 425 | 850 | 1275 | 1701 | 2126 | 2551 | 2976 | 3401 |
| 10 | Nut Wizard | 722 | 1444 | 2166 | 2889 | 3611 | 4333 | 5055 | 5777 |
| Labor cost difference | | 297 | 594 | 891 | 1188 | 1485 | 1782 | 2079 | 2376 |
| 12 | Maxi Vac | 510 | 1020 | 1531 | 2041 | 2551 | 3061 | 3571 | 4081 |
| 12 | Nut Wizard | 867 | 1733 | 2600 | 3466 | 4333 | 5199 | 6066 | 6933 |
| Labor cost difference | | 356 | 713 | 1069 | 1426 | 1782 | 2138 | 2495 | 2851 |
| 15 | Maxi Vac | 638 | 1275 | 1913 | 2551 | 3189 | 3826 | 4464 | 5102 |
| 15 | Nut Wizard | 1083 | 2166 | 3250 | 4333 | 5416 | 6499 | 7582 | 8666 |
| Labor cost difference | | 445 | 891 | 1336 | 1782 | 2227 | 2673 | 3118 | 3564 |

[z]Maxi Vac (Greystone Vacuums, Monroe, WA); Nut Wizard (Holt's Nut Wizard, Douglas, GA).
[y]1 kg = 2.2046 lb.

**Table 5. Fixed and variable equipment costs for a modified pasture vacuum (Maxi Vac) and a manual nut-harvesting tool (Nut Wizard) at various chinese chestnut yields.[z]**

| | Yield (kg)[y] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 | 8000 |
| Harvest method | $ | | | | | | | |
| Maxi Vac | 896 | 1014 | 1131 | 1248 | 1370 | 1483 | 1600 | 1718 |
| Nut Wizard | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |

[z]Fixed costs for the Maxi Vac (Greystone Vacuums, Monroe, WA) include depreciation of the total cost of the equipment over 7 years ($729 per year), as well as towing equipment rental cost ($50 for all levels of production). Fixed costs for the Nut Wizard (Holt's Nut Wizard, Douglas, GA) includes $13 replacement cost. Variable costs for the Maxi Vac include fuel, oil, lubricant, and maintenance costs ($2.76 per hour).
[y]1 kg = 2.2046 lb.

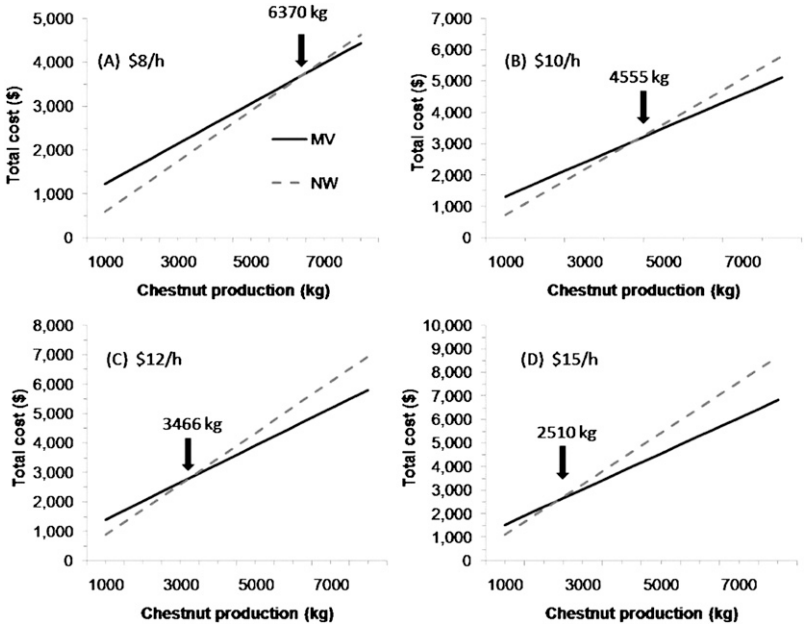


**Fig. 2. Sensitivity analysis of total costs (equipment and labor costs) for a modified pasture vacuum [Maxi Vac (MV); Greystone Vacuums, Monroe, WA] and a manual nut-harvesting tool [Nut Wizard (NW); Holt's Nut Wizard, Douglas, GA] at various chinese chestnut production levels and wage rates of (A) $8 per hour, (B) $10 per hour, (C) $12 per hour, and (D) $15 per hour. Values above arrows indicate the production level where total costs of both types of equipment are equal; 1 kg = 2.2046 lb.**

labor, 2.8 ha of chestnut trees with a typical nut yield are needed to cover the additional cost of the modified Maxi Vac as compared with the Nut Wizard. At the highest wage ($15 per hour), labor and equipment costs for the vacuum were recovered with 1.1 ha of chestnut trees with typical nut production.

## Conclusions

Pickup time for harvesting chinese chestnuts was faster with a Paddock Vac than with a Nut Wizard. However, sorting plant material after picking up chestnuts with the PaddockVac was time-consuming. With larger equipment and modifications to facilitate sorting, harvest time with the Maxi Vac was less than that of the Nut Wizard. Although the Maxi Vac is relatively inexpensive as compared with other mechanized harvest equipment, it is an additional cost for those who lack financial resources as new, small producers. However, as labor costs and production increase, it becomes more efficient and economical to use a modified Maxi Vac as compared with a Nut Wizard.

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