DESIGN, CONSTRUCTION, AND EVALUATION OF AN ALMOND END-ROW NUT SWEEPER

by

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TITLE : Design, Construction, and Evaluation of an Almond End-row Nut Sweeper

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ACKNOWLEDGEMENTS

First and foremost, I give thanks to God for blessing me with the opportunity to study what I love at one of the best Universities in the nation. Also, I’d like to thank my parents for supporting me throughout my educational career, both emotionally and financially, as well as encouraging me to always strive to be the best person I could possibly be.

Second, I would like to thank my advisor, Dr. Mark A. Zohns, for offering good, sound advice during the design and construction of this project, especially during the times where I thought I knew what I was doing, but needed a little reality check.

Third, I would like to thank the BRAE Department Lab Technician, Virgil Threlkel, for putting up with me as one of his employees and always being there to offer advice on how to properly fabricate a part, as well as offering the occasional comedic relief during those times where I was feeling stressed out from the pressure of finishing my project on time.

Lastly, I would like to thank the entire BRAE Department Faculty and Staff. Thank you for doing what you do and always encouraging the students to really embrace the Cal Poly motto of “Learn by Doing” (and sometimes “Learn by Re-Doing”). As Dr. Zohns likes to say, “There’s two ways of doing things: The Right Way, and Again.”
This senior project discusses the design, construction, and evaluation of an almond end-row nut sweeper. The sweeper attached to the three-point hitch of a John Deere orchard tractor using a Category 2 hitch and was used to sweep nuts back into the orchard after they had been swept into windrows. This system worked by utilizing the tractor hydraulics to power an 18 inch diameter cylinder brush.

Proper field testing of the implement could not be done during the academic year in which this project was constructed since this implement was designed to be used as part of the California almond harvest, which occurs from late August to early September. However, preliminary tests were conducted at the Cal Poly Feed Mill by staging a mock almond windrow using almond hulls, and sweeping them along the concrete floor with the implement. These tests indicated that with some minor modifications, the implement should perform as intended.
DISCLAIMER STATEMENT

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INTRODUCTION

California almonds are the largest tree-nut crop produced in California, both in total acreage as well as monetary value. Almond production in California accounts for 100% of the nation’s commercially grown almond supply as well as over 70% of the world’s supply (USDA, 2015). The majority of almond production occurs in the central valley, between Bakersfield and Red Bluff, with Fresno, Kern, Madera, Merced, and Stanislaus counties leading the way. In California, there are approximately 6,000 growers contributing to this huge market (Waterford Nut Company, 2015). Motte Ranches, Inc. in San Joaquin, California is one of these growers, with approximately 530 acres of almonds in production.

Being one of the largest commodities in California Agriculture, many man hours are logged each year in the production of almonds with the majority taking place during harvest. The almond harvest can be a long, drawn out process with many stages. First, the nuts are shaken off the trees and onto the ground, shown in Figure 1. The nuts must then sit for several days to dry out.

![Figure 1. Tree shaker shaking nuts off of tree.](image)

Next, mechanical sweepers go through the orchard, sweeping the nuts into windrows in the middle of the tree row, as seen in Figure 2. Again, the nuts sit for a few days to continue drying until the leaves mixed in with the nuts are completely dry. This makes the harvesting process easier by preventing plugging of the machine due to excess moisture.
Figure 2. Orchard sweeper sweeping nuts into a windrow.

After the sweepers go through the field, the resulting windrow, shown in Figure 3, extends past the end of the field by several feet, and can be as large as 18-24 inches wide and 4-6 inches tall, or larger depending on the crop yield. In order for the harvester to pick up the entire crop and still have enough room at the end of the field to turn around, the nuts must be brought back into the field, ideally a distance of one tree spacing (approximately 20 feet). The current method of sending hand labor crews out to the field with rakes is inefficient, both in the amount of time it takes to complete the job, as well as in the ability of labor crews to complete the task properly and consistently.

Figure 3. Finished windrow ready to be harvested.

Farmers have expressed a desire for an implement that can attach to the back of a small tractor that would complete the job faster and better than hand labor crews could ever do. Nikkel Iron Works Corp. is working on a design for such an implement that works in the same fashion as a Box Scraper. This senior project will focus on designing an implement that will accomplish the same task through the use of brushes/sweeping elements, rather than a scraper.
LITERATURE REVIEW

A search was conducted for End-Row Nut Sweepers that could be attached to the three-point hitch of a tractor. A search was also conducted to determine the need and viability of such a piece of equipment.

Nikkel Iron Works Corp. has developed a similar piece of equipment that accomplishes the same objective by way of a scraping method, as seen in Figure 4.

![Figure 4. Nut Crowder™ being tested in the field (Nikkel Iron Works, 2015).](image)

The Nut Crowder™ works by simply dragging the almonds back into the field, and once the operator has traveled the desired distance into the orchard, he or she opens the door on the back by way of the tractor’s hydraulics to allow the nuts to flow out the back of the implement as the tractor continues to travel forward into the orchard, maintaining the same approximate size and shape of the windrow.

Frank Russell Inc. has also developed a similar style implement, called the “Nut Row Pro”; Figure 5. It works in a similar manner as the Nut Crowder, except that it does not have a hydraulically actuated door in the back to release the nuts as the tractor travels. Rather, the operator must slowly raise the implement off the ground in order to feather the nuts into the existing windrow.
One interesting feature about the Nut Row Pro is that it can swivel to be used in either the forward (pull) or reverse (push) directions. This implement does not require the use of the tractor’s hydraulics system.

The implement being designed in this senior project will accomplish the same goal by way of a sweeping element. The reason for using a sweeping method rather than a scraping method for this project is to reduce the amount of dirt that would get mixed in to the windrow. The top soils in the almond orchards at Motte Ranches, Inc., whom this product is being developed for, are very soft and powdery, which makes the scraping method a last resort.

The most common method of moving nuts back into the orchard involves the use of hand labor crews with rakes. This method takes a long time to complete the job, as well as introduces too much dirt into the almond windrow. Excess dirt in the windrow has two main negative effects. One is that it covers up nuts at the bottom of the windrow, which causes the harvester to leave some of the crop behind. The second negative effect is that excess dirt could cause damage to the harvesting equipment. Also, the amount of time and money saved by switching from manual labor to the use of a tractor will very easily offset the cost of fuel to operate the tractor and implement. A crew of field workers could take several days to complete the job. One objective behind the design of this implement is to cut the amount of time required to complete the task down from several days, to maybe 1 day to finish a field.
PROCEDURES AND METHODS

Design

Figure 6. SolidWorks rendition of frame design.

Frame. The sweeper frame had to be designed to be used on a small John Deere orchard tractor with a Category 2 three-point hitch. It also had to be easily attached and detached to the tractor by only one person, so as to limit the amount of labor required to operate it. The sweeper frame also had to be able to withstand a possible collision with a tree while being used in the field. The frame also must be able to accommodate a 5 foot long cylinder brush that will be sweeping the almonds along the ground. Calculations (shown in Appendix C) indicated that constructing the frame from 2” x 2” x 1/8” square tubing would provide adequate strength. However, 2 1/2” x 2 1/2” x 3/16” square tubing was chosen because it was the closest size material that B&B Steel had in stock at the time that the material was ordered. By analyzing the frame as a cantilever beam with both a point load and a moment, applied by the brush and motor, at the unsupported end, the 2” x 2” x 1/8” tube provided a factor of safety of 3.25. The 2 1/2” tube provided a factor of safety of 7.35. This extra safety factor will help to compensate for unknown load factors such as drag force of the implement along the ground, or even the force it could potentially experience during a collision with a tree. Solid 2 ¼” x 2 ¼” tul bar was used to attach the three-point hitch to the implement.

Sweeping Mechanism. The implement was designed to accommodate a 5 foot long nylon bristle cylinder brush, with an outer diameter of 18” at the ends of the bristles. The goal of the brush was to be able to sweep the piles of almonds without moving an excessive amount of dirt. The bristle type was chosen because of its stiffness and ability to complete the desired task. The large diameter was chosen to allow the nuts to build up in front of the brush without spilling over the top as the tractor moved through the field. The brush was designed to be driven by a hydraulic motor that would be run off of the tractor’s hydraulic system. An implement from a previously abandoned project that was
sitting by the scrap bin on the BRAE Ramp happened to have an identical brush to what this project required mounted to it. The hydraulic motor and drive shaft were mounted inside of the drum of the brush, which helped to maintain as narrow of a profile as possible as well as prevent any damage to the motor and/or drive shaft due to a collision with a tree.

**Nut Guide Plates.** The guide plates were designed to funnel the nuts into a central point on the brush in order to maintain the shape and approximate size of the windrow. The guide plates needed to be tall enough to allow the nuts to build up between them without spilling over the top. Original considerations were made to make the opening between the guide plates adjustable depending on the width of the windrow, but afterwards was determined to be unnecessary. See Appendix B for a technical drawing of the Guide Plates as well as the orientation in which they were mounted in the frame.

**Fabrication**

All fabrication took place in BRAE Shop 6. All material was cut on the band saw and welded together using a MIG welder. Care was taken to ensure all measurements were correct and no material was wasted.

Figure 7. Frame sides mounted to the brush.

**Frame.** Figures 8 and 9 show some of the fabrication process for the main frame of the sweeper. In order to get the correct angle for the drop section of the frame, the pieces were cut on the band saw with a 22.5° bevel, and when assembled formed an interior
angle of 135°. The front of each side rail was cut at a 45° angle and capped to seal the tube, be less of a catching hazard, and also be aesthetically pleasing.

![Figure 8. Construction of the main frame side rails.](image)

Each member was clamped solid to the work table to prevent them from moving during the welding process. They were allowed to completely cool before the clamps were removed, thereby virtually eliminating any warpage of the material, which helped to keep the frame as straight as possible.

![Figure 9. Tul bar being welded into place.](image)
Sweeping Mechanism. The sweeping mechanism was already assembled and scavenged from an abandoned project from years past. It had some intricate mounts due to the fact that the hydraulic motor was mounted inside of the brush. Rather than try to redesign the motor mount, it was easier to make a matching bracket for the frame to attach to. Figure 10 shows this bracket.

![Custom mounting bracket with hydraulic motor inside of brush.](image)

Figure 10. Custom mounting bracket with hydraulic motor inside of brush.

Nut Guide Plates. The guide plates were drawn in AutoCAD and cut out of 3/16” steel plate on the CNC plasma cutter in Shop 6. They measure 18 inches tall and 30 inches long with a 2 inch flange on the bottom. An arc with a 9 inch radius was cut out of the rear-most side of each guide plate to allow them to be mounted as close to the brush as possible. Figure 11 shows the AutoCAD drawing of the plates. Braces were mounted inside the frame for the guide plates to attach to, as shown in Figure 12. To attach the plates to the frame, a piece of 2 ½” square tube was welded to the back of each plate. A piece of 2” square tube was welded to the brace in the main frame, and the larger tube attached to the plate was slid over the top of the smaller tube. Holes were drilled through each tube so that pins could be inserted to lock the plates in place so that the implement could rest on the ground without resting on the brush. This was done to prevent deformation of the brush during the offseason. While in use, the pins would be removed and the plates would be allowed to slide freely up and down the 2” tube by way of gravity. This is to allow the operator to partially lift the implement off of the ground
while leaving the plates on the ground as the tractor continues to move forward to allow the nuts to feather into the existing windrow.

Figure 11. AutoCAD drawing of nut guide plate.

Figure 12. Braces for mounting the guide plates.
Figures 13 and 14 show the completed frame before and after paint.

Figure 13. Completed frame before paint.

Figure 14. Completed frame after paint.
RESULTS

Field tests were not able to be conducted during the academic school year in which this project was fabricated as this implement was designed to be a part of the almond harvesting process, which doesn’t begin until late August or early September. However, some preliminary tests were conducted at the Cal Poly Feed Mill by hooking the implement up to a small tractor and sweeping a pile of almond hulls along the concrete floor of the Mill. The results from these preliminary tests indicated that the sweeper should be able to complete the job as it was intended to do after some minor modifications are made. Figure 15 shows the sweeper being tested at the Field Mill.

Figure 15. Sweeper being tested at the Cal Poly Feed Mill.

The main issue that was seen during testing was that when the hulls held between the guide plates built up above the midline of the brush, the brush began to pull them up and over the top and drop them behind the brush. Also, the speed that the brush was turning was too high, even at the lowest RPM possible, and would throw almond hulls in all directions.
DISCUSSION

End Row Sweeper Cost Analysis

Table 1 shows the Bill of Materials for this project. The original budget of this project was $2,500. The implement was able to be constructed for just under $1,500.

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<th>Description</th>
<th>Unit</th>
<th>Price/unit</th>
<th>Total Price</th>
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<td>$72.40</td>
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<td>$150.00</td>
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<td>ea</td>
<td>$4.49</td>
<td>$13.47</td>
</tr>
<tr>
<td>3</td>
<td>Rust-Oleum Crystal Clear Enamel</td>
<td>ea</td>
<td>$4.99</td>
<td>$14.97</td>
</tr>
<tr>
<td>4</td>
<td>Ace brand 15 oz spray paint - John Deere Green</td>
<td>ea</td>
<td>$4.99</td>
<td>$19.96</td>
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<td>$708.00</td>
<td>$708.00</td>
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<td>$348.00</td>
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<td>$12.98</td>
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<tr>
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<td>ft</td>
<td>$2.49</td>
<td>$12.45</td>
</tr>
</tbody>
</table>

Table 1. Project Bill of Materials and final build cost.

Most field workers are payed minimum wage, which, in California, is currently $10 per hour. Working a 10 hour day, that is equivalent to $100 per day, per employee. A typical crew of 5 workers can rake a 100 acre field in 2 days. Since each field could have anywhere from 2 to 4 different varieties of almonds, the field will have to be raked an equivalent number of times. A field that has 4 varieties of almonds could cost a farmer around $4,000 in labor fees to rake the almonds back inside the edge of the field. The sweeping implement could be sold to farmers for $2,500, making close to $1,000 in profit for the fabrication company, and would potentially pay for itself during its first season of use by saving the farmer several $1,000 in labor fees.
RECOMMENDATIONS

The main objective of this design is to offset the cost of hand labor crews in the almond harvesting process.

Instead of using 2 ½” x 2 ½” x 3/16” square tubing, downsizing the frame to a smaller material size would help save weight as well as material cost required to fabricate this implement. Also, using a hollow tul bar rather than a solid bar would save close to 50 lbs. There is also a large section of brush that is not being used on both sides of the windrow. Again, downsizing the length of the brush would help to save weight along with fabrication expenses.

The complete, fully assembled sweeper weighed in at 460 pounds. Cutting down on weight wherever possible would make handling of the implement during the hitching process much easier. The implement is light enough to be easily attached to the tractor by one person, but making the implement lighter would be more desirable.

During testing, the brush had a tendency to throw almond hulls in all directions. A shield should be added above the guide plates and in front of the brush to help better contain the nuts that get thrown into the air. The shield should span the entire width of the guide plates and contact the brush just below the centerline of the brush to reduce the likelihood of nuts being drug up and over the top of the brush as they build up between the guide plates. If the brush RPM still proves to be too high, a bypass-type flow control valve can be installed in the circuit to reduce the amount of oil being sent to the motor.
REFERENCES


APPENDIX A
HOW THIS PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR
HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

Major Design Experience

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes fundamental elements as outlined below. This project addresses these issues as follows.

Establishment of Objectives and Criteria. Project objectives and criteria are established to meet the needs and expectations of Motte Ranches, Inc. See "Design Parameters and Constraints" section below for specific objectives and criteria for the project.

Synthesis and Analysis. This project incorporates bending stress calculations, hydraulic system limitations/requirements, and the consideration of alternate sweeping/crowding methods.

Construction, Testing and Evaluation. The almond end-row nut sweeper was designed, constructed, tested and evaluated.

Incorporation of Applicable Engineering Standards. The project utilizes AISC standards for allowable bending stresses and ISO standards for hydraulic circuit schematics.

Capstone Design Experience

The BRAE senior project is an engineering design project based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses). This project incorporates knowledge/skills obtained from these key courses:

- BRAE 129 Lab Skills/Safety
- BRAE 133 Engineering Graphics
- BRAE 151 AutoCAD
- BRAE 152 3D Solids Modeling
- BRAE 234 Mechanical Systems
- BRAE 421/422 Equipment Engineering
- ME 211/212 Engineering Statics/Dynamics
- CE 204/207 Strength of Materials
- ENGL 149 Technical Writing

Design Parameter and Constraints

This project addresses a significant number of the categories of constraints listed below.
**Physical.** The implement must be able to mount to the three-point hitch of a small to mid-size orchard tractor using a category 2 three point hitch. The fully assembled implement measured just over 6 feet wide, 4 feet in length, and approximately 3.5 feet tall.

**Economic.** The cost of design/construction should not exceed $2,500. The implement should be easily attached and operated by one person. The project met this goal with a final build cost of approximately $1,500, and one person can very easily attach and detach the implement to the hitch of the tractor.

**Environmental.** The implement is able to move the almonds without moving excessive amounts of dirt, resulting in less dust particles being put into the air.

**Sustainability.** This implement sweeps the almonds without moving an excessive amount of soil, resulting in less dust released into the air, as well as less removal of nutrient rich top soil.

**Manufacturability.** While this is a “one-off” prototype, it is important to consider currently-available materials and components. This was done throughout the entirety of the project.

**Health and Safety.** Hydraulic hoses were properly sized to prevent accidental “blow outs” and any necessary guards were fabricated and installed to ensure operator safety.

**Ethical.** Operator safety was not neglected in order to meet other constraints of the project such as Economics or Sustainability.

**Social.** While not directly related to the scope of this project, this system could result in the displacement of labor, resulting in having to retrain workers for a new job skill.

**Political.** Care must be taken to ensure that there is no copyright infringement on design.

**Aesthetic.** The finished implement was spray painted to protect metal surfaces from rust and corrosion, as well as to provide a professional look.

**Other – Operational.** The implement must maintain the shape and approximate size of the windrow to ensure that all nuts will be picked up by the harvester. The project successfully met these goals.
APPENDIX B
DESIGN DRAWINGS
Frame Assembly

All material is hot rolled mild steel
Material is 2.5" sq. w/ 3/16" wall
Quantity: 1

Andrew Mancini
Frame Support Bar
Material is 2.5" sq. w/ 3/16" wall
Quantity: 1
Material is 2.5" sq. w/ 3/16" wall
Quantity: 1

Andrew Mancini

Right Brush Mount

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL
ANGULAR: MACH BEND TWO PLACE DECIMAL THREE PLACE DECIMAL

TOLERANCES:

INTERPRET GEOMETRIC TOLERANCING PER:

FINISH MATERIAL

UNLESS OTHERWISE SPECIFIED:

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF [INSERT COMPANY NAME HERE]. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF [INSERT COMPANY NAME HERE] IS PROHIBITED.

REVDWG. NO.

NAME DATE

Q.A.

MFG APPR.

CHECKED

ENG APPR.

DRAWN

INTERPRET GEOMETRIC TOLERANCING PER:

APPLICATION

DO NOT SCALE DRAWING

Dwg. No.

Size

Scale

Comments

Weight

Sheet
Material is 1.5" sq. w/ 1/8" wall
Quantity: 2
Material is 2.5" sq. w/ 3/16" wall
Quantity: 1
Material is 2.5" sq. w/ 3/16" wall

Quantity: 1
**Title:** Bearing Mount

**Material:** 1.5" x 1/4" flat

**Quantity:** 1

**Dimensions:**
- Length: 5.50"
- Width: 2.00"
- Thickness: 0.25"
- Diameter: 0.56" TYP - x2

**Notes:**
- R.188 TYP - x4
- UNLESS OTHERWISE SPECIFIED:
  - SCALE: 1:1
  - WEIGHT:

**Comments:**
- Andrew Mancini
- Q.A.
- MFG APPR.
- ENG APPR.

**Drawing Information:**
- DRAWN: [Signature]
- CHECKED: [Signature]
- ENG APPR.: [Signature]
- MFG APPR.: [Signature]

**Interpret Geometric Tolerancing Per:**
- MILLIMETERS

**Symbol:**
- G.A.

**Application:**
- USE ON

**Interpretation:**
- DO NOT SCALE DRAWING

**Material:**
- [Company Name]
Material is 2.5" sq. w/ 3/16" wall

Quantity: 2
Material is 3/16" plate

Quantity: 1

Andrew Mancini

Left Guide Plate
APPENDIX C
DESIGN CALCULATIONS
The calculations to determine the size of material to be used for the frame are as follows:

The frame was modeled as a cantilever beam with a length of 35 inches. The brush and motor assembly were modeled as a point load at the end of the beam, and a moment, also applied to the end of the beam. The point load had a magnitude of 120 lbs., as this is what the fully assembled brush and motor weighed. The motor used is an Eaton H-series motor that is capable of producing 750 in-lbs. of torque. Shown below are the FBD, and the Shear and Moment diagrams for the frame, and the calculations to get the reaction forces.

\[ \sum F_y = 0 \]
\[ R_A - P = 0 \]
\[ R_A = P = 120 \text{ lbs} \]

\[ \sum M_A = 0 \]
\[ M_A - M - P (35 \text{ in}) = 0 \]
\[ M_A = M + 35P \]
\[ M_A = 750 \text{ in} \cdot \text{lbs} + 35 \text{ in}(120 \text{ lbs}) = 4950 \text{ in} \cdot \text{lbs} \]

\[ M_{max} = M_A = 4950 \text{ in} \cdot \text{lbs} \left( \frac{1 \text{ ft}}{12 \text{ in}} \right) = 412.5 \text{ ft} \cdot \text{lbs} \]

**From Steel Construction Manual:**

**2” x 2” x 1/8” sq. tube:**

\[ M_n = 1.34 \text{ kip} \cdot \text{ft} = 1340 \text{ ft} \cdot \text{lbs} \]

\[ \text{Factor of Safety} = \frac{M_n}{M_{max}} = \frac{1340 \text{ ft} \cdot \text{lbs}}{412.5 \text{ ft} \cdot \text{lbs}} = 3.25 \]

**2 1/2” x 2 1/2” x 3/16” sq. tube:**

\[ M_n = 3.03 \text{ kip} \cdot \text{ft} = 3030 \text{ ft} \cdot \text{lbs} \]

\[ \text{Factor of Safety} = \frac{M_n}{M_{max}} = \frac{3030 \text{ ft} \cdot \text{lbs}}{412.5 \text{ ft} \cdot \text{lbs}} = 7.35 \]
\[ P = 120 \text{ lbs} \]

\[ R_A = 120 \text{ lbs} \]

\[ M = 750 \text{ in-lbs} \]

\[ M_A = -4950 \text{ in-lbs} \]

\[ R_A = 120 \text{ lbs} \]

\[ M = 750 \text{ in-lbs} \]