Department of Biosystems and Agricultural Engineering
MICHIGAN STATE UNIVERSITY

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Biosystems Design Projects

Improved hydraulic-powered plastic mulch removal implement for MSU Student Organic Farm

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Background

Weed suppression and removal is one of the most labor intensive and expensive components of organic farming (Drost & Maughan, 2016). Many growers, including Student Organic Farm (SOF) at Michigan State University (MSU), have come to rely on plastic mulch to control weeds in place of herbicides.

Plastic mulch is a polyethylene film about 1/32 in thick that helps to retain soil moisture, moderate soil temperature, and suppress weed growth (Ngouajio, 2018). The SOF gets their embossed black and white plastic mulch from TRICKL-EEZ Irrigation Inc (Trickl-eez, n.d.). An implement pulled behind a tractor is used to stretch the plastic over a raised crop bed and bury the edges beneath 2.75 in of soil. One of the main drawbacks to using plastic mulch is the difficulty of removal. The plastic mulch is thin, weakens over the growing season and tears easily near the buried edges; thus, it causes the accumulation of small plastic debris in the soil over time (Huang, et al. 2020.)

Figure 1. Previously used SOF implement

Objectives

Design a plastic mulch lifting system that meets the following performance criteria.

- A production rate of 12 beds/hour, each bed 5 ft by 150 ft
- The implement should roll the plastic into a compact bundle for easy removal
- The implement must not exert a greater force on the plastic than the material strength (i.e., no mulch tearing)

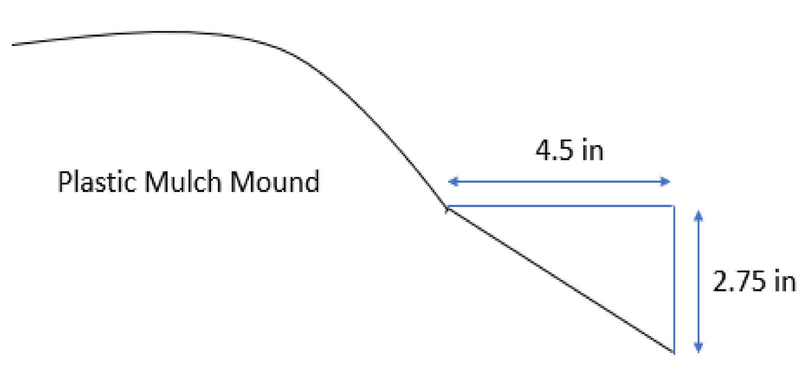

Figure 2. Plastic Mulch Mound Sideview

Constraints

Constraints for the project include

- Any solution must comply with organic farming standards (Legal Information Institute, n.d.)
- Removal early/mid fall after harvest
- No removal shortly after rain, as the soil becomes too heavy increasing tearing
- Implement sized to a plastic width of 4ft
- Remove 2 ac / season
- Available tractor 60 hp

Figure 3. Row of plastic mulch and drip tape

Design Alternatives

Initial Considerations

- Biodegradable mulch
  - ❖ Challenging to source biodegradable mulch in compliance with organic farming standards (Corbin, et al. 2019)
- Paper mulch
  - ❖ Difficult to apply
  - ❖ Concerns with PFAS leaching (Glenn et al. 2021)
- Straw cover
  - ❖ Can add seed to the soil when applied

Component Alternatives with Plastic Mulch Removal Implement

- Soil loosening implement
  - ❖ Chisel plow
  - ❖ Undercutting discs
  - ❖ L-shaped tillage blade
- Power source
  - ❖ Ground driven
  - ❖ Hydraulically driven
  - ❖ PTO driven
- Collection
  - ❖ Single reel winding mechanism
  - ❖ Double reel winding mechanism
  - ❖ Collection by hand

Selected Design

The selected design is a hydraulically-driven, single-sided plastic collection reel that uses an L-Shaped blade to undercut the soil. This configuration was chosen based on its weighted rankings of safety, reliability, ease of use, cost and manufacturability.

Soil loosening implement : L-shaped blade

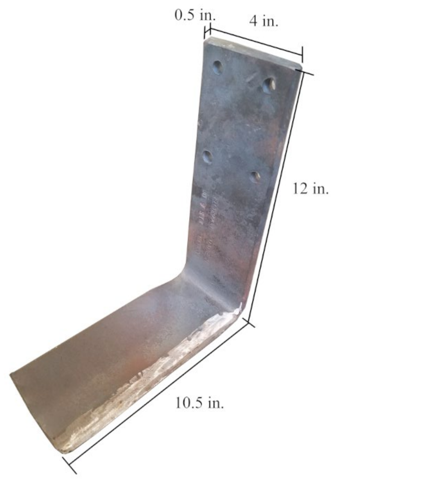

Figure 4. L-shaped blade with dimensions

The L-Shaped blade is wide enough to accommodate errors in steering the tractor and provides ample lifting of the plastic.

Power source: Hydraulicly driven

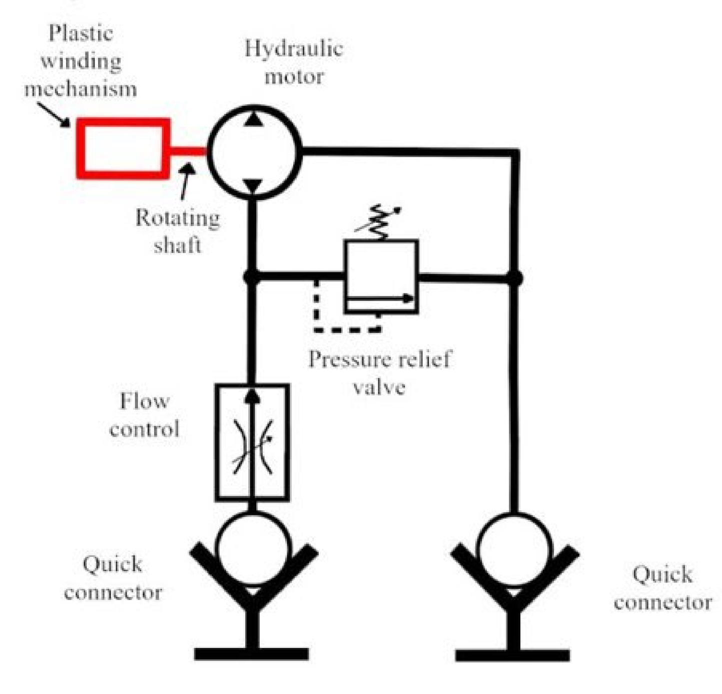

Figure 5. Hydraulic system schematic

Using a hydraulic system allows for constant tension to be applied to the plastic. Flow control allows for adjustment of reel speed and the pressure relief valve allows for control of reel torque.

Figure 6. Hydraulic motor and controls

Collection: Single reel winding mechanism

Utilizing a single reel to collect the plastic exceeds the minimum speed of collection and keeps the design within budget.

Design Parameters

The implement is designed to be mounted on a toolbar from the SOF and attached to a tractor via a 3-point hitch. A frame made of 2" square steel tubing with 3/16" thick walls was constructed to hold the hydraulic motor and winding reel. The height of the reel is 4.5 feet off the ground for easy removal of the plastic and to ensure that debris can fall off as winding occurs. Gauge wheels are mounted to the ends of the toolbar for smooth travel and L-shaped blade depth control.

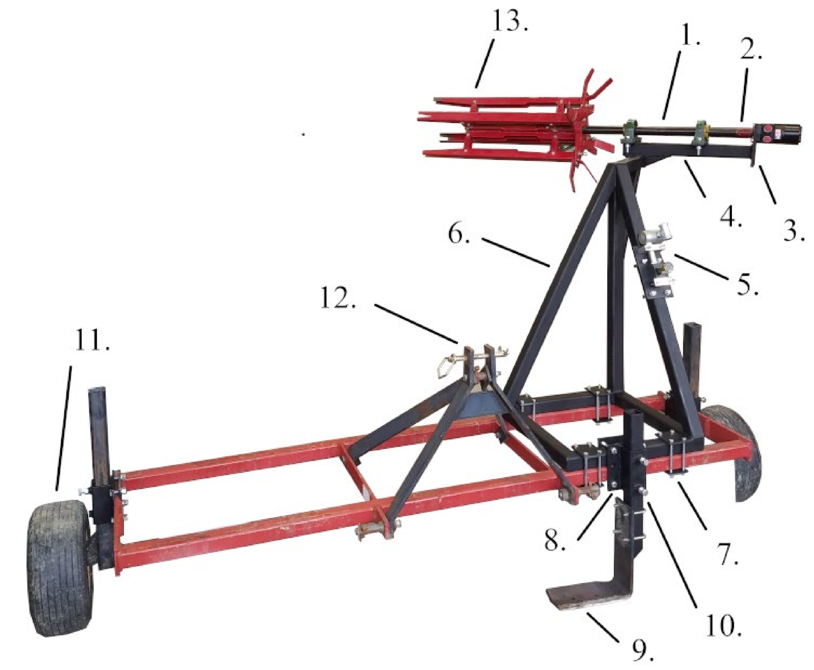

Figure 7. Final manufactured prototype

1. Reel shaft
2. Reducer coupling
3. Mounting plate
4. Bearing arm
5. Valve mounting plate and fixtures
6. Reel support frame
7. Mounting plates
8. Adjustable brackets
9. Custom L-shaped tillage blade
10. Tillage blade arm
11. Gauge wheels
12. 3-point hitch
13. Plastic winding reel

Key Equations

Flow rate:

$$Q\ (lpm) = 30\ lpm = \frac{D*n}{1000} = \frac{D*98\ RPM}{1000}$$

$$D = 309\ cm^3 = 18.9\ \text{in}^3$$

The flow rate equation was used to calculate the displacement (D) of the hydraulic motor based on the flow (Q) from the tractor's hydraulic system and the required rotational speed of the reel (n).

Shaft torque:

$$\text{Max. Shaft Torque} = \frac{D*p}{20*pi}$$

$$T\ Max. = 357\ Nm = \frac{293cm^3 * p}{20*pi}$$

$$p = 72.6\ \text{bar} = 1053\ \text{psi}$$

The equation for shaft torque was used to find the pressure range (p) of the system based on the displacement (D) along with min. and max. torque (T) needed to lift the plastic mulch.

Economics

Current practice yearly cost:

$$\left(\sim 100\ beds \times \frac{20\ minutes}{bed} \times \frac{1\ hour}{60\ minutes}\right)\left(7\ workers \times \frac{\$12}{1\ hour}\right) = \$2{,}797$$

Projected cost with implement:

$$\left(\frac{2\ hours}{25\ beds} \times 100\ beds + 2\ hours\ bale\ collection\right)\left(2\ workers \times \frac{\$12}{1\ hour} + \frac{2.5\ gallons\ diesel}{1\ hour} \times \frac{\$3.50}{gallon}\right) = \$328$$

Manufacturing Cost: $989.70

$$\frac{\$2797 - \$328}{\$989} = 2.5$$

Return on investment of 2.5 over a one-year period

Figure 8. Row of plastic mulch installed for testing purposes

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