BETWEEN-ROW MOWER DESIGN FOR WEED CONTROL IN ORGANICALLY GROWN NO-TILL SOYBEANS

A Thesis

Presented to

The Faculty of the Graduate School

at the University of Missouri

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

GABRIEL AYICHIM ZULKARINI ABDULAI

Dr. Kerry Clark, Thesis Supervisor

JULY 2018

The undersigned, appointed by the dean of the Graduate School,

have examined the thesis entitled

BETWEEN-ROW MOWER DESIGN FOR WEED CONTROL IN ORGANICALLY GROWN NO-TILL SOYBEANS

Presented by Gabriel Ayichim Zulkarini Abdulai

A candidate for the degree of Master of Science, Biological Engineering

And hereby certify that, in their opinion, it is worthy of acceptance.

____

Dr. Teng Lim

____

Dr. Kerry Clark

____

Dr. Leon Schumacher

____

Dr. Steve Borgelt

ACKNOWLEDGEMENTS

A local proverb in my home country states that ‘when someone has been good to you, appreciate them and be grateful’ It is therefore with heartfelt gratitude that I want to thank Dr. Kerry Clark for providing me with this great opportunity to grow in knowledge and to contribute to the field of mechanical weed control in organic no-till. I am most grateful for this opportunity and the scholarship given me. I also want to thank Dr. Leon Schumacher for his encouragement. Your counsel and mentorship has been helpful and contributed to making me a better student. I am also grateful to Dr. Teng Lim for his advice and support in the pursuit of my master’s degree. I want to also thank Dr. Steve Borgelt for broadening my horizon in hydraulics. Dr. Rob Myers supported and encouraged me greatly in my pursuits. I am also grateful to Dr. Mark Ellersieck for his help in analyzing my data.

Betzy Valdez and Ricardo Costa were helpful on the field, assisting with weed collection and other field activities. I also want to say thank you to Pieter Los, for his support and help on the field. I am also grateful to Zhang Xiqiao for his help in SolidWorks. I am thankful to Benson Naylor and Gordon Ellison (Gina) for their advice and help in the construction of the mower.

I want to thank my wife, Nahja Abdulai for her support and love. You have been amazing. I love you so much. My family in Ghana, my mum and siblings, their love and support has been amazing. Finally, and most importantly I am most grateful to God for His grace, love and strength throughout the pursuit of this degree. I am forever grateful.

TABLE OF CONTENTS

List of Tables

Table **Page**

List of Figures

Figure **Page**

Chapter Two

Chapter Three

Chapter Four

APPENDICES

BETWEEN-ROW MOWER DESIGN FOR WEED CONTROL IN ORGANICALLY GROWN NO-TILL SOYBEANS

Gabriel Abdulai

Dr. Kerry Clark, Thesis Advisor

ABSTRACT

Weeds are a major challenge in organic no-till soybean production. They impair crop growth and result in yield loss. Innovative weed control methods need to be developed and experimented with in organic no-till agriculture to reduce weed density and improve organic yield. In 2017, mowing between crop rows was compared to cultivation in two central Missouri locations (Herman and Bradford Research Center). Cereal rye (*Secale cereale* L.) was used as a cover crop in some mowing treatments. Treatments included 1) pre-plant tillage + cultivation; 2) pre-plant tillage + mowing for weed control; 3) organic no-till using cover crops + mowing for weed control; and 4) organic no-till using cover crops + no subsequent weed control. Weed control treatments were conducted when seedlings were 4 in (10.2 cm) and repeated as needed until canopy closure. Broadleaf and grass biomass was collected between-row and in the row of organic soybeans to evaluate the efficacy of the weed treatment. Weed biomass was not significantly different at either testing locations. Yield from mowing with cover crop was 22 percent higher than cultivation treatments in both locations. Mowing between rows and cultivation has high potential for crop damage during operations. Between-row mowing with cover crops has great potential for weed control in organic soybean production and can be utilized in organic no-till.

CHAPTER ONE

1.0 Introduction

Mass media conversation on the safety of food has driven the conversation on organic no-till agriculture. The need to sustain soil health and plant life has also pushed a global research on organic food production. Organic no-till is a form of sustainable agriculture that combines organic and no-till agriculture. This form of agriculture contributes to soil fertility, reduces production costs by up to 96% and improves crop yields over time (Derpsch et al. 2001).

While organic agriculture disallows synthetic herbicide, no-till agriculture precludes the use of soil disturbing equipment (Derpsch et al. 2001). An organic no-till farming system can provide environmentally friendly substitute to conventional pesticide system (Stockdale et al. 2001; Biao et al. 2003). Organic agriculture has seen a tremendous increase in ground under cultivation across the globe. Yussefi (2006) reported that the annual growth rate of organic farming was estimated to be 20% for the last ten years resulting in an estimated 31 million hectares increase in farmland and trade globally.

Farmers who transition from conventional to organic production are challenged with limited natural fertilizer and pesticides use, increased use of organic matter, changes in machinery and the introduction of new agricultural practices (Organic Farming Research Foundation 1999). Weed control without herbicides has limited the adoption of organic farming in the United States and farmers who have adopted organic practices list weed management as one of the road blocks to organic no-till farming practices (Organic Farming Research Foundation 1999).

1.1 Justification

Walz (1999) observed that weeds are a barrier to organic no-till adoption. The need to control weeds on organic no-till farms have resulted in the development of many innovative weed management techniques. Fontanelli et al. (2015) indicated that the use of novel weed control methods led to a substantial weed reduction. These innovative technologies (flaming, precision hoeing and rolling harrow) increased crop yield, decreased power requirement and increased the profits of farmers. Tillage systems affect the biotic and abiotic environment of soil microorganisms. In a conventional study comparing tillage and weed seed in soil, no-till decreased weed seed numbers by 40% relative to herbicides alone (Yenish et al. 1992).

The use of cover crops for weed control in organically grown soybeans is an important practice. Biomass from cover crops decompose over the growing season to supply crop nutrients, prevent erosion, and serve as primary weed control. Though cover crops suppress weeds, weeds still emerge through the crimped cover crop to compete with established crops. To control weeds, some technologies have been developed and applied to manage weeds in organic no-till farming systems. These methods have included high residue cultivation, flame applicators, hot water applicators and weed pullers.

The goal of this research was to offer a novel alternative to some other weed management systems (hot water or high residue cultivation). Mowing is an old technology which has been used in land scape, pasture and weed management for over a century. Between-row mowing utilizes the fast-moving blades of tractor-mounted mower to defoliate the weeds and terminate their growth.

Donald et al. (2001) examined the impact of between-row mowing and banded herbicide application on no-till soybeans and corn and observed that between-row mowing as a mechanical weed control approach has great potential of suppressing weeds in no-till corn and soybeans. Donald (2000) also stated that mowing close to the soil surface (less than 3.8 cm - 1.78 in) several times between-rows destroyed young annual grasses and broadleaf weeds. Donald (2007) also suggested that the sale and marketing of between row mowers as a cultivation equipment could provide farmers with an alternative approach to weed control in no-till farming. Between-row mowing is also suitable for agricultural systems where the use of synthetic substances is not allowed. This technology will provide farmers with an innovative tool to effectively control between-row weeds in organically grown no-till soybeans. When weeds are properly controlled, crops thrive resulting in increased yield. This current research is a continuation of what was begun over a decade ago by William Donald and his colleagues at USDA-ARS in Columbia (Clark 2018).

1.2 Specific Objectives

1. To design and fabricate a three-point hitch between-row (four) mower driven by a remote PTO hydraulic pump.
2. To determine the effects of the developed between-row mower on weed control and soybean yields.

1.3 Chapter One Reference

Biao X., Wang X., Ding Z. and Yang Y. (2003) Critical impact assessment of organic agriculture. J. Agric. Environ. Ethics. 16:297-311.

Clark K. (2018) Personal Communication. University of Missouri, Columbia.

Derpsch R., Friedrich T., Kassam A., Li H.W. (2010) Current status of adoption of no-till farming in the world and some of its main benefits. Int. J. Agric. and Biol. Eng. 3:1−25.

Donald W. W. (2000) Timing and frequency of between-row mowing and band-applied herbicide for annual weed control in soybean. Agron. J. 92:1013-1019.

Donald W. W. (2007) Between-Row mowing systems control summer annual weeds in no-till grain sorghum. Weed Tech. 21:511-517.

Donald W. W., Kitchen N. R., and Sudduth K.A. (2001) Between-row mowing + banded herbicide to control annual weeds and reduce herbicide use in no-till soybean (Glycine max) and corn (Zea mays). Weed Tech. 15:576–584.

Fontanelli M., Christian F., Luisa M., Michel P., Michele R., and Andrea P. (2015) Innovative Strategies and Machines for Physical Weed Control in Organic and Integrated Vegetable Crops. Chem. Eng. Trans. 44.

Greenland D. (2000) Effects on soils and plant nutrition. In: Tinker, P.B. (Ed.). Shades of Green-A review of UK Farming Systems. Royal Agricultural Society of England, Warwickshire, pp. 6-20.

Organic Farming Research Foundation (1999) Final Results of the Third Biennial National Organic Farmers' Survey. Santa Cruz, California.

Stockdale E. A., Lampkin N. H. and Hovi M. (2001) Agronomic and environmental implications of organic farming systems. Advances in Agronomy 70: 261–327.

Walz E. (1999) Third Biennial National Organic Farmers' Survey. Santa Cruz, CA: Organic Farming Research Foundation

Yenish J. P., Doll J. D. and Buhler D. D. (1992) Effects of tillage on vertical distribution and viability of weed seed in soil. Weed Sci. 40: 429-433.

Yussefi M. (2006) Organic farming worldwide (2006) Overview and mains statistics. In: Willer, H., M. Yussefi. The world of organic agriculture. Statistics and emerging trends (Eds.). International Federation of organic agriculture movements (IFOAM), Bonn Germany and Research Institute of organic agriculture (FiBL), Frick, Switzerland, pp. 23-37.

CHAPTER TWO

2.0 Literature Review

2.1 Organic Farming

Organic farming has been described as ecological or sustainable agriculture because of its role of ensuring renewed continuation of agro-ecological systems (Gosling et al. 2005). Sustainability was defined by the World Commission on Environment and Development (1987) as satisfying the demands of the contemporary generation without jeopardizing the needs of posterity. The word organic cannot be used on non-organic food products, this situation prevents indiscriminate and wrong labeling of food products in some countries (FAO 1988).

Lampkin (1994) observed that organic farming functions to provide the right environment to improve the living and non-living environment of plants. Yussefi and Willer (2003) further described organic agriculture as a practice which provides both a sustainable and viable environment for soil living organisms and plants. Organic farming prohibits the use of synthetic pesticides and fertilizers but utilizes agricultural practices such as crop rotation, plant spacing, cover crops and composting in crop production (Kuo et al. 2004).

2.2 Advantages of Organic agriculture

2.2.1 Improved Soil Living Organism Activity

Organic farming creates a favorable environment for soil living organisms to thrive. This practice increases the activity of soil micro and macro living organisms. Soil microorganisms such as bacteria and fungi population increase with organic agriculture practices (Gunapala and Scow 1998). When non-organic fields were converted to 100 percent organic, fungi, bacteria and earthworm population improved significantly (Scow et al. 1994; Matsubara et al. 2002). A study conducted to compare three agricultural systems: (a) cover crops with animal droppings only, (b) cover crops only and (c) nitrogen fertilizer with cover crops recorded. The two systems with cover crops recorded higher population and activity of soil microbes than the conventional systems (Wander et al. 1994).

2.2.2 Enhanced Soil Physical Characteristics

Organic substances such as animal litter used in place of synthetic inputs such as inorganic fertilizers can enhance soil physical properties. This results in improved soil porosity, soil bulk density and texture (Petersen et al. 1999). Reduced bulk density improves pore space and aeration resulting in effective drainage of the soil (Werner 1997). Tester (1990) also showed that applying manure improved soil porosity resulting in improved infiltration rate.

2.2.3 Organic Matter Improvement

Soil organic matter can be defined as the proportion of soil that is comprised of natural materials in various stages of decomposition. Soils with capacity to support plant growth whiles ensuring the survival of soil living organisms often have between three to six percent organic matter (Fenton et al. 2008). Organic farming can increase soil organic matter content (Alvarez et al. 1988). Organic matter build-up in fields recently converted to organic often takes time but consistently increase with time (Clark et al. 1998; Kuo et al. 1997).

2.3 Market for Organic Corn and Soybeans

Organic production has seen a tremendous growth since the late 1990s. Organic production in the United State has doubled chiefly due to high demand for organically grown food. In 2008, organic food sales hit a record of $21.1 billion which was five times higher than recorded in 1997(Greene et al. 2009). The import of organic corn and soybeans increased because of high local demand which surpassed supply. Multinational companies which trade in organic corn and beans depended primarily on local supply in 2004 but 38 percent of those companies outsourced organic products (Greene et al. 2009).

Greene et al. (2009) also observed that organically grown soybean was more profitable in 2006 than conventional soybeans. High profitability was traced to price premiums paid for organically grown soybeans. Though high premiums have been paid for organically grown soybeans, this has not drastically increased the acreage of land under which organic soybean is cultivated

2.4 No-Till Agriculture

No-till agriculture is a conservative agricultural practice where seeds of crops are placed into an untilled soil by creating slender openings and placing the seed at a set depth to ensure seed soil contact (Phillips and Young 1973). Derpsch et al. (2010) revealed that the ground under which no-till is practiced globally increased from 2.8 million ha to 6.2 million ha within a decade. Out of the 6.2 million ha, the United States of America recorded over 4.65 million ha. Weed control in no-till is often performed with the following practices and strategies to avoid weed regrowth (Derpsch et al. 2010).

- Crop rotation
- Cover crop integration
- Use of natural herbicides

2.4.1 No-till and Cover Crops

No-till without cover crops reduces growth and crop yield (Ashburner 1984). A study by Wall (1999) in Bolivia revealed that no-till with cover crops produced high yields as compared to conventional and minimum tillage. The lowest yields were recorded in no-till without the use of cover crops. These results were not different from that obtained by Sayre et al. (2006). These researches showed that the yield of no-till wheat and maize without cover crop was lower than with no-till with cover crop. The researchers concluded that no-till without cover crops greatly affects crop yield.

Cover crops function to improve crop yield, soil biotic and abiotic environment. The many benefits of no-till agriculture stem from cover crop usage (Derpsch 2007). No-till is not the only factor contributing to increased crop yield but when shared with cover crops, this combination contributes to the performance of this agricultural practice.

Cover crops provide the right environment for soil living organisms such as fungi, protozoa and earth worms to thrive. The absence of cover crops increases the rate of erosion, run-offs, reduced biological activity and yields (Govaerts et al. 2007). When cover crops are crimped using a chevron crimper, they provide a mulch to suppress weeds preventing their early weed emergence.

2.4.2 Advantages of No-till agriculture (Derpsch et al. 2010)

- Reduces fuel use by 66%
- Reduces CO_2 emissions from soil by preventing organic matter oxidation
- Decreases production costs by 96%

2.5 Weeds in Organic Farming

Rao (2000) observed that weeds can rob crops of about half of soil micro and macro minerals and close to a quarter of water stored in soil. A study was conducted in 2015 to determine the biggest challenges of farmers who organically grow wheat and corn (McBride et al. 2015). These chanllenging areas included weed control, ways to increase yields and the complex certification process of converting to organic. The survey further revealed that 40% of both corn and wheat farmers reported weeds as a hindrance to organic agriculture. The absence of synthetic herbicides in organic crop production makes weed control difficult for organic farmers as compared to conventional farmers (McBride el al. 2015).

2.5.1 Weed Management Methods

Some scientists have theorized that the early man probably realized that when crops were produced without some other plants, their yields increased. This resulted in the early man identifying what was a weed and what was not (Hay 1974). The concept of weed management therefore has been in existence for over a millennium (Rao 2000). Weed control ranges from selecting the right machinery to selecting the right pesticide required for weed management, all of which are expensive. Weeds not only steal nutrient from crops, they compete with crops for sunlight, moisture and are host to insects and pest (Abu-Hamdeh 2003). To effectively control weeds, one silver bullet doesn't exist, but an integrated approach is required. These approaches often include cultural, mechanical and chemical methods.

2.5.2 Mechanical weed control

2.5.3 Between-Row Mowing

Mowing is the process whereby any part of the plant (weed) is physically defoliated resulting in physical damage and stalled growth (Donald 2007). Between-row mowing is the practice where weeds between rows of crops are mowed to reduce/terminate them. In this practice, weeds are mowed close to the ground without causing damage to crop. This practice has great promise of success in reducing the effects of weeds in no-till agricultural systems. Negative preconception on the role of mowing in controlling weeds has probably discouraged many weed scientists from incorporating it into weed management systems (Donald 2007).

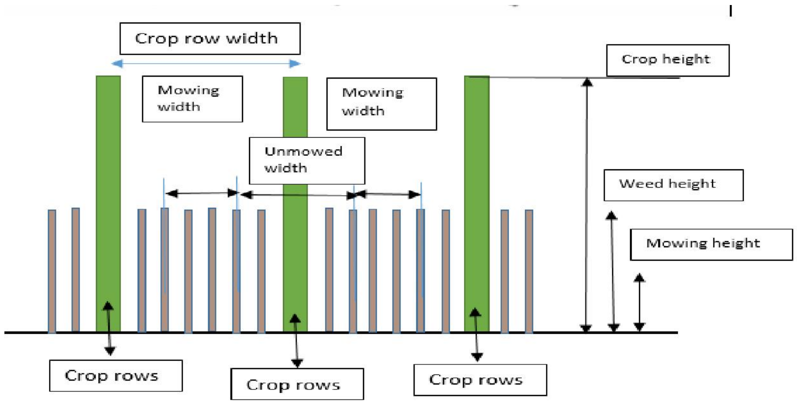


Figure 2.1: Between-row weeds and crop (Donald 2007).

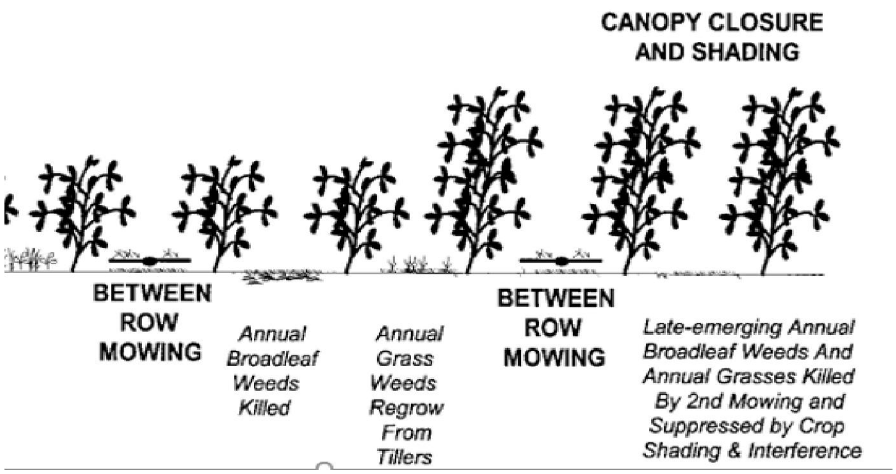


Figure 2.2: Soybean development over production period with between-row mowing practice (Donald 2007).

2.5.3.1 Importance of Between-Row Mowing

Between-row mowing suppresses weeds and promotes the growth of crops with the intent of increasing crop yield. Mowing reduces weed competition and increases weed mortality, preventing weeds from producing viable seeds. Mowing results in the removal of leaves and stems of weeds leading to a decrease rate of photosynthesis (Donald 2007).

Moreover, mowing changes the living and non-living environment of mowed plant. Non-living factors such as light, temperature and soil moisture among others are affected by mowing. Mowing allows more light unto the soil surface which was initially covered with weeds. This results in improved intensity, availability and quality of light at the soil surface and on leaves below the canopy of row crops (Donald 2007). Muensher (1980) also indicated that mowing can be undertaken when herbicide application and cultivation were not feasible.

2.5.3.2 When to Mow

Donald (2007) observed that some weeds can withstand mowing whiles others cannot. Weeds intolerant to mowing are weeds that die back after one or two mowing activities. Resilient weeds on the other hand are weeds which can withstand one or two mowing sessions and continue to production seed. However, mowing frequency and timing can suppress weed growth. To properly eliminate weeds from the crop's environment, knowledge of the way weeds respond to mowing is necessary. Knowledge of the stage of growth, whether the weed is an annual or perennial and the physiology of the weed is relevant information that is worth considering before mowing (Diaz et al. 1999).

Perennial broadleaf weeds develop tolerance to mowing when they attain a certain height because they form adventitious buds, stolons, bulbs and rhizomes which serves as carbohydrate reserves (Donald 2007). Regular mowing can exhaust the carbohydrate reserves of the rhizome resulting in reduced growth and productivity of the weed (Aldrich and Kremer 1997). Timely mowing reduces weed density and prevents weed seed production. Mowing at the right time also reduces weed density and prevents weed growth to produce seeds (Thill et al. 1993). However, untimely mowing has its consequences as well. This results in the spread of weed seed which can result in increased weed population in subsequent production years.

2.5.3.3 Mower Equipment

Commercial mowers have been around for the past century after Edwin Beard produced the first mower in England (Wikipedia 2018). After the first mower was developed, many improvements have been added to the mowers used today. Self-controlled, intelligent/smart, brush hog and finish mowers all demonstrate how far mowers have progressed over the past decade. Improvements in mower technology have also occurred in their power sources. The original mower was manually pushed to effect mowing, but the invention of the engine transformed the mower. Mechanical power produced from gasoline and electrical engines/motors have been developed and used on different mowers. Mowers act in two ways: impact and shear cutting (O'Dogherty and Gale 1991). Impact cutting involves blades splitting plants at high speed. The process involves a contact between the blades and the weed. The blade cuts off stems, leaves and other parts of the plant which interacts with the blade/plastic cord of the mower. The shear acting mowers have parts which acts in a reciprocating motion like scissors or sickles to cut the weed (Donald 2007). Common types of commercial mowers include (Persson 1987):

- Rotary or disc mowers
- Flail mowers
- Reciprocating sickle bar mowers
- Reel mowers (Shear cutting)

2.5.3.4 Rotary mowers

Rotary mowers are machines that cut plant tissue using mowing elements (blade or plastic cord) rotating at a high speed horizontally (Hunt 2001). The horizontal speed of the mower usually ranges between 2000 and 4000 revolutions per minute (Virginia Cooperative Extension 2014). Rotary mowing elements will usually include single blades, arms with knives on their ends (flat, suction, pickup), or plastic cord of various thicknesses. Rotary mowers are usually operated tipped forward at an angle relative to the ground to reduce re-mowing cut foliage.

2.6 Hydraulic Between-row mower

A hydraulic between-row mower was developed by William Donald and his team in the United State Department-Agricultural Research Service (USDA-ARS) in the late 1990's to control weeds between crop rows. This between-row mower was attached to a Hagie high boy sprayer that was once used at the University of Missouri Bradford Research Center in Columbia, Missouri. The Hagie 8240 high boy sprayer (Hagie Manufacturing, Clarion, Iowa) with an attached four row mower was developed to mow weeds in soybeans when they were three inches tall or at a height of between 0.5-1.0 in (1.27-2.54 cm) above the soil surface between crop row widths (29.92 in - 76.2 cm). The hydraulic motors on the mower were connected in series and powered by the onboard hydraulic pump on the Hagie high boy sprayer.

Figure 2.4: Hagie 8240 four row field mower (Gabriel Abdulai)

2.7 Chapter Two Reference

Abu-Hamdeh N. H. (2000) Effect of weed control and tillage system on net returns from bean and barley production in Jordan, 45:2.23–2.28.

Aldrich R. J. and Kremer R. J. (1997) Principles in weed management. Iowa State University Press.

Alvarez C. E., Garcia C. and Carracedo A. E. (1988) Soil fertility and mineral nutrition of an organic banana plantation in Tenerife. Biol. Agric. and Hort. 5: 313-323.

Ashburner J. E. (1984) Dryland tillage practices and studies in Algeria. In: FAO Panel of Experts on Agricultural Mechanization, 6th Session, October, Adana, Turkey, pp. 22.

Clark M. S., Horwath W. R., Shennan C. and Scow K. M. (1998) Changes in soil chemical properties resulting from organic and low-input farming practices. Agron. J. 90: 662-671.

Díaz S., Cabido M. and Casanoves F. (1999) Functional implications of trait–environment linkages in plant communities. Ecological Assembly Rules Perspectives Advances, Retreats (eds E. Weiher & P. Keddy), pp. 338–362. Cambridge University Press, Cambridge, UK

Derpsch R., Friedrich T., Kassam A. and Li H. W. (2010) Current status of adoption of no-till farming in the world and some of its main benefits. Int. J. Agric. and Biol. Eng. 3:1—25

Derpsch R. (2007) How to get no-tillage to the next level. In: Proc. No-Till on the Plains Winter Conference AIM Symposium, 1 February 2007, Salina, Kansas.

Edward-Jones G. and Howells O. (2001) The origin and hazard of inputs to crop protection in organic farming systems: are they sustainable? Agric. Syst. 67:31-47.

Fenton M., Albers C., Ketterings Q. (2008) Soil Organic Matter. Agron. Fact Sheet Series: Fact Sheet 41. Cornel University Cooperation Extension.

Food and Agriculture Organization (1998) Evaluating the potential contribution of organic agriculture to sustainability goals. Environment and Natural Resources Service. Sustainable Development Department. FAO's technical contribution to IFOAM's Scientific Conference, Argentina, November 1998. http://www.fao.org/DOCREP/003/AC116E/AC116E00.HTM Accessed March 3, 2018.

Greene C., Dimitri C., Lin B., McBride W., Oberholtzer L. and Smith T. (2009) Emerging Issues in the U.S. Organic Industry Econ. Info. Bulletin Numb. 55.

Gosling P. and Shepherd M. (2005) Long-term changes in soil fertility in organic arable farming systems in England, with particular reference to phosphorus and potassium. Short communication. Agric. Ecosyt. Environ. 105: 425-432.

Govaerts B., Fuentes M., Mezzalama M., Nicol J. M., Deckers J., Etchevers J.D., Figueroa-Sandoval B. and Sayre K. D. (2007) Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage residue and crop rotation managements. Soil Tillage Res. 94:209–219.

Hunt D. (2001) Farm power and machinery management, Tenth edition. Ames: Iowa State University.

Kuo S., Ortiz Escobar M. E., Hue N. V. and Hummel R. L. (2004) Composting and compost utilization for agronomic and container crops. In: Pandalai (Ed.). Recent Res. Dev. and Environ. Bio. Res. Signpost. pp. 451- 513.

Matsuraba Y., Hasegawa N., Fukui H. (2002) Incidence of fusarium root rot in asparagus seedlings infected with Arbuscular mycorrhizal fungus as affected by several soil amendments. J. Japan Soc. Hort. Sci. 71 (3): 370-374.

Muensher W. C. (1980) Weeds, Second edition. Ithaca, NY: Cornel University Press.

O'Dogherty M. J. and Gale G. E. (1991) Laboratory studies of the effect of blade parameters and stem configuration on the dynamics of cutting grass. Journal of Agric. Eng. Res. 49:99-111.

Parker Hannifin Corporation (2003) Gerotor Pump and Motor. Aluminum High Speed, Low Torque Series. Catalog HY09-PGG/MGG/US. Accessed from http://transistor-man.com/files/fission_product/pdf/hydraulic_pump_manual.pdf on 7th of July 2018.

Persson S. (1987) Mechanics of cutting plant material. American Society of Agricultural Engineers Monograph Number 7. St. Joseph, MO

Petersen C., Drinkwater L. E. and Wagoner P. (1999) The Rodale Institute Farming Systems Trial: The first fifteen years. Kutztown, PA: The Rodale Institute.

Phillips S. and Young H. (1973) No-Tillage Farming. Reiman Associates, Milwaukee, Wisconsin. pp. 224.

Rao V. S. (2000) Principles of Weed Science, Second Edition, Science Publishers, Plymouth.

Sayre K., Govaerts B., Martinez A., Mezzalama M., Martinez M. (2006) Comparison of alternative conservation agriculture technologies for rainfed production in the highlands of Central Mexico. Proceedings on CD, 17th ISTRO Conference, Kiel, Germany, 28 August – 3 September 2006, pp. 1012 – 1018.

Scow K. M., Somasco O., Ferris H, Gunapala N, Lau S., Venette R, Miller R, and Shennan C. (1994). Transition from conventional to low-input agriculture changes soil fertility and biology. Cal. Agric. 48: 20-26.

Tester C. F. (1990) Organic amendment effects on physical and chemical properties of a sand soil. Soil Sci. Soc. Am. J. 54:827-831.

Thill D. C., O'Donovan J. T. and Mallory-Smith C. A. (1993) Integrated weed management strategies for delaying herbicide resistance wild oats. Phyto protection 75 (Suppl.): 61 – 70.

Virginia Cooperation Extension (2014) Rotary Mowers Safety: Lawn Care Training Guide. Mower Care and Safe Use. PublicationBSE-47P. Accessed from https://pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/BSE/BSE-47/BSE-47NP-PDF.pdf on March 30 2018.

McBride W. D., Greene C., Linda F. and Mir A. (2015) The Profit Potential of Certified Organic Field Crop Production, ERR-188, U.S. Department of Agriculture, Economic Res. Service.

Wall P. (1999) Experiences with crop residue cover and direct seeding in the Bolivian highlands. Mount. Res. and Dev. 19: 313 – 317.

Wander M. M., Traina S. J., Stinner B. R., Peters S. E. (1994) Organic and conventional management effects on biologically active soil organic matter pools. Soil Sci. Soc. Am. J. 58: 1130-1139.

World Commission on Environment and Development (1987) Our Common Future. Oxford University Press, Oxford.

Wikipedia (2018) Edwin Beard Budding. Accessed from https://en.wikipedia.org/wiki/Edwin_Beard_Budding on the July 5 2018.

Werner M. R. (1997) Soil quality characteristics during conversion to organic orchard management. Appl. Soil Ecol. 5:151-167.

Yussefi M. and Willer H. (2003) The World of Organic Agriculture-Statistics and Future Prospects. International Federation of Organic Agriculture Movements (IFOAM).

CHAPTER THREE

3.0 Materials and Methods

3.1 Background

The treatments in the field test study for the between-row mower were: 1) tilled field + cultivation for weed control; 2) tilled field + mowing for weed control; 3) crimped cover crop + mowing for weed control; and 4) crimped cover crop + no subsequent weed control (after several weeks into the study this was determined to not be feasible and weeds were mowed). The study was conducted on a 0.23ha (0.58ac) field at the Bradford Research Center, University of Missouri research farm located in Columbia, MO (38.8929 º N, 92.2010 º W). The predominant soil series at the Bradford Research Center is Mexico silt loam (pH of 6.7 and 3.8% organic matter). The field received organic certification through Quality Certification Services (QCS, Gainesville, FL).

Before the onset of the study, the field was made ready in the fall of 2016. The site was mowed with a 4.6 m (15.1 ft) John Deere Bush Hog (John Deere, Moline, IL). Organic compost from poultry manure (3-2-2) (Early Bird Composting, California, MO) was applied with a New Holland 155 spreader (New Holland Ag., New Holland, PA) at 3.6 mT ha^{-1}. The site was then disked with a True-Tandem disk harrow 375 with 61 cm blades and 23 cm spacing (Case IH, Racine, WI) twice to incorporate the compost. Experimental plots measured 6.10 m x 9.14 m (20 ft x 30 ft).

In addition to the research field at the Bradford Research Center, a similar study was conducted at 1002 high way 19-North of Herman-Missouri (38.7042 ° N, 91.4374 ° W) on a commercial farm. The area of the field at Herman-Missouri was 0.17 ha (0.41

acres). The predominant soil series at the research site is Moniteau silt loam. The study site was prepared for initiation of the experiment in the fall of 2016. The site was mowed with a 1.524 m (5 ft) 2011 Bush Hog 296 Rotary Cutter (John Deere, Westfield, Iowa) and disked to incorporate plant biomass.

Annual cereal rye (*Secale cereal* L.) (123.3 kg ha^{-1}) was planted on 20 October 2016 with a Tye no-till drill (Tye CO. Lockney, Texas), at 19 cm (7.48 in) row spacing at both locations in no-till plots. On 13 May 2017, soybean (Emerge E3782S, maturity 3.7) was planted at a rate of 165,000 seeds ha^{-1} (66,773 seeds /acre)for till plots and 192,000 seeds ha^{-1} (77,700 seeds/acre)(for no-till treatments in 2017 with a four-row planter (John Deere, Moline, IL). A higher seeding rate in no-till plots was to ensure that crop stand was within an acceptable population. Soybean was planted into the standing annual cereal rye cover crop in no-till treatments. The cover crop was terminated by crimping immediately after planting soybeans using roller-crimper (I&J Mfg., Gap, PA). Tilled plots had no cover crop and were tilled using the same tillage equipment previously mentioned. Row spacing was 76 cm (29.92 in), providing eight-rows per treatment plot. Germinated plants were counted per plot 3 weeks after germination. This was done by placing a 2.36 m (7 ft) rod along the second row, when placed 1.52 m (5 ft) away from the edge of the field.

Grass and broadleaf weed biomass was collected between and in the rows of crop for each treatment in two randomized locations in each plot using a 0.09 m^2 (1 ft^2) quadratic frame. Grasses and broadleaf weeds were separated and oven dried, then weighed. Weed treatments were first performed when weed seedlings were 10.2 cm (4 in) high and repeated as necessary until soybean canopy closed between-rows. Two sets of weed samples were collected during the study. The first set was collected before any weed treatment and the final before harvest.

Between-row mowing was undertaken using a between-row mower which was developed at the Bradford Research Center of the University of Missouri. This between-row mower was originally developed by Dr. William Donald and his team in the late 1990s (Clark 2018). The fabricated mower was attached to an 8240 Hagie high boy sprayer by replacing its spray boom. Instead of using the mower with the Hagie 8240 for this research, it was detached and a three-point hitch fabricated onto it. The hydraulic motors were initially connected in series with mowing plastic cords used for cutting. The cutting units were later changed to 56 cm (22 in) mower blades. The motors connections were also changed to parallel using a manifold and later changed to a hydraulic flow divider, remote hydraulic PTO pump, heat exchanger and a reservoir.

Soybeans at the Bradford Research Center was harvested on 30 September 2017 from four center rows manually using a Stihl Combi System Adjustable Trimmer (km56Rc model-STIHL Incoperated,Virginia Beach, VA) and were later threshed in an Almaco plot thresher (Nevada, IA). The middle four rows of the soybeans at Herman was harvested using a John Deere four-row (John Deere, Moline, IL) combine harvester on 3 October 2017 .

The 30-year average rainfall for Boone County was 1,083 mm (42.6 in). In 2017, 838 mm (33 in) of rain was recorded until November of 2017. The highest rainfall collected in 2017 was recorded from April to July, with a total accumulation of 528.1 mm (20.8 in) for that period.

The experimental design for this study was a randomized complete block design. Data was analyzed using SAS Studio 3.7 statistical software (SAS Inst., Cary, North Carolina) and SAS 9.4 statistical software (SAS Inst., Cary, North Carolina). Treatment and replication were considered random effects whereas crop was considered fixed. Statistical significance was at $p \leq 0.05$. When treatment effects were significant, means were separated using Fisher's least significant difference (LSD). The mower design was accomplished using AutoCAD 2018 (Autodesk Inc., McInnis Parkway, San Rafael,CA) and SolidWorks 2017 (Dassault Systèmes SolidWorks Corporation, Wyman Street, MA).

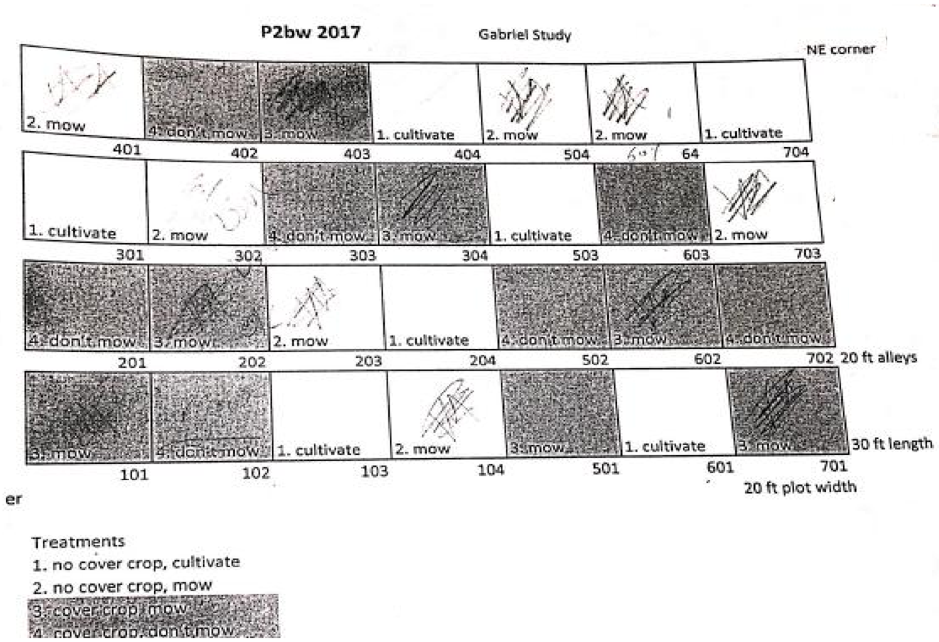


Figure 3.1: Bradford Research Center Field arrangement

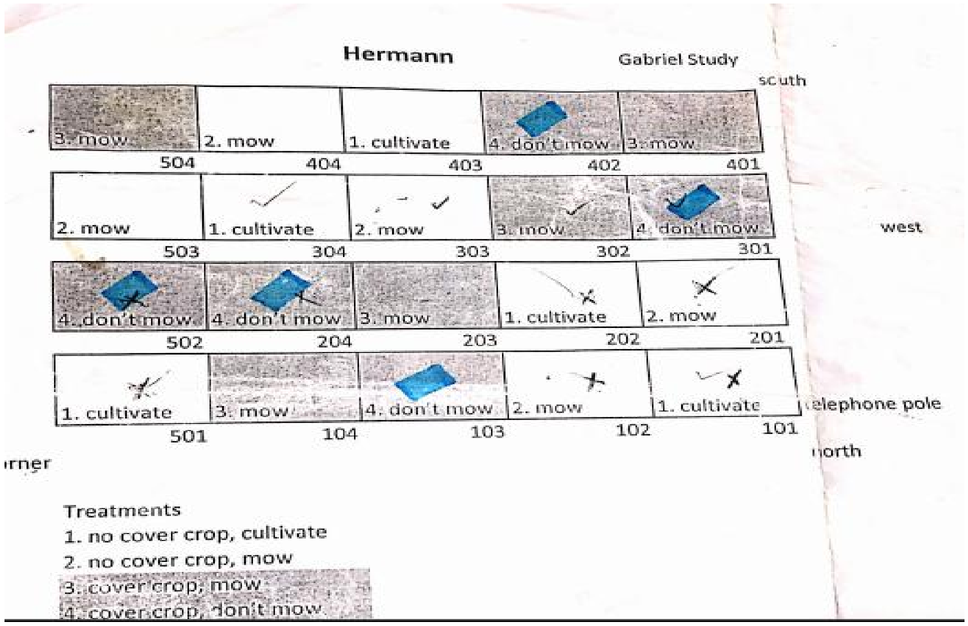


Figure 3.2: Herman Plot arrangement

3.2 Mower Description

The mower which was initially built by Dr. Donald Williams and his team from the USDA-ARS was re-developed and its efficiency tested. The original mower was attached to a Hagie 8240 high boy sprayer to mow four rows with five cutting units. The spray boom was replaced with the mower. The attachement of the mower to the Haigie 8240 made it impossible to be attached to a tractor .

Moreover, the breakdown of the Hagie 8240 resulted in the team deserting the mower. In order to get it working and to make it versatile, the mower was detached from the Hagie and a three-point hitch fabricated unto it. By using the three-point hitch, the modified mower could be hitched to different tractors. The mower consisted of five hydraulic motors (Gresen MGG20030- Parker Hannifin Corporation, Mayfield Heights, Ohio) mounted separately unto each cutting unit with a shaft connected to its output shaft via a sleeve coupling.   The cutting unit consisted of a square pipe of 4 in x 4 in (0.10 m x 0.10 m) with a one inche pillow block bearing (UCP204-12) welded to the square pipe to hold the rotating shaft firmly. A trans torque with a bushing was mounted at the base of the cutting unit to prevent the shaft from moving upwards or downwards during motion.

A one inche flange bearing (UCF205-16) was mounted below the sqare pipe to hold the shaft firmly, preventing side movements. Since the shaft running at a high speed, it was important to secure it firmly in place to avoid possible harm to the user. The motors of each mower unit were initially connected in series whiles using plastic cords as cutting units. The plastic cords were functioning initially but broke or got entangled with other componenets making them less efficient. Uninsulated electric cables were replaced with plastic cords but also failed to work because they unwinded during mowing operation. The ends of the cables were later crimped but kept breaking. It was therefore necessary to look for a solution that was more efficient with fewer challenges. Mower blades (0.56 m, 22 in) mulching blades, MTD, LLC, Cleaveland, Ohio) became the final option for use on the mower because it was easier to mount the blades and the blades lasted longer than the plastic cords and uninsulated electric cables. The series connection between hydraulic motors failed with only the first three hydraulic motors running when connected to the tractor. The cause of this problem was linked to pressure drop across each hydraulic motor during flow.

In order to solve this problem, other connection methods were used. A hydraulic manifold was mounted unto the mower to test with a parallel motor connection. This was meant to improve the efficiency and consistency of the mower. However, this method was not efficient because hydraulic fluid flowed only in the direction of least resistance. This implied that the hydraulic fluid moved to hydraulic motors which were not expereincing any form of load from mowing. The final option was to combine a hydraulic power take off pump and flow dividers (Figure 3.3). Flow dividers divide flow in equal units and distribute it amongst the motors whilst maintaining a constant pressure distribtion amongst the motors. A hydraulic power take off pump (Prince Manufacturing Corporation, North Sioux City, South Dakota) with input to the the tractor's PTO draws hydraulic fluid from a reservoir mounted on the mower to feed the motors under pressure. One advantage of remote PTO pump is its ability to maintain constant flow no matter the load. These types of pumps do not sense load making them the best suited for mowing operations. Hydraulic fluid returning from the hydraulic motors passed through a manifold then to a heat exchanger and back to the resevoir mounted on the mower.

Figure 3.3: Between-row mower with hydraulic PTO pump and flow dividers before field test (Gabriel Abdulai)

3.3 Hydraulic Motor Connection

Connecting hydraulic motors is important to ensure their effective operation. Motors can be connected in many ways. In this research, three connection methods were studied.

3.3.1 Series Connection

In this type of connection, the hydraulic motors were coupled to allow hydraulic fluid to flow from one motor to the next until the hydraulic fluid returns to the reservoir or tank (Figure 3.5). Despite the high pressure that was associated with series connection, pressure drop across each motor decreased motor performance. This connection caused pressure drops across each motor as hydraulic fluid moved from motor to motor. This condition decreased blade speed and sometimes no observed movement of the mower blade. To ensure that all motors ran efficiently, the pump's head pressure had to be equal to the sum of the individual pressure of each motor which was impossible. High pump pressure beyond the hydraulic motors resulted in its damage (Pump pressure = 2500 psi (17,237 kPa), Motor pressure = 1500 psi (10,342 kPa). Connection in series resulted in the damage of two hydraulic motors which was costly ($430) and time consuming to replace (Figure 3.4).

Figure 3.4: Cracked motor from high pressure pump output (Gabriel Abdulai)

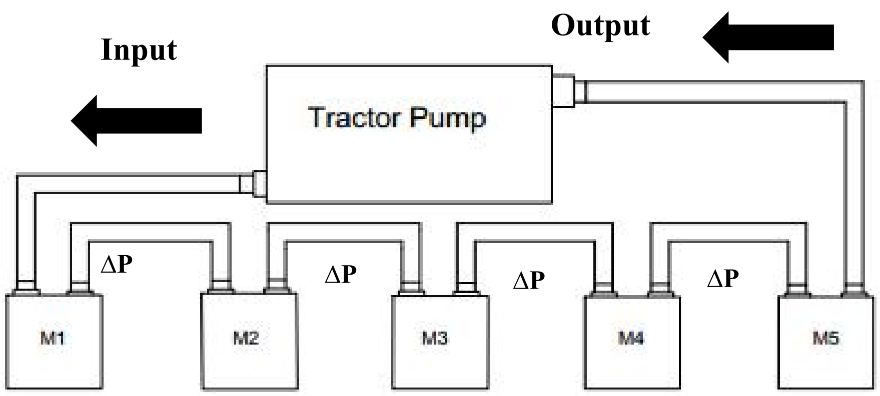


Figure 3.5: Schematic of pressure drop across motors in series connection (M1: Motor 1, M2: Motor 2, M3: Motor 3, M4: Motor 4, M5: Mower 5 ΔP: Pressure drop)

3.3.2 Parallel Connection

The parallel connection tested in this research used a hydraulic manifold as the main distribution block (Figure 3.6). This setup included a central distribution point from which hydraulic fluid flowed into the inlets of the motors and flowed out to the exit manifold. Although the parallel connection was safe during operations (not resulting in any damage to hydraulic motors), the use of a manifold affected the mowing output of the motors. This was observed in reduced motor speeds when loads (weed density) increased. It was also observed that hydraulic fluid flowed to hydraulic motors with least resistance (least weed density) hence slowing down the mower blades and ultimately mowing efficiency.

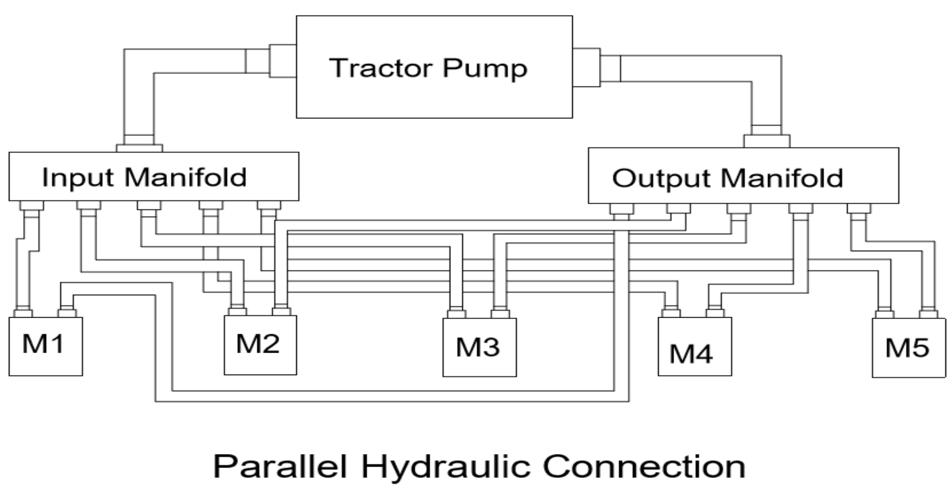


Figure 3.6: Schematic of parallel connection of hydraulic motors (M1: Motor 1, M2: Motor 2, M3: Motor 3, M4: Motor 4, M5: Mower 5)

3.4 Flow Divider

A flow divider is a device which divides flow under pressure into equal or unequal forms. Flow is usually divided into equal forms such 50:50 or 25:25:25:25 or unequal forms such as 40:60 ratios. Figure 3.7 shows the combination of the flow divider and other components on the four-row mower. These devices are often manufactured by hydraulic companies who predetermine these ratios. Flow dividers could be spool type or gear type. Flow dividers are very efficient in dividing and distributing flow. One four-section (25:25:25:25) and one two-section (50:50) flow dividers were used in this study (Figure 3.8). The four-row mower used two (2) flow dividers (four and two sections) and the two-row mower used one four-section divider. The flow dividers used in this study maintained relatively good flow and pressure during mowing operations. Based on the specification in Table 3.1, a 0.25 in^3/rev 9 gpm (4.097 cm^3/rev,34.07 l/min) section rotary flow divider was chosen.

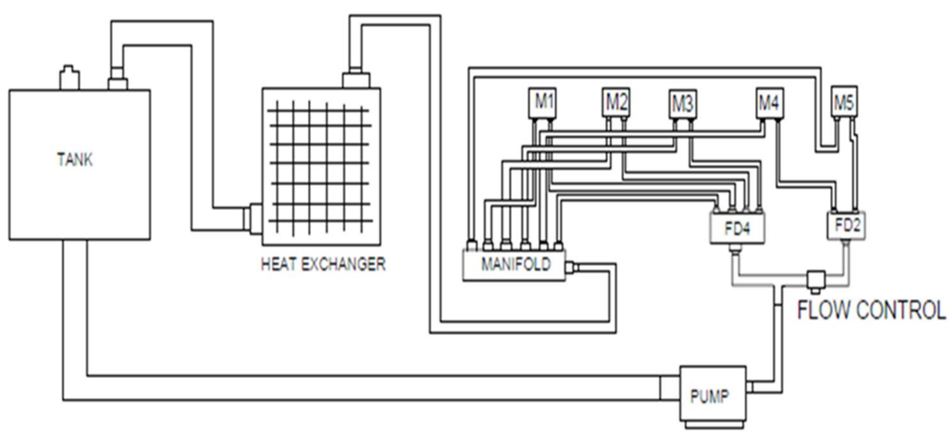


Figure 3.7: Schematic drawing showing hydraulic connection on the mower with flow dividers, tank and heat exchanger (M1: Motor 1, M2: Motor 2, M3: Motor 3, M4: Motor 4, FD4: Four Section Flow Divider, FD2: Two Section Flow Divider)

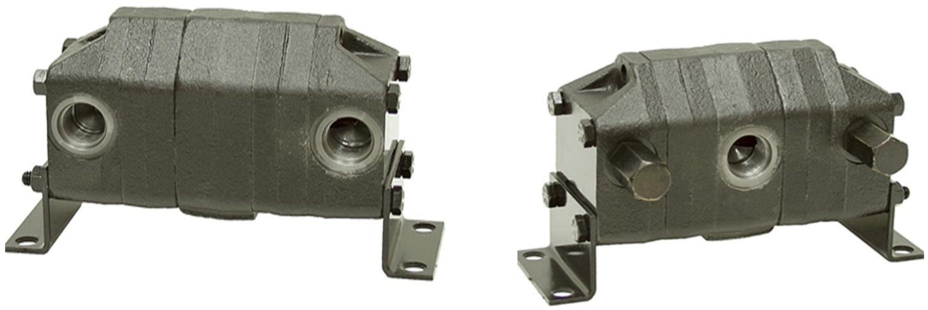


Figure 3.8: Output and input sides of a two-section flow divider (Surplus Center, Lincoln, Nebraska)

Table 3.1: Specifications of the flow divider used in the study (Surplus Center, Lincoln, Nebraska)

Specification	**Properties**
Flow Division	50:50
Displacement per section	0.25 cubic per inches
Input Flow	
Minimum Input	4.35 gpm
Maximum Input	9.78 gpm
Output Flow per section	
Minimum Output	2.17 gpm
Maximum Output	4.89 gpm
Maximum Input Pressure	3000 psi
Maximum Output Pressure	3500 psi
Factory set differential PSI between sections	750psi
Relief valves adjustment	500 - 1000psi

3.5 Hydraulic Motor Selection

The volumetric displacement of the motor is an important factor to consider when selecting hydraulic motors and pumps. The unit for volumetric displacement for a hydraulic pump or motor is in^3/rev. This factor determines the amount of fluid required to rotate the shaft of the motor at a certain speed. This value is often given by the manufacturer. Below is a data acquired from Parker Hannifin (Parker Hannifin Corporation, Mayfield Heights, Ohio) which was used for selecting the right motor. The important specifications are provided in the following figures and tables.

Figure 3.9: 0.70 in^3/rev (11.47 cm^3/rev) Parker MGG20030-BA1A3 hydraulic motor used on the four-row mower (Parker Hannifin Corporation 2003).

Table 3.2: MGG motor model specification at 1000 revolutions per minute (Parker Hannifin Corporation 2003)

Model No.		**MGG20010**	**MGG20016**	**MGG20020**	**MGG20025**	**MGG20030**
Displacement Per Revolution		0.22 in^3 (3.57 cm^3)	0.37 in^3 (6.09 cm^3)	0.45 in^3 (7.37 cm^3)	0.58 in^3 (9.50 cm^3)	0.70 in^3 (11.47cm^3)
Maximum Rated RPM		5000	5000	5000	5000	5000
Rated Flow Rate 1000rpm		0.95gpm (3.6 l/min)	1.62gpm (6.1 l/min)	1.95gpm (7.4 l/min)	2.51gpm (9.5 l/min)	3.03gpm (11.5 l/min)
Maximum Rated Pressure	**Continuous**	2000 PSI (138 bar)	2000 PSI (138 bar)	2000 PSI (138 bar)	2000 PSI (138 bar)	1500 PSI (103.5 bar)
	Intermittent	2500 PSI	2500 PSI	2500 PSI	2500 PSI	2000 PSI
Output Torque per 1000 PSI		35 in.lbs. (40 kg-cm)	59 in.lbs. (69 kg-cm)	72 in.lbs. (83 kg-cm)	92 in.lbs. (107 kg-cm)	111 in.lbs. (159 kg-cm)

The specifications of the various motor models were considered in selecting the right motor for the mower. During the calculations, 2500 rpm was used based on available literature on appropriate mowing speed to accomplish excellent mowing (Virginia Cooperation Extension 2014). The calculations were done for five (5) motors in figure 3.4.

John Deere 6200 Data

Type:	closed-center pressure flow compensated (PFC)
Capacity:	12.4 gal [46.9 L]
Pressure:	2900 psi [200 bar]
Total flow:	18 gallons per minute [68.1 liters per minute]

Figure 3.10: Specification of tractor used in the study (Tractordata.com 2018)

The equations and calculations below were used in determining the required flow rates of the various motors.

$Q = V_m \times N$ ……………………………………………………equation (1)

Where:

Q = Flow Rate

V_m = Volumetric Displacement

N = Rotational Speed

$Q_{tractor\ pump}$ = Tractor's pump Flow Rate

$Q_{5\text{-}motors}$ = Hydraulic Motor Flow rate

But the $Q_{pump} > Q_{5\text{-}motors}$

Q_{pump} = 16 gallons per minute

At **0.218 in^3 per revolution** volumetric displacement, flow Q is equal to

$$Q = \frac{0.218in\text{^}3\ x\ 1\ gal\ x\ 2500\ rev}{rev\ x\ 231in\text{^}3\ x\ min} = 2.36\text{gal/min}$$

But 5 motors = 2.36gal/min x 5 = **11.80 gal/min**

At **0.372 in^3 per revolution** volumetric displacement, flow Q is equal to

Q = $\frac{0.372 in^3 \ x \ 1 \ gal \ x \ 2500 \ rev}{rev \ x \ 231 in^3 \ x \ min}$ = 4.03 gal/min

But 5 motors = 4.03gal/min x 5 = **20.13 gal/min**

At **0.450 in^3 per revolution** volumetric displacement, flow Q is equal to

Q = $\frac{0.450 in^3 \ x \ 1 \ gal \ x \ 2500 \ rev}{rev \ x \ 231 in^3 \ x \ min}$ =4.87gal/min

But 5 motors = 4.87gal/min x 5 = **24.35 gal/min**

At **0.580 in^3 per revolution** volumetric displacement, flow Q is equal to

Q = $\frac{0.580 in^3 \ x \ 1 \ gal \ x \ 2500 \ rev}{rev \ x \ 231 in^3 \ x \ min}$ =6.28gal/min

But 5 motors = 6.28 gal/min x 5 = 31.39 **gal/min**

At **0.700 in^3 per revolution** volumetric displacement, flow Q is equal to

Q = $\frac{0.700 in^3 \ x \ 1 \ gal \ x \ 2500 \ rev}{rev \ x \ 231 in^3 \ x \ min}$ = 7.58gal/min

But 5 motors = 7.58gal/min x 5 = 37.88 **gal/min**

3.6 Required Flow Against Displacement

Figure 3.11 shows that as volumetric displacement of the motors increased, the flow requirement also increased. Based on this information, the motor with the lowest flow requirement will often be the best choice, however, on the four-row mower the 0.70 in^3/rev (11.47cm^3/rev) motor was used because they were already mounted on the original mower and will be expensive to replace them all. On the two-row mower, 0.218 in^3 /rev (3.57 cm^3 /rev) motors were used.

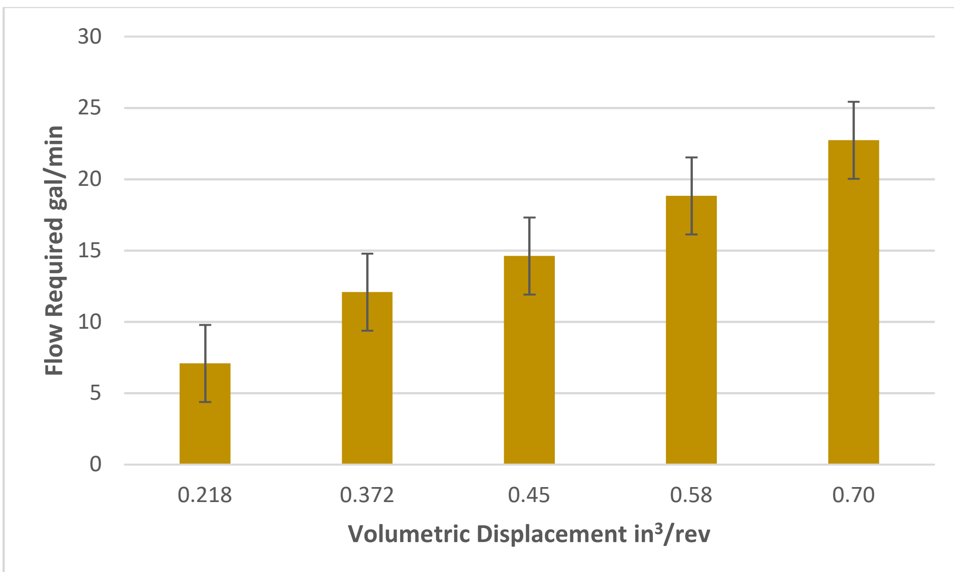


Figure 3.11: Flow requirement versus volumetric displacement (Gabriel Abdulai)

3.7 Chapter Three Reference

Parker Hannifin Corporation (2003) Gerotor Pump and Motor. Aluminum High Speed, Low Torque Series. Catalog HY09-PGG/MGG/US. Accessed from http://transistor-man.com/files/fission_product/pdf/hydraulic_pump_manual.pdf on July 7,2018.

Surplus Center (2018) 0.25 cu in 9 GPM 2 Section Rotary Flow Divider MTE. Accessed from https://www.surpluscenter.com/Hydraulics/Hydraulic-Valves/Divider-Valves/0-25-cu-in-9-GPM-4-Section-Rotary-Flow-Divider-MTE-9-8403-4.axd on July 17, 2018.

TractorData.com (2018) John Deere 6200. Accessed from http://www.tractordata.com/farm-tractors/000/1/6/166-john-deere-6200.html on July 17, 2018.

CHAPTER FOUR

4.0 Results and Discussion

4.1 Herman Crop Yield

Grain yield at Herman in 2017 was generally higher than in Bradford. Results from the yield data showed that mowing with cover crop recorded the highest yield followed by non-mow with cover crops and cultivation treatments but were not significantly distinguishable (Figure 4.1). Yield from mowing with cover crop was five percent higher than in the control and 22 percent higher than in cultivated treatments. High cover crop density at Herman provided a dense mulch base which prevented the early emergence of weeds and affected soybean yield.

Yields from conventional soybeans in 2017 from the Missouri State Agriculture overview was 3295.25 kg/ha which was 16.5 percent higher than the highest yield recorded for mowing with cover crops (Missouri State Agriculture Overview 2018). General, organically grown soybeans often have lower grain yields than conventional soybeans. Lower yield in organic crops often range between 8 to 25% (Clark et al. 1999; Seufert et al., 2012)

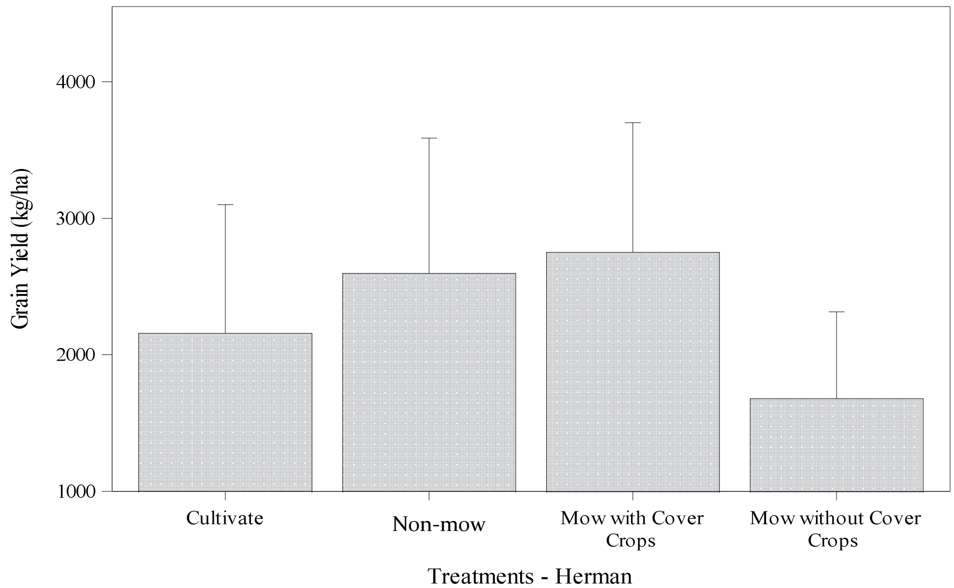


Figure 4.1 Mean organic no-till soybean yield in 2017 in Herman as impacted by weed management and cover crops. Means were distinguished using Fisher's Protected LSD at p = 0.05. Vertical bars indicate the standard deviation

4.2 Bradford Crop Yield

Soybean grain yield in mowing with cover crops at Herman was three-fold higher than in Bradford. The low yield at Bradford could be associated with low cover crop density which was unable to effectively suppress weeds resulting in reduced soybean yield Moreover, mowing problems from not following the planting pattern resulted in soybean damage and could have contributed to reduced plant stand and ultimately yield. Damage rows where not measured but there was an observed damage to crop rows. Mowing with cover crops produced the highest crop yield but was not statistically different from mowing without cover crops and cultivation (Figure 4.2). Yield from mowing with cover crops was 22.2 percent higher than cultivation. Aside from mowing damage and poor cover crop stand at Bradford, low soil productivity might have also contributed to low yield at Bradford.

The soils series at Herman (Moniteau silt loam) though poorly drained was more fertile than at Bradford (Mexico silt loam).

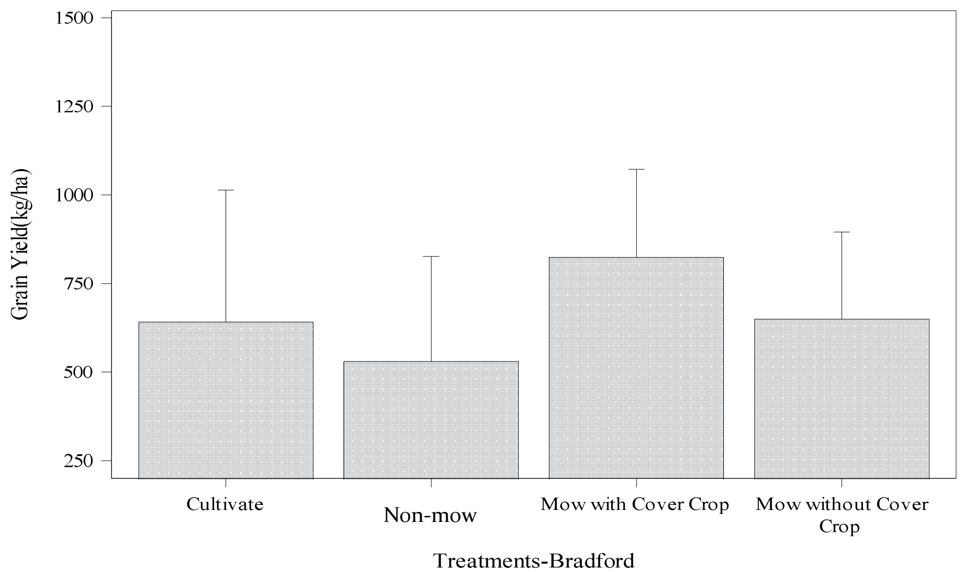


Figure 4.2. Mean organic no-till soybean yield in 2017 at Bradford Farm at the University of Missouri as impacted by weed management and cover crops. Means were distinguished using Fisher’s Protected LSD at p = 0.05. Vertical bars indicate the standard deviation

4.3 Herman Weed Biomass

The weed biomass collected at Herman consisted of both grass and broadleaf weeds in 2017. By collecting weeds between and in the rows of soybean, the efficacy of the weed treatment was tested. Grasses collected included giant foxtail (*Seteria faberi Herrm*.) and yellow foxtail (*Pennisetum glaucum*.) while the broadleaf weeds were common cocklebur (*Xanthium strumarium L*.) and water hemp (*Amaranthus rudis Sauer*.)

In 2017, 18 days after planting (DAP) of soybeans at Hermann the first set of weed biomass was collected and represented the initial quantity of weeds before any weed treatment. The second weed biomass was collected 144 days after planting at the end of the season. Broadleaf weeds between-rows were 15.2 percent higher in mowing without cover crops than in cultivation (Figure 4.3). Between-row broadleaf weeds and grasses were absent in mowing with cover crops (Figure 4.3). However, between-row grasses were two-fold higher in cultivated treatments than in mowing without cover crops treatment. The non-mow treatments with cover crops also recorded low levels of between-row grasses and broadleaf weeds (Figure 4.3) but there was no significant difference between cultivation and mowing with cover crops.

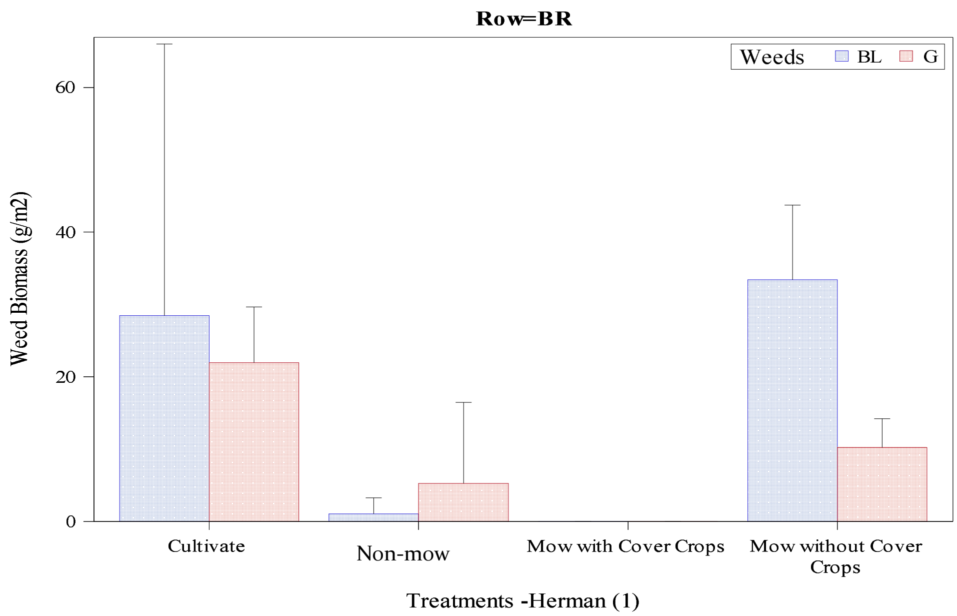


Figure 4.3. Mean between-row broadleaves and grasses collected at the start of the season before treatments were conducted in Herman in 2017. Means were distinguished using Fisher's Protected LSD at p = 0.05. Vertical bars indicate the standard deviation. BR: Between-row weeds, BL: Broadleaf weeds, G: Grasses.

Weeds in the rows of organically grown soybeans were like those between the rows. Mowing with cover crops treatments recorded no weeds in the rows but this was not significantly different from the rest of the treatments as the initial weeds in the rows were low (Figure 4.4).

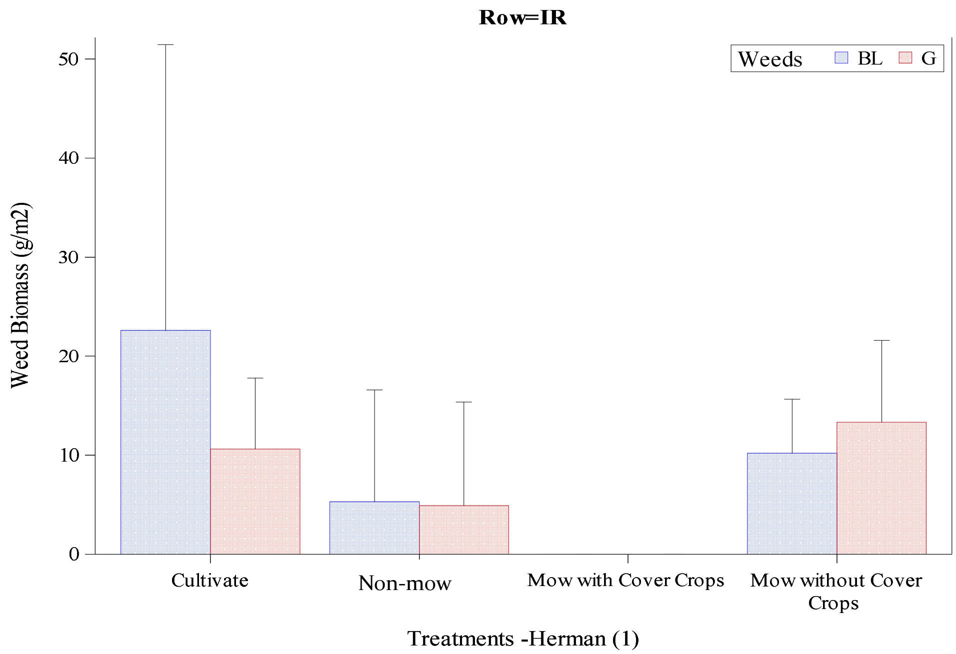


Figure 4.4. Mean in-row broadleaves and grasses collected at the start of the season before treatments were conducted in Herman in 2017. Means were distinguished using Fisher's Protected LSD at p = 0.05. Vertical bars indicate the standard deviation. IR: In-row weeds, BL: Broadleaf weeds, G: Grasses.

At the end of the season, weed biomass was collected to ascertain the efficacy of the weed treatment. The results showed that mowing (with and without cover crops) and cultivation efficiently controlled grasses and broadleaf weeds. Between-row broadleaf weeds were five times lower in cultivated treatments than in mowing with cover crops but was not significantly different (Figure 4.5). Broadleaf between-rows decreased in the order of treatments, cultivate<non-mow<mow with cover crops<mow without cover crops. There was no statistical difference between the treatments. Grasses were efficiently

controlled in cultivated, mowing with cover crops and mowing without cover crops treatments. Though broadleaf weeds were lower in cultivation, they were not significantly different from other treatments (Figure 4.5).

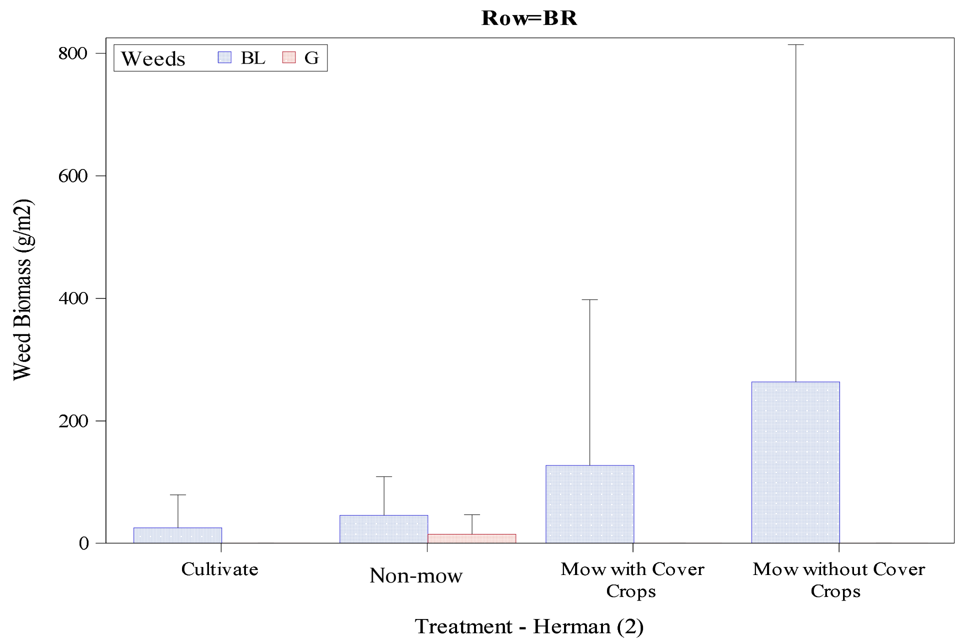


Figure 4.5. Mean between-row broadleaves and grasses collected at the end of the season when all treatments were conducted in Herman in 2017. Means were distinguished using Fisher's Protected LSD at p = 0.05. Vertical bars indicate the standard deviation. BR: Between-row weeds, BL: Broadleaf weeds, G: Grasses.

The use of cover crops suppressed weed germination causing soybeans to thrive whiles keeping weed in check. There was no statistical difference between grasses and broadleaf weeds in the rows of cultivation and mowing with cover crop treatments. In-row grasses were lower in cultivation and mowing without cover crops than the control and mowing with cover crops but were not significant. Broadleaf weeds in the rows of soybeans that were mowed with cover crops were four-fold lower than plots which were cultivated

(Figure 4.6). In treatments which were mowed without cover crops, broadleaf weeds in the rows were four-point five times higher than in plots that were mowed with cover crops. The control showed similar characteristics as mowing with cover crops (Figure 4.6).

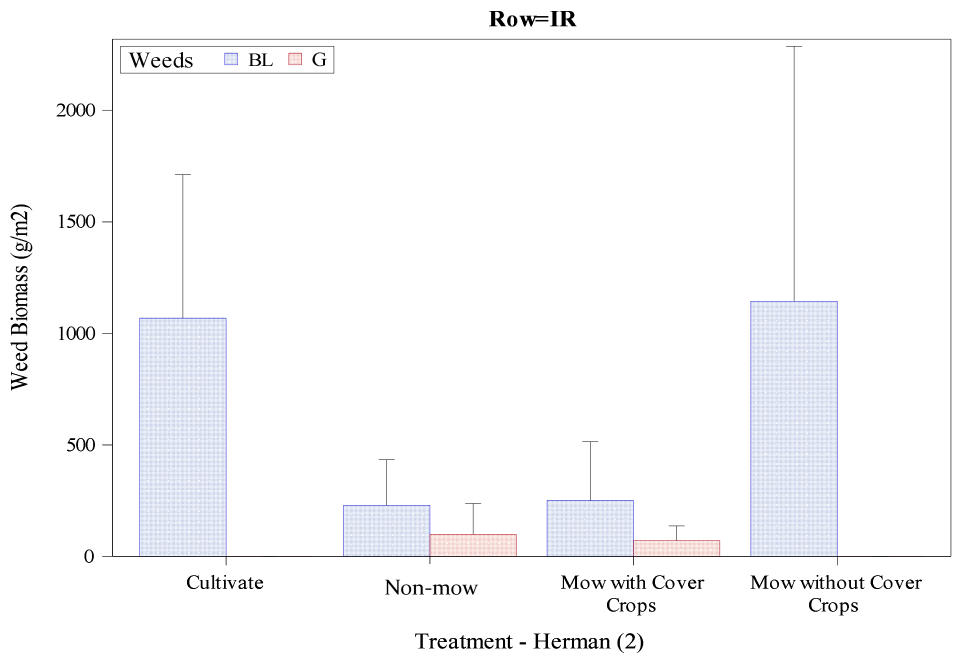


Figure 4.6. Mean in-row broadleaves and grasses collected at the end of the season when all treatments were conducted in Herman in 2017. Means were distinguished using Fisher's Protected LSD at $p = 0.05$. Vertical bars indicate the standard deviation. IR: In-row weeds, BL: Broadleaf weeds, G: Grasses.

4.4 Bradford Weed Biomass

The weed biomass collection systems that was used at the Bradford Research Center of the University of Missouri was similar to the techniques used at Herman. Initial weed biomass collected revealed that grasses between-rows of cultivated treatments were lower than in mowing with and without cover crop. Between-row grasses in mowing with cover crops was 92 percent higher than in cultivation treatment (p=0.05) (Figure 4.7). This was similar to mowing without cover crop treatments and significantly different from cultivation treatments. Broad leaf weed biomass in mowing without cover crops was 2.6 times lower than mowing with cover crop. Between-row broadleaf were 43 percent lower in mowing without cover crops than cultivation but was not statistically different (Figure 4.7).

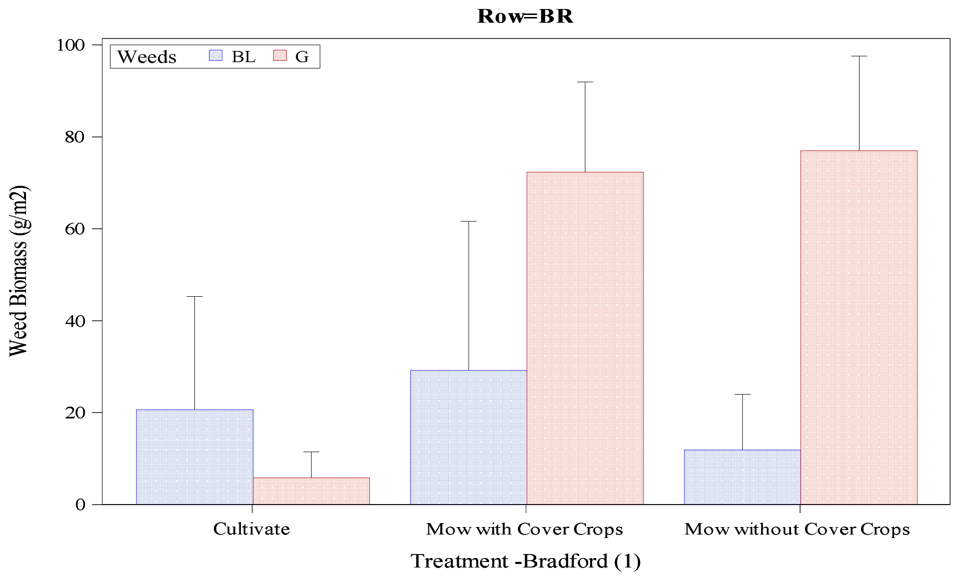


Figure 4.7. Mean between-row broadleaves and grasses collected at the start of the season before treatments were conducted at the Bradford Research Center in 2017. Means were distinguished using Fisher's Protected LSD at p = 0.05. Vertical bars indicate the standard deviation. BR: Between-row weeds, BL: Broadleaf weeds, G: Grasses.

In the rows of organic no-till soybeans, grasses in mowing with cover crops were 26.2 percent lower than mowing without cover crops (Figure 4.8). Treatments that were cultivated had nine percent higher grass production when compared to grasses mowed with cover crops with cover crops than in cultivation and mowing with cover crops. In-row broad leaves were lower in mowing without cover crops than in cultivation and mowing with cover crops. In-row broadleaf in mowing without cover crops was 27 percent lower than in cultivation treatments but not significantly different. In-row broadleaf weeds in mowing with cover crops was 20 percent higher than mowing without cover crops (Figure 4.8).

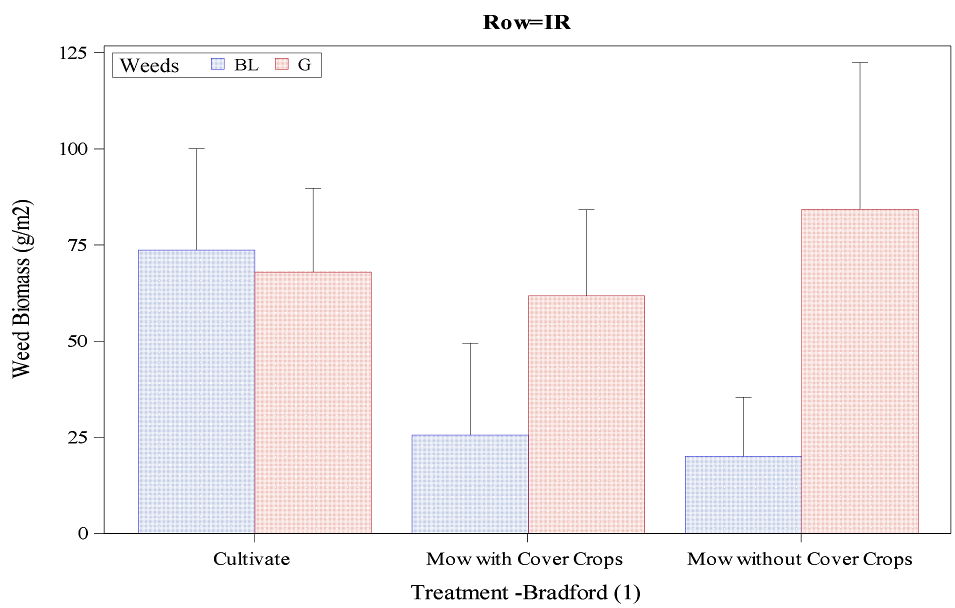


Figure 4.8. Mean in-row broadleaves and grasses collected at the start of the season before treatments were conducted at the Bradford Research Center in 2017. Means were distinguished using Fisher's Protected LSD at $p = 0.05$. Vertical bars indicate the standard deviation. IR: In-row weeds, BL: Broadleaf weeds, G: Grasses.

After applying the various weed treatments, the weed biomass collected revealed that between-row broad leaves were lower in mowing with /without cover crops than in cultivation but was not statistically significant. Between-row grasses in cultivation treatments were completely controlled, meaning that no grasses were found between the rows of cultivated treatments as compared to mowing with/without cover crops which recorded some grasses. Between-row grasses obtained from mowing with cover crops were similar to mowing without cover crops. Between-row broadleaf weeds were efficiently controlled in mowing treatments. In mowing without cover crops treatments, broad leaves were completely controlled then followed by mowing with cover crops and cultivation. Between-row broadleaf weeds were seven times lower in mowing with cover crops than cultivation but were statistically indistinguishable. Matured grasses yellow and giant foxtail have rhizomes that stores starch for plant development and growth activities. Mowing of grasses decreases the starch reserves and slows grass growth whiles cultivation destroys the weed by uproots it from the ground removing its rhizomes killing the weed plant. This situation could have resulted in the decreased grass population in cultivation as compared to mowing with and without cover crops. However, broadleaf weeds like water hemp do not have rhizomes for starch reserves and so get destroyed after one mowing pass during mowing resulting in low broad leaf population

In-row broadleaf weeds in mowing without cover crops was lower than mowing with cover crops and cultivation but was not statistically different. Broadleaf weeds in mowing without cover crops were one point four-fold lower than mowing with cover crops (Figure 4.9). Cultivation treatments recorded six times higher broadleaf weeds than mowing without cover crops treatments (Figure 4.9) but were not significantly different.

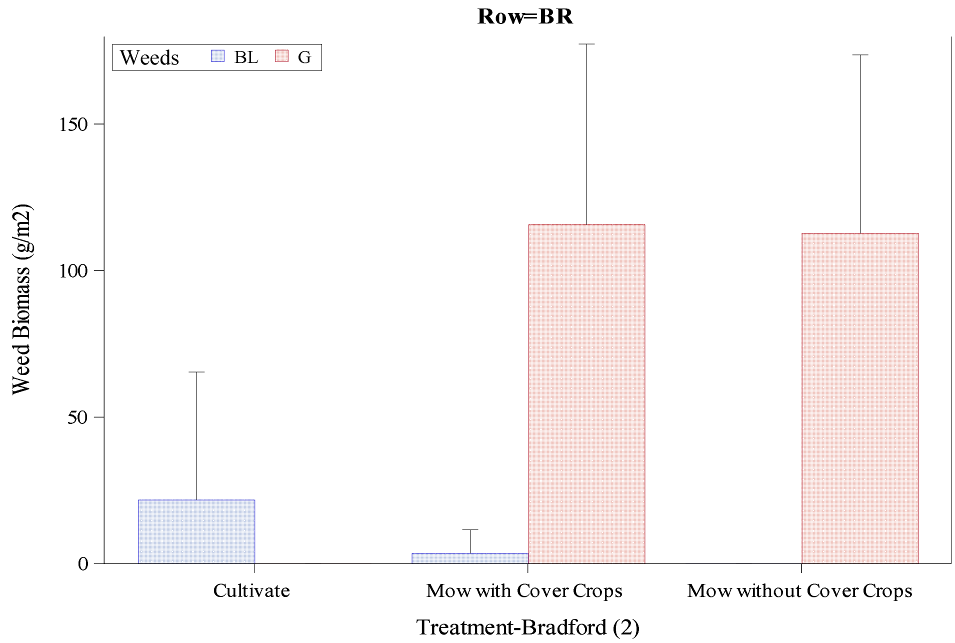


Figure 4.9. Mean between-row broadleaves and grasses collected at the end of the season after all treatments were conducted at the Bradford Research Center in 2017. Means were distinguished using Fisher's Protected LSD at p = 0.05. Vertical bars indicate the standard deviation. BR: Between-row weeds, BL: Broadleaf weeds, G: Grasses

Grasses in the rows of mowing with cover crops treatments were lower than other treatments. Grasses in the rows of mowing with cover crops treatments were 22.1 percent lower than mowing without cover crops. Cultivation treatments were also 34.3 percent higher than mowing with cover corps treatments (Figure 4.10). The use of cover crops contributed to decreased grasses and broadleaf growth in the rows of organic no-till soybeans.

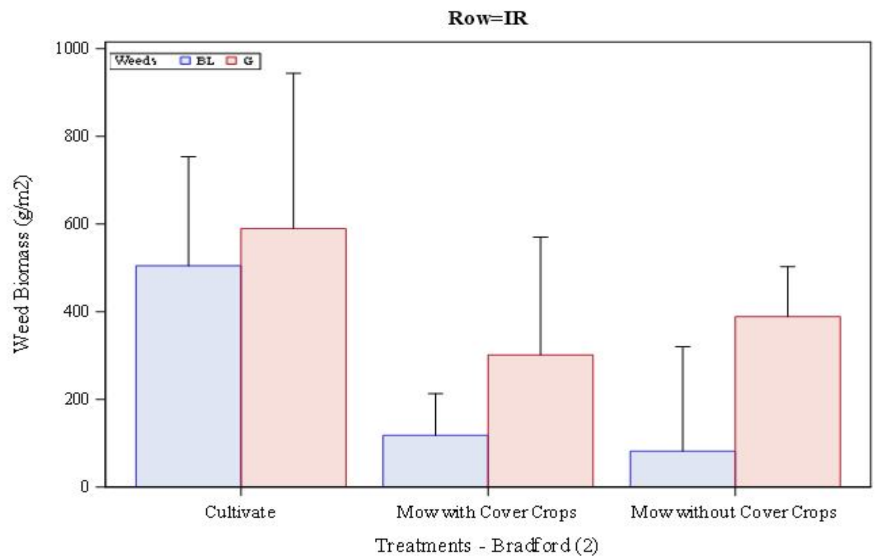


Figure 4.10. Mean in-row broadleaves and grasses collected at the end of the season after all treatments were conducted at the Bradford Research Center in 2017. Means were distinguished using Fisher's Protected LSD at p = 0.05. Vertical bars indicate the standard deviation. IR: In-row weeds, BL: Broadleaf weeds, G: Grasses.

4.5 Cover Crops

The cover crops established were annual cereal rye (*Secale cereal* L.). Annual cereal rye was established for plots where treatments required cover crops. Cover crops established in Herman recorded higher density than at Bradford but was statistically indistinguishable. Cover crop density at Herman was 10.2 percent higher in Herman than at Bradford (Figure 4.4). The maximum above ground biomass density recorded at Herman was 1,255 kg/ha which was higher than the maximum recorded at Bradford 1,152 kg/ha. Contrary to what was found in Herman and Bradford, Jackson et al. (1993) reported 2,070 kg/ha above ground biomass for cereal rye. Though this was considerably higher than both sites, higher above ground biomass contributed to better weed control in Herman.

Mulch produced by the termination of cover crops provided primary weed control, suppressing weeds and delaying their emergence. This situation reduced weed density in plots with cover crops when compared to others without.

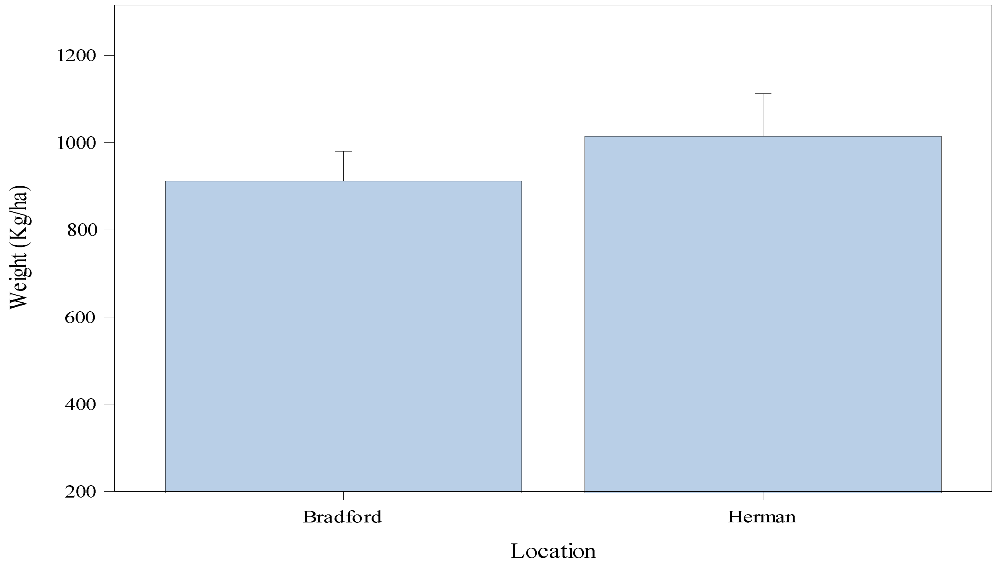


Figure 4.11. Mean cover crop biomass collected in 2017 at the Bradford Research Center of the University of Missouri and Herman before planting. Means were distinguished using Fisher's Protected LSD at $p = 0.05$. Vertical bars indicate the standard deviation. Second weed biomass collected after weed treatment

4.6 Herman Mowing Damage

Damage to plant stands occurred during between-row mowing. This situation resulted in the destruction of the soybean crop stand. In 2017, ten percent of soybean stand was damaged after three mowing sessions (Figure 4.12). This was greater than the five percent damage caused by cultivation. Damage caused by mowing was also caused by differences in machinery rows. Planting was undertaken by means of a four-row planter with some rows being narrower than others. This condition resulted in crop damage for the narrow rows. Damage caused by mowing resulted from the operational challenges with using a tractor without an accurate global positioning system (GPS). The absence of an accurate GPS contributed to the mower trailing off the row during mowing operations. Although the data for crop damage was not available at Bradford, physical observation confirmed that frequent mowing without an accurate GPS poses serious risk to soybean crop damage.

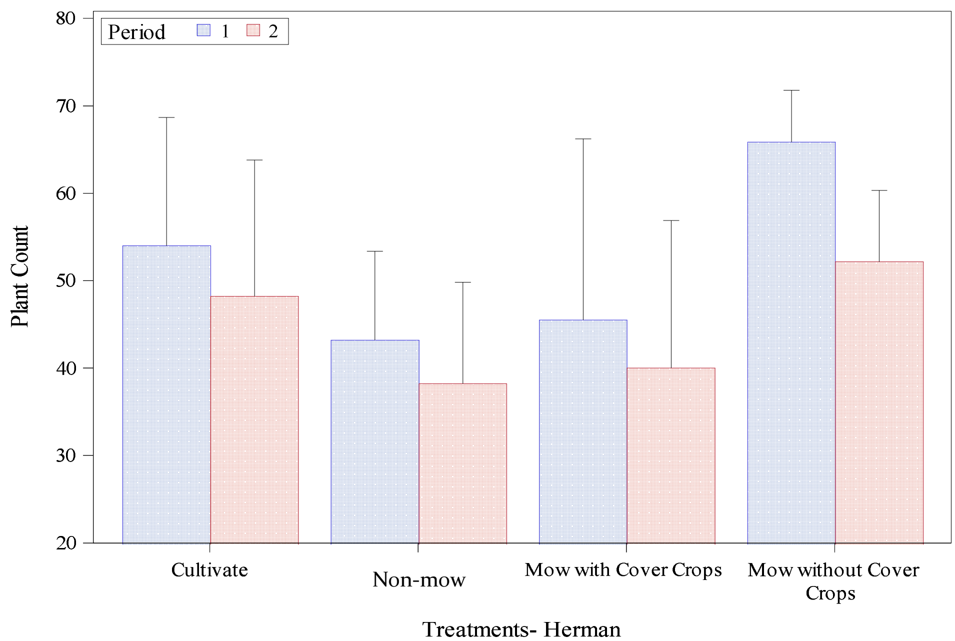


Figure 4.12. Mean plant count in 2017 at Herman as impacted by the different weed management techniques. Means were distinguished using Fisher's Protected LSD at p = 0.05. Vertical bars indicate the standard deviation. The periods represent before and treatment of the weed management method.

4.7 Chapter Four Reference

Clark S., Klonsky K., Livingston P., Temple S. (1999) Crop-yield and economic comparisons of organic, low-input, and conventional farming systems in California's Sacramento Valley. American Journal of Alternative Agriculture 14:109-121.

Jackson L. E., Wyland J. and Stivers L. J. (1993) Winter cover crop to minimize nitrate losses in intensive lettuce production. J. Agric. Sci. 121:55-62.

Launch Grow Joy (2018) How to price your products - a simple formula. Accessed from https://www.launchgrowjoy.com/how-to-price-your-products/ on June 19, 2018.

Missouri State Agriculture Review 2017 (2018) Accessed from https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=missouri on July 9, 2018.

Seufert V., Ramankutty N., Foley J.A. (2012) Comparing the yields of organic and conventional agriculture. Nature 485:229-232

CHAPTER FIVE

5.0 Conclusion and Recommendation

5.1 Conclusion for Objective One (1)

A three-point hitch four and two-row between-row mower was fabricated and evaluated for its performance. The four-row between-row mower was fabricated using a 16gpm 540 rpm remote pump. The mower used an 18-gallons reservoir to supply five hydraulic motors (MGGC20030-Parker Hannifin Corporation, Mayfield Heights, Ohio). The three-point hitch design of the mower made it adaptable to different tractors. The two mowers built were the two and four-row mowers.

5.2 Conclusion for Objective Two (2)

Between-row mowing was efficient at controlling matured broadleaf weeds and grasses which competed with organically grown no-till soybeans. The study revealed that between-row mowing with cover crops produced higher yields than cultivation and mowing without cover crops but was not statistically significant. Between-row mowing was more effective at controlling broadleaf weeds than grasses. The use of cover crops contributed to weed suppression and contributed to decreased grasses and broadleaf weeds in the rows of organically grown no-till soybeans.

5.3 Recommendations for Future Studies

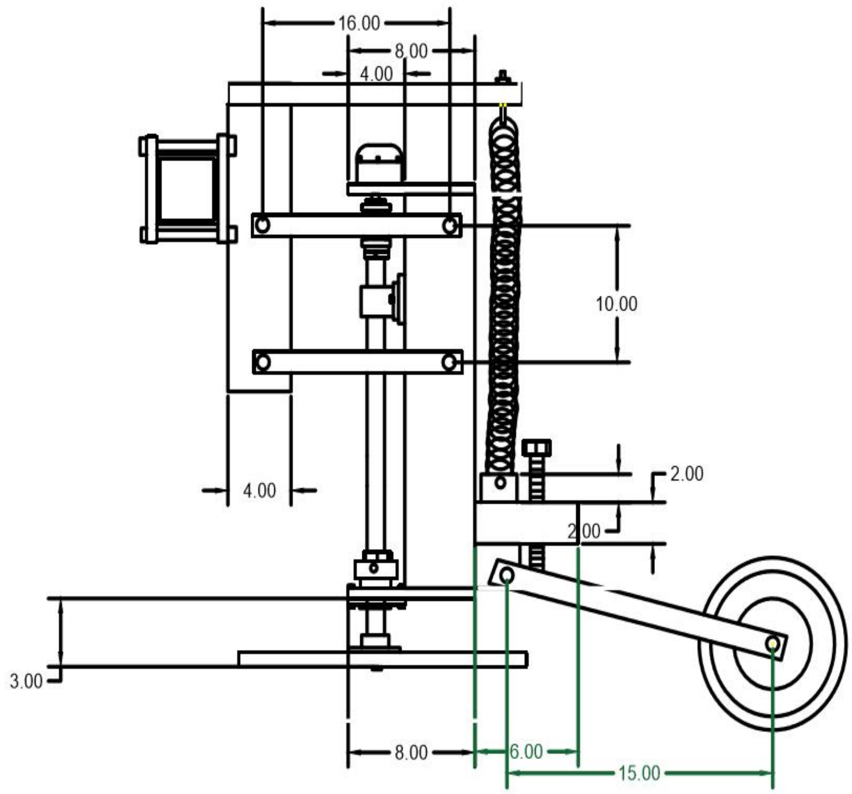
Between-row mowing is an innovative weed management technology that has great potential. Future studies into the commercial viability of the between-row mower will help determine if this technology can be made affordable and available to farmers.

Secondly, determining the effects of forward speed on mowing efficiency will contribute greatly to understanding ways to increase the forward speed during mowing. Finally, future studies to determine the pressure losses across the motors and ways to adjust flow divider pressure relief valve will improve the efficiency of the mower.

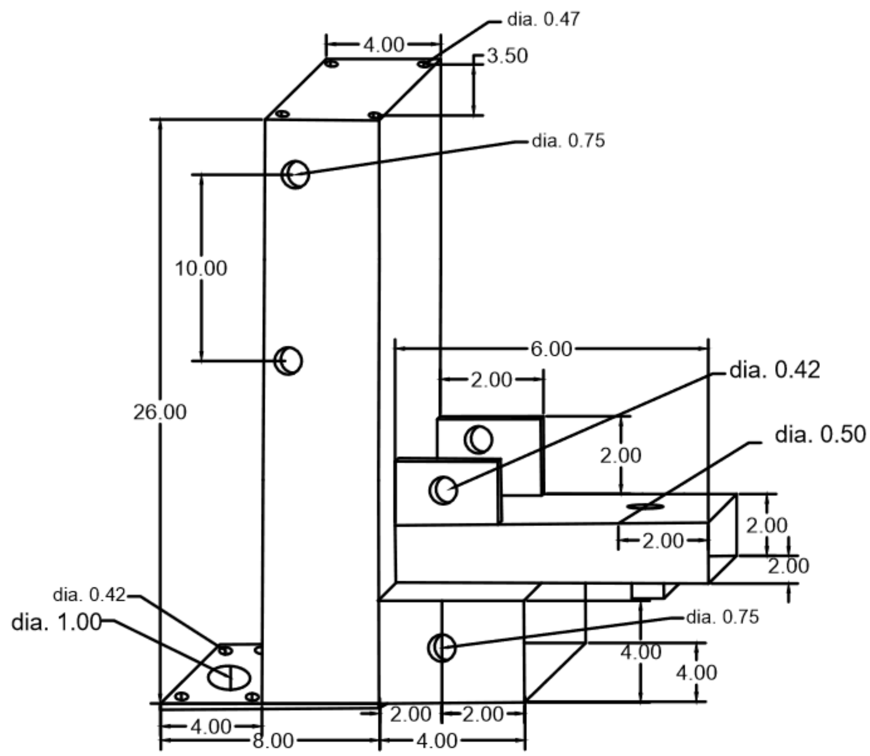
5.0 APPENDICES

Dimensions in inches

Two decimal places



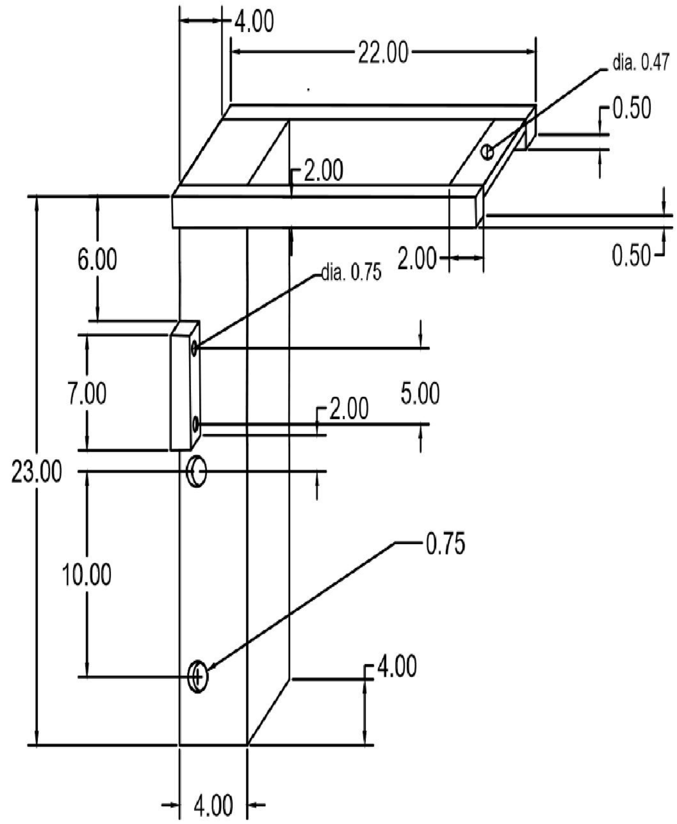
Appendix 5.1 Two-Row and Four-Row Cutting Units



Dimensions in inches

Two decimal places

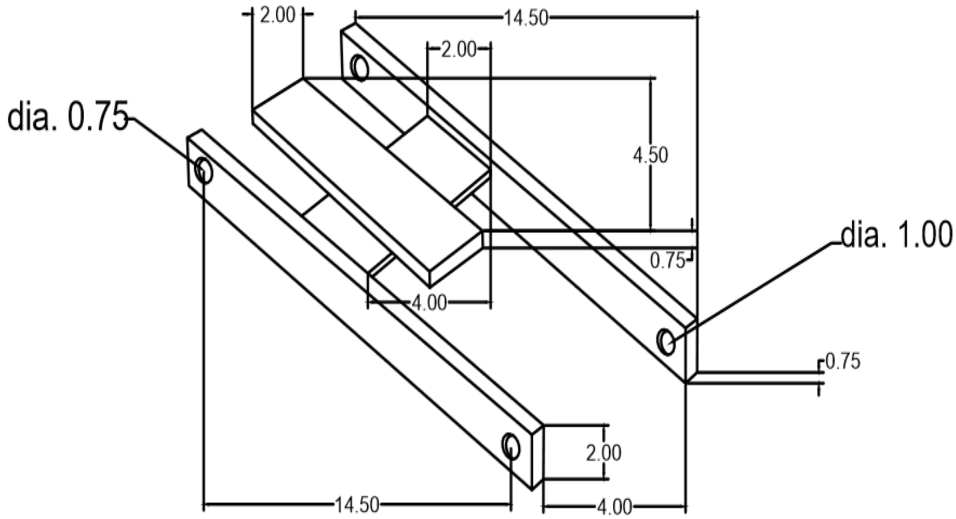
Appendix. 5.2 Side View of Cutting Unit (dia: diameter)



Dimensions in inches

Two decimal places

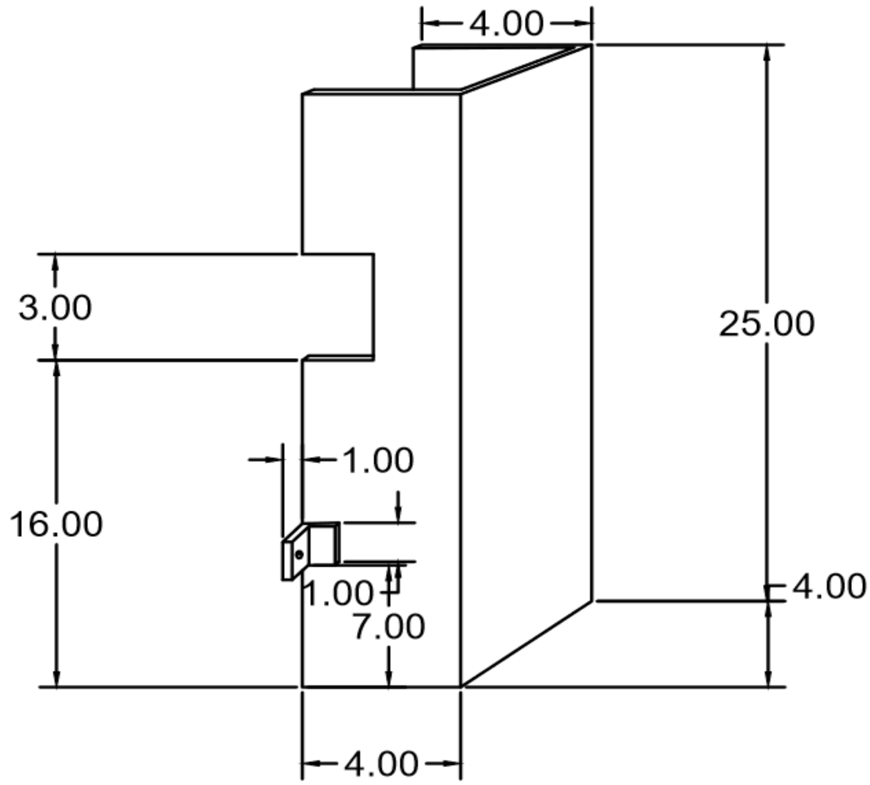
Appendix 5.3 Tool Bar Connection (dia: diameter)



Dimensions in inches

Two decimal places

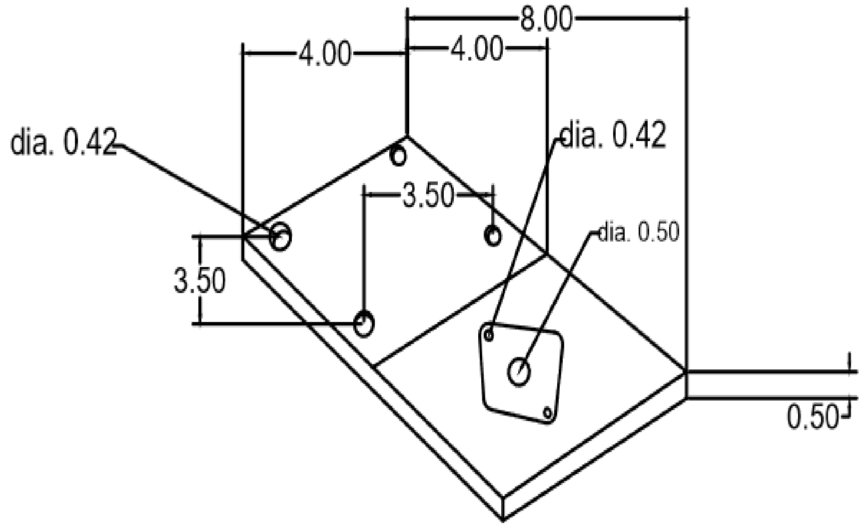
Appendix 5.4 Wheel Bracket (dia: diameter)



Dimensions in inches

Two decimal places

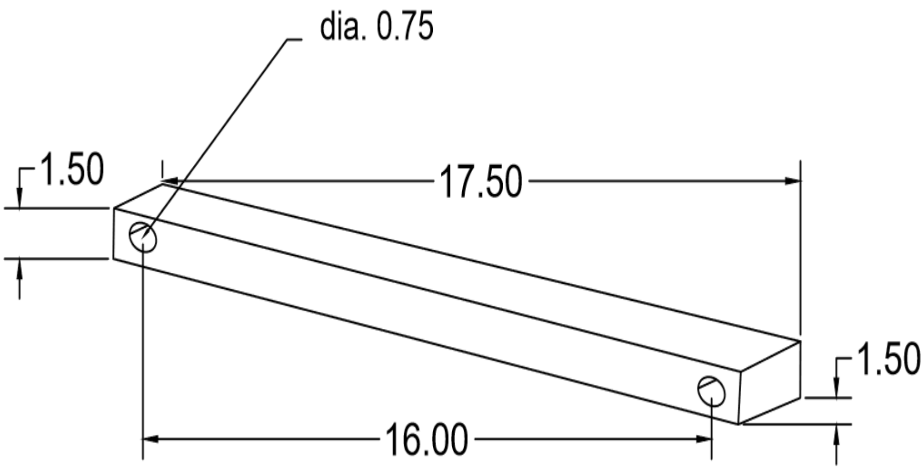
Appendix 5.5 Shaft Shield



Dimensions in inches

Two decimal places

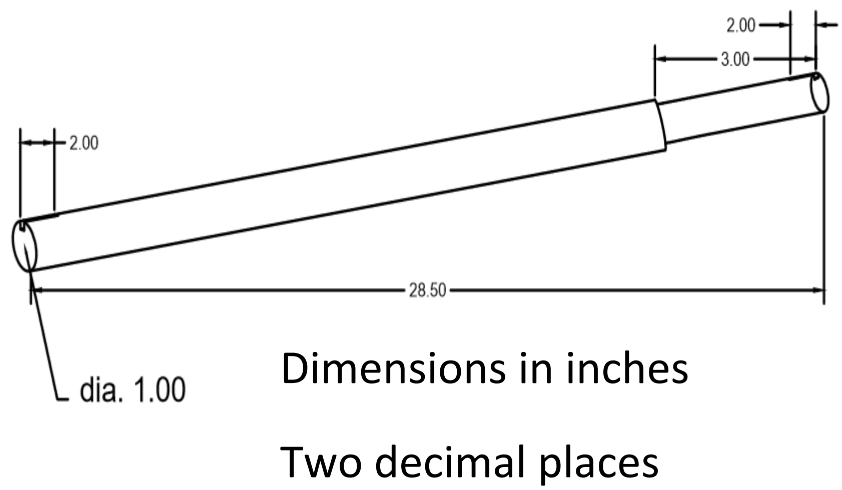
Appendix 5.6 Hydraulic Motor Housing (dia: diameter)



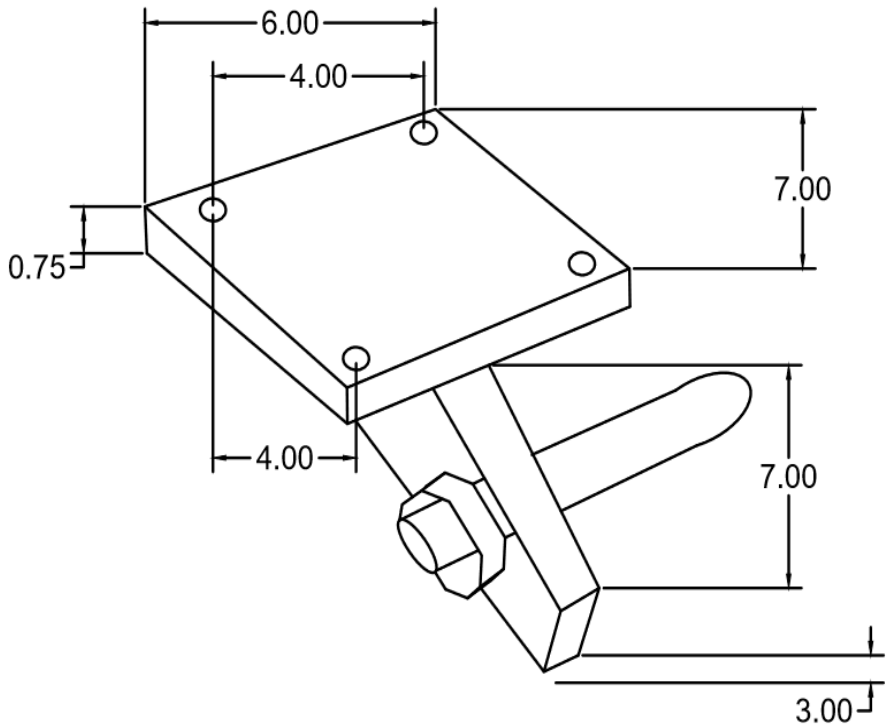
Dimensions in inches

Two decimal places

Appendix 5.7 Connecting Rod (dia: diameter)



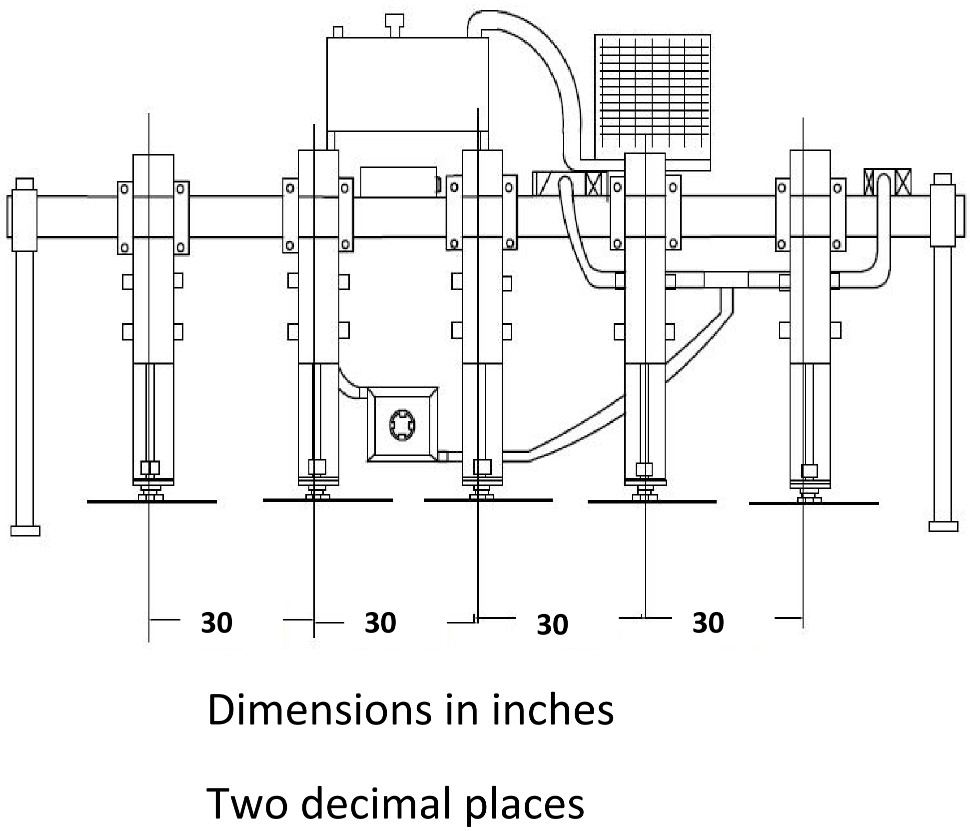
Appendix 5.8 Shaft (dia: diameter)



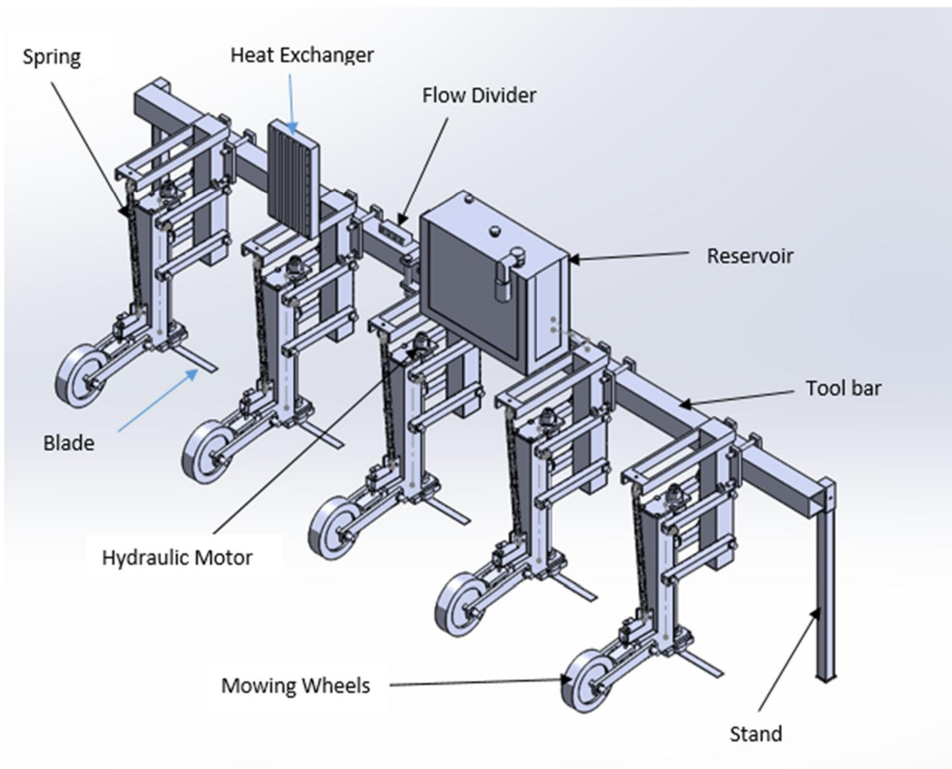
Dimensions in inches

Two decimal places

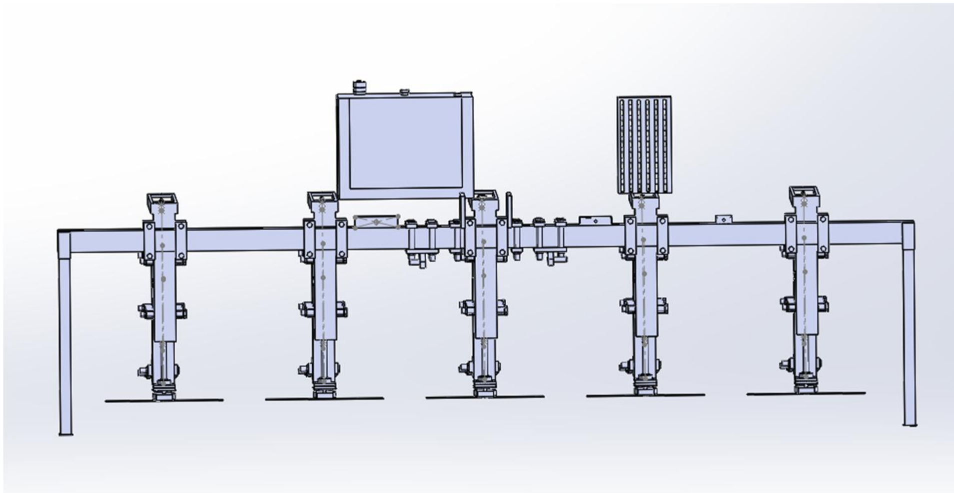
Appendix 5.9   Lower Links (dia: diameter)



Appendix 5.10   Front View Four-Row Mower



Appendix 5.11 Isometric view of mower with labels



Appendix 5.12   Front view of four-row mower

Field before mowing was conducted

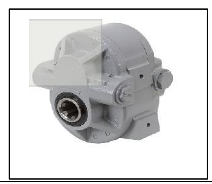
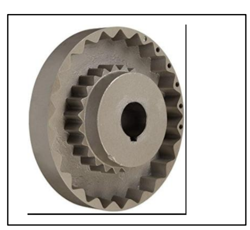
Field after mowing was conducted

Frequent mowing until canopy closure

Appendix 5.13 Mowing effects on weed density in organically grown no-till soybeans

Appendix 5.14 Two-row mower

Table 5.1: Parts and location of parts used in construction

No.	Part Number	Company
1.	0.218 cu in Parker MGG20010-BA1A3 Hydraulic Motor Model MGG20010BA1A3 Displacement 0.218 cu.in. /rev. Pressure 2000 PSI continuous 2500 PSI intermittent Speed 5000 RPM max as motor 3500 RPM max as pump	Surplus Center (https://www.surpluscenter.com/Brands/Parker/0-218-cu-in-Parker-MGG20010-BA1A3-Hydraulic-Motor-9-1180.axd) 
2.	Trans torque (1inch inner shaft) KEYLESS BUSHING, SHAFT DIA. 1.0000 IN	IBT Industrial Solution, Jeff City 2401 Industrial Dr, Jefferson City, MO 65109 Phone: (573) 635-1042 
3.	9.76 cu in 21.2 GPM 540 RPM Dynamic GP-PTO-A-9-6-S Hydraulic PTO Pump Manufacturer Dynamic Model GP-PTO-A-9-6-S Disp. 9.76 cu. in. / rev. Pump Type Gear Pressure 2500 PSI max. Speed: 540 RPM Flow: 21.2 GPM at 540 RPM	Surplus Center (https://www.surpluscenter.com/Brands/Dynamic/9-76-cu-in-21-2-GPM-540-RPM-Dynamic-GP-PTO-A-9-6-S-Hydraulic-PTO-Pump-9-8902-9.axd) 
4.	JEM Type Coupling Sleeve - 8, JEM, One Piece Solid, Thermoplastic Elastomer	IBT Industrial Solution, Jeff City 2401 Industrial Dr, Jefferson City, MO 65109 Phone: (573) 635-1042 
5.	Martin Quadra-flex flange	IBT Industrial Solution, Jeff City 2401 Industrial Dr, Jefferson City, MO 65109 Phone: (573) 635-1042  

6.	Pillow Bearings (One (1) inch)	Missouri Power Transmission 1801 Santa Fe Pl, Columbia, MO 65202 Phone: (573) 474-1446 
7.	Flange Bearings (One (1) inch)	Missouri Power Transmission 1801 Santa Fe Pl, Columbia, MO 65202 Phone: (573) 474-1446  
8.	I- bolts 0.75 inches	Lowes  
10.	Mower Blades	22 inch mower blades were purchased from Lowes s home improvement hardware store. 26 inch mower blades were purchased from 
11.	Hoses	Half (0.5in) inch hydraulic hoses IBT Industrial Solution, Jeff City 2401 Industrial Dr, Jefferson City, MO 65109 Phone: (573) 635-1042 

Table 5.2: Material Cost for the 4-row mower

No.	Part Description	No. of pieces	Unit Price ($)	Net Amount ($)
1.	0.218 cu in Parker hydraulic motor	5 pcs	196.00	980.00
2.	Trans torque	5 pcs	75.00	375.00
3.	9.76 cu in hydraulic pump	1 pcs	298.40	279.95
4.	Pump torque bar	1pc	49.95	49.95
5.	Coupling sleeve	5 pcs	39.80	199.00
6.	Martin Quadra-flex flange	5 pcs	25.00	125.00
7.	Pillow bearings	5 pcs	9.37	46.85
8.	Flange bearings	5 pcs	9.37	46.85
9.	Hoses (half inch)		500.00	500.00
10.	Hydraulic couplings	30pcs	5.00	150.00
11.	Mower blades (22 inch)	5 pcs	15.99	79.95
12.	Bushing	5	20.00	100.00
13.	**Steel Material** 4in x 4in square pipe 2in x 2in square pipe 1inch shaft 2inch x 0.75inch plate		500.00	500.00
14.	Wheel	5 pcs	30.00	150.00
15.	Four section flow divider	1pc	416.95	416.95
16.	Two section flow divider	1pc	219.25	219.25
18.	Bolts and nuts		300.00	300.00
19.	Reservoir	1 pc	194.95	194.95
20.	Heat Exchanger	1 pc	300.00	300.00
	Total			**5013.7**

Appendix 5.15 Mower Commercialization

The time required to build the mower will depend on the man power available. The estimated time spent building this mower will take a couple of weeks. The construction of the mower does not require special machines. A band saw, drilling machine, lathe machine and welding machines are common machines which will be required in production. The total cost of $ 5,013.7 constitutes the cost of materials in constructions without labor cost. Labor cost will often be dependent on the shop where the mower is constructed. In order to determine the commercial cost of the product, it is important to consider the material and labor cost as shown in the equation below. Though labor was not included in estimating the overall cost of the mower, the final cost of the mower will be twice the value of raw materials ($5,013.7 x 2 = $10,207.4). Multiplying the labor and material cost ensures that profits and overheads are well covered.

(Labor + Materials) x 2 = Wholesale Price (Launch Grow Joy 2018)