Influence of Planter Width, Planting Speed, and Perimeter-to-area ratio on Field Efficiency for Row Crop Planters

A Thesis Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Colburn James Condra
August 2017

Copyright © 2017 by Colburn James Condra
All rights reserved.

ACKNOWLEDGEMENTS

First, I would like to thank my parents, grandparents, and family for all the love and support throughout all my endeavors in my life. Thank you to my loving and dearest wife Sarah for supporting me and always reminding me to do my best in anything I do. Without my wife and families love and support, this would not have been possible to accomplish and I would not be the person I am today.

To the Biosystems Engineering and Soil Science department at UT, thank you for giving me a graduate teaching/research assistantship and the opportunity to pursue a master's degree in Biosystems Engineering Technology. I would like to acknowledge my mentor's, Dr. William Hart and Dr. Michael Buschermohle for allowing me to be their graduate student and for guiding and teaching me along this endeavor of pursuing my master's degree. Thanks to both of you, for teaching me inside and outside of the classroom, including me in Extension and professional meetings, and for also instilling in me, life lessons and values.

I would like to acknowledge my committee member, Dr. Aaron Smith, for all the hard work, suggestions, and knowledge to help improve my study. Also, I want to thank Dr. Arnold Saxton for his help in analyzing the data for my study. Finally, I would like to thank Tim Grant and John Taylor for not only being great coworkers but great friends and helping me anytime I needed it.

ABSTRACT

Field efficiency is defined as the percentage of time a machine operates at its rated speed and width while in the field. The main goal of this study was to determine the influence of planter width, planting speed, and perimeter-to-area ratio on field efficiency of row crop planters. Planting data was collected for this study from fields in Tennessee and Oklahoma using three different planter widths 12.2-m, 18.3-m, and 24.4-m and two planter types, John Deere ExactEmerge™ and John Deere MaxEmerge™. The 12.2-m wide planter was operated in Tennessee in 50 fields totaling 588 hectares, two 18.3-m wide planters were operated in Oklahoma in 95 fields totaling 2,718 hectares, and a 24.4-m wide planter was operated in Oklahoma in 25 fields totaling 879 hectares. A Vector GL1000 data logger was used to collect various data messages that could be imported into ArcMap 10.4 for final post-processing of the data. Within ArcMap, field boundaries were created by following exterior planter passes and end rows, and then buffering this boundary half of the planter width to acquire the total planted area of the field. All data contained within each field boundary were assigned to that field for final processing. A planter operation classification system was developed to define the different planting operations that were being performed in the field. The final totals from the different planting operations for each field were inputted into an Excel spreadsheet to calculate field efficiency values. Results indicated: i) there were differences between Tennessee and Oklahoma in regards to field characteristics; ii) perimeter to area ratio had a

major influence on field efficiency; iii) increasing planter width decreased field efficiency; and iv) increasing planting speed decreased field efficiency. Increasing planting speed by almost 5 km/h, for a high-speed 12.2-m planter, was equivalent to the effective field capacity of an 18.3-m conventional planter. Lastly, increasing planting speed by at least 3.3 km/h, for a high-speed 18.3-m planter, was equivalent to the effective field capacity of a 24.4-m conventional planter.

TABLE OF CONTENTS

Chapter One Introduction and General Information 1

Chapter Two Literature Review 3

Field Machine Efficiency 3

Row End Turning 7

Row Length 9

Optimum Planting Windows 10

Seed Loading 11

Chapter Three Materials and Methods 13

Data Collection 13

Planter Operation Data Processing 17

Planting Operation Variables 18

T_{PL} – Time planting (actual) 18

T_{TN} – Time turning (actual) 19

T_{TR} – Time infield travelling (actual) 19

$T_{F/UF}$ – Time folding/unfolding (based on planter width) 20

T_{SL} – Time loading seed (based on sec/ha) 20

T_{SD} – Time checking seed depth (constant for all fields) 21

Other – Non-productive time 21

Perimeter-to-Area Ratio 23

Simulated Planting Speeds 23

Field Efficiency and Capacity Equations 24

Multiple Linear Regression Methods 25
Chapter Four Results and Discussion 27
Observed Data Planting Operation Variables 27
Planting Speed 27
Turning Speed and Turn Time 28
Infield Travelling Speed 29
Folding/Unfolding 30
Observed Data 30
Simulated Planting Speeds 36
Multiple Linear Regression Results 40
Perimeter-to-Area Ratio vs Field Efficiency 43
Planting Speed vs Field Efficiency 44
Planter Width vs Field Efficiency 48
Effective Field Capacity vs Planting Speed 52
Chapter Five Conclusions and Recommendations 56
Chapter Six Future Research 58
List of References 60
Vita 64

LIST OF TABLES

Table 3.1. CAN bus messages recorded by Vector GL1000 compact data logger 16

Table 3.2. Planter operation classification values assigned to post-processed data 18

Table 4.1. Average planting speed (km/h) for three planter widths 27

Table 4.2. Average turning speed (km/h) for three planter widths 28

Table 4.3. Average turning time (sec) for three planter widths 29

Table 4.4. Average infield travelling speed (km/h) for three planter widths 29

Table 4.5. Constant folding/unfolding times (sec) based on planter width 30

Table 4.6. Multiple linear regression results for all simulated speed data 42

LIST OF FIGURES

Figure 3.1. Distribution of field size by planter width 14

Figure 3.2. Vector GL1000 Compact Data Logger 15

Figure 3.3. CAN bus diagnostic port inside tractor cab 16

Figure 3.4. Example of processed field showing planting operations 22

Figure 4.1. Planter width vs obsvered field efficiency by planter widths 33

Figure 4.2. Perimeter-to-area ratio (P/A) vs observed field efficiency by planter widths 34

Figure 4.3. Relationship between field size and perimeter-to-area ratio 35

Figure 4.4. Field efficiency vs. constant simulated speed at 8.0 km/h by three planter widths 37

Figure 4.5. Field efficiency vs. constant simulated speed at 11.3 km/h by three planter widths 38

Figure 4.6. Field efficiency vs. constant simulated speed at 16.1 km/h by three planter widths 39

Figure 4.7. Field efficiency for three planting speeds at a planter width of 12.2-m 45

Figure 4.8. Field efficiency for three planting speeds at a planter width of 18.3-m 46

Figure 4.9. Field efficiency for three planting speeds at a planter width of 24.4-m 47

Figure 4.10. Field efficiency for three planter widths at a planting speed of 8.0 km/h 49
Figure 4.11. Field efficiency for three planter widths at a planting speed of 11.3 km/h 50
Figure 4.12. Field efficiency for three planter widths at a planting speed of 16.1 km/h 51
Figure 4.13. Effective field capacity for high speed 12.2-m wide planter vs. conventional 18.3-m wide planter with increasing simulated speeds 54
Figure 4.14. Effective field capacity for high speed 18.3-m wide planter vs. conventional 24.4-m wide planter with increasing simulated speeds 55

CHAPTER ONE
INTRODUCTION AND GENERAL INFORMATION

Machine field efficiency is an important factor for producers making machinery/purchasing decisions for their farming operation. It is crucial for producers to understand how field efficiencies are calculated and how these efficiencies can aid them in making their machinery/purchasing decisions. “Field efficiency is the ratio of effective field capacity to theoretical field capacity, expressed as decimal value (ASAE S495.1, 2005). With today’s advancement in machinery technology, more specifically planter technology, farmers/operators must be able to incorporate these new precision farming techniques into their specific farming operation to maximize profitability. Renoll (1979) stated that “farm machinery cannot be engaged in productive work 100 percent of the field time.” Due to farmers/operators not having the capabilities of being productive at all times, this places more emphasis on being more efficient with their operation.

Many factors affect machine efficiency while operating in the field. ASAE EP496.3 (2006) indicates that “the following activities account for the majority of time lost in the field; turning and idle travel, materials handling (i.e. seed, fertilizer, chemicals, water, harvested material), cleaning clogged equipment, machine adjustment, and lubrication and refueling (besides daily service).” Turning time can affect machine efficiency based on the turning area of the field, how wide an operator’s turns are, and how fast these turns can be executed.

Loading seed can lower field efficiencies due to the time it takes to stop planting operations to fill the planter with seed, and any other materials such as fertilizers, water, and/or chemicals.

A field's physical characteristics are another key factor that influences all the above factors. Field characteristics include field size and shape, topography, ruts, plant residues, field surface, and row lengths. These field characteristics can either have a positive or negative effect on field efficiency based on whether the field has a regular or irregular shape. Any lost productive time associated with these field characteristics will decrease overall field efficiency of the farming operation.

Three objectives were verified for this study; 1) determine the relationship that planter width and planting speed have on field efficiency; 2) determine the influence that field characteristics (i.e. perimeter-to-area ratio) have on field efficiency; and 3) determine a function to calculate field efficiency based on the variables examined in objectives one and two. The hypothesis of this study is planter width, planting speed, and perimeter-to-area ratio all have an effect on decreasing overall field efficiency.

CHAPTER TWO
LITERATURE REVIEW

Field Machine Efficiency

ASAE standard D497.7 (2011) reports that field efficiencies for row crop planters range from 50 to 75 % for planting speeds of 6.5 to 11.0 km/h. The average field efficiency reported in this standard is 65 percent at a rated speed of 9.0 km/h. Field efficiency indicates how well machinery is suited for use within a particular field. It examines the relationship between actual productive time in the field and overall time spent in the field. Actual productive time in the field for planting operations is time spent planting. Non-productive times include turning time, infield travelling time, time loading seed, time spent folding/unfolding the planter, adjustments made to the machine or equipment and any other items relative to planting when not in the field.

Renoll (1970) created a field machine index (FMI) to indicate how well adapted a specific field is for the use of machinery. This index involves row end turning conditions and row length which has a direct influence on the actual field production and total turning time. His FMI was expressed as the ratio between productive machine time to the sum of productive machine time plus row end turning time, or, FMI = (A-B-C) / (A-B) x 100, where the three variables of the ratio were; (A) total time for completion of operation in the field, (B) total non-

production time which does not include turning time, and (C) total turning time. All three items listed above were expressed in minutes.

Field machine index can be implemented in different ways to help a farmer improve machinery efficiency within their farming operation. A farm manager who has a choice of planting some fields and leaving out others could use the FMI concept and plant those fields best suited for machinery use (Renoll, 1979). Renoll (1979) reported a high FMI correlates with high acre per hour machine capacity. With this holding true, FMI can also be helpful in determining the machinery's projected hours of use. Renoll (1979) concluded that if the FMI is high for one machine, then FMI for another machine (i.e. planter, combine, or sprayer) will be high when the machine is used in that same field. Fields which are reasonably well suited for machinery use will have a field machine index of 88 or more (Renoll, 1979).

As stated previously, field efficiency is the ratio of effective field capacity to theoretical field capacity, expressed as decimal value" (ASAE S495.1 2005). ASAE standard S495.1 (2005) defines effective field capacity as the actual rate of land or crop processed in a given time. Theoretical field capacity can be defined as a machine running at its maximum capacity at 100% of its effective width at a given speed during the machines operation (ASAE S495.1 2005). Theoretical field capacity can be expressed as follows.

Equation 2.1. Theoretical field capacity

$$Field\ Capacity_{Theoretical} = \frac{s * w}{10} \quad (2.1)$$

where

s = speed (km/h)
w = width (m)
Constant = 10

An operator cannot operate a machine at its theoretical field capacity 100 percent of the time in the field due to various factors that include field characteristics; obstacles within fields; turning and idle traveling; handling seed, chemicals, and fertilizers; machinery adjustment, lubrication, and refueling; and other downtime. Consequently, effective field capacity is always less than theoretical field capacity, thus, field efficiency is always less than 100 percent. Effective field capacity estimates how much area a machine can cover in a given amount of time. Effective field capacity can be expressed as follows.

Equation 2.2. Effective field capacity

$$Field\ Capacity_{Effective} = \frac{s * w * FE}{10} \quad (2.2)$$

where

s = speed (km/h)
w = width (m)
FE = field efficiency (decimal form)
Constant = 10

When calculating planting efficiency, a variety of infield planting operations must be considered, such as planting, turning, infield travelling, unfolding/folding

the planter, seed loading, and checking seed depth. Buschermohle et al. (2016) included these infield planting operations and defined planting efficiency as the total time spent planting divided by the total time in the field which included the amount of time spent planting, turning, travelling within the field, loading seed, checking seed depth, and folding/unfolding the planter. Planting efficiency can be expressed as follows.

Equation 2.3. Planting efficiency

$$Planting\ Efficiency\ (E_f) = \frac{T_{Planting}}{T_{Total}} \tag{2.3}$$

where

$T_{Planting}$ = total time planting (sec)
T_{Total} = total time spent in field (sec)

Grisso et al. (2000) conducted a study determining field efficiencies from spatial data. This study used five fields to compare results from planting corn and soybeans. Fields which were flat with straight-rows were compared to fields with contours that had slopes ranging from 3 % to 5 %. They reported that comparing fields with contours versus fields with straight-rows reduced field efficiencies by 10% to 20% for planting and harvesting. Taylor et al. (2001a) conducted a study using 4.6-, 9.1-, and 12.2-m planters in Northeast Kansas. Average machine field efficiencies for the 4.6-, 9.1-, and 12.2-m planters were 75.5 %, 60.9 %, and 58.4 %, respectively. Average planting speed for the three widths were 7.6, 7.4, and 7.6 km/h, respectively. Average planting speed across all three planters from the study was 7.6 km/h. Taylor et al. (2001a) found that as planter width increased

overall field efficiency decreased, and an increase in planter width increased overall field capacity in ha per hour. Taylor et al. (2001a) concluded that as a planter's width increased, overall machine field efficiencies will decrease, but field capacity will increase. They also concluded that field size did not impact overall field efficiencies.

Buschermohle et al. (2016) conducted a study using different planter widths to determine the influence of planter width, planting speed, and seed loading methods on planting efficiencies for cotton. In this study planter widths of 11.6-, 17.4-, and 23.2-m were compared to determine overall field efficiency and effective field capacity values. They reported overall field efficiency values for the three planter widths of 11.6-, 17.4-, and 23.2-m ranged from 54.1 % to 76.4 %, 46.3 % to 70.1 %, and 41.1 % to 65.7 %, respectively. Effective field capacity values for the three planter widths ranged from 5.7 to 12.1 ha/h, 7.9 to 15.5 ha/h, and 9.8 to 18.4 ha/h, respectively. Buschermohle et al. (2016) concluded that as planter width increased for a given planting speed, overall planting efficiency decreased, but planting capacity increased.

Row End Turning

The amount of time spent turning at row ends can greatly affect the overall field efficiency of the machine. The surface condition of the turning area and the size of the area provided for turning may influence the overall turning time. When the surface condition of the turning area is not smooth, for example due to

tillage, the time it takes to execute a turn has been shown to increase. Renoll (1969) tested a 4-row planter under varying field conditions and found that making a turn on smooth surface conditions took an average time of 13.2 seconds, compared to 17.6 seconds when turning on rough surface conditions (i.e. rocks, ditches, sloping or terraces). Thus, turning in rough field conditions resulted in a 75 percent increase in overall turning time compared to turning in areas where the surface conditions were smooth and compact.

Turning area must be large enough for an operator to make a smooth continuous turn. Renoll (1969) reported that larger row crop machines such as cotton pickers and combines need twice the length of the machine to turn efficiently. Hannah (2016) indicated turns in headland areas are longer with raised implements not in use and headland areas are larger with wider equipment. Renoll (1969) conducted a study determining farm machinery performance with 1-row, 2-row, and 4-row machines. His study found that large and easy semi-circle turns minimized the amount of time required per turn. If the turn area was too small, the operator oftentimes must back up the tractor and planter to be able to align with the next planter pass. Field's having an irregular shape can also impact turning times due to the difficulty of the operator to turn the tractor and planter in the desired turning path.

Row Length

Row length has a tremendous influence on machine field efficiency and is influenced by field size, terrace arrangements, and row arrangements. Row length, percent turning time, and down-the-row speed have been shown to be interrelated (Renoll, 1969). If any of these factors are changed, a machine's field efficiency will change as well. Renoll (1979) reported that turning makes up only 6 to 10 percent of the total time spent in the field in fields with good turning conditions and row lengths long enough for the machine being used. When considering larger farm operations, field size, row lengths, and machine size all influenced turning time. As machine size increases, the length of the rows and the size of the field must increase to maximize machine field efficiency. Renoll (1979) conducted a study on farm machinery performance to determine the influence of row length, field size, and machine size. Renoll (1979) reported that if field efficiency is to be kept high for larger machines, they should be used in fields where the majority of the rows exceed 700 feet.

Row direction can be dependent on terraces located within the field and can either run parallel or nonparallel to the terraces. Renoll (1979) reported that using a 4-row cultivator with row lengths running parallel to the terraces had an end row turning time of 8 percent of the total time spent in the field and an average speed of 7.4 km/h. While the row lengths that were nonparallel to the terraces had end row turning times of 14 percent and an average speed of 6.4 km/h. In the same study, another factor, field capacity was examined. The field

capacity with the rows running parallel to the terraces was 2.6 ha/h compared to 2.0 ha/h in fields with rows running nonparallel to the terraces.

Optimum Planting Windows

Planting crops during optimum planting windows is crucial for achieving the greatest possible yield. Taylor et al. (2001b) conducted a study using precision agriculture technologies to determine the relationship between time within planting window and ensuing yield for corn planted in Kansas. They reported that planting earlier in the optimum planting window resulted in greater yields and yields decreased as planting season continued. Staggenborg et al. (1999) conducted a two-year study at three locations in Kansas determining the influence that planting dates have on corn yield. They reported that at five of the six location-years, being able to plant in the window between early April and May resulted in similar grain yields. However, they found that delaying planting until early June reduced grain yields on average 89 bu/hectare across all six location-years. Swanson and Wilhelm (1996) conducted a similar study on planting date versus corn yield. They reported the optimal planting window for south central Nebraska was May 2 to May 10. Salmerón et al. (2016) conducted a study determining yield response to planting date among soybean maturity groups for irrigated production in the Midsouth. The study took place in multiple locations over multiple years with six locations in 2012 and eight locations in 2013 and 2014. Salmerón et al. (2016) reported optimum planting dates that maximized yields were dependent on location and maturity group that ranged from March 22

to May 17. If planting was delayed until mid-May through early June, reduced yields by 0.09 % to 1.69 % per day were experienced with the greatest yield loss coming from the southernmost locations. Furthermore, having sufficient planting equipment and improving field capacity has a direct impact on yield/production.

Seed Loading

Seed loading is another key attribute to examine when determining overall field efficiencies. Buschermohle et al. (2016) conducted a study to determine how various seed loading methods influenced machine field efficiency for cotton planting. The three seed loading methods used included filling individual seed hoppers with bags, filling individual seed hoppers with seed tenders, and filling central fill hoppers with seed tenders. Seeding rate used in the study was based on seconds per hectare which was determined by taking the total time for loading seed and dividing it by the total number of hectares planted at a known seeding rate. Buschermohle et al. (2016) reported loading 12 individual row unit seed hoppers with 2 bags per row unit by hand required a total time of 11.9 minutes or 60 seconds per row unit. Loading the same individual seed hoppers with a seed tender required a total time of 8.9 minutes or 45 seconds per row unit. Average time to load a central fill unit with two bulk boxes of seed required a time of 11.2 minutes. It is known that operators do not stop in every field to load seed. Often operators will load enough seed to plant multiple fields to decrease overall seed loading time. Buschermohle et al. (2016) reported that using a seeding rate of 3 seeds per 0.31 meter, loading individual seed hoppers with bags required a time

of 13.1 sec per hectare while using a seed tender required 9.9 sec per hectare. When using bulk boxes to load central fill hoppers, seed loading time decreased to 3.7 sec per hectare. For this study, total seed loading time for a field was calculated by multiplying seed loading rate by total number of hectares planted for each field.

CHAPTER THREE
MATERIALS AND METHODS

Data Collection

Planting data was collected in Tennessee and Oklahoma during the 2016 planting season using three different planter widths. As shown in Figure 3.1, field size varied for each planter width. In western Tennessee, planting data was collected operating a John Deere 12.2-m wide ExactEmerge™ planter in 50 fields totaling 588 hectares, with the majority of these fields smaller than 20 hectares. Planting data in Oklahoma was collected using both an 18.3- and a 24.4-m wide planter. A John Deere 18.3-m wide ExactEmerge™ planter was used in northcentral, Oklahoma and a John Deere 18.3-m wide MaxEmerge™ planter was used in western Oklahoma. These two planters combined were operated in 95 fields totaling 1,891 hectares with a majority of these fields greater than 20 hectares. In central and western Oklahoma, data was collected with a 24.4-m John Deere MaxEmerge™ planter operated in 25 fields totaling 879 hectares with a majority of the fields being greater than 20 hectares. Tractor operators were allowed to continue planting operations normally without any influence from the researchers.

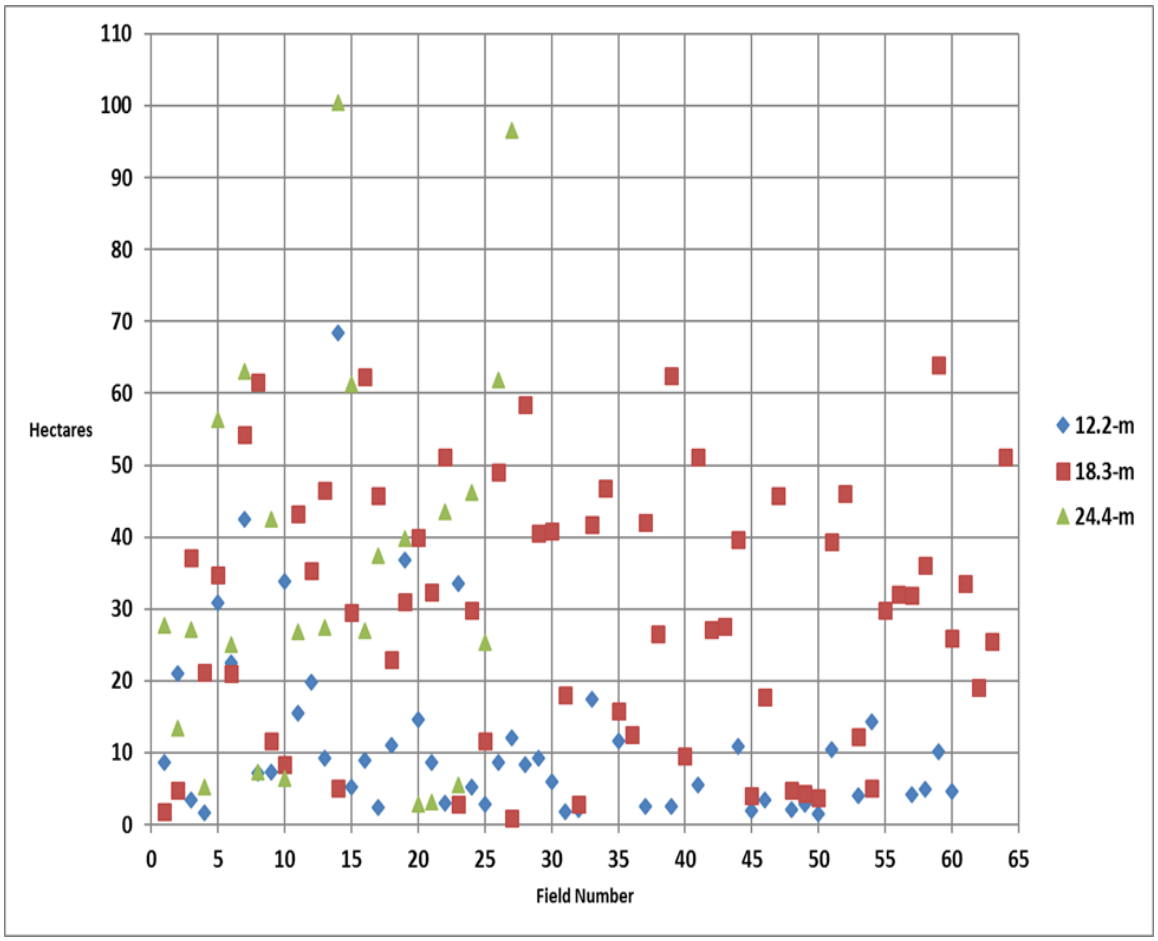


Figure 3.1. Distribution of field size by planter width

Data was collected using a Vector GL1000 Compact Data Logger connected to the Controller Area Network (CAN) Diagnostics Port located in the tractor cabs (figures 3.2 and 3.3). The data logger was set to begin recording data once the ignition key switch was in the on position and the tractor's GPS system had a fixed GPS signal. Messages collected from the CAN bus are shown in Table 3.1. Planting position was based on the status of the Selective Control Valve 1 (SCV1) that operated the planter's hydraulic lift system. When the status of SCV1 valve was open, the planter was assumed to be in the ground planting. In the closed position, the planter was assumed to be in the up position and not planting. After data collection was completed, the logged files were uploaded into Vector CANoe software and exported as a MATLAB format. MATLAB software was used to standardize the data from each CAN bus message into 1-sec intervals. Once data standardization was completed, data was exported as a comma-separated value (CSV) file.



Figure 3.2. Vector GL1000 Compact Data Logger

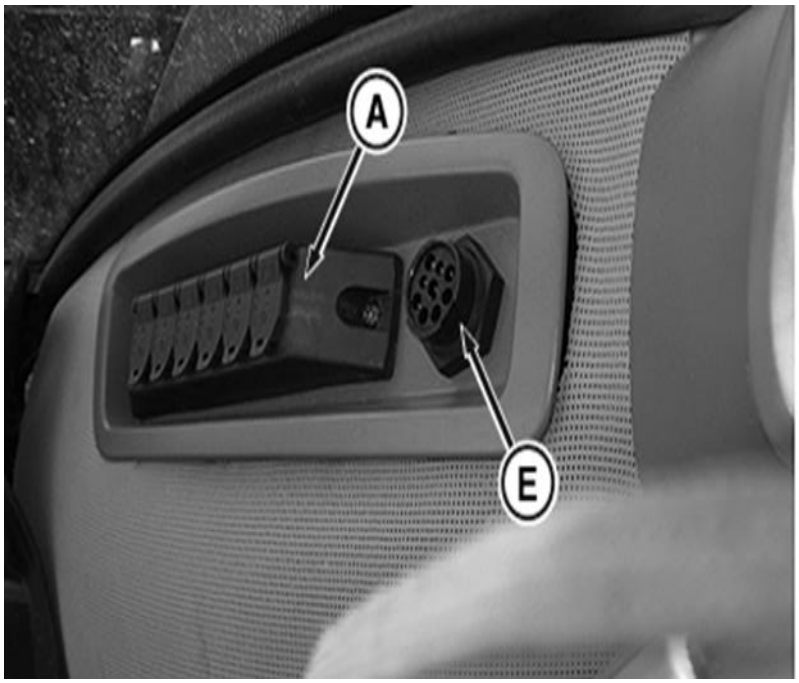


Figure 3.3. CAN bus diagnostic port inside tractor cab

Table 3.1. CAN bus messages recorded by Vector GL1000 Compact Data Logger

CAN Bus Messages	
Latitude	Ground Speed
Longitude	Distance
GPS Time	Hitch Position
Altitude	Hitch Force
Heading	Selective Control Valve 1 (SCV1)
Pitch	Selective Control Valve 2 (SCV2)
Fuel Use	Selective Control Valve 3 (SCV3)
Engine Speed	Selective Control Valve 4 (SCV4)

Planter Operation Data Processing

ArcMap 10.4 software (ESRI, 2016) was used for post-processing of all converted MATLAB data. CSV files were first imported into ArcMap using the Geographic Coordinate System WGS84 then projected in North American Datum (NAD) 1983 Universal Transverse Mercator (UTM) zone 14 for Oklahoma and zone 16 for western Tennessee. Three steps were used for final data processing; 1) creating individual field boundaries; 2) associating data within each field boundary; and 3) assigning new classification values to the data points. Polygons were drawn first in ArcMap following the outside planter pass and/or end rows to create an inside boundary for each field. Next, these inside boundaries were buffered out half the planter width to generate the final field boundary which included the entire planted area of each field. Two different attribute tables were associated with each field. The first attribute table was associated with area and perimeter with its columns expressing measurements in acres and feet, and hectares and meters. These measurements were calculated using the Calculate Geometry tool. The second attribute table was associated with the planting data map. The variables associated with this attribute table included all variables listed in Table 3.1. All planting data that fell inside the planted area field boundary was assigned to that field. Based on the position of the SCV1 valve, data was visually processed and assigned a classification number based on the planting operations listed in Table 3.2.

Table 3.2. Planter operation classification values assigned to post-processed data

Value	Planting Operation Variables	Color Code
0	Other (non-productive time)	Purple
1	Turning	Red
2	Planting	Green
3	Infield Travelling	Blue
4	Folding	Orange
5	Unfolding	Yellow

Values of the planting operation variables were derived from the data processing analysis of the individual planted fields. Planting operation variables obtained from the analysis performed in ArcMap 10.4 were time planting, time turning, time spent travelling within the field, and time spent folding/ unfolding the planter. Values for these planting operation variables were determined from the attribute table.

Planting Operation Variables

T_{PL} – *Time planting (actual)*

Time spent planting was determined by analyzing each individual field identifying planter passes and determining where the operator began and ended the turns. Analyzing these values included looking at the ID number of each data point and determining how speeds varied from each data point. With these two parameters, and the position of the SCV1 valve either open, with the planter in

the ground planting or closed, with the planter out of the ground not planting, a planting operation value of two was assigned to the data. Data points with a planter operation value of two and a speed greater than 0.08 km/h were summed to determine total time spent planting in each individual field.

T_{TN} – Time turning (actual)

Time spent turning was determined the same way planting times were determined. By using the parameters of ID number, planting speed, and position of SCV1 valve either open, with the planter in the ground planting or closed, with the planter out of the ground not planting, a planting operation value of one was assigned for turning. Data points with a planter operation value of one and a speed greater than 0.08 km/h were summed to determine total time spent turning in each individual field.

T_{TR} – Time infield travelling (actual)

Travel time was assigned to data points when the planter was traveling within the field with the SCV1 valve closed with the planter raised or out of the ground. Any data points that indicated the planter was traveling from one part of the field to another to finish out planting or traveling across the field to exit were assigned a planting operation value of three. Any infield traveling that resulted from loading seed, refueling, or other planting operations that were unknown to the researchers were assigned a planting operation value of zero.

$T_{F/UF}$ – Time folding/unfolding (based on planter width)

Time spent folding and unfolding the planter were determined by analyzing data points where the operator entered and exited the field. Using the ID number and speed associated with each data point, it could be determined if the operator either folded or unfolded the planter when entering or exiting the fields. Using these parameters, a planting operation value of four for folding and five for unfolding was assigned to the data points. After all fields had been processed, values were averaged for each of the planter widths, and an overall value for each planter width was determined. Average time spent folding and unfolding the planter used in all planting efficiency analysis were 90 sec, 100 sec, and 120 sec for the 12.2-m, 18.3-m, and 24.4-m wide planters, respectively.

T_{SL} – Time loading seed (based on sec/ha)

Seed loading time could not be determined from the raw data due to researchers not being present at the time of planting, therefore time spent loading seed was based on results reported by Buschermohle et al. (2016). This study reported that the average time to load central fill planters with corn seed using seed tenders was 8.4 sec per hectare. Therefore, time spent loading the planter with corn seed was determined by multiplying total hectares in the field by 8.4 sec/ha.

T_{SD} – Time checking seed depth (constant for all fields)

Due to researchers not being present during time of planting it was unknown if operators stopped planting in each field to check whether the planter was planting seed at a proper seed depth. Thus, based on the results reported by Buschermohle et al. (2016), time spent checking for proper seed depth one time in each field resulted in a value of 300 sec used for all fields.

Other – Non-productive time

Non-productive time was determined by analyzing each field and determining if any cluster of data points exceeded a total idle time of 120 sec. These non-productive times could have been for repairing broken equipment, refueling, operator downtime, maintenance, or other unaccounted-for times. These times were recorded into the Excel file but were not used in any calculations for this study.

An example of the processed data with the associated planting operation values are shown in Figure 3.4. After all fields were processed, the values for individual fields and each planting operation of the classification system were added to an Excel spreadsheet for further analysis.

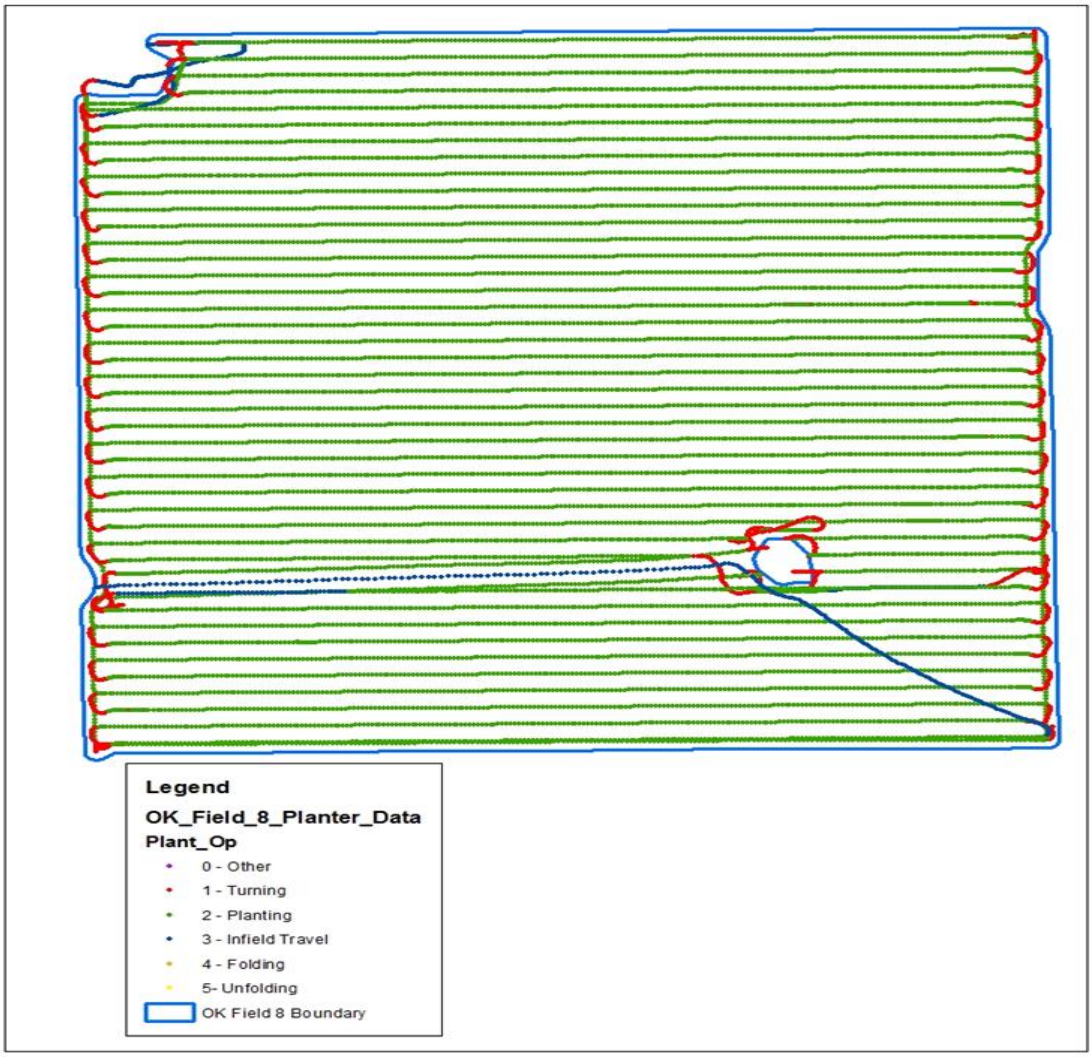


Figure 3.4. Example of processed field showing planting operations

Perimeter-to-Area Ratio

Perimeter-to-area ratio helps to describe how a particular field looks in terms of being regular or irregular shaped. This variable can be expressed as follows.

Equation 3.1. Perimeter-to-area ratio

$$Perimeter - to - area\ ratio = \frac{Perimeter\ (m)}{(Hectares * 10{,}000)} \tag{3.1}$$

A lower perimeter-to-area ratio can be associated with fields being more regular shaped (typically large fields) and the higher values would indicate more irregular shaped fields (typically small fields).

Simulated Planting Speeds

Raw data consisted of planting speeds that were selected by the operator while planting. The rational for selecting these speeds was unknown to the researchers. Planting speeds could have been selected due to comfort of planting at a certain speed, tractor capacity, or unrecorded field characteristics (i.e. ruts, plant residue, and topography). Actual planting speeds ranged from 8.1 to 14.5 km/h. However, it was decided to use simulated speeds to simplify the model and cover a wider range of planter speeds, since 1) the John Deere ExactEmerge™ planter was capable of planting at speeds of up to 16.1 km/h (John Deere, 2015); 2) similar planter widths in the study were operated at different speeds by different operators; and 3) for a given planter, speeds varied

within a field. Therefore, once the raw data had been analyzed, processed, and entered into an Excel spreadsheet, simulation speeds ranging from 6.4 – 19.3 km/h at 1.6 km/h increments, were used to calculate planting time (sec), total time (sec), efficiency (%), and capacity (ha/h). Calculated planting time for each field consisted of dividing the known total planting distance for a particular field by each of the simulated planting speeds and multiplied by a constant of 0.28 m/sec to determine a value for total planting time. Total time spent in the field was computed by adding planting time to total non-planting time. Once these two values were calculated, field efficiency and observed field capacity values were derived from Equations 3.2 and 3.3 in the next section.

Field Efficiency and Capacity Equations

Field efficiencies for each individual field were calculated by dividing the observed field capacity by the theoretical field capacity as follows.

Equation 3.2. Field efficiency

$$Field\ Efficiency = \frac{Observed\ Field\ Capacity}{Theoretical\ Field\ Capacity} = \frac{Observed\ Field\ Capacity}{\frac{Speed * Width}{10}} \quad (3.2)$$

The speed used to calculate the theoretical field capacity was the average of all planting data points, with speed greater than 0.08 km/h from a single field. Observed field capacity is expressed as follows.

Equation 3.3. Observed field capacity

$$Observed\ Field\ Capacity = \frac{Hectares}{T_{PL}T_{TN}T_{TR}T_{F}T_{UF}T_{SL}T_{SD}} \quad (3.3)$$

where

T_{PL} = Time planting (actual)
T_{TN} = Time turning (actual)
T_{TR} = Time infield travelling (actual)
T_{F} = Time folding (determined by planter width)
T_{UF} = Time unfolding (determined by planter width)
T_{SL} = Time loading seed (determined by hectares multiplied by a constant of 8.4)
T_{SD} = Time checking seed depth (constant for all fields 300 sec)

Multiple Linear Regression Methods

A multiple linear regression model using simulated speeds ranging from 6.4 – 19.3 km/h at 1.6 km/h increments was estimated to determine the influence of planting speed, planting width, and perimeter-to-area ratio on field efficiency. The regression model was estimated using the Proc GLM procedure in SAS version 9.4 (SAS Institute, 2004). Three primary variables were included in the regression model; planter width, planting speed, and perimeter-to-area ratio. Interactions between primary variables were also added to the model, consisting of planter width by planting speed, planter width by perimeter-to-area ratio, and lastly, planting speed by perimeter-to-area ratio. The interaction variables were added to the model to determine the variation created from interactions between different variables. The regression model can be expressed as follows.

Equation 3.4. Regression model

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_1 X_2 + \beta_5 X_1 X_3 + \beta_6 X_2 X_3 + \varepsilon \quad (3.4)$$

where

Y = predicted field efficiency
β_0-β_6 = estimated coefficients
X_1 = planter width (m)
X_2 = planting speed (km/h)
X_3 = perimeter-to-area ratio
ε = independent and identically distributed error term

CHAPTER FOUR
RESULTS AND DISCUSSION

Observed Data Planting Operation Variables

Planting Speed

Average observed planting speeds in km/h for individual fields were recorded in an Excel spreadsheet for all three planter widths used in the study. All speeds for three planter widths 12.2-, 18.3-, and 24.4-m were used to calculate an average, maximum, minimum, and median planting speed which are shown in Table 4.1. As can be seen, all planter widths were planting at similar speeds. Observed speeds indicated a planter width of 12.2-m had the highest planting speed of 13.9 km/h, slowest planting speed of 8.2 km/h, and highest average planting speed of 11.2 km/h. Observed planting speeds could have been selected due to planter performance at a certain speed, tractor capacity, or unrecorded field characteristics (i.e. ruts, plant residue, and topography).

Table 4.1. Average planting speed (km/h) for three planter widths

	12.2-m	**18.3-m**	**24.4-m**
Average	11.2	11.1	10.9
Maximum	13.9	13.1	12.0
Minimum	8.2	8.6	9.4
Median	11.3	11.3	10.8

Turning Speed and Turn Time

Average observed turning speeds in km/h and average turning times in seconds for individual fields were recorded in an Excel spreadsheet for all three planter widths. All speeds and turning times for planter widths of 12.2-m, 18.3-m, and 24.4-m were used to calculate an average, maximum, minimum, and median turning speed and turning time which are shown in Tables 4.2 and 4.3. Results indicated a planter width of 18.3-m had the highest turning speed of 11.1 km/h. A 12.2-m planter had the lowest turning speed of 4.5 km/h. These results could be explained by perimeter-to-area ratios with the 18.3-m width planter being used in lower perimeter-to-area ratio fields (large or regular shaped), while the 12.2-m width planter was used in the larger perimeter-to-area ratio fields (smaller or irregular shaped). Additionally, turning speeds and times could be effected by operator preference, width of planter, or unrecorded field conditions (i.e. ruts, plant residue, and topography).

Table 4.2. Average turning speed (km/h) for three planter widths

	12.2-m	**18.3-m**	**24.4-m**
Average	7.3	7.8	7.7
Maximum	9.6	11.1	9.2
Minimum	4.5	5.1	6.5
Median	7.2	7.8	7.7

Table 4.3. Average tuning time (sec) for three planter widths

	12.2-m	18.3-m	24.4m
Average	20.6	21.3	24.2
Maximum	44.9	35.9	32.6
Minimum	9.4	13.7	18.9
Median	20.6	21.4	24.0

Infield Travelling Speed

Observed infield travelling speeds in km/h for individual planted fields were recorded and entered into an Excel spreadsheet for three planter widths of 12.2-m, 18.3-m, and 24.4-m. Speeds for all planter widths were used to calculate an average, maximum, minimum, and median infield travelling speed which are shown in Table 4.4. Results showed a planter width of 24.4-m had the highest infield travelling speed of 11.9 km/h, while the 12.2- and 18.3-m both had the lowest infield travelling speed of 3.7 km/h. Infield travelling speeds could be effected by the field characteristics (i.e. ruts, plant residue, and topography).

Table 4.4. Average infield travelling speed (km/h) for three planter widths

	12.2-m	18.3-m	24.4-m
Average	10.3	9.0	9.4
Maximum	14.0	13.5	11.9
Minimum	3.7	3.7	6.3
Median	10.4	9.2	9.8

Folding/Unfolding

Based on results reported by the observed data, values for all planter widths were determined from the average time spent folding and unfolding the planter in each field. A constant time in seconds was determined for planter widths of 12.2-, 18.3-, and 24.4-m as shown in Table 4.5.

Table 4.5. Constant folding/unfolding times (sec) based on planter width

	12.2-m	**18.3-m**	**24.4-m**
Folding	90	100	110
Unfolding	90	100	110

Observed Data

Observed field efficiencies for three planter widths are shown in Figure 4.1. As can be seen, observed field efficiencies varied widely across the three planter widths. Field efficiencies varied due to planting fields that had different perimeter-to-area ratios. Observed field efficiencies for the three planter widths of 12.2-, 18.3-, and 24.4-m ranged from 36.8% to 80.0%, 38.0% to 84.1%, and 37.2% to 80.6%, respectively. It was expected that as planter width increased observed field efficiency would decrease. However, as can be seen in Figure 4.1, as planter width increased observed field efficiency did not decrease between the 12.2-m and 18.3-m planter, but did decrease between the 18.3-m and 24.4-m planter. Results concluded from this study are not similar to results reported by

Taylor et al. (2001a). These results, could be attributed to the 12.2-m wide planter only being operated in Tennessee and the 18.3- and 24.4-m wide planters only being operated in Oklahoma. The potential to operate the 12.2-m wide planter in Oklahoma could increase the observed field efficiency values to simulate the expected decrease in efficiency across the three planter widths. The same could be assumed for the 18.3-m planter, if operated in Tennessee, the observed field efficiency values would decrease to show an overall decrease in field efficiency between the three planter widths. As shown in Figure 4.2, an increase in perimeter-to-area ratio, decreased field efficiency for all planter widths. Based on an analysis of perimeter-to-area ratios, the 12.2-m wide planter was used in the entire range from small to large perimeter-to-area ratio fields in Tennessee, the 18.3-m wide planter was used in small to medium perimeter-to-area ratio fields in Oklahoma and the 24.4-m wide planter was used in small to medium perimeter-to-area ratio fields in Oklahoma. Thus, the larger planters were never operated in fields with large perimeter-to-area ratios (small or irregularly shaped fields). As perimeter-to-area ratio increased, fields become smaller and/or more irregular shaped. This could explain why the 18.3- and 24.4-m wide planters were used in the larger, more regular shaped fields of Oklahoma and not used in Tennessee due to the size of the planter. The larger number of smaller and/or irregular shaped fields in Tennessee explains the use of a smaller 12.2-m wide planter due to the ability of being able to maneuver a smaller planter more efficiently in smaller fields. These results conclude that perimeter-to-area

ratio had a major influence on observed field efficiencies. Figure 4.3 illustrates the relationship between perimeter-to-area ratio and the size of the planted area of the fields in hectares. Smaller perimeter-to-area ratios (0.005 – 0.015) are fields that were planted mainly with the 18.3- and 24.4-m wide planters. Fields that fall within the medium range of perimeter-to-area ratios (0.015 – 0.030) were planted with all three planter widths. Lastly, larger perimeter-to-area ratios (0.030 – 0.060) were planted primarily with the smaller 12.2- and 18.3-m wide planters. Operating larger planter widths in smaller perimeter-to-area ratio fields could be explained by locations of the fields in Northern and Western, Oklahoma, and due to these fields having a more regular shape. While smaller planter widths used in larger perimeter-to-area ratio fields is due to Western, Tennessee having more irregular shaped fields. Smaller planter widths are easier to maneuver and turn in smaller, irregular shaped fields where there is less area for turns to occur. A greater difference in field efficiencies could be explained by the data if the 12.2-m wide planter had been operated in the Oklahoma where fields were typically larger with smaller perimeter-to-area ratios, and contrary if the 18.3- and 24.4-m wide planters could have been operated in the smaller, larger perimeter-to-area ratio Tennessee fields.

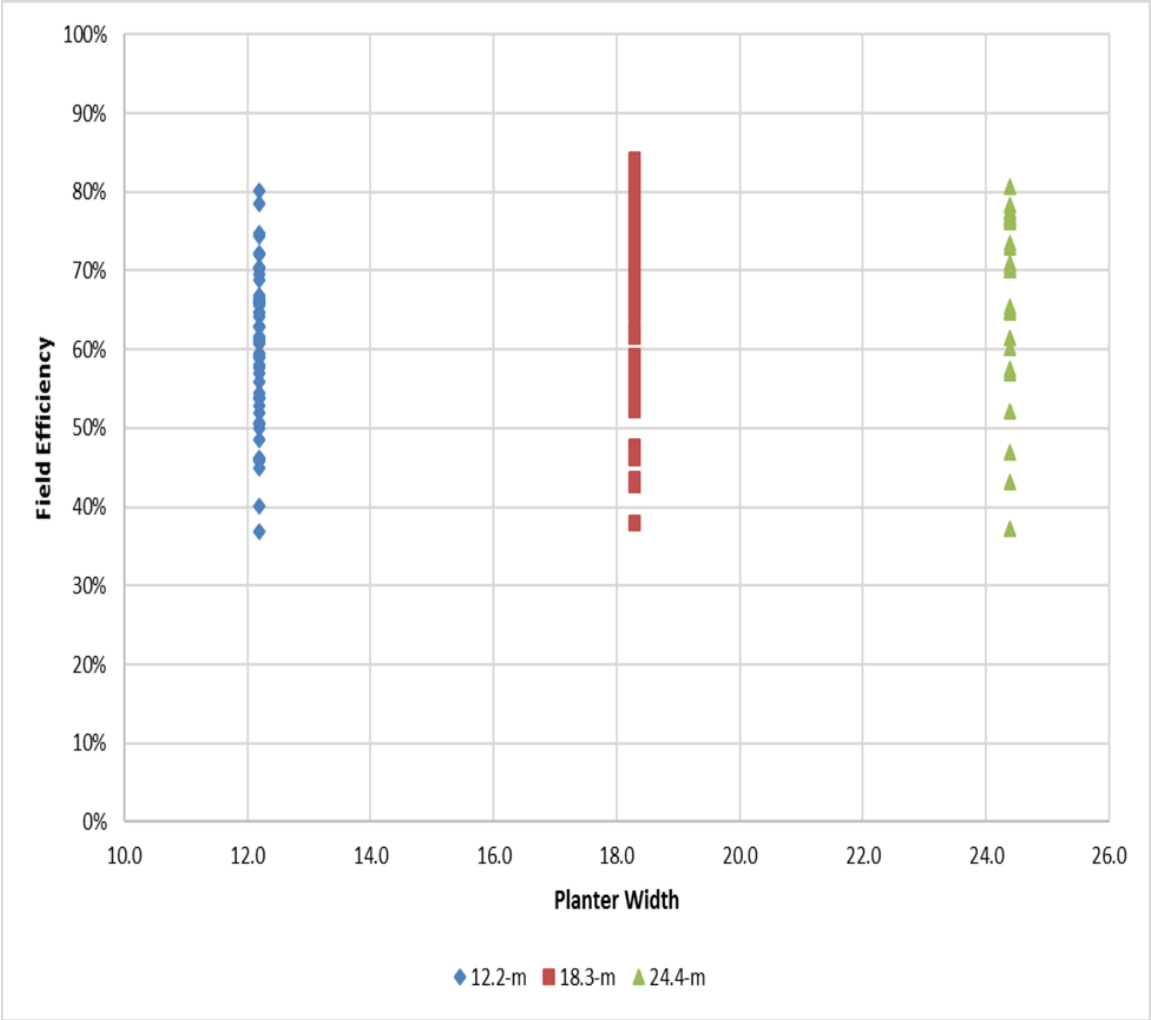


Figure 4.1. Planter width vs. observed field efficiency by planter widths

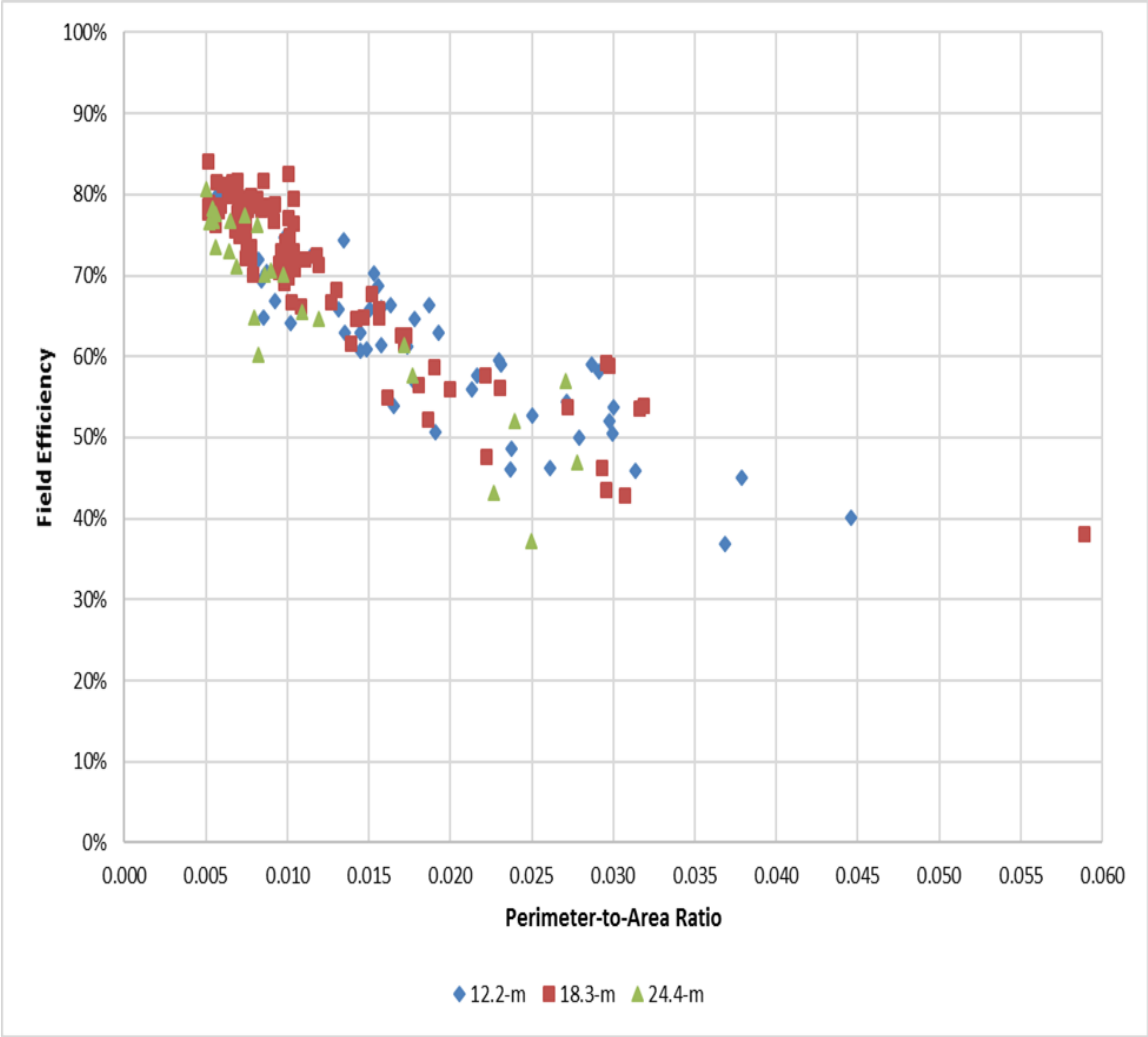


Figure 4.2. Perimeter-to-area ratio (P/A) vs observed field efficiency by planter widths

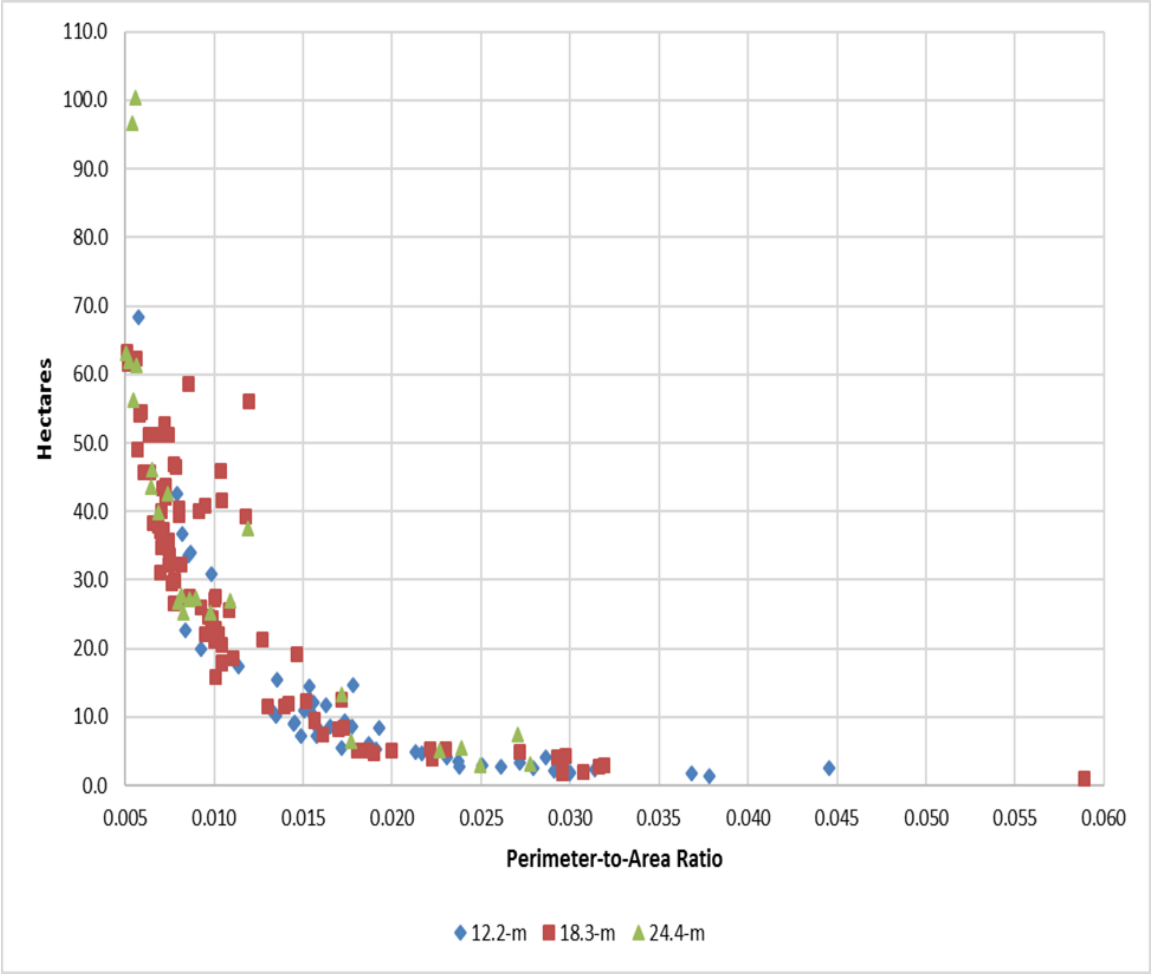


Figure 4.3. Relationship between field size and perimeter-to-area ratio

Simulated Planting Speeds

Planter widths of 12.2-, 18.3-, and 24.4-m at a constant simulated planting speed of 8.0 km/h were used to observe the influence of increasing planter widths on field efficiencies. All fields with observed perimeter-to-area ratios were used in this part of the analysis. Figure 4.4 shows that maintaining a constant planting speed of 8.0 km/h, as planter width increased from 12.2- to 24.4-m, overall field efficiency decreased. Field efficiencies for a 12.2-, 18.3, and 24.4-m wide planter ranged from 36.5 % to 83.6 %, 48.9 % to 83.0 %, and 51.5 % to 81.9 %, respectively. These results hold true for constant simulated speeds of 11.3 km/h and 16.1 km/h as shown in Figures (4.5 and 4.6). Figure 4.5 illustrates maintaining a constant simulated speed of 11.3 km/h for the three planter widths of 12.2-, 18.3-, and 24.4-m resulted in field efficiencies of 29.1 % to 78.5%, 42.3 % to 77.9 %, and 45.2 % to 76.8 %, respectively. Field efficiencies of 18.1 % to 70.7 %, 32.5 % to 70.3 %, and 35.7 % to 69.3 % for the three planter widths of 12.2-, 18.3-, and 24.4-m, respectively, were observed at a constant simulated speed of 16.1 km/h (Figure 4.6). Results indicate that as planter width increased for a constant simulated speed, field efficiencies decreased over all planter widths and effective field capacity increased. Our results are similar to those concluded by Taylor et al. (2001a).

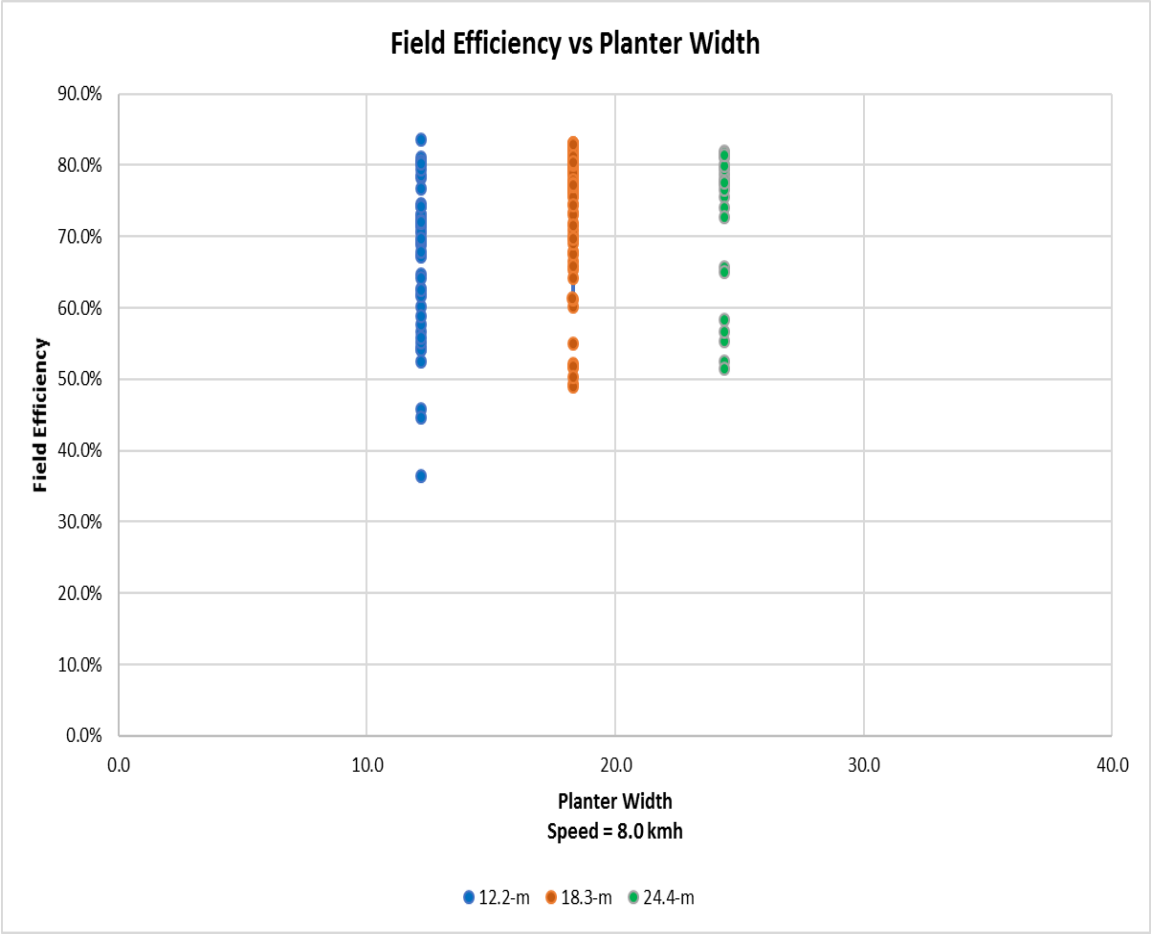


Figure 4.4. Field efficiency vs constant simulated speed of 8.0 km/h by three planter widths

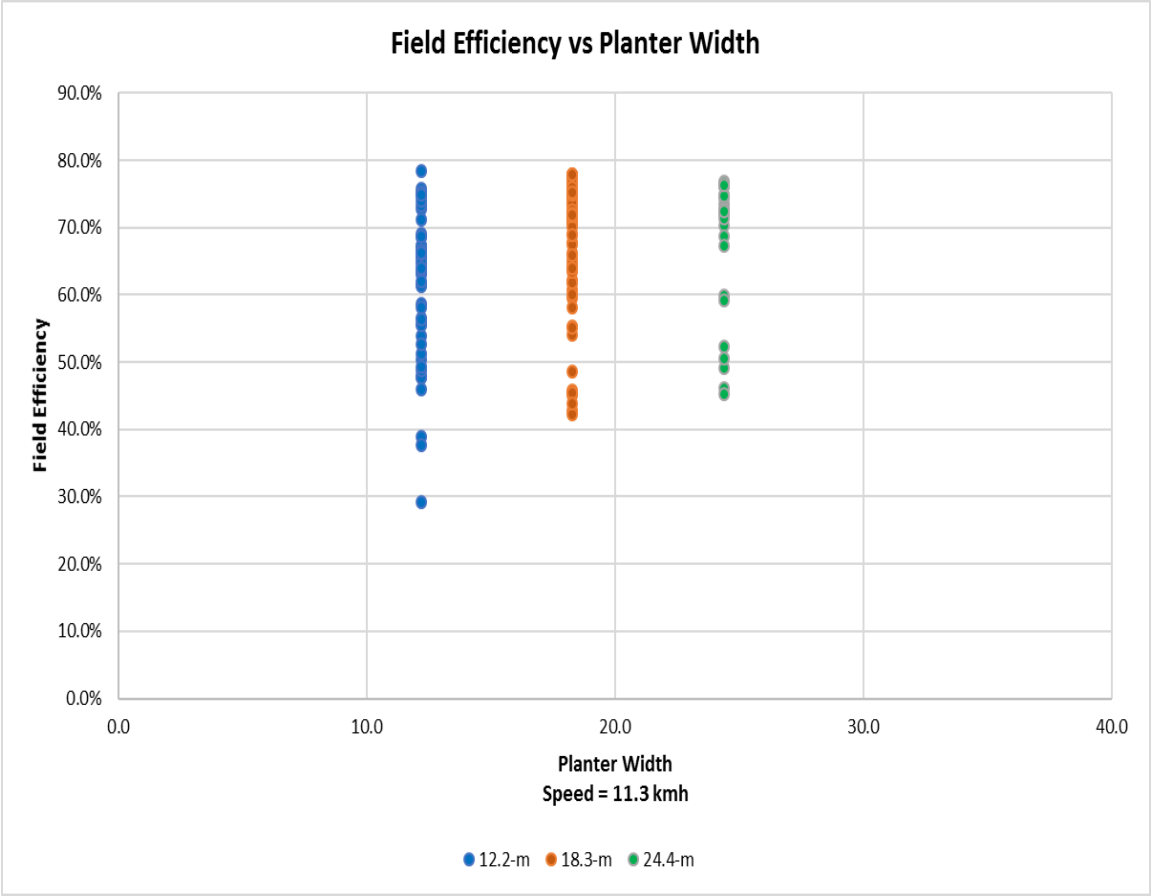


Figure 4.5. Field efficiency vs constant simulated speed of 11.3 km/h by three planter widths

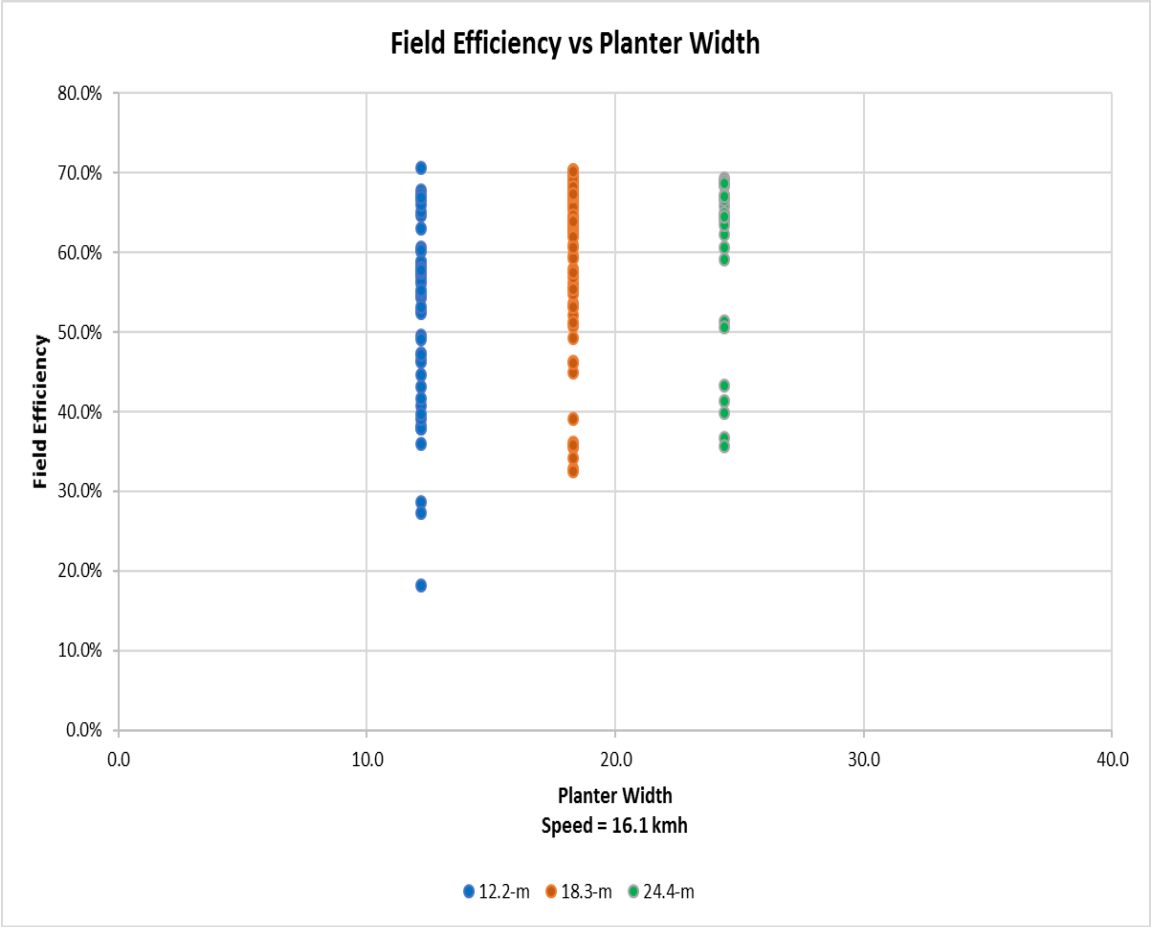


Figure 4.6. Field efficiency vs constant simulated speed of 16.1 km/h by three planter widths

Multiple Linear Regression Results

Regression analysis results are shown in Table 4.6. The developed linear regression model had an R^2 of 0.85 indicating 85% of the variation in field efficiency was described by the independent variables. The overall model had a Pr > F value (< 0.0001) which is less than our alpha level of 0.05 indicating that the variables planter width, planter speed, and perimeter-to-area ratio have an effect on overall field efficiency. Additionally, all statistically significant variables had the expected sign associated with the coefficient values (negative coefficients indicating variables decreased overall field efficiency (Table 4.6)). Analyzing primary variables individually, speed and perimeter-to-area ratio are highly significant while planter width was not. Planter width had an estimated coefficient of -0.00176 and a p-value of 0.2309. Planter width would likely be significant if all three planters had planted the same group of fields, however this would also increase the correlation between planter width and perimeter-to-area ratio. Planting speed had an estimated value of -0.01532 with a p-value of < 0.0001. Perimeter-to-area ratio had an estimated coefficient of -9.53753 and a p-value of < .0001. Due to planting speed and perimeter-to-area ratio being dependent on the previous variable, planter width is required to remain in the model even though it was not significant (p = 0.2309).

The interactions of planter width by perimeter-to-area ratio and planting speed by perimeter-to-area ratio were significant while planter width by planting speed was not significant. Planter width by perimeter-to-area ratio had an

estimated coefficient of -0.10071 and a p-value of 0.0253. Planting speed by perimeter-to-area ratio had an estimated coefficient of -0.17132 and a p-value of < 0.0001. Both interactions had P-values that were less than alpha (0.05) which indicates that they were significant to the model in decreasing overall field efficiency. Planter width by planting speed was not significant with an estimated coefficient of 0.00002 and a p-value of 0.8000. Even though planter width by planting speed was not significant and did not have the correct sign associated with the coefficient value, it was still included in the model due to the preceding interactions being dependent on the planter width by planting speed interaction variable. Therefore, based on the results concluded from the multiple linear regression model, planter width, planter speed, perimeter-to-area ratio, and interactions planter width by planting speed, planter width by perimeter-to-area ratio, and planting speed by perimeter-to-area ratio all have an effect on decreasing overall field efficiency. For example, increasing perimeter-to-area ratio by 0.01 for a 12.2-m wide planter at a simulated speed of 8.0 km/h will decrease the overall field efficiency by 12.1%. Based on results reported in Table 4.6 an estimated regression equation for determining field efficiencies can be expressed as follows.

Table 4.6. Multiple linear regression results for all simulated speed data

Description	Variables	Coefficient	Prob(p)
Intercept	β_0	1.04848	< 0.0001
Width (m)	β_1	-0.00176	0.2309
Speed (km/h)	β_2	-0.01532	< 0.0001
PA	β_3	-9.53753	< 0.0001
Width (m) * Speed (km/h)	β_4	0.00002	0.8000
Width (m) * PA	β_5	-0.10071	0.0253
Speed (km/h) * PA	β_6	-0.17132	< 0.0001
R^2		0.85	

Equation 4.1. Estimated multiple linear regression model

$$FE = 1.04848 + (-0.00176 * w) + (-0.01532 * s) + (-9.53753 * pa) + (0.00002 * w * s) + (-0.10071 * w * pa) + (-0.17132 * s * pa) \quad (4.1)$$

where

FE (Y) = Field Efficiency
w (X_1) = width of planter (m)
s (X_2) = planting speed (km/h)
pa (X_3) = perimeter-to-area ratio

Perimeter-to-Area Ratio vs Field Efficiency

Predicted field efficiency curves based on perimeter-to-area ratio at planting speeds of 8.0, 11.3, and 16.1 km/h are shown in Figures 4.7, 4.8, and 4.9 for planter widths of 12.2-, 18.3-, and 24.4-m, respectively. Planting speeds of 8.0, 11.3, and 16.1 km/h were chosen for this analysis due to planting speeds ranging between 8 – 16 km/h within the observed data. As expected, fields with smaller perimeter-to-area ratios (larger and/or less irregular-shaped) had higher predicted field efficiencies than fields with higher perimeter-to-area ratios (smaller and/or more irregular shape) for a given planting speed and planter width. For the 12.2-m wide planter (Figure 4.7), predicted field efficiencies decreased from 84.5% to 29.9%, 79.4% to 22.2%, and 71.7% to 10.8% for planting speeds of 8.0, 11.3, and 16.3 km/h, respectively. Predicted field efficiencies for the 18.3-m wide planter (Figure 4.8) decreased from 83.2% to 25.8%, 78.1% to 18.2%, and 70.5% to 6.9% for planting speeds of 8.0, 11.3, and 16.1 km/h, respectively. Predicted field efficiencies for the 24.4-m wide planter (Figure 4.9) decreased from 81.9% to 21.8%, 76.9% to 14.2%, and 69.3% to 2.9% for planting speeds of 8.0, 11.3, and 16.1 km/h, respectively. These results clearly showed that field characteristics (size and shape) have a major influence on field efficiency regardless of planter width or planting speed contrary to the results concluded by Taylor et al. (2001a) explaining that field size did not impact overall field efficiencies.

Planting Speed vs Field Efficiency

Predicted field efficiency decreased as planting speed increased for all three planter widths. As shown in Figure 4.7 for a field with a perimeter-to-area-ratio of 0.01, predicted field efficiency decreased from 78.4% to 64.9% when planting speeds increased from 8.0 to 16.1 km/h. Thus, increasing planting speed from 8.0 to 16.1 in this field resulted in a 13.5% decrease in field efficiency. As the perimeter-to-area ratio increased to 0.04, predicted field efficiency decreased from 42.0% to 24.3% when planting speeds increased from 8.0 to 16.1 km/h. Thus, increasing planting speed from 8.0 to 16.1 km/h in this field resulted in a 17.7% decrease in field efficiency. Therefore, as perimeter-to-area ratio increases, the decrease in percentage of field efficiencies increases. A similar trend was found with the other planter widths. Factors influencing these results include operator preference, field characteristics (size and shape), field conditions (ruts, plant residue, and topography), and crop type.

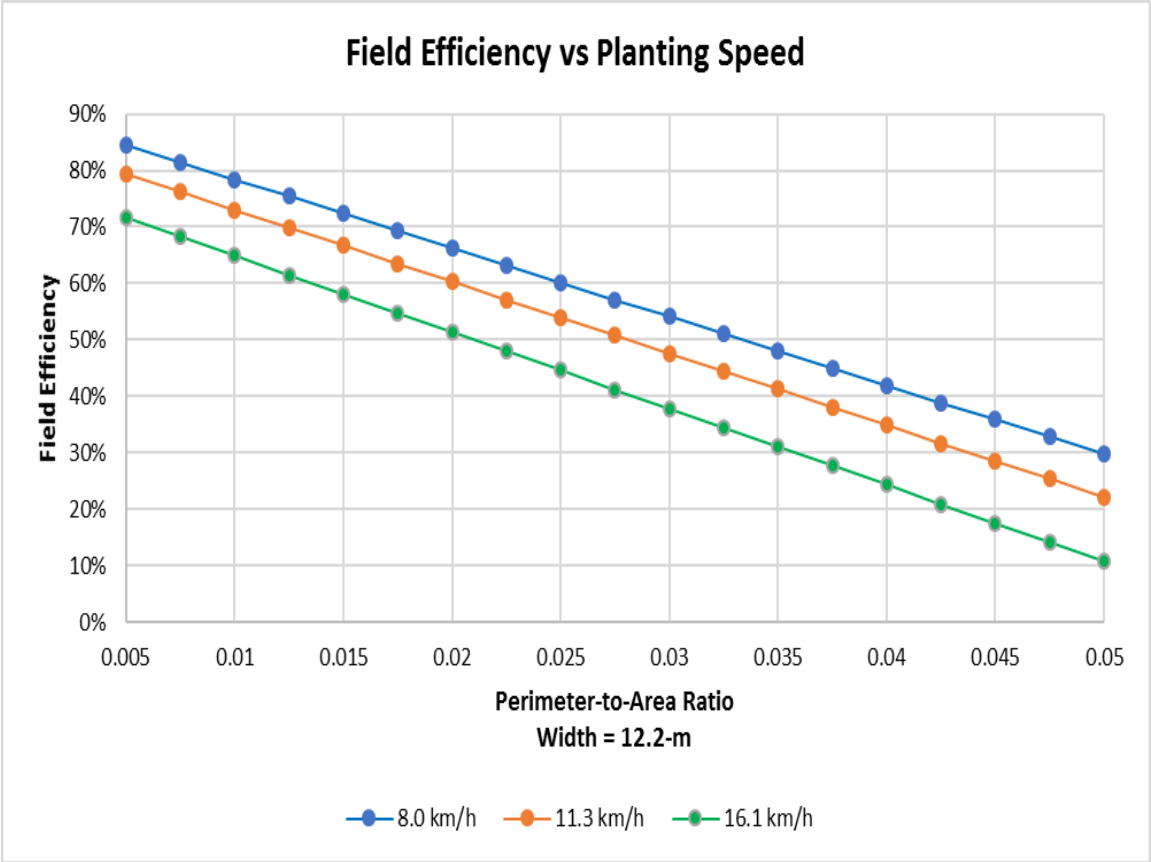


Figure 4.7. Field efficiency for three planting speeds at a planter width of 12.2-m

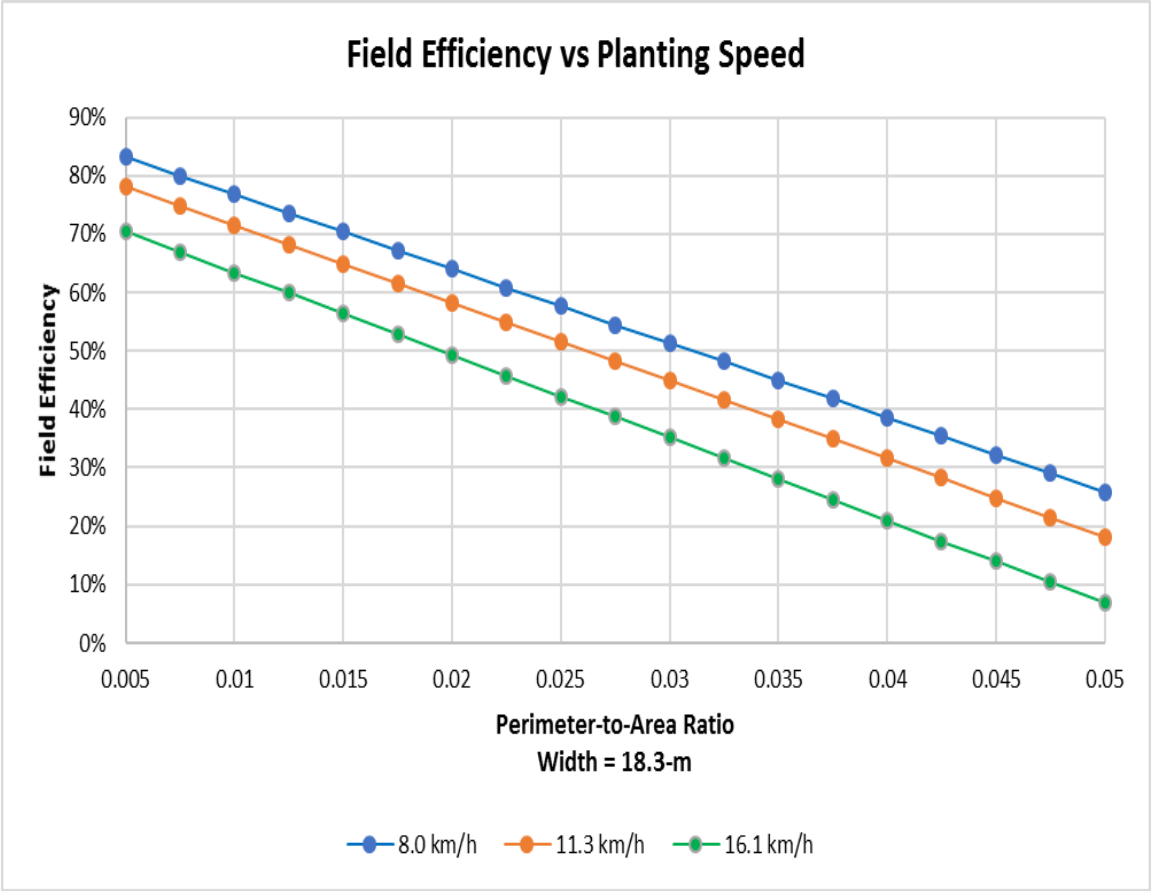


Figure 4.8. Field efficiency for three planting speeds at a planter width of 18.3-m

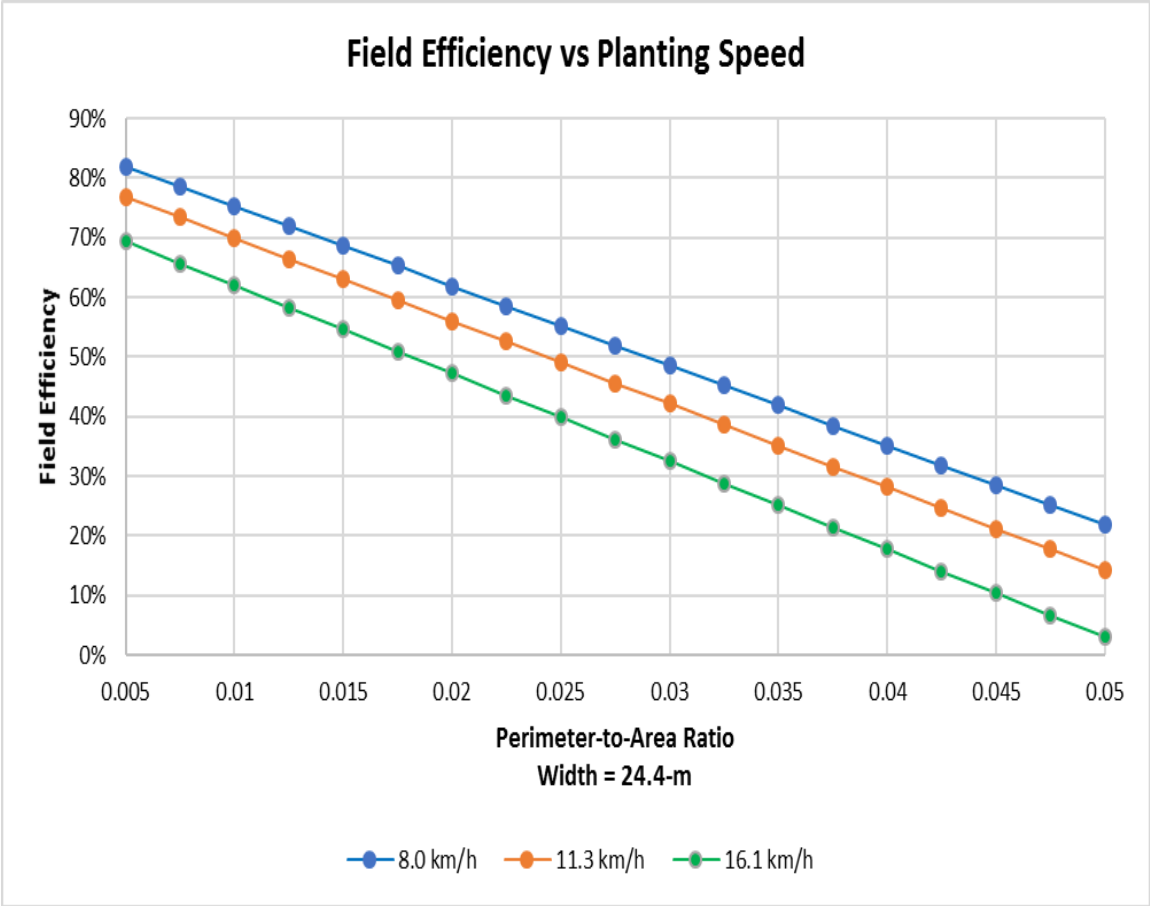


Figure 4.9. Field efficiency for three planting speeds at a planter width of 24.4-m

Planter Width vs Field Efficiency

Modelling planter width versus field efficiency resulted in a decrease in predicted field efficiency when planting speed was held constant while increasing planter width and perimeter-to-area ratio. At a planting speed of 8.0 km/h, predicted field efficiency decreased from 84.5% to 29.9%, 83.2% to 25.8%, and 81.9% to 21.8% across the perimeter-to-area ratio range from 0.005 to 0.05 for the 12.2-, 18.3-, and 24.4-m wide planters, respectively. This trend held true for planting speeds of 11.3 and 16.1 km/h for the three planter widths of 12.2-, 18.3-, and 24.4-m (Figures 4.11 and 4.12). Predicted field efficiency at a planting speed of 11.3 km/h decreased from 79.4% to 22.2%, 78.1% to 18.2%, and 76.9% to 14.2% for the 12.2-, 18.3-, and 24.4-m wide planters, respectively (Figure 4.11). At a planting speed 16.1 km/h, predicted field efficiency decreased from 71.7% to 10.8%, 70.5% to 6.8%, and 69.3% to 2.9% for the 12.2-, 18.3-, and 24.4-m wide planters, respectively. Predicted field efficiencies for the 8.0 km/h planting speed were slightly greater than the 11.3 and 16.1 km/h planting speeds, which can likely be attributed to the factors that affect planter widths such as field characteristics (size and shape) and field conditions (topography). Results concluded from the study were similar to those found by Buschermohle et al. (2016). For a constant planting speed, as perimeter-to-area ratio and planter width increased, overall field efficiency decreased.

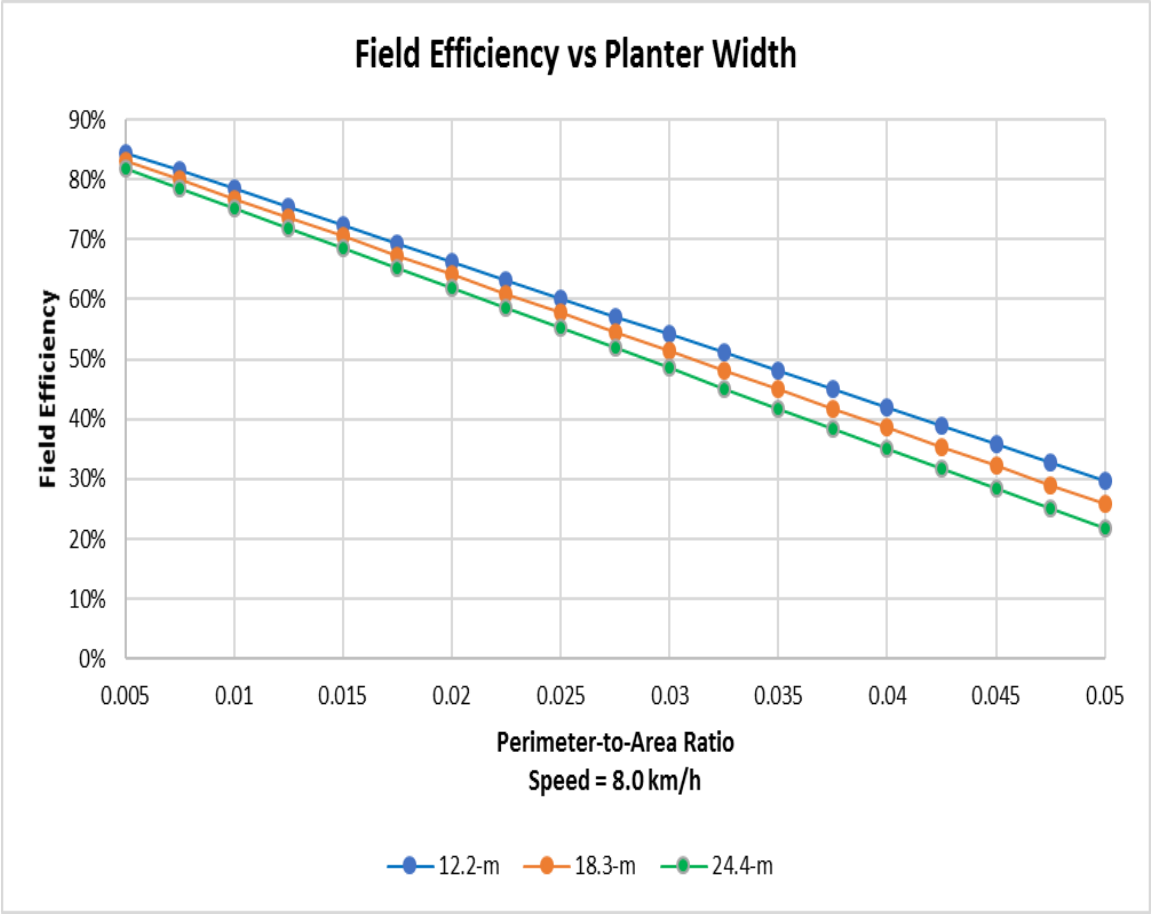


Figure 4.10. Field efficiency for three planter widths at a planting speed of 8.0 km/h

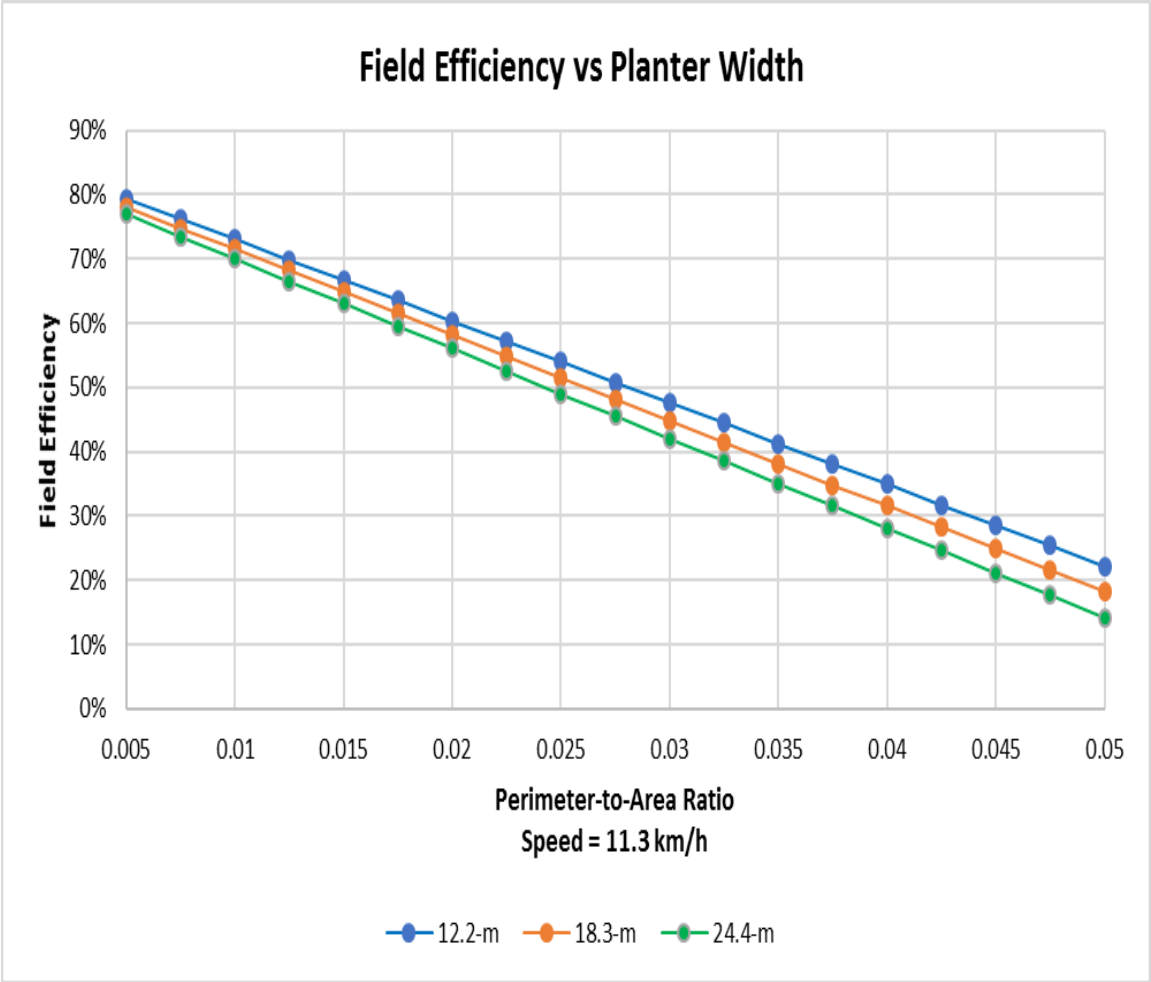


Figure 4.11. Field efficiency for three planter widths at a planting speed of 11.3 km/h

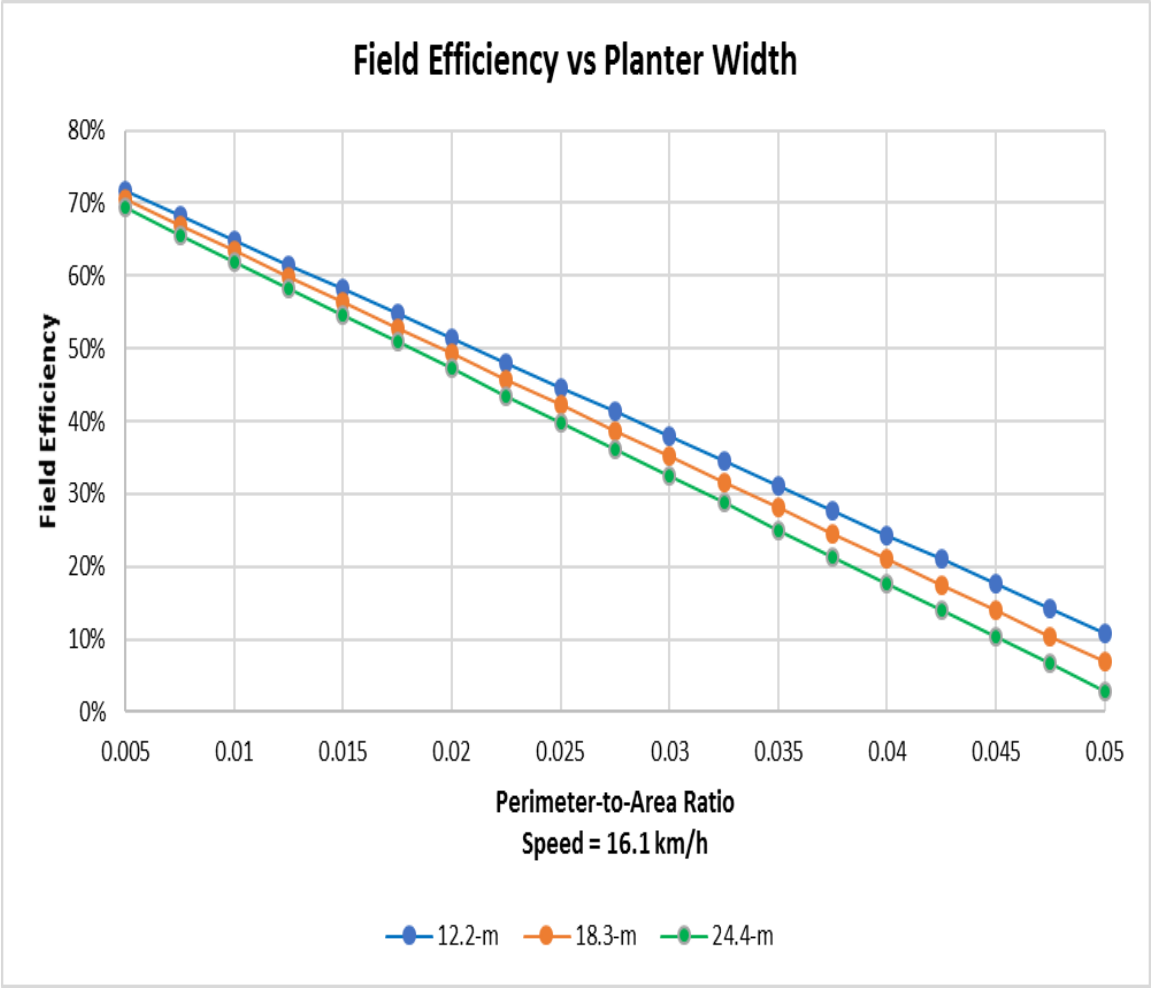


Figure 4.12. Field efficiency for three planter widths at a planting speed of 16.1 km/h

Effective Field Capacity vs Planting Speed

A producer's main concern from the perspective of field capacity and efficiency should be to operate at the highest possible effective field capacity while maintaining the highest efficiency possible. One way to increase effective field capacity is to increase speed while planting. To illustrate this point, planting speeds of 8.0, 9.7, 11.3, 12.9, 14.5, and 16.1 km/h were used for a 12.2-m wide high-speed planter and 8.0 km/h was used for an 18.3-m wide conventional planter to produce field capacity curves shown in Figure 4.13. Perimeter-to-area ratios ranged from 0.005 to 0.05 for the increasing planting speeds. Effective field capacity for the high-speed, 12.2-m wide planter at 8.0 km/h ranged from 2.9 ha/h to 8.3 ha/h. Increasing the simulated planting speed to 12.9 km/h resulted in an effective field capacity range of 2.9 ha/h to 12.1 ha/h. Effective field capacity for the conventional 18.3-m wide planter at 8.0 km/h ranged from 3.8 ha/h to 12.3 ha/h. Based on these results, a 12.2-m wide high-speed planter planting at 13.0. km/h can achieve approximately the same effective field capacity as an 18.3-m wide conventional planter planting at 8.0 km/h. However, if speed cannot be increased due to factors associated with field characteristics and planting conditions the producer should consider utilizing a wider 18.3-m planter and remain at a planting speed of 8.0 km/h for the desired effective field capacity.

A similar trend was observed when analyzing a high-speed 18.3-m wide planter compared to a conventional 24.4-m wide planter (Figure 4.14). Effective field capacity for a high-speed 18.3-m wide planter at 8.0 km/h ranged from 3.8

ha/h to 12.3 ha/h. Increasing the simulated planting speed to 11.3 km/h resulted in effective field capacities ranging from 3.8 ha/h to 16.1 ha/h. Effective field capacity for the conventional 24.4-m wide planter at 8.0 km/h ranged from 4.3 ha/h to 16.1 ha/h. Based on these results, an 18.3-m wide high-speed planter operated at 11.3 km/h will achieve approximately the same effective field capacity as 24.4-m wide conventional planter operating at 8.0 km/h. Based on these results, field characteristics, such as field size and shape, planter width, and planting speed are factors that must be considered when making planter purchasing decisions.

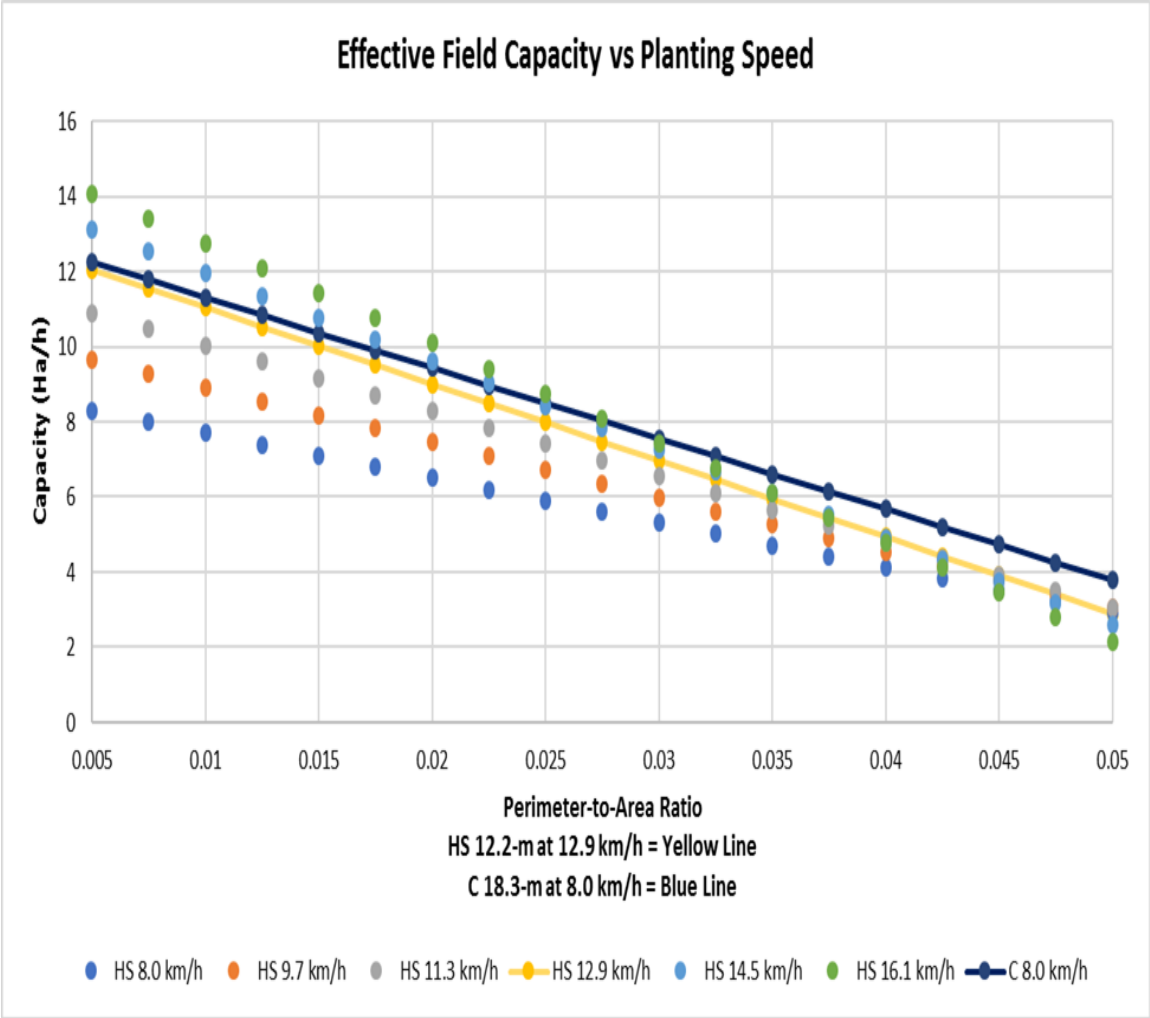


Figure 4.13. Effective field capacity for high speed 12.2-m wide planter vs conventional 18.3-m wide planter with increasing simulated speeds

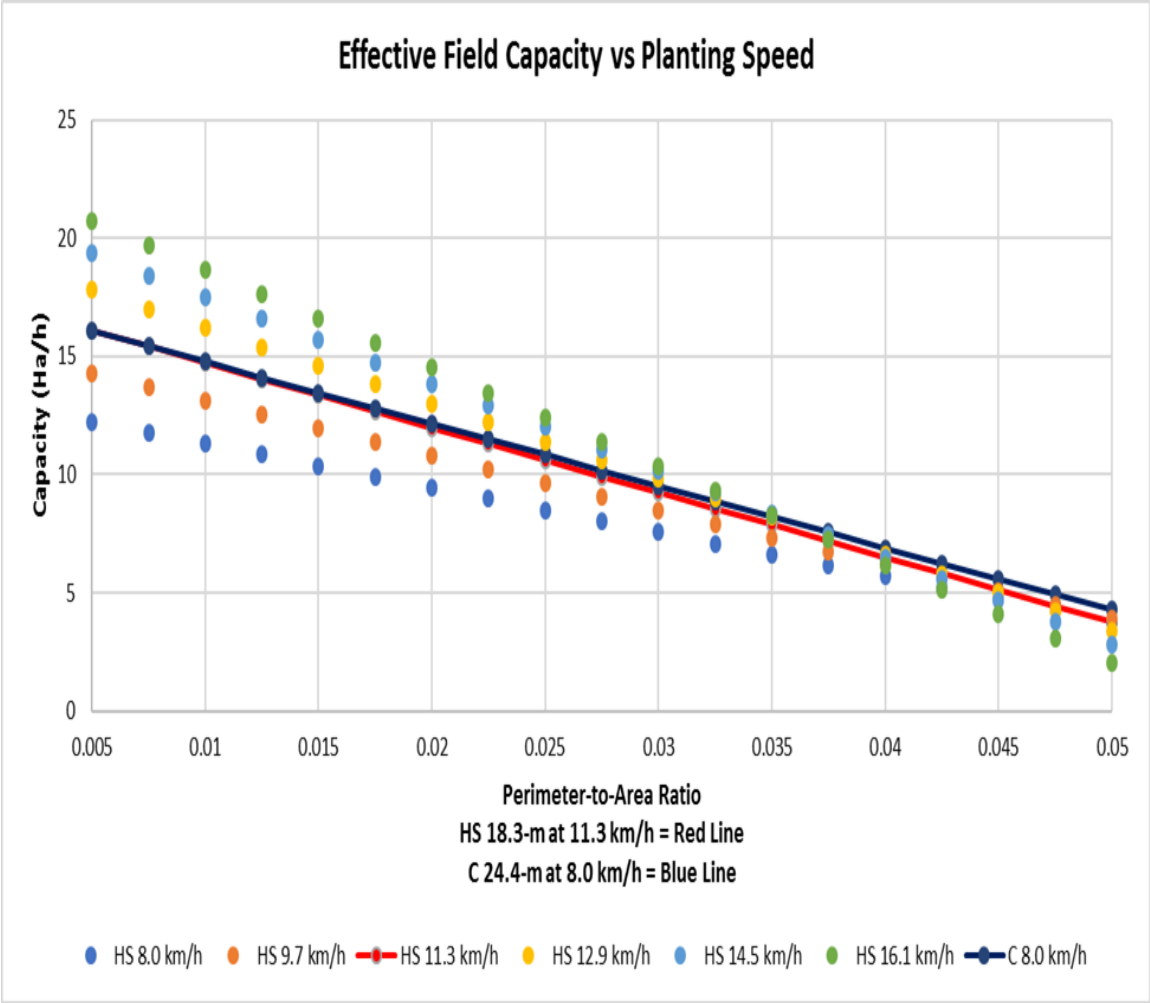


Figure 4.14. Effective field capacity for high speed 18.3-m wide planter vs conventional 24.4-m wide planter with increasing simulated speeds

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

Results from this study showed that evaluating field efficiencies based on various planter widths and planting speeds can be a useful tool in aiding producers in evaluating their farming operation in regards to machinery size selection and efficiency needs. These data can assist producers in becoming more efficient and provide information on what they can incorporate into their farming operation to improve their overall field efficiency and effective field capacity.

Multiple linear regression results indicate that planter width, planting speed, perimeter-to-area ratio, and interactions planter width by planting speed, planter width by perimeter-to-area ratio, and planting speed by perimeter-to-area ratio all influenced overall field efficiency. Results indicated that the primary variable perimeter-to-area ratio and interactions planter width by perimeter-to-area ratio and planting speed by perimeter-to-area ratio had the greatest effect on overall field efficiency. Perimeter-to-area ratio had an effect on the width of the planter and the planting speed that a producer/operator used while planting.

Increasing simulated planting speed and perimeter-to-area ratio while maintaining planter width constant decreased overall field efficiency. Increasing planter width and perimeter-to-area ratio while maintaining planting speed constant decreased overall field efficiency. Increasing planting speed by almost 5 km/h for a 12.2-m wide high-speed planter resulted in approximately the same

effective field capacity as a conventional 18.3-m wide planter operated at 8.0 km/h. Increasing planting speed by at least 3.3. km/h for an 18.3-m wide high-speed planter resulted in approximately the same effective field capacity as a conventional 24.4-m wide planter operated at 8.0 km/h.

Producers should examine their farming operation as a whole before making machinery purchases. It may be more beneficial to plant with a narrower high-speed planter or with a wider conventional planter, or a combination of the two depending on individual circumstance. Field characteristics and field conditions where the planter will be operated and the economic value associated with the producers farming operation play a major role in deciding whether planting faster or planting wider is a better choice for the producer's farming operation. A model for field efficiency has been determined such that field efficiency is a function of planter width, planting speed, perimeter-to-area ratio, and the interactions planter width by planting speed, planter width by perimeter-to-area ratio, and lastly planting speed by perimeter-to-area ratio all have an influence on overall field efficiency.

CHAPTER SIX
FUTURE RESEARCH

Examining theoretical field capacity with three main variables; planter width, planting speed and perimeter-to-area ratio and interactions planter width by planting speed, planter width by perimeter-to-area ratio, and planting speed by perimeter-to-area ratio have proven to be a feasible way to calculate field efficiencies. Results concluded from this study can be used not only for calculating field efficiencies, but also for making machinery purchase decisions. For example, which planter style (narrower high-speed planter, wider conventional planter, or combination of both planters) would peak field efficiencies, achieve the greatest possible field capacity (ha/hr), and remain within the farming operations budget.

Future research should be focused on determining how to use planter width, planting speed, and perimeter-to-area ratio to optimize machinery purchase decisions. Furthermore, including a risk analysis for regional planting windows due to weather may be necessary for making more holistic machinery purchase decisions.

Planting operations including; time planting, time turning, time infield travelling, time folding/unfolding, time loading seed and time checking seed depth proved to be a viable way to calculate observed field capacities. Future research should include investigating larger fixed times associated with the planting operation checking seed depth as planter width increases. Additionally, a

sensitivity analysis for planting operations with a fixed time as it relates to planter width should be performed to determine impacts on field efficiency results.

LIST OF REFERENCES

ASABE Standards. (2011). D497.7: Agricultural Machinery Management Data. St. Joseph, MI: ASABE.

ASABE Standards. (2006). EP496.3: Agricultural Machinery Management. St. Joseph, MI: ASABE.

ASABE Standards. (2005). S495.1: Uniform Technology for Agricultural Machinery Management. St. Joseph, MI: ASABE.

Buschermohle, M. J., A. Smith, C. Boyer, and R. G. Bowling. 2016. Influence of Planter Width, Planting Speed and Seed Loading Methods on Planting Efficiency for Cotton Production. Proceedings 2016 2016 Beltwide Cotton Conference, National Cotton Council of America., New Orleans, LA. Jan 5-7.

ESRI. (2016). ArcGIS Desktop: GIS. Ver. 9.4. Redlands, CA: ESRI Headquarters.

Grisso, R. D., Jasa, P. J., Rolofson, D. (2000). Field efficiency determination from spatial data. ASABE Paper No. 001013. St. Joseph, MI: ASABE.

Hannah, M. (2016). Estimating the Field Capacity of Farm Machines. Ag Decision Maker Information Files. Paper 8. http://lib.dr.iastate.edu/pubs_agdm/8

John Deere. (2015). Planting Equipment Drawn and integral planters, ExactEmerge, MaxEmerge 5e, and MaxEmerge 5 row units. Online product brochure. 12-15. Moline, IL.

Renoll, E. S. (1970). A Method for Predicting Field-Machinery Efficiency and Capacity. *Transactions of the ASAE*, pp. 448-449.

Renoll, E. S. (1969). Row-crop Machinery Capacity as Influenced by Field Conditions. Bulletin 395. Auburn University Agricultural Experiment Station, Auburn, AL.

Renoll, E.S. (1979). Using farm machinery effectively. Bulletin 510. Auburn University Agricultural Experiment Station, Auburn, AL.

Taylor, R. K., Schrock, M. D., Staggenborg, S. A. (2001a). Using GPS Technology to Assist Machinery Management Decisions. ASABE Paper No. MC01-204. St. Joseph, MI: ASABE.

Taylor, R. K., Dhuyvetter, K. C., Kastens, T. L., Staggenborg, S. A. (2001b). Using GPS Technology to Evaluate Corn Planter Performance. ASABE Paper No. 01-1030. St. Joseph, MI: ASABE.

SAS. (2004). SAS: Statistics. Ver. 9.4. Cary, NC: SAS Institute, Inc.

Staggenborg, S. A., Fjell, D. L., Devlin, D. L., Gordon, W. B., Maddux, L. D., Marsh, B. H., (1999). Selecting Optimum Planting Dates and Plant Population for Dryland Corn in Kansas: Journal of Production Agriculture, 12(1), 85-90.

Swanson, S. P., Wilhelm, W. W. (1996). Planting Date and Residue Rate Effects on Growth, Partitioning, and Yield of Corn: Agronomy Journal, 88(2), 205-210.

Salmerón, M., Gbur, E. E., Bourland, F. M., Buehring, N. W., Earnest, L., Fritschi, F. B., . . . Purcell, L. C. (2016). Yield Response to Planting Date Among Soybean Maturity Groups for Irrigated Production in the US Midsouth, Crop Science, 56(2), 747-759.

VITA

Colburn James Condra was born on December 5, 1991 in Nashville, TN to parents Steve and Laurie Condra of Lebanon, TN. He attended Tuckers Crossroads Elementary School and then Lebanon High School. Cole was very active in athletics and enjoyed the outdoors. Upon graduation from high school, he chose to pursue an Agricultural Engineering Technology degree from Tennessee Technological University in Cookeville, TN. In July 2015, Cole accepted a graduate teaching/research assistantship at the University of Tennessee in Knoxville, and began the master's program in Biosystems Engineering and Soil Science with a concentration in Biosystems Engineering Technology focusing on precision agriculture technologies.