Machine systems to enhance agronomic response in seeding technologies

by

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Abstract

The importance of proper planting and crop establishment cannot be underestimated, as they directly affect crop yield, quality, and overall agricultural productivity. Growers have varying field conditions and adopt different planting strategies, and each requires a unique approach to achieve desired agronomic responses. Hence, proper selection and adoption from existing precision planting technologies suited for their conditions is essential to optimize crop input resources and enhance crop yields.

This research examined two essential aspects of precision planting systems and its application into two different growers' situation. The first study involved assessing the effectiveness of row cleaners within air-seeders in high-residue environments, and, second study analyzes the performance of high-speed planting on no-till fields. A novel methodology based on a computer vision system was developed to objectively evaluate the effectiveness of row cleaners installed on single-disc air seeders in creating optimal seed furrow conditions for improving seed placement. Through the implementation of a tailor-made data acquisition system and the operation of an air seeder across different wheat residue conditions, the study demonstrated the feasibility of quantifying row cleaner operation in real time, exposing the possibility of assessing the performance of varying row cleaner models for air seeders on an unbiased and repeatable way, and also paving the way for automating control decisions during seeding processes. High-speed planting experiment involved comparing the performance of two precision planting systems on corn, evaluating various parameters, including planting accuracy, frame flexibility, overall productivity, downforce control, and section control.

Findings revealed subtle differences between the two planting systems on productivity and planting quality. Still, there are notable differences on flexibility depending on the frame of each planter utilized as well as a slight difference in plant spacing.

Overall, these studies contribute to advancing agricultural technology by providing objective methodologies for assessing and improving seeding and planting practices, ultimately enhancing efficiency and productivity in modern farming operations. The learning also set a baseline for future research on air seeder row cleaners and for upcoming research on row crop planter performance.

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Acknowledgements

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Chapter 1 - Introduction

World population is constantly growing, and in such a situation the food production chain faces the challenge of providing healthy and sustainable food to every human being on the Earth. Besides this, food production has increasing costs. Sustainability is a key factor to enhance food production while reducing costs to the minimum whenever this is possible. This means that the food production system needs to be as efficient as possible, starting with this in every farm. The main focus of the research presented in this thesis aims to help farmers to be more efficient on row crop production systems by enhancing seeding equipment performance and providing tools and resources to be used by farmers to make better decisions while planting crops.

Planting and seeding are the very first tasks that occur in a field every season, and it's the kickoff for the food production system. We all rely on that system to feed a growing population, on a healthy and sustainable way. This means that efficiency and sustainability need to be taking into account from the very first moment. Lots of variables are already fine-tuned to achieve this goal, but other variables are not that much. Precision agriculture technologies play a key role when it comes to efficiency and sustainability enabling producers to save inputs and maximize outputs.

The studies conducted by our team, and presented in this thesis, are covering both efficiency and sustainability on row-crop production systems while planting. Part of this thesis will focus on enhancing seeding quality for small grains using air-seeders while another part will focus on high-speed planter productivity, understanding productivity as overall planter performances without decreasing planting quality. Firstly, a novel methodology for assessing row cleaner performance on air seeders using computer vision will be proposed: row cleaners create an adequate seedbed for crops and boost their early-stage growth. Secondly, high-speed planter performance analysis is conducted in order to provide input on planter selection for each field and planting condition, seeking to conduct planting tasks in a shorter amount of time, but without loosing planting quality across varying field conditions.

Nowadays, row cleaners on small grain seeding equipment are not a common practice, and several gaps can be found on this technologies. The scope of this thesis is not to compare the performance of different aftermarket products, but to develop an objective and repeatable way of quantifying their operation on no-till conditions. On the other hand, high-speed planting solutions are widely spread across the USA, but most of the time the producers pick a planter led by their loyalty to a brand or because an agricultural equipment company offers a better deal. Both are valid reasons, but this thesis will provide robust information on each planting solution so farmers can have another resource to understand which piece equipment fits best their needs.

Both topics are of great interest for farmers, industry, community and academia. Farmers will be benefited since they will be able to enhance production while reducing inputs (including time they need to use to run equipment), industry can learn about their own products and how they are performing on the field and check if they are able to cover the customer's needs, community will benefit from this since if production increases, prices eventually decrease and also they will be able to get food produced on a more sustainable way, and lastly, academia can set new baselines and topics for conducting further research and develop new agricultural systems.

Overall, this thesis will cover a gap in knowledge in term of row-cleaners for air-seeders and a gap in knowledge in term of high-speed planters performance analysis. Therefore, this research was conducted with two main objectives: 1) develop an objective and repeatable methodology for assessing and quantifying row-cleaner operation within air-seeders using computer vision and 2) analyze and describe the performance of two high-speed planting solutions from two competitive brands under varying real-life field conditions.

Chapter 2 - Quantifying row cleaner operation within air-seeders using computer vision

Introduction

Nowadays, agriculture is getting more competitive than ever, with rising input costs and with crop prices thar are not increasing as much as them. This situation means that producers have to be more efficient and go over details that could be set aside a few years ago. In order to achieve this efficiency goal, many growers are pushed to farm more acres within the same timeline. More acres to plant in the same window of time and higher costs force growers to find technological solutions for their farming operations to be more effective and efficient.

In many situations, in order to farm a larger amount of acres within the same time frame, operators are forced to increase working speeds of the equipment. This can result in poor planting quality, density loss and, potentially, yield and economical loss (Tóth et al., 2021). To avoid reaching this situation, equipment manufacturers provide different accessories for machinery systems to improve efficiency, enhance productivity and increase yields. Unfortunately, most of the times, those promises are not sustained by real numbers or objective and trustworthy data or information.

As part of facing this productivity challenge, producers that utilize single-disc air-seeders to drill crops like wheat, canola and soybeans are increasing their operating speed even if farming on no-till ground. A very common issue while conducting seeding operations is hair-pinning (Fig. 1): this is the name given to the situation where the opening disc introduces residue into the seed trench, generating air-pockets around the seed that reduce seed-to-soil contact. Getting poor seed-to-soil contact reduces the amount of nutrients and moisture that the seed can absorb to emerge, so seedlings are weaker and some seeds won't be able to germinate (Blunk et al., 2021). As part of targeting that problem, some manufacturers started to offer different kinds of row-cleaners. These devices are aimed to remove the residue from the surface in order to leave a clean and even trench for the opening disc to put the seed, but at the same time, removing residue from the trench should not affect depth by getting in the way of gauge wheels. At this point, it must be pointed out that gauge wheels are responsible for setting seeding depth as well as depth uniformity, so if there is residue on their path, they will run on an uneven surface and won't provide uniform depth. Another benefit of row cleaners is that, as they remove residue from the trench, seedling will get better and faster emergence (Li et al., 2015) as they do not have to struggle to grow through the residue as well as they'll get more sunlight and higher temperatures (Al-Mulla et al., 2013).

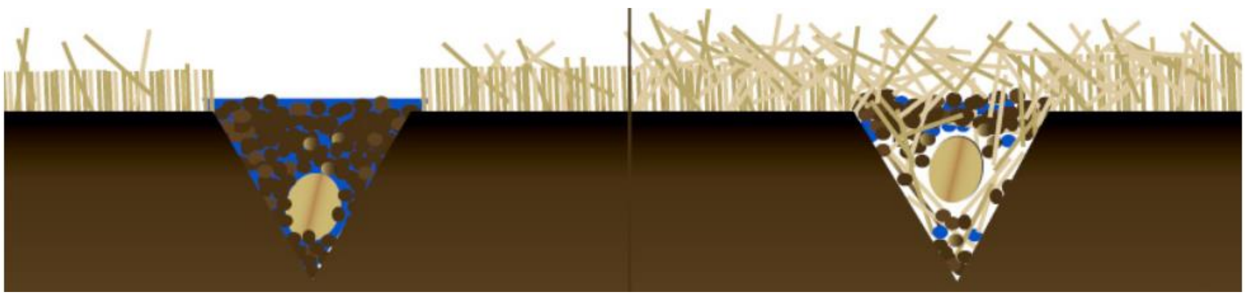

Figure 2.1. Hair-pinning: left hand side image shows ideal situation while left hand side image shows hair-pinning situation

Besides having a wide offer of these aftermarket parts, none of them provide un-biased and objective information to potential buyers of their products so they can make the right call. Most of the times, to evaluate the performance of several of these parts visual evaluations are conducted as well as yield assessments that many times do not have a statistical analysis. Therefore, the purpose if this study is 1) to develop a methodology to quantify row cleaner operation within air-seeders on an un-biased, objective, simple and repeatable manner and 2) set the baseline for future research towards automating row cleaner settings in real time. For achieving the goals of this study, computer vision will be employed.

Methodology

Air-Seeder setup

An air seeder (N500C, Deere and Company, Moline, IL, USA) with 48 single-disc row units spaced at 7.5 inches apart hooked to a MFWD tractor (8R310, Deere and Company, Moline, IL, USA) (Fig. 2) was used for this experiment. It was equipped with electric seed meters and a Central Commodity System (CCS). Four different aftermarket row cleaners (Wheel Residue Manager, Aricks, Corowa, New South Wales, Australia; 2966-004 Air Adjust, Yetter, Colchester, IL, USA; Prototype A, Manufacturer not to be disclosed, Somewhere; Prototype B, Manufacturer not to be disclosed) were installed wherein three of them were automatically controlled by pneumatic downforce system and one was manually adjusted. The system utilized to manage the row cleaner's settings is of importance in order to get an even and clean trench: if downforce pressure on the row cleaner is too high it might remove soil, while if downforce is not enough the row cleaner won't be able to remove residue as expected. If settings are manual or mechanical the operator will have to go through a more tedious process to set it the correct way and might not achieve the expected result since manual regulations are limited. Must also take into account that pneumatic systems can be set inside the tractor's cab while manual/mechanical setting need to be done outside the cab and the air-seeder cannot be moving. Another advantage of pneumatic controlled row cleaners is that they usually have a wider travel so it is hard for them to lose contact with the soil, but manual/mechanically controlled row cleaners have a more limited travel what leads them to lose ground contact while running over terraces.

Figure 2.2. John Deere 8R310 Tractor and John Deere N500C air-seeder

A Basler color camera (acA720-290gc, Basler AG, Ahrensburg, Germany) paired to a ruggedized 12.5 mm fixed focal lens (LM12HC-V, Kowa, Nagoya, Japan) (Fig. 3) was mounted on the air seeder's frame using a 3D printed mount, designed using CAD models, that fitted the frame using generic U-bolts, at a height of 60 centimeters (Figure 4). Closing wheel, opening disc, seed boot and firming wheel were removed from each row unit where the row cleaner was installed. This provides a better view of our Area if Interest (AOI) which is the trench created by the row cleaning device. Gauge wheel is in charge of maintaining the chosen seeding depth, for that reason it was left in place to avoid any damage to the row unit caused by touching the ground and to analyze if residue was moved towards the path of the gauge wheel by the row cleaner, what can affect seeding depth. No seed was utilized since emergence, depth or yield is not within the scope of this study.

Figure 2.3. Basler acA 720-290gc HD camera and Kowa LM12HC-V ruggedized lens

Figure 2.4. Camera inside the 3D-printed mount, fitted to the air-seeder's frame

Data Acquisition System

A data acquisition system, which components were packaged in a hard case (Fig. 5), was installed on the air seeder in order to get the necessary data to train a computer vision model after running the equipment on a field. This device was developed comprising NI cDAQ 9174; NI c-series module NI-9203; and fanless pc (LEC-2580P-711A, Lanner Electronis, Mississauga, ON, Canada) to capture data from a camera.

This color camera (acA720-290gc, Basler, Ahrensburg, Germany) with a rugged lens (LM12HC-V, Kowa, Nagoya, Japan)) providing a 720x290 pixel resolution, 40 frames per second (fps) and gigabit ethernet connectivity (GigE) was connected to the data acquisition system using a 10 m GigE cable (2000028341, Basler AG, Ahrensburg, Germany).

The fanless PC (LEC-2580P-711A, Lanner Electronics, Mississauga, ON, Canada) had an Intel® Core™ i7-6600U CPU, 2x RJ45 & 4x PoE high-performance IPC with Intel® 6th Gen Skylake Core™ i7 CPU and overall memory of 16 GB. The software was written in the National Instruments LabVIEW platform. The data acquisition system was controlled on a real-time basis from the cab of the tractor with a laptop computer (Latitude 5430, Dell, Round Rock, TX, USA) that was connected to the data acquisition system using the previously mentioned ethernet cable (Fig. 6). A proper mount was developed to fit the data acquisition box on the air seeder frame (Fig. 7).

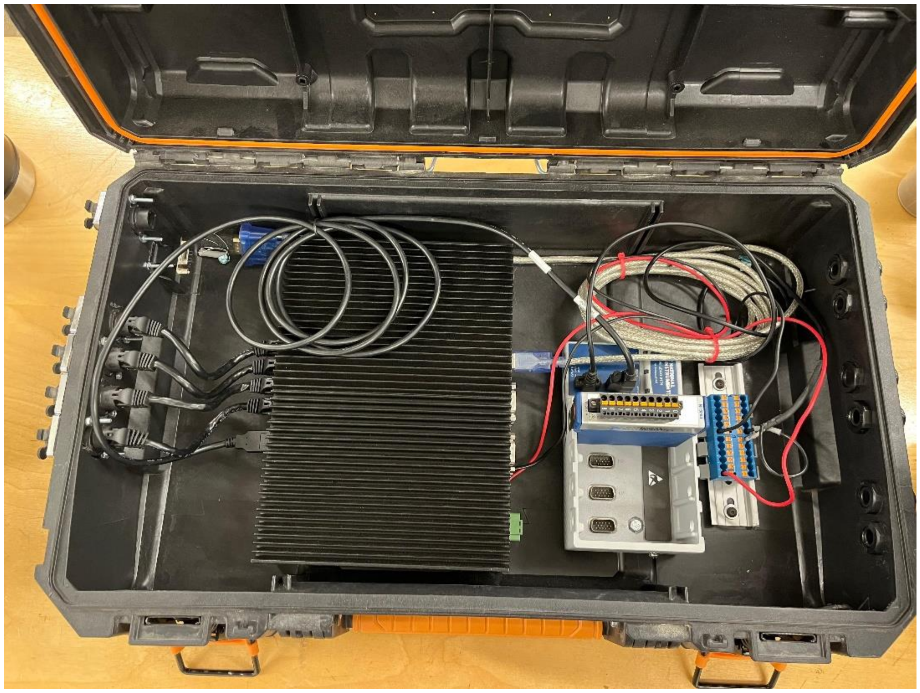

Figure 2.5. Data Acquisition Box, containing the Data Acquisition System

Figure 2.6. Dell Latitude laptop computer with tailored software in the tractor cab

Figure 2.7. DAQ box sitting on the tailor-made mount fitted on the air-seeder

Field description

The field where test runs were performed is located in Clay County, Kansas (39°17'25.1"N 96°58'37.2"W). The field utilized no-till management with different amounts of residue along the field from a previous wheat crop. The soil type found predominantly in the field was Crete Silt Loam according to the USDA Web Soil Survey (USDA-NRCS). Three different zones were defined according to the amount of residue: high, medium and low. This was done as a way of evaluating the proposed computer vision system under different residue conditions. In order to define these three zones, residue was collected from different 1-square foot spots, dried using an air-forced oven before weighing to determine the amount of residue expressed as kilograms per hectare. The weight was used to label each zone while the criteria was classifying the lightest 3 samples as “Low Residue”, the heavier 3 samples as “High Residue” and the 3 samples in between each other as “Medium Residue”. Before setting the residue sampling locations, a visual assessment was conducted in order to determine 3 different residue zones.

Data processing and analysis

Even though the objective of this study was not to generate a model to evaluate how each row cleaner works, data was analyzed using different computer vision models and algorithms. In order to do that, a set of images acquired during the experiment were selected and labeled using segmentation and augmentation techniques. We won’t go deeper into this topic since it is not the aim of this thesis and this data process and analysis was just conducted to check if the computer vision system worked correctly and if data acquired while running equipment was good for calibrating and running computer vision model that would enable further analysis on row cleaner performance.

Results and discussion

Row cleaner performance on air seeders assessment is not easy, with changing field and residue conditions the result and outcome can be completely different, and many times the person who evaluates the performance can be biased and provide feedback that is not necessarily accurate or that does not match other people’s thoughts. Therefore, the idea of using computer vision for improving the process of evaluating row cleaners on a real-time basis came up, since this could provide an un-biased, repeatable, simple and objective quantification of the performance of a row cleaner. Computer vision could easily be the right tool to achieve our goals on this study, using a very clean and neat working process (Fig. 8).

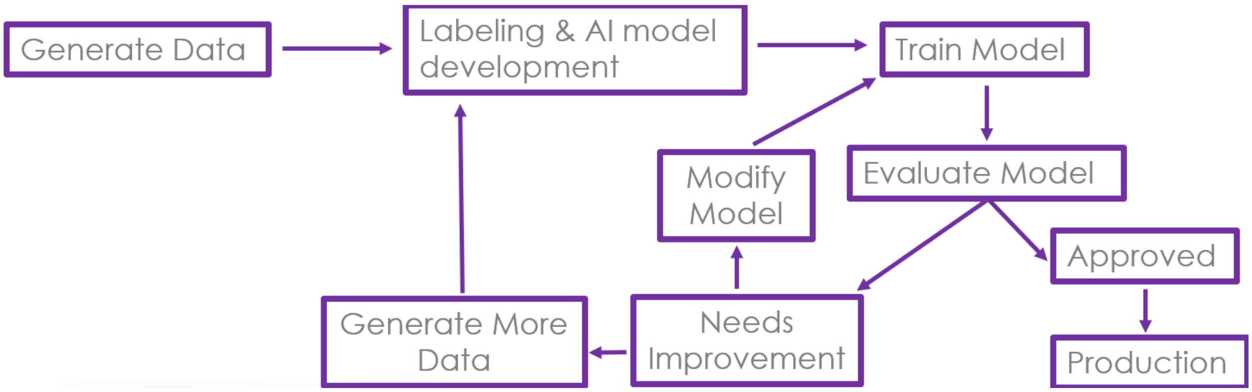

Figure 2.8. Flowchart describing how we work with the data acquired by our system

The system that was introduced during this study, despite needing more work and research conducted on it, demonstrated that quantifying the performance of row cleaners installed on air seeders is possible and it shows that a number can be put on that operation. The outcome we got from this technology is a percentage of cleanliness of the trench, meaning that it provides a certain number indicating how much soil is not covered with residue compared to the total area of the image the system analyzed. Besides this is a simple and neat system that could be easily adapted and installed on any box-drill or air seeder with a Central Commodity System or a pull-behind cart. The only devices needed to do this are the following, keeping in mind that the system needed to be as simple as possible: color camera, camera mount, ethernet cable, laptop and a data acquisition box (Fanless PC with tailor-made software and computer modules). Once the data is obtained in the field, for analysis purposes a computer suited with the analysis model would be enough.

The camera would capture images from the trench that is being created by the row cleaning device, those images are processed and stored by the software equipped by the fanless PC and then the laptop is used to manage the whole system from the tractor's cab on a real-time basis. The software also allows the operator to change the camera and image settings according to the needs of the operation that is being conducted (type and amount of residue, characteristics of the row cleaning device, and other variables that might change such as sunlight). Ideally, this system can be taken to production and operate on a real-time basis as part of the main goal of automating planting and seeding processes.

In wheat, canola and soybean, the main crops seeded with this type of equipment, is important to get a clean and even trench for improving emergence and crop evenness, both will increase productivity during the crop development cycle and will enhance yield. Crops that do not get a clean and even trench might have to overcome emergence issues that can potentially reduce attainable yields. Nowadays, inputs like seeds and fertilizers have increasing costs which actual crop prices are not able to match, meaning that input prices are increasing faster than output prices. This means that producers have to maximize the return they get for their investment: new technologies applied to machinery systems that are already available in the market can assist to fine-tune input management and usage, enhancing overall farming profitability.

The final goal of the system introduced in this study is to help producers understand which devices can be attached to their existing equipment and provide the best return to their investment. As proposed in this experiment, a certain number can express which row cleaner device works better and this can help producers to make better decisions for improving their equipment and that will ultimately allow farmers to get better yields, therefore a better return over their investment.

Conclusion

After analyzing and understanding the data obtained while conducting this study, it is clear that a numbers can be used to quantify how a row cleaner performs its task: while nowadays is a subjective operation where an individual will set a score on each row cleaning device, the system introduced in this study was successful on quantifying row cleaner operations on a timely, simple, un-biased and repeatable way. More research and exploration needs to be done in order to improve the model's accuracy, but the base has been set.

It must not be ignored the fact that the next step of this development is to perform this quantification process on a real-time basis, this means while the row cleaner is actually operating in the air seeder. This is another big step towards the automation of agricultural machinery systems, which will eventually lead to a more efficient and profitable way of farming land in the United States and the rest of the world.

Chapter 3 - Comparing and evaluating the performance of two high-speed planting solutions

Introduction and background

The machinery market is getting more competitive year after year, and manufacturers are investing significant amounts of money to find and provide solutions to the issues customers face daily in the field. The main objective of this is to make farming operations easier and safer, and at the same time, they should be faster, involving a higher comfort standard. Provided this scenario, some companies benchmark their products against their competence; that way, they can evaluate how their products perform and, if needed, improve them so they can sell the equipment that can better address their customers' needs.

In this case, our partner John Deere came to us so we could benchmark a planting solution from John Deere and a planting solution from a competitive brand (Fendt – AGCO Group), understanding the term "planting solution" as a Tractor and planter together. The main goal of this project was to evaluate and compare the performance, ease of use, visibility, quality, and planting efficiency of two planters attached to two different tractors. To achieve that goal, a scorecard was provided for both planting solutions. A team of Deere engineers took some measurements before planting, and other data was gathered manually with data acquisition systems while planting. Lastly, agronomic observations and measurements were made after planting, including drone flights to check corn emergence and section control performance. As far as this thesis is concerned, measurements taken by our partner are not disclosed.

Methodology

For conducting this benchmarking project, a field located South - East of Miltonvale, Kansas (North-Central Kansas – Cloud County) was selected (Fig. 1) from a cooperator who runs a large farming operation. Before selecting the field, a few guidelines were set:

- No-till
- Irrigated
- Crop: corn
- Minimum size of 65 hectares
- Slopes and terraces
- Despite not being flat, the soil must be even (similar yield potential)
- Even headlands, so both planters had the same planting situation (headland vs not headland)

According to these guidelines, we selected this no-till 80 hectares field with soybean residue, irrigation, slopes, and terraces while still having an even potential yield across the whole field. To determine this last condition, input from the cooperator was taken into account and yield monitor data from the last five seasons was analyzed (soybeans and corn). The field was split into two equal halves to implement planting with both planting solutions, considering that the field is planted on an East-West direction. The northern part of the field was planted with Fendt, and the second treatment in the southern part was planted with Deere. It is worth mentioning that a small part of dryland in the southernmost part of the field was not considered for measuring the different parameters, as mentioned in the Experiment and Methodology section.

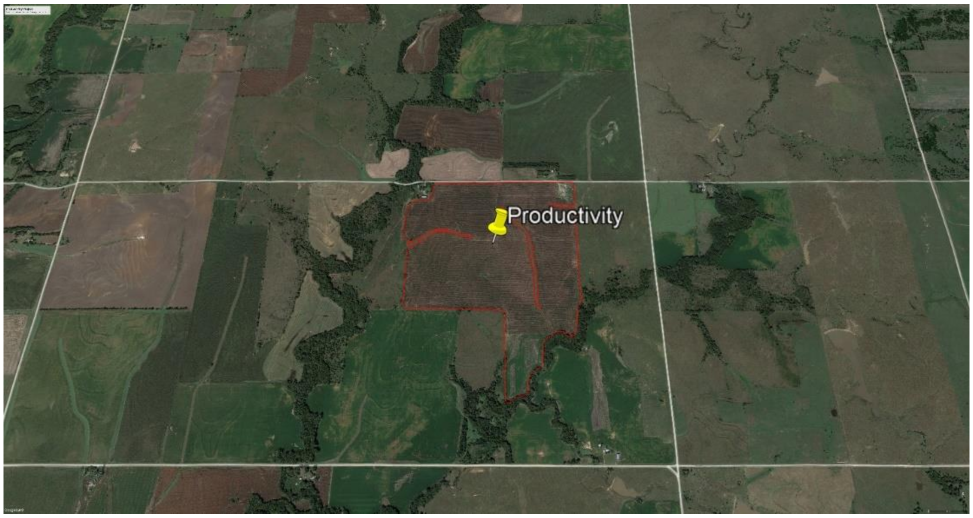

Figure 3.1. Field location (Miltonvale, Cloud County, KS).

Since the field was irrigated, the farmer provided a planting prescription for the whole field using variable rate seeding (Fig. 2 and Table 1): corners – dryland and pivot – irrigated was the criteria, while keeping a constant rate for in-furrow fertilizer (Table 2). Due to the cooperator plan for this field, two hybrids were used (Table 3); one for each planter. Unfortunately, this limited the potential for further agronomic parameters analysis, such as emergence speed, NDVI, and yield, since the genetics heavily influences all those parameters. Some more details, such as planting date, moisture, seeding rate, and other agronomic facts were analyzed using QGIS (GIS Software) and as-applied data.

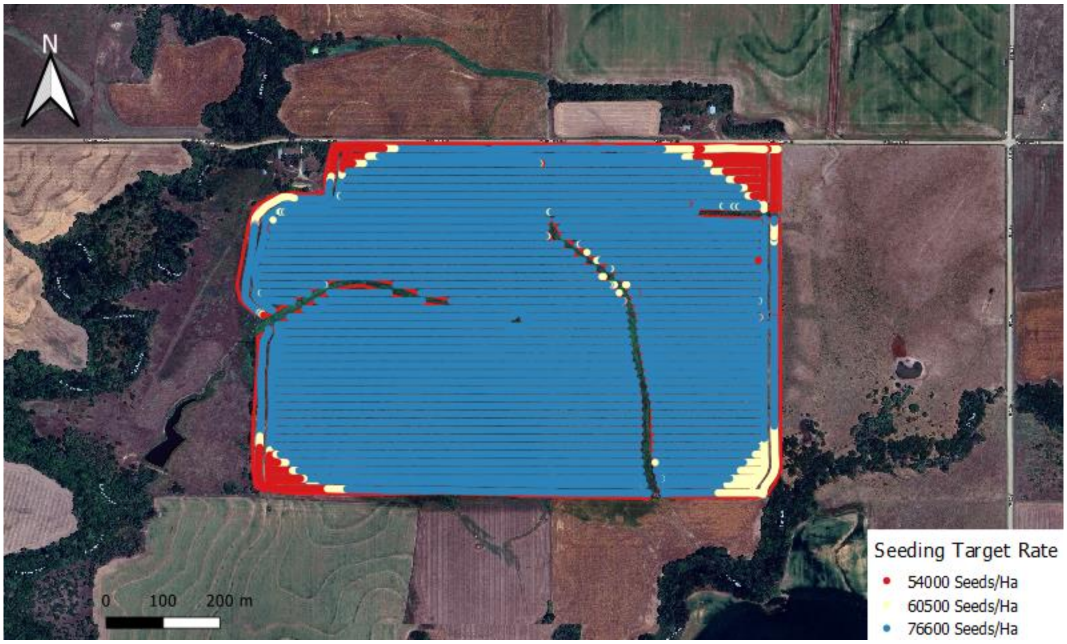

Figure 3.2. Target seeding rate for the entire field. Prescription provided by farmer.

Prescription Rate (seeds/ha)	Seeding Rate (As-Applied seeds/ha)	Establishment (plants/ha)	Survival Rate
76601	78210 - JD	80379 - JD	103%
(PIVOT)	76682 - FENDT	66989 - FENDT	87%

Table 3.1. The prescription rate for the pivot (irrigated) and corners (dryland), the applied seeding rate for the pivot, established plants for the pivot, and survival rate as a percentage for the pivot.

In- Furrow Fertilizer	Applied Rate Avg.
Pro-Zinc 10 8-0-0	2.34 lts/ha
10-34-0 SOL	3.4 gal/ac
Brigade	5 floz/ac

Table 3.2. Fertilizer and insecticide rate (constant rate).

Planter	Hybrid	Has	Planting Date	Previous crop
JD	NK 1523 (Syngenta)	41	04/19/2023	Soybean
Fendt	Channel 217-01 VT2P	40	04/19/2023	Soybean

Table 3.3. The hybrid used in each planter, acres planted by each planter, planting date, and previous crop in the field.

Equipment and Methodology

Two MFWD tractors (8R 410, Deere and Company, Moline, IL, USA – Fig. 3 - and Fendt Vario 1050 – Fig. 4 -, AGCO Corp., Duluth, GA, USA) and two row crop planters (1775 NT 24R30, Deere and company, Moline, IL, USA and Fendt Momentum 24R30, AGCO Corp., Duluth, GA, USA) were utilized for this study. Both 24-row planters had 30 inches row spacing configuration. The Deere planter was hooked to the Deere tractor and the Fendt planter was utilized with the Fendt tractor, which had 100 additional horsepower compared to the Deere tractor. Fendt Momentum planter had planted 2000 hectares before this study while the John Deere planter was brand new. The Fendt planter was equipped with Precision Planting row units (Clean Sweep row cleaners, V-Drive seed meters, SpeedTube, Furrow Force closing system, and Smart Firmers) while the John Deere planter was equipped with Exact Emerge seed meters (Deere and Company, Moline, IL), independent hydraulic row downforce control, pneumatic row cleaners and mechanic closing wheels with OEM rubber wheels.

Figure 3.3. John Deere 8R 410 and John Deere 1775 NT Planter 24R30

Figure 3.4. Fendt 1050 Vario and Fendt Momentum 24R30 planter

The John Deere planter was instrumented with a custom-made DAQ box developed at Kansas State University. National Instruments c-RIO controller and c-series modules collected high-speed multi-channel data (Fig. 5 and 6) to record sensor and GPS (GNSS receiver with base station, Topcon, GR5) data into a .csv file. Accelerometers (3741E1210G, PCB Piezotronics, Depew, NY, USA - row-unit vertical movement) and hydraulic pressure transducers (HAD 846K-A-5000-000, HYDAC, Glendale Heights, IL, USA – downforce margin and applied downforce) were installed on alternate rows, and existing OEM load cells were tapped to collect respective data. The DAQ system captured data at 100 Hz (100 samples per second) and then downscaled to record at 10 Hz (10 samples per second – downscale). The data recorded was used to develop maps for applied downforce, downforce margin, speed, gauge wheel load, and row acceleration, with high spatial accuracy.

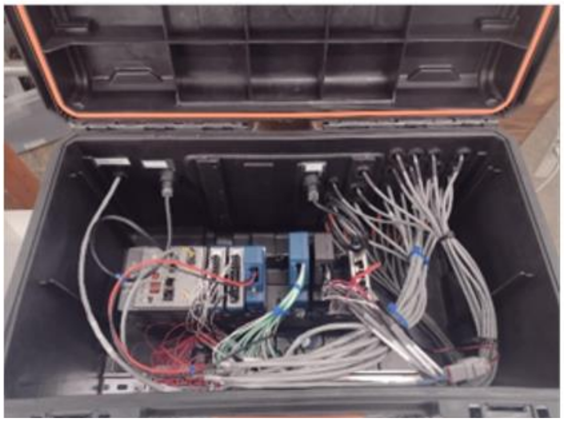 

Figure 3.5. DAQ box, showing cRIO and NI hardware (left), and Dual frequency GNSS – RTK base station (right).

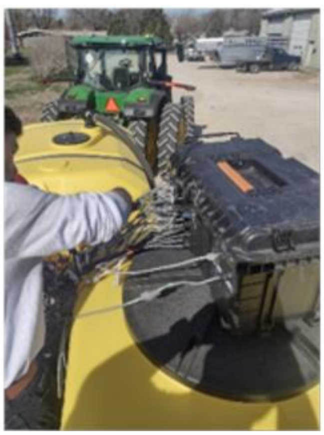  

Figure 3.6. DAQ box mounting on the planter (left), accelerometers mounted on the row unit (middle), and hydraulic pressure transducers (right).

A Deere team wired up the Fendt planter and installed a DAQ box and two John Deere StarFire 7000 receivers on rows 1 and 24 (Fig. 7). The same team installed cameras inside the Fendt tractor cab to monitor the operator's comfort, movements, and other parameters related to his well-being inside the tractor's cab. Before planting, the Deere engineers conducted several tests and measurements on both planters, such as weighing both planters and checking active weight distribution, including other setup checks. This information is not to be disclosed in this thesis since it exceeds its purpose.

Figure 3.7. John Deere Starfire 7000 installed on row-1 and row-24 of Fendt planter.

In order to be able to benchmark both planters and tractors, John Deere provided a scorecard that served as a guide for gathering useful data for comparison. The key focus was on quantifying productivity (acres per hour) on straight passes, turning, and headlands.

Results and Discussion

Seeding rate – As-applied Data

As-applied seeding rate was different for both planters (Fig. 8 and Table 1) even though the same prescription rate was used. It is interesting to see how each planter was on target (Fig. 9) or off target (Fig. 10) compared to the prescription (Table 1). Results showed that there was a difference in the accuracy of the John Deere planter when it came to prescription seeding rate vs applied seeding rate vs stand count. For Fendt, the average applied seeding rate within the pivot was almost the same as the prescription rate. On the other hand, for Deere, there was a 2% difference between the prescription rate and the applied seeding rate, being higher than the applied rate. Besides this, when stand count measurements were conducted, it was found that the part of the field planted with the Deere planter had more plants than the as-applied rate, which probably means that there were issues with the Exact Emerge system itself. This also happened in other fields planted with this machine. For this field, the difference between as-applied seeding rate and the actual stand count was around 2100 seeds/ha (3%), though actually that difference could be larger if we take into account that not all the seeds that go to the ground emerge and provide a healthy plant (this information is provided by the seed corn breeder, and is expressed as germ. %).

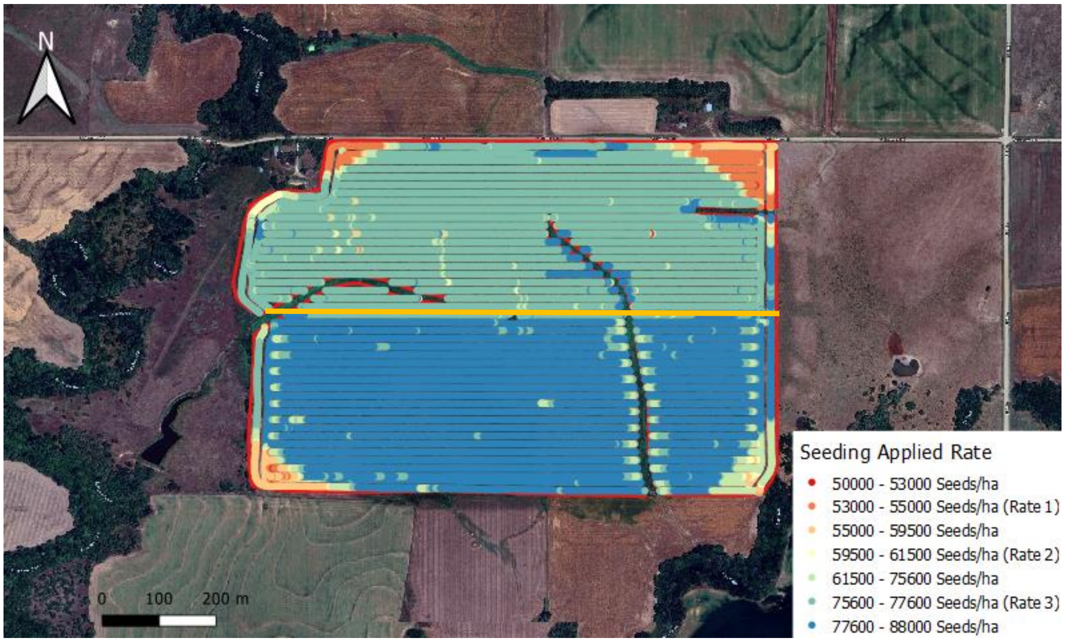

Figure 3.8. As-applied seeding rate (above yellow line FENDT, below yellow line DEERE). Each rate considers +/- 1000 seeds/ha

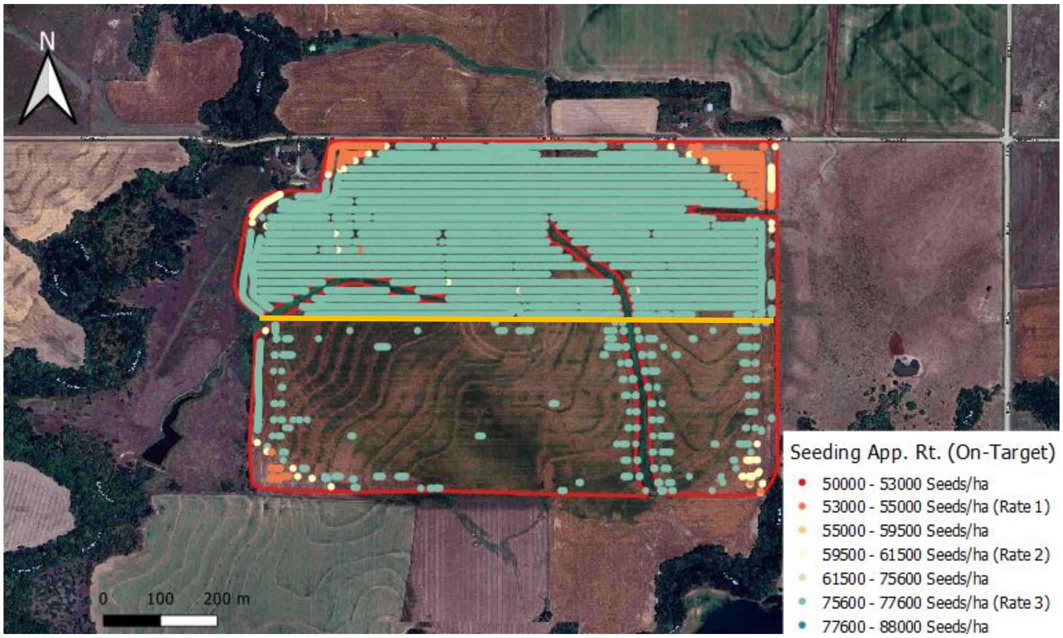

Figure 3.9. As-applied seeding rate, on-target values only corresponding to Rates 1, 2 and 3 (above yellow line FENDT, below yellow line DEERE).

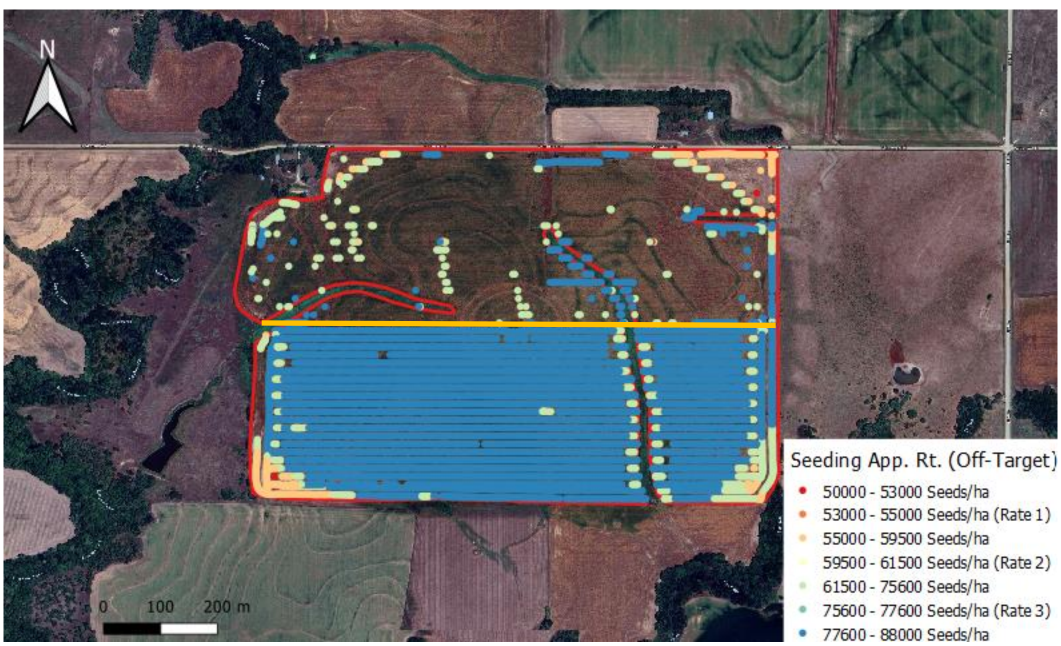

Figure 3.10. As-applied seeding rate, off-target values only (above yellow line FENDT, below yellow line DEERE).

Flexibility

One of the main differences was that the Deere planter had a cleaner and simpler frame that looks lighter and more agile and convenient for an unforeseen repair in the field. Meanwhile, the Fendt planter has a bigger and heavier frame, but this frame had more flexing points than the Deere, though this might lead to a more complex structure; Fendt planter possessed a double frame (a main one and a secondary one).

This difference in flexing points was clearly visible in the field, particularly when the planter went over terraces (Fig. 11 and 12). While the Deere struggled to close the trench and left the seed exposed, the Fendt worked as intended while planting over terraces and it was hard to tell that the land had already been planted (Fig. 13). The Deere had the tendency to dig over the terrace instead of running over it, that way the row cleaners removed soil from the trench, so the closing devices could not close the trench and seeds were left exposed with poor to none seed-to-soil contact. Most of the times, exposed seeds wouldn't be able to turn into healthy plants due to fungi and bugs that could easily damage them, so there will were spots with no plants or very few plants. Besides this, poor or none seed-to-soil contact lead to poor emergence and, if plants emerge, they usually are weaker.

When it comes to Fendt, flexibility was superb, leaving no trenches open and no seeds exposed. This led to a uniform plant stand over terraces, with no differences between flat terrain and slopy one. The results could be attributed to the more complex, but very efficient, double frame possessed by the Fendt Momentum.

Finally, it is worth mentioning that the Deere planter performance when planting over terraces was also related to the travel direction: depending on which direction it was travelling, it would dig on one side or the other, but not the whole planter (Fig. 14)

Figure 3.11. As-applied seeding rate, off-target values only (above yellow line FENDT, below yellow line DEERE).

Figure 3.12. John Deere 1775 24R30 rolling over terraces, poor flexibility can be observed in this case. Three sections are clearly defined: 2 wings, one central.

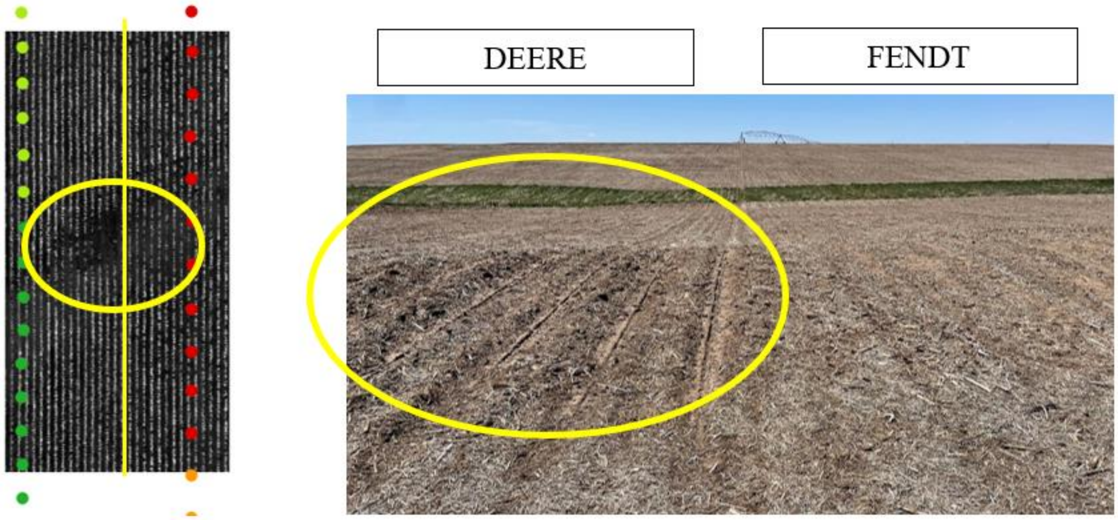

Figure 3.13. On the right hand picture, we see how Deere planter digs into the soil and does not close the trench when running over terraces while Fendt does a better job and closes the trench. On the left-hand picture UAV data (corn stage: V4) shows the lack of plants in that part of the field, this is due to seed exposed and poor seed to soil contact. This situation repeated in most of the terraces across the field.

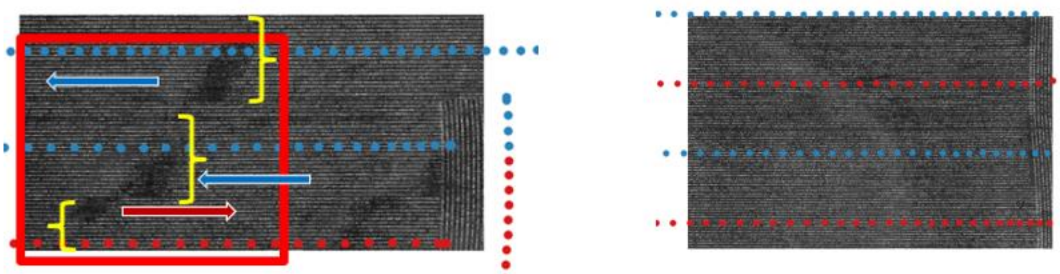

Figure 3.14. UAV images (Corn stage: V4) for Deere (left) and Fendt (right), terrain was the same in both cases. It is easily noticeable that depending on the travel direction (red/blue arrows – yellow brackets indicate planter width) the Deere will dig into the soil only on one side of the planter, and that can be seen in the field while comparing passes that are next to the other but have different travel direction. On the other hand, for the same kind of terrain, Fendt makes no differences between passes besides not digging into the soil and flexing over terraces.

Productivity

When it comes to productivity, both planters performed in a similar way: both planting solutions are top of the line when it comes to 24 row planters and MFWD tractors. Very small differences were observed between Deere (all field 55.1 has/h) and Fendt (all field 52.9 has/h) planter (Table 4 and Fig. 15 and 16), and potentially could be due to the fact that headlands and waterways for the Fendt portion of the field were bigger and with a more complex shape (Fig. 17).

Fend - Headlands	
Statistic	Value
Count	1275
Mean	38.9
Median	41.7
St dev	8.9
Minimum	0.3
Maximum	48.7
Range	48.3
Q1	38.1
Q3	44.7

Fendt - Not Headland	
Statistic	Value
Count	5102
Mean	49.3
Median	54.3
St dev	10.6
Minimum	0.8
Maximum	69.2
Range	68.4
Q1	46.1
Q3	55.5

Fendt - All	
Statistic	Value
Count	6377
Mean	47.2
Median	52.9
St dev	11.1
Minimum	0.3
Maximum	69.2
Range	68.9
Q1	43.2
Q3	55.2

JD - Headlands	
Statistic	Value
Count	1265
Mean	41.4
Median	46.1
St dev	10.6
Minimum	1.5
Maximum	48.8
Range	47.3
Q1	42.5
Q3	46.7

JD - Not Headland	
Statistic	Value
Count	5241
Mean	50.8
Median	55.9
St dev	11.0
Minimum	1.4
Maximum	59.9
Range	58.5
Q1	47.2
Q3	56.8

JD - All	
Statistic	Value
Count	6506
Mean	49.0
Median	55.1
St dev	11.5
Minimum	1.4
Maximum	59.9
Range	58.5
Q1	46.0
Q3	56.6

Table 3.4. Statistics on productivity expressed as hectares per hour (has/h) for both planting solutions. For better understanding, statistics were divided into headlands, not headlands, and the whole field ("All"). Both maps were cleaned before processing them with QGIS.

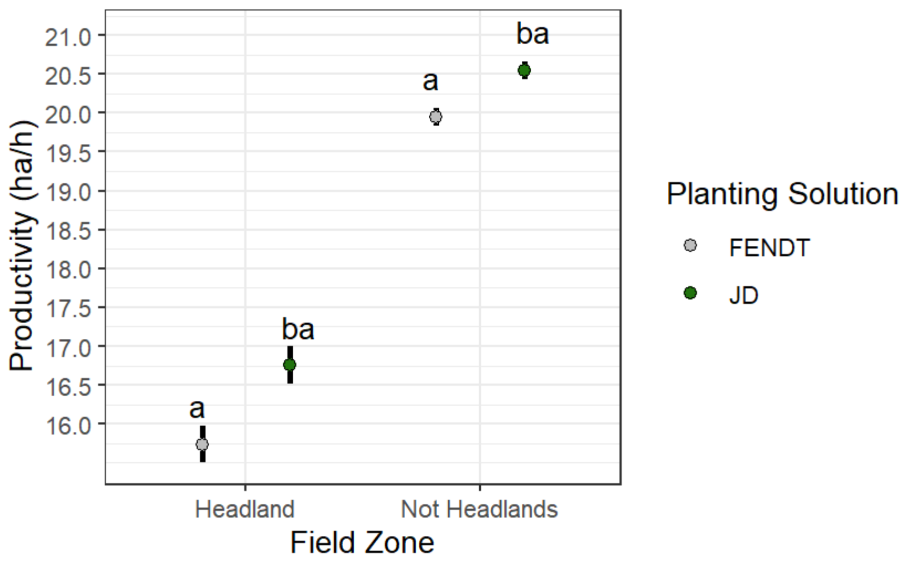

Figure 3.15. Standard Error for the mean productivity, expressed in hectares per hour (ha/h). Standard error is small due to the nature of the data analyzed (as-applied data, many samples).

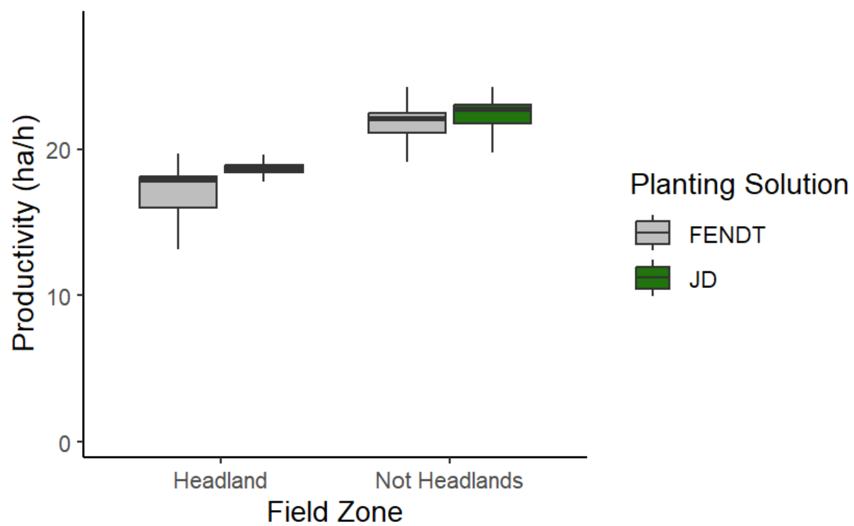

Figure 3.16. Productivity, expressed in hectares per hour (ha/h).

Figure 3.17. Headlands, straight passes (not headlands) and waterways for both planting solutions.

Section Control

A section control assessment was also performed for both planters, but unfortunately, something went wrong with the Fendt Momentum, so the section control did not perform correctly: gaps could be found when leaving the headlands and overlapping could be found when entering headlands (Figure 18). This was likely to have been a human error while setting and checking the section control and potential setting up a correct (higher) look ahead time within the controller for Fendt (1 second instead of 0.5 seconds)

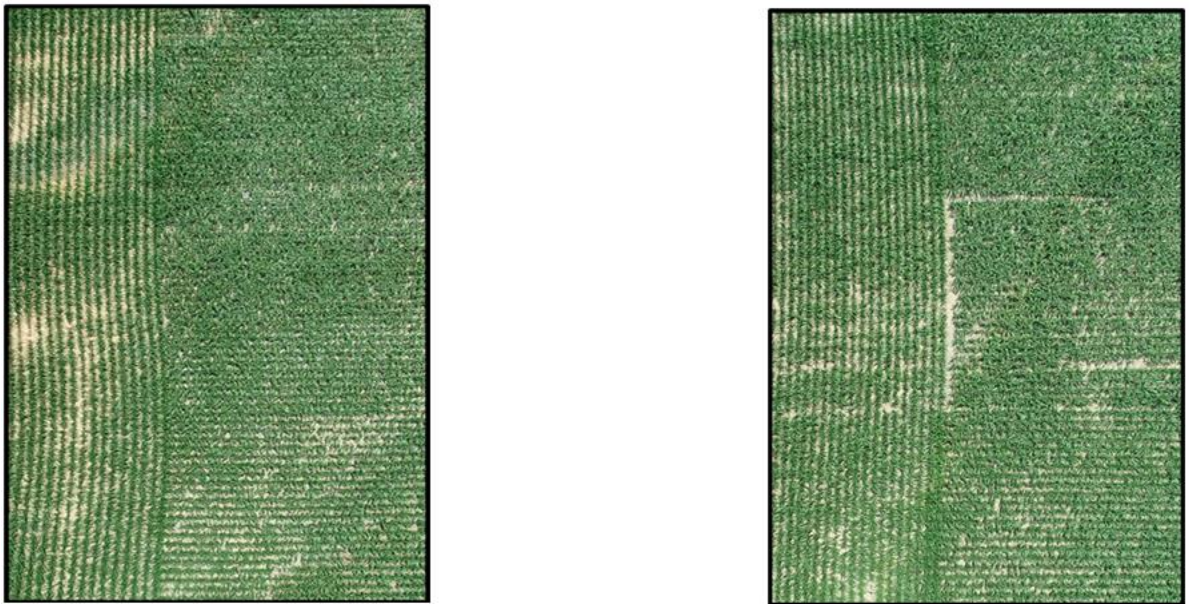

Figure 3.18. UAV images for showing how section control performed in each planter. Left-hand for Deere and right-hand for Fendt.

Agronomy: spacing

Even though there was no plan of taking agronomic measurements, while scouting the crop there was a clear difference in spacing between corn planted with Deere planter and Fendt planter. This motivated an in-depth assessment of spacing. Twelve 5.33-meter strips were marked for each planter, in those strips spacing between plants was measured and the results showed that Spacing CV was better (smaller) for the Deere planter (Fig. 19 and Table 5), it also served to confirm that the Deere planter planted more seeds than it was supposed to. Measurements were taken when crop stage was V6.

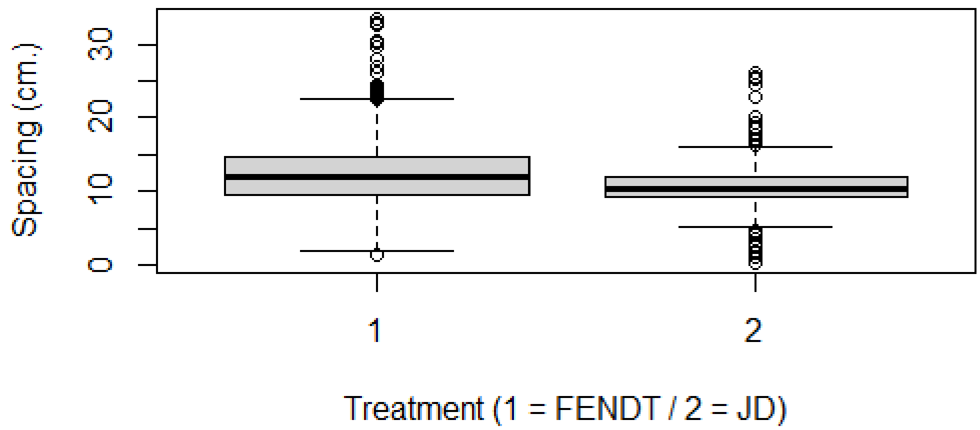

Figure 3.19. Spacing expressed in inches for both planters

Final stand spacing summary - Centimeters								
Planter	No. of Obs.	Spacing Target	Spacing Mean	Spacing Median	Spacing Min.	Spacing Max.	Spacing SD	Spacing CV (%)
Fendt	310	17	20	19	3	53	9	42
JD	380	17	17	17	1	41	5	30

Table 3.5. Spacing summary for both planters in pivot area. Observe better spacing CV for Deere, though spacing median was below spacing target (meaning more plants per acre than the ones expected – take into account that spacing target is for seed not for plants).

Agronomy: yield

When it comes to yield, we must take into account that both treatments (Deere and Fendt) cannot be compared directly since different corn hybrids were used in each planter. This means that if yields are different, we cannot attribute that difference to a better or worse planting quality since the hybrid itself might have an effect.

Al things considered, we decided to focus on crop performance over terraces to check if there was a difference between both planters. Besides the fact that we could see a clear performance difference between planters while planting over terraces, Fendt did better, we could not find any differences when it comes to yield by analyzing the yield monitor (Fig. 20), though it seems that the part of the field planted with the Deere planting solution yielded better, we can say that is due to grain moisture. This does not mean there was no difference, but it shows that it was not captured by the combine's monitor since the area was very small. Despite this, we could clearly tell there were no plants where the Deere planter did not close the trench correctly.

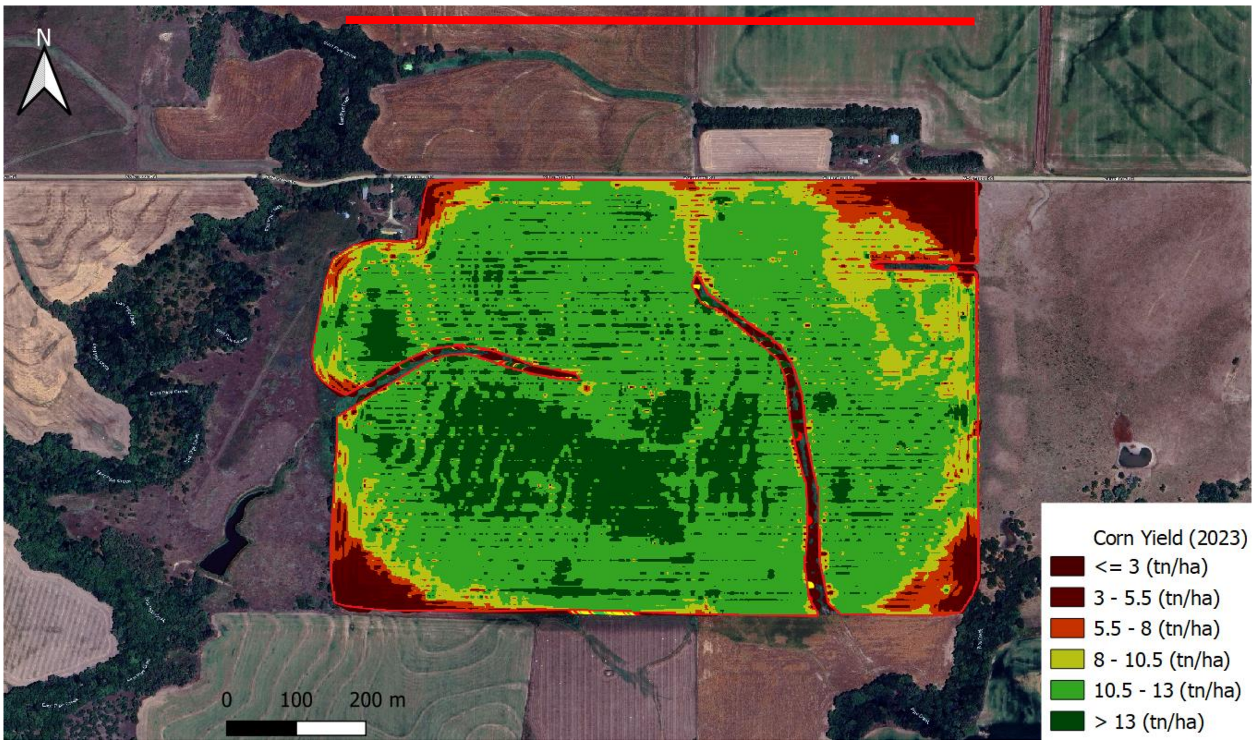

Figure 3.20. Yield monitor: yield expressed as tn/ha (above red line FENDT, below red line DEERE).

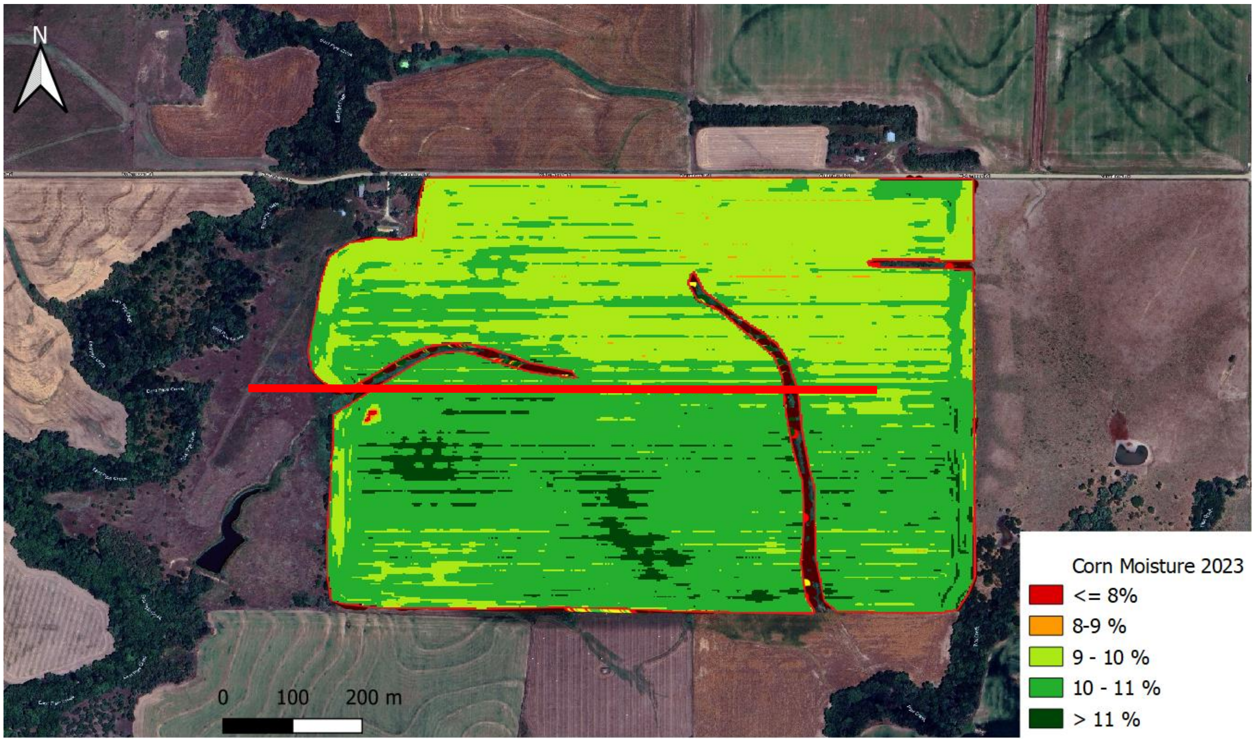

Figure 21. Yield monitor: moisture expressed as % (above red line FENDT, below red line DEERE)

Conclusion

This research provided the following findings:

1. Both planters provided a good overall planting quality, they are expensive pieces of equipment and they perform accordingly
2. Depending on the field, flexibility can make a difference while planting over terraces. A more complex frame can provide better flexibility, and that can lead to better planting quality over terraces, enhancing crop yield
3. Spacing was better on Deere, CV is significantly smaller
4. Flexibility and planting quality over terraces was better in Fendt

As a conclusion it can be stated that high-speed planting solutions operate and perform good over varying field conditions, but still there are designs that can provide benefits for certain kind of terrain though they might have some downsides like complexity and weight.

This study sets a baseline for further research on this topic, and provides important input for researchers: using same hybrids is a must to compare planters (we do care about yield), developing DAQ systems that are the same for each piece of equipment (same data and criteria) and attention should be put into setting and configurations (for example, section control).

Chapter 4 - Conclusion

Summary of findings

Planting and seeding equipment available nowadays is equipped with precision agriculture technology such as hydraulic downforce, intelligent weight distribution, electric seed metering systems and all kinds of sensors for improving seed placement while conducting seeding operations. The ultimate goal of these systems is to improve yields and profitability. This research was focused on finding novel ways of assessing row cleaners for air-seeders and provide input for those who are looking for a planting solution that can fulfill their needs.

The computer vision system introduced for quantifying row cleaner performance on air seeders proved to be a good methodology with solid arguments: it provides a simple and repeatable tool for evaluating the performance of row cleaners while operating under varying conditions on no-till fields. This means that, even though that further research might need to be conducted, the baseline has been set.

Regarding the high-speed planting solution study, it has been found that not every planter will perform the same under varying field conditions. Frame structure plays a key role in flexibility as well as different models of row units and their components will impact seed placement across the field. Despite having similar technologies, some planting solutions provided by different agricultural equipment brands are more suitable for certain conditions while others will perform better if the field changes. This does not mean that one is better than the other, but it does imply that the right planting solution should be carefully chosen taken various aspects into consideration.

Implications

A changing and challenging agriculture requires modern and up to date solutions. The use of computer vision and artificial intelligence models is here to help us improve our machinery systems, and the progress is being made very quickly. The study shows how a computer vision system can help asses different aspects of agricultural equipment and improve it on a very convenient and efficient way.

Also, we learn from this study that big investments on equipment need a thorough analysis and understanding of different variables that play a role in planting operations. Producers need to understand how their field look like so they can get the most suitable equipment for it, in order to be as efficient as possible. The resources and tools for enhancing profitability are available for achieving these goals.

Future work

Future work is recommended for each of the studies discussed in this thesis. Further research is needed to improve the computer vision model, and eventually, this can be deployed on air-seeders for real-time row cleaner performance analysis in order to make on-the-go adjustments according to seeding speed, crop and field conditions. Regarding high-speed planting solutions, it is recommendable to repeat the study across more fields, that way more data can be gathered for understanding what does a planting solution need in order to perform better in each field.

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