Field testing, evaluation, and demonstration of small, light-weight, autonomous planter used to plant soybeans

Final Report by Salin 247, Inc.

for the

Iowa Soybean Association

October 18, 2022

This final report of Salin 247's project "Field testing, evaluation, and demonstration of small, light-weight, autonomous planter used to plant soybeans" contains information from the **June 10 Update Report** as well as new information gathered since the Update Report from June 10. Information also includes some data and insights from field testing done in Tennessee in mid-June and Kansas in early July.

Project goals

As a reminder, the goals of the "Field testing, evaluation, and demonstration of small, light-weight, autonomous planter used to plant soybeans" are:

- Field test planting capabilities of the **Salin 247** small, autonomous farm machinery platform
- Demonstrate the feasibility of using small, light-weight, autonomous planters
- Quantify and evaluate the mechanical and economic performance of the planting capability of the platform
- Gather feedback and critique from pilot growers
- Communicate the project work and findings with soybean growers and the soybean industry
- Develop a plan for working with the ISA Research Center for Farm Innovation (RCFI) field research team as well as a plan for collaborating with the On-farm Research Network in conducting on-farm research

Salin 247 prototype planter

The Salin 247 prototype autonomous planter is a 4-row, 30" row planter powered by a 10-kwh Lithium Iron Phosphate (LiFePO4) battery. The prototype has four tracks, each with a 5-kw electric motor, a 20-1 gearbox, and controller. The machine has a hydraulic system for raising and lowering the planter and also has an air compressor for air bag down force. The machine is guided using software and RTK GPS. We have a custom-made base station that we bring to each field.

Field tests

Salin 247 conducted field testing on four Iowa farms. In addition, we did June and July testing on two farms in Tennessee and one farm in Kansas. Testing was done planting only soybeans. Each field test ranged in size from four to 22 acres. The field tests started on May 15 in Boone County, IA and the last field was planted on July 1 in Kansas. Six of the seven fields were no-till fields. Two of the fields were double crop soybeans planted into winter wheat stubble. All the fields were planted with 30" row spacing although the Cass County, IA field was planted twice in order to get to a 15" row space. As noted below, six of the seven fields (i.e., the no-till fields) had varying amounts of severe soil compaction. Farmers from all seven farms were quite helpful in terms of preparing for the planting tests and providing feedback.

Due to cool, wet conditions in Iowa this spring, we did not start our planting tests until May 15, a month later than we anticipated. As a result, we cancelled testing on five Iowa fields including three corn fields and two soybean fields. In addition, the number of acres planted on each test field was lower than originally planned.

Test field summary for 2022 Salin 247 planting tests

2022 Field Test Fields											
County	**State**	**Field size**	**Crop**	**Previous crop**	**No-till**	**Strip-till**	**Row width**	**Population**	**Seed container**	**Planting dates**	**Acres planted**
Boone	IA	40	Soybeans	Corn	No	No	30	140,000	Bags	May 15-17	22
Floyd	IA	36	Soybeans	Corn	Yes	No	30	140,000	Seed box	Jun 2	8
Cass	IA	20	Soybeans	Corn	Yes	No	15	140,000	Seed tender	May 23	6
Muscatine	IA	30	Soybeans	Soybenas	Yes	No	30	139,000	Bags	May 30	5
Hardin	TN	40	Soybeans	Soybenas	Yes	No	30	150,000	Seed tender	Jun 13-15	9
Henry	TN	8	Soybeans	Wheat	Yes	No	30	140,000	Seed tender	Jun 16-17	4
Bourbon	KS	6	Soybeans	Wheat	Yes	No	30	140,000	Bags	Jul 1	4

Performance metrics

Salin 247 captured data and assessed the autonomous planter performance based on four key metrics including:

- Planter performance
- Navigation performance
- Soil compaction impact
- Energy use

Performance results based on these metrics are provided below.

Planter performance data

The Salin 247 planter uses Precision Planting technologies that capture data for a number of different performance indicators. Some of the key indicators are:

- Clean furrow
- Downforce
- Furrow quality
- Ground contact
- Population
- Productivity
- Singulation
- Skips
- Soil moisture
- Soil temperature

2022 Field Test Planter Performance Result Summary

	Boone Co., IA	Cass Co., IA	Cass Co., IA	Muscatine Co., IA	Floyd Co., IA	Hardin Co., TN	Henry Co., TN	Bourbon Co., KS
		First pass	*Second pass*					
Crop	Soybeans	Soybeans	Soybeans	Soybeans	Soybeans	Soybeans	Soybeans	Soybeans
Previous crop	Corn	Corn	Corn	Soybeans	Corn	Soybeans	Wheat	Wheat
Tillage system	Reduced-till	No-till	No-till	No-till	No-till, fall VT	No-till, spring VT	No-till	No-till
Row width	30	30	30	30	30	30	30	30
Clean furrow (%)	93.90%	92.70%	91.50%	96.00%	95.20%	93.70%	83.90%	87.90%
Down force margin (PSI)	51.6	3.57	3.35	2.48	7.49	3.66	1.35	4.5
Furrow quality (%)	87.70%	65.30%	69.70%	93.10%	88.50%	84.40%	80.60%	85.80%
Ground contact (%)	98.30%	66.70%	61.50%	60.10%	66.30%	50.00%	39.00%	57.70%
Population (1000 seeds/acre) target	140	70	70	139	140	150	75	150
Population (1000 seeds/acre) actual	138.8	70	70.5	138.9	139.5	150.4	77.1	148.9
Singlation (%)	99.0%	99.7%	99.7%	99.6%	99.0%	98.8%	99.5%	98.3%
Skips (%)	0.9%	0.2%	0.2%	0.2%	0.6%	0.3%	0.4%	1.6%
Soil moisture (%)	25.4%	25.7%	25.2%	35.3%	33.7%	36.7%	41.0%	25.3%

Planting performance across the seven test fields was generally good. Planted seed populations were extremely close to target populations. The minor exception was the Boone County, IA field where we struggled some with the vacuum system motor. Singulation, skips, and doubles percentages were very good despite planting in some challenging no-till conditions.

It should be noted that we did not exceed a planting speed of 3.5 mph and most of the test planting was done at 2.5 to 3.0 mph. These lower speeds likely contributed to good planting performance measurements.

One of the challenges was related to down force on no-till fields where parts of these fields had significant soil compaction. Due to the relative light weight of the Salin 247 planter, we struggled in some parts of test fields to provide the needed downforce to keep the double disk openers at the proper depth. We did not measure planting depth directly, but down force margin and ground contact measurements were variables we monitored along with manual digging to determine planting depth. Our planting depth target was 1.5 inches to 2.0 inches depending on field conditions. In all of the no-till fields, there were areas of the fields where we were planting at less than desired depth. To correct this, we added tractor weights to the planter. We added between 100 pounds and 900 pounds of tractor weights depending on soil conditions. In the four Iowa fields, we did not exceed 400 pounds of added weight.

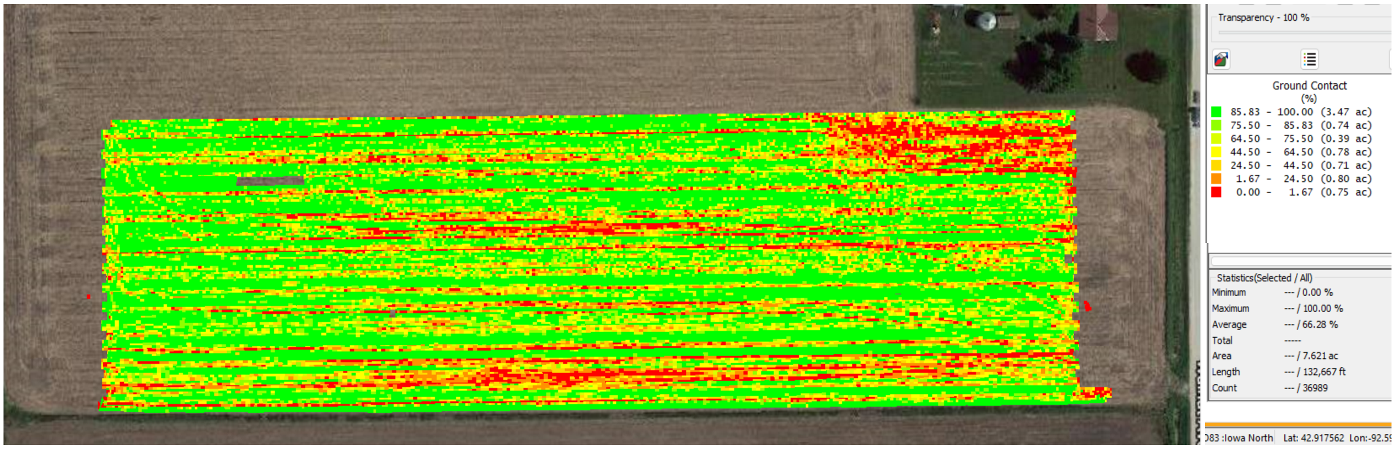
Despite the downforce challenges and planting at less than desired depth in some parts of the test fields, emergence on all of the test fields was very good. We did not take post-emergence stand counts but only made visual observations. It should be noted that six of the seven fields we planted received anywhere from 0.4 inches of rain to 2.0 inches of rain within one to three days of planting. These rains surely helped with getting even emergence on the test fields.

Even though planting performance can generally be characterized in these tests as good to excellent, there are a couple of areas that need further testing. We need to test at higher speeds. We would like to collect more data with the correct planter configuration at speeds of 5 to 6 mph. There will also be value in testing at speeds of 8 to 10 mph using “speed tube” technologies. The current planter configuration uses Martin-Till row cleaners. These row cleaners worked well with the our current 30-inch row configuration. With a 15-inch configuration, we are likely going to need to test the use of coulters in front of the double disk openers.

Many of the planting performance metrics can be evaluated spatially using GIS software. We are using the Ag Leader SMS software to manage and evaluate the data. A couple of examples are shown below for the Floyd County, IA test field.

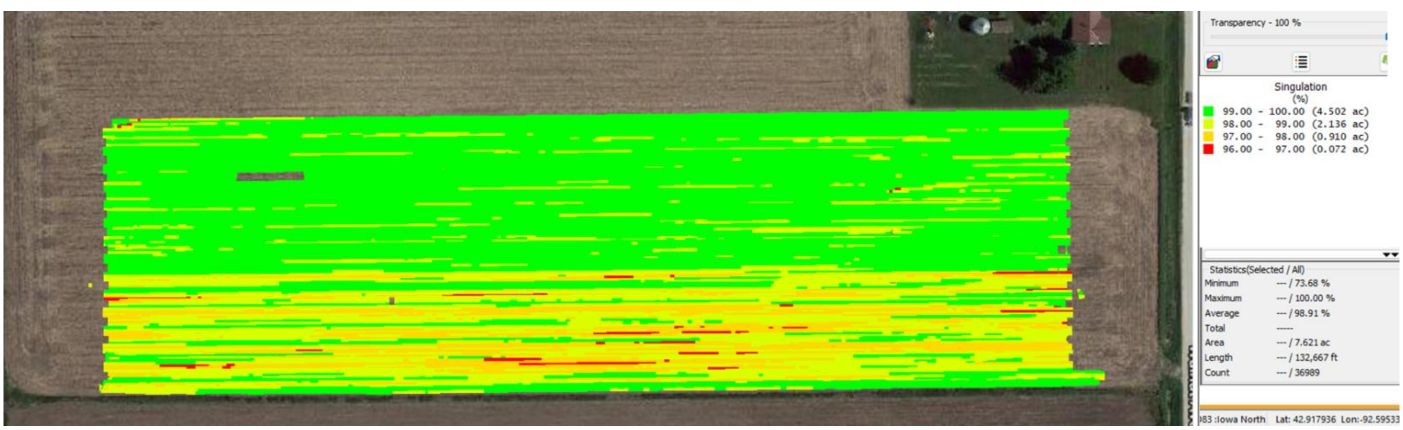
The first map shows ground contact by row for the Floyd County, IA test field. Red on the map indicates low levels of ground contact between the gauge wheels and the ground. This is an indication of the degree of soil compaction in the top couple inches of soil. The most severe soil compaction is showing up in areas of the field traveled most frequently by heavy farm equipment. These are areas of the field where we struggled to plant at targeted depth.

Floyd County, IA test field ground contact map



The second map below shows the seed singulation data for the Floyd County, IA field. Singulation is an important measure of planter performance and was generally very good where we planted at 2.5 mph but went down slightly when we increased speed to 3.0 mph. Interestingly, seed singulation improved when we increased speed to 3.5 mph.

Floyd County, IA test field seed singulation map



In order to save space in this report, we will only show these two example maps. Additional, mapped data can be provided to those interested.

Beyond looking at data collected and evaluating metrics, another important approach to evaluating the Salin 247 autonomous planter performance was the "eyeball" test. We collected a large amount of image and video during planting as well as post-emergence. Below are two examples.

The image below is from the Boone County, IA test field taken on July 12. This field received about 13 inches of rain within 10 days of being planted by Salin 247. Despite the heavy rain, emergence was very good although there are places in the field (not seen with this image) where the stand was impacted by moving water through the field. It was the first time in about 80 years that this field was planted without using a tractor. This field was harvested on October 6 with a whole field average of about 60 bu/acre. We will be receiving detailed yield files when the grower finishes harvest.

Boone County, IA test field, July 12, 202

The image below is from the Floyd County, IA test field taken on July 29. The impacts of areas of higher soil compaction in this field (see SMS map above) did not significantly impact emergence due in part to good rains following planting. The areas of severe soil compaction (northeast part of field) are not shown in this image but did experience a reduction in stand count. As of October 17, this field had not been harvested, but when available yield monitor data will be correlated with compaction data to if there was a statistically significant yield impact.

Floyd County, IA test field, July 29, 2022

Navigation performance

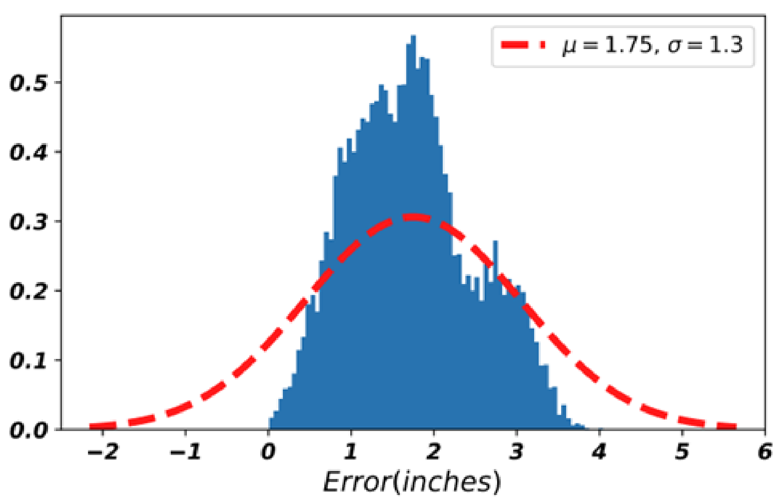
Navigation performance was measured using two variables – mean absolute error relative to the AB (i.e., navigation) line and standard deviation of error relative to the AB line. The table below shows navigation performance averages for the four Iowa test fields. Our goal is a mean absolute error of 2.0 inches or less with a standard deviation of 1.0 inches or less. At a target planting speed of 2.5 mph, the mean absolute error and standard deviation of the error was acceptable. In the Floyd County, IA field, were collected data for three target planting speeds – 2.5, 3.0, and 3.5 mph. Navigation performance at speeds above 2.5 mph did not meet our level of acceptable performance.

Field test navigation error summary

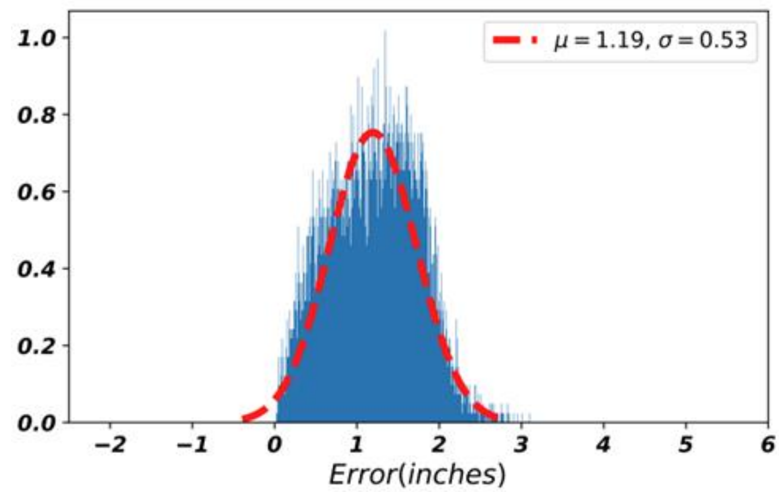
Farm	Target Speed	Absolute error	
		Mean	**Std. Dev.**
	mph	*inches*	
Boone County, IA	2.5	1.75	1.3
Cass County, IA	2.5	1.19	0.53
Muscatine County, IA	2.5	1.9	1.01
Floyd County, IA	2.5	1.4	0.64
	3	3.07	1.51
	3.5	3.07	1.24

Navigation error comes from two sources – "wobble" error and "offset" error. From the error distribution error data (distribution charts below) and from visual observation during planting and post-emergence, we have concluded that most of the error at higher speeds is from offset error. This type of error occurs when the autonomous planter does not always converge to the AB line during a pass through the field. Instead of a 30-inch distance between passes, we might see a 33- or 34-inch distance.

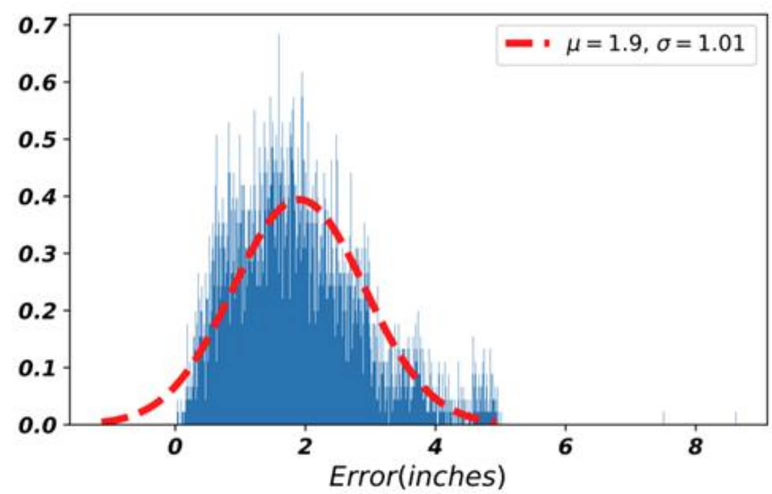
Boone County, IA test field navigation error distribution, 2.5 mph



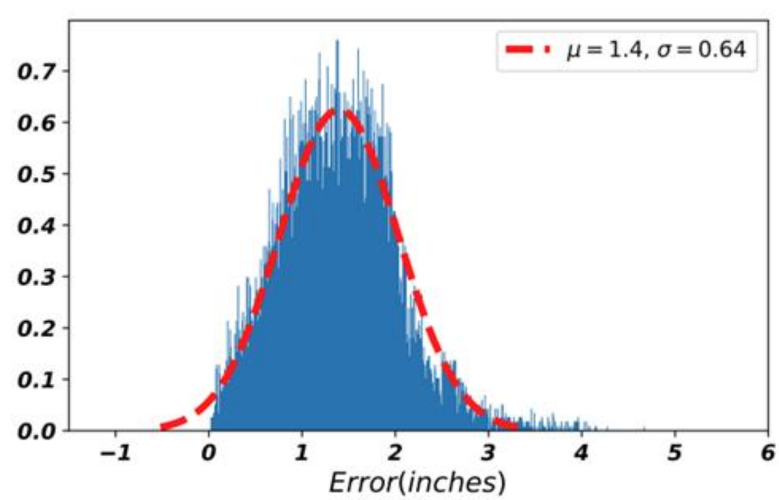
Cass County, IA test field navigation error distribution, 2.5 mph



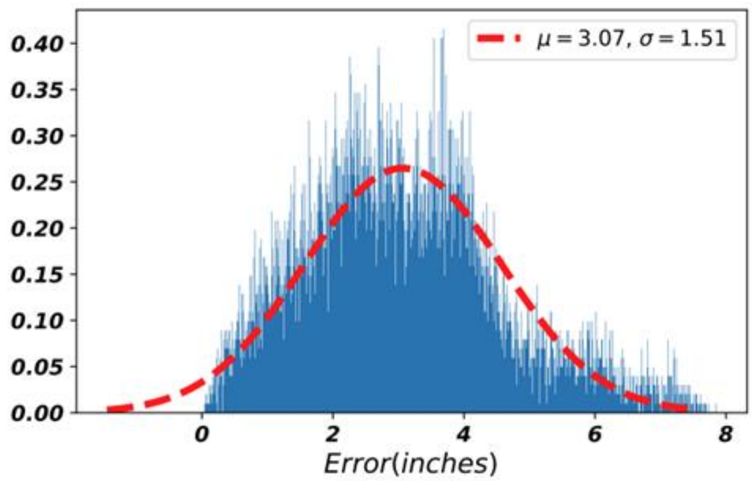
Muscatine County, IA test field navigation error distribution, 2.5 mph



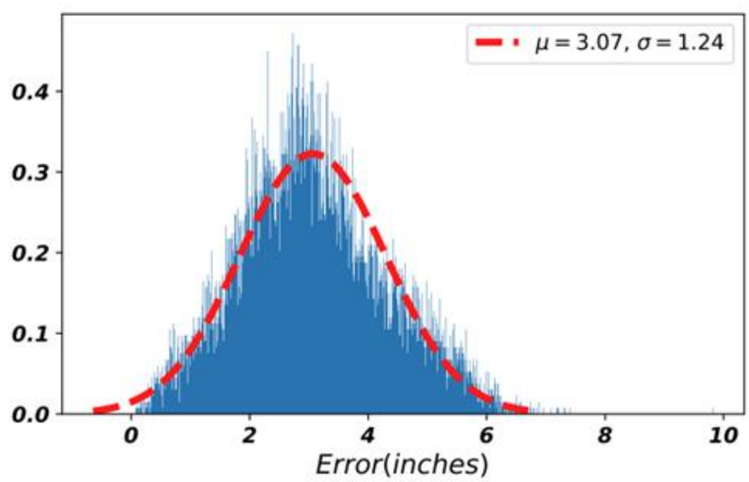
Floyd County, IA test field navigation error distribution, 2.5 mph



Floyd County, IA test field navigation error distribution, 3.0 mph



Floyd County, IA test field navigation error distribution, 3.5 mph

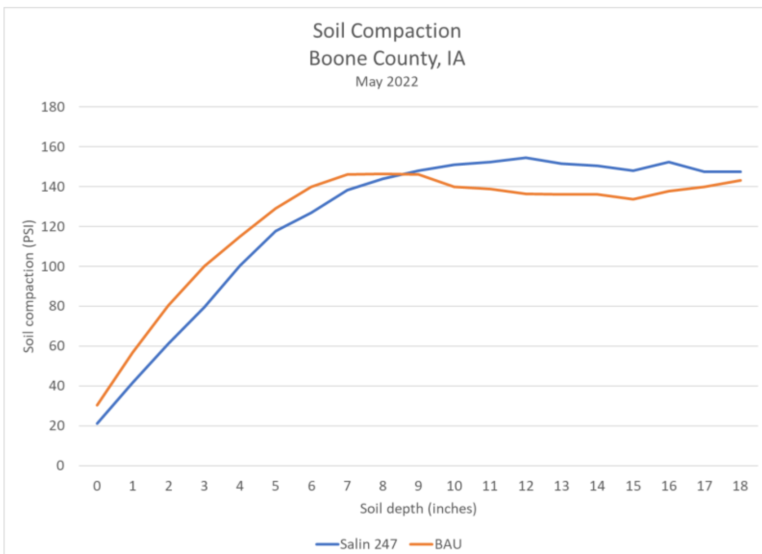


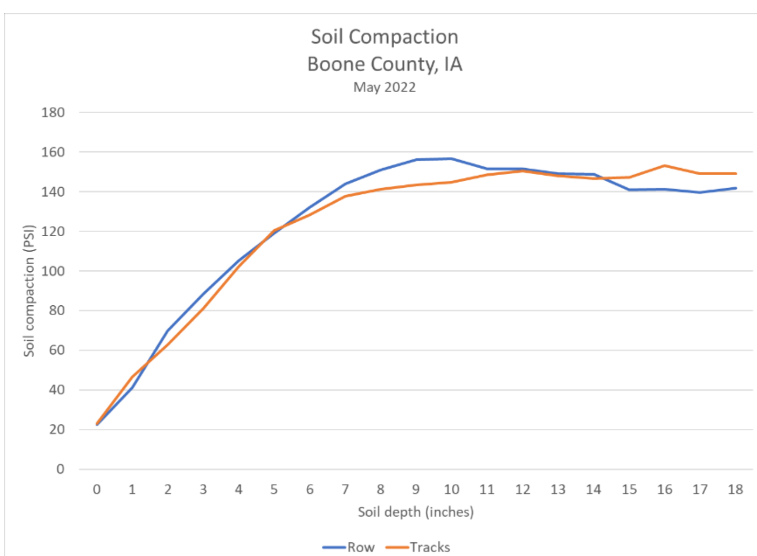
Based on learnings from the navigation error data, we are planning to implement and test an alternative navigation algorithm. Our preliminary testing shows that the new algorithm nearly eliminates the “offset” error we see at higher speeds.

Soil compaction data

Soil compaction data was collected on each of the seven test fields using a digital penetrometer that records soil compaction (PSI) every one inch of soil depth from 0 to 18 inches. Soil compaction measurements were taken for business as usual (BAU) and for Salin 247 planted areas of each field. BAU areas of the fields were areas planted by the farmer using their own planting equipment. Soil compaction measurements were taken at selected (not completely random) locations in the field with 6 to 12 penetrometer probes for each location with probes taken 10 inches apart across the planted rows. As a result, some samples were taken on tire/track tracks and some were taken where the tracks/wheels had not traveled. Results from two of the test fields are shown below.

The two charts below are derived from penetrometer data taken in the Boone County, IA field (10 sample locations with 12 sample probes per location for 120 samples). This was a conventionally-tilled field. BAU compaction was slightly higher than Salin 247 compaction in the upper eight inches of the soil. The second Boone County chart below shows that the Salin 247 planter had a negligible impact on soil compaction.

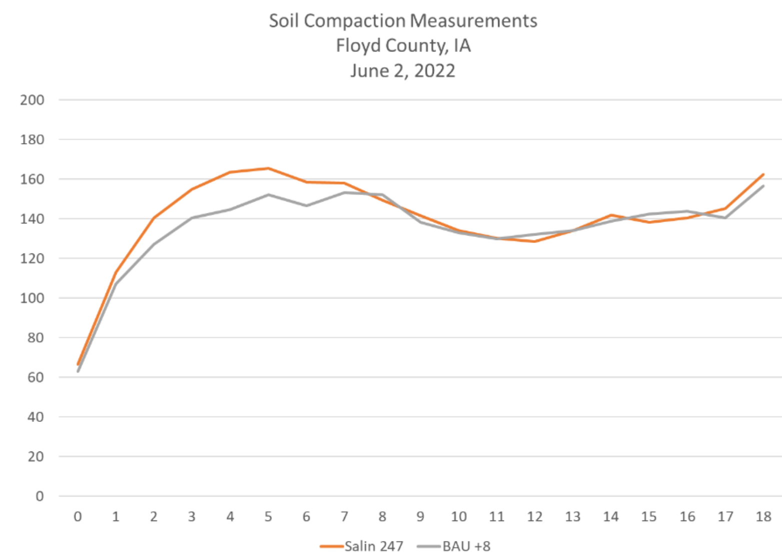


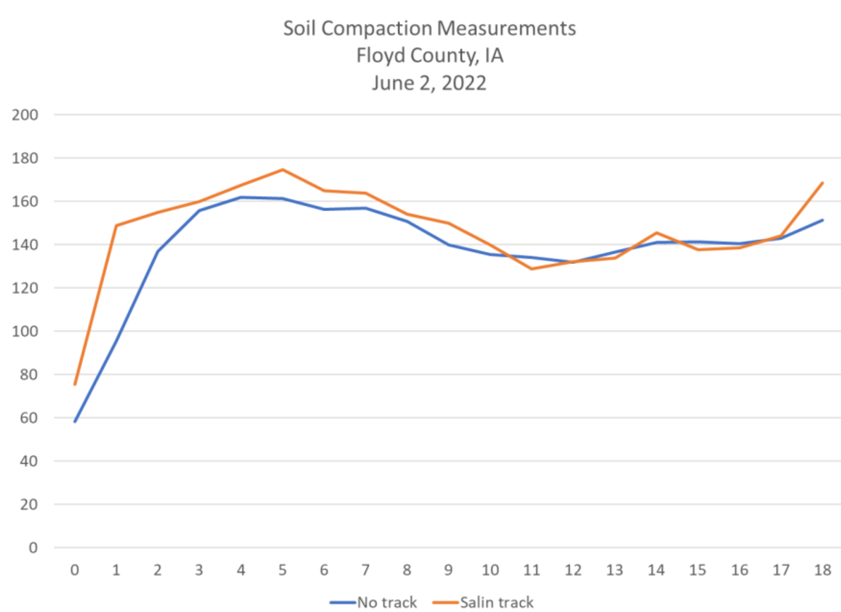


The two charts below are derived from soil compaction data from the Floyd County, IA field. This was a no-till field although a light vertical tillage tool was used in the fall to break up corn residue. Nine locations and six samples per location for a total of 54 samples.

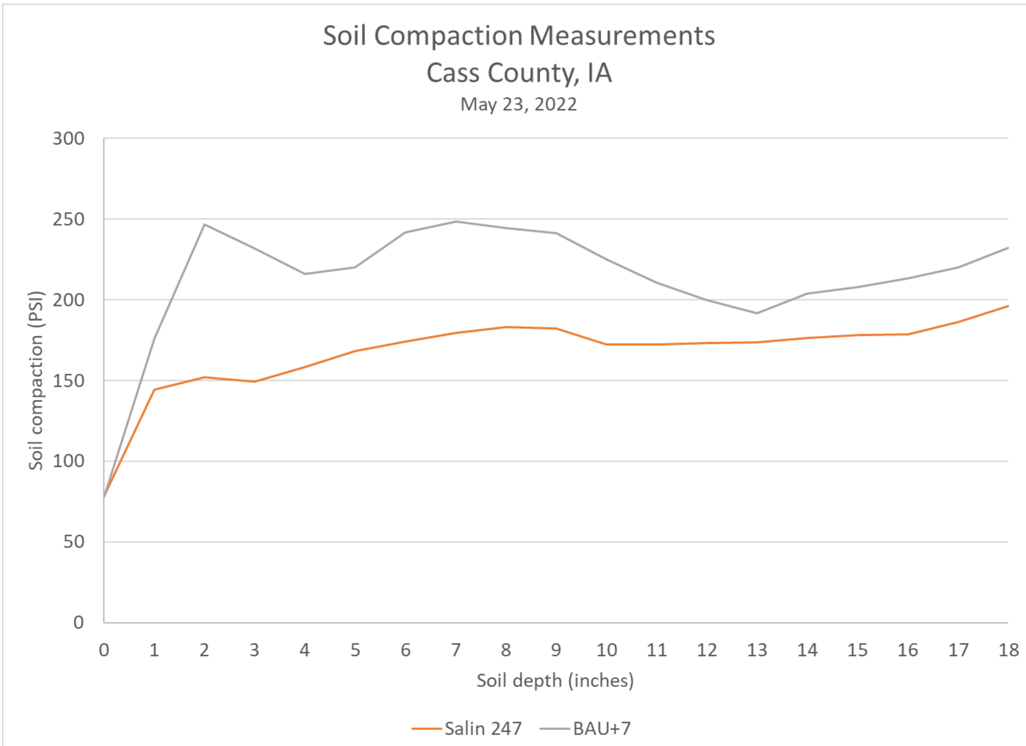
Data from this field shows that the Salin 247 planted portion of the field had soil compaction that was somewhat higher compaction than the BAU +8 (grower planted part of the field that was planted 8 days earlier) part of the field. The eight-day difference in Salin 247 planting versus BAU planting could explain part of this compaction difference.

The second chart below shows that soil compaction under the Salin 247 tracks in the field was slightly higher than where tracks did not run. Not surprisingly, the highest increased compaction was in the top inch of soil.





The chart below is derived from penetrometer data taken in the Cass County, IA field (10 sample locations with 6 sample probes per location for 60 samples). This was a soybean after corn no-till field. BAU compaction was higher than Salin 247 compaction throughout the soil profile, but the BAU sample locations were located at the edge of the field where soil compaction is expected to be higher due to higher traffic in that part of the field. This field had some compaction sample points where compaction exceeded 300 PSI. We did not collect data on tracks versus no-tracks Salin 247 planted areas.

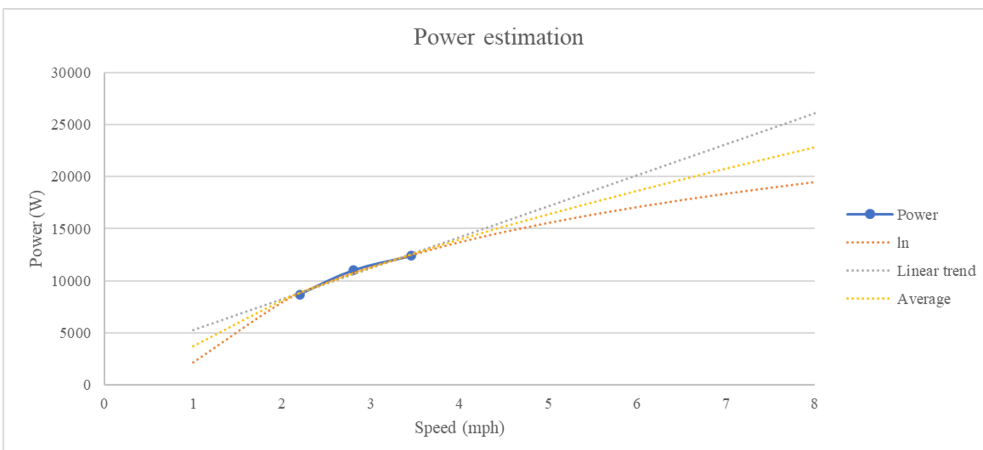


Energy use

Collecting energy use estimates was not part of the original project scope, but information on energy use is important in order to size battery and generator capacities. Energy usage data was collected at three average speeds – 2.2, 2.8, and 3.5 mph (target speeds were 2.5, 3.0, and 3.5 mph). Using this energy use data, energy use was estimated for speeds lower than 2.8 mph and greater than 3.5 mph (up to 8 mph). The objective is to plant at a minimum speed of 5.5 mph. With the Salin 247 prototype, a 4-row planter planting at 5.5 mph would require about 18 KW of power which means the current 10 KWh battery (the size currently on the prototype) would need to be recharged or swapped every 30 minutes. The energy use is higher than what we expected. One question we have now is What is the difference in energy use for tracks versus wheels? Would a wheeled version of our planter require less energy and, if so, how much less?

Energy use information from these tests will help us as we define an optimal size of planter, batteries, and generators. This information will also help us decide between on-board battery charging versus remote (e.g., end of field) charging.

Energy use estimates for the 4-row Salin 247 track planter at selected planting speeds



Energy use estimates for selected Salin 247 track planter sizes and planting speeds

	Per row			2-row			4-row			7-row		
Speed (mph)	ln	Linear	Average	ln	Linear	Average	ln	Linear	Average	ln	Linear	Average
1.0	550	1321	935	1099	2642	1871	2199	5284	3742	3848	9247	6548
2.0	1994	2065	2029	3988	4130	4059	7975	8259	8117	13956	14454	14205
2.5	2459	2437	2448	4917	4873	4895	9835	9747	9791	17210	17057	17134
3.0	2838	2809	2824	5677	5617	5647	11354	11234	11294	19869	19660	19765
3.5	3160	3180	3170	6319	6361	6340	12638	12722	12680	22117	22263	22190
4.0	3438	3552	3495	6876	7105	6990	13751	14209	13980	24065	24866	24465
5.0	3903	4296	4099	7805	8592	8199	15611	17185	16398	27319	30073	28696
5.5	4101	4668	4385	8202	9336	8769	16405	18672	17538	28709	32676	30692
6.0	4282	5040	4661	8565	10080	9322	17130	20160	18645	29977	35279	32628
7.0	4604	5784	5194	9207	11567	10387	18415	23135	20775	32225	40486	36356
8.0	4882	6527	5705	9764	13055	11409	19527	26110	22819	34173	45692	39932
	8-row			11-row			15-row			24-row		
Speed (mph)	ln	Linear	Average	ln	Linear	Average	ln	Linear	Average	ln	Linear	Average
1.0	4398	10568	7483	6047	14531	10289	8246	19815	14031	13193	31705	22449
2.0	15950	16518	16234	21931	22713	22322	29906	30972	30439	47850	49555	48703
2.5	19669	19494	19581	27045	26804	26924	36880	36550	36715	59007	58481	58744
3.0	22708	22469	22588	31223	30894	31059	42577	42129	42353	68123	67406	67764
3.5	25277	25444	25360	34756	34985	34870	47394	47707	47551	75831	76331	76081
4.0	27502	28419	27961	37816	39076	38446	51567	53285	52426	82507	85256	83882
5.0	31221	34369	32795	42929	47257	45093	58540	64442	61491	93664	103107	98386
5.5	32810	37344	35077	45113	51348	48231	61518	70020	65769	98429	112032	105231
6.0	34260	40319	37290	47107	55439	51273	64237	75599	69918	102780	120958	111869
7.0	36829	46269	41549	50640	63620	57130	69055	86755	77905	110487	138808	124648
8.0	39055	52220	45637	53700	71802	62751	73227	97912	85570	117164	156659	136911

Soybean yield data

We did not ask collaborator growers to collect detailed yield data for us, and as this report is being prepared, only one of the test fields has been harvested. Growers have told us, however, they will share any yield-related information that they do collect at harvest. The first field we planted in Boone County, IA has been harvested and yielded approximately 60 bushels per acres. The grower will provide us with the yield monitor data file follow harvest. Yield data that is received will be correlated with selected data collected at planting.

Key learning

General observations

The following is a summary of some of our general observations and key learnings so far from the field tests.

- The prototype planter did a very good job of planting (in terms of population, singulation, doubles, skips, depth, etc.) when field conditions were in good shape and there was minimum soil compaction
- In areas of the fields where soil compaction was high, keeping the gauge wheels on the ground and the double disk openers in the ground was a challenge due in part to the light weight of the prototype planter.
    - As a result, we had to add weight to the left and right back of the machine as well as to the left front
    - Adding additional weight helped but did not completely solve the problem on some of them most compacted soil
    - Adding weight did increase energy use
- Related to the above issue, we learned that weight balance (front to back and left to right) are important for our planter. When planting, a large portion of the weight of the machine is on the front tracks. As a result, when using high downforce, the back tracks loose some traction. However, on turns when the planter is raised, a large portion of the weight is on the back tracks which occasionally causes the front tracks to spin.
- We had some navigation degradation at higher speeds (i.e., above 3 mph).
    - We have observed and data collection has shown that the machine does not converge to the AB line at higher speeds
    - We are looking into reasons including uneven left to right weight balance
    - We are also testing a new navigation algorithm that seems to eliminate some of the navigation error (i.e., offset error)
- Energy use for planting with the prototype is somewhat higher than our original estimates.
    - To address this issue in the short-run, we installed a generator on the machine to keep the batteries charged. This may or may not be a permanent solution. We are looking at the energy use requirements at various speeds and planter sizes and based on that information, we will be formulating a battery management strategy
- We burned up the electric motor to our vacuum system twice. Our theory is that dust is getting into the motor bearings and causing trouble. We have a short-term work-around solution but need to address the ultimate cause of the problem.
- We increase soil compaction only a negligible amount with our light-weight planter
- We generally feel very positive about the performance of the prototype planter. When we solve the weight balance, energy use, and navigation issues, we will have an impressive machine for autonomous planting.

Grower feedback

We have gotten feedback from our collaborator growers on a range of things. They understand that we were testing a prototype in the field and so they provided more ideas than critique. They also asked a lot of questions. A sampling of the feedback is below.

- Growers generally agreed that we need to plant at 5 to 6 mph. Some are also interested in planting at 6 to 10 mph with speed tubes
- Our navigation errors are less of an issue with soybeans than they will be with corn
- Most agree we will need to add more weight in order to get to needed downforce
- All growers that have used row-by-row hydraulic downforce recommend we use the same
- Growers agree that an efficient and reliable docking station is needed for seed refilling
- A central seed box would probably work better than individual seed boxes
- Use of the generator to keep the batteries charged was not a concern
- All collaborator growers either already plant at 15-inch rows or would like to evaluate 15-inch rows so they thought we should also have the capability to plant 15-inch rows
- Most growers asked if we planned to go beyond a 1-foot planter toolbar
- Growers understand that we need to develop the ability to control the Precision Planting functionality remotely (currently the 20/20 monitor is located on the planter)
- Growers like our tracks but understand the turning issues we are having need to be corrected and going to wheels is not a big concern
- Growers understand that we need to correct our cooling system
- Growers don't have strong feelings about electric but aren't opposed to it if we can make battery charging easy (either on-board charging or battery swapping)
- Growers recommend coulters instead of row cleaners when planting 15-inch rows
- Growers are asking how multiple machines in the field working together will work
- Growers are asking if the docking station will be stationary or mobile
- Growers are asking how field layout and navigation will work
- A couple of growers wondered if the Salin 247 planters will work together with their existing planters in terms of sharing as planted data, for example
- Our collaborator growers were very intrigued with the Salin 247 autonomous planter and were also extremely helpful for us

Grower Outreach

Salin 247 scheduled demonstration and field days in order to get feedback beyond the collaborative growers. Key events included:

- Invited growers and others to the Floyd County, IA farm the day of planting on June 2
- Conducted a Field Day for ISA at the Becks Hybrids farm near Colfax, IA on August 4
- Conducted a Field Day at the ISU farm near Lewis, IA in August
- Conducted a Field Day at the North Iowa Community College in Mason City in September
- Attended the Farm Progress Show near Boone, IA in Aug/Sep
- Featured on Farm Next RFDTV program in August

2022/2023 ISA Research Project

The 2022/2023 ISA Research Project will focus on continuing to evaluation key Salin 247 autonomous planter performance but also to use the autonomous planter to implement on-farm trials on 10 farms. We are currently working with ISA on defining the details of the on-farm trial plan. Salin 247 is very appreciative of the valuable support we are getting from ISA on our testing and evaluation of small-scale, light-weight, autonomous farm equipment.

Based on our research and testing so far, we feel that the small-scale, light-weight autonomous platform for planting soybeans (and corn) is not only feasible but will ultimately be shown to be economically advantageous as well.