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Real-time gauge wheel load variability on planter with downforce control during field operation

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Abstract. *Downforce control allows planters to maintain gauge wheel load across a range of soil resistance within a field. Downforce control is typically set for a target seed depth and either set to manually or automatically control the gauge wheel load. This technology uses load cells to actively regulate downforce on individual row units by monitoring target load on the gauge wheels. However, no studies have been conducted to evaluate the variability in gauge wheel load observed during planter operation under real-world field conditions. Therefore, the objective of this study was to 1) evaluate real-time gauge wheel load variability across planter rows given a target gauge wheel load for a planter equipped with downforce control and 2) compare and contrast gauge wheel load measurements across differing rows to intercept downforce control diagnostics. A 12-row planter equipped with hydraulic downforce control was utilized for planting three fields. The planter was segregated into four sections, each with independent downforce control via two bending beam load cells to record gauge wheel load. Control-section 1 and 3 comprised 3 rows units each on the left and right side of the planter bar. Control section 2 involved 4 row units following the tire tracks and section 4 was two rows in the middle. The downforce system utilized four hydraulic blocks each controlling downforce to maintain target gauge wheel load for the respective row units. The planter was set to plant at 5.2 cm depth and the target gauge wheel load was set at 91 kgf. A data acquisition system recorded real-time GPS, planting speed, load cells output, and planting status at 10 Hz. Data was analyzed to compute average gauge wheel load across each of the 8-row units with load cells, and average gauge wheel pressure for each of four sections. Average required downforce variability across control sections and percent area planted with beyond ± 20% of target gauge wheel load were computed. Results suggested that more than 50% of the field was planted with gauge wheel load beyond ± 20% of target. There was also significant difference in actual gauge wheel load across the four control sections. Future studies will be designed to understand conditions impacting variability in gauge wheel load and ability of the modern downforce system to seeding depth under real-world conditions.*

Keywords. *Precision agriculture, planters, rate control, planter downforce, gauge wheel load, real-time*

Introduction

Seeding performance of planters can be evaluated by the seeding depth, the uniformity of seeding depth, and the early crop performance, such as speed of crop emergence and plant populations. (Doan, V et al. 2005). Variation in planting depth, non- uniform surface crop residue distribution in no-tillage systems, microsite variation in the seed bed condition, and seed vigor are major factors responsible for uneven time of seedling emergence in the field (Andrade and Abbate, 2005). Insufficient seeding depth results in a poor crop emergence (Janelle et al. 1993). It is well documented that crop stand is important in determining final grain yield (Evans and Fisher, 1999; Tollenaar and Wu, 1999, Lawles, K. et al, 2012). Planting depth studies show not only that fewer plants emerge when seeds are planted deep but also that those emerging may take longer to reach the pollination stage which reduces grain yield from 6 to 22% (Nafziger, 2012).

To achieve uniform seedling emergence requires placing seeds at the required depth consistently, seed by seed, and row by row, and involves the proper down force management during planting. Maintaining a constant down force while seeding will help to achieve a uniform seeding depth under a uniform soil condition. However, determining the amount of down force can be difficult as this can be affected by varying soil types, types of tillage, soil moisture, residue conditions and speed of planting. Variation in down force load of gauge wheels may vary seed depth and compaction around the seed (Hanna, et al. 2010). Increasing downforce generally increases seeding depth (Janelle et al. 1993). Conversely if excessive downforce is applied, especially in soft or moist soils, it can produce sidewall compaction, which can lead to poor root development. Firm soil limits penetration by the seed opener, which may make it difficult for the depth wheels to make solid contact with the ground surface. This situation may result in a shallower planting depth (Gratton et al. 2003). Generally, most planters have increased soil contact pressure of depth wheels by increasing down spring tension through parallel links attaching the planter row units to the toolbar frame. Some newer planters use a central adjustment for soil contact force of depth wheels through use of pneumatic diaphragms to transfer weight to row units.

It is essential to find the right balance of pressure to provide adequate seed to soil contact, but without causing over-compaction (Hanna, H.M. 2009). It can be very challenging to find the optimum down force to help provide the favorable soil environment for seeds as planting conditions are typically less than ideal. Seed depth may vary on uneven land because the press wheels control depth at some distance from the seed opener. For uniform planting on uneven fields, each row unit should operate independently of the others (Buchholz, D. et al,1993). Most planters have various means on controlling downforce by row units or by sections using either a spring tension device, airbags, or hydraulic cylinders. It can be automatically controlled using sensors by increasing or decreasing air pressure or hydraulic pressure and instantaneous adjustments can be made as field conditions change.

Methodology

Field tests were conducted using a 12-row Horsch (Horsch Maschinen GmbH, Schwandorf, Germany) planter with variable rate and section control technology. The row units were spaced at 762 mm. The planter was operated using a John Deere 8270R tractor. The planter control was accomplished using a 2630 John Deere (GreenStar-3, Deere and Company, Moline, IL, U.S.A.) field computer connected to the planter electric control unit, hence forth referred as ECU, (Horsch Maschinen GmbH, Schwandorf, Germany) through ISOBUS. The planter was programmed to implement automatic section control by shutting individual row motors (BG 45x15 SI, Dunkermotoren GmbH, Schwarzwald, Germany) on or off based on coverage map. In order to maintain seed spacing during planter speed transitions, ECU utilized feedback from ground speed radar (Radar III, Dickey-John Corp., Auburn, IL, U.S.A.) which was sent to each row motor control module (Horsch Maschinen GmbH, Schwandorf, Germany) to generate target motor rpm based on seed population using a planetary gearbox (PLG 42S, Dunkermotoren GmbH, Schwarzwald, Germany). The seed tube sensor on each row unit (Hy Rate Plus, Dickey-John Corp., Auburn, IL, U.S.A.) provided feedback on seed singulation, doubles and misses, to field computer.

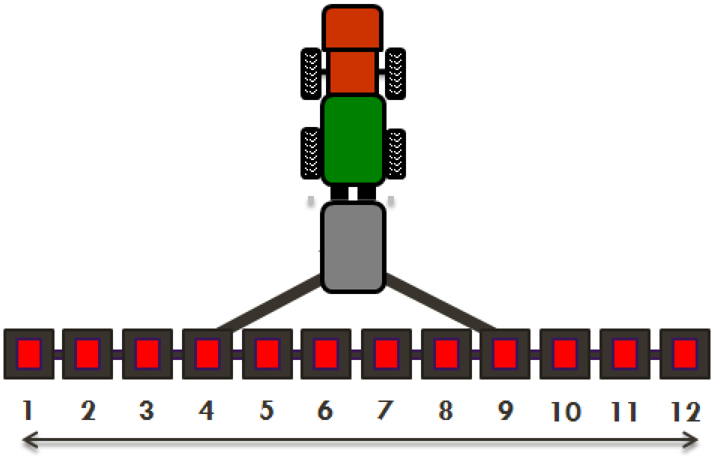


Figure 1. Planter layout containing 12 row units numbered 1 through 12 from left to right. Each row units was equipped with a load sensor.

Soil EC

The Soil EC is a measure of the ability of the soil to conduct electricity and is typically reported in milliSiemens per meter (mS/m). An electrical current may be conducted through soil via 1) soil solution of water and ions within a web of pores; 2) cations attached to the surfaces of clay particles and; soil particles connected to each other. Research has shown soil EC measurements association with soil properties like soil texture, drainage condition and subsoil characteristics (Kitchen et al., 2003; Grisso et al., 2009). Therefore, spatial soil EC data were compared with average gauge wheel loading to quantify if average gauge wheel load distinctly vary for regions with EC variability.

On-the-go soil apparent electrical conductivity (EC) was measured using Veris Mobile Sensor Platform (MSP) (EC Surveyor 3150, VERIS Technologies, Salina, KS, U.S.A.). The Veris MSP was mounted on the three point hitch of a Kubota M9000 tractor. The Veris EC Mapper within MSP was programmed to measure EC at both shallow (0 to 0.3 m) and deep (0.0 to 0.9 m). The MSP was operated at 18.3 m transects. The Veris SoilViewer v2.70 logged real-time point data and GPS data. Sample locations were selected based on EC zonal characteristics then soil cores were collected from each zone for laboratory analysis. The sample locations were selected representing the soil with low, medium, and high EC measurements. The average soil moisture during EC mapping was 34.5% volumetric water content (HydroSense II, Campbell Scientific, Logan, UT, U.S.A.). Soil samples were analyzed by the Department of Agronomy Soil Test Lab at Kansas State University. Laboratory and in-field measurement data were sent to Veris Technologies for calibration and EC map EC maps were generated using ArcGIS (ESRI, Redlands, CA, U.S.A.). For finding correlation between the soil EC and gauge wheel load, a random location within each soil EC zone with an area of 5000 m^2 was selected. All the data points within the selected area were average to calculate an average gauge wheel load to plot on the EC map in ArcGIS.

Planter Field Tests

Field tests were conducted with a standard planter setting to plant at 50.8 mm depth by properly setting the gauge wheel. The planter was programmed to plant the growers' status quo population of 28,500, 30,000 and 32,000 corn seeds per acre in Field A, Field B, and Field C, respectively. The experiments were conducted consistent with no-till management. The planter was instrumented with load sensors (6784, Horsch Maschinen GmbH, Schwandorf, Germany) mounted on all 12 row units to measure gauge wheel loading (Figure 2). The designed measurement range of load sensors was up to 1,000 kg with a linear response on the scale of 4-20 mA. Planting speed and position data were collected simultaneously using a sub-inch GPS unit (GR5, Topcon Positioning Systems, Inc., Livermore, CA, U.S.A.). A data acquisition system was developed to record signals from the eight load sensors, ground speed radar, and GPS data at 10 Hz, as a text file.

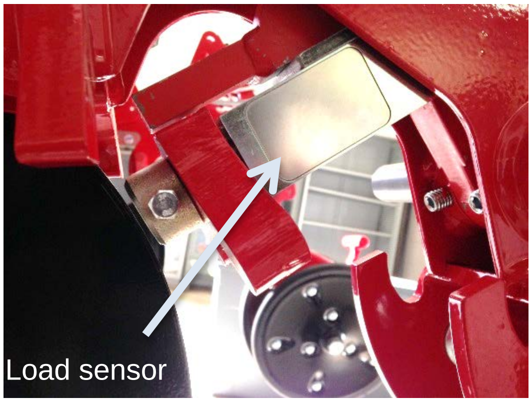


Figure 2. Load sensor mounted on the cam assembly placed across the gauge wheel arms.

The load sensors were calibrated in the laboratory using known weights to record sensor signal versus kgf data. A regression line was fitted to sensor signal versus kgf data to convert real-time load sensor signal to kgf representing gauge wheel loading (Figure 1). Real-time gauge wheel load across all rows were analyzed to calculate gauge wheel load range across all rows and quantify the percent time that gauge wheel loading was 1) within the target range of ±22.7 kgf of the target 45.4 kgf, 2) greater than target range, and 3) less than the target range. The average gauge wheel load from all rows, gauge wheel load range, and planting speed were mapped using ArcMap 10.1 (ESRI, Redlands, CA, U.S.A.).

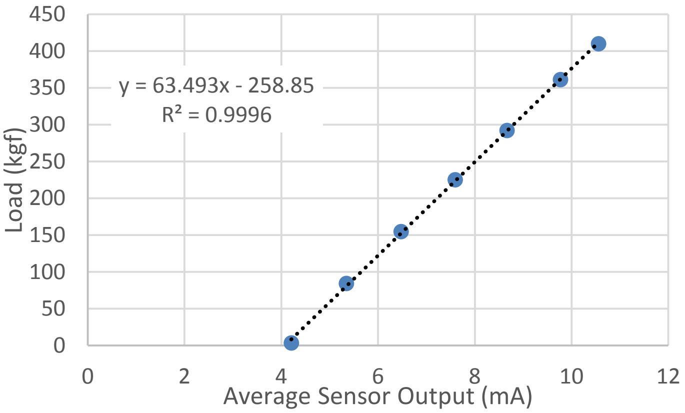


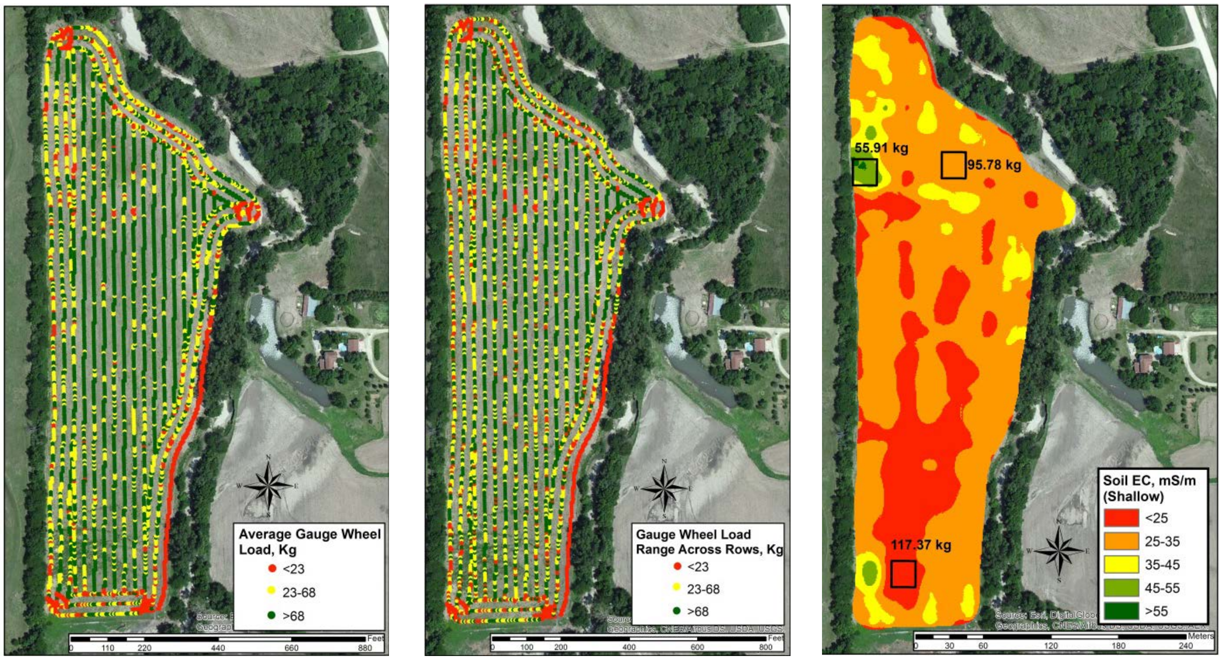
Figure 3. Regression line fitted between known loads versus load sensor output

Results and Discussion

Results from the three fields, Field A (7 ha), Field B (4 ha), and Field C (11 ha), highlighted that real-time gauge wheel loading varied continuously throughput planting operation (Figure 4 through 6). The results indicated that desired fixed downforce of 45.4±22.7 kgf (23-68 kgf) was achieved for only 23% of the time. The gauge wheel load was below the target range for 17% and above the range for 60% of the time. These results suggested that desired gauge wheel loading was not achieved for the 77% of the time for the three fields (Figure 7). The gauge wheel loading lower than the desired value could impact seeding depth and higher than desired could result in excessive side wall compaction. The seeds planted at lower than target gauge wheel loading may get placed at undesirable depth and moisture zone leading to weak root growth or poor germination. Likewise the seeds planted with greater than target gauge wheel loading may have excessive side wall compaction leading to delayed emergence.

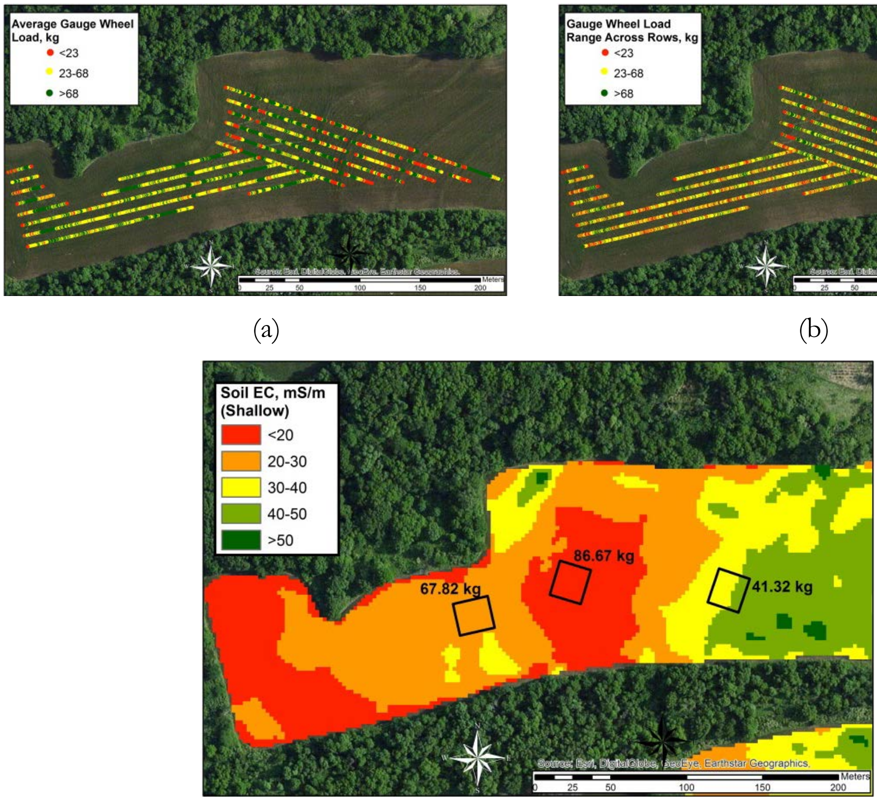
The gauge wheel load range across the 12 row units were greater than 68 kgf for 74% of the time and was within 23 kgf for 24% of the time (Figure 4b through 6b and Figure 8). The gauge wheel load range of more than 68 kgf indicated that for 74% of the time row units required different level of loading. Therefore one single setting for the entire toolbar would not be sufficient to achieve target gauge wheel loading across all the row units.

Real-time gauge wheel loading was found to be strongly correlated to soil EC for all fields (Figure 4c through 6c). Different soil EC zones within each field exhibited significantly varied average gauge wheel loading values. The soil EC maps also showed that soil texture varied across the field. It should be noted that the planting period experienced many rainfall events and the average moisture during planting varied from 34% to 42%. However, less than desired rainfall or more varied moisture can further impact the gauge wheel loading due to varied soil resistance to planter row unit opening discs. Overall the different soil EC zones exhibited gauge wheel loading from 41 to 117 kgf indicating the fixed downforce system would not be able to provide the continuously varying downforce for target gauge wheel loading. The gauge wheel load range of > 68 kgf also suggested that multiple sections would be required as row to row downforce varied in the field. The gauge wheel load was above and below the target range for 60% and 17% of the time which also indicated that active downforce control should have control setup to implement loading and unloading of row units based on planting in heavier and lighter soils respectively. Further studies with active downforce control needs to be conducted to assess if the technology can achieve target gauge wheel loading and uniform seeding depth.



(a) (b) (c)

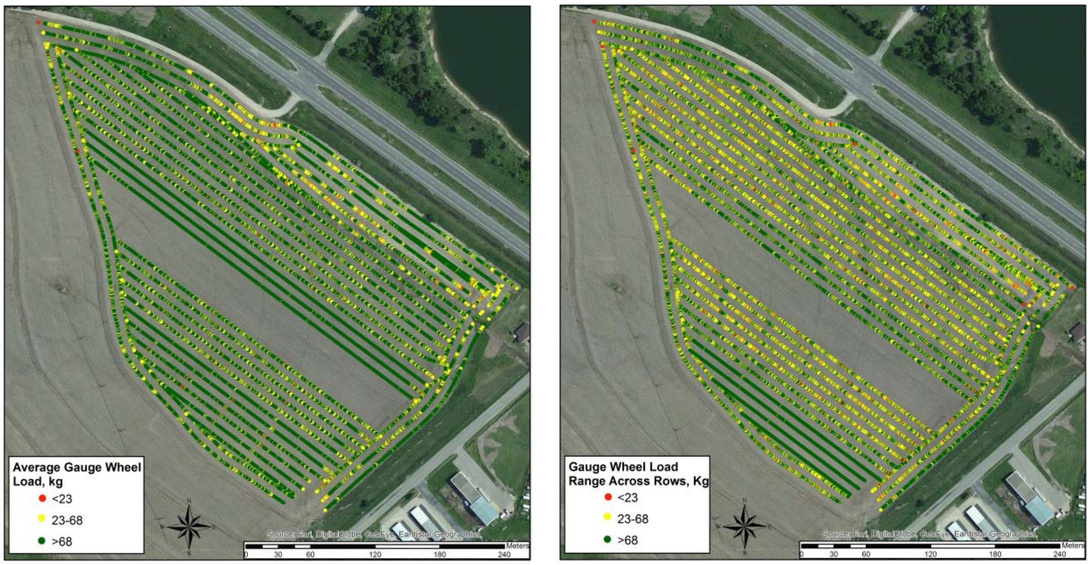
Figure 4. Average gauge wheel load (a); gauge wheel load range (b) and; average gauge wheel load at three random locations with different EC (c) for Field A.



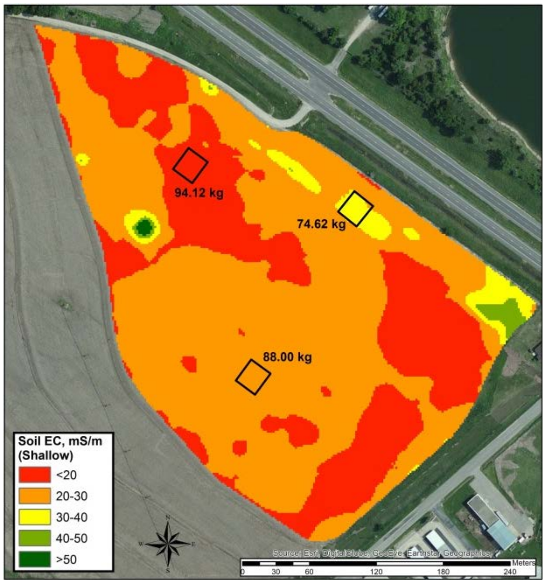
(a) (b)

(C)

Figure 5. Average gauge wheel load (a); gauge wheel load range (b) and; average gauge wheel load at three random locations with different EC (c) for Field B.



(a) (b)



(c)

Figure 6. Average gauge wheel load (a); gauge wheel load range (b) and; average gauge wheel load at three random locations with different EC (c) for Field C.

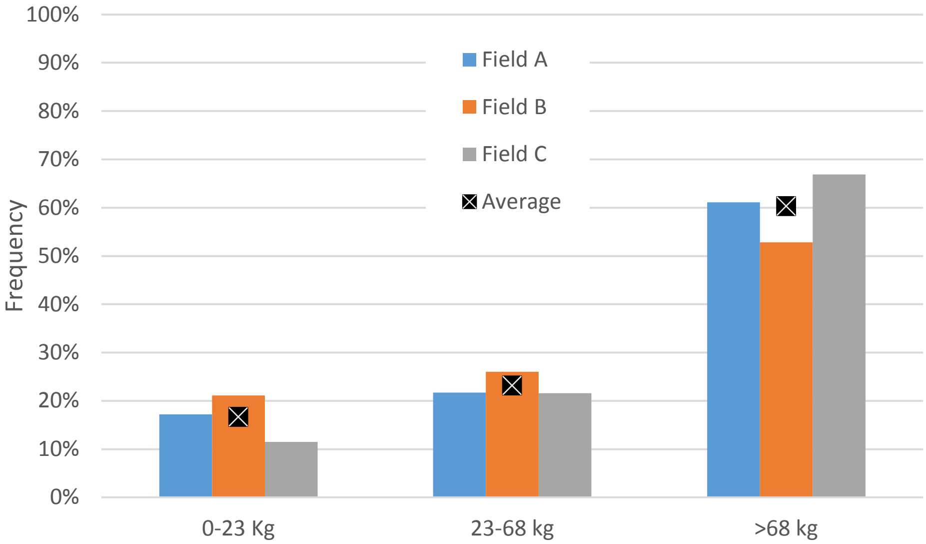


Figure 7. Percent time average gauge wheel loading was within and beyond the target range of 23 to 68 kgf for Field A, Field B and Field C. The average represents percent time gauge wheel load was within each load category collectively for Field A, Field B and Field C.

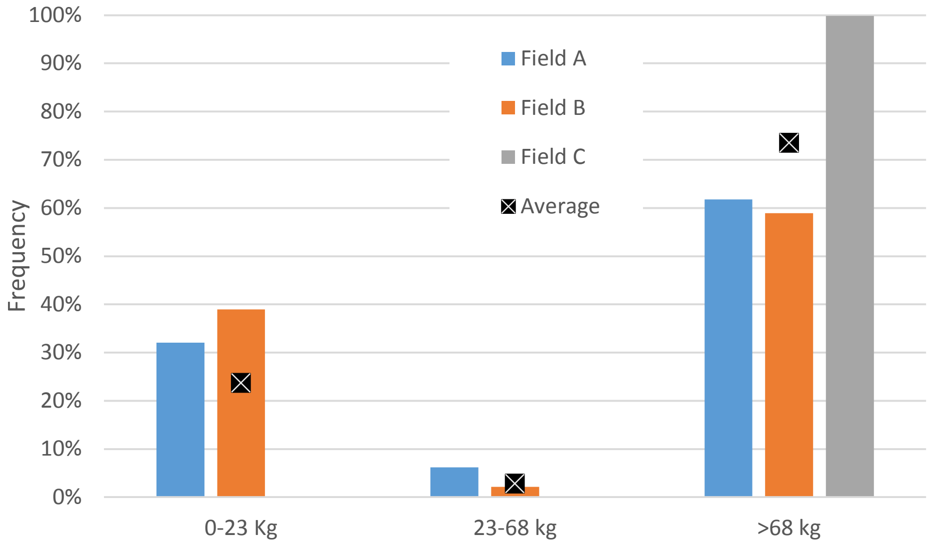


Figure 8. Percent time gauge wheel load range was within and beyond the 23 to 68 kgf for Field A, Field B and Field C. The average represents percent time gauge wheel load was within each load category collectively for Field A, Field B and Field C.

Summary

Overall, the real-time average gauge wheel load varied across the field due primarily to the soil EC or soil texture. The gauge wheel load was lower and higher than the target loading for 17% and 60% of time respectively. On an average for all fields, the gauge wheel range was more than 68 kgf for 74% of the time indicating that row units had varying gauge wheel loading. These results indicated the need for active downforce control to maintain target gauge wheel loading to counter the varying soil resistance on opening discs. It is also indicative that multiple control section would be needed to accurately implement desired gauge wheel loading in order to achieve uniform seeding depth. Results from all three fields also exhibited that active downforce control system should have functionality to load and unload the row units based on field conditions as real-time gauge wheel load was >68 kgf for 60% of the time. Excessive load on gauge wheel would result in excessive side wall compaction and poor root growth.

This project also emphasis that gauge wheel load was highly correlated to soil EC. Therefore, field studies needs to be conducted with active downforce control system at different planting speeds and downforce setting to quantify gauge wheel load uniformity and planting depth.

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