As-applied Maps of Planter Performance During Corn Planting – How the Numbers Looks Like After Plant Emergence

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Abstract.

High-quality planting operations are important for high yield crops. Poor distribution compromises emergence and plant development, thus affecting crop productivity. Therefore, uniformity of seed distribution in the soil, with adequate depth and spacing, is essential for high yield. Moreover, embedded electronics on modern planters allow data collection from sensors that provide information regarding planter performance such as measurements of seed spacing quality (doubles, skips, acceptable and coefficient of variation), gauge wheels contact to soil, downforce applied to furrow opener, and even vibration. All that information can be used for real-time operation monitoring for eventual decisions to be made during the operation, as well as the generation of the as-applied maps to use in other steps of the whole Precision Agriculture analysis cycle. Numerous studies have been dedicated to evaluating seed counting sensors, types of metering devices, and the effect of working speed on longitudinal distribution, as well as other factors influencing planter performance. However, most of these investigations are conducted at the bench level, employing methodologies such as planting conveyors, image analysis, and other controlled arrangements. In contrast, there is still a lack of research that directly evaluates the quality of such as-applied maps generated based on the information provided by the planter's embedded systems. When performing plant spacing measurements on Mato Grosso farms, researchers have observed that plants distribution was often diverging from *what was recorded and presented on as-applied maps, especially regarding acceptable and coefficient of variation. Therefore, the objective of this work was to conduct a study considering the numbers found on planters as-applied maps and numbers measured directly in field. The work was carried out in February of 2026, in two different fields of a farm located in Ipiranga do Norte (MT) during corn planting operation. The machines were equipped with 20 rows using electric drives running pneumatic seed meters and commercial embedded electronics to monitor operation, a very popular equipment in the region. The collected data was extracted from planter monitor using SMS basic (Agleader). The data was then exported on ".csv" format and post-processing for it and as-applied map compilation was carried out on Matlab (2024). Planter performance was manually evaluated in three different locations of each field. On each location, plants spacing was measured on different rows resulting in a minimum of 130 meters of rows evaluated split on three or more replicates. The performance parameters such as doubles, skips, acceptables and coefficient of variation were computed and compared with data obtained from the as-applied maps. The results indicated that the evaluated as-applied information tend to underestimate parameters such as CV and skips and overestimate acceptable.*

Keywords.
Planter performance, As-applied maps, Precision Agriculture.

1 Introduction

High-quality planting operations are among the most important factors influencing crop establishment and yield potential. Uniform seed distribution, with adequate depth and spacing, promotes proper plant emergence and reduces intraspecific competition for water, light, and nutrients. Conversely, the occurrence of skips, doubles, and high variability in plant spacing can negatively affect crop development and reduce productivity (Chim et al. 2014; Badua et al. 2021).

Plantability can be defined as the ability of a planter to distribute seeds uniformly while maintaining the target population and the desired spacing between plants (Fernandes et al. 2019). To evaluate planting quality, parameters such as skips, doubles, singulation, and the coefficient of variation (CV) of plant spacing are commonly used (Kachman and Smith 1995; Bozdoğan 2008).

Advances in Precision Agriculture have led to the incorporation of embedded electronic systems into modern planters, allowing real-time monitoring of planting operations. These systems use sensors installed on each planting row to detect seed passage through the metering system and seed tubes, providing performance indicators related to seed distribution quality. In addition to real-time monitoring, the collected data can be used to generate georeferenced information, commonly referred to as plantability maps or as-applied maps (Gil and Carnasa 1996).

Numerous studies have focused on evaluating seed counting sensors, metering devices, and the effects of operating speed on seed distribution quality. Most of these investigations are conducted under controlled conditions using laboratory test benches, planting conveyors, image analysis systems, and other experimental arrangements (Nardon and Botta 2022). However, studies directly evaluating the ability of planter-generated as-applied maps to represent the actual plant distribution observed after crop emergence under commercial field conditions remain limited.

Although seed sensors can provide highly accurate measurements of seed passage, the information recorded by these systems represents only the events detected during the planting operation. Several factors occurring after seed detection, including seed movement within the seed tube, displacement in the furrow, improper planting depth, germination failure, pest damage, diseases, and early plant mortality, may alter the final plant distribution observed after emergence (Nardon and Botta 2022). Consequently, planter-recorded parameters may not fully represent the conditions effectively established in the field.

During evaluations of plant spacing distribution conducted in commercial production fields in the state of Mato Grosso, Brazil, it was observed that the parameters presented by as-applied maps frequently differed from those obtained through post-emergence field measurements, particularly regarding singulation and coefficient of variation. This observation highlights the need to validate the information provided by embedded monitoring systems before it is used for agronomic analyses and decision-making processes.

Therefore, the objective of this study was to compare planter performance parameters obtained from commercial as-applied maps with those measured directly in the field after corn emergence.

2 Materials and Methods

The study was conducted in February 2026, after corn emergence, in two fields located in the municipality of Ipiranga do Norte, Mato Grosso, Brazil. Planting was carried out using a commercial planter equipped with 20 rows pneumatic seed meters electrically driven, with target seed rate of 68.000 seeds.ha^{-1} at 0,6 m row spacing, and equipped with a embedded electronic monitoring system capable of recording planter performance parameters such as skips (SK), doubles (DO), acceptable (AC) and coefficient of variation (CV). The seed sensor was an optical type located at about halfway into the delivery seed tube.

By the time the field evaluation (plant counts) was ready to be conducted (14 to 16 days after planting), researchers did not have access to the planter's log file to process the as-applied map. Therefore, six sampling zones were randomly chosen across two corn fields for data collection.

Plantability parameters, regarding longitudinal spacing, were computed according to (Kachman and Smith 1995; Nardon and Botta 2022) in which a tolerance (tol%) around the theoretical reference spacing (xref) is applied to define spacings considered as skips (SK), doubles (DO), acceptable (AC). Along with those parameters, a measure of relative dispersion (CV- Coefficient of Variation), was also computed. Kachman and Smith (1995) reported a tolerance of 50%, whereas some studies have used smaller tolerances for parameter calculation, as reported by Nardon and Botta (2022). Therefore, 50 and 30% were used in this study for performance comparison purposes.

The proposed method suggests that at least 250 spacings should be used for parameters computation, thus imposing a slow and intensive labor task when such measurements are accomplished manually. Such tasks should be carried out throughout planting operations to very planter performance; however, operators, field managers (or any professional), don't have that kind of time, and therefore, use a smaller dataset such as 5 to 10 meters using tape measure. For this study, it was necessary to have a reasonable sample size; thus, a plant counting apparatus similar to the one proposed by Ferrari (2016) was used. The system consisted of a high-resolution rotary encoder (1024 PPR) connected to the wheel axle, a push button, and a GNSS receiver. The encoder was responsible for recording the displacement (based on the wheel radius) along the planting row, while the push button was triggered at each plant incrementing a counter. The information was recorded on a SD card, and it was used to calculate plant spacings (therefore, performance parameters), based on the information obtained from the rotary encoder. GNSS information was used for georeferencing the sampling zone since it was a low-cost, low-accuracy receiver. Using this apparatus, it was possible to collect a minimum of 130 m (broken into a minimum four replicates at each zone), resulting in a minimum of 500 spacings considering the target seed rate and row spacing. Therefore, the classical 10 m plant count was recorded using a tape measure to evaluate the impact of a smaller sample size in this type of study. Once the planter log file was obtained, data conversion was accomplished using SMS Basic (AgLeader) software and saved into csv format. The data were then processed by algorithms developed in MATLAB R2024a (MathWorks Inc., Natick, MA, USA), where the data were organized, filtered and matched with sampled zones evaluated with the plant count apparatus. This step was accomplished by drawing a polygon mask around the area where plant count was taken so the planter performance parameters from each method (plant count apparatus and embedded seed monitor system) could be compared. Data comparison was simply accomplished by descriptive statistics using MatLab boxplot graphs.

3 Results and Discussion

The selected data from the as-applied maps were grouped by the zones, and therefore, boxplot graphs were plotted for data comparison. For all the six evaluated zones selected for the analysis, ground speed of the planter around 8,5 ± 0,5 $km.h^{-1}$.

Plantability parameters obtained from field measurements (considering 50% tolerance around xref) and from the as-applied maps are presented in Figure 1.

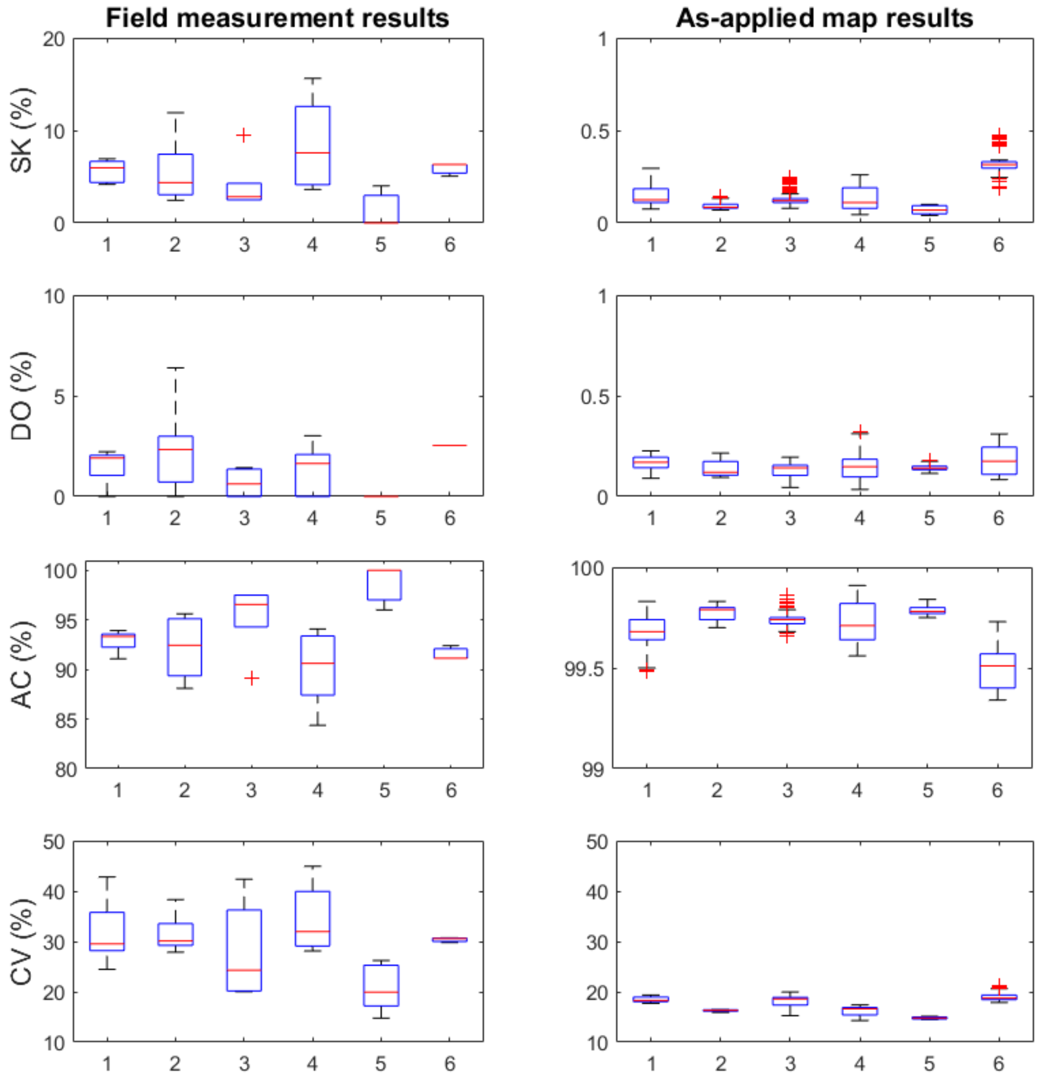

Fig 1. Comparison between planting performance parameters measured in the field considering 50% tolerance around the xref and those provided by the as-applied map

It can be observed that the SK measured in the field was substantially higher than the values provided by the planter monitoring system. While field evaluations showed values predominantly ranging from 5 to 15%, the as-applied maps indicated SK percentages close to below 0,5% across all evaluated zones. Measures of DO were also substantially lower on the as-applied maps as compared to field measurements, even though there was zero DO in some of the field measurements in all zones except zone 6. Obviously, a great difference for AC was also found between as-applied maps and field measurements, since SK and DO were greatly underestimated on the as-applied maps. The values above 99% from the as-applied maps are unrealistic, while the range 85 to 97% (majority 90 to 95%) found in the field evaluations is consistent with numbers found in literature (Cortez et al. 2020; Nadin et al. 2019).

There was also found a great difference regarding the CV values where field results presented values mainly around 30% except zone 5, while the as-applied maps results presented upper limits at 20%. Nadin et al. 2019 also reported CV around 34 % for the similar working speed (8 to 8.5 $km.h^{-1}$), even though there are reports stating that CV below 30% is desired for corn crops.

The differences found between as-applied maps and the field measurements can be easily explained by the fact that the planter monitor records seed passage during the planting operation, whereas field evaluations reflect the final outcome after seed deposition, seed-soil interaction, germination, emergence, and early plant establishment. Therefore, plant position after emergence will reflect not only seed-metering errors, but also seed displacement within the furrow, emergence failures, poor seed-to-soil contact, and effects related to soil physical conditions.

Furthermore, longitudinal distribution uniformity has direct agronomic importance. According to Chim et al. (2014), variations in plant spacing affect competition among plants for light, water, and nutrients, potentially reducing resource use efficiency and limiting crop yield potential. Thus, the greater variability observed in the field indicates that the differences between as-applied and the actual plant distribution may have important agronomic implications.

Planter performance parameters calculated based on 30% tolerance around xref are presented in Figure 2. As expected, the more restrictive classification criterion resulted in significant changes in the planting performance parameters, especially for DO results, thus substantially changing the values of AC as well.

The value mean values obtained from manual measurements performed with a measuring tape is also presented on Figure 2. Note that the mean values obtained through manual measurements follow a similar trend when compared to the plant counter apparatus, except for zone number four. Note that estimates of DO was majorly presenting lower values, below the lower boundaries of data variation obtained from the plant count apparatus, thus increasing AC values. The CV values was majorly underestimated, except for zone four and zone six, where the mean value was found within the 25^{th} – 75^{th} percentile range. It is important to point out that small samples (such as 10 m length taken with the tape measure) will often misrepresent the reality in the field.

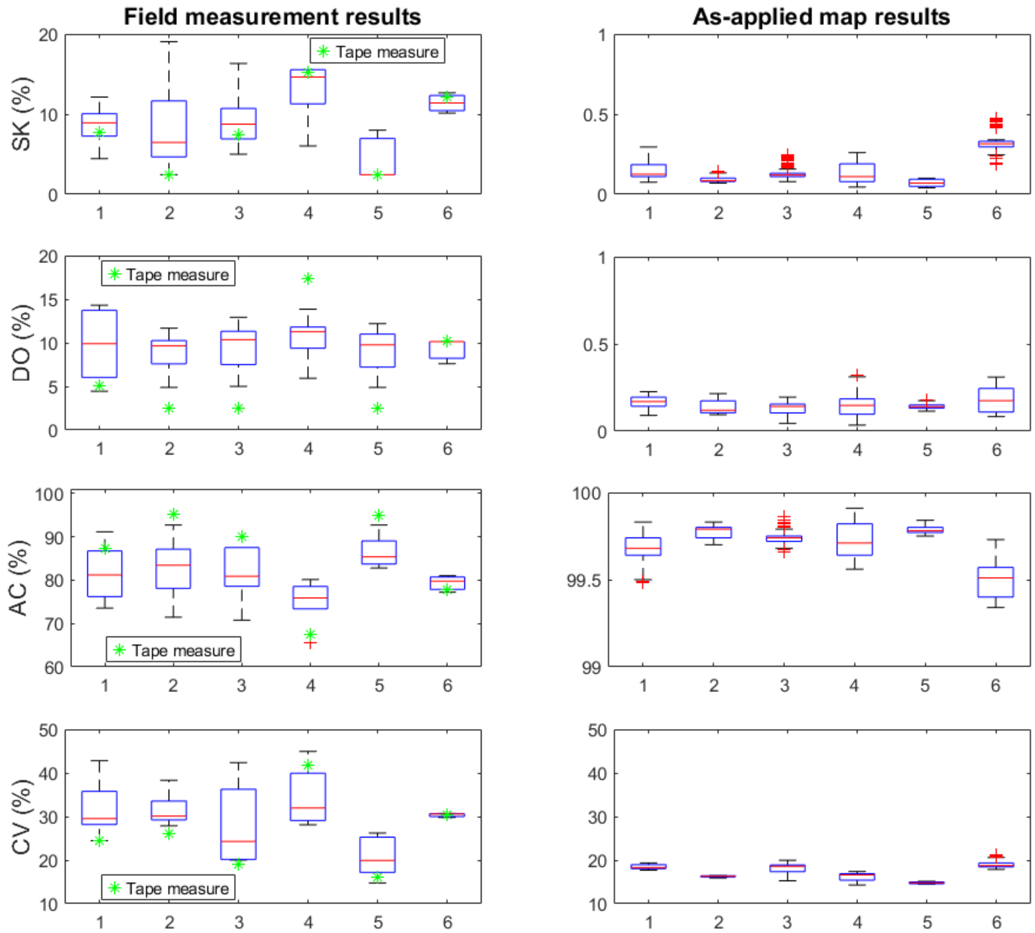

Fig 2. Comparison between planting performance parameters measured in the field considering 30% tolerance around the xref and those provided by the as-applied map. Green marks represent mean values obtained from 10 meters sample taken with the tape measure

4 Conclusions

The comparison between field observations and the as-applied planting performance maps revealed substantial differences in the evaluated parameters. In general, the embedded monitoring system reported lower skip percentages, lower coefficients of variation, and higher singulation values than those observed in the field. So, as-applied maps information overestimates the quality of longitudinal plant distribution when compared with the distribution effectively observed after crop emergence. Therefore, the information provided by embedded monitoring systems should be interpreted with caution when used for agronomic assessments and decision-making processes.

Further studies should be conducted in order to investigate the factors responsible for the discrepancies observed between the parameters recorded during planting operations and the final plant distribution after crop emergence. Such studies may contribute to improving embedded monitoring systems and to the development of planting performance maps that more accurately represent actual field conditions.

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