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Evaluation of Centrifugal Spreader Response to Variable Rate Application by Using Task File Data

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Abstract: In the site-specific fertilization based on a variable rate prescription, the application accuracy and distribution of the spreader are the key points when it comes to applying fertilizer with centrifugal disk spreaders. The application error occurs mainly due to inaccurate position, the delayed response of the spreader to rate changes and application width errors across the management zones. This study aims to evaluate the application error occurring due to rate changes at management zone boundaries across the application width of the spreader. Towards this aim, a variable rate fertilizer application was performed using a centrifugal spreader. The performed task data that included a spatial field application file in ISO XML format was recorded from a dedicated in-cab terminal to generate the "as-applied" point map. A two-dimensional (2D) matrix method based on a 2D triangular distribution was used to generate the as-applied rate to examine if it results in more accuracy to assess the applied amount of fertilizer at intersections of the management zones. The resulted "as-applied" map, as well as the raw data one, were compared with the prescription map to extract absolute errors. Statistics of absolute error resulted from the comparison was assessed to examine the application accuracy. The mean value and standard deviation of the error for the distributed rate were 13.4 and 11 kg ha^{-1}. These figures were equal to 17.5 and 12.7 kg ha^{-1} for the error of the raw data "as-applied" map. Evaluation of covered area by the error in percentage also indicated a higher value for the raw data "as-applied" map than that for the distributed one.

Keywords: Application error, as-applied rate, can-bus; spreading pattern distribution.

1. INTRODUCTION

Site-specific application of fertilizer based on a variable rate prescription map has shown significant potential to achieve a lower input and higher yield, in terms of using fertilizer efficiently and boosting economic benefit. By defining crop needs using advanced variable rate technologies (VRT) and online nitrogen sensors as well as taking soil specialty into consideration, the delivery of fertilizers as accurately as possible has been improved (Baillie *et al.*, 2018; Muñoz-Huerta et al., 2013; Lindblom et al., 2017; Basso et al., 2016). Nevertheless, the performance of the spreader, in terms of application accuracy affected by position, time response of the spreader to rate changes and wide working width, should be estimated.

In recent years, precision agriculture for many types of crops has included variable rate application (VRA) of fertilizer, which could be map-based or sensor-based (Ess *et al.,*2001; Yule *et al.*, 2013). Between these two methods, the map-based application is widely used by farmers. Many types of geographical information systems have been used to generate an application map, while there are also latest commercial farm-management systems and software architectures (e.g. FarmWorks[1], Ag Leader SMS[2], PDP Lite[3] and so on) available to do that. An application map contains specific tasks, in terms of application rates across the field and field constraints, together with geographical locations and field boundaries. The machine defines the location using a global navigation satellite system (GNSS) antenna to apply the prescribed rate at the specific locations on the field. Transferring the developed application map into the process could be done through control systems that use ISO 11783 (designated as ISOBUS) standard. ISOBUS can offer the necessary communication infrastructure in agricultural machinery to control and receive feedback signals in a standardized manner (Paraforos et al., 2019). Therefore, it could be stated that the accuracy of the application is more related to the machine performance and other VRTs such as GNSS and variable-rate controllers than software performance (Fulton et al., 2003; Li et al., 2016; Abbou-ou-cherif et al., 2017).

Variable-rate treatments come with limitations if VRT cannot provide sufficient accuracy in applying fertilizer according to the corresponding prescription map (Chan et al., 2004). There have been many studies conducted on investigating the accuracy of map-based VRA of fertilization (Chan et al., 2002; Chandel et al., 2016; Lindblom et al., 2017). Most of them have evaluated the application accuracy based on the position and response error resulted from the spreader performance. Griepentrog and Persson (2001) assessed the application accuracy of fertilization considering the positional lag of a spinner disc spreader. The effect of the distribution of spreading patterns, GNSS receiver latency, and offset

[1] agriculture.trimble.com/solutions/data-management
[2] https://www.agleader.com/farm-management/sms-software/
[3] www.fairport.com/en/features-en

distances were thoroughly investigated by many researchers (Fulton et al., 2001; Fulton et al., 2013; Yang et al., 2018). In addition, Abbou-ou-Cherif et al. (2017a, b) carried out an enhanced simulation of the in-field performance of the centrifugal spreader by considering irregularity in field conditions. However, there have been very limited studies evaluating rate response of the spreader, in terms of application width, to changes at management zone boundaries. Thus, the first step would be to define differences between the applied and prescribed rates over critical areas where the management zone does not correspond to the position and application width of the spreader.

This paper aims to evaluate the application errors attributable to the response of the mismatched working width of the spreader to the corresponding prescription map. A triangular distribution should be assumed to produce a surface layer of the applied rate. This assumption was carried out since the distribution pattern of the employed spreader is supposed to be defined in the next step of the research. An error map resulting from a comparison between the produced "as-applied" map and the corresponding prescription map should be carried out to estimate the errors.

2. MATERIALS AND METHODS

2.1 Instrumentation

A mounted centrifugal disk spreader (ZA-V, AMAZONEN-Werke H. Dreyer GmbH & Co. KG, Hasbergen, Germany) with a capacity of 2 t and a working width of up to 36 m was used to perform the fertilization task (Fig. 1a).

To achieve a desired degree of overlapping, 8 sections of the spreader were set along its working width. As the spreader was ISOBUS compatible, a dedicated CCI 100 in-cab terminal (Competence Center ISOBUS e.V., Germany) was responsible for the communication between the spreader, the tractor, and the operator, in terms of control and job management (Fig. 1b). The tractor's GNSS antenna with sub-meter accuracy (RTK-DGNSS, ±2 cm track to track accuracy and ±2 repeatable accuracy) was employed to provide location information for the tractor in-field position and the section-border-boundary control of the spreader performance. The distance between the GNSS antenna and the center point of the spreader was taken into consideration in the settings of the dedicated in-cab terminal to determine the point locations of the applied rate.

2.2 Application specifics

All field experiments were carried out at the research farm "Ihinger hof" of the University of Hohenheim. A field with an area of 1.2 ha was selected to perform VRA of fertilization. The area of 1.2 ha was chosen in the field with an area of 3.6 ha where geometrical singularities like non-parallel lines, the effect of start and end of lines on the dose rate and conditions on the application width can be avoided (Virin et al., 2006). The field was cultivated with winter wheat (*Triticum aestivum L.*). Multi-spectral imagery (Green, Red, RedEdge and Near Infrared) of the selected field was collected before the application. The NDVI (Normalized Difference Vegetation Index) map was created in Pix4D software (Pix4D, Ecublens, Switzerland) using the collected imagery. The farm's agronomical advisor used historical yield data from the previous year and the obtained NDVI map to develop the prescription map of VRA (Fig. 2a).

The prescription contained three management zones with an application rate of 120, 150, and 180 kg ha^{-1}. KAS (Kalk-Ammon-Salpeter) granular fertilizer (diameter of 3.2-3.9 mm) with a content of 27% nitrogen was chosen for the application. The operation speed of the tractor and working width for the application were set to 10 km h^{-1} and 24 m, respectively. The application width of the operation was 48 m.

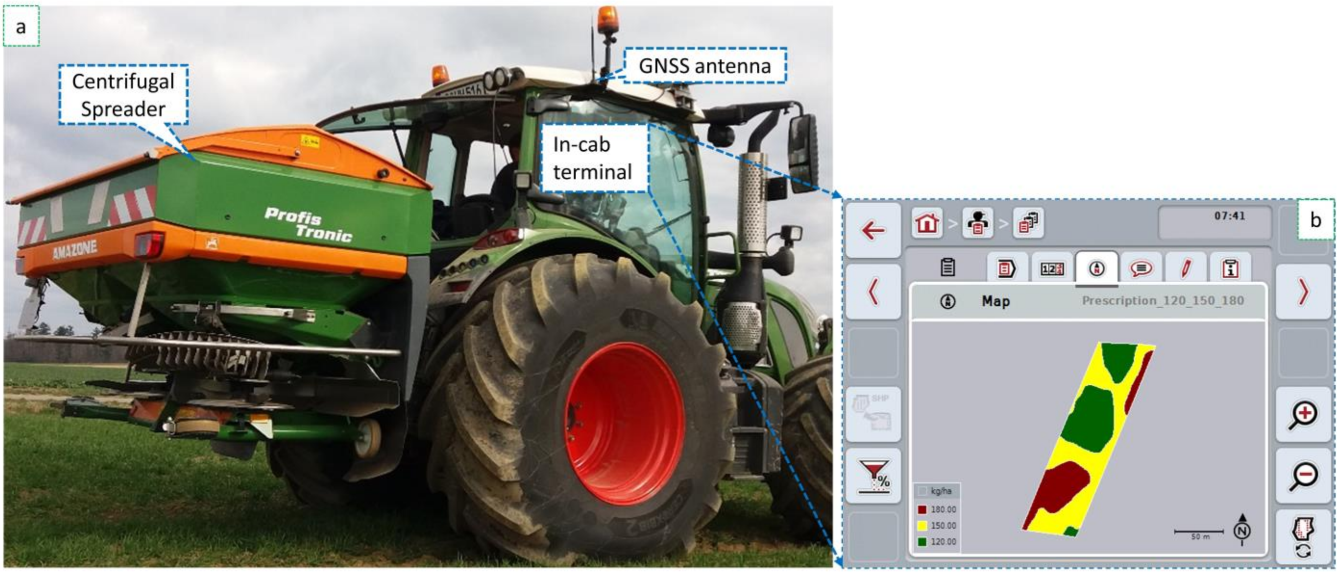

Figure 1. (a) The centrifugal spreader mounted on the tractor and (b) the displayed application map on the dedicated in-cab terminal.

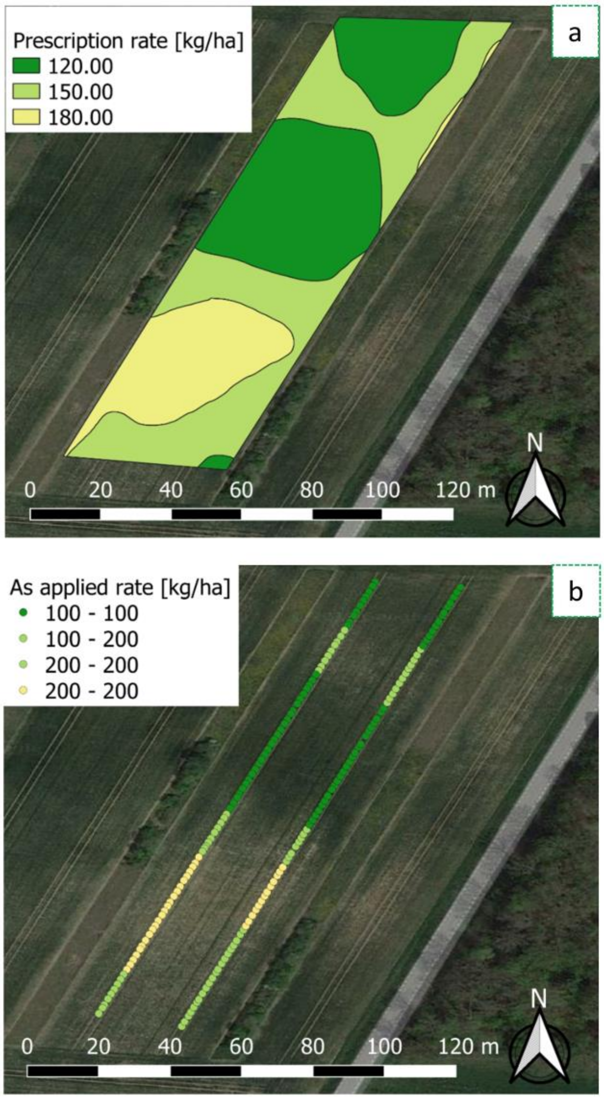

Figure 2. (a) The prescription map for variable rate application of fertilization and (b) the generated "as-applied" point map.

Based on the recommendation for the spreader settings for the different growth stages of the crop from the manufacturer, the distance between the wheat tips and the spreading disc was fixed at 0.25 m for the current growth stage. Considering the field shape and size, the border and section control functions were activated. The performed task data, in terms of spatial field application file in ISO XML format, was recorded from a dedicated in-cab terminal of the spreader to generate the "as-applied" point map (Fig. 2b). Each point in the generated "as-applied" map characterized the spatial information about the location of the sample, the applied rate, and the applied conditions.

2.3 Distribution for spreading pattern and application errors

A combination of triangular and rectangular spreading patterns could be assumed to achieve an even distribution under optimum conditions and to avoid some potential errors ('Fertiliser box', 2017). A 2D triangular distribution was applied on each point of the generated "as-applied" map. This was done over 24 m of throwing width for the side of spreading, where there was no condition applied. This was repeated for the other side of spreading with a rectangular distribution by considering the applied boundary conditions during the fertilization, as shown in Fig. 3. Increments of the applied distribution along the transversal distance were 6 m since the spreader had four sections activated on each side during the application.

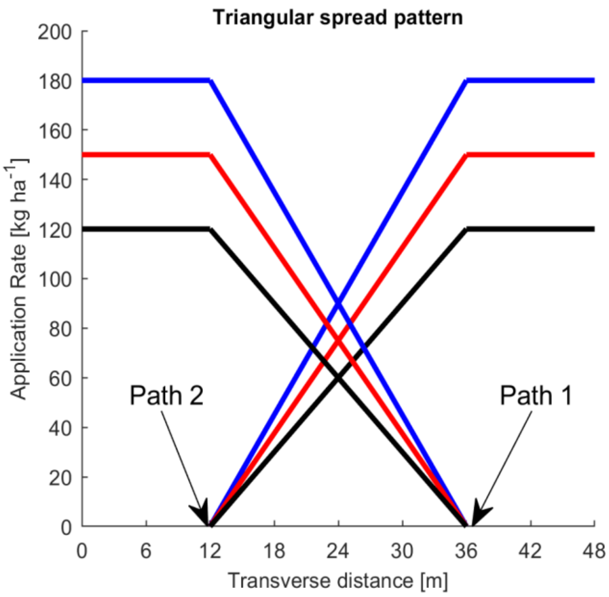

Figure 3. Two-dimensional view of the triangular distribution of spreading patterns at the three-application rate.

The prescription map was re-polygonized based on a hexagon grid to generate sample points at the centroids of the hexagons using Quantum Geographic Information System (QGIS) software.

The generated sample points of the prescription map as well as the recorded "as-applied" spatial data were defined in the ellipsoidal system (WGS 84) referenced as latitude, longitude, and height axes. To simplify the computations, conversion from WGS 84 to UTM (UniversalTtransverse Mercator) was carried out using MATLAB programming package. After the conversion of the "as-applied" map, the offset distance between the focal point of the spreading pattern and the reference point of the spinning disk (14.75 m) and geometrical dimensions of the tractor and spreader were considered to correct the location of the "as-applied" points. The converted prescription point map is shown in Fig. 4a. The "as-applied" point map was generated based on two cases. In the first case, only recorded applied data was linearly interpolated using *griddata* function in MATLAB (Fig. 4b). The second case used the distributed "as-applied" points to be interpolated. The resulted spreading patterns from applying the triangular distribution were overlaid on the interpolated application map (Fig. 4b and c). In both cases, the interpolation, in terms of scattering the data, was carried over the surface coordinates of the prescription map.

The main aim of interpolating both the distributed and raw application points over the coordinates of the prescription map was to make them corresponding to each other to define the absolute error. To estimate the produced error, its statistics based on the mean value, standard deviation, maximum and minimum values were carried out. In addition to this, the percentage of the covered area of the application map by an error occurring due to shifts in the management zones over the application width of the spreader was evaluated.

3. RESULTS AND DISCUSSION

Since both the recorded and distributed "as-applied" map corresponded to the prescription map, in terms of sample points with the same coordinates, the absolute error was defined by extracting the prescribed rate from the applied

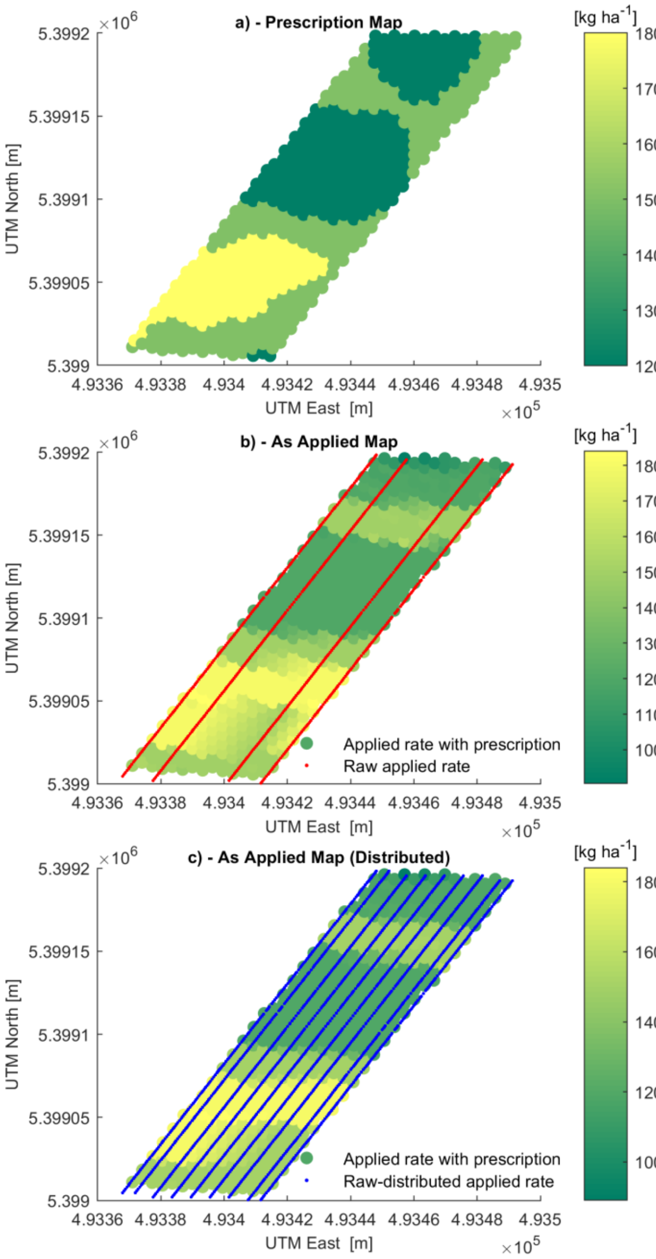

Figure 4. (a) The prescription map produced by applying hexagon gridding versus to (b) "as-applied" from ISOXML task file and (c) distributed "as-applied" map resulted from interpolation over the surface coordinates of the prescription map.

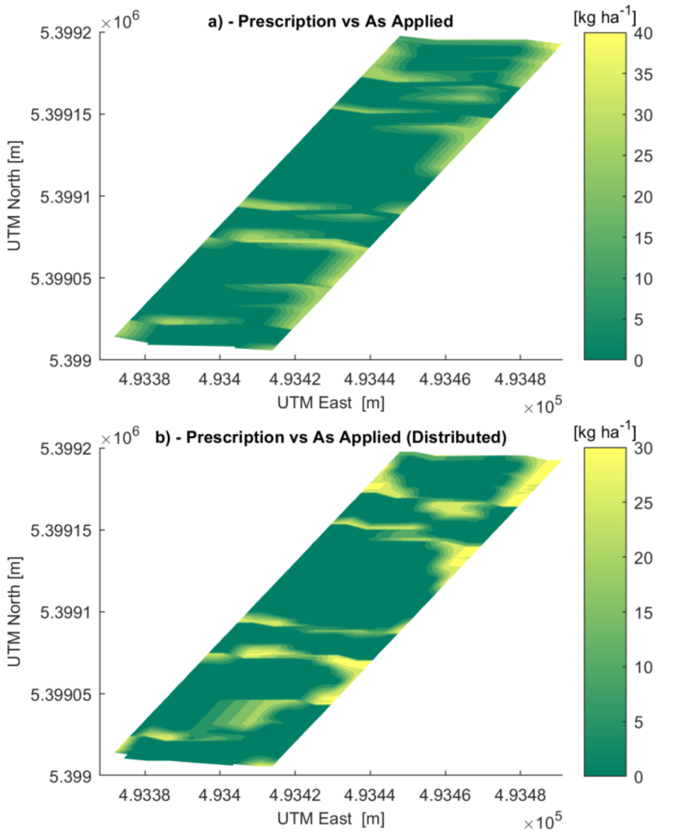

Figure 5. Application error map for (a) recorded and (b) distributed applied rate.

ones. The only absolute error without categorizing them as over and under-application errors since the selection of the geometrical field shape assisted to avoid non-parallel lines and constraints on the application width. Subsequently, the extracted values for the errors were interpolated to indicate as an error map. Fig. 5a and b demonstrate the application error map resulted from the recorded and distributed "as-applied" map, respectively.

The statistics of the absolute error are shown in Table 1. The mean values of the errors resulted from both methods are below 10% of the application rate that could be defined as a threshold of the errors (Virin et al., 2006). From the agronomical point of view, farmer's recommendation that was up to 8% of N content of the used fertilizer was considered. The mean value and standard deviation of the absolute error for the applied rate from ISOXML task file were higher than that for the distributed ones with the differences of approximately 4 and 1.8 kg ha^{-1}. The maximum of the errors for the applied rate from the task file also indicated a significantly higher value with a discrepancy of 8.5 kg ha^{-1} than the maximum error of the distributed one. The percentage of the "as-applied" map area covered by errors was higher with the value of 52.1% than the error covered area of the distributed one with 41.9%. In addition to the statistical analyses, the probability distribution of the absolute error was assessed to highlight the difference in the accuracy of the recorded and distributed maps, as illustrated in Fig. 6a and 6b.

Table 1. Statistics of the absolute error for the applied rate from the task file and distribution.

Parameters	"As-applied" rate	Distributed "as-applied" rate
Mean value [kg ha^{-1}]	17.5	13.4
St. Deviation [kg ha^{-1}]	12.7	11
Minimum [kg ha^{-1}]	1.42	1.42
Maximum [kg ha^{-1}]	41	32.5
Error covered area [%]	52.1	41.6

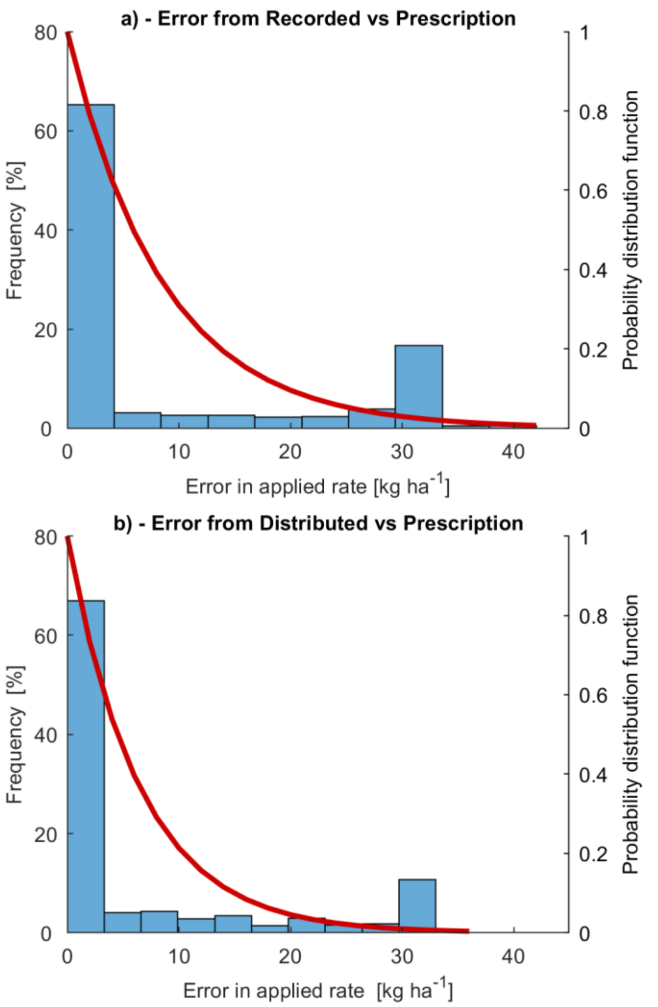

Figure 6. Histogram (blue) and probability distribution function (red) of the absolute errors resulted from the comparison between the prescription map and the generated "as applied" maps.

The histograms for the variation in the absolute error of both the recorded and distributed applied rate were best fitted by the exponential distribution with mean value equal to 5.9 and 7.8, respectively. It can be noticed that the 95th percentile of the applied rate from the task file was lower than 30 kg ha^{-1}. This figure for the distributed applied rate was equal to 26.1 kg ha^{-1}.

4. CONCLUSIONS

Instrumentation and techniques for variable rate application of fertilization using a centrifugal spreader were presented. The "as-applied" map was generated by utilizing a triangular distribution that provided better accuracy to evaluate the application maps. The prescribed rate, according to the location of the spreader in the specified zone, was applied along the entire length of the application width that crossed the boundaries of the specified management zone. Therefore, the generated "as-applied" map for both raw and distributed rate indicated potential errors occurring at management zone boundaries, in terms of intersections of management zones, where the rate changes were supposed to happen based on the prescription map.

By assessing the absolute error that was resulted by comparing the generated application maps with the prescription map, it was possible to quantify over- and underapplied areas of the specified field and to highlight the effect of the management zone dimension on the application spreading width. Besides, the application error map for the distributed applied rate showed a comparatively lower error with a mean value of 13.4 kg ha^{-1} than that for the recorded applied rate with a mean value of 17.5 kg ha^{-1}. The same figures were observed for the other error statistics and the covered area by the absolute errors. This means that more accuracy for assessing the application map could be achieved by applying the distribution of the spreading pattern. The defined methodology would be the main principle in the future step of the research, where the distribution of the spreading pattern will be experimentally validated and implemented into the assessment of the spreader performance in a three-dimensional manner. This will also be performed by considering a more accurate positioning system (i.e. a total station) that has been examined in the past (Paraforos et al., 2017) and the in-field dynamics of the spreader.

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