Field Level Management and Data Verification of Variable Rate Fertilizer Application

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Abstract. *Increased cost efficiencies and ease of use make spinner-disc spreaders the primary method of applying fertilizers throughout much of the United States. Recently, advances in spreader systems have enabled multiple fertilizer products to be applied at variable application rates. This provides greater flexibility during site-specific management of in-field fertility. Physical and aerodynamic properties vary for fertilizer granules of different sources and densities, these properties in turn affect the uniformity of distribution. The purpose of this study was to evaluate the effect of fertilizer composition on distribution uniformity between independently metered and blended fertilizer sources, and determine the effect of metering type on spread of multiple products. A spreader with a dual bin, and the ability to independently meter two products onto spinner-discs was used for this study. Prior to spreading fertilizer, particle analysis determined that the bulk density of diammonium phosphate (DAP), muriate of potash (KCl), and a blended fertilizer (10-26-26) were 1009, 1105, 1025* kg/m^3*, respectively. All three fertilizer sources were broadcast and nutrient distributions determined. Specifically, the DAP components of the patterns were analyzed for any changes across all three fertilizer sources. DAP only spread patterns differed from that of the independently metered and the blended mixture, while the independently metered and blended fertilizer patterns were almost identical. Pan collection test results showed independently metered DAP and potash spread patterns were not significantly different than the blended mixture. These results indicate that there is a need for dynamically changing spreader adjustments during a variable rate scenario.*

Keywords. *fertilizer, uniformity, variable-rate, distribution, swath, application rate, broadcast*

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Introduction

Application of granular fertilizers to amend soil fertility levels is a common practice across North American agriculture. Amendments in soil fertility are needed to ensure proper fertilization of major row crops. If fertilizer application is found to be non-uniform it can be detrimental to crop yields for certain types of fertilizers (Ndiaye & Yost, 1989). Lutz et al. (1974) found significant yield differences related to non-uniform fertilizer distribution in corn. In severe cases, Jensen and Pesek (1962) stated that yield losses by nutrient segregation alone may reach 313 kg/ha. In order to maximize the yield potential of each seed, non-uniform applications must be minimized through adjustment of spreader settings depending on the fertilizer blend. Spread uniformity, or lack thereof, is an important parameter to evaluate when utilizing these types of fertilizer spreaders.

A wide range of factors can influence spread uniformity either positively or negatively. One such factor is variances in material properties of the fertilizers being spread. Material properties of different fertilizers substantially affect the trajectories of the fertilizer particles when in flight and their influence on spread distribution is difficult to quantify (Hofstee & Huisman, 1990). Bulk density and particle size are one of the major contributors to the distribution pattern of fertilizer particles across the swath (Reed & Wacker, 1970). Significant disparities in distribution of P2O5 and K2O across the swath when spreading blended fertilizers at different rates were found by Virk et al. (2013). Yule (2009) found inefficient spreading of KCl from a blend including KCL and superphosphate fertilizers in experiments evaluating distribution patterns. Pitt et al. (1982) found that particle size variability has no effect directly behind the spreader and can cause a 7% increase in spread variability at the edges of swath. Virk et al. (2013) stated further research is needed to evaluate different blended fertilizers that are applied with spinner fertilizer spreaders. It is desirable to reduce variabilities in factors that affect the spread to keep total applied variability at a minimum for the growing crop.

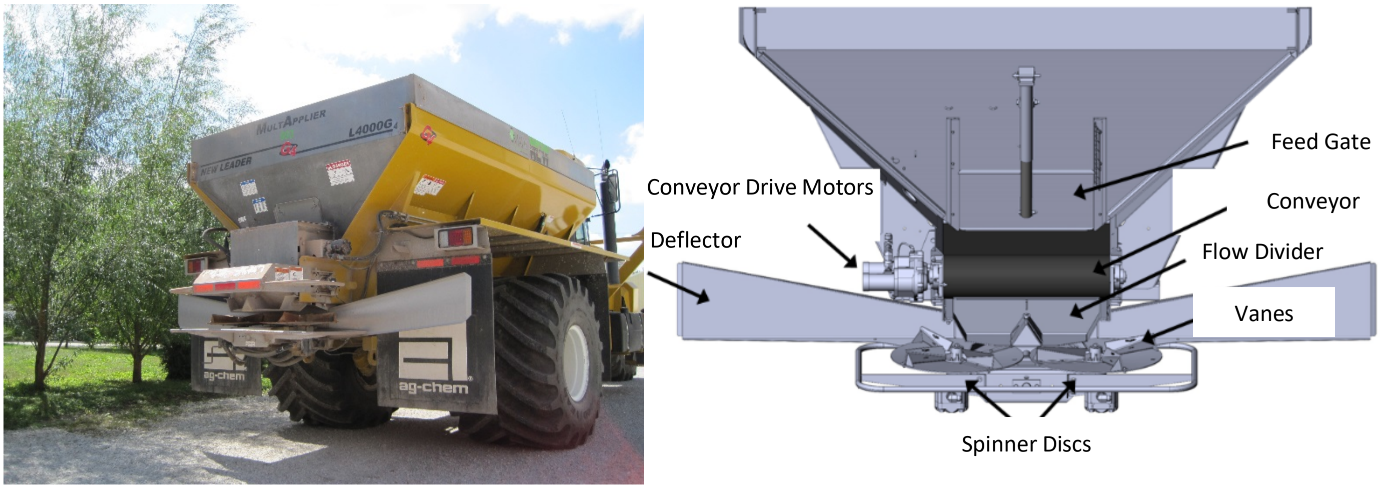
Spinner-disc spreader technologies recently have advanced to allow independent metering of multiple products from the spreader bin onto the spinner-disc. Operators can now spread multiple blends of fertilizer simultaneously, or spread individual constituents of the desired fertilizer blend independently. Currently, common practice for most agricultural operations is to spread a blended product of multiple fertilizer components. Both methods of application (independently metered and blended) induce particle interactions that affect the uniformity of spread in some manner. It is assumed that independently metered fertilizers perform similarly to those in the blended form. However, distribution variability based on method of product application needs to be investigated in greater detail.

Variable-rate fertilizer applications are used to apply specific amounts of fertilizers to sub-field zones based on its needed nutrients. These methods of varying the rate can result in uneven distribution of fertilizers when rates changes quickly between zones. Currently, when spreaders are calibrated, the calibration is conducted in a static state where a single target application rate, single product, and single swath widths are chosen. During testing, the spreader is adjusted until it is properly calibrated for this static state. However, when applying in a variable rate scenario with an independently metered machine, the rate and blend of the applied fertilizer is constantly changing. By changing the product and application rate during operation, the spreader is almost never being operated at the same parameters for which it was calibrated. Operation outside of the calibrated range can induce undesirable variability of fertilization within the swath.

In this study was the method of application was compared by analyzing the distribution uniformity differences between blended and independently metered fertilizers. Distribution uniformity was measured in two scenarios: (1) phosphorous spread patterns (P_2O_5) when spread alone, independently metered, or in a blend and (2) if distribution of P_2O_5 and K_2O across the swath remains uniform whether independently metered or in a blend.

Materials and Methods

Throughout all distribution uniformity testing, a New Leader L428G4 MultApplier Bed self-propelled spreader with a dual bin, and the ability to independently meter two products onto spinner-discs was used (Figure 1a). The spreader was calibrated before use in the fertilizer tests according to the manufacturer's recommendations. All fertilizer distribution tests were conducted using pan testing standards from ASABE Standard S341.4 (2015) and ISO 5690/2 (1984).



(a) (b)

Figure 1. New Leader L428G4 MultApplier Bed self-propelled spreader used for all fertilizer uniformity tests (a), labeled components at rear of spinner-disc spreader for reference (b).

Test Setup

A total of 54 tests were done for various settings of the New Leader L428G4 self-propelled spreader evaluating a number of parameters including: fertilizer source (DAP or Potash), type of fertilizer metering (independently metered or blended), application rate (kg/ha), spinner-speed (RPM), and divider size (cm). This paper will discuss only the tests done on the fertilizer source and fertilizer metering type variables. Spreader settings that were held constant for all tests discussed in this paper are as follows: spinner speed – 750 RPM, divider size – 8.25 cm, DAP target rate – 253 kg/ha, and potash target rate – 174 kg/ha.

Metal collection pans (Figure 2) measuring 0.2 m^2 were spaced on 0.8 m intervals across the swath ranging ~21 m on either side of the spreader with two 1.5 m gaps to ensure clearance of spreader tires. Collection pans measured 50.8 cm long, 40.6 cm wide, and 10.2 cm tall. A 10.2 by 10.2 cm gridded divider was inserted in the pan to prevent fertilizer particles from bouncing out of the pan. Visual observations were made to verify that minimal segregation occurred to the blended fertilizers while loading the spreader. Edge-of-field loading was practiced to ensure blended fertilizer mixtures had minimal opportunities to segregate during transport. These tests were all conducted in the same field at the E.V. Smith Research Center in Shorter, Alabama. The field in which this test was conducted was cultivated to ensure a smooth operating surface and marking flags were placed in the middle and at the front of each collection pan to ensure test repeatability.

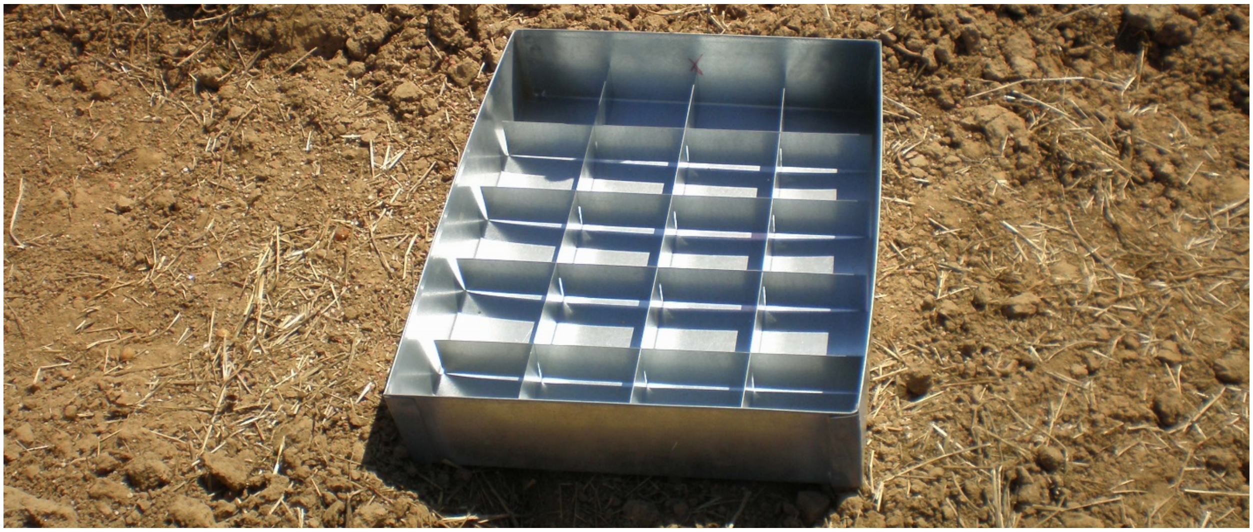


Figure 2. Collection pans of 0.2 m^2 surface area were used for all uniformity tests.

At the conclusion of each pass with the spreader, the pans were bagged and weighed to collect total mass, P_2O_5, and K_2O content. Field data was then used to generate an application rate for each swath under examination.

Fertilizer Analysis

An in-situ bulk density instrument (Berckes Manufacturing, Canby, MN USA) was used to measure the bulk density of both DAP and potash. Bulk samples were collected at random locations from the spreader hopper during both stationary and pan testing to determine particle size and particle density of fertilizers. These samples were collected in labeled plastic bags and sealed afterwards. A camsizer (Model No. 216753, Retsch Technology GmbH, Germany) was used to measure particle size distribution. Five hundred grams from each bulk sample was used to determine particle size distributions. Particle size was reported as d_{16}, d_{50} and d_{84} (d_x: x is the mass fraction passing the sieve of mesh d).

The Granular Spread Index (GSI) was computed using Equation 1 to quantify particle size variability. GSI is a measurement of variability in particle size distribution of a fertilizer, ideally values would remain under 15 to ensure uniform spread. Values observed before spreading were slightly higher than desired, but are still satisfactory for this application.

$$GSI = \frac{(d_{84} - d_{16})}{2\ x\ d_{50}}\ x\ 100 \tag{1}$$

Where: d_{84} and d_{16} = diameter of particle size at 84% and 16% percentile level, respectively for a sample

d_{50} = the median particle size

Data Analysis

Summaries for each grouping of four tests were generated using collected mass values for DAP and potash at each pan collection. This was done in order to display a representation of swath uniformity, and calculate optimal swath widths for each product. Single-pass and multiple-pass (race track method; ASABE Standards, 2009) application rate patterns were established for each test and summarized in Microsoft Excel. These patterns allow for the variability of spread using multiple products to be clearly visualized. For objective one, correlations between DAP patterns were calculated in order to quantify the difference between metering types. For both the independently metered and blended fertilizer tests, a target ratio of 1:1 (P_2O_5:K_2O) was set allowing for a tolerance range of ±0.1. Ratios were calculated through the mass measurements of particles split between DAP and potash. Due to differing bulk densities, when measuring by mass the 1:1 target ratio equates to a 56.5% - 43.5% (P_2O_5:K_2O) mass fraction. For objective two, this product ratio was observed and recorded from measuring the mass of P_2O_5 and K_2O in each collection pan after every test. Correlations between product ratios for both the independently metered fertilizer tests and the blended fertilizer tests were calculated using Microsoft Excel to determine the correlation coefficient (R).

Results

Material Properties

Prior to spreader uniformity testing, particle analysis from the camsizer instrument determined material properties (Table 2) for each of the fertilizers in question. Potash fertilizer had the highest recorded bulk density value 1105 kg/m^3 and also the highest GSI value. DAP fertilizer was the most uniform with a GSI value of 18.1 and had the lowest bulk density of 1009 kg/m^3. As expected the blended product recorded values in between the values observed for the two constituents of the blend. All measured fertilizer particles recorded a D_{50} value of 2.9 mm, resulting in a very uniform blended fertilizer.

Table 2. Granular Fertilizer Material Properties

	Formulation (N-P-K)	Bulk Density (kg/m^3)	D_{50} (mm)[2]	GSI[2]
DAP	18-46-0	1009	2.9	18.1
Potash	0-0-60	1105	2.9	22.4
Blend[1]	10-26-26	1025	2.9	20.7

[1] Fertilizer blends were mixed using DAP and Potash fertilizers

[2] D_{50} = median particle size, GSI = Granulometric Spread Index

These properties reflected desired characteristics for spreading multiple products due to the relatively uniform values of bulk density, D_{50}, and GSI. Similarity in particle size will lead to higher rates of uniformity across the swath width.

Phosphorus Spread Pattern

Spread patterns for the DAP component of all three fertilizer loadings were analyzed for uniformity and to detect any differences that may exist. The DAP component application rates for the DAP only source are displayed below in Figure 3. For the target application rate of 253 kg/ha, a "W" shaped spread pattern was observed within the 30 m target swath. However, this is not a concern because this study was focused around the effect of material properties rather that application settings. Generally, application rates were higher on the outer edges of the swath, and lower in between with the exception of directly behind the applicator.

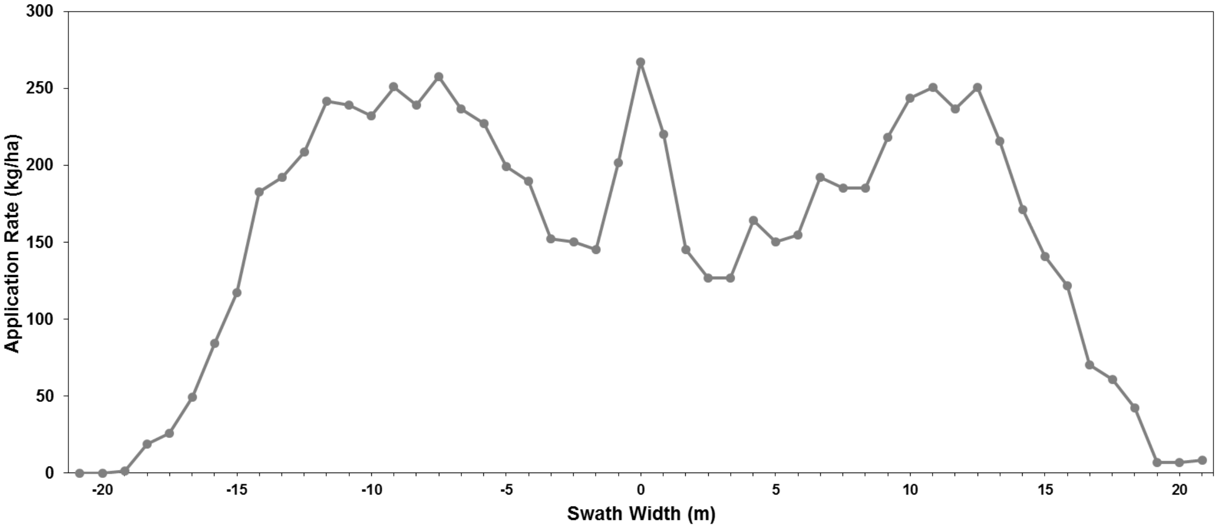


Figure 3. DAP component application rates for DAP only fertilizer source. This pattern displays a "W" shaped spread pattern, depositing more DAP fertilizer on the outer edges of the 30 m target swath width.

Figure 4 displays the DAP component application rates for the independently-metered P-K fertilizer source and is displayed below. For the target application rate of 253 kg/ha, a "W" shaped spread pattern was observed within the 30 m target swath, but is not as pronounced as the DAP only source "W" spread pattern. This pattern differs from that of the DAP only pattern most likely due to particle interactions with Potash particles during the travel of the DAP fertilizer particles from the spinner to the ground (R = 0.905). This data suggests that during operation the spreader, if operated without adjustment, can produce a non-uniform application if changing product blends quickly (VRT scenario).

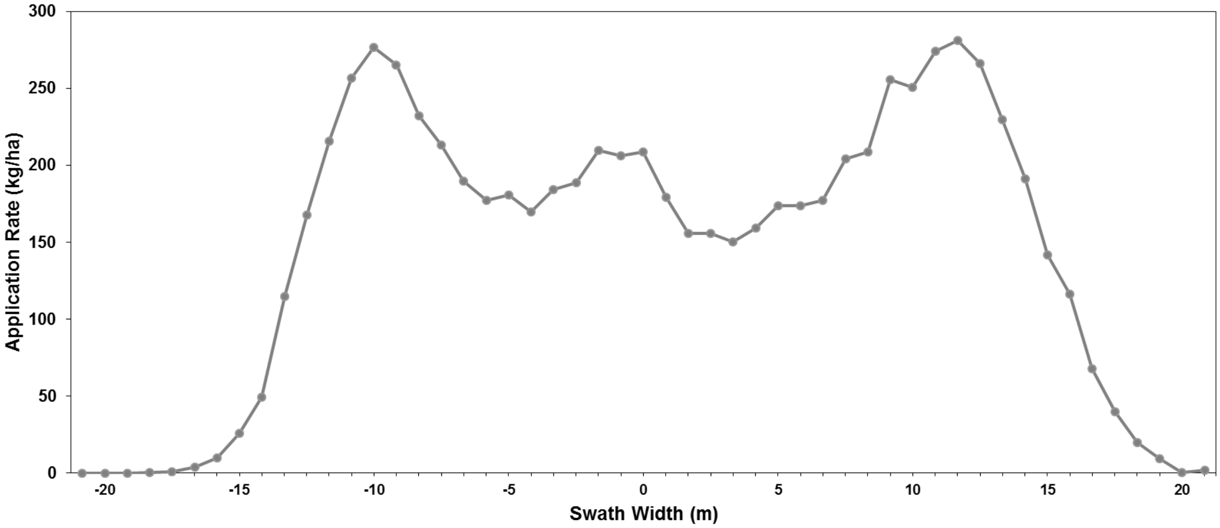


Figure 4. DAP component application rates for independently-metered fertilizer source. This pattern displays a "W" shaped spread pattern, depositing more DAP fertilizer on the outer edges of the 30 m target swath width. This pattern differs significantly from the preceding DAP only spread pattern (R = 0.906).

Figure 5 displays the DAP component application rates for the blended fertilizer sources. For the target application rate of 253 kg/ha, a "W" shaped spread pattern was observed within the 30 m target swath, but is not as pronounced as the DAP only spread pattern. This pattern differs from that of the DAP only pattern most likely due to particle interactions with Potash particles during the travel of the DAP fertilizer particles from the spinner-discs to the ground. Very minimal differences are observed in application rates across the swath in comparison to the independently-metered fertilizer source (R = 1.000).

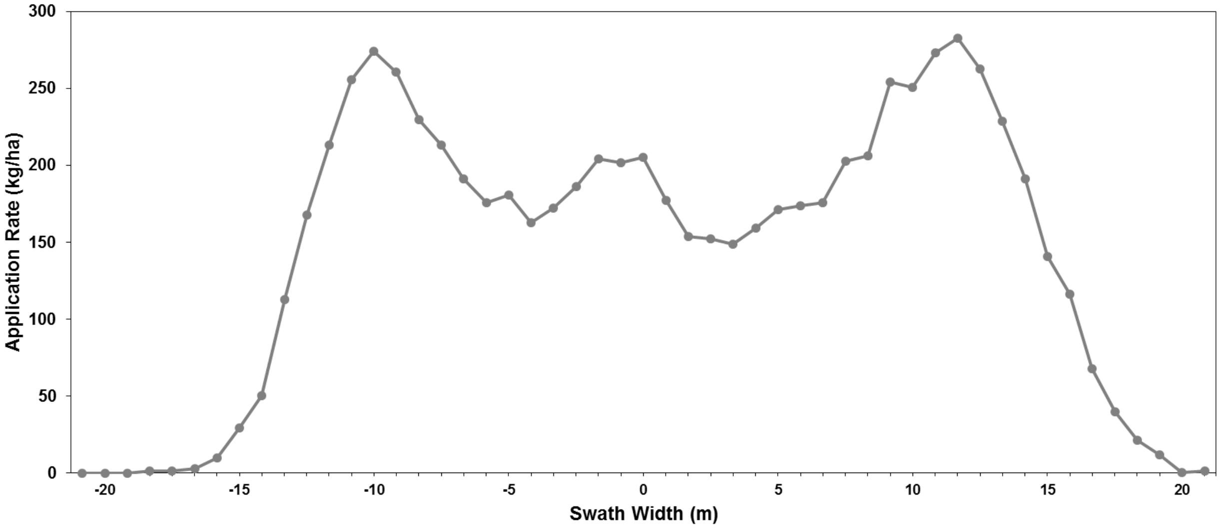


Figure 5. DAP component application rates for the blended fertilizer source (10-26-26). This pattern displays a "W" shaped spread pattern, depositing more DAP fertilizer on the outer edges of the 30 m target swath width. This pattern differs significantly from the preceding DAP only spread pattern (R = 0.905), but is virtually identical to the preceding independently-metered fertilizer source.

A visualization of DAP spread uniformity for all three spreader scenarios is displayed in Figure 6. The high correlation between independently metered and blended fertilizer spreads are observed, as well as the difference between those and the DAP only spread pattern.

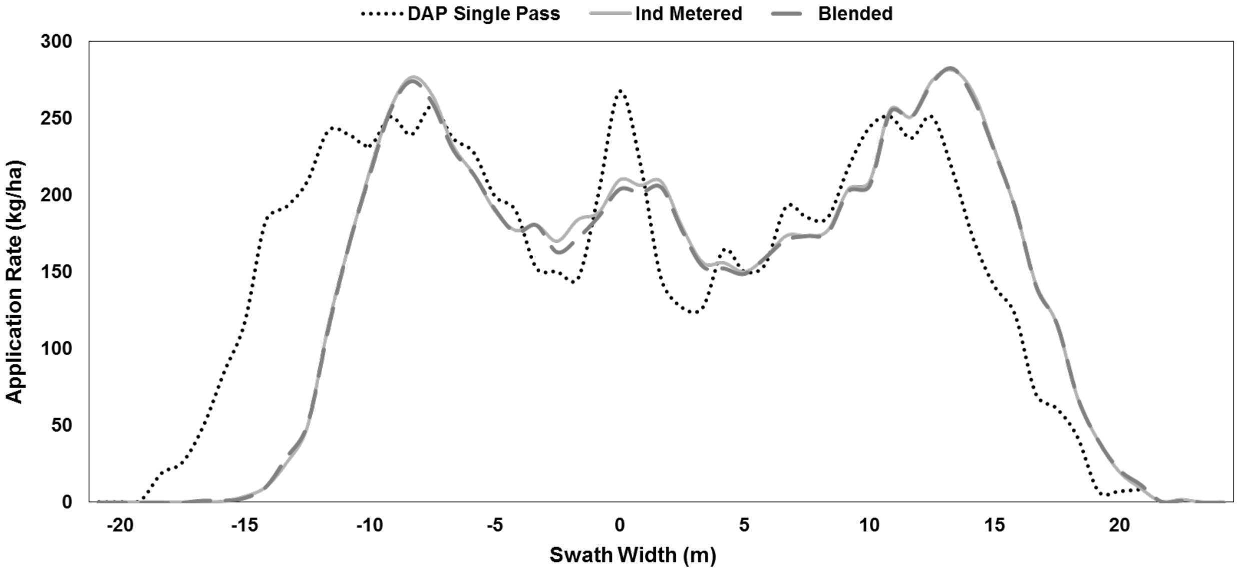


Figure 6. DAP component application rates all fertilizer sources at target swath width of 30 m. Independently-metered and blended fertilizer sources differ minimally between each other (R = 1.000). Both independently-metered and blended fertilizer sources have differences compared with DAP only spread pattern (R = 0.906 and R = 0.905, respectively).

Correlations between the each respective type of fertilizer composition were determined and are displayed below in Table 3. These values show very minimal differences in the DAP component spread patterns between the independently-metered fertilizer source and the blended fertilizer source. Variances were detected between the DAP component spread patterns when comparing both the independently-metered fertilizer source and the blended fertilizer source to the DAP only fertilizer source.

Table 3. Spread patter correlation values between various fertilizer blends

Comparison Type	R
Ind Metered vs. Blended	1.000
Blended vs. DAP only	0.905
Ind Metered vs. DAP only	0.906

Pan Collection Analysis

Figure 7 displays the recorded application rates, reported for each fertilizer constituent, for the independently metered fertilizer source. Generally, the DAP components of the fertilizer source were spread further away from the centerline of the spreader, while the potash components were found closer to the centerline of the spreader. This effect can be attributed to the intrinsic ballistic properties of the fertilizer blend rather than a spreader settings. Of the 55 collection pans in the test, only four of them received the desired ratio of P_2O_5:K_2O.

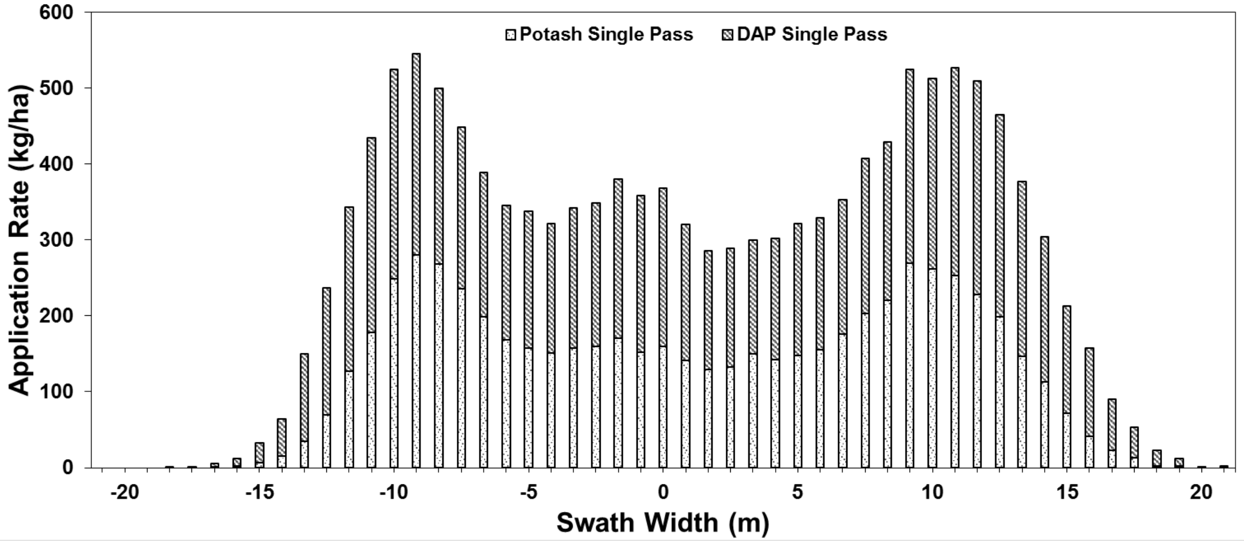


Figure 7. Single-pass observed application rate levels for P_2O_5 and K_2O when fertilizer is independently metered from the spinner-disc spreader

Figure 8 displays the recorded application rates for the blended fertilizer source. Generally, the DAP components of the fertilizer source were spread further away from the centerline of the spreader, while the potash components were found closer to the centerline of the spreader. This effect can be attributed to the intrinsic ballistic properties of the fertilizer blend rather than a spreader settings. Of the 55 collection pans in the test, only five of them received the desired ratio of P_2O_5:K_2O.

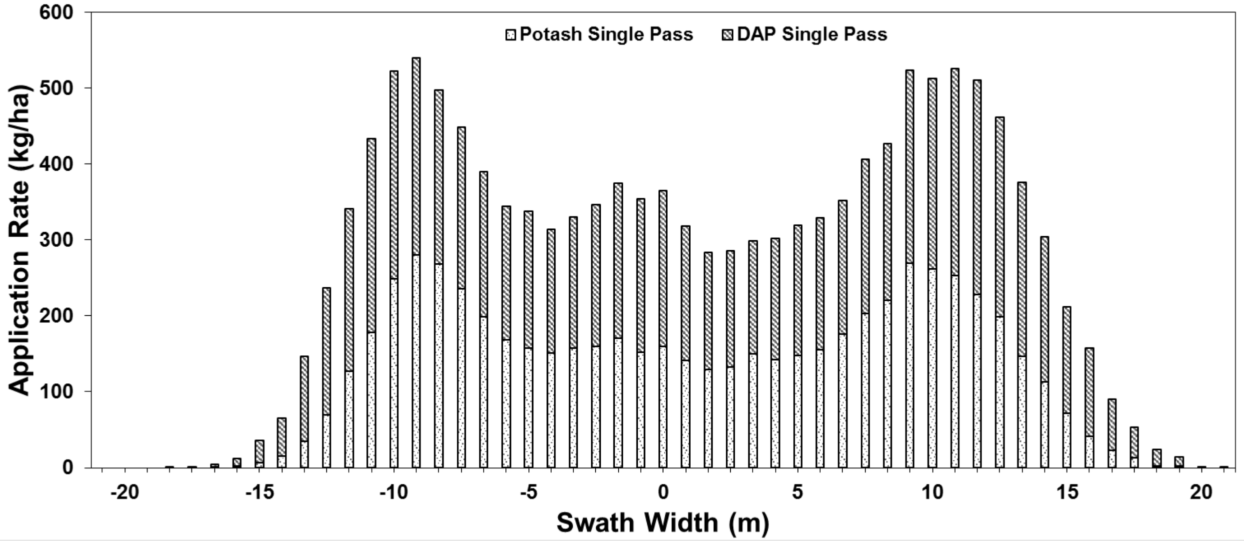


Figure 8. Single-pass observed application rate levels for P2O5 and K2O when fertilizer is blended prior to spread by the spinner-disc spreader

Conclusion

Phosphorus Spread Pattern

Variability in the phosphorus patterns between the DAP only fertilizer source and both the independently-metered and blended fertilizer sources indicate the need for adjustment of spreader settings before changing products. During variable rate spreading of two fertilizer sources with an independently-metered dual bin applicator, occasionally the target application rate of one product will drop to 0 kg/ha while simultaneously needing a high application rate of the second product. In this case, the spreader settings that were once properly tuned for the target blend of two products will now be incorrect because only one of the products is being spread. Due to the lack of variation between the independently-metered fertilizer source and the blended fertilizer source, it can be assumed that minimal variability of spread can be attributed to the type of fertilizer metering. However, if operating in a variable rate scenario, blended products would restrict the flexibility to quickly and accurately change products in the field.

Pan Collection Analysis

Pan collection analysis for both the independently-metered and blended fertilizer sources indicated there was minimal variability between metering type as related to measured ratio of P_2O_5:K_2O collected in each pan. While the majority of the product ratios were not within the target range (0.9-1.1; P_2O_5:K_2O), the lack of variability for ratios between metering types ($R = 0.98$) indicated the variability is not a function of metering type. The effect of observed application rate differences for both P_2O_5 and K_2O can be attributed to the fertilizer material properties that lead to non-uniform product ratios.

In order to maximize the level of accuracy attained by a variable-rate, independently-metered spreader, the settings associated with that spread must be able to adjust in-field based on the specific product(s) and associated target rate(s). Additionally, fertilizer material properties will always have a major effect on flight trajectories of granular fertilizer particles and uniformity of target product ratios regardless of metering type.

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