EXPERIMENTAL INVESTIGATION ON DYNAMICS OF PRECISION SPREADING OF GRANULAR FERTILIZERS

Egle Jotautiene, Antanas Juostas, Edvardas Vaiciukevicius, Rolandas Domeika
Vytautas Magnus University, Lithuania
egle.jotautiene@vdu.lt, antanas.juostas@vdu.lt,
edvardas.vaiciukevicius@vdu.lt, rolandas.domeika@vdu.lt

Abstract. Smart fertilizer technologies enhance agricultural efficiency by accelerating processes, increasing crop yields, and minimizing environmental impacts. The primary objective of fertilization is to apply fertilizers as uniformly and precisely as possible across the soil surface. To increase fertilizer efficiency, fertilization techniques and technologies are constantly being improved, fertilizer quality is being improved, and optimal fertilizer rates are being selected. The appropriate fertilizer rate is influenced by the soil composition, its physical and chemical properties, and the specific requirements of the crops being cultivated. Uneven fertilizer distribution affects yields: it reduces fertilizer efficiency, increases nutrient losses, and has a negative impact on the environment. This article presents experimental studies of a centrifugal double-disc fertilizer spreader that can apply fertilizers at a variable rate. The research aimed to assess how the spreader maintained both the uniformity and application rate of the fertilizer. Comparative tests were conducted with mineral and organic granular fertilizers. The findings indicate that the spreader speed significantly affected the uniformity of fertilizer distribution across the soil surface. When applying mineral granular fertilizers, the most uniform distribution was observed at an application rate of 200 $kg \cdot ha^{-1}$. In contrast, the uniformity of fertilizer distribution when applying organic granular fertilizers was optimal at a rate of 600 $kg \cdot ha^{-1}$. The coefficients of variation calculated for both cases were within the recommended limits for optimal fertilizer application.

Keywords: fertilizers, smart technologies, spreading dynamics, fertilization rate.

Introduction

Variable rate application of granular fertilizers not only contributes to increasing agricultural efficiency but also addresses environmental sustainability issues, which is why this area remains important for research. Variable rate fertilization allows the amount of fertilizer to be adjusted to the nutrient needs of a specific soil area in the field. This means that different parts of the field, with different yield potential or nutrient content, are supplemented with the missing amount of fertilizer. This method of fertilization contributes to increasing yields and improving product quality [1].

Antille et al. found that uneven fertilizer application can reduce crop yields and also result in inefficient fertilizer use [2]. This suggests that understanding the mechanics of fertilizer application is essential to improving fertilizer efficiency.

Organic fertilizers do not contain harmful chemicals that contribute to water and soil pollution. Therefore, their application is more sustainable. Most often, the spread method of spreading bulk mineral and organic fertilizers is used to fertilize crops. The most important factor when spreading bulk fertilizers is to spread them as evenly as possible in the soil [3]. The physical properties of fertilizers, including particle size and shape, are very important when studying their flight dynamics during spreading [4].

Recent scientific experimental and theoretical studies analyse the factors influencing the most rational operation of fertilizer application systems. The integration of precision agricultural technologies, such as GPS and GIS, has changed the perception of the fertilization process. These technologies allow for real-time and crop-specific fertilizer application, which makes the fertilization process more efficient [5].

Kazlauskas (2024) states that the variable rate of fertilization depends on the variability of soil properties in the field. It was found that when fertilizing at a variable rate, winter wheat bushiness increased by an average of 5.5% compared to when applying a uniform fertilization rate. Fertilization at a variable rate also resulted in a higher average protein content in winter wheat grains. In addition to better grain quality parameters, during variable fertilization, nitrogen N fertilizer savings of 14 $kg_N \cdot ha^{-1}$ were observed annually [6].

This leads to the economic consequences of precise distribution. Studies indicate that improved spreading accuracy can enhance profitability by reducing fertilizer waste and optimizing crop yields [7].

DOI: 10.22616/ERDev.2025.24.TF158

Matthews and Grové discuss how variance in spreading systems can significantly impact economic outcomes, highlighting the importance of precision in agricultural practices [8].

In conclusion, the dynamics of precision spreading of granular fertilizers involve a complex interplay of mechanical design, physical properties of fertilizers, and technological advancements in agriculture. Future research should continue to explore these interactions to develop more efficient and sustainable fertilizer application methods.

The aim of this article is to investigate a centrifugal double-disc fertilizer spreader that can apply fertilizers at a variable rate by experimental studies.

Materials and methods

An experimental study of the distribution of mineral and organic granular fertilizers on the soil surface was carried out based on the ASAE S341.5 standard [9]. A centrifugal double-disc fertilizer spreader AMAZONE ZA-V 3200 (Fig. 1 a) was used for fertilizer distribution. The studies were carried out on a 22.0 ha field, spreading fertilizers at a variable fertilizer rate according to a map of phosphorus content in the soil. The fertilizer distribution rate was regulated by the AMAZONE Ama Tron 4 control terminal. The tractor driving speed was 12 $km \cdot h^{-1}$. Spreading width – 24 m. The following fertilizer rates were used during the study: mineral fertilizer rate 200 $kg \cdot ha^{-1}$, organic fertilizers were spread at 200, 400 and 600 $kg \cdot ha^{-1}$ rate, according to a pre-prepared map. For measurement accuracy the 22.0 ha area was divided in 4 sections with 3 passes each. During each single fertilizing application pass the collected fertilizers were scaled. So, the measurements were repeated 3 times with 4 different fertilizer rates. The spread fertilizer granules are collected in special boxes, which are arranged in one line perpendicular to the direction of travel. For spreader testing 13 fertiliser collecting boxes were used. The fertiliser collecting box dimensions – 0.5 x 0.5 m. There was a 2 m gap between the boxes. The amount of fertilizer in each box was weighed using a Bushel manufacturer's scale with an accuracy of 0.1 g.

Before spreading, the condition of the fertilizer fraction in the fertilizer box was visually assessed, because the condition of the fertilizer affects the uniformity of fertilizer spreading. Granulated cylindrical NPK 4-8-1.2 fertilizer of poultry manure was used for the research (Fig. 1 b). Its composition is: organic matter is 82.02%, organic carbon – 41.66%, nitrogen – 4.61%, phosphorus – 1.19% and potassium – 2.32%. The average diameter of the organic pellets was 6 mm. Ammonium sulfate was used for spreading mineral fertilizers as a comparative study to assess uniformity. The form of mineral ammonium sulfate fertilizers: granular fertilizer particles 1-5 mm in size (Fig. 1 c). This is one of the most popular types of fertilizers. Mineral fertilizers were spread without applying a variable rate. According to the fertilizer manufacturer, the recommended fertilization rate for cereals is 200-400 $kg \cdot ha^{-1}$. The minimum recommended rate chosen during the study was 200 $kg \cdot ha^{-1}$.

During the survey, the wind speed did not exceed 5 m s^{-1}. The weather was sunny, the temperature was about 10°C.

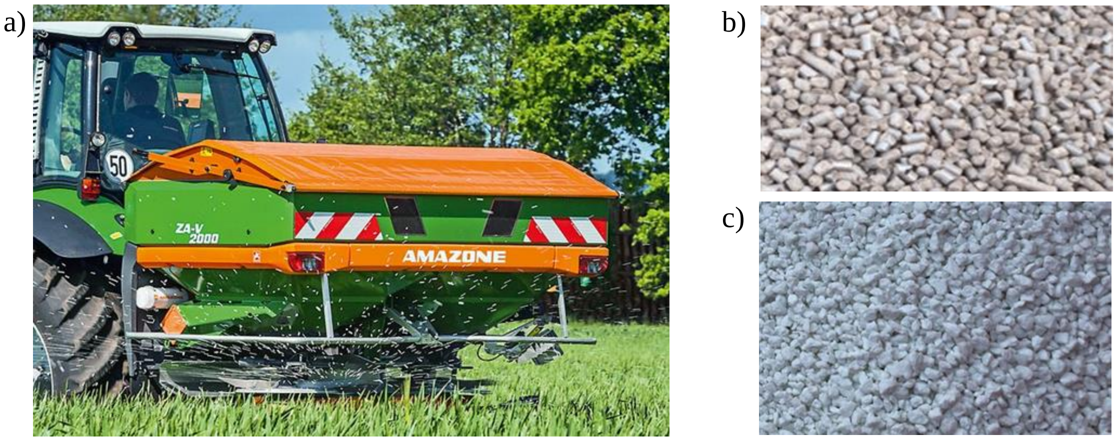

Fig. 1. **Spreader and fertilizer:** a – centrifugal fertilizer spreader AMAZONE ZA-V 3200 [10]; b – NPK 4-8-1.2 fertilizer; c – mineral fertilizer

The results were processed using mathematical statistical methods, also estimating the spreading unevenness coefficient [11].

Results and discussion

The study used high-quality fertilizers, not crumbled, not compacted, of appropriate hardness. The image of the fertilizers used in the study is presented in the methodology section (Fig. 1 b and c). The Antille et al. found that the particle landing distance was greater than for biosolid granules which had a similar particle density but with a significantly smaller diameter value.

Since the field was spread with organic fertilizers at a variable rate, it was investigated which fertilizer rate was spread most evenly. Earlier studies [2; 12], which reported the use of organomineral fertilisers (OMF) derived from nutrient-enriched biosolid granules, indicated the need to determine the suitability of these materials for application with standard fertilizer spreading equipment. It was determined that the uniformity of fertilizer distribution was when a rate of organic granular fertilizers was 600 kg·ha^{-1}. Figure 2 presents the results of the applied fertilization rate of these organic granular fertilizers.

The presented average values of the obtained results are derived from three spreading runs. During all repetitions, the largest amounts of fertilizer weight were determined in the central part of the spreader. The largest average amount of fertilizer fell out in the left side box placed 4 m from the center of the spreader and amounted to 8.33 g. The smallest amount fell out on the left edge in left side box placed 10 m from the center of the spreader and amounted to 6.00 g. However, when the results are evaluated by a second-order polynomial curve, the equation of which is given in Fig. 2, it is noticeable that the fertilizer was distributed symmetrically on both sides of the spreader. The average difference between the amounts of fertilizer dropped in the central boxes compared to the boxes in the extreme positions was about 1.33 g.

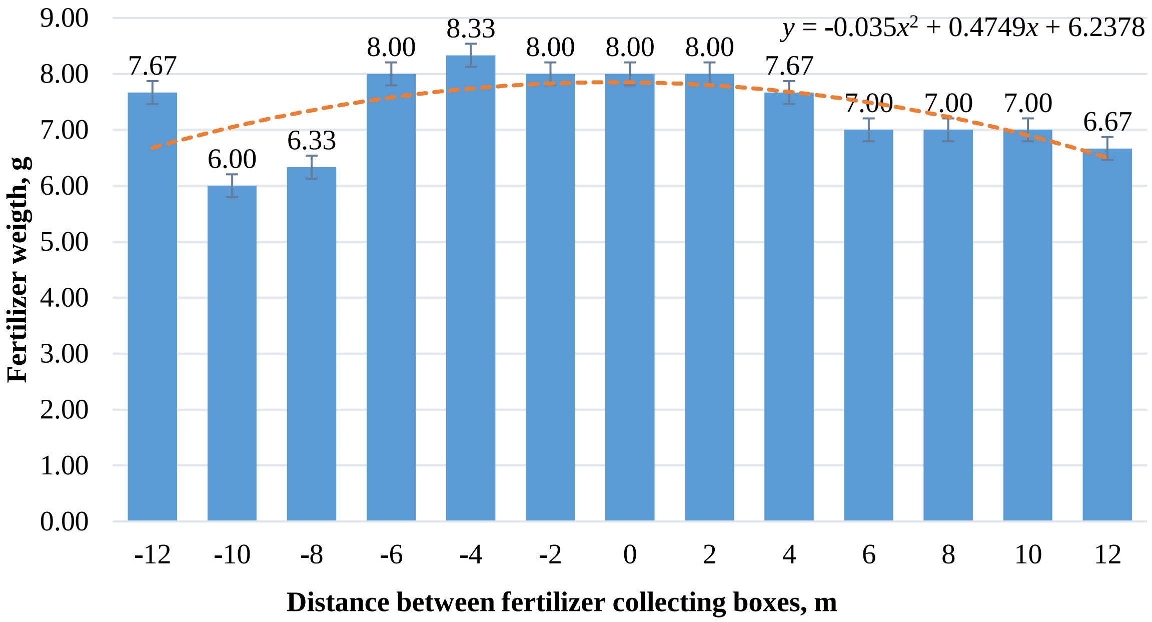

Fig. 2. **Experimental granulated organic fertilizer application schedule at a spreading rate of 600 kg·ha^{-1} (prefixes L-left and R-right stay for fertilizer sides)**

Figure 3 presents the results of mineral granular fertilizers collected in boxes. Also presented are the average values of the results derived from three spreading runs. During the experiment, the uniformity of mineral fertilizer application showed better results when the coefficient of variation was less than 10%. However, when spreading organic fertilizers, the coefficient of variation was best at 600 kg·ha^{-1}, and did not exceed the 10% permissible limit of unevenness of application. After evaluating the results with a second-order polynomial curve, the equation of which is presented in Fig. 3, it is noticeable that the fertilizer was distributed symmetrically on both sides of the spreader and the curve is close to a straight line. The weights of fertilizers in each test box were very similar. The earlier research [2] suggested that it may not be possible to work with tramlines spaced more than 18 m apart depending on the required overlapping between adjacent bouts, the shape of the spreading pattern and the machinery settings. Regardless, the experiment showed that not only mineral fertilizers were spread within tolerance limits, but also organic fertilizers are possible to spread evenly with centrifugal spreaders. However, it should be noted that adjustments to the spreading parameters are necessary, taking into account the physical and mechanical properties of organic fertilizers.

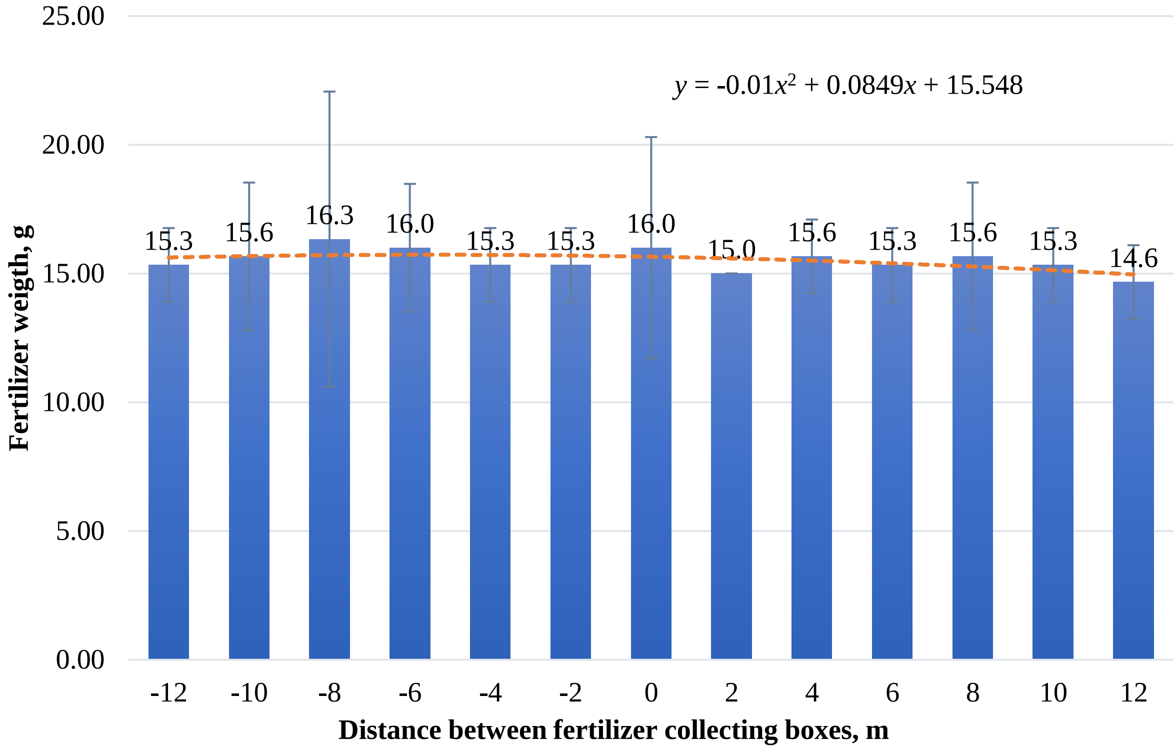

Fig. 3. **Experimental granulated mineral fertilizer spreading schedule, when the spreading rate is 200 kg·ha^{-1}**

The coefficient of variation is one of the main indicators that assess the quality of fertilizer spreading on the fertilizer distribution surface. In the case of organic fertilizer spreading, the coefficient of variation ranged from 4.9% to 8.74%. Since the value of the coefficient of variation did not exceed the permissible limit of 10%, it can be assumed that the data dispersion is within the requirements. In the case of mineral fertilizer spreading, the coefficient of variation ranged from 7.16% to 9.51%. The value of the coefficient of variation also did not exceed the permissible limit of 10%.

Conclusions

1. It was determined that when spreading at a variable rate according to the phosphorus content deficiency in the field, the most rational rate of organic granular fertilizers was 600 kg·ha^{-1} at a speed of 12 km·h^{-1}. Organic fertilizers are spread qualitatively, because the values of the coefficient of variation do not exceed the permissible limits of 10%.
2. Although the manufacturers recommend a mineral fertilizer rate of 200-400 kg·ha^{-1}, when spreading fertilizers at a speed of 12 km·h^{-1}, the fertilizer distribution is uniform at a rate of 200 kg·ha^{-1}. Uniform spreading was shown by the values of the coefficient of variation, which were from 7.16% to 9.51%. Meanwhile, when spreading mineral fertilizers at a rate of 200 and 400 kg·ha^{-1}, the variation coefficients were 15.65% and 13.83%, respectively, which exceeds the permissible norms for uneven spreading.
3. In summary, it can be stated that organic granular fertilizers can be spread at a variable rate using a centrifugal double-disc fertilizer spreader designed for spreading mineral fertilizers.

Author contributions

Conceptualization, E.J., methodology, E.J., A.J., E.V. and R.D., formal analysis, E.J., A.J., E.V. and R.D., investigation, E.J., A.J., E.V. and R.D., data curation, E.J., A.J., E.V. and R.D., writing – original draft preparation, E.J., A.J., E.V. and R.D., writing – review and editing, E.J., A.J., E.V. and R.D., visualization, E.J., A.J., E.V. and R.D., project administration, E.J., funding acquisition, R.D. All authors have read and agreed to the published version of the manuscript.

References

[1] Wang Y., Zhu Y., Zhang S., Wang Y. What could promote farmers to replace chemical fertilizers with organic fertilizers? J. Clean. Prod. 2018, 199, pp. 882-890. DOI: 10.1016/j.jclepro.2018.07.222

[2] Antille D. L., Godwin R. J. Determining the particle size range of organomineral fertilisers based on the spreading characteristics of the material. In 2013 Kansas City, Missouri, July 21-July 24, 2013 (p. 1). American Society of Agricultural and Biological Engineers.

[3] Bivainis V., Jotautienė E., Lekavičienė K., Mieldažys R., Juodišius G. Theoretical and experimental verification of organic granular fertilizer spreading. Agriculture, 13(6), 2023, p 1135.

[4] Jotautienė E., Bivainis V., Karayel D., Mieldažys R. Theoretical and Experimental Verification of the Physical-Mechanical Properties of Organic Bone Meal Granular Fertilizers. Agronomy, 14(6), 2024, p. 1171.

[5] Cupiał M., Kowalczyk Z. Computer-aided fertilisation using the Nawozy-5 (Fertiliser-5) software. In BIO Web of Conferences. Vol. 10, 2018, pp 2002. EDP Sciences.

[6] Kazlauskas M. Assessing the impact of precision seeding and fertilization methods on winter wheat and the environment. Kaunas, 2024. 192 p.

[7] Grafton M. C. E., Yule I. J., Manning M. J. A review of the economic impact of high levels of variance in fertiliser spreading systems. In Proceedings of the New Zealand Grassland Association. Vol. 75, 2013, pp. 131-136.

[8] Matthews N., Grové B. Economic evaluation of increased nitrogen fertiliser prices on risk-efficient fertiliser applications. Outlook on Agriculture, 52(4), 2023, pp. 434-445.

[9] ASAE S341.5; Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders. American Society of Agricultural and Biological Engineers: St. Joseph, MI, USA, 2018; pp. 1-8

[10] Amazone. [online] [07.03.2025]. Available at: https://andrewsymons.co.uk/product/amazone-za-v-3200-profis-tronic-fertiliser-spreader/

[11] Pekarskas J., Pocius A., Čekanauskas S., Godvaišis T. Scientific research project. Research into the production of organic granular cattle manure fertilizers, their fertilization methods and their effectiveness for plants. Academy, 2013. (In Lithuanian).

[12] Antille D.L. Formulation, utilisation and evaluation of organomineral fertilisers. Engineering Doctorate Thesis. School of Applied Science, Cranfield University, UK, 2011.