EXPERIMENTAL AND NUMERICAL RESEARCH OF GRANULAR MANURE FERTILIZER APPLICATION BY CENTRIFUGAL FERTILIZER SPREADING

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Abstract. Conventional, intensive farming depletes the soils. In order to preserve yields, mineral fertilizing rates are being raised, which even more is damaging the soil and the environment. One of the ways to contribute to the implementation of the principles of sustainable agriculture is organic fertilizers. Granular manure, meat-and-bone meal, RPK, and other fertilizers are currently widely used. Different fertilizer spreaders can be used to spread the fertilizer: direct spreading, centrifugal, precision. In this work, experimental field fertilizer spreading studies were performed using organic granular cylindrical manure fertilizers with an average diameter of 4.79 mm, length 7.86 mm, and density 1390 kg m^{-3}. The study was performed using a mounted two-disc centrifugal fertilizer spreader. Two spreading disc blades of different lengths were used to spread the organic fertilizer. Two different fertilizer spreading methods were used in the study: one directional and gradual. When using the fertilizer, the uniformity of spreading was assessed over the entire working width of the spreader according to standardized methodologies. A significant difference was not found between the two driving modes. A typical gradually decreasing trend of the fertilizer weight distribution from the centre of the spreader was obtained. The results showed that as the spread rate of the fertilizer was higher, the distribution was more uniform. Complementing and expanding the possibilities of the experimental research, studies of the dispersion of analogous granules under analogous conditions by the modelling DEM software were performed. The mean of the numerical values was obtained 10% lower than the experimental one. This discrepancy may have been due to the granule properties, environmental parameters, and other factors that were not enough evaluated in the software.

Keywords: granular manure fertilizer, centrifugal fertilizer spreader, DEM, spreading simulation.

Introduction

Soil productivity is one of the most important environmental factors guaranteeing the survival of humanity. Preserving the world's soil resources is essential to achieve the necessary increase in agricultural production and feed 9-10 billion people [1]. At the same time, the proper use of both mineral and organic fertilizers is very important for the implementation of the principles of sustainable agriculture and the EU green course [2]. All fertilizers are used to improve or maintain crop yields. As crop yields increase over time, higher soil organic matter and higher biological activity are achieved than without fertilizers. In many cases, long-term use of fertilizers increases water stability, porosity, infiltration, and hydraulic conductivity, and reduces bulk density [3]. However, too low or too high fertilizer spread rate reduces yields [4; 5].

Research is being carried out with centrifugal spreaders, which are currently mainly used to spread organic granular fertilizers on the soil surface. Organic granular fertilizers can be fertilized by leaching or by incorporation into the soil. The most important thing in fertilizing granular fertilizers is to spread them as evenly as possible in the soil. When fertilizer is applied to the soil, it is necessary for the fertilizer to get as close as possible to the roots and for the cultivated crop to be able to easily absorb it. Due to uneven application of fertilizers in the soil, the plants mature unevenly, lie down and differ in colour. The unevenness of the fertilizer application should not exceed 10% of limits. Research shows that the rate of nitrogen release determines N_2O emissions. Thus, fertilization with granular manure fertilizers needs to meet the nitrogen demand of the crop and at the same time reduce N_2O emissions [6]. However, experimental studies are time-consuming and costly. Computer simulations are also used to develop new scattering models. The spreading dynamics of fertilizer particles were found to be influenced by the rotational speed and position of the rotating discs, the angle of the disc blade, the size and location of each discharge on the disc, the discharge flow, the machine movement speed, and the working width [7; 8]. For spreading of organic granular fertilizers using mineral fertilizer spreaders, it is important to develop spreading methods that do this as optimally, quickly, cheaply and reliably as possible [9].

Granular organic fertilizers are more suitable for spreading with centrifugal spreaders and are easier to transport and store. According to the research conducted in Italy, granular fertilizers (made from swine manure solid fraction composted with wood chips) were the formulation with the best resistance to fragmentation induced by spreader vanes. Granules (made from swine manure composted with sawdust) were the formulation showing better longitudinal and transverse distribution while granules (made from swine manure solid fraction) were the one showing good transverse but poor longitudinal distribution [10].

The aim of the work is an experimental and numerical way to analyse a granular manure fertilizer application by centrifugal fertilizer spreading.

Materials and methods

The main properties of granular organic fertilizers used for the experiment are presented in Table 1. The properties of the granules used in the study are presented in Table 1. Positions 1-4 were identified by the study authors after at least 6 measurements. The remaining properties are specified by the manufacturer of the granular fertilizer [11].

Table 1

Granulated organic manure pellet main characteristics

No.	Characteristics	Value
1.	Granule diameter, mm	4.79 ± 0.16*
2.	Granule length, mm	7.86 ± 0.71*
3.	Granule solid density, kg·m^{-3}	1390.0 ± 21.0*
4.	Granule bulk density, kg·m^{-3}	651.2 ± 28.0*
5.	Quantity of dry material, %	90.0
6.	Ratio of C/N appr.	9.0
7.	pH appr.	7.0
8.	N, total%	4.0
9.	P_2O_5, %	3.0
10.	K_2O, %	2.5
11.	MgO, %	1.0
12.	CaO, %	9.0
13.	Fe, mg·kg^{-1}	700.0

*Confidence interval at significance level α = 0.05

Spreading of granular fertilizers was performed using a two-disc centrifugal fertilizer spreader Amazone ZA-M-1001. The tests were performed using 410 and 290 mm long fertilizer spreading vanes and their rotation angles were determined according to the manufacturer’s recommendations for organic granular fertilizers. The fertilization rate of the fertilizer was determined before the spreading tests. For this purpose, one disc was removed from the spreader and a special purpose container was hung in its place under the adjustable hopper opening. As the tractor PTO shaft rotated, the spreader control program calculated the fertilizer spread rate based on the amount of the fertilizer spread over the set time. The uniformity of fertilizer spreading was determined using special fertilizer collection pans 500 mm long, 400 mm wide and 100 mm deep, the layout of which is shown in Figure 1.

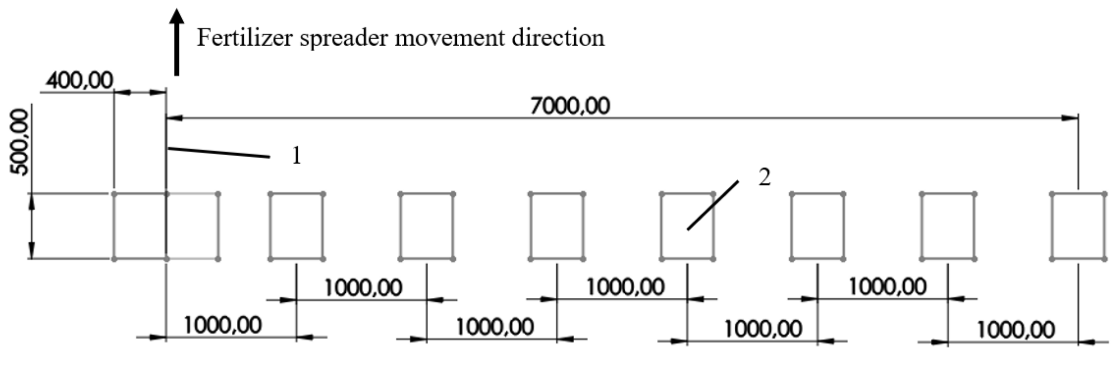

Fig. 1. L**ayout of the fertilizer collection pans:** 1 – fertilizer spreader centre; 2 – collection pans

The amount of accumulated fertilizer in the boxes was weighed on an electronic scale with an accuracy of 0.1 g. The rate of fertilizer application was selected based on the available data from the created dose maps and was determined using a spreading control computer. In the field where the fertilizer collection boxes were placed, the fertilizer application doses were 200 and 400 kg·ha^{-1}, respectively. The fertilizer manufacturer [11] recommends the use of significantly higher spreading rates for these granular fertilizers (up to 1000 kg·ha^{-1}), but in this study, lower spreading rates recommended for specific field areas were chosen based on the available dose map data.

Spreading studies of granular organic fertilizers were carried out in a flat field of about 13.5 ha. The tractor with the spreader was travelling at a constant speed of about 6.5 km·h^{-1}. Two different methods of driving the tractor with the spreader were used: 1) one-way and 2) gradual. When spreading in the one-way method, the tractor with the spreader always ran parallel in the same direction; spreading on the right side was covered by spreading on the left side. In the case of a gradual spreading operation, the tractor and the spreading van were driven in parallel, but with a change in direction; the right-hand spreading thus carried out was covered by the right-hand spreading of the next spreading. The significance of the difference between the experimental results of these two scattering methods was determined using the *t*-Test (Two-Sample Assuming Unequal Variances with a significance level $\alpha = 0.05$).

During the tests, the fertilizer in the hopper was not wet, did not stick together, and approximately the same amount of fertilizer was maintained in the hopper. Each fertilizer application was repeated 3 times using two different spread rates and two different driving methods. The day was overcast, the air temperature was 3-4 ºC, the wind speed was less than 2.0 m·s^{-1}, the relative air humidity was 85%.

Computer simulations of fertilizer spreading using the discrete element method (DEM) were performed. The fertilizer spreading modelling research methodology used granules, contact surfaces, etc., the properties are presented in the authors' work [12], which also used 200 kg·ha^{-1} and 400 kg·ha^{-1} spreading rates of granular fertilizers. This allowed using the properties of analogous granules and contact surfaces required for the modelling of fertilizer spreading, which have already been verified in this authors' work (mentioned before spreading rates). In this work the modelling studies performed were supplemented by an experimentally determined fertilizer spreading coefficient, which allowed to specify more precisely the fertilizer spread at different fertilizer rates in the DEM modelling program.

Results and discussion

The results of distribution of the spread rate of granular fertilizers at a fertilizer spread rate of 200 kg ha^{-1} with the tractor with the spreader moving in one direction are shown in Figure 2. In addition to the results of the experimental studies, this diagram presents the results of computer modelling studies of spreading of these fertilizers.

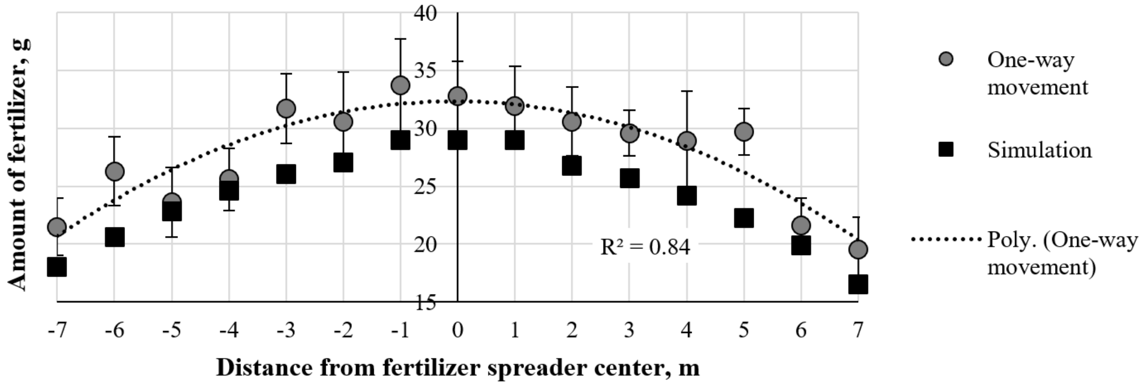

Fig. 2. **Distribution of fertilizer application at a rate of 200 kg·ha^{-1} at a one-way run**

As we can see from the presented results, the distribution of fertilizer application is not even; the highest amount of fertilizer applied was obtained at the centre of travel of the spreader and the lowest at the edges; the same tendency was presented in the work [13]. The obtained tendency of the amount of fertilizer distribution is close to the square polynomial, obtained $R^2 = 0.84$. The results of computer modelling showed an average of about 9.8% lower application rate. Figure 3 below shows the spreading results for the same fertilizer spread rate for the tractor with a spreader driving gradually.

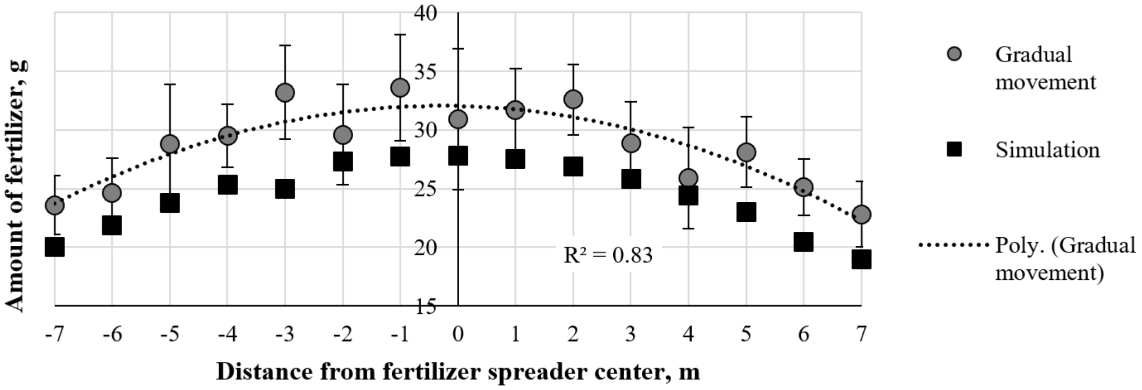

Fig. 3. **Distribution of fertilizer application at a rate of 200 kg·ha^{-1} at a gradual run**

As we can see from the presented results, the distribution trend is very close to the results of one-way driving. The results of computer modelling showed an average of about 8.5% lower application rate. No statistically significant difference (*t*-Test: Two-Sample Assuming Unequal Variances *p*-value = 0.28; *p*-value > α) was found between the averages of the applied fertilizer at $\alpha = 0.05$ when comparing one-way and gradual driving methods with each other. It can be concluded that the gradual spreading was more even, as the marginal collection pans yielded on average about 10% more fertilizer. The modelling results did not show this difference.

Using twice as high fertilizer application rate (400 kg·ha^{-1}), very similar experimental and computer simulation results were obtained. During the simulation, on average, about 10% less fertilizer was applied, and during the experiment, more even distribution of the fertilizer was obtained using the gradual spreading method. About 7.8% more fertilizer was stored in the side fertilizer collection pans than in one-way driving. No statistically significant difference (*p*-value = 0.19; *p*-value > α) was found between the averages of the applied fertilizer at $\alpha = 0.05$ when comparing one-way and gradual driving methods with each other for the 400 kg·ha^{-1} fertilizer application rate. In Figure 4 below only one-way driving test results are presented.

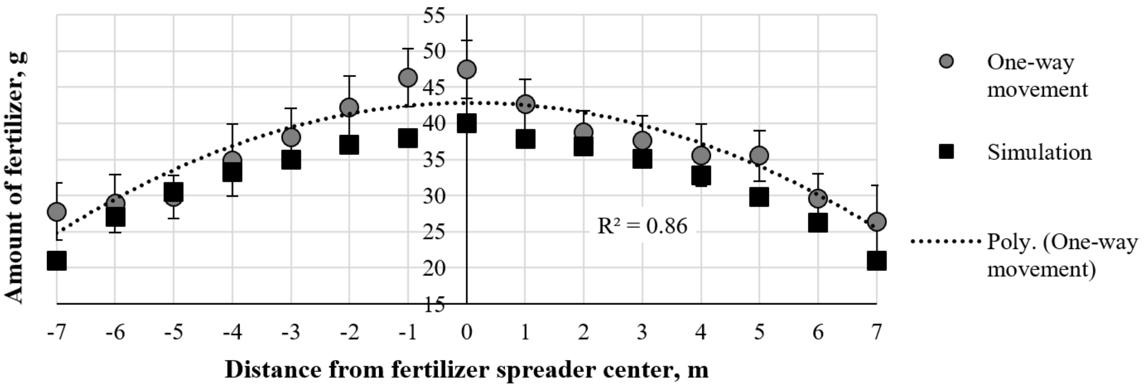

Fig. 4. **Distribution of fertilizer application at a rate of 400 kg·ha^{-1} at a one-way run**

Summarizing all presented research results, it can be stated that the nature of the spread pattern of granular fertilizers is quite close to the results of analogous granular fertilizer spreading presented in previous works [12; 13]. It can also be stated that the modelling results obtained by using the additional parameter fertilizer spreading coefficient in the (DEM) modelling were quite close to those obtained during the experiment in terms of nature and weight values of the spread fertilizer. The obtained relatively close experimental and modelling results will allow further research using higher application rates of granular organic fertilizers. Also, in the absence of a statistically significant difference between the two different fertilizer spreading methods, it will be appropriate to use only one fertilizer spreading method in further studies, changing other important spreading parameters.

Conclusions

1. Experimentally determined fertilizer spreading coefficients were used to model spreading of granular organic fertilizers using the discrete element DEM method, which allowed us to obtain more accurate fertilizer modelling results.
2. It was found that the trends in the distribution of fertilizer obtained during the experiment and modelling were close, and the modelling showed an average of about 10% lower amount of fertilizer applied.
3. No statistically significant difference was found between the averages of the results of the one-way and the gradual spreading methods, but the results show that the fertilizer was spread more evenly with the gradual application, there was about 8.9% more fertilizer in the outer boxes.

Author contributions

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

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