Basic Research for the Development of Fertiliser Spreaders

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SUMMARY

The knowledge of the physical characteristics of fertiliser particles is essential for the constructors and operators of fertiliser distributors. Among physical characteristics, the most important are the frictional and aerodynamic properties for the description of particle movement. Adjustable angled slopes, shearing boxes and various rotating disks are used to identify frictional properties. We have developed a high precision shearing box with digital force measuring cells and a distance signaller (incremental transducer) that we use for slide tests efficiently. We measured the frictional characteristics of 6 different fertilisers: the inner coefficient of friction and the coefficient of friction on ten test surfaces most commonly used in machinery, and we specified the relationship between displacement, loading and the coefficient of friction. We can conclude that the material of the frictional surface significantly influences the force of friction.

However, our experience tells us that the shearing box is not suitable for the measurement of the inner friction, since the examined particles slide on the metal surface of the shearing box in a growing extent in the course of displacement, so it does not measure the real inner friction. Therefore, in our experiment we have developed rotating shearing equipment with a constant shearing surface to identify the inner friction. We tested the equipment with fertilisers and we identified the inner frictional characteristics of 6 different fertilisers. With the developed rotating shearing apparatus we could measure the real inner friction of the particles.

To identify the aerodynamic characteristics of granules, wind tunnels and free-fall tests are used. An elutriator have been developed for our investigation. We have used fertilisers for testing the measuring equipment and we have identified the aerodynamic characteristics of 6 different fertilisers.

Keywords: *shearing box, rotating shearing apparatus, elutriator, coefficient of friction, aerodynamic properties*

INTRODUCTION

Technologies and techniques applied in agriculture have undergone significant changes recently. The design of machines is influenced by an increasing range of considerations, such as reliability, durability, compactness, excellent working quality, energy-efficient operation, and aspects of environmental protection. The standards machines have to meet are becoming stricter. The construction of machines, earlier based on generally applied experimentation, is not viable without a theoretical basis and modelling methods based on measurements. The knowledge of the characteristics of the particles used is a key issue in the process of design. As a result, the study and investigation of the characteristics of particles used in agriculture, mainly of their physical properties, have become a significant area of agricultural research. Granular particles are of special importance as they come into close contact with various machines in the course of particle movement and spread.

A thorough knowledge of the most important physical characteristics (size, shape, sphericity, density, moisture content, friction characteristics, aerodynamic properties) of granular particles is essential for the precise construction and reliable operation of agricultural machines.

The efficiency of fertiliser distribution should be improved, because of the need to save costs and energy, environmental control measures are growing stricter. One should also take into account high yields and high quality production. One of the core research areas of the Department of Agricultural Engineering of the University of Debrecen is to define the main technical features which influence the even spreading of fertilisers, so we have been developing fertiliser spreaders for many years. The Department has developed a suitable testing method and created the technical conditions necessary for successful research.

The performance of fertiliser distributors and, therefore the evenness of the spread pattern, depend to a large extent on the physical properties of fertiliser particles. Many physical properties are relevant during spreading, but the coefficient of friction and the aerodynamic resistance coefficient are the most important (Hofstee et al., 1990). The measuring of the coefficient of friction and the aerodynamic properties of different fertiliser particles are discussed below.

MATERIALS, METHODS AND EXPERIMENTS

We undertook our experiments on 6 different fertilisers, paying special attention to the different properties of the chosen types. For the investigation of physical properties, we found it essential to have fertiliser particles which were soft and hard, of spherical and irregular shape, and different of size and size distribution. Therefore we chose 3 nitrogen (Ammonium Nitrate, Calcium Ammonium Nitrate, Urea) one potassium and 2 NPK fertilisers. Investigations were performed in the analytical laboratory of the Department of Agricultural Engineering. The temperature of the laboratory was kept at 20°C, and relative humidity varied between 25-35%. To identify the aerodynamic properties, we chose 108-108 particles per variety. The moisture content of the samples was defined at 103±1°C in the course of 72 hours` drying.

To determine the size and shape of the particles, the three principal dimensions were measured using a digital micrometer (smallest measurement 0,01 mm). To obtain the mass, each particle was weighed on a precision electronic scale within 0,1 mg.

The angle of repose of fertilisers was measured using a topless box made of plywood, 300x300 mm in cross-section and 400 mm in height, where the front panel (with the exception of a height of 100 mm) was removable. The box was filled with fertiliser, then the front section was removed quickly but smoothly. By the aid of the fertiliser level measurable above the outlet (*a*) and box size vertical to the outlet (*b*) the angle of repose was calculated on the principle of $tg\alpha = a/b$.

A friction-measuring device was developed (Csizmazia et al., 2001) for measuring the inner friction of grains and the coefficient of friction on different surfaces. The device contains a shearing box of two pieces with a cross-section of 200x200 mm and with an inner height of 60 mm. In the course of measuring, the lower frame of slight resistance was moved whilst passing over a row of ball bearings. An electric motor moved the drag frame back and forth, with the help of diverting switches. Between the drag frame and the shearing box a flat-link chain driven by a chain wheel established the link (closed mesh). The cell that measured the drag force within the range of 1000 N was built into the vertical pulling arm of the drag chain. Dislocation was measured by an incremental rotating transducer, producing 2000 signals per rotation. A cell to measure the power with a range of 1000 N was adjusted to the top of the shearing box. Loading was performed with the help of a system of arms, with weights placed on the scale pan, at a gear transmission of 25x.

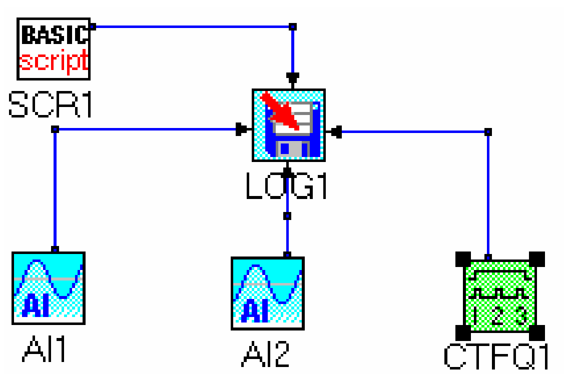
The equipment for the investigation of friction was supplemented by a rotating shearing apparatus to measure the inner friction. The apparatus consisted of two rings with an inner diameter of 250 mm and with an inner height of 60 mm, of which the upper ring is fixed and can be loaded, the lower ring could be rotated. The diameter of the core parts of the ring was 100 mm. The planes partitioned the inner space of the rings into compartments of 120°. In other respects, this apparatus is similar to the shearing box.

SYSTEM OF DATA COLLECTION FOR THE EQUIPMENT

The system for the measurement and collection of data collects and processes the data transmitted by the two force measuring cells and the dislocation signaler. The data are received by two analogous and one impulse counting input of the computerized, multifunctional data collector card. The type of the measuring card is Advantech PCL 818HG. The same card provides stabilized direct current (DC) of 9V for the force measuring cells, and supplies the rotating transducer with 10V. A PCL 8115 type wiring card facilitates electric connection, placed in the box adjusted to the measuring Figure. VisiDAQ 3.1 enters the measured data into the computer. The user surface of the program provides easy planning for measurement setup, as well as opportunities for the routine writing of Basic.

The unit of type **SCR1** (*Figure 1*) generates the time from the launch of measurement. The **CTFQ1** unit enters and counts the impulses given by the incremental transducer. The **A/1** analogous input unit reads the value of electric voltage provided by the vertical force-measuring cell, whereas the **A/2** analogous input unit reads the electric voltage given by the cell measuring the drag force. The outgoing signals of **SCR1**, **CTFQ1**, **A/1** and **A/2** units connect to the **LOG1** unit, and write the measured data in a text file (the frequency of writing is one tenth of a second). We processed and analyzed the completed files using Excel (Polyák, 2001).

Figure 1: **Collection of measured data**



An elutriator was designed and constructed (Csizmazia et al., 2000) for measuring the suspension velocity of particles. The equipment consists of a 865 mm long plexiglass vertical tube with a diameter of 100 mm in which an airflow is supplied by a centrifugal fan. The air velocity was regulated with the modification of the fan's rpm. The air flowed from the fan through a plenum chamber upward into the 400 mm long test zone of the elutriator. A stainless steel screen with bore size of 0,55 mm (about 46 mesh) separated the test zone from the plenum chamber and supported the particles until the test began. Numerous holes were bored in to the mantle of the plexiglass tube along the test zone. Theoretically specified and precisely constructed perforation decreases air velocity by 20% in the test zone, so the suspension velocity of particles can be measured efficiently. Perforation decreases the boundary layer and allowed the formation of a relatively flat velocity profile in the test zone. A recovery head was connected to the top of the test channel to collect the air-entrained particles, which moved from the tube.

Air velocity in the bottom of the test tube was controlled by the differential pressure as read on an inclined tube micromanometer, which was connected to a Pitot tube. Since the air velocity decreased along the test zone, it had to be measured in the different height of the test tube. Six holes were bored along the test zone to measure the air velocity with a thermal sensor (Testo 445).

CALIBRATION OF THE MEASURING CELLS AND THE INCREMENTAL SIGNALLER

The calibration of the measuring cells was accomplished with a series of weights of F2 accuracy class. The force measured by the cells was increased in 8 steps from 12,26 N to 735,75 N. The calibration graph of the loading cell is given in *Figure 2*. It can be established that the connection between the normal force and the electrical signals transmitted by the cells is linear. The excellent value of the correlation coefficient (0,99) proves the high accuracy of the cells. The calibration graph of the drag force measuring cell is given in *Figure 3*.

Figure 2: **Calibration graph for loading cell**

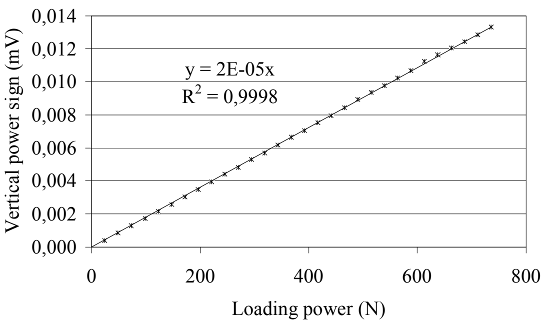
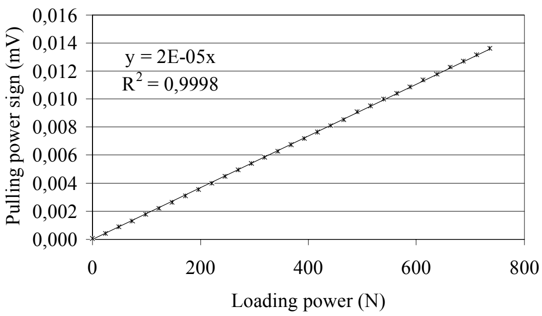
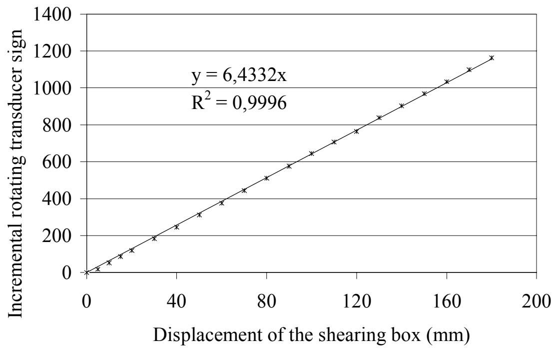


Figure 3: **Calibration graph for drag force measuring cell**



The calibration of the incremental signaller was accomplished by measuring the number of signals transmitted during the displacement of the pulling frame from 5 mm to 180 mm in 5 mm, then 10 mm steps. The calibration graph is shown in *Figure 4*. It can be established in this case, too, that the connection between the displacement of the pulling frame and the number of transmitted signals is linear. The excellent value of the correlation coefficient (0.99) indicates the reliability of the signaller.

Figure 4: **Calibration graph for rotating transducer**



CALIBRATION OF THE ELUTRIATOR

Air velocity profiles were measured in the test section of the elutriator at vertical distances of 62, 160, 265 and 365 mm up from the lower hole line (*Figure 5*). The figure shows that air velocity began to decrease only 2-3 mm from the walls. *Figure 6* shows the air velocity was measured in the test section of the elutriator without the boundary layer at different vertical distances from the lower hole line. The air velocity changes approximately linearly along the axis of the test zone. The decrease in air velocity was about 20%. Comparing the air velocity at the beginning of the test zone (v_o) to the air velocity change along the test zone (v) gave a linear equation (*Figure 7*).

Figure 5: **Air velocity profiles in the test section at different distances from the lower hole line**

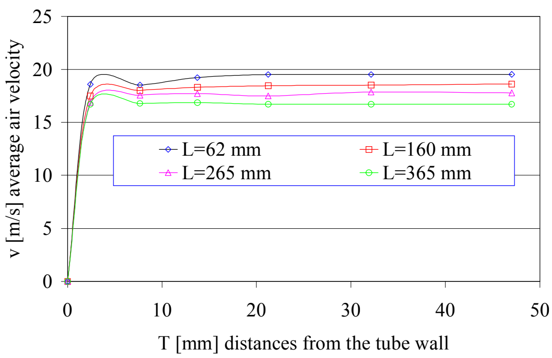


Figure 6: **Air velocity profiles in the test section**

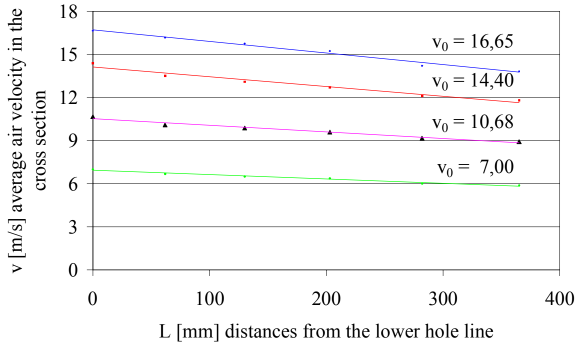
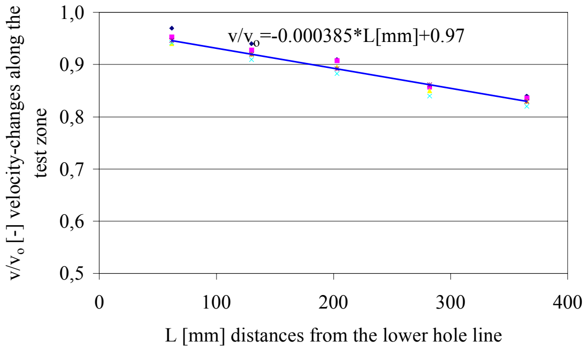
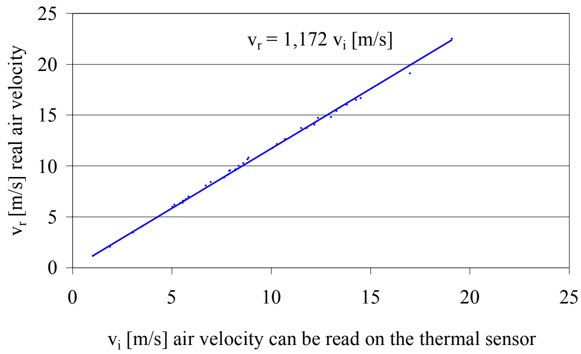


Figure 7: **Velocity changes along the test zone**



The thermal sensor (Testo 445) was calibrated in a ventilation shaft. The results of the calibration test are seen in *Figure 8*. The comparison of the air velocity that can be read on the thermal sensor (v_i) to the real air velocity (v_r) gave a linear equation.

Figure 8: **Calibration graph for thermal sensor**



RESULTS

The values of the angle of repose were in increasing order Ammonium Nitrate (29°), Calcium Ammonium Nitrate and Urea (32-32°), NPK 15-15-15 (35°), Potash (37°) and NPK 2-18-18 (335°) (*Table 1*).

Table 1

Friction properties of different fertilizers by loading of 2,5 [N/cm²]

Properties		Ammonium Nitrate	Calcium Ammonium Nitrate	Urea	Potash	NPK 15-15-15	NPK 2-18-18
Angle of repose		29	32	32	37	35	35
Inner frictional coefficient	calculated from angle of repose	0,55	0,62	0,62	0,75	0,70	0,70
	with the shearing box	0,58	0,62	0,54	0,91	0,86	0,70
	with the rotating shearing apparatus	0.37	0.42	0.35	0.52	0.56	0.51
Frictional coefficient on various surfaces	Stainless steel	0,20	0,29	0,18	0,26	0,22	0,25
	Black steel	**0,32**	**0,40**	**0,35**	**0,44**	**0,39**	**0,57**
	Galvanized steel	0,30	0,32	0,24	0,26	0,23	0,40
	Aluminum	0,28	0,28	0,23	0,19	0,19	0,26
	PVC	0,25	0,29	0,23	0,21	0,20	0,24
	Bakelite	0,23	0,21	0,24	0,17	0,25	0,18
	Teflon	**0,15**	0,19	**0,09**	0,14	**0,07**	0,15
	Plexiglass	0,20	0,25	0,17	0,16	0,16	0,15
	Glass	0,15	**0,14**	0,14	**0,08**	0,08	**0,12**
	Plywood	0,29	0,31	0,33	0,33	0,34	0,29

The values of the internal friction (measured with rotating shearing apparatus) were Urea (0,35), Ammonium Nitrate (0,37), Calcium Ammonium Nitrate (0,42), Potash (0,52), NPK 15-15-15 (0,56) and NPK 2-18-18 (0,51) (*Table 1*). For the 6 investigated fertilisers, we show the relations between dislocation and pulling power and the relations between dislocation and the coefficient of friction by different loads by urea. In relation to the displacement, in the case of various loads, the measured pulling force did not change significantly with displacement in the case of the smallest load (*Figure 9*). In the case of greater loads, pulling force initially increased in relation to displacement, then, after a displacement of 45-50 mm, which is equivalent to the 12-13° rotation of the apparatus, they remained unchanged along the whole displacement path (170 mm, in the domain of 45° rotation). We calculated the μ values, which increased gradually in the case of each fertilizer and each load, then, after a domain of 45-50 mm, they were found to remain at a constant value along the whole displacement (rotation) domain (*Figure 10*).

Figure 9: **Relations between dislocation and pulling power**

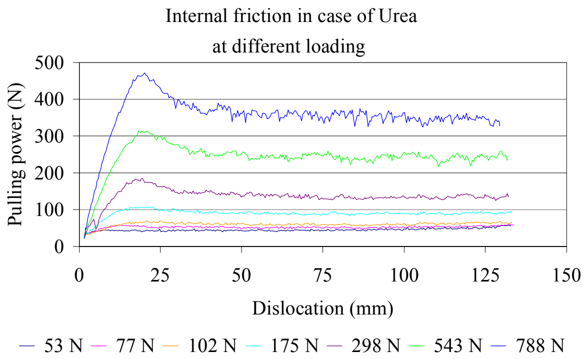
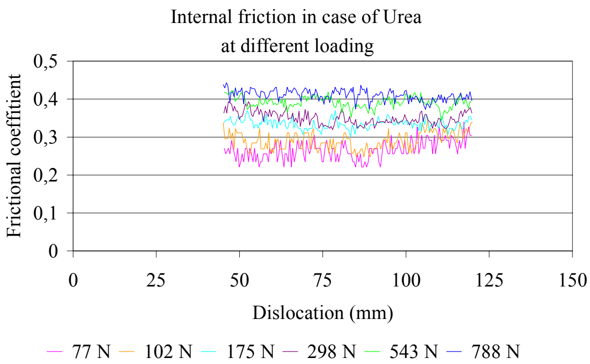


Figure 10: **Relations between dislocation and coefficient of friction**



The values of the frictional coefficient on different surfaces for different fertilisers (measured with shearing box) can be seen in *Table 1*. While the maximum values of the coefficient of friction were presented on black steel, the minimum values of the coefficient of friction were presented on teflon (Ammonium Nitrate, Urea, NPK 15-15-15) and on glass (Calcium Ammonium Nitrate, Potash, NPK 2-18-18). For the 6 investigated fertilisers, we show the relations between dislocation and pulling power and the relations between dislocation and coefficient of the friction by different loads by potash. In relation to the displacement, in the case of various loads, the measured pulling force did not change significantly with displacement in the case of the smallest load (*Figure 11*). In the case of greater loads, pulling force initially increased in relation to displacement, then, after a displacement of 10 mm they increased on a small scale. We calculated the μ values, which increased gradually in the case of each fertilizer and each load, then after a dislocation of 10 mm they increased on a small scale (*Figure 12*). The values of μ decreased by increasing the load.

Figure 11: **Relations between dislocation and pulling power**

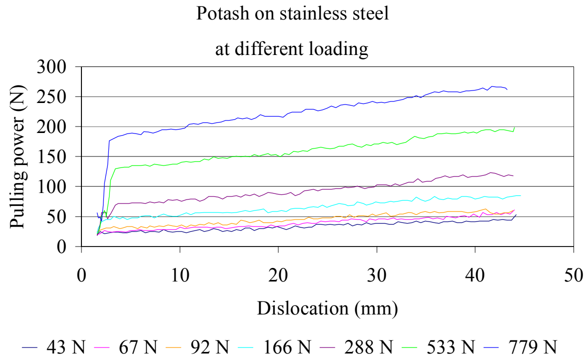
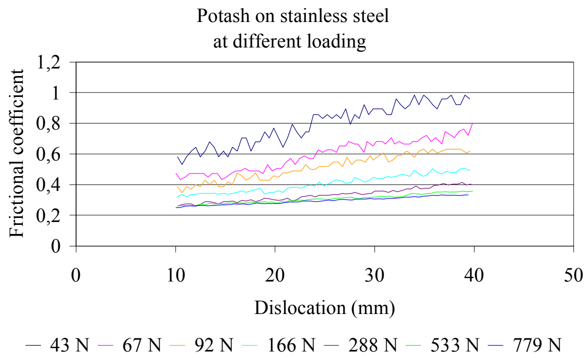


Figure 12: **Relations between dislocation and coefficient of friction**



108-108 particles were measured from the 6 investigated fertilisers to determining the aerodynamic properties. The average values by NPK 2-18-18 seen in *Table 2* were found in case of particles sizes (length/width/thickness) 6,674/5,795/5,117 mm, particle mass 0,205 g, terminal air velocity (v_t) 11,387 m/s, air resistant coefficient (c_w) 0,778. We show the terminal velocity plotted against m_a (mass falling on a unit area of the particles) values by NPK 2-18-18 fertilizer (*Figure 13*).

Figure 13: **The ratio of terminal velocity and mass falling on a unit area in case of NPK 2-18-18 fertiliser**

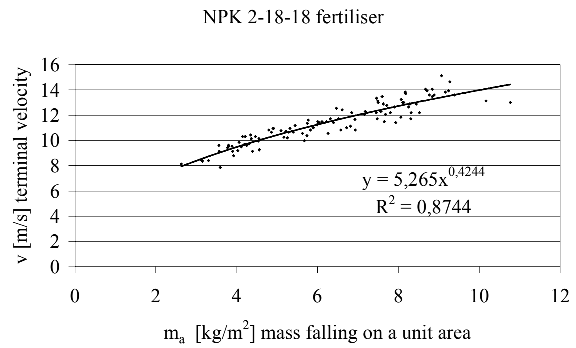


Table 2

Aerodynamic properties of different fertilizers

Properties		Ammonium Nitrate	Calcium Ammonium Nitrate	Urea	Potash	NPK 15-15-15	NPK 2-18-18
Expected value	Length	3,39	4,73	2,50	5,22	5,21	6,67
	Width	3,27	4,19	2,41	3,83	4,31	5,79
	Thickness	2,75	3,83	2,29	3,06	3,58	5,12
	Mass	0,0259	0,0675	0,0095	0,0571	0,0685	0,2045
	Sphericity	0,9199	0,8996	0,9622	0,7586	0,8346	0,8752
	ma	3,25	4,53	2,02	4,59	4,42	6,30
	v_t	9,53	11,43	7,82	8,72	9,94	11,39
	C_w	0,59	0,56	0,54	1,01	0,73	0,78
Standard deviation	Length	0,78	0,82	0,39	0,96	1,16	2,05
	Width	0,57	0,64	0,31	0,61	0,83	1,68
	Thickness	0,42	0,57	0,29	0,59	0,56	1,47
	Mass	0,010	0,029	0,004	0,020	0,028	0,149
	Sphericity	0,073	0,060	0,031	0,087	0,079	0,077
	ma	0,44	0,70	0,24	0,65	0,87	1,88
	v_t	0,77	0,64	0,50	1,03	0,90	1,61
	C_w	0,066	0,055	0,036	0,197	0,085	0,091

CONCLUDING REMARKS

We can conclude that the coefficient of friction and the aerodynamic properties of the 6 investigated fertilisers widely differ, which is highly disadvantageous for adjusting and operating fertiliser spreaders and that it can be a serious source of error in fertiliser distribution.

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