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Research into engineering and operation parameters of mineral fertiliser application machine with new fertiliser spreading tools

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Abstract. The output capacity of the machine for top spreading the soil with solid mineral fertilisers can be raised by means of increasing its working width. The authors have carried out field trials and field experiment investigations with the MVU-8 granulated mineral fertilizer spreading machine equipped with two prototype units of the centrifugal fertiliser spreading tool, in which the axis can be tilted at different angles to the vertical line. In accordance with the results of the completed investigations, it has been established that setting the axial tilt angle of the centrifugal operating device in the fertiliser spreading tool within the range of 25–30° provides for achieving a productivity of the combined tractor-implement unit for applying mineral fertilisers at a level of 35–40 ha per working shift hour. The best performance in the fertiliser application with regard to both the working width and the fertiliser placing distribution uniformity is ensured at angles of inclination of the disc in the fertiliser spreading tool with respect to the horizontal plane within the range of 25–30°. At these angles, the uneven distribution of the fertiliser over the working width is equal to 19.2%, the uneven distribution of the fertiliser along the unit's line of travel is equal to 8.9%, while the deviation in the dosage of the applied fertilisers from the set value is equal to 7.5%.

Key words: distribution uniformity, inclination angle, fertiliser, spreading disc, uneven distribution.

INTRODUCTION

As is known, the output capacity of the machine for top spreading the soil with mineral fertilisers and chemical soil improvers equipped with centrifugal fertiliser spreading tools depends on its working width, the tractor-implement unit's operating rate of travel and the shift time utilisation rate (Adamchuk, 2002). In view of the fact that the resource for improving the productivity by increasing the unit's operating travel rate as well as the shift time utilisation rate has been used up, the only reserve for its improvement is the increase of the working width. That said, the working width of the mineral fertiliser top dressing machine, in its turn, depends on the absolute velocity of the departure of mineral fertiliser particles from the fertiliser spreading tool and the angle between its vector and the horizontal plane as well as the height above the field surface level, at which the fertiliser spreading tool is installed (Villette et al., 2005; 2007).

At the same time, the following circumstances have to be taken into account, when analysing the possible ways to design new fertiliser spreading tools for the purpose of increasing the mineral fertiliser spreading range and, accordingly, the working width of the machine:

– physical and mechanical properties of the mineral fertilisers supplied by the chemical industry currently to both the Ukrainian market and the international one, have for the last decades remained unchanged. Therefore, it can be forecasted that in the decade to come the physical and mechanical properties of mineral fertilisers, such as the dimensions and strength of the granules, the coefficient of friction for fertiliser particles on the vane surfaces, which have an effect on the spreading distance, will not change (Grift et al., 2006; Van Liedekerke et al., 2009; Biocca et al., 2013);

– spreading disc vanes manufactured with the use of polymer parts or state-of-the-art composite materials, on the surfaces of which the mineral fertilisers particles slide, have relatively small coefficients of friction, which results in the increased absolute velocity of the fertiliser particle departure from the fertiliser spreading tool. However, that has already been widely implemented in the engineering of new agricultural machinery and, therefore, hardly can be of great importance specifically with regard to the mineral fertiliser top dressing (Yildirim, 2006; 2008);

– raising the absolute velocity of the fertiliser particle departure from the fertiliser spreading tool by means of increasing the outer diameter of its spreading disc is in practice impossible, since this way, the same as in the preceding item, has been used up and the further augmentation of the disc diameter in the tool under consideration is restricted by the design layouts of mineral fertiliser top dressing machines (Adamchuk, 2006; Villette et al., 2008; 2010);

– raising the absolute velocity of the fertiliser particle departure from the fertiliser spreading tool by means of increasing its spreading disc rotation frequency is, again, not possible for practical purposes. The research carried out in the recent years has shown that the vanes of fertiliser spreading tools, which entrain the mineral fertiliser particles, apply to them impact force, which results in the disintegration of the granules and production of powder fractions (Adamchuk, 2006). It is to be taken into account that at higher rotation frequencies in the fertiliser spreading tool a considerable mass of dust and fine fraction is produced, which has a significantly reduced "tossing" property when spread in the air. That results in spreading the fertiliser within a much shorter range, than in case of spreading intact granules;

– way of increasing the angle between the vector of the absolute velocity, with which mineral fertiliser particles depart from the fertiliser spreading tool, and the horizontal plane, by means of increasing the vane setting angle in the horizontal plane, has also been used up by now in the existing tools with vertical rotation axes;

– as regards the height above the field surface, at which the fertiliser spreading tool is positioned, it is not much appropriate for two reasons. Firstly, it has no significant effect on the increase of the working width in mineral fertiliser top dressing machines.

Secondly, the height, at which such fertiliser spreading tools can be installed, is limited by the elevation of the process bin's bottom, which cannot be positioned much higher.

On the assumption of the above-mentioned limiting factors and after the analysis of the above-said, it can be stated that increasing the working width is a topical problem in the design of new models of solid mineral fertiliser top dressing machines, which can be equipped with centrifugal disc-type fertiliser spreading tools. This problem has to be solved by way of carrying out the necessary scientific research.

The topical issues of raising the efficiency in the application of mineral fertilisers and the work processes of their placing in the soil have until now been subjects of study for many scientists. For example, in the studies by Scheufle & Bolwin (1991), Frode & Lorenzo (2001), Rainer (2001), Yasenetsky & Sheychenko (2002), Lawrence et al. (2007, White et al. (2007), Šima et al. (2013), Bulgakov et al. (2017), Marinello et al. (2017), Virro et al. (2020), it has been established that the efficiency of using mineral fertilisers depends not only on the fertilisers themselves, but also on the methods of their placing in the soil. The principal factor that limits the efficiency in the spreading application of mineral fertilisers is the uniformity in their distribution over the area of the field. This factor has a material effect on the ripening of the plants, the variation of the yield within the limits of one field and, overall, its decline.

Such scientists as Adjetey et al. (1999), Yasenetsky & Sheychenko (2002), White et al. (2007), Ma et al. (2009) have proved that the applied mineral fertilisers must be the direct source of nutrients for the plants, therefore, during their application they have to be placed in the soil in such a way that they become readily available for the active parts of the plants' root systems. Placing mineral fertilisers close to the roots of agricultural plants creates the increased nutrient concentration zone for the roots. That facilitates the absorption of the fertilisers and improves their application efficiency. Fertilisers need be placed as in the top layers of the soil, so in the deeper ones, their concentration being in proportion to the development of the plants' root systems.

The research carried out by various scientists has also greatly contributed to the elaboration of the fundamental principles for modelling the mineral fertiliser spreading by centrifugal tools. In particular, Yasenetsky & Sheychenko (2002), Aphale et al., (2003), Dintwa et al. (2004), Villette et al. (2007), Jones et al. (2008), Olt & Heinloo (2009), Hijazi et al. (2010), Antille et al. (2015), Lü et al. (2016), Kobets et al. (2017), Liu et al. (2018), Bulgakov et al. (2020) have carried out in-depth studies on the development of the fundamental principles for modelling both the process of top dressing with mineral fertilisers and the equipment for its implementation. However, the models generated in these studies are based on certain assumptions, which makes their practical application problematic. Those deficiencies have been eliminated by Adamchuk (2006) in the simulation model that he developed for the mineral fertiliser spreading process stipulating that its implementation requires carrying out separate experimental investigations. However, his approach did not cover such issues as the schematic model of the centrifugal spreading tool, in which the working axis is set with tilt with respect to the vertical line.

Meanwhile, in accordance with the working hypothesis developed by the authors, that is exactly the feature that will provide for increasing the mineral fertiliser particle spreading range and, accordingly, expanding the working width and improving the output capacity of the machines for top dressing with mineral fertilisers.

The aim of the paper was to improve the output capacity of the machines for top dressing with solid mineral fertilisers by means of increasing their working widths through the implementation of new fertiliser spreading tools with tilted axes.

MATERIALS AND METHODS

For the purpose of carrying out field tests and field experiment investigations, the authors used the MVU-8 machine for the application of granulated mineral fertilisers and chemical soil improvers, which was equipped with two new prototype centrifugal fertiliser spreading tools developed by the authors (Bulgakov et al., 2021), the axes of which could be set at different angles of tilt with respect to the vertical line (Fig. 1).

Figure 1. General appearance of improved-design machine for top dressing with mineral fertilisers, lime and gypsum equipped with two fertiliser spreading tools with tilted axes during its field testing and field experiment investigation: a – side view; b – rear view.

During the field testing of the above-mentioned machine for top dressing with mineral fertilisers, it was equipped with fertiliser spreading tools, the axes of which were tilted at an angle of 30° with respect to the vertical line (Fig. 2).

Figure 2. General appearance of prototype fertiliser spreading tools with tilted axes installed in improved-design machine for top dressing with mineral fertilisers.

Both the fertiliser spreading tools with tilted axes were kinematically linked with the power take-off shaft of the carrying tractor, while the fertiliser feeder - with the transport wheel of the machine. The powering on and off of the fertiliser feeder drive was controlled by the tractor operator remotely with the use of the tractor's hydraulic system.

The operation of the machine equipped with the fertiliser spreading tools with tilted axes proceeded as follows. As the tractor-implement unit under consideration travelled forward, the rolling wheels of the machine's running gear drove the closed loop of the fertiliser feeder, the top run of which entrained fertilisers and brought them out from the body through the outlet slot in the form of a layer of a certain height. From the feeder the mineral fertilisers arrived to the fertilizer guides, which divided them into two equal flows and also forwarded them into the feed zones of the fertiliser spreading tools with tilted axes. When the fertilisers departed from the fertilizer guides, they were entrained by the vanes of the discs in the fertiliser spreading tools with tilted axes that performed rotary motion. Under the action of the centrifugal force the fertiliser granules accelerated moving along the vanes in the direction from the centre of the fertiliser spreading tool to the peripheral ends of the vanes. After reaching the vane ends, the fertilisers departed from the fertiliser spreading tools and flew in the set directions. The presence of two fertiliser spreading tools with tilted axes provided for the generation of two mineral fertiliser particle seeding fans, each in the form of a sector with an angle at centre of 90°. On account of the received reserve of kinetic energy and under the action of the gravity force, the fertiliser granules moved in the air in the direction from the fertiliser spreading tools to the field surface. The machine propelled by the carrying tractor travelled linearly forward, therefore, the mineral fertiliser granules falling on the soil surface formed its continuous sheet cover.

The distribution uniformity in the spreading with fertiliser across the machine's working width and along the line of the unit's travel was determined as the coefficient of variation of the fertiliser mass distribution over the standard trays (GOST 28714-2007) that were placed in a horizontal area of the field in accordance with the layout presented in Fig. 3. During the experiment, the wind velocity did not exceed 2 m s^{-1}, its value was determined with the use of the MS-13 cup anemometer.

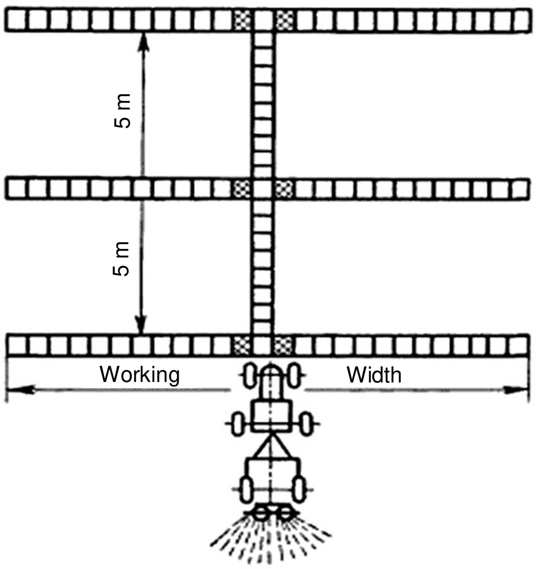

Figure 3. Layout of placing trays in single replication for determining values of distribution uniformity in spreading with mineral fertilisers.

The machine equipped with the fertiliser spreading tools with tilted axes developed by the authors and carried by the tractor was tested with its use for the operations of the basic application of granulated superphosphate and nitroammophoska.

During the experimental investigations, the following application dosages were assumed for the above-mentioned mineral fertilisers: in case of granulated superphosphate, the application rate was equal to 400 kg ha^{-1}, in case of nitroammophoska - 300 kg ha^{-1}.

Prior to carrying out field experiment investigations, the authors performed the assessment of the properties of the process material, i.e. the above-mentioned mineral fertilisers. During the application, they had the following grain-size compositions:

– granulated superphosphate:
  ≤ 1 mm – 5.0%;
  $\geq 1 - \leq 2$ mm – 20.3%;
  $\geq 2 - \leq 3$ mm – 40.7%;
  $\geq 3 - \leq 4$ mm – 23.4%;

≥ 4 mm – 10.6%;
- nitroammophoska:
  ≤ 1 mm – 2.1%;
  ≥ 1– ≤ 2 mm – 32.3%;
  ≥ 2– ≤ 3 mm – 59.1%;
  ≥ 3 mm – 6.5%.

The investigation of the performance figures of the mineral fertiliser top dressing machine with the new fertiliser spreading tools with tilted axes was carried out in field conditions in the fields of the Olenevskoye Experimental Farm under the National Research Centre of Institute of Agricultural Engineering and Electrification, where the machine performed the operation of top dressing the soil with mineral fertilisers before its cultivation.

The mineral fertiliser application machine travelled at a process speed of 12.5 km h^{-1}.

RESULTS AND DISCUSSION

Fig. 4a represents the results obtained when determining how granulated superphosphate distributed over the trays placed in accordance with the layout shown in Fig. 3. In the course of the field experiment investigations, the total range of the effective seeding of granulated superphosphate, that is, the spreading width provided by the machine equipped with two fertiliser spreading tools with tilted axes was equal to 58 m. At the same time, within the spreading width of 58 m, the uneven application of granulated superphosphate was equal to ± 65.4%, which did not meet the agricultural engineering requirements to the top dressing of the soil with mineral fertilisers. In view of that fact, in order to find out the working width of the machine, it was necessary to determine first the size of the overlap between the adjacent runs of the unit, which had to be selected so as to ensure that the uneven application of granulated superphosphate over the working width did not exceed ± 20%. As is seen in Fig. 4b, the above-mentioned condition was met at a working width of 39 m. In that case, the uneven application of granulated superphosphate over the working width was equal to ± 18.5%.

Apart from that, a large series of experiments has been carried out in order to investigate the effect of the angle of inclination of the disc in the fertiliser spreading tool with a tilted axis with respect to the horizontal plane on the working width of the machine.

In accordance with the design of the multifactorial experiment, the authors have carried out such an amount of tests, when each separate test (with one dosage and one type of mineral fertiliser) is repeated in three replicates. The triple replication of each test is in compliance with the requirements to the accuracy and validity of experimental investigations established in this branch of agricultural engineering.

As a result of the completed research, it has been established (Fig. 5) that increasing the angle of the discs' inclination to the horizontal plane results in the expansion of the machine's working width. However, the above-mentioned relation follows a special pattern, that is, increasing the said angle of inclination by the same amounts, but at different values of the angle produces different increments in the working width.

The analysis of the diagram presented in Fig. 5 indicates that the most intensive growth of the machine's working width (84.8%) takes place, when the disc's angle of inclination to the horizontal plane increases from 0 to 10°. In that interval, the working width of the machine increases from 16.5 m to 30.5 m, that is, by a factor of 1.85. The further augmentation of the disc setting angle with respect to the horizontal plane from 10° to 20° results in the increase of the machine's working width by 14%, i.e. from 30.5 m to 35.0 m, that is, by a factor of 1.15. Again, further increasing the disc setting angle from 20° to 30° brings about a rise in the working width of the machine by a factor of 1.11 (or by 11.4%). Finally, when the disc setting angle with respect to the horizontal plane is increased from 30° to 40°, that produces no increment in the working width of the machine subject to maintaining the uneven application of fertiliser within the range of ± 20%.

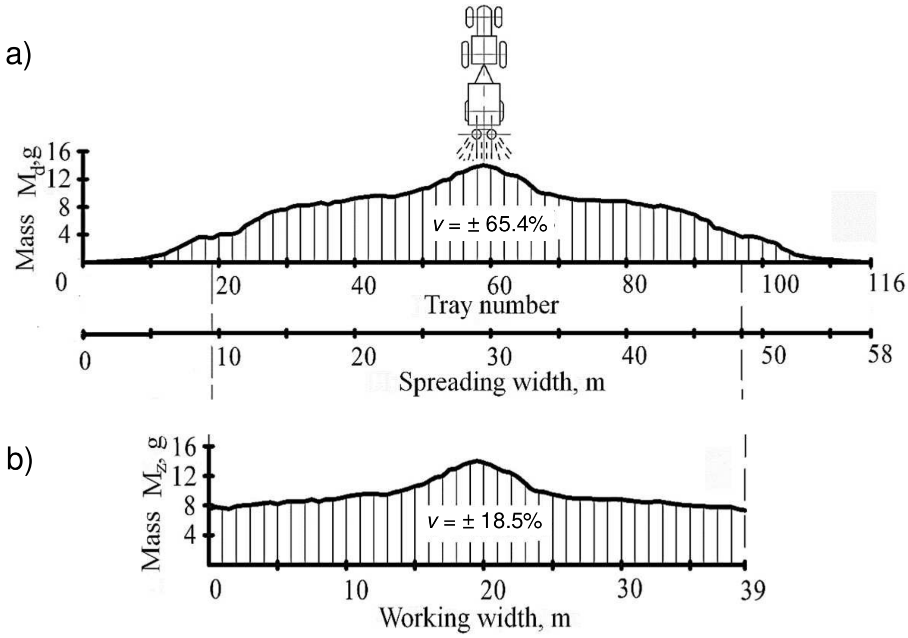

Figure 4. Mass distribution of granulated superphosphate: a – over spreading width (M_d); b – over working width (M_z).

On the basis of the above results of field experiment investigations, the following conclusion can be made: the rational values of the angle, at which the disc in the fertiliser spreading tool is inclined to the horizontal plane, are found within the range of 25–30°. Despite the fact that at such a setup the disc in the fertiliser spreading tool is inclined, unlike the disc in the machine of the standard design, the experimental investigations carried out by the authors have given evidence that this new design feature has virtually no effect on the consumption of energy, as compared to the basic machine for application of fertilisers, in which the

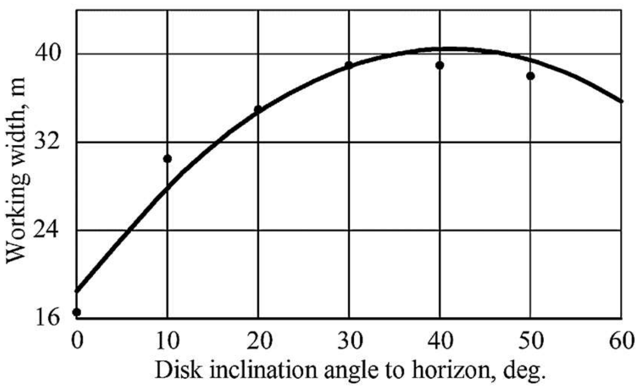

Figure 5. Relation between machine's working width and discs' angle of inclination to horizontal plane in application of granulated superphosphate.

the spreading disc is set up horizontally. The analysis that has been done by the authors has revealed that the improvements ensuring greater mineral fertiliser spreading distances are achieved in case of the new setup solely on account of the changes in the trajectory of the tossing and the further flight of mineral fertiliser particles. Meanwhile, the absolute velocities of the mineral fertiliser particles departing from the horizontally positioned disc (commercial machine) and the disc set up at an angle of tilt (machine of the authors' improved design) are equal. And that implies also the equal consumption of energy and fuel. The power consumption tests carried out by the authors have resulted in establishing that every spreading disc consumes about 0.5 kW of power irrespective of its angle of tilt.

Moreover, it is necessary to note that in the course of the field experiment investigations, the uneven application of mineral fertilisers across the working width did not exceed ± 20%, along the line of travel - ± 10%, which is in compliance with the requirements set for the quality of performing the process of mineral fertiliser application.

The relation between the working width of the machine and the disc's angle of inclination to the horizontal plane α is best approximated by the quadratic polynomial equation of the following form:

$$B = -0.0204\alpha^2 + 1.3493\alpha + 17.229. \quad (1)$$

Taking into account the above expression (1), the output capacity of the tractor-implement unit per hour of shift time can be determined with the use of the following expression:

$$W = 0.1(-0.0204\alpha^2 + 1.3493\alpha + 17.229) \cdot V_p \cdot \tau, \quad (2)$$

where V_p – operating speed of the unit (km h^{-1}); τ – the working time usage factor.

The working time usage factor τ depends on the following two parameters:

1. Mineral fertiliser application dosage
2. Operation pattern of the solid mineral fertiliser application unit.

The unit can operate on either the single-pass pattern or the reload pattern. The single-pass pattern implies loading the process bin directly at the mineral fertiliser barn, where the unit drives after each pass to load its bin. With this pattern, there is direct dependence on the bin capacity and the distance between the place of fertiliser application and the barn. In this case, the value of the coefficient under consideration is τ = 0.40–0.75. When the reload pattern is used (bin is charged in the field), the value of the coefficient is τ = 0.80–0.95. The authors used the single-pass pattern, when carrying out the experimental investigations and comparison tests. The value of the coefficient is assumed to be τ = 0.7 (distance to the barn was 1.0–1.5 km on the average, bin capacity was 400 kg).

The analysis of the expression (2) has proved that, when the centrifugal tool axis is set at an angle of tilt within the range of 25–30°, the output capacity of the tractor-implement unit for mineral fertiliser application is at a level of 35–40 ha h^{-1}.

The performance data of the machine recorded in the course of its field testing are presented in Table 1.

The analysis of the field testing results has proved the consistency and efficiency in the performance of the work process of granulated mineral fertiliser application by the machine equipped with the improved-design fertiliser spreading tool with a tilted axis developed by the authors.

Table 1. Results of field testing of MVU-8 machine for application of mineral fertilisers, lime and gypsum equipped with fertiliser spreading tools with tilted axes

Indicator	Fertilizer spreader MVU-8	Improved-design machine
Operating speed (km h^{-1})	12.0	12.0
Working width (m)	20.0	39.0
Uneven distribution of fertiliser across working width (%)	18.3–19.4	18.4–19.2
Uneven distribution of fertiliser along unit's line of travel (%)	9.2–9.8	8.9–9.6
Deviation from pre-set fertiliser application dosage (%)	8.3–8.5	7.2–8.9

In accordance with (GOST 28714-2007), the authors have determined the coefficient of variation *v*, which specifies the distribution uniformity of mineral fertilisers. According to the results of the statistical estimation, it has the following values:

– uneven distribution of mineral fertilisers with regard to the spreading distance is equal to 10%;

– uneven distribution of mineral fertilisers over the effective seeding width does not exceed 20%.

The above figures give evidence of the high quality achieved in the performance of the work process under consideration.

CONCLUSIONS

1. The most intensive rise in the working width of the machine for top dressing with mineral fertilisers (84.8%) takes place, when the angle of inclination of the disc in the fertiliser spreading tool with a tilted axis with respect to the horizontal plane is increased up to 10°. Within that range, the machine's working width expands from 16.5 m to 30.5 m, that is, by a factor of 1.85. Further increasing the disc setting angle with respect to the horizontal plane up to 30° provides for adding another 11.4–14.0% to the working width of the machine, i.e. increasing it by a factor of 1.11–1.15. Raising the disc setting angle with respect to the horizontal plane from 30° to 40° subject to maintaining the uneven application of fertiliser within the range of ± 20% results in virtually zero growth of the machine's working width.

2. The best performance in the application of fertilisers with regard to both the working width and the distribution uniformity in fertiliser spreading is ensured at the angles of inclination of the disc in the fertiliser spreading tool with a tilted axis with respect to the horizontal plane within the range of 25–30°. Within that range, the following is observed:

– uneven application of fertilisers across the working width is equal to 19.2%;

– uneven application of fertilisers along the unit's line of travel is equal to 8.9%;

– deviation in the dosage of the placed fertilisers from the set value is equal to 7.5%.

The obtained data on the quality of the application of mineral fertilisers by the machine equipped with the new fertiliser spreading tool with a tilted axis developed by the authors meet the standard requirements to the quality of performing the work process under consideration.

REFERENCES

Adamchuk, V. 2006. *Mechanical-technological and technical bases of increase of efficiency of introduction of firm mineral fertilizers and chemical fertilizers*. The Abstract of the Dissertation of the Doctor of Technical Sciences. National Agrarian University. Kyiv, 40 pp. (in Ukrainian).

Adamchuk, V. 2002. Substantiation of the model of application of mineral fertilizers. Interagency thematic scientific collection. *Mechanization and electrification of agriculture* **86**, 90–99 (in Ukrainian).

Adjetey, J.A., Campbell, L.C., Searle, P.G.E. & Saffigna, P. 1999. Studies on depth of placement of urea on nitrogen recovery in wheat grown on a red-brown earth in Australia. *Nutrient Cycling in Agroecosystems* **54**(3), 227–232. doi: 10.1023/A:1009775622609

Antille, D.L., Gallar, L., Miller, P.C.H. & Godwin, R.J. 2015. An investigation into the fertilizer particle dynamics off the disc. *Applied Engineering in Agriculture* **31**(1), 49–60.

Aphale, A., Bolander, N., Park, J., Shaw, L., Svec, J. & Wassgren, C. 2003. Granular fertiliser particle dynamics on and off a spinner spreader. *Biosystems Engineering* **85**(3), 319–329. doi: 10.1016/S1537-5110(03)00062-X

Biocca, M., Gallo, P. & Menesatti, P. 2013. Aerodynamic properties of six organo-mineral fertilizer particles. *Journal of Agricultural Engineering* **44**, Art. E83, 411–414.

Bulgakov, V., Adamchuk, V., Arak. M., Petrychenko, I. & Olt, J. 2017. Theoretical research into the motion of combined fertilizing and sowing tractor-implement unit. *Agronomy Research* **15**(4). 1498–1516. doi: 10.15159/AR.17.059

Bulgakov, V., Adamchuk, V., Kuvachov, V., Shymko, L. & Olt, J. 2020. A theoretical and experimental study of combined agricultural gantry unit with a mineral fertilizer spreader. *Agraarteadus/Journal of Agricultural Science* **31**(2), 139–146. doi: 10.15159/jas.20.15

Bulgakov, V., Adamchuk, O., Pascuzzi, S., Santoro, F. & Olt, J. 2021. Experimental research into uniformity in spreading mineral fertilizers with fertilizer spreader disc with tilted axis. *Agronomy Research* **19**(1), 28–41. doi: 10.15159/AR.21.025

Dintwa, E., Van Liedekerke, P., Olieslagers, R., Tijskens, E. & Ramon, H. 2004. Model forsimulation of particle flow on a centrifugal fertiliser spreader. *Biosystems Engineering* **87**(4), 407–415. doi: 10.1016/j.biosystemseng.2004.01.001

Frode, B. & Lorenzo, H. 2001. The nutritional control of root development. *Plant and Soil* **232**(1–2), 51–68. doi: 10.1023/A:1010329902165

GOST 28714-2007. 2020. Machines for spreading solid mineral fertilisers. Test methods. Standardinform, 45 pp.

Grift, T.E., Kweon, G., Hofstee, J.W., Piron, E. & Villette, S. 2006. Dynamic Friction Coefficient Measurement of Granular Fertiliser Particles. *Biosystems Engineering* **95**(4), 507–515. doi: 10.1016/j.biosystemseng.2006.08.006

Hijazi, B., Baert, J., Cointault, F., Dubois, J., Paindavoine, M., Pieters, J. & Vangeyte, J. 2010. A device for extracting 3d information of fertilizer trajectories. In: *XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)*, Québec City, Canada June 13–17, 8 pp.

Jones, J.R., Lawremce, H.G. & Yule, I.J. 2008. A statistical comparison of international fertiliser spreader test methods – Confidence in bout width calculations. *Powder Technology* **184**(3), 337–351. doi: 10.1016/j.powtec.2007.09.004

Kobets, A.S., Naumenko, M.M., Ponomarenko, N.O., Kharytonov, M.M.,Velychko, O.P. & Yaropud, V.M. 2017. Design substantiation of the three-tier centrifugan type mineral feritilzers spreader. *INMATEH, Agricultural Engineering* **53**(3), 13–20.

Lawrence, H.G., Yule, I.J. & Coetzee, M.G. 2007. Development of an image-processing method to assess spreader performance. *Transactions of the ASABBE* **50**(2), 397–407.

Liu, C., Song, J., Zhang, J., Du, X. & Zheng, F. 2018. Design and performance experiment on centrifugal fertilizer spreader with a cone disc. *International Agricultural Engineering Journal* **27**(1), 44–52.

Lü, J., Shang, Q., Yang, Y., Li, J. & Liu, Z. 2016. Performance analysis and experiment on granular fertilizer spreader with cone disc. *Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering* **32**(11), 16–24. doi: 10.11975/j.issn.1002-6819.2016.11.003

Ma, Q., Rengel, Z. & Rose, T. 2009. The effectiveness of deep placement of fertilisers is determined by crop species and adaphic conditions in Mediterranean-type environments:A reviw. *Australian Journal og Soil Research* **47**(1), 19–32. doi: 10.1071/SR08105

Marinello, F., Pezzuolo, A., Gasparini, F. & Sartori, L. 2017. Integrated approach for prediction of centrifugal fertilizer spread patterns. *Agricultural Engineering International: CIGR Journal* **19**(3), 1–6.

Olt, J. & Heinloo, M. 2009. On the formula for computation of flying distance of fertilizer´s particle under air resistance. *Agraarteadus/Journal of Agricultural Science* **20**(2), 22–25.

Rainer, F. 2001. *Ergbnisse der Umfrage*. Schweiz. Landtechnik, **63**(6), pp. 4–6.

Scheufle, B. & Bolwin, H. 1991. Einsatzempfehllungen für die Mineraldüngung unter Grossflächenbedingungen. *Aqrartechnik*. **41**(3). pp. 114–116.

Šima, T., Krupi©ka, J. & Nozdrovický, L. 2013. Effect of nitrification inhibitors on fertiliser particle size distribution of the DASA ® 26/13 andf ENSIN ®fertilisers. *Argronomy Research* **11**(1), 111–116.

Van Liedekerke, P., Tijskens, E. & Ramon, H. 2009. Discrete element simulations of the influence of fertiliser physical properties on the spread pattern from spinning disc spreaders. *Biosystems Engineering* **102**, 392–405. doi: 10.1016/j.biosystemseng.2009.01.006

Virro, I., Arak, M., Maksarov, V.V & Olt, J. 2020. Precision fertilisation technologies for berry plantation. *Agronomy Research* **18**(S4), 2797–2810. doi: 10.15159/AR.20.207

Villette, S., Cointault, F., Piron, E. & Chopinrt, B. 2005. Centrifugal Spreading: an Analytical Model for the Motion of Fertiliser Particles on a Spinning Disc. *Biosystems Engineering* **92**(2), 157–164. doi: 10.1016/j.biosystemeng.2005.06.013

Villette, S., Cointault, F., Zwaenepoel, P., Chopinrt, B. & Paindavoine, M. 2007. Velosity measurement using motion blurred images to improve the quality of fertiliser spreading in agriculture. In: *Proceedings of SPIE – The International Society for Optical Engineering*, **6356**, Art. 635601.

Villette, S., Gée, C., Piron, E., R. Martin, R., Miclet, D. & Paindavoine, M. 2010. Centrifugal fertiliser spreading: velocity and mass flow distribution measurement by image processing. In: *Proceedings of AgEng 2010, International Conference on Agricultural Engineering*, Clermont Ferrand, France, 10 pp.

Villette, S., Piron, E., Cointault, F. & Chopinet, B. 2008. Centrifugal spreading of fertiliser: Deducing three-dimensional velocities from horizontal outlet angles using computer vision. *Biosystems Engineering* **99**(4), 496–507. doi: 10.1016/j.biosystemseng.2017.12.001

White, P.J., Wheatley, R.E., Hammond, J.P. & Zhang, K. 2007. Minerals, soils and roots. Potato Biology and Biotechnology: Advances and Perspectives, 739–752. doi: 10.1016/B978-044451018-1/50076-2

Yasenetsky, V. & Sheychenko, V. 2002. Mineral spreaders for farms of all forms of ownership. *APK technique* **12**, 16–17 (in Ukrainian).

Yildirim, Y. 2006. Effect on vane number on distribution uniformity in single disc rotary fertilizer spreaders. *Applied Engineering in Agriculture* **22**(5), 659–663.

Yildirim, Y. 2008. Effect of vane shape on fertilizer distribution uniformity in single disc rotary fertilizer spreaders. *Applied Engineering in Agriculture* **24**(2), 159–163.