EXPERIMENTAL INVESTIGATIONS ON THE SURFACE APPLICATION OF SUPERPHOSPHATE BY THE FERTILISER SPREADING TOOL WITH INCLINED AXIS
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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ПОВЕРХНЕВОГО ВНЕСЕННЯ СУПЕРФОСФАТУ РОЗКИДАЧЕМ ДОБРИВ З ПОХИЛІЙ ВІССЮ ОБЕРТАННЯ

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ABSTRACT
One of the possible ways to significantly increase the spreading distance of fertilisers (and, accordingly, efficiency) by the fertiliser spreading tools may be creation of a structure with an inclined axis of rotation. For experimental investigations an experimental setup was developed and a solid mineral superphosphate granular fertiliser was used as a material. Increasing the angle of inclination of the disc of the fertiliser sowing tool with an inclined axis in a horizontal plane from 0 to 30º at a disc rotation frequency of 1000 min^{-1} leads to an increase in the effective sieving distance of granulated superphosphate by 34.9. It has been established that the best indices of mineral fertilisation both in terms of the operating width and the irregularity of the fertiliser introduction are provided at the angles of inclination of the disc of the new fertiliser distributing tool in a horizontal plane within 25-30º.

АНОТАЦІЯ
Одним з можливих способів значного збільшення дальності розкидання мінеральних добрив знаряддями для розкидання добрив може бути створення конструкції розкидача з похилою віссю обертання. Для досліджень була розроблена експериментальна установка, а в якості матеріалу використано тверде мінеральне гранульоване добриво – суперфосфат. Збільшення кута нахилу диска розсівного апарату добрив з похилою віссю в горизонтальній площині від 0 до 30^{O} при частоті обертання диска 1000 min^{-1}. призводить до збільшення розкидання гранульованого суперфосфату на 34.9%. Встановлено, що найкращі показники внесення мінеральних добрив як по ширині захоплення, так і по рівномірності внесення добрив забезпечуються при кутах нахилу диска нового розподільника добрив в горизонтальній площині в межах 25-30^{O}.

INTRODUCTION

Despite the expansion of biological farming, the use of mineral fertilisers is still the most important means of increasing the soil fertility and reaching high yields of agricultural crops *(Antille et al., 2015; Adamchuk and Moiseenko, 2001; Vilde and Rucins, 2008).* Application of mineral fertilisers is carried out mainly using centrifugal spreaders *(Dintwa et al., 2004; Kobets et al, 2017; Przywara, 2015).* When creating new models of machines for surface application of solid mineral fertilisers, which are equipped with centrifugal disc fertiliser dispensing working tools, increasing the operating width is an urgent problem *(Abbou-ou-Cherif et al., 2019; Bulgakov et al., 2020).*

In the known centrifugal fertiliser dispensing tools with a vertical axis of rotation, an increase in the angle of descent of the fertilisers to the horizon is formed only due to the speed of the fertiliser particles moving along the blade of the disc (the transfer speed). At the same time the main share of the absolute spreading speed of fertilisers by the fertiliser spreading tools is the transfer speed but the relative speed does not exceed 15% of the indicated absolute speed (*Adamchuk, 2003; Bulgakov et al., 2016; Villette et al., 2007)*.

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This gives grounds to formulate the following working hypothesis: the direction of the transfer speed at an angle to the horizon by setting the axis of the fertiliser spreading tool with an inclination to the vertical will provide an increase in the sowing distance of fertilisers, and, accordingly, an increase in the productivity of the machines.

An important quality criterion of the fertiliser spreaders is to ensure a sufficiently uniform application of the layer over the entire soil surface *(Grift and Kweon, 2006; Koko and Virin, 2009).* The distance from the disc increasing, the mass of the scattered fertilisers decreases; therefore, to ensure a uniform layer on the soil surface, the operating width should be less than the maximum spreading distance (i.e., total overlap of layers during the adjacent passes should be ensured). Due to the impact of many factors it is difficult to theoretically calculate the distribution of the fertiliser mass along the operating width *(Biocca et al., 2013; Bulgakov et al., 2019)* therefore it is necessary to conduct experimental investigations for a specific type of fertiliser.

The issues of increasing the efficiency of the technological process of applying mineral fertilisers to the soil have been relevant for scientists from many countries of the *world (Antille et al., 2015; Dintwa et al, 2004; Kobets et al., 2017; Adamchuk, 2003).* They have found out that the efficiency of the use of mineral fertilisers depends not only on the fertilisers themselves but also on the methods of their application. Many scientists were engaged in the improvement of the technological process of applying mineral fertilisers *(Przywara et al., 2020; Hofstee and Huisman, 1990).* It has been established by the conducted investigations that the main factor of the factors limiting the efficiency of fertiliser application is uneven distribution of the fertilisers over the field area. The latter significantly affects maturation of the plants, produces uneven yield and, in general, its lowering. However, their studies do not consider the installation scheme of the axis of the fertiliser spreading tool with an inclination to the vertical.

The aim of the work is an experimental investigation of the superphosphate introduction process by centrifugal disc fertiliser dispensing tools, the axes of which are installed obliquely.

MATERIALS AND METHODS

Experimental investigations were carried out using the developed methods and current state standards, regression analysis, statistical methods for processing the research results, standard and specially created experimental equipment. The calculations of the performed measurements were made using a PC in the Microsoft Office Excel 2007 software environment *(Adamovics et al., 2018; Dospehov, 2012; Moise et al., 2019; Ivanovs et al., 2014; Burdo et al., 2017).*

To carry out the experimental investigations on surface introduction of granular superphosphate, we developed and manufactured a special experimental setup (Fig. 1).

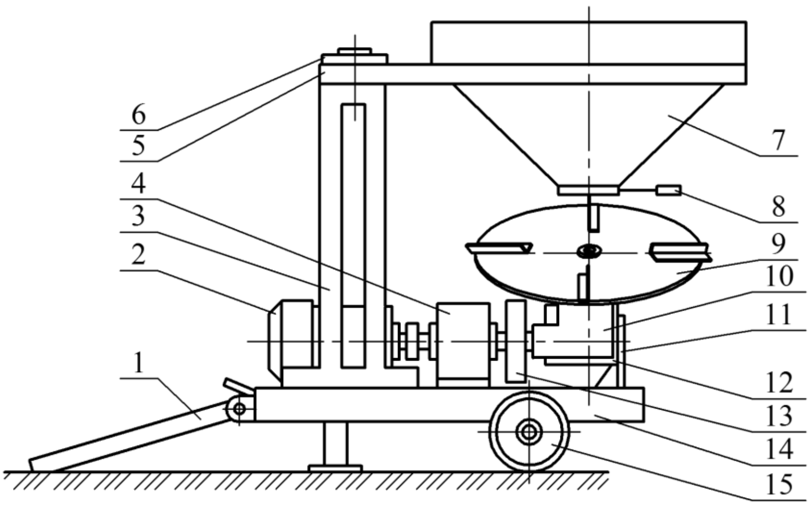

Fig. 1 - A structural diagram of the experimental setup for studying the surface application of superphosphate

1 – handle; 2 – electric motor 2; 3 – movable frame; 4 – chain variator; 5 – rotatable frame; 6 – joint for turning of the frame; 7 – hopper; 8 – shutter; 9 – spreading tool with an inclined axis; 10 – bevel gearbox; 11, 12 – brackets; 13 – overrunning clutch; 14 – the main frame; 15 – the supporting wheel

The design of the specially created experimental setup included a main frame *14* that was mounted on two wheels *15* and a support leg. A handle *1* was pivotally fixed on the main frame with the use of which, if necessary, the experimental setup on wheels *15* was moved to the place of experiments on a specially prepared site. On top of the main frame there were installed an electric motor *2*, a chain variator *4* and a bevel gearbox *10* which carry out a kinematic connection through the connecting and the overrunning *13* clutches. The bevel gearbox was fixed to the frame through brackets *11* and *12* having grooves for fastening, which make it possible to adjust the angle of inclination of the gearbox output shaft to the horizontal plane. On the output shaft of the bevel gearbox there was installed a fertiliser spreading tool with an inclined axis *9* which included a flat disc with four grooved blades radially fixed on its upper surface. The outer ends of the blades protruded beyond the disc. A movable frame *3* was installed on the main frame *14* with the possibility of longitudinally adjustable movement.

The design of the drive of the fertiliser spreading tool with an inclined axis provided for the possibility to change both the rotational frequency of its disk and the possibility to adjust the inclination angle of the disc to the horizontal plane.

In the process of experimental research we used the basic provisions of the standards *(European Standard EN 13739-2, Standard GOST 28714-2007).*

During the experimental investigations of the process of applying mineral fertilisers by means of this fertiliser spreading tool with an inclined axis, there were used granular superphosphate fertilisers, common in agriculture. Characteristics of the granular superphosphate used: - the average moisture content - 3.1%; -the average value of the bulk density - 1085 kg m^{-3}; - the coefficient of friction on steel - 0.51;- granulometric composition:< 1 mm - 4.9%;≥ 1 - < 2 mm - 20.6%; ≥ 2 - < 3 mm - 40.2%; ≥ 3 - < 4 mm - 24.7%; ≥ 4 mm - 9.6%.

Fig. 2 - A general view of the experimental setup with installed containers for studying the distribution of fertilisers in the direction of dispersion (for clarity, the rotatable frame and the hopper are removed)

RESULTS

A graphic interpretation of the research results is shown in Figs. 3 - 6.

According to the results of the research it was established that changing the angles of inclination of the disc to the horizontal plane within 0^o - 30^o, the increase in the frequency of rotation of the disc leads to an increase in both the efficient spreading distance of granulated superphosphate in the direction of its spreading and the distance from the fertiliser spreading tool with an inclined axis to the containers for collecting fertilisers with a maximum proportion of the sown fertiliser mass.

For example, at the disc rotation frequency of 600 min^{-1} and the horizontal position of the disc of the fertiliser spreading tool, the granular superphosphate is efficiently dispersed on an area by up to 35 containers (17.5 m) inclusive (Fig. 3 a), and the maximum proportion of the mass of the sown fertilisers (6.5%) falls into 12 containers (6 m).

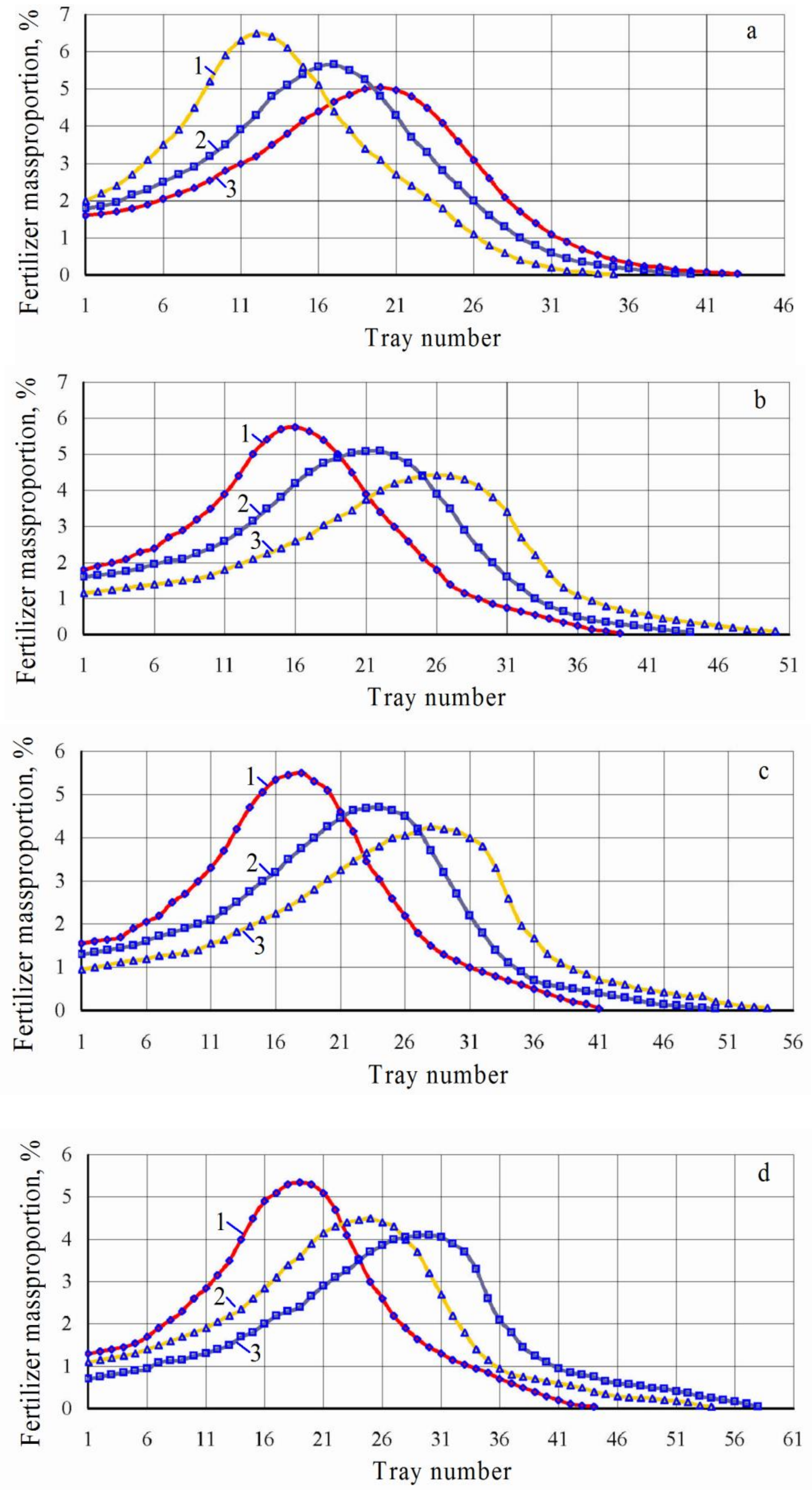

Fig. 3 - Dependence of the granulated superphosphate distribution by a fertiliser spreading tool with an inclined axis in the direction of distribution in containers on the rotation frequency of its disc and the angle of inclination

a, b, c, d – the angle of inclination of the disc to the horizontal plane, respectively, 0°, 10°, 20°, 30°;
1, 2, 3 – the rotation frequency of the disk, respectively, 600; 800; 1000 min^{-1}

Increasing the rotational frequency of the disc from 600 to 800 min^{-1} leads to an increase in the efficient spreading distance of the granulated superphosphate at the level of 40 containers (20 m). At the same time the maximum percentage of the sown fertiliser mass (5.65%) falls into 17 containers (8.5 m).

That is, there is an increase in the efficient sowing distance of the fertiliser by 14.3%, the distance from the fertiliser spreading tool with an inclined axis to the container with the maximum proportion of the fertiliser mass - by 41.7%, and a decrease in the specified proportion of the fertiliser mass by 1.15 times.

A similar phenomenon occurs when there is an increase in the rotational frequency of the disc of the fertiliser spreading tool with an inclined axis from 800 to 1000 min^{-1}; the efficient spreading distance of the granular superphosphate increases by 7.5%, the distance from the operating tool to the container with the maximum proportion of sown fertilisers is 17.6%, and the maximum proportion of the fertiliser mass that has fallen into the container has decreased by 1.12 times. Based on the results of the experimental research, it can be concluded: an increase in the disc rotation frequency leads to an increase in the efficient spreading distance of the granular superphosphate, which in turn leads to an increase in the distance from the fertiliser spreading tool with an inclined axis to containers with the maximum proportion of the sown fertiliser mass, as well as to a decrease the maximum proportion of the mass of the fertilisers distributed in containers. In addition, the increase in the rotational frequency of the disc from 600 to 1000 min^{-1} when the disc is horizontal, ensures an increase in the efficient spreading distance of the granular superphosphate by 22.9%, and an increase by 66.7% of the distance from the fertiliser spreading tool to the containers with the maximum proportion of the distributed fertiliser mass, which has decreased by 1.29 times.

The described regularities of the impact of the rotational frequency of the disc of the fertiliser spreading tool with an inclined axis upon the distribution of the granulated superphosphate in the direction of its spreading also take place under the condition of an increase in the angle of inclination of the disc to the horizontal plane (Fig. 3 b - 3 c). The results of investigations on the impact of the values of the angle of inclination of the disc of the fertiliser spreading tool with an inclined axis to the horizontal plane upon the granulated superphosphate spreading indices are shown in Fig. 4 - 6 as graphical dependencies.

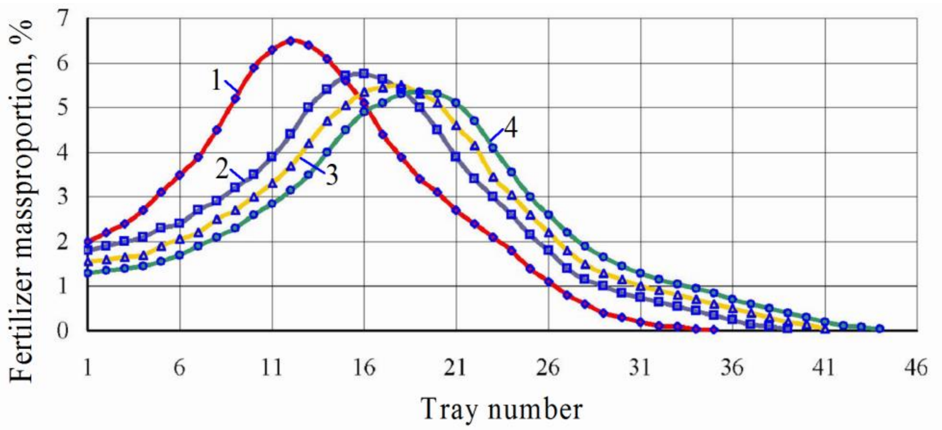

Fig. 4 - Dependence of the granular superphosphate distribution by the fertiliser spreading tool with an inclined axis in the direction of spreading at a disc rotation frequency of 600 min^{-1} on the angle of its inclination to the horizontal plane

1, 2, 3, 4 – the angle of inclination of the disc to the horizontal plane, respectively, equal to 0º, 10º, 20º, 30º

As the disc installation angle in the horizontal plane grows, a graphical dependence corresponds to a larger value of the disc inclination angle, in which the distribution of the entire mass of the granular superphosphate is characterised by a relative displacement to the right of its individual masses, sown into containers at a relatively greater distance from this fertiliser spreading working tool. For example, when the rotational frequency of the disc of fertiliser spreading tool is equal to 600 min^{-1} (Fig. 4) and the disc is installed horizontally, granular superphosphate is efficiently dispersed on the area of up to 35 containers (17.5 m) inclusive, the maximum percentage of the fertiliser mass (6.5%) falls into 12 containers (6.0 m). When the disc is installed at an angle of 10° to the horizontal plane, the granular superphosphate is efficiently dispersed on an area of up to 39 containers (19.5 m) inclusive; the maximum proportion of the mass of the sown fertilisers (5.75%) goes into 16 containers (8 m). An increase in the angle of installation of the disc of the fertiliser spreading tool with an inclined axis to the horizontal plane up to 20° causes an increase in the efficient spreading distance of the granulated superphosphate to 41 containers (21.5 m), an increase in the distance from the fertiliser spreading tool with an inclined axis to the container with a maximum proportion of the mass of sown fertilisers up to 9 m (18 containers) and a decrease in the maximum proportion of the mass of the sown granulated superphosphate in a container to 5.5%. When the indicated angle increases to 30°, the indicators characterising the distribution of fertiliser among the containers are, respectively: the efficient distribution distance - 22 m (44 containers), the distance from the fertiliser spreading tool having an inclined axis to the container with a maximum proportion of the sown fertiliser mass - 9.5 m (19 containers), the maximum proportion of the mass of the sown fertilizers in a container is 5.35%.

The results show that at a disc rotation frequency of the fertiliser spreading tool with an inclined axis of 600 min-1 changing the angle of its installation in the horizontal plane from 0º to:

– 10° leads to an increase in the efficient distribution distance of the granulated superphosphate by 11.4%, the distance from this fertiliser spreading tool to the container with a maximum proportion of the sown fertiliser mass - by 33.3%, and a decrease in the indicated fraction of the mass by 1.13 times;

– 20º leads to an increase in the efficient spreading distance of the granulated superphosphate by 17.1%, the distance from this fertiliser spreading tool to a container with the maximum proportion of the sown fertiliser mass - by 50%, and a decrease in the indicated fraction of the mass by 1.18 times;

– 30º leads to an increase in the efficient spreading distance of the granulated superphosphate by 30.3%, the distance from this fertiliser spreading tool to a container with a maximum proportion of the sown fertiliser mass - by 58.3%, and a decrease in this fraction of the mass by 1.21 times.

According to the results of the experimental investigations of the impact of the installation angle of the disc of the fertiliser spreading tool with an inclined axis to the horizontal plane at a frequency of its rotation of 800 min^{-1} upon the distribution of the granulated superphosphate in the direction of its spreading, it was found (Fig. 5) that an increase in its inclination angle to 10º leads to an increase in the efficient distribution distance of the granulated superphosphate up to the level of 44 containers (22 m) inclusive, an increase in the distance from this fertiliser spreading tool to the container with a maximum proportion of the sown fertiliser mass up to 11 m (22 containers), and the reduction of the maximum proportion of the sown fertiliser mass in the container up to 5.1%.

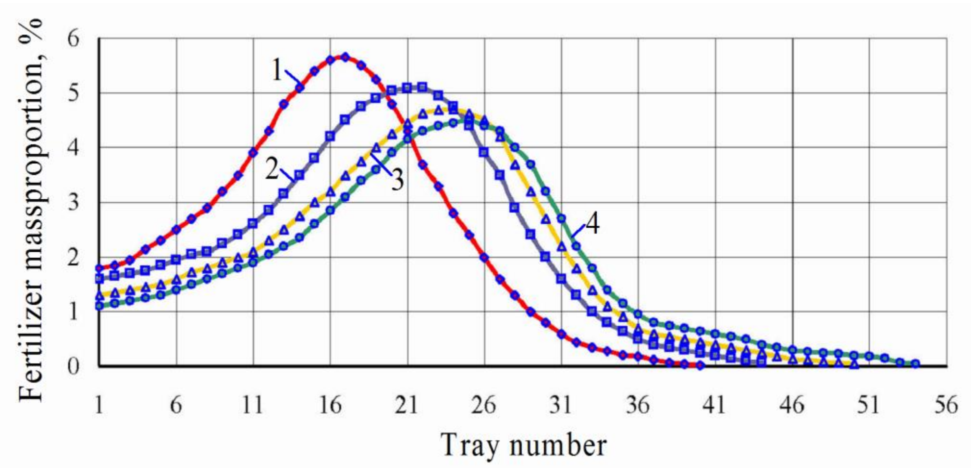

Fig. 5 - Dependence of the granulated superphosphate distribution by the fertiliser spreading tool with an inclined axis in the direction of distribution at a disc rotation frequency of 800 min^{-1} on the angle of its inclination to the horizontal plane

1, 2, 3, 4 – the angle of inclination of the disc to the horizontal plane, equal, respectively, to: 0º, 10º, 20º, 30º

The subsequent increase in the angle between the disc and the horizontal plane also causes an increase in the indicators characterising the spreading distance of the granular superphosphate. For example, an increase in the installation angle of the disc of the fertiliser spreading tool with an inclined axis to the horizontal plane up to 20° leads to an increase in the efficient spreading distance of the granulated superphosphate up to 50 containers (25 m) inclusive, an increase in the distance from this fertiliser spreading tool to the container with a maximum fraction of the sown fertilisers mass up to 12 m (24 containers), and reduction of the maximum proportion of the seeded granulated superphosphate mass in a container to 4.7%. When the indicated angle increases to 30°, the indicators characterising the distribution of fertiliser among the containers are, respectively: the efficient spreading distance - 27 m (54 containers), the distance from this fertiliser spreading tool to the container with a maximum proportion of the sown granulated superphosphate mass - 12.5 m (25 containers), the maximum proportion of the mass of sown fertilisers in the container is 4.5%.

When the rotational frequency of the disc of the fertiliser spreading tool with an inclined axis is equal to 800 min^{-1}, changing the angle of its installation in the horizontal plane from 0° to:

– 10° leads to an increase in the efficient distribution distance of the granulated superphosphate by 10%, the distance from this fertiliser spreading tool to the container with a maximum proportion of the sown fertiliser mass - by 29,4%, and a decrease in the indicated fraction of the mass by 1.11 times;

– 20° leads to an increase in the efficient distribution distance of the granulated superphosphate by 25%, the distance from this fertiliser spreading tool to the container with a maximum proportion of the sown fertiliser mass - by 1.2 times;

– 30° leads to an increase in the efficient distribution distance of the granulated superphosphate by 35%, the distance from this fertiliser spreading tool to the container with a maximum proportion of the sown fertiliser mass – by 47.1%, and a decrease in the indicated fraction of the mass by 1.23 times.

The results of investigations of the impact of the disc installation angle from the indicated fertiliser spreading tool to the horizontal plane at a rotation frequency of 1000 min^{-1} upon the distribution of the granulated superphosphate in the direction of its spreading are shown in the form of graphical dependences, presented in Fig. 6.

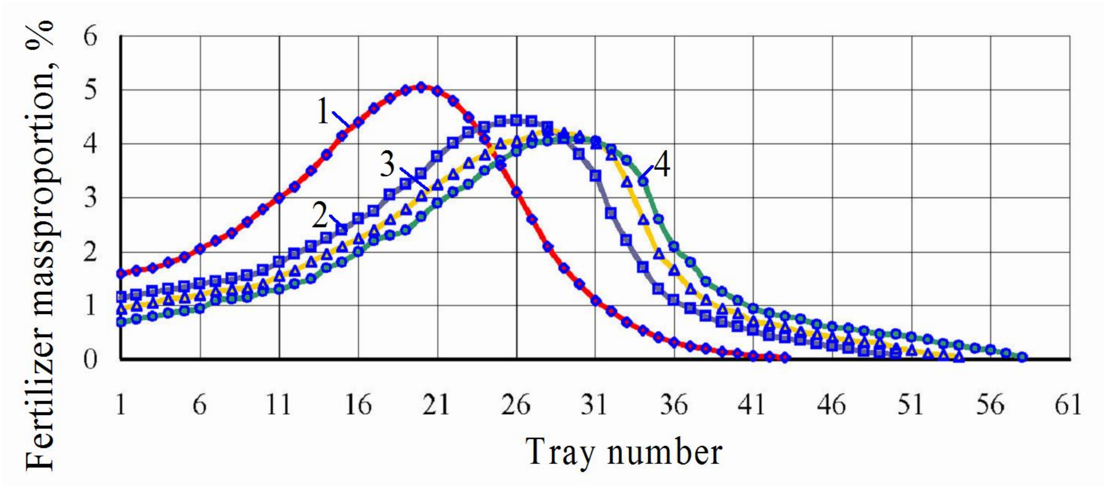

Fig. 6 - Dependence of the granulated superphosphate distribution by the fertiliser spreading tool with an inclined axis in the direction of spreading in containers at the disc rotation frequency of 1000 min^{-1} on the angle of its inclination to the horizontal plane:

1, 2, 3, 4 – the angle of inclination of the disc to the horizontal plane equal, respectively, to: 0°, 10°, 20°, 30°

It has been found that the increase in the angle of inclination of the disc of the fertiliser spreading tool with an inclined axis to 10° leads to an increase in the efficient spreading distance of the granulated superphosphate up to 50 containers (25 m) inclusive, an increase in the distance from the fertiliser spreading tool with an inclined axis to a container with a maximum proportion of the sown fertilisers mass up to 13 m (26 containers), and reduction of the indicated maximum fraction of the mass to 4.42%. With a subsequent increase in the angle between the disc and the horizontal plane, there is also an increase in the indicators characterising the distance of spreading of the granular superphosphate.

In particular, the increase in the disc angle of this fertiliser spreading tool with an inclined axis to the horizontal plane up to 20° causes an increase in efficient spreading distance of the granulated superphosphate up to 54 containers (27 m) inclusive, an increase in the distance from this fertiliser spreading tool having an inclined axis to the container with a maximum proportion of the mass of the sown fertilizers up to 14 m (28 containers), and a decrease in the maximum proportion of the sown granulated superphosphate mass in a container up to 4.25%.

The indicated tendency to change the studied parameters is also characteristic when the angle of inclination of the disc to the horizontal plane is increased up to 30°. Under these conditions the efficient spreading distance of the granular superphosphate increases to 29 m (58 containers), the distance from this fertiliser spreading tool to the container with a maximum proportion of the sown granular superphosphate mass increases to 14.5 m (29 containers), and the maximum proportion of the fertiliser mass in the containers decreases to 4.1% of its total sown mass.

Based on the obtained research results, it can be concluded that at a rotational frequency of the disc of the fertiliser spreading tool with an inclined axis equal to 1000 min^{-1}, changing the angle of its installation in a horizontal plane from 0º to:

– 10º leads to an increase in the efficient distribution distance of the granulated superphosphate by 16.3%, the distance from this fertiliser spreading tool to the container with a maximum proportion of the sown fertiliser mass - by 30%, and a decrease in the indicated fraction of the mass by 1.14 times;

– 20º leads to an increase in the efficient distribution distance of the granulated superphosphate by 25.6%, the distance from this fertiliser spreading tool to the container with a maximum proportion of the sown fertiliser mass - by 40%, and a decrease in the indicated fraction of the mass by 1.19 times;

– 30º leads to an increase in the efficient distribution distance of the granulated superphosphate by 34.9%, the distance from this fertiliser spreading tool to the container with a maximum proportion of the sown fertiliser mass – by 45%, and a decrease in the indicated fraction of the mass by 1.23 times.

The research results on the granulated superphosphate distribution by the fertiliser spreading tool with an inclined axis in the direction of its spreading in containers show that, with an increase in the rotational frequency of the disc from 600 to 1000 min^{-1} within all the studied installation values of the angle of the disc of this fertiliser spreading tool to the container, there is an increase in both the efficient spreading distance of the granular superphosphate and the distance from this fertiliser spreading tool to the container with a maximum proportion of the sown fertiliser mass. For example, an increase in the efficient spreading distance of the granular superphosphate is at the angles: 0º - 22.9%, 10º - 28.2%, 20º - 31.7%, 30º - 31.8%, and the increase in the distance from the fertiliser spreading tool to the container with a maximum proportion of the sown fertiliser mass will be at the angles: 0º - 66.7%, 10º - 62.5%, 20º - 55.5%, 30º - 52.6%.

At a constant rotational frequency of the fertiliser spreading disk in all the kinematic modes of its operation an increase in the installation angle of the investigated disc of the fertiliser distributing tool to the horizontal plane led to an increase in the indicators characterising the granulated superphosphate distribution in containers in the direction of its spreading. In particular, when the rotational frequency of the disc of this fertiliser spreading tool is equal to 1000 min^{-1} the increase in the efficient spreading distance of the granular superphosphate is, increasing the inclination angle of the disc from its horizontal position to 10º - 16.3%, 20º - 25.6%, 30º - 34.9%, and increasing the distance from the working tool to the container with a maximum proportion of the sown fertilisers mass: 10º - 30%, 20º - 40%, 30º - 45%. Increasing the inclination angle of the disc to the horizontal plane leads to an increase in the indicators characterising the spreading distance of the granular superphosphate and the working width of the machine for applying mineral fertilizers. Besides, the intensity of increasing these indicators is the highest when the inclination angle of the disc to the horizontal plane is increased from 0 to 10°, and there is a decrease in the indicated intensity as it continues increasing to 30°. Thus, the fertiliser spreading tool with an inclined axis of rotation ensures an increase in the indicators characterising the distribution of the granulated superphosphate in the direction of its distribution over a greater distance than that by the conventional fertiliser spreading tool with a vertical axis of rotation.

CONCLUSIONS

- ✓ The disc fertiliser spreading tool, the axes of which are installed obliquely, reliably ensures implementation of the technological process when the rotation frequency of its disc changes from 600 to 1000 min^{-1} and the installation angle of the disc changes to the horizon from 0 to 30°.
- ✓ The rational values of the rotational frequency of the disc of the new tool are 1000 min^{-1} for the introduction of the granular superphosphate
- ✓ An increase in both the rotational frequency of the disc of the new tool from 600 to 1000 min^{-1} and its inclination angle to the horizontal plane from 0 to 30º led to:
  – significant displacement of the entire fertilizer mass from the tool in the direction of their spreading;
  – increasing the efficient spreading distance of mineral fertilisers;

– increasing the distance from the tool to the containers into which the maximum proportion of the fertiliser mass was spread.

✓ Increasing the inclination angle of the disc of the fertiliser spreading tool with an inclined axis in the horizontal plane from 0 to 30º, at the disc rotation frequency of 1000 min^{-1} leads to an increase in: the efficient spreading distances of the granulated superphosphate by 34.9%, the distance from the tool to containers with a maximum proportion of the sown fertiliser mass by 45.0%, and a decrease in the indicated proportion of the fertilizer mass by 1.23 times.

✓ The best indicators of the fertiliser application both in terms of the working width of the operation and its unevenness are provided at the disc inclination angles of the new tool in the horizontal plane within 25-30º.

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