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Influence of dynamical factors on safe work with a fertilizer spreader

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Abstract. The efficiency of mineral manure most often depends on the evenness of its distribution. The dynamics of the spread of the particles of the mineral manure in regard to the fixed and variable parameters of the imitative model of the spreader have been analyzed. The programmable location of a particle on soil depends on the movement trajectory of the particle on the disc and in the air, which eventually determine the final distribution of particles.

The research considered the flow of the manure particles from the spread opening of the manure-box, the trajectory on the disc and in the air, the place of a particle on the surface of the ground as well as on how these trajectories depend on the characteristics of the spreader and particles. The trajectory of particle in the air is the function of its initial velocity and direction, by which the particle leaves the surface of the disc. It determines the final place of the particle on the surface of soil with respect to disc.

One of the accidental factors influencing the trajectory of a particle is the impact of spreader lean on hilly soil on the discharge angle of manure particles and the distance of particle fly in the distribution sector.

The dependence of the spreading distance of the manure particles on the initial speed of the particle and the trajectory angle of a disc has been obtained. It was established that when the aggregate moves, the trajectory angle changes due to the roughness of the ground from the one that was set constructively up to the largest value when a particle flies farthest.

Under the influence of random factors, the angle between the spreader's disc plane and a plane of soil surface can increase up to 8 degrees; therefore the distance of particle's wafting increases.

Key words: Dynamics, ballistics, dispersion of mineral fertilizers, variation factor, rate of fertilizers

INTRODUCTION

The evaluation of energy potential of plant fertilization depends on the energy accumulated in additional yield, which in turn is directly related to the evenness of the spread of mineral fertilizers. When unevenness of spread exceeds even 20%, it may reduce their effectiveness up to 35–44% (Kučinskas, 2000). This reduces productivity considerably and at the same time increases the overdose of fertilizers.

For effective utilization of mineral fertilizers it is necessary to ensure even spread of particles depending on the width of the lot, driving direction and minimal loss due to spreading outside the limits of the lot, at the same time reducing environmental damage as much as possible.

The most popular and most widely used are single disc and two-disc spreaders with disc-shape operating parts. These mechanisms allow regulation of manure distribution width regarding the configuration of a particular field and the amount of manure depending on requirement and norm.

However the main indicators which characterize a spreader's performance should be considered to be fertilization norm and spreading evenness. Fertilization norm becomes the main indicator of the expected yield and has a considerable impact on the evenness of spread.

The dynamics of particles' spread is influenced by the fixed and variable parameters of constructional and technologic processes of a spreader. These include constructional and geometrical parameters of centrifugal disc, the position and shape of manure discharge opening, the spot at which the particles get on the disc, the norm of manure flow discharging on the disc, driving speed, distribution lot width, etc. The programmable place of a particle on soil depends on the movement trajectory of the particle on the disc and in the air, which eventually determine the final distribution of particles. There are numerous accidental factors which contribute to the changes of particle movement during the technologic process (Vasilenko & Vasilenko, 1980; Sato, 1988; Urba, 2000).

Although the impact on plants under outdoor conditions is seen only when the unevenness of fertilizers spread is 25–30%, (Kučinskas, 2000) the economic effectiveness is significantly reduced by much less deviation from the even spread.

Fertilizer spreaders by Bogballe, Amazone, Sulky, etc have good indicators of quality: in laboratory tests, the spread unevenness (variation coefficient *K*) of these machines appeared to be less than 5–10%. Nevertheless, theses indicators can change markedly under outdoor conditions.

By the time the manure particle reaches a particular spot on the ground surface it has already passed through two stages: the first is when the particle moves onto the horizontal and spins around the vertical axle surface of the disc; the second begins when the particle leaves the disc and moves along the particular trajectory until it hits the ground surface. In other words, the programmed place of the particle on the surface of the ground depends on the trajectory of the particle movement on the disc and in the air, which ultimately determines the spread of the particles.

The initial position of the particles on the disc is adjusted by the construction and the geometrical parameters of the spread and manure-box openings. The flow of particles to the disc is distributed with the help of the pallets. The trajectory of the manure particles, the direction of the movement on disc as well as the speed while leaving the disc are determined by the form of the pallets and their position on the disc.

The trajectory of the particle in the air is the function of its speed and direction where the particle leaves the disc and determines the final place of the particle on the surface of the ground with regard to the spreader.

While optimizing the technologic process of the spread of the mineral manure it is important to evaluate the environmental factors and their influence. One factor, previously mentioned, is the environmental resistance force F_p which depends on the speed of the particle movement, its shape, the roughness of its surface and its dimensions. When the speed is not intense ($V \leq 0.2$ m s^{-1}), then this force is proportional to the speed of the particle (Urba, 2000):

$$F_p = kV \tag{1}$$

where k - the coefficient of proportion alternatively called the coefficient of the viscous friction, kg s^{-1};
V - the speed of the particle movement, m s^{-1}.

When the speed of a particle increases ($V > 0.2$ m s^{-1}), the resistance force F_p increases more and can be expressed as follows (Urba, 2000):

$$F_p = k' V^2 \tag{2}$$

where k' - the coefficient of proportion, kg s^{-1}.

The salience of soil or field determines the position of the spreader's disc while the placement of manure particles on the disc and the angle of particle throw trajectory with horizontal plane are constantly changing. The spot where the particle gets on the disc determines the initial velocity and direction of its vector while the latter two factors determine the distance of particles' discharge and their distribution on the soil surface.

OBJECTS AND METHODS

The evenness of fertilization spread on soil surface depends on a trajectory of separate particles in space. The trajectory of a particle in air is a function of its speed and direction at which the particle leaves the disc, and it determines the final location of a particle on soil surface with respect to spread. The object of this research is the trajectories of a material fertilizer particle during the technologic process of fertilization and dynamic factors which influence these trajectories.

The aim of this research is on the basis of optimization and results obtained to determine the parameters of particle trajectory after solving the differential equations of particle movement, depending on the influencing spread factors which vary during the technological process.

The theoretical and experimental research applying the laws of classical dynamics (Pocius et al., 2006; Pocius & Šniauka, 2007) was aimed to analyze and determine the dependency of particle trajectories and spreading evenness on the accidental factors which occurred during the technologic process.

The rate of fertilizer mass flow (kg s^{-1}) which gets on the disc may be regulated by changing the opening angle (measured by degrees) of discharge opening. The particle mass flow is a product of fertilizer rate (kg ha^{-1}), driving speed (m s^{-1}), width of the lot (m) and value 10^{-4}. Mass flow rate is a relative value which depends on the percentage of fertilizer particle fractions' distribution in the whole mass of particles (Table 1).

Table 1. Distribution of fertilizer particle fractions.

Type of fertilizers	Measurements of particle fractions, mm							
	>5.0	5.0—3.75	375.0—3.0	3.0—2.0	2.0—1.0	1—0.5	0.5—0.25	<0.25
	Distribution of particle fractions, %							
e. g. Potash 60%	1.8	23.0	49.0	26.0	0.2	—	—	—
Katium chloride	—	4.0	15.0	10.0	15.0	25.0	27.0	4.0
Amm. Sulphide 24% N	—	0.8	3.7	11.5	50.0	34.0	—	—
e. g. NPK 3—21—21	0.4	30.5	18.3	45.0	3.6	2.2	—	—

The particle having spread from the spread opening of the manure-box gets on the surface of a disc on the particular point which coordinate can be determined as follows: with regard to the drive direction of the starting point of the spread opening using φ_0 angle, using the biggest $\varphi_0 + \varphi_d$ (where φ_d is the operating angle of the opening); with the help of the internal diameter r_0 from the centre of the disc and external diameter r_i (Fig.1).

After reaching the surface of the disc at a certain pint, the coordinates of which vary depending on the salience of soil and which is at a distance r_0 from the centre of the disc the particle moves towards the edge of the disc, the radius of which is r_d.

The further trajectory of the movement of the particle depends on its initial speed V_0 obtained while separating from the disc as on the height H_0 of the disc from the surface of the ground.

When the disc of a spreader rotates at the angular speed $\omega = 75.2\ s^{-1}$, fertilizer particle moves on the surface of the disc at the relative speed V_r thus drawing a particular trajectory. This arc of the trajectory was proposed (Vasilenko & Vasilenko, 1980) to be considered as a logarithmical spiral. The movement of a particle in this case is influenced by the rotational movement of the disc when the particles acquires the elevating speed $V_e = \omega \cdot r_d$. The speed V_0 which is provided for the particle on the disc will depend on the sizes of the both constituents V_r and V_e, which in turn influences the width of fertilizer distribution lot.

The second—order differential equation of the relative movement of fertilizer particle which rotates on the disc along the spatula will be as follows:

$$\ddot{r} + 2f\omega\dot{r} - \omega^2 r + fr = 0 \quad (3)$$

where r - the distance the particle travels towards the direction of the radius of disc, m;

f is the rate of friction between a particle and the disc.

The rate of friction between a particle and the disc depends on the physical-mechanical features of mineral fertilizers and the features of the disc surface; it may vary in the interval of $f = 0.15...0.7$ (Pocius & Šniauka, 2007).

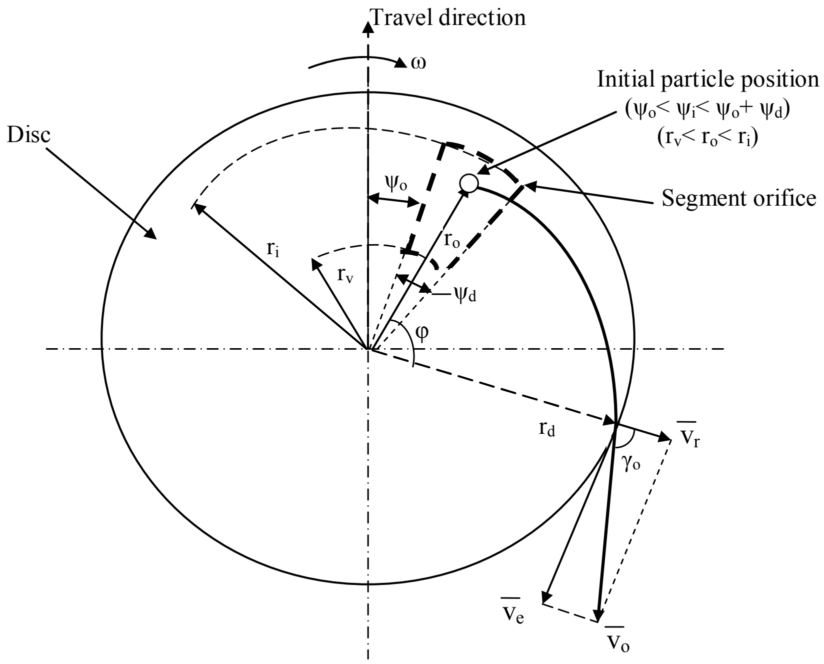

Fig. 1. Parameters of particle position.

Initially a fertilizer particle is on the disc at the height of H_0, and is then thrown at the angle α_0 having the initial velocity V_0 (Fig. 2). The size of the mentioned angle will depend on the disc turning angle φ during the movement of the particle on the disc and the spreader's accidental side leaning angle β. When the range of angle β is $\beta \gtreqless 0^0$ and a particle is thrown from the height H_0 at the angle α_0 the trajectory of the particle movement shall be expressed by the following elementary equations:

$$\ddot{X} + k_0 \cdot \dot{X} = 0; \tag{4}$$

$$\ddot{Y} + k_0 \cdot \dot{Y} = -g; \tag{5}$$

$$Y = \pm X tg\beta. \tag{6}$$

where $\ddot{X}, \ddot{Y}$ - the projections of the particle acceleration to the coordinates, m s^{-2};

$\dot{X}, \dot{Y}$ - the projections of the particle speed to the coordinates, m s^{-1};

X, Y - the coordinates of a particle.

Equation (6) is the equation of soil ascension.

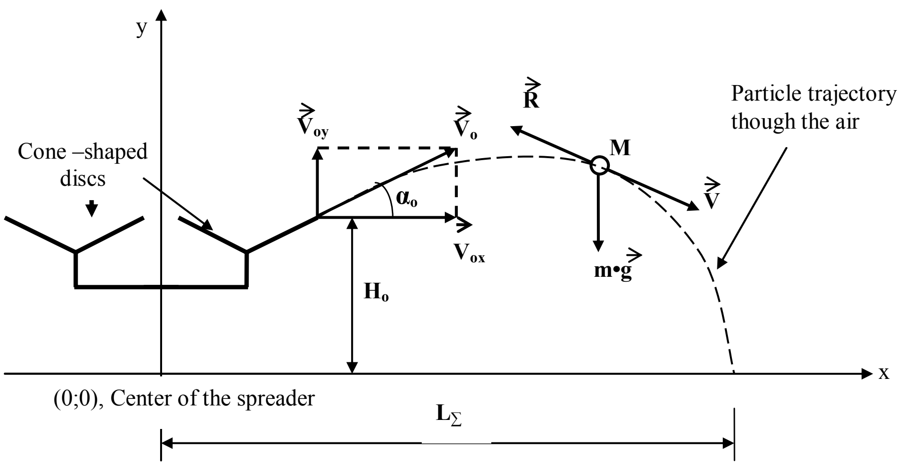

Fig. 2. Particle trajectory though the air

Deducting time t from the solutions of equations and accepting that $x = L$, it is obtained that the distance L of the particle which was thrown up and down by the angle α_0 at the ascension is expressed by the equation.

The tests have been performed under open air conditions when wind speed was no more than 2 m s^{-1}, driving speed – 8 km h^{-1}, angular speed of fertilizer distribution – 75.2 rad s^{-1}, height of soil irregularities – up to 0.2 m, and the machine side lean angle uphill was up to 8 degrees. The experiments have been performed using complex fertilizer NPK 3—21—21, ammonia nitre N 24, and AB "Litosfa" granular superphosphate; fertilizer rates were 120, 300 and 450 kg ha^{-1}, spreading fertilizer in various widths of the lot. The evenness of fertilizer distribution was evaluated according to LTS ISO 5690 – 1: 1997 requirements.

RESULTS AND DISCUSSION

Separate solutions of the differential equation of the movement of fertilizer particle on the disc surface, with respect to time and when the angular speed of the disc is fixed $(w = \text{const})$ allow determining the dependence of disc turning angle φ on the place where the particle gets on the disc r_0 (Fig. 3) and friction rate f (Fig. 4), when the particle moves on the disc surface along the spatula. The results obtained during the experimental tests are very close to theoretical calculations, which allow making conclusions on the influence of some dynamic factors during the simulations seeking to determine the location of a particle on the surface.

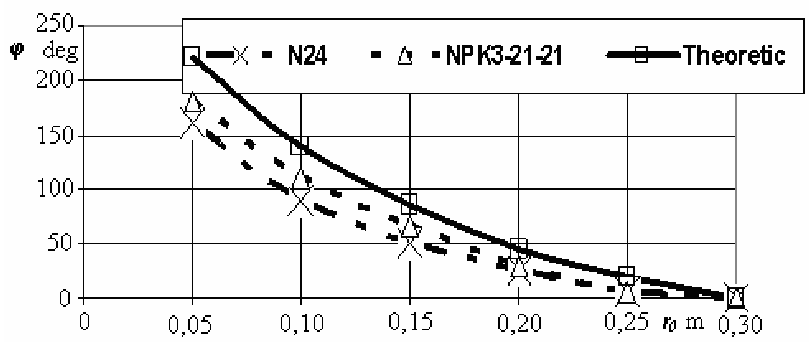

Fig. 3. The dependence of the disc turning angle φ on the radius r_0 when the particle gets on the disc: **—x—** φ = - 91 ln(r_0) – 117,16; R^2 = 0,99; -Δ- φ = - 105,6 ln(r_0) – 133,88; R^2 = 0,99; —□— φ = - 125,57 ln(r_0) – 153,48; R^2 = 0,99

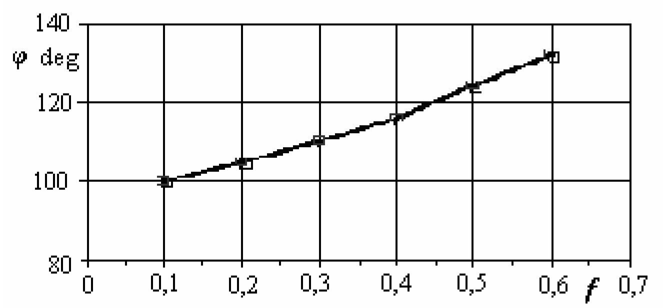

Fig. 4. The dependence of the disc turning angle φ on the particle slide friction rate f: φ = 62,57 f +92,60, R^2 = 0,98

When fertilizer distribution disc is conical, or depending on the distribution adjustment and set—up the actual angle between the initial speed vector V_0 while leaving the disc and the horizon α_0 is positive, i.e. the particle will be ejected. However, α_0 may vary depending on the relief of the field. This in turn will influence the distance a particle covers, the width of distribution lot and the evenness of distribution. The larger inequalities of the surface, the larger will be the disc leaning angle and width of a lot (Table 2).

Table 2. Increase in lot width depending on soil inequalities.

height of inequalities, *m*	0	0,024	0,049	0,073	0,099	0,123	0,147	0,172	0,197
increase of the angle α_0, degrees	0	1	2	3	4	5	6	7	8
increase in lot width, *m*	0.00	0.33	0.68	1.04	1.42	1.81	2.21	2.63	2.80

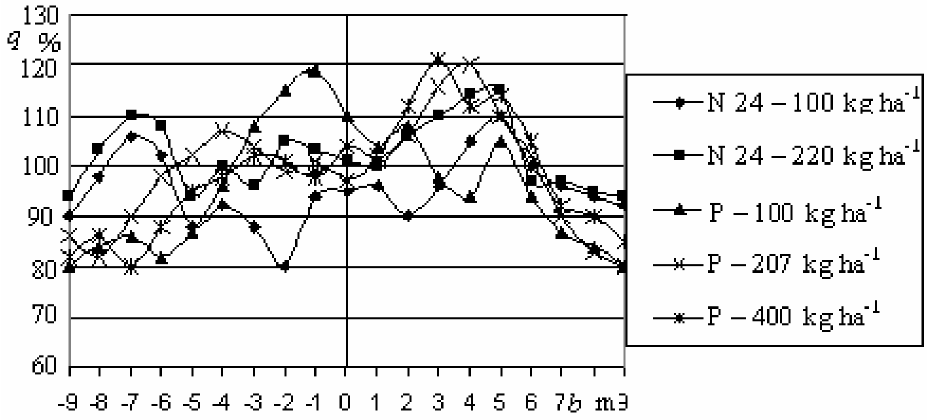

Fig. 5. The dependence of fertilizer rate *q* (%) on the width of the lot *b* (m).

Having soil surface inequalities of up to 0.2 m, the distribution disc lean angle may vary from 0° to 8° and the working width of the lot will be up to 2.8 m.

The manufacturing tests performed have proved that the evenness of mineral fertilizer distribution is influenced by the working width of the lot, rate of the fertilizer distributed, and the kind of fertilizer (i.e. the composition of their particles' fractions) (Fig. 5).

Although the spreader is adjusted for the symmetrical distribution of a fertilizer, the actual amount of fertilizer in the lot on both sides of the symmetrical axis vary from 2.3 to 20%. This difference increases even more when increasing the rate of the fertilizer.

In all the experiments the rate of a fertilizer in the middle of the lot and near the symmetrical axis is significantly larger. The amount of fertilizer decreases disproportionately to the distance from the symmetrical axis.

When spreading superphosphate and having a lot with the working width of 15 m, the actual rate deviation exceeds the permissible level significantly. The deviation increases even more when increasing the rate of fertilizer selected. All these factors influence the evenness of distribution. The dependence of the evenness (which is expressed by the rate of variation) of fertilizer rate distribution when spreading ammonia nitre N24 is presented in Fig. 6.

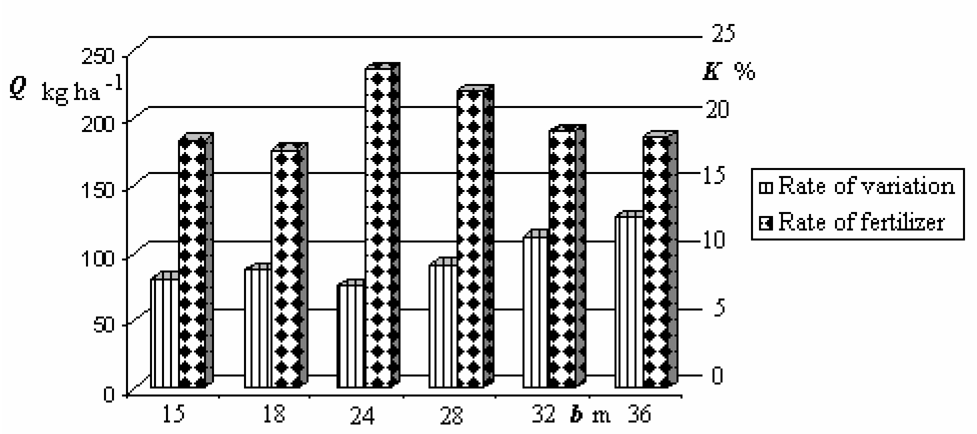

Fig. 6. The dependence of the rate of variation *K* (%) and the rate of fertilizer *Q* (kg ha^{-1}) on the width of lot *b* (m).

The results obtained proved that increasing the width of fertilizer distribution increases the rate of variation. The alteration of the rate of fertilizer is more clearly expressed and visible. It is believed that in the lots of larger width the evenness of fertilizer distribution and the rate of fertilizer are influenced more by other accidental dynamic factors, such as soil surface inequalities, jolts, wind direction and wind speed variations, etc.

CONCLUSIONS

The analytic dependencies of initial particle velocity obtained to determine the orientation of its vector and flying distance allow solving the problem of manure distribution evenness in the width of a lot.

Uneven distribution of particles in a spreading distance shows influence of air resistance and other environmental factors on the particle's velocity and the distance changes; this is typical for material particles possessing different mechanical properties.

It is purposeful to use an imitative simulation system for analyzing movement of a material particle in environment with air resistance. The developed system of differential equation of the particle movement can be solved at constant and changeable parameters of the model.

The angle of hilly slopes has uneven impact of the particle flying distance. The negative value of the angle has less influence on the particle flying distance than the positive.

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