**UNIVERSITY "POLITEHNICA" OF BUCHAREST**
**THE FACULTY OF BIOTECHNICAL SYSTEMS ENGINEERING**
**DOCTORAL SCHOOL OF BIOTECHNICAL SYSTEMS ENGINEERING**

# Doctoral Thesis Abstract

# STUDIES AND RESEARCHES ON SPREADING THE SOLID ORGANIC FERTILIZERS

*(Keywords: fertilizer, spreader, manure, organic, agriculture)*

**Author:**
**Eng. Vasilica POPA (ȘTEFAN)**

**Thesis supervisor:**
**Univ.Prof.Ph.D.Eng.: Ladislau DAVID**

**Bucharest**
**2020**

# REZUMAT

Îngrășămintele organice naturale au fost și vor rămâne principală sursă de îmbunătățire a calității solului prin beneficiile aduse de transformarea acestora în humus. În același timp, distribuirea lor în mod necorespunzător aduce grave prejudicii mediul înconjurător, fiind o sursă importantă de poluare, dacă sunt administrate excesiv și neuniform. Totodată, dacă se administrează în cantități reduse, efectul asupra beneficiilor aduse plantelor nu va fi cel scontat.

Teza de doctorat ***„Studii și cercetări privind distribuirea îngrășămintelor organice solide”*** prezintă o sinteză a cercetărilor teoretice şi experimentale cu privire la determinarea parametrilor constructivi şi funcționali optimi ai echipamentelor de distribuit îngrășăminte organice solide care să permită efectuarea unei lucrări eficiente.

Studiul documentar realizat, cu privire la echipamentele de distribuit îngrășăminte organice, evidențiază soluțiile constructive reprezentative. Pentru determinarea parametrilor constructivi optimi, a fost elaborat un model matematic, care prin simulări numerice, a permis optimizarea mașinii de administrat îngrășăminte organice solide cu rotoare verticale. S-a studiat influența diferiților parametri (turația rotoarelor, unghiul înclinare al rotoarelor, coeficientul de frecare dintre îngrășăminte și suprafața metalică, coordonatele inițiale ale punctelor de plecare, debitele de alimentare) și s-au determinat traiectoriile particulelor de la desprinderea de pe spira elicoidală până la aterizarea pe sol. S-au putut determina astfel, distribuții teoretice în diverse condiții de lucru pentru un singur organ de lucru dar și pentru mașina cu patru rotoare.

Pentru validarea modelului matematic propus, s-au efectuat cercetări experimentale privind: debitul specific de material realizat de un beater al mașinii și de mașină; uniformitatea de distribuție în patru variante de amplasare a rotoarelor; lățimea de lucru optimă; gradul de mărunțire a materialului distribuit; debitul de îngrășământ distribuit şi corelat cu viteza de lucru a maşinii pentru o normă impusă; optimizarea parametrilor constructivi şi funcţionali ai echipamentului de distribuit îngrăşăminte (turaţia rotoarelor distribuitoare; unghiul de înclinare a rotoarelor; debitul de alimentare cu material), în vederea optimizării indicilor calitativi ai lucrării de fertilizare organică

Cercetările experimentale efectuate au permis determinarea formei funcțiilor de regresie multivariabile de formă politropică și polinomială, utile pentru aprecierea indicilor constructivi, funcționali și calitativi ai echipamentului de distribuit îngrășăminte organice solide. S-au făcut unele recomandări pentru distribuirea compostului și a gunoiului de grajd semifermentat.

# ABSTRACT

Natural organic fertilizers have been and will remain the main source of improving soil quality through the benefits of their turning into humus. At the same time, their improper spreading causes serious damage to the environment, being an important source of pollution if they are administered excessively and unevenly. At the same time, if they are administered in small quantities, the effect on the benefits brought to the plants will not be the expected one.

The PhD. thesis ***"Studies and researches on spreading the solid organic fertilizers"*** presents a synthesis of theoretical and experimental research on determining the optimal constructive and functional parameters of equipment for spreading solid organic fertilizers that would allow an efficient work.

The documentary research carried out on the equipment for spreading organic fertilizers highlights the representative constructive solutions. In order to determine the optimal constructive parameters, a mathematical model was elaborated, which through numerical simulations, allowed the optimization of the four-beater machine for organic fertilizer spreading. The influence of different parameters (beater speed, beater tilt angle, coefficient of friction between fertilizers and metal surface, initial coordinates of starting points, feed rates) was studied and the trajectories of the particles from detaching from the beater until reaching the ground were determined. It was thus possible to determine theoretical distributions under various working conditions for a single working beater but also for the four-beater machine.

Experimental researches were carried out to validate the proposed mathematical model by: experimental determination of the specific flow of material achieved by a single beater and by the entire machine; determining the spreading uniformity in four variants of beater placement; determining the optimal working width; determining the degree of shredding of the distributed material; determining the feed flow and the working speed of the machine for an imposed rate; setting and adjusting the constructive and functional parameters of the equipment for fertilizer spreading (distributing beater speed, beater tilt angle, the material feed flow), in order to ensure optimal parameters and to obtain a maximum degree of spreading uniformity.

The experimental tests allowed determining multivariable regression functions of polytropic and polynomial form for assessing the constructive, functional and qualitative indices of the equipment for spreading solid organic fertilizers. Some recommendations regarding the spreading of compost and semi-fermented manure have been made.

# CONTENT

**CHAPTER 5**

**CHAPTER 6**

**CHAPTER 7**

# LIST OF NOTATIONS AND SYMBOLS

## CHAPTER 2

U [%] - moisture content
$\rho$ [kg/m$^3$] - fertilizer density
TS [%] - total solid
$X_{gm}$ [mm] - particle length
$\mu$ - coefficient of friction

## CHAPTER 4

$q_t$ [kg/s] - conveyer flow
$B_t$ [m] - conveyer width
h [m] - fertilizer height in the bin
$v_t$ [m/s] - conveyer speed

## CHAPTER 5

$Ff$ [N] - friction force between the particle and the helical surface
$F_c$ [N] - centrifugal force
$G$ [N] - gravitational force
$N$ [N] - normal force to a surface
$v_\theta, v_r$ [rad/s] - angular and radial velocity
$a_\theta, a_r, a_n$ [m/s$^2$] - angular, radial and normal acceleration

## CHAPTER 6

S1, S2 ,S3 [m$^2$] - surfaces determined by the particles leaving the 3 zones of the helical beater
$A_{1-7}$ [m$^2$] - surface areas determined by overlapping surfaces S1, S2 and S3
$Q$ [kg/s] - feed flow rate
$S_i$ [m$^2$] - investigated surface area
$\sigma_i$ [kg/m$^2$·s] - specific material flow
$G_{ud}$[%] - degree of uniformity

## CHAPTER 7

$g_m$[%] - shredder degree
$x_1$ , $x_2$ , $x_3$ - independent variables
y - dependent variable
$G_{ud\ (I)}$ - polytropic function expressing the degree of uniformity of compost / semi-fermented waste
$G_{ud\ (II)}$ - polynomial function expressing the degree of uniformity of the compost / semi-fermented waste
$N$ - polynomial function that expresses the administered fertilizer rate

# INTRODUCTION

The doctoral thesis ***"Studies and researches on spreading the solid organic fertilizers"*** is structured in 8 chapters, developed in 201 pages containing 177 figures, 78 tables, 165 mathematical relations, 16 annexes totaling 37 pages and the bibliography consisting of 153 references.

***Chapter 1 "Importance and objectives of the doctoral thesis"*** presents the importance of the topic addressed and the objectives pursued at the elaboration of the thesis.

***Chapter 2 "General considerations regarding the physical and mechanical properties of solid organic fertilizers used in agriculture"*** presents the importance of fertilization with organic fertilizers as well as the physical and mechanical properties of fertilizers that influence the spreading process with specialized technical equipment.

***Chapter 3 "Constructive and functional solutions of technical equipment for solid organic fertilizer spreading"*** presents the type of machines and the equipment used for solid organic fertilizer spreading, highlighting the constructive solutions, the technical and functional characteristics, as well as the working process performed by them.

***Chapter 4 "Stage of theoretical and experimental research on the working process of the equipment for solid organic fertilizer spreading"*** presents a synthesis of theoretical and experimental research on the spreading of solid organic fertilizers. It starts by pointing out the theoretical aspects regarding the movement of particles both on the surface of the spreading equipment and in space, determining the main factors that influence the spreading. The current state of experimental research shows a series of experimental results obtained by researchers in the field of organic fertilizer spreading.

***Chapter 5 "Mathematical modeling of solid organic fertilizer spreading"*** presents the mathematical modeling of solid organic fertilizer spreading process for the helical beater. The model allows the theoretical study of the behavior of the technical system considering different constructive and functional factors, under different working conditions, by computer simulation.

***Chapter 6 "Experimental research of the equipment for solid organic fertilizer spreading"*** presents the stationary and working test methodology of the solid organic fertilizer spreader as well as the experimental tests performed with the organic fertilizer spreader when stationary and under operation.

***Chapter 7 "Processing and interpretation of experimental data"*** presents the calculating algorithm of multivariable functions coefficients of polytropic and polynomial form. The multivariable functions for the specific material flow in transverse and longitudinal plane, the degree of uniformity of the spreading and the fertilizer rate distributed per hectare were determined.

***Chapter 8 "General conclusions, contributions, perspectives"*** presents the general conclusions of the theoretical and experimental research shown in the doctoral thesis, personal contributions, revaluation of results and future research directions.

# CHAPTER I
# IMPORTANCE AND OBJECTIVES OF THE DOCTORAL THESIS

## 1.1. The importance of the approached topic

The demand for soil fertilization comes from a continuous increase in organic agricultural products but also from the need to restore the degraded agricultural lands.

The uneven distribution of fertilizers on the soil means that, in some areas, a low fertilizer amount does not contribute to improving soil quality or as a nutritional supplement for plants. At the same time, in too large quantities, a local pollution of the soil may result, affecting the groundwater.

Although the spreading equipment has been developed continuously, the uniformity of the distribution over the total spreading width doesn't meet the agrotechnical requirements, because in the lateral extremities of the spreading pattern the quantities of distributed material are much smaller than in its center. It is therefore, necessary that the obtained data at a single machine pass to be analyzed in order to establish an optimal working width, using the overlapping method at a following pass.

Regarding the growing demand for ecological agricultural products but also considering the environmental protection, the continuous improvement of solid organic fertilizers spreading machines is a necessary and indispensable concern for researchers in the field.

## 1.2. Doctoral thesis objectives

The main objective of the thesis is to optimize the process of solid organic fertilizers distribution. The specific objectives of the thesis are:

- to elaborate a synthesis regarding the physical and mechanical properties of the solid organic fertilizers that influence the working process of the machine;
- study on the construction and working process of the equipment for organic fertilizer spreading;
- mathematical modeling of the working process and elaboration of a modeling program of the equipment for solid organic fertilizer spreading to analyze the influence of its different constructive and functional parameters;
- performing numerical simulations to trace the trajectories of fertilizer particles both on the surface of the beater and in space, until they reach the ground, in order to provide recommendations on the constructive and functional parameters of the machine;
- carrying out experimental research of a single beater but also of the machine in operation in order to validate the proposed mathematical model;
- determination of multivariable functions to calculate the qualitative working indices of the machine: degree of distribution uniformity, fertilizer rate, working width for which the uniformity degree corresponds to the current regulations.

# CHAPTER II
# GENERAL CONSIDERATIONS REGARDING THE PHYSICAL AND MECHANICAL PROPERTIES OF SOLID ORGANIC FERTILIZERS USED IN AGRICULTURE

## 2.1. Notions about soil fertility

In this sub-chapter are presented notions about soil fertility by increasing the humus content but also a series of benefits for the soil by using organic fertilizers. Among them are mentioned: increasing the soil porosity and permeability for air and water [27, 28], supplying nutrients for plants, reducing the apparent density by increasing the content of administered organic matter; reducing resistance to soil work; increasing soil resistance to wind and water erosion;

### 2.2. Solid organic fertilizers used in agriculture

The most common organic fertilizers are: manure, compost, various vegetable wastes, green manure, household waste, garden soil, urine and manure must, poultry manure, sludge from wastewater treatment plants or from the bottom of the lake (sapropel), peat, biochar or bio-carbon. Among the natural organic fertilizers, the most important and easy to procure is manure.

### 2.3. General considerations regarding the correct application of organic fertilizers

In this subchapter are provided guidelines for the correct application of fertilizers both quantitatively and in terms of application period, recommendations on composting platforms and rules for environment protection against nitrate pollution. Recommendations are also made with respect to the application as uniform as possible.

### 2.4. Physical and mechanical properties of solid organic fertilizers

The physical and mechanical characteristics of organic fertilizers that influence the quality of the fertilization work are presented in this subchapter.

#### *2.4.1. Dry matter content*

The dry matter content is determined by gravimetric method, by losing the liquid content after the sample is dried in an electric oven at 105 ± 0.5°C, where it is kept until constant mass is reached:

$$MU = \frac{m_f}{m_i} \cdot 100\ [\%] \tag{2.1}$$

where $m_i$ - the initial sample mass weighed before drying, [g]; $m_f$ - the final sample mass weighed after drying, [g]

#### *2.4.2. Humidity*

The moisture content of the material (U) or its liquid content is the mass of liquid that is lost during drying in the oven. It is calculated with 2.2 [59, 60]:

$$U = \frac{m_i - m_f}{m_i} \cdot 100[\%] \tag{2.2}$$

where $m_i$ - the initial sample mass weighed before drying, [g]; $m_f$ - the final sample mass weighed after drying, [g]

#### *2.4.3. Density of organic fertilizers*

The density of the distributed material is determined by weighing the mass loaded into the machine bin, relative to the bin volume [33, 60]:

$$\rho = \frac{Mg}{Vm} \quad [\mathrm{kg/m^3}] \tag{2.3}$$

where $\rho$ - is density, [kg/m$^3$]; $M_g$ – fertilizer mass, [kg]; $V_m$ – bin volume, [m$^3$].

#### *2.4.4. Particle size*

This feature is very important because, after distribution, the aggregates must not exceed 6 cm in length. If the particles are larger, fertilization will be done in excess in those areas [64, 65, 66].

#### *2.4.5. Friction coefficient*

The friction coefficient between the material and various surfaces used in the construction of the equipment for solid organic fertilizer spreading is a very important factor to study as it gives an indication on the fertilizer distribution length and the moment of detachment of the fertilizers from the blades of the beater.

### *2.4.6. Natural slope angle*

The material natural slope angle represents the angle between the generator of the bulk material cone and the horizontal flat surface on which it is deposited freely. There is a method for determining the natural slope angle, which is closely correlated with the consistency of the material, which can be observed visually, with values between $4^o$ and $50^o$ [67].

### *2.4.7. Normal stress*

Penetration resistance is the ability of solid organic fertilizers to resist the penetration of a rigid body. It decreases as the humidity increases [61].

### *2.4.8. Shear stress*

A shear vane apparatus is used to determine the shear strength of organic fertilizers in the field. Shear strength $\tau$ varies from 3 kPa to 50 kPa [57]. When inserting the device into the mass of material, a major problem in determining the shear strength was the high content of straw.

## 2.5. Conclusions

Organic fertilizers used in agriculture are: manure, compost, sewage sludge, poultry manure, biochar, green manure, vegetable waste. Of these, the most representative is manure known for its outstanding agrochemical and agronomic value.

The physical and mechanical properties that influence the most the performance of technical handling and spreading equipment are: dry matter content, density, particle size, friction characteristics (static coefficient of friction), normal stress, shear strength; natural slope angle.

# CHAPTER III

# CONSTRUCTIVE AND FUNCTIONAL SOLUTIONS OF TECHNICAL EQUIPMENT FOR SOLID ORGANIC FERTILIZER SPREADING

This chapter presents different constructive types of distribution devices used for the spreading of solid organic fertilizers.

## 3.1. Classification

Machines for the administration of solid organic fertilizers are intended for the administration on the surface of the soil, especially of manure and compost [69] and can be classified according to several criteria, but the most important is the distribution apparatus type. These machines may have a distribution apparatus with horizontal beaters, vertical beaters, centrifugal discs and shredding beaters, chains and weights; vane turbine type apparatus;

## 3.2. Indicators for evaluating the performance of organic fertilizer spreaders

For evaluating the performance of solid organic fertilizer spreaders, the most important indicators are [66, 69]: fertilizer rate, feed rate, specific flow rate, maximum distribution width, effective working width, cross distribution uniformity, longitudinal distribution uniformity.

## 3.3. Technical equipment for soil fertilization with horizontal beaters

From the analysis of the constructive solutions it is noticed the existence of several constructive variants of the distribution devices with horizontal beaters.

### *3.3.1. Spreading equipment with one horizontal beater*

The first category includes machines with a single beater arranged horizontally, represented schematically in fig.3.1.

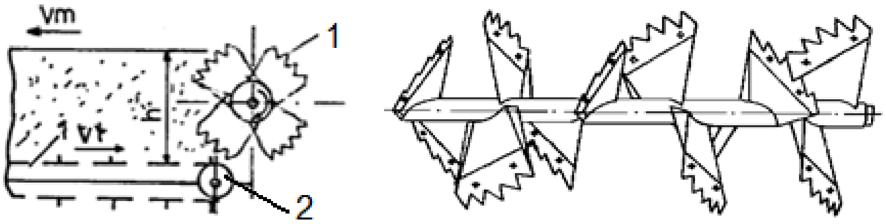


***Fig. 3.1.*** Spreading machine with a beater arranged horizontally [69]

The active parts are blades with serrated knives arranged on 2 helical coils symmetrical left-right to the central axis of the machine and are welded on a shaft, forming together the beater. The blades are arranged inclined to obtain a maximum spreading width but also to ensure uniformity of transverse distribution.

The machines for organic fertilizer spreading, built on this principle, make spreading areas equal to (1… 1.5) $B_t$, $B_t$ being the width of the spreader. The diameter of the beaters is generally 300… 550 mm and the peripheral speed is 4… 12 m/s (n = 300… 850 rpm).

### *3.3.2. Spreading equipment with two horizontal beaters*

The manure spreaders with two horizontal beaters can distribute a larger amount of material because the bin is double compared to the first variant. In order to even out the material in the unloading area, a finger flattening element (fig.3.8 and 3.9) was made at the top of the spreading beaters [80].

These machines have a big disadvantage, namely the small width of fertilizer spreading, between 2 and 4 m, requiring a larger number of passes, resulting in soil compaction during the fertilization work and high fuel consumption per unit area fertilized.

***Fig. 3.8.*** MIG-6 Manure spreader [80]

***Fig.3.9.*** Pronar manure spreader [81]

### *3.3.3. Spreading equipment with three horizontal beaters*

In order to improve the fertilization process, the constructive solutions of the distribution devices with horizontal beaters have been permanently improved, reaching the realization of some devices with three spreading beaters, of different shapes, with different directions of movement [85].

***Fig.3.14.*** MIG 10 machine spreading apparatus.1 superior beater; 2. intermediate beater,3 lower beater [86]

***Fig.3.15.***Machine with three horizontal beaters [88]

In conclusion, it can be stated that although spreading devices were designed even with three beaters and the constructive solutions of the beaters' active parts have been continuously improved, they favorably influence only the shredding degree of the distributed fertilizer and help obtain better longitudinal and transverse spreading uniformities, the spreading width is reduced, reaching twice the width of the machine bin. This makes the fertilization work be long, requiring many passes on the crop to be fertilized thus producing increased soil compaction.

## 3.4. Technical equipment for soil fertilization with vertical beaters

Machines with vertical beaters have the working parts built similarly to those presented in the previous subchapter, noting that, at the base of the beaters, discs with vanes have been provided. There is an even number of beaters, two or four and they rotate in opposite directions, half left, half right.

During the work, the beater takes the material of height $h$ brought by the conveyor, fragments it and evacuates it from the machine. The width of the spreading area in the case of these machines is (3… 5) $B_t$, where $B_t$ is the bin width [69].

***Fig. 3.24.*** Fertilizer spreader with 4 vertical beaters with continuous coil [90]

***Fig. 3.26.*** Fertilizer spreader with 2 vertical beaters with blades [82]

In the variants with two vertical beaters, large diameters are observed so as to take over the material brought by the conveyor. The actuation of the beaters is done by APP in all constructive variants

## 3.5. Technical equipment for soil fertilization with vane discs

Fertilizer spreaders with horizontal beaters have been improved by adding centrifugal discs to the base of the conveyor (fig.3.29) [93].

For this type of equipment, the speed of the horizontal beaters is much lower, as they only have the role of crushing the material. The material thus crushed falls on the discs with vanes and is spread by centrifugation, the discs having a speed of 400 - 700 rpm.

With this system it is observed that the distribution width increases from 2 - 3 m to 10-12 m, the material being much better crushed, but scattered in a thinner layer.

***Fig.3.29.*** Centrifugal spreader

## 3.6. Technical equipment with side-discharge

Another category of machines is that in which the distribution is made on the side of the machine (fig. 3.32). The distribution device is a beater arranged horizontally in the discharge area, which distributes both solid and semi-liquid fertilizers.

***Fig.3.32.*** SAMAS Side Discharge Organic Fertilizer Spreader [96]

***Fig.3.37.*** Turbine spreader [93, 95]

The machine has on the bottom of the bin a helical conveyor arranged along a helical line that shreds and brings the material to the evacuation zone from where it is taken by the distribution device.

Another variant of the distribution system with side discharge is the large diameter turbine type system, represented in fig.3.37, operated by means of an actuating group, from the power take-off of the tractor. By orienting the outlet of the turbine and by changing the position of the deflector vanes, variable working widths can be achieved, and by changing the speed of the scraper conveyor and the speed of the turbine, different fertilizer rates can be administered per unit area.

### 3.7. Technical equipment for soil fertilization with administration from piles

The technical equipment that distributes organic fertilizers directly from the piles left in the field is of older manufacture and is also used to crush the sugar beet or straw leaves left behind by the combine harvesters in the field.

The machine for administering organic fertilizers from piles, ROTO-4 (France) is a mounted, light, simple machine but with a robust construction (fig.3.42).

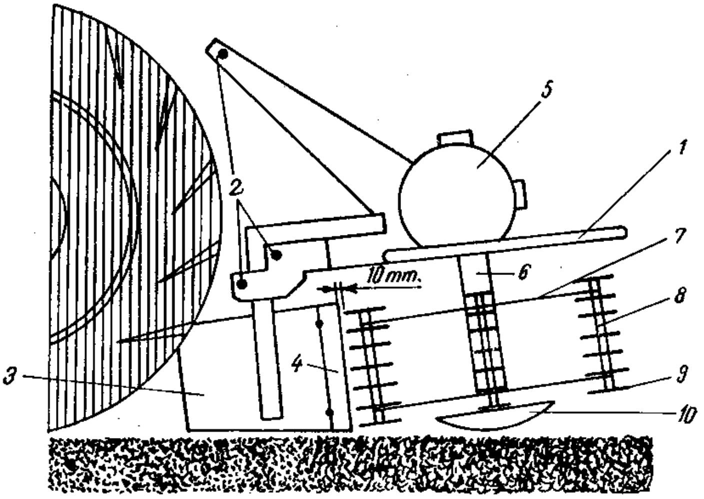


***Fig.3.40.*** ROTO 4 pile organic fertilizer delivery machine [71, 101]

The machine passes over the fertilizer left in piles (5 m spacing between piles), and dislocates and spreads it.

### 3.8.Conclusions

The performance of the equipment for organic fertilizer spreading is influenced by the following physical and mechanical characteristics of the fertilizers: dry matter content, density, particle size, friction characteristics and shear properties.

The working capacity of the machine is influenced by the spreading width, the unit speed of movement, the useful volume of the bin.

Manure spreaders with horizontal beaters achieve working widths of approx. (1… 1.5) $B_t$, $B_t$ being the width of the machine. The diameter of the spreading beaters is generally 300… 550 mm and the peripheral speed is 4… 12 m/s (n = 300… 850 rpm), the width reaching 2 ... 3.5 m [69].

Fertilizer spreaders with vertical beaters achieve working widths of (3… 5) Bt. The diameter of the spreading beaters is 450… 600 mm, and the speed is 300… 950 rpm depending on the tractor in the unit.

The machines with centrifugal disc spreading apparatus, placed at the base of the horizontal beaters, achieve the largest distribution widths, reaching up to approx. 22 m, in the conditions of a higher degree of crushing.

The power required to drive the feed conveyors varies between 5-6.5 hp (7-9 kW), for operating the spreading devices 10-15 hp (7-11 kW)

# CHAPTER IV
# STAGE OF THEORETICAL AND EXPERIMENTAL RESEARCH ON THE WORKING PROCESS OF THE EQUIPMENT FOR SOLID ORGANIC FERTILIZER SPREADING

## 4.1. Calculating the feed flow of the spreading device

The best-known feeding systems of the spreading device are the scraper conveyors. The scrapers of different sections, are mounted on two or four chains. Conveyor flow is [69]

$$q_t = B_t h v_t \rho \text{ [kg/s]} \qquad (4.1)$$

where $B_t$ is conveyor width, m;

$h$ the height of the fertilizer layer, m;

$v_t$ – conveyor speed, m/s ;

$\gamma$ - fertilizer density , kg/m$^3$ ;

Considering the amount of fertilizer to be distributed per unit area $N$ (kg/ha), the required $q_t$ flow rate will be [69]:

$$q_t = B_t v_m \frac{N}{10^4} \text{ [kg/s]} \qquad (4.2)$$

where: $B_m$ is the working width (spreading width) of the machine, in m;

$v_m$ - forward speed of the machine, in m/s.

## 4.2. Study of the movement of fertilizer particles on the horizontal spreading apparatus

During the working process, the horizontal beater with blades takes the material from the machine and throws it behind it (fig.4.4).

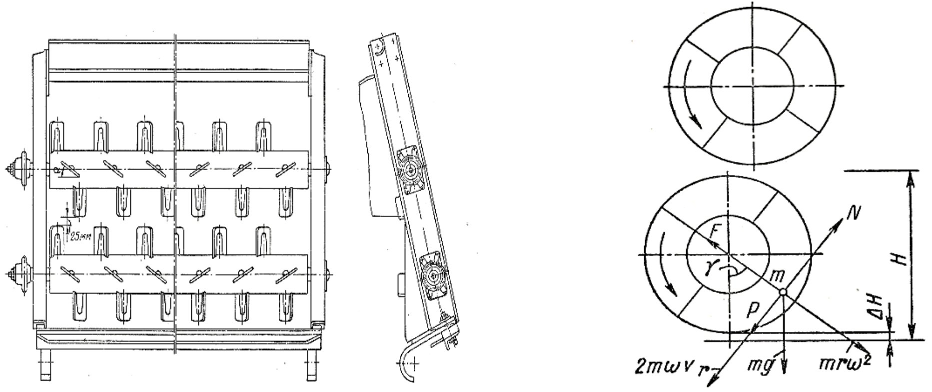


***Fig.4.1.*** Scheme of forces actuation on the material mass on the beater blade [102]

The particle will be discarded from the beater blade after it is dislocated from the mass of material in the bin. In order for the material to be thrown behind the machine and not returned to the hopper, the throw must take place in the upper part of the dial 2 of the beater circumference, meaning, in the case of the blade rotation angle $\gamma = 180°$, and this is possible if the distributor is loaded with a layer of material $H > D + \Delta H$ ($D$= diameter of the bit, $\Delta H$ - distance between the beater blades and the bottom of the bin, fig.4.1) [102].

Throwing the mass of material off the beater blade is possible if [102]:

$$m_g cos\gamma + m\omega^2 r \geq \mu(mgsin\gamma + 2m\omega v_r)mg \qquad (4.4)$$

where $\mu$ –is the coefficient of friction between the particle and the pallet;

$v_r$ –relative speed along the blade

The force with which the mass of material is thrown off the blade will be:

$$R = mgcos\gamma + m\omega^2 r - \mu(mgsin\gamma + 2m\omega v_r \qquad (4.5)$$

Equaling equations (4.4) and (4.5) and ignoring the $2m\omega v_r$ member due to the low value of the velocity $v_r$, the relative velocity of the material is [102]:

$$v_0 = \sqrt{\frac{1}{k_n}[gcos(\gamma+\varphi)+\omega^2 r]} \tag{4.8}$$

To increase the spreading width, the blades are fixed to the shaft at an angle α to the axis of rotation (fig. 4.2). In this case, due to the inclination of the blade, the absolute velocity component $v_0 \cos\alpha$ will appear along the beater axis, equal to $v_0 \cos\alpha \sin\alpha$ , which will influence the increase of the spreading width. It is obvious that the maximum value of the spreading width will be in the case of the maximum value of the component $v_0 \cos\alpha \sin\alpha$, and this is possible when $\alpha=45°$. To increase the s spreading width, the blades are placed inclined in one direction and in the other direction, in equal shares. (Fig.4.3).

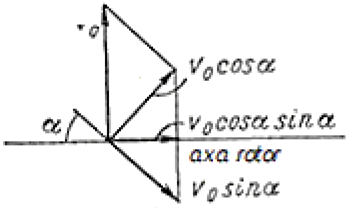


***Fig. 4.2.*** The determination of the velocity component to the beater axis [102]

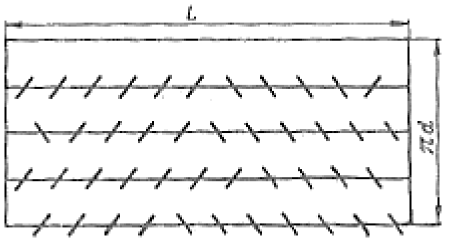


***Fig.4.3.*** Scheme of inclined blades location [102]

### 4.3. Study of the movement of fertilizer particles in the helical beater-type spreading apparatus

During the working process, the kinematics of the fertilizer particles entrained by the vertical spreading apparatus is influenced by the weight force of the particle, the friction force between the particle and the beater blades and the centrifugal force acting on the particle.

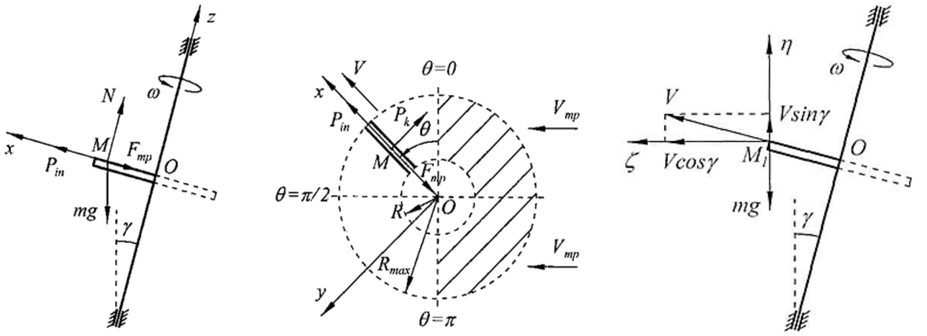


***Fig.4.4***. Forces acting on material point M, on an inclined helical beater [89]

On the surface of the beater is considered a material point, M, which has a complex motion, characterized by parametric equations of motion, on the three axes, Ox, Oy and Oz (Fig. 4.4) [89].

$$\begin{cases} m\ddot{x} = P_{in} - F_{mp} - mg\sin\gamma\sin\theta; \\ m\ddot{y} = -P_{\kappa} - mg\sin\gamma\cos\theta; \\ m\ddot{z} = N - mg\cos\gamma. \end{cases} \tag{4.9}$$

where:

m is the mass of the material point;

$\ddot{x}, \ddot{y}, \ddot{z}$- accelerations on Ox, Oy, Oz axis;

$P_{in}$ – centrifugal force;

$F_{mp}$ – friction force on the surface of the disc;
g – gravitational acceleration;
N – normal reaction at the surface of the coil;
θ, γ – angles to the axes;
ω – angular speed of the beater;
M- position where the fertilizer material point is, on the coil

According to the assumptions that $y = \dot{y} = \ddot{y} = 0$ and $z = \dot{z} = \ddot{z} = 0$, and taking into account equation (4.9), the normal coil force, *N* is:

$$N = mg\cos\gamma \tag{4.10}$$

Friction force $F_{mp}$ is given by relation:

$$F_{mp} = fN = f\cdot mg\cdot\cos\gamma \tag{4.11}$$

where *f* is the coefficient of sliding friction between the manure particle and the surface of the coil.

Centrifugal force is given by relation $P_{in} = m\omega^2 x$ (4.12)

Taking into account that $\theta = \omega t$, and considering the relations (4.10) and (4.11), from eq. (4.9) is deduced: $\ddot{x} - \omega^2 x = -g\sin\gamma(\omega t) - fg\cos\gamma$ (4.13)

Solving the differential equation will lead to the equation of displacement on Ox, as a function of time: $x(t) = x^* + \bar{x}$ resulting $\dot{x} = C_1\omega e^{\omega t} - C_2\omega e^{-\omega t} + \frac{g\sin\gamma}{2\omega}\cos\gamma$ (4.18)

The movement in the air after detachment from the beater is given by:

$$\begin{cases} m\ddot{\eta} = -mg; \\ m\ddot{\varsigma} = 0. \end{cases} \tag{4.19}$$

where: $t = t_0 = 0; \eta_0 = \eta(0) = 0; \xi_0 = \xi(0) = 0; \dot{\eta}_0 = V\sin\gamma; \varsigma_0 = V\cos\gamma,$ (4.20)

then:

$$\begin{cases} \eta = -\frac{gt^2}{2} + Vt\sin\gamma; \\ \varsigma = Vt\cos\gamma. \end{cases} \tag{4.21}$$

the time until reaching the ground is:

$$t_n = \frac{V\sin\gamma + \sqrt{V^2\sin^2\gamma + 2gH'}}{g}. \tag{4.22}$$

and the flight interval is:

$$\xi_n = \left(\frac{V\sin\gamma + \sqrt{V^2\sin^2\gamma + 2gH'}}{g}\right)V\cos\gamma. \tag{4.23}$$

### 4.4. Study of the movement of fertilizer particles on the vane disc type spreading device

It was considered a solid fertilizer spreading device consisting of a beater with vanes and a stationary disc, figure 4.5.

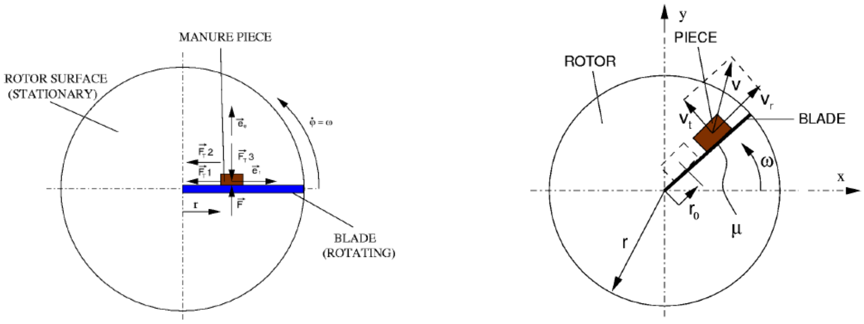


***Fig.4.5.*** Top view of the device composed of beater with vanes and stationary disc [104]

The motion of the particle is described by the laws of dynamics and for simplification the polar coordinate system is used. The motion of the particle is given by the equations in the radial direction $(\overrightarrow{e_r})$ and tangential direction $(\overrightarrow{e_\varphi})$.

The friction force $\left(\overrightarrow{F_T}1\right)$ between the particle and the stationary disc, the friction force $\left(\overrightarrow{F_T}2\right)$ between the vane and the particle, the radial force $(m \cdot \overrightarrow{a_r})$ act on the radial direction (fig.4.5).

On the tangential direction $(\overrightarrow{e_\varphi})$ act (fig.4.5): the tangential force $(m \cdot \overrightarrow{a_r})$ and the force of the vane $\left(\vec{F}\right)$ which causes the appearance of the friction force $\left(\overrightarrow{F_T}2\right)$ between the particle and vane. The friction force between the particle and the surface of the disc $\left(\overrightarrow{F_T}3\right)$ must be also taken into account [104].

The equations of motion are as follows [104]:

- on the radial direction $\overrightarrow{e_r}: -F_T1 - F_T2 = m \cdot \vec{a}_r = m \cdot (\ddot{r} - r \cdot \dot{\varphi}^2)$ (4.24)
- on the tangential direction $\overrightarrow{e_\varphi}: F = m \cdot \vec{a}_\varphi = m \cdot (\, r \cdot \ddot{\varphi} + 2 \cdot \dot{r} \cdot \dot{\varphi}\,)$ (4.25)

Eq. (4.23) and (4.25) are solved as differential equations:

$$\ddot{\vec{r}} + 2 \cdot \mu \cdot \dot{\vec{r}} \cdot \omega - \dot{r} \cdot \omega^2 = -(\mu \cdot g + \mu^2 \cdot g) \tag{4.26}$$

The differential equation (4.26) is solved for the homogeneous part (coefficients $\lambda_1$ and $\lambda_2$) and the inhomogeneous part (D) [104]:

$$\lambda_1 = -\mu \cdot \vec{\omega} + \vec{\omega} \cdot \sqrt{\mu^2 + 1}$$

$$\lambda_2 = -\mu \cdot \vec{\omega} - \vec{\omega} \cdot \sqrt{\mu^2 + 1}$$

$$D = \frac{\mu \cdot \vec{g} + \mu^2 \cdot \vec{g}}{\vec{\omega}^2}$$

where *g =9.81m/s*$^2$

$$\vec{r}(t) = \frac{(r_0 - D) \cdot \lambda_2}{\lambda_2 - \lambda_1} \cdot e^{\lambda_1 \cdot t} + \frac{r_0 - D}{1 - \frac{\lambda_2}{\lambda_1}} \cdot e^{\lambda_2 \cdot t} + D \tag{4.27}$$

$$\dot{\vec{r}}(t) = \overrightarrow{v_r} = \lambda_1 \frac{(r_0 - D) \cdot \lambda_2}{\lambda_2 - \lambda_1} \cdot e^{\lambda_1 \cdot t} + \lambda_2 \frac{r_0 - D}{1 - \frac{\lambda_2}{\lambda_1}} \cdot e^{\lambda_2} \cdot t \tag{4.28}$$

Relation (4.28) shows the variation of the velocity of the fertilizer particle in the direction of movement along the disc vane.

There is also the tangential velocity $\overrightarrow{v_t}$ which depends only on the radius *r* and the angular velocity *ω*. The resulting velocity *v* is [104]:

$$\vec{v} = \sqrt{\overrightarrow{v_t}^2 + \overrightarrow{v_r}^2} \tag{4.29}$$

The position of the point where the particle touches the ground is [104]

$$L_t = \upsilon \cdot \cos(\alpha) \cdot t^2 \tag{4.30}$$

$$h_t = \upsilon \cdot \sin(\alpha) - \frac{1}{2} \cdot g \cdot t^2 \tag{4.31}$$

where *Lt* is the distance traveled by the particle;

*α* - the angle between the ground and the throwing direction

$h_t$ - maximum particle height in flight;
$t$ - time spent by the particle in flight.

Under these conditions the following equations result [104]

$$t = \sqrt{\frac{2 \cdot h}{g}} \tag{4.32}$$

$$L_x = t \cdot \upsilon_x \tag{4.33}$$

The numerical simulations performed must take into account the boundary conditions, namely the beater radius ($r$), the beater speed ($n$), the distance from the beater to the ground ($h$), as well as the coefficient of friction between the manure and the surface on which it slides ($\mu$). The results of the numerical simulations are shown in Figures 4.9 and 4.10

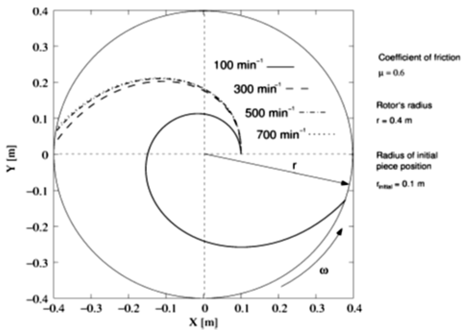


***Fig.4.9.*** Particle motion for different beater rotation frequencies [104]

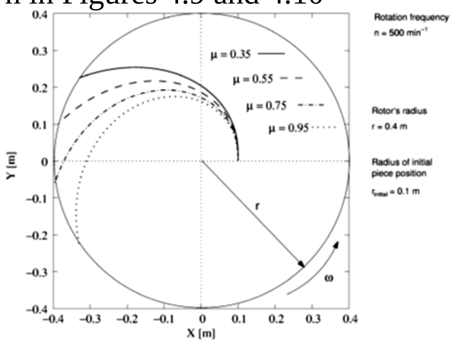


***Fig.4.10.*** . Particle motion for different coefficients of friction [104]

The numerical simulations performed for a number of 2000 particles are presented in figure 4.13. Viewed from above, the distribution is made by an arc of a circle its size depending on the speed at which the particle detaches from the beater. The figure shows a relatively uniform distribution along the distance of 17 m.

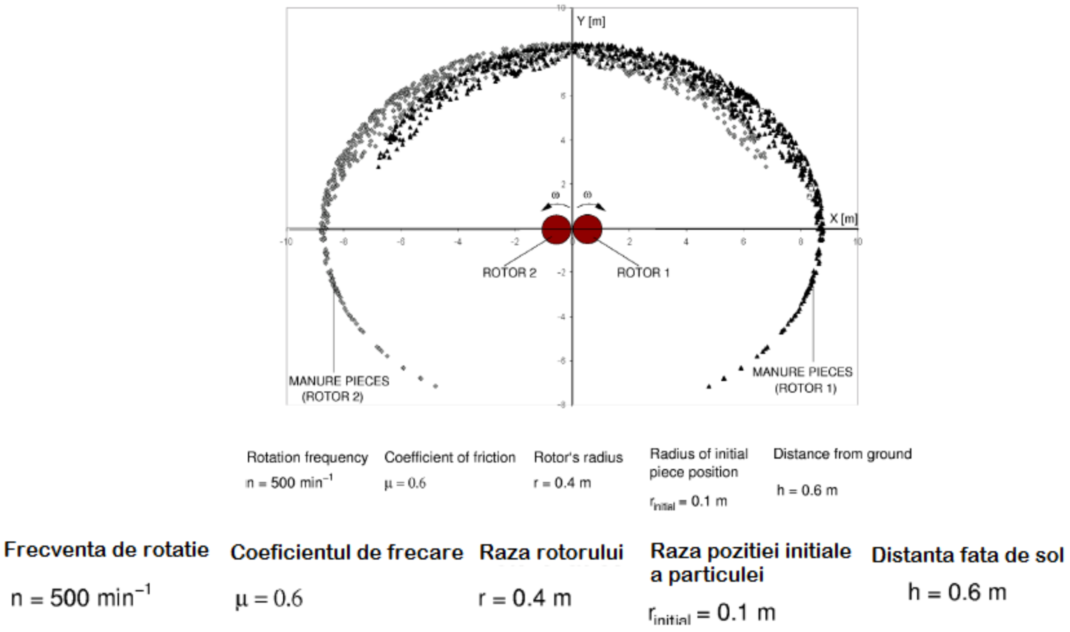
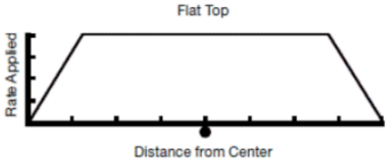
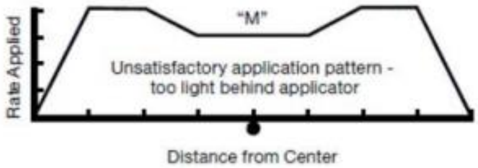
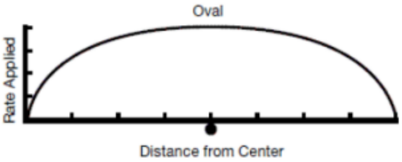
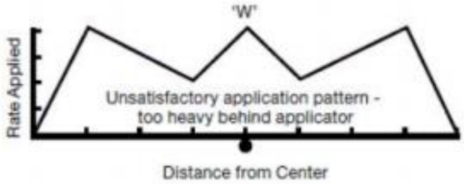
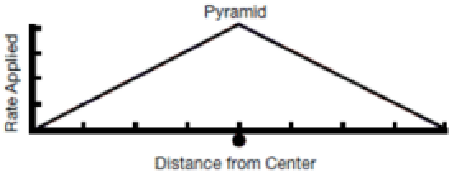
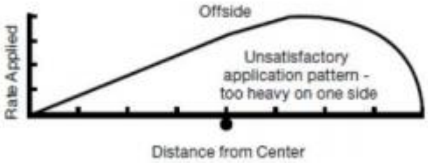


***Fig.4.13.*** Distribution of fertilizer particles [104]

## 4.5. Fertilizer spreading patterns

At a single pass the accepted spreading patterns are trapezoidal, oval/Gaussian or triangular (Table 4.1). They have a symmetrical shape to the center allowing subsequent overlaps that would reach a degree of uniformity of 100%.

***Table 4.1.*** Single-pass spreading patterns [105, 106, 107]

| Desirable single-pass spreading patterns | Undesirable single-pass spreading patterns |
|---|---|
|  |  |
|  |  |
|  |  |

The overlapping scheme of three successive paths to obtain the actual working width (orange line fig. 4.14) is used to evaluate the spreading uniformity and the actual working width for the fertilization work. Current standards provide an accepted degree of uniformity with values above 75% [20].

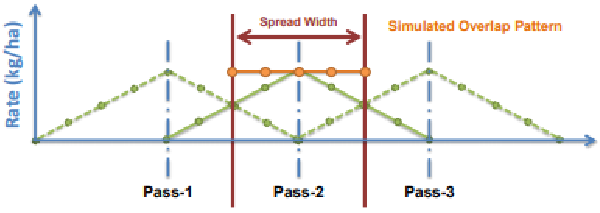


***Fig.4.14.*** Graphical representation of overlapping three passes' patterns [105]

Table 4.2 shows the number of pattern shapes obtained in 41 possible machine-material configurations or adjustments for the spreading of compost and manure by the authors of the paper [108].

Tabel.4.2. [108]

***Tabel.4.2***. Spreading patterns' profiles [108]

| | Triangle profile  | Trapezoidal profile  | "M" Profile  |
|---|---|---|---|
| Vertical beater spreaders | 11 | 9 | 8 |
| Disc and vane spreaders | 0 | 10 | 3 |

## 4.6. Experimental researches on the machine for solid organic fertilizer spreading MIG - 5

The experiments of the MIG 5 machine, with a single fertilizer spreading beater were performed in order to determine the following indices: machine flow, uniformity of distribution, shredding degree of manure, effective working width, doses of possible fertilizer to be administered; energy indices. The machine has a spreading beater width of 1800 mm and a speed of 285 rpm.

Among the results obtained from the experiments we mention:

- The *flow* of the machine had values between 236 and 2466 kg/min

- The *uniformity of* the transversal *distribution* had values between 77.7% and 84.1% and the uniformity on the direction of advance of the machine had values between 78.9 and 89.6%;

- The *shredding degree* had values between 60.8 and 67.5%;

- Total *spreading width* was 4 m of which 3.25 m had a uniform spreading;

- The *rates* obtained for fermentable manure possible to be distributed vary between 14.4 t/ha and 176.4 t/ha, and for fresh manure between 5 and 45.7 t/ha

### 4.7. Experimental researches on the machine for solid organic fertilizer spreading MIG - 12

The experimental researches carried out with the MIG-12 manure spreading machine with a spreading apparatus with 4 vertical beaters were carried out in order to determine, the functional characteristics, the qualitative working indices and the energy indices. The semi-mounted machine has a capacity of 12 t, length of 7370 mm, width of 2420 mm and height of 3165 mm [111].

The *effective working width* for the distribution of fermented manure had values between 7 and 9 m (the average being 7.88 m), and for the distribution of unfermented manure the actual width had values between 7 and 8 m (the average being 7.63 m).

The *total working width* averaged 13.2 m.

The *manure shredding degree*, which depends on the degree of manure fermentation, on the machine flow and on the type of active spreading bodies, had values between 82.7% and 89.3% in the distribution of fermented manure and 79.7% - 88, 3% in the distribution of unfermented manure.

The *spreading uniformity* on the working width achieved by the MIG 12 machine at the laboratory field tests, had values between 70 and 76.7% when spreading the fermented manure and 70.1… 78.6 % when spreading the unfermented manure.

The average values of the doses of fermented and unfermented manure that can be spread per hectare with the MIG 12 machine are between 0.7 t/ha and 254 t/ha.

### 4.8. Conclusions

For the feed system of the spreading apparatus, it was found after the analysis performed, that, in the most of the applied constructive solutions, the scraper conveyor is used, with a range of variation of the transport speed between 1.5 - 50 mm/s .

For the vertical helical beater spreader, the movement of fertilizer particles on the beater surface and in the air until landing on the ground was studied.

Acceptable solid fertilizer spreading patterns in a single pass are trapezoidal, oval/Gaussian or triangular.

Regarding the width of the cross-sectional spreading, the authors of the research reached the following conclusions:

- for the *spreading equipment with vertical beaters*, the spreading width has values between 5 and 12 m;
- for *vane disc spreading equipment*, the distribution width is between 10 and 18 m.

From the presented researches it can be noticed which are the constructive and functional parameters that directly influence the spreading of solid organic fertilizers, namely:

- constructive parameters of the spreading device: diameter of coils/blades, height of the beater, inclination of the blades/beater, distance from the ground to the beater;
- beater speed, which for the presented constructive solutions must be between 300 and 700 rpm;
- physical - mechanical properties of the fertilizer (coefficient of friction, humidity, density, etc.);
- distributed fertilizer flow;
- working speed of the machine.

# CHAPTER V
# MATHEMATICAL MODELING OF SOLID ORGANIC FERTILIZER SPREADING

## 25.1. Objectives of the modeling program

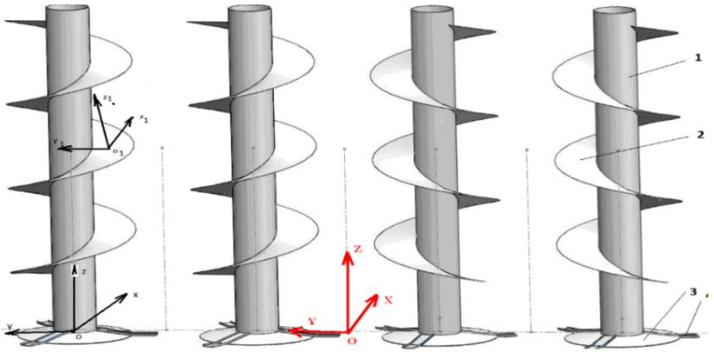
The main objectives are:

- determination of the area where the spiral feeding takes place and the place where the fertilizer particles can leave;
- analysis of the movement of material particles on the helical surface. The time required for detachment from the helical surface and the coordinates of the detachment point shall be determined;
- analysis of the movement of material particles after detachment from the helical surface and their intersection with the ground;
- elaboration of programs for dynamic calculation and graphical representation of the trajectories of the material particles for determining the distribution area for each beater;
- determination of the surfaces covered on the ground with the material distributed by a beater;
- determining the amount of material falling to the ground for different feed rates;
- determination of the flows and theoretical rates achieved by the machine.

In the mathematical model made for the study of the distribution of fertilizer particles, it is considered that the solid fertilizer particle is a material point.

## 5.2. Modeling program algorithm

A particle of material on the surface of the beater moves according to the laws of dynamics [124, 125]. Due to the forces exerted on the particle as a result of the beater rotation, the particle moves on the beater surface and then in the air until intersecting the ground. To simplify the model, the friction force between the particle and the air was neglected.



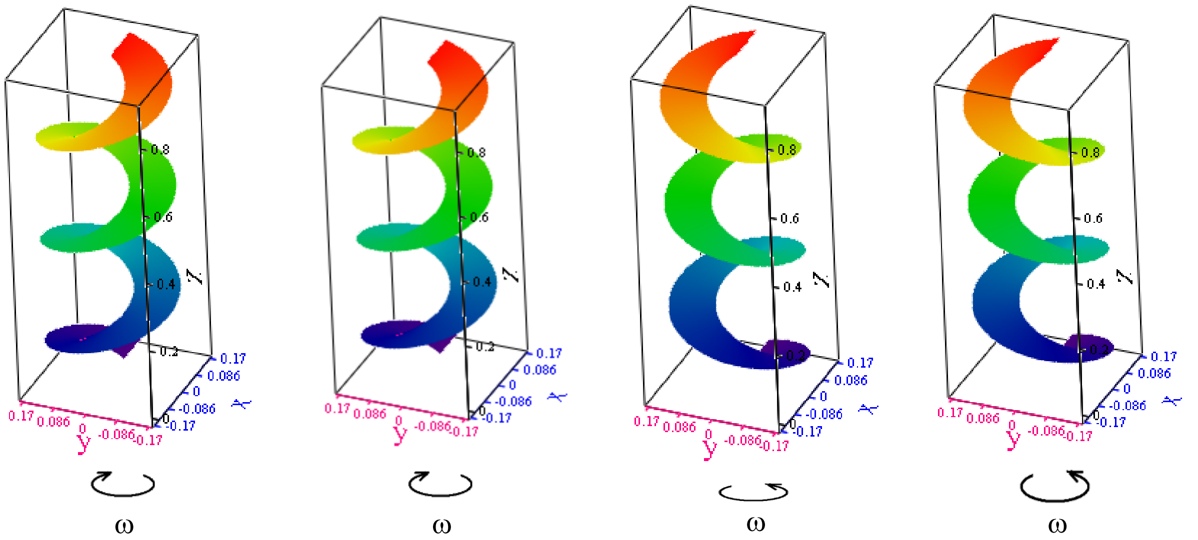


***Fig.5.1.*** Spreading device with four vertical beaters
*a) representation of the spreading apparatus (3D Solid Works view) 1. shaft; 2. helical coil; 3.disc; 4.vane;*
*b) generation of helical surfaces of the spreading apparatus in the Mathcad program [127]*

It is considered a local coordinate system of a coil, $o_1x_1y_1z_1$ (Fig. 5.1.a) and the parametric equations of the helical surface are written, with pitch $p_s$, left hand spiral (the sign of $y$ is negative) and the right hand spiral (the sign of $y$ is positive) [124, 125, 128]:

$$\begin{cases} x = r\cos\theta \\ y = \pm r\sin\theta \\ z = \mathrm{K}(r) + p\theta,\ p > 0,\ p \in R \end{cases} \tag{5.1}$$

where $r$ is radial coordinate; $\theta$ - angular coordinate; ; $p_s$ - the pitch of the helical coil, $K(r)$ - the function that gives the shape of the helical coil (the radial deformation of the surface is zero for the classical helical surface).

It is considered a material point $M$ on the helical surface. Friction force $F_f$, centrifugal force $F_c$, gravity force $G$ and normal force $N$ act on it. The particle moves on the helical surface with speed $v_t$ (fig.5.3).

After balancing forces

$$m\vec{a} = \vec{F}_c + \vec{G} + \vec{N} + \vec{F}_f \tag{5.3}$$

the velocity is:

$$\vec{v} = \frac{d\vec{r}}{dt} = \dot{\vec{r}} \tag{5.4}$$

acceleration is:

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{r}}{dt^2} = \ddot{\vec{r}} \tag{5.5}$$

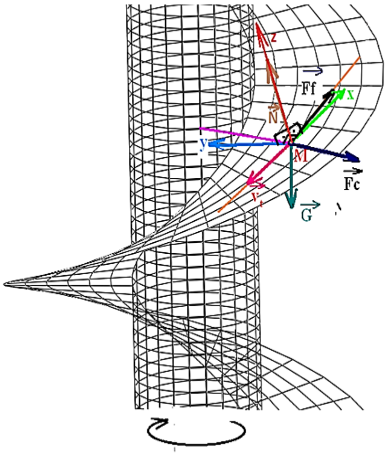


***Fig.5.3.*** The forces acting on the particle of material M on the helical surface

After defining the velocity and acceleration on radial, angular and normal direction, in polar and Cartesian coordinates and after defining the forms for all the forces that act on the M point, the equations of motion in the radial and angular direction is found:

$$\begin{cases} \ddot{r} = 2\dot{\theta}^2 r - \dfrac{\mu}{\sqrt{r^2+p^2}}(gp - 2pr\dot{r}\dot{\theta})\dfrac{\dot{r}}{\sqrt{\dot{r}^2+(r^2+p^2)\dot{\theta}^2}} \\ \ddot{\theta} = \dfrac{-\dfrac{1}{\sqrt{r^2+p^2}}(gp+\mu gr+2\mu pr\dot{r}\dot{\theta})\cdot\dfrac{\sqrt{r^2+p^2}\,\dot{\theta}}{\sqrt{\dot{r}^2+(r^2+p^2)\dot{\theta}^2}} - \dfrac{2r\dot{r}\dot{\theta}}{\sqrt{r^2+p^2}}}{\sqrt{r^2+p^2}} \end{cases} \tag{5.30}$$

The initial conditions are given by the radius *$r_0$* and angle *$\theta_0$*:

$$\begin{aligned} x_0 &= r_0 \cdot cos(\theta_0) \\ y_0 &= r_0 \cdot cos(\theta_0) \\ \dot{r}_0 &= vt \cdot cos(\theta_0) \\ \dot{\theta}_0 &= \omega + \frac{vt \cdot cos(\theta_0)}{r_0} \end{aligned} \tag{5.31}$$

In Cartesian coordinates the velocities are :

$$\begin{aligned} \dot{x}_0 &= \dot{r}_0\, cos(\theta_0) - r_0 \cdot \dot{\theta}_0\, sin(\theta_0) \\ \dot{y}_0 &= \dot{r}_0\, sin(\theta_0) + r_0 \cdot \dot{\theta}_0\, cos(\theta_0) \end{aligned} \tag{5.32}$$

where $v_t$ is the speed at which the particle reaches the helical surface (speed of the scraper conveyor which feeds the spreading apparatus with material)

The system of equations (5.30) cannot be solved analytically but only numerically, on the computer, because it has the secondary derivatives of $r$ and $\theta$ depending on the first derivatives and on the other parameters of the system.

The equations of motion of the particle after leaving the helical coil are [118, 125, 124]:

$$\begin{cases} x(t) = \dot{x}_0(t - t_0) + x_0 \\ y(t) = \dot{y}_0(t - t_0) + y_0 \\ z(t) = -\dfrac{g}{2}t^2 + (\dot{z}_0 + g \cdot t_0)t + z_0 - \dot{z}_0 t_0 - \dfrac{g}{2}{t_0}^2 \end{cases} \tag{5.33}$$

where :

$$\begin{cases} \dot{x}(t) = \dot{x}_0 \\ \dot{y}(t) = \dot{y}_0 \\ \dot{z}(t) = -g \cdot t + z_0 + gt_0 \end{cases}$$

(5.34)

where *t* is the time of the particle in flight until landing on the ground (h=0, in our case z=0);

$t_0$- the time after which the particle leaves the beater from the movement on the helical surface described above;

$\dot{x}_0$ - initial velocity of the particle on the *ox* axis;

$\dot{y}_0$ - initial velocity of the particle on the *oy* axis;

$\dot{z}_0$ - initial velocity of the particle on the *oz* axis;

$z_0$ - the height from which the particle starts moving;

*g* - gravitational acceleration.

Equation 3 of system of equations 5.33 will be solved analytically and the time after which the particle lands on the ground will result ($z$=0).

We will note the coefficients of *t* as follows:

$$\boldsymbol{A} = \frac{-g}{2};\ B = \dot{z}_0 + g t_0;\ \boldsymbol{C} = \boldsymbol{z_0} - \boldsymbol{\dot{z}_0 t_0} - \frac{g}{2}\boldsymbol{t_0}^2$$

The following solutions result:

$$\begin{cases} t_1 = \dfrac{-B + \sqrt{B^2 + 4 \cdot A \cdot C}}{2 \cdot A} \\ t_2 = \dfrac{-B - \sqrt{B^2 + 4 \cdot A \cdot C}}{2 \cdot A} \end{cases} \tag{5.35}$$

The landing time *t* is the maximum between the solutions $t_1$ and $t_2$.

To solve on the computer by the numerical method Runge Kutta Order 4, we used the program Mathcad, the system of differential equations (5.30) in explicit form, i.e. explaining the secondary derivatives of $r$ and $\theta$ depending on the first derivatives and on the other system parameters [129, 130]. Equations (5.30) and (5.34) describe the movement of fertilizer particles from the first contact with the beater until they reach the soil surface.

### 5.3. Study of the movement of the fertilizer particle according to the coefficient of friction

For the study of the movement of the fertilizer particle on the surface of the helical coil, the following initial data were considered: beater speed n=540 rpm; the maximum diameter of the helical coil 0.345 m; the minimum diameter of the helical coil 0.115 m; helical coil pitch 0.3 m; beater length 0.9 m; the angle of inclination of the coil, corresponding to the maximum diameter, 15°; the starting movement point is corresponding to the radius $r_0$=0.115 m and the angle θ=270°; coefficient of friction with metallic surface μ=0.8; The inclination of the beater with respect to the vertical axis α=10°.

Fig.5.6 shows graphically the motion of the particle on the helical surface having as starting point $r_0$=0.115 m and θ=270°. The final trajectory, on the helical coil and in the air, is presented in fig. 5.13.

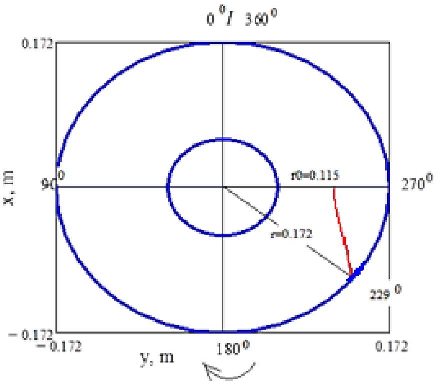


*Fig. 5.6.* Movement of particles on the helical surface (top view)

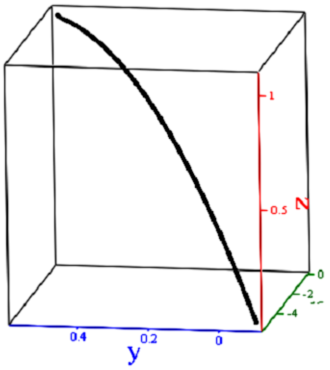
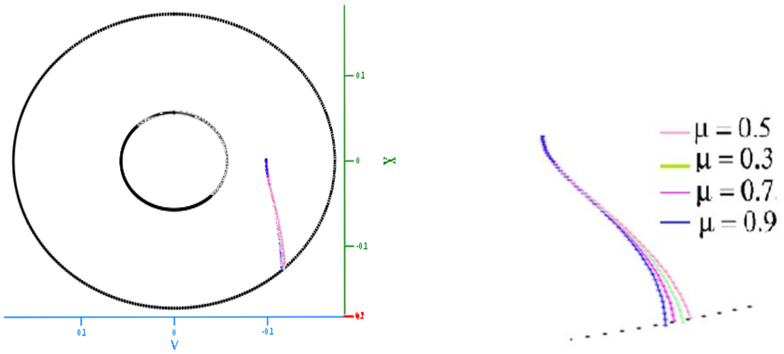


*Fig. 5.13.* Fertilizer particle trajectory

The motion of a particle starting from the average radius r=0.115m, θ=270°, rotational speed *n*=540 rpm and friction coefficients $\mu$ =0.3; 0.5; 0.7;0.9 is analyzed (Fig.5.15).



a) b)

*Fig.5.15.* Particle trajectory as a function of the coefficient of friction between the particle and the beater a) the movement on the helical surface; b) the movement on the helical surface - detail;

From the obtained data it can be noticed that the leaving time from the helical surface is extremely close, which indicates that the movement it is not influenced by the coefficient of friction, fact also found by the authors of the paper [104].

### 5.4. Study of the movement of the fertilizer particle according to the beater speed

The motion of the fertilizer particles under the action of the helical coil is analyzed considering three beater speeds, namely 100, 300 and 700 rpm and three initial starting positions of the particles namely $r_0$=0.075m, $r_1$=0.114m and $r_2$=0.162m.

The trajectories of the particles on the helical coil are presented in fig.5.16. It is observed that particles that start from the same point at a lower speed stay longer on the helical coil than some that are released at a higher speed. The results obtained are in line with those obtained by the authors of the paper [104].

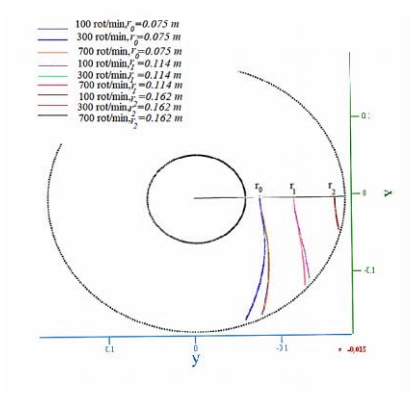
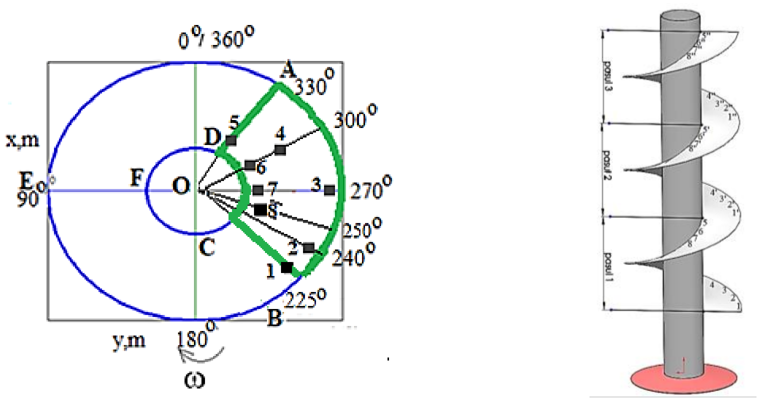


***Fig.5.16.*** Particle trajectories on the helical coil at different beater speeds

Simulations were performed for a series of significant points 1-8 (Fig.5.19 a and b).



a)

b)

***Fig.5.19***. Starting points of fertilizer particles. a) top view b) 3D view

Fig.5.21 shows the surfaces on which the fertilizer particles, detached from the first pitch of the helical coil (zone 1), are thrown for all three beater speeds considered. It is found that at higher speeds, larger soil surfaces are covered with material.

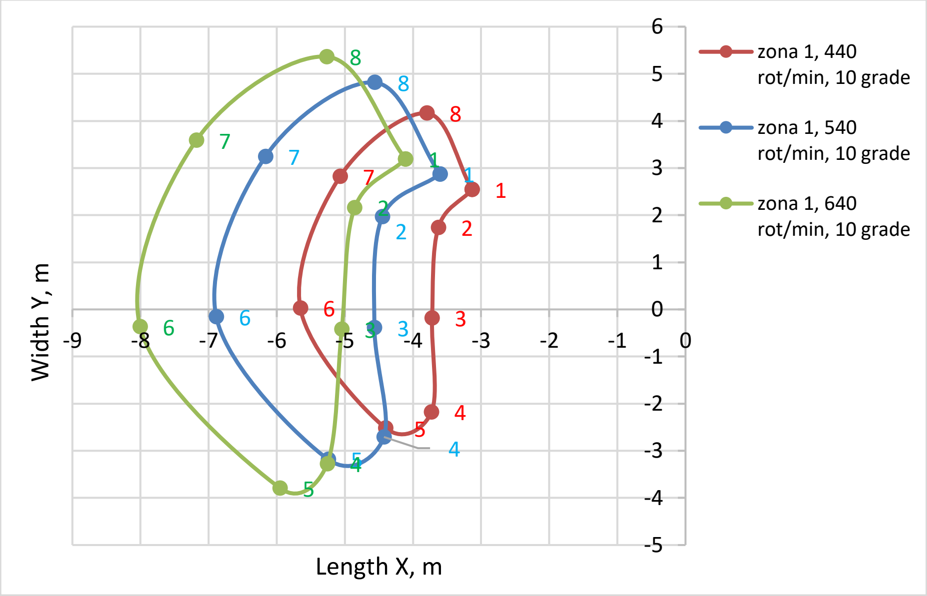


***Fig.5.21.*** The surfaces on which the fertilizer particles detached from the helical coil in zone 1 are thrown, at different speeds and a 10° angle of inclination of the beater

## 5.5. Study of the movement of the fertilizer particle according to the beater angle of inclination

From the numerical simulations presented in this subchapter it resulted that at the 15° inclination of the beater the greatest throwing distance of the particles is obtained, because this inclination corresponds to the horizontal throwing (having $Ø_{max}$=0.345 m). Analyzing the results, one notices a greater distribution width (L=11.2 m) of fertilizers at the inclination α=15° of the beater compared to the width obtained for 10 and 20°.

The surface on which the fertilizer particles are thrown, resulting from the graphical analysis, is 59.5 m$^2$, in case of the beater inclined at an angle of 10°, 71.89 m$^2$ in case of an inclination angle of 20° and it has the maximum value of 86.28 m$^2$ for the beater inclination angle of 15°.

## 5.6. Theoretical spreading on the soil of solid fertilizer

For the beater speed of 540 rpm and its inclination angle of 15°, considered optimal from the previous analysis, the spreading of solid fertilizer on the ground was determined. The specific flow rate of fertilizer, meaning the quantity of material that reaches the soil in one second, collected from 1 square meter, spread in the transverse direction (perpendicular to the forward direction of the machine) is shown in Figure 5.29.

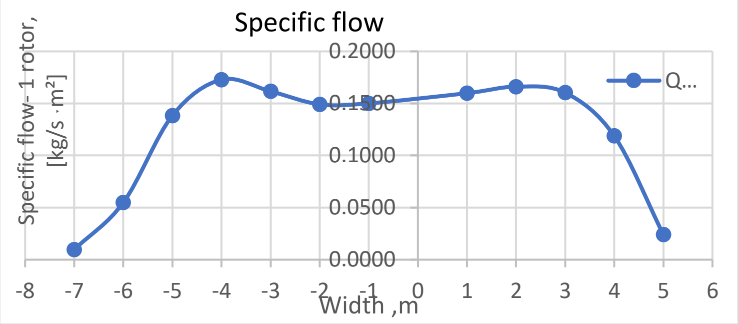


***Fig.5.29.*** Transverse distribution pattern of the specific fertilizer flow. for a single beater at flow rate q=1.53 kg/s

Summing 4 distribution patterns of the specific fertilizer flow, two being in the mirror of the others, we obtained the theoretical distribution that can be obtained by the machine with 4 beaters arranged at equal distances from each other, for the flow of 6 kg/s, beater speed 540 rpm and beater inclination angle of 15° (fig.5.33).

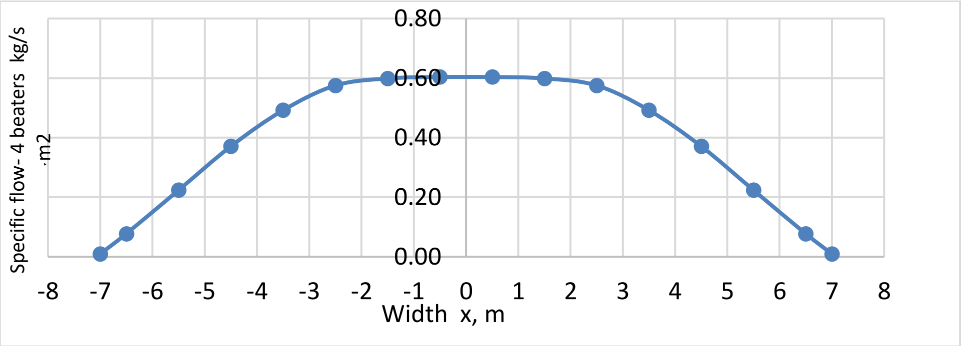


***Fig.5.33.*** Theoretical cross-distribution of specific fertilizer flow made by the 4 adjacent beaters, flow rate Q=6 kg/s, beaters inclination angle 15°

Another way of performing the distribution process of solid fertilizer was also analyzed, taking into account the following hypotheses:

- narrow the interval 1-8 by eliminating the extreme points (5 and 8) in figure 5.21;
- it is assumed a higher concentration of particles released on the interval 250° - 330°, which makes having higher values of the distributed material specific flow on the pattern center. The amount of fertilizer distributed in the extreme area decreased by 70-80% and the amount in the central area increased by 40-50% (green pattern).

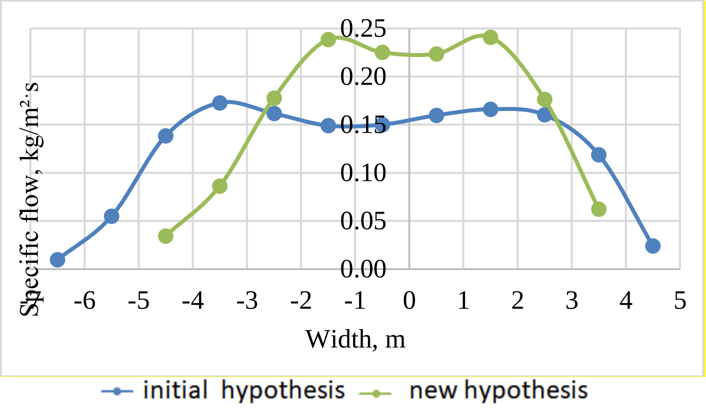


***Fig.5.35.*** Transverse distribution pattern of the specific fertilizer flow, for a single beater at flow rate Q = 1.53kg/s compared to that obtained with the new hypotheses

A higher concentration of material distributed in the central area is observed, which can be compared with the one obtained after physical experiments will be made. Then, it will be possible to observe which of the two variants will be more appropriate.

The calculation was repeated for 4 adjacent beaters arranged at 0.5 m between them and the following distribution variant presented in fig.5.36 resulted. The values of the specific flow rates are aligned with the axis of the machine (halfway between the beater 2 and 3).

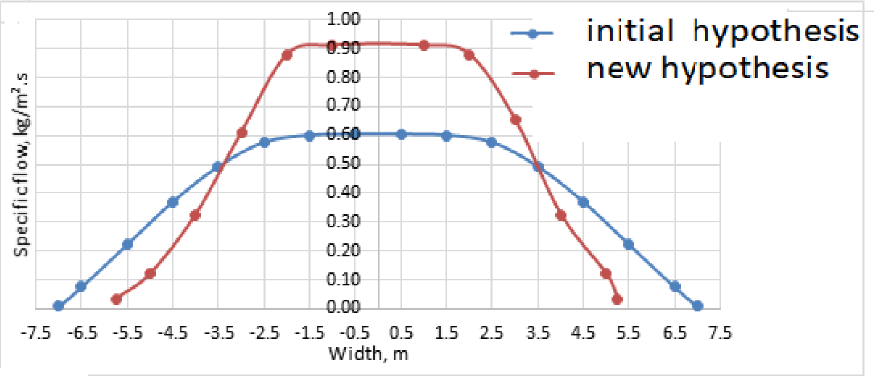


***Fig.5.36.*** Theoretical specific flow for 4 beaters calculated in the 2 theoretical variants , Q=6 kg/s

The maximum width obtained in this variant is cc. 11 m compared to 13 m previously calculated and the maximum value of the specific flow is 0.9 kg/m²·s compared to 0.6 kg/m²·s.

## 5.7. CONCLUSIONS

From the numerical simulations performed using the presented modeling program, the constructive and functional parameters were noticed that directly influence the distribution of organic fertilizers on the soil, implicitly the quality of the fertilization work:

- dimensions of the distribution device (maximum and minimum diameter, pitch and number of helical turns, distance from the ground, length of the beater);
- coefficient of friction between the material and the helical coil;
- initial position of the material on the coil given by the radius $r_0$ and the angle θ;
- beater speed;

- inclination angle of the beater;
- working flow of the machine.

The solid fertilizer particles are thrown at the greatest distance at a beater inclination of 15°, namely 9.59 m, and at the smallest when the inclination angle of the beater is 10°, i.e. 8.11 m. Since a beater inclination of $15^0$ corresponds to the horizontal throwing of fertilizer particles leaving the helical coil at its maximum diameter ($Ø_{max}$=0.345 m) it is recommended to choose beater inclination at 15°. At this inclination, the maximum theoretical distribution width of 13.1 m is also obtained.

The surface on which the fertilizer particles are thrown increases from 59.5 $m^2$ corresponding to the inclination of the beater with an angle of 10° to 71.89 $m^2$ for the angle of 20° and has a maximum value of 86.28 $m^2$ for the beater inclination angle of 15°.

There are single, double and triple covered surfaces so that there will be a maximum amount of fertilizer particles in the central area. A symmetrical soil fertilizer distribution pattern is obtained with minimum values at the extremities and approximately constant in the central area.

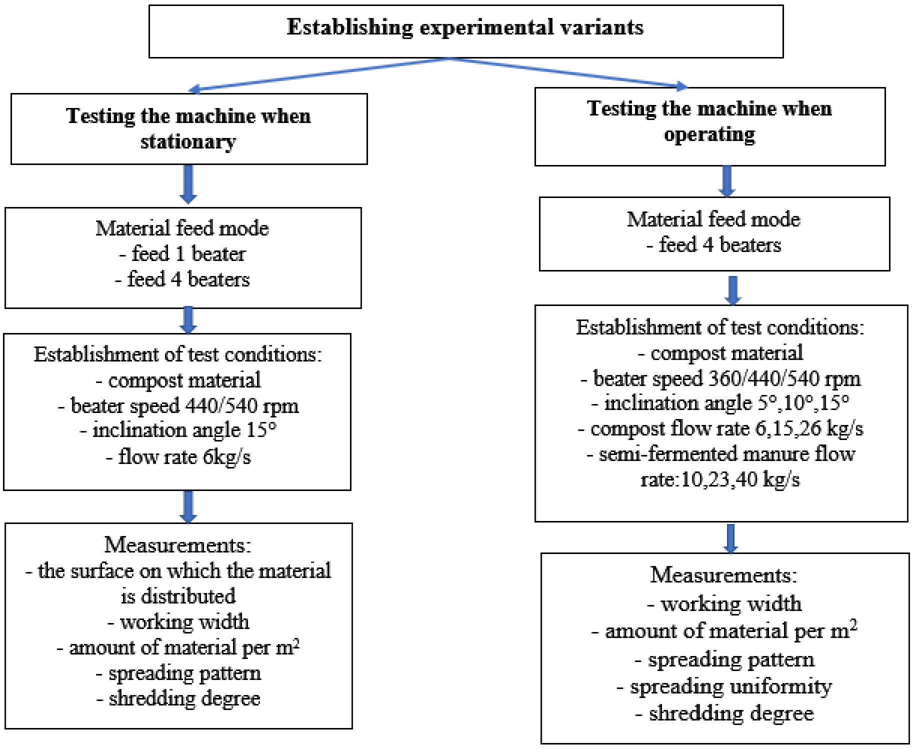
# CHAPTER VI
# EXPERIMENTAL RESEARCH OF THE EQUIPMENT FOR SOLID ORGANIC FERTILIZER SPREADING

## 6.1. Objectives of experimental research

The experimental researches verified the hypotheses that were the basis of the theoretical studies conducted by the author and presented in the previous chapter, regarding the working process of the machine for solid organic fertilizer spreading, allowing the investigation of phenomena for which, in the theoretical research, a series of simplifying hypotheses were made because of the complexity of the phenomena studied.

The main objective of the experimental research was to determine the influence of the constructive and functional parameters of the helical beater on the process of solid organic fertilizer administration in order to optimize the qualitative indices of the process.

## 6.2. Programming the tests



### 6.3. Presentation of the equipment used for the tests

The machine for solid organic fertilizer spreading with helical coil used for carrying out the experimental research (fig.6.2) is intended for fertilizing lowlands with a maximum slope of 6°, for cereal crops, industrial plants, vegetables, etc.

***Fig. 6.2.*** Machine for solid organic fertilizer spreading

### 6.4. Preliminary tests

The ***slope of the two lands*** where the experiments were carried out was determined with a clinometer, which registered 1° and 2° which falls within the maximum of 6° provided in the above-mentioned standard.

The average ***wind speed*** is 1.62 m/s, which is in line with the recommendations of the cited standards.

***Density*** of organic fertilizers: the density of the compost used was $\rho$=510 kg/m$^3$ obtained as an average of the 5 samples of material taken from the manure platform and that of the semi-fermented manure was 800 kg/m$^3$.

The obtained ***humidity*** was 72.33% for compost and 81.73% for semi-fermented manure.

### 6.5. Experimental stationary tests of the helical beater

In the experimental research carried out in the first phase, the aim was to evaluate the working performance of a distribution device which hypothetically had a single beater with helical coil, whose dimensions had been optimized based on mathematical modeling.

From the obtained data it results that the speed of movement of the conveyor varies continuously, from 0.0028 m/s at grade 1 of the flow regulator, to 0.0253 m/s at grade 10 of the flow regulator. The feed rate was between 1.53 and 6.38 kg/s for compost and between 2.4 and 10 kg/s for semi-fermented manure.

The beater was tested for two beater speeds, namely 440 and 540 rpm and the specific flow rates in the transverse direction were obtained for the time of 25 s during the test.

***Table 6.7.*** Transverse distribution of compost made by the beater
at the speed $n_1$= 440 rpm, theoretical flow q=1.53 kg/s and time 25 s

| Material specific flow, [kg/m$^2$·s] | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Width, [m] | -3.5 | -2.5 | -1.5 | -0.5 | 0.5 | 1.5 | 2.5 | 3.5 | |
| Total material amount [kg/m$^2$] | 3.2380 | 4.4415 | 5.5270 | 7.1050 | 6.7380 | 6.3200 | 4.6955 | 1.6160 | *39.681* |
| Specific flow rate [kg/s m$^2$] | 0.1295 | 0.1777 | 0.2211 | 0.2842 | 0.2695 | 0.2528 | 0.1878 | 0.0646 | *1.5872* |

The distribution width made under these conditions is 8 m and it was found that the highest values of material are recorded in the center of the surface and the values are smaller and smaller on the edges, as we approach the extremities.

***Table 6.9.*** Transverse distribution of compost made by the beater
At the speed $n_1$=540 rpm, theoretical flow q=1.53 kg/s and time 25 s

| Material specific flow, [kg/m²·s] | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Width, [m] | -4.5 | -3.5 | -2.5 | -1.5 | -0.5 | 0.5 | 1.5 | 2.5 | 3.5 | |
| Total material amount [kg/m$^2$] | 0.1851 | 1.5125 | 3.9375 | 5.7175 | 6.99 | 7.7 | 7.4661 | 4.8225 | 2.1765 | *40.5077* |
| Specific flow rate [kg/s m$^2$] | 0.0074 | 0.0605 | 0.1575 | 0.2287 | 0.2796 | 0.308 | 0.2986 | 0.1929 | 0.087 | *1.6203* |

The amount of material distributed in 25 seconds was 40.5077 kg which corresponds to a specific flow of 1.6203 kg/s m$^2$.

## 6.6. Stationary tests of the machine for solid organic fertilizer spreading

### 6.6.1. Determining the optimal variant of beater location

Following the experimental tests of the beater, the spreading of the fertilizer on the ground was determined and we decided to choose the most favorable option for the location of the 4 beaters in order to obtain an optimal distribution. Considering that the width of the machine is 2 m, the beaters were placed at a distance of 0.5 m between them, in a transverse plane .

It is observed that for Variant 1 the best values are obtained for the degree of uniformity calculated in two ways (41.65% on the entire distributed width and 73.85  on the actual working width). It turns out that the optimal position of the beaters is variant 1, even if the resulting total distribution width is the smallest (9.5 m)

### 6.6.2. Stationary test of the machine for solid fertilizer spreading

The stationary test of the modified machine, with the beaters mounted in variant 1 was made in the following working conditions: beater speed: n=540 rpm; inclination angle of the beaters: 15°; location of beaters: variant 1; spread fertilizer flow rate: Q=6 kg/s; type of spread material - compost; test duration: t=25 s. The results show a distribution width of 12 m and a concentration of the material in the central area.

## 6.7. Experimental test of the machine for solid organic fertilizer spreading in operation

### 6.7.1. Methodology of experimental tests and performing the tests in operation

During the experimental tests the following parameters were adjusted:

- beater speed: 360, 440 and 540 rpm corresponding to 1500, 2000 and 2200 rpm of the tractor engine speed;
- feed rate for compost (with density 510 kg/m$^3$, humidity 52%): 6, 15 and 26 kg/s corresponding to three speeds of the scraper conveyor, namely 0.006, 0.0143 and 0.025 m/s;

- for semi-fermented manure, material with a density of 800 kg/m$^3$, humidity 75% was used and the working flows at the same speeds of the conveyor were 10, 23 and 40 kg/s;
- vertical inclination angle of the beaters: 5°, 10° and 15°.

The experimental data, which contain 631 records, are presented in tables 6.18-6.23.

### 6.7.2. Experimental determination of energy indices of the machine

#### *6.7.2.1. Traction force*

From the records made for the distribution of manure with a density of 420 kg/m$^3$, with the machine bin loaded with a mass of 2560 kg, values of traction force between 520 ... 740 daN were recorded.

#### *6.7.2.2. Pressure force of machine drawbar on the tractor coupling device*

During the work, when performing the spreading tests on a soil worked by plowing and discing, when distributing the manure with a density of 420 kg/m$^3$, with the machine bin loaded with the mass of 2560 kg, values of the pressure force between 85 ... 620 daN were registered on the coupling device.

#### *6.7.2.3. Resistant torque when acting the beaters*

The recorded values show that the APP-resistant moment of the tractor at beaters idling state had the average value of 57.98 [daN·m] and the maximum moment had the average value of $M_{max\ med}$ =119.19 [daN·m], at the first test recording a maximum $M_{max}$= 144.9 [daN·m].

The torque resistant moment of the tractor power take-off shaft during operation was 19.27 [daN·m].

#### *6.7.2.4. Power required for towing the machine*

The power required for towing the machine in operation, loaded with a payload of 5 tons, traveling at a speed of 8.70 km/h, corresponding to the 3rd gear, operating on stubble has values between 10.42 and 14.31 kW and when the machine work on plowed ground, a traction power between 19 and 27.02 kW is required.

#### *6.7.2.5. Power required to drive the beaters*

The power required to drive the beaters of the machine, when spreading the manure with a density of 420 kg/m$^3$, had values between 5.25 ... 32.22 kW for conveyor speed, for the values of $v_{transporter}$= 0.14 ... 0.86 m/min.

### 6.8. CONCLUSIONS

The experimental tests for stationary machine with the beater inclined by 15° in vertical plane, with the optimal dimensions obtained following the theoretical modeling of the working process, were performed under the following conditions:

- spread fertilizer: compost;
- theoretical feed flow of the beater, q=1.53 kg/s;
- beater speed, $n_1$=440 rpm and $n_2$=540 rpm.

In the experimental research performed when stationary, for beater speed $n_1$= 440 rpm, the results were:

- the amount of material spread in 25 seconds was 39.68 kg, which corresponds to a specific flow of 1.5872 kg/s m$^2$;
- the distribution width was 8 m, the largest amount of material being in the center of the surface and decreasing towards the extremities.

The experimental research performed with the speed of beaters, $n_2$=540 rpm led to the following results:

- the amount of material spread in 25 seconds was 44.48 kg, which corresponds to a specific flow of 1.6203 kg/s m$^2$.
- the spreading width was 9 m, the largest amount of material being in the center of the surface and it decreases towards the extremities.

# CHAPTER VII
# PROCESSING AND INTERPRETATION OF EXPERIMENTAL DATA

Experimental data processing was done in order to obtain the multivariable regression function of polynomial and polytropic form that allow approximating the functional and/or qualitative indices for solid organic fertilizer spreading machine

## 7.1. Processing of experimental data obtained in the stationary test of the beater

The obtained experimental data were used to draw the variation patterns of the specific compost flow, spread both in the transverse direction (fig.7.3) and in the longitudinal direction (fig.7.4), for the two speeds of the beater (440 and 540 rpm).

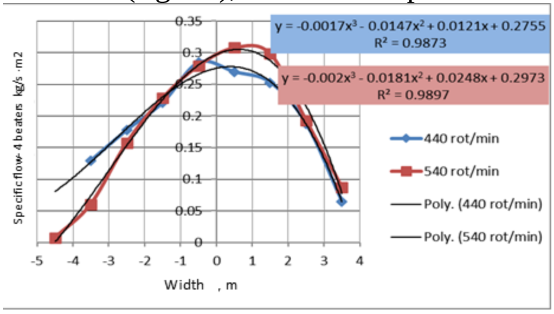


***Fig. 7.3.*** Variation of the specific material flow spread by the beater in the transverse direction

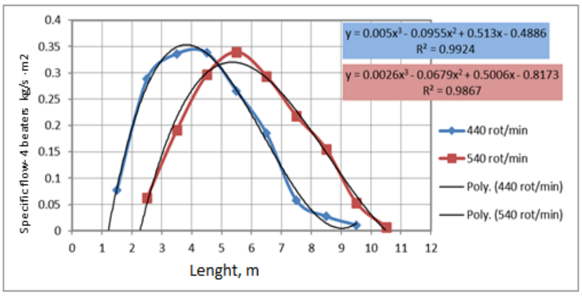


***Fig. 7.4.*** Variation of the specific material flow spread by the beater in the longitudinal direction

Fig.7.3 shows that the width of the surface on which the compost is spread increases from 8 m, for the beater speed of 440 rpm, to 9 m, when the speed is 540 rpm.

Fig. 7.4 shows that the length of the surface on which the compost is spread is 9 m, noticing that at a speed of 540 rpm the compost is thrown further by the beater. It is found that the area on which the compost is thrown increases with increasing speed of the beater.

The specific material flow rate in the transverse plane as a function of the beater speed (*n*) and the throwing distance in the transverse plane ($d_t$) can be calculated with the relation 7.5 [141]. The graphical representation of this function is shown in figure 7.5. The square of the correlation coefficient of R$^2$=0.973.

$$f(n,d_t) = -1{,}204\times10^{-14} + 1{,}1076\times10^{-3}\cdot n - 0{,}034\times d_t - 1{,}016\times10^{-6}\times n^2 + \\ +6{,}845\times10^{-5}\times n\times d_t - 0{,}015\times {d_t}^2 \tag{7.5}$$

The specific flow rate of material in the longitudinal plane as a function of speed (*n*) and the throwing distance in the longitudinal plane ($d_l$) can be calculated with relation 7.6. The graphical representation of this function is shown in figure 7.6. The square of the correlation coefficient of R$^2$=0.912.

$$f(n,d_l) = -2{,}18\times10^{-14} + 1{,}766\times10^{-3}\cdot n - 0{,}049\times d_l - 4{,}113\times10^{-6}\times n^2 \\ + 4{,}225\times10^{-4}\times n\times d_l - 0{,}015\times {d_l}^2 \tag{7.6}$$

After processing the experimental data, a comparison was made between the data obtained experimentally at the beater test and the theoretical data obtained with the mathematical modeling program, presented in Chapter 5, for cross-sectional spreading.

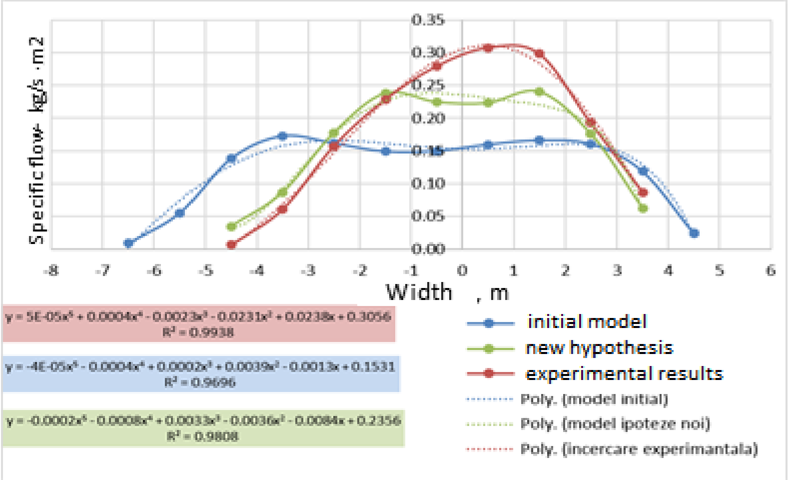


***Fig.7.7.*** Experimental data versus mathematical model, cross-sectional spreading

By comparing the obtained patterns, it is confirmed that the hypotheses made when modeling the working process regarding the higher concentration of particles detached from the range 250°-330° were correct. It is observed, on the graphs, a quantity of fertilizer spread in the extreme area reduced by 70-80% and an increase in the amount of fertilizer spread in the central area.

## 7.2. Processing the experimental data obtained in the test of the solid fertilizer spreading machine when stationary

The obtained data during the stationary test of the solid fertilizer spreading machine, regarding the flow of spread fertilizers, were reported to the unit of time, resulting the specific flow rate, meaning the quantities of material spread in one second per square meter.

It is observed that the highest values are recorded in the center of the surface (maximum value about 0.343 kg/s·m²); in the transverse plane we have a distribution on 12 m and in the longitudinal plane on 11 m.

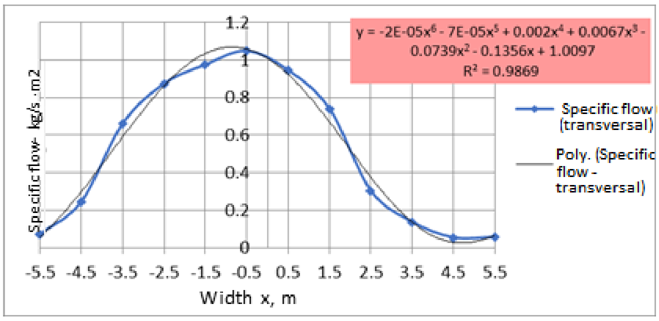


***Fig. 7.9.*** Variation of the specific material flow spread by the machine in the transverse direction

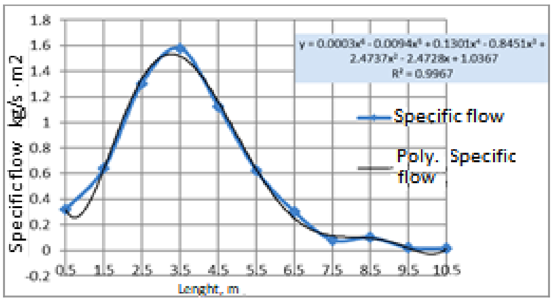


***Fig. 7.10.*** Variation of the specific material flow spread by the machine in the longitudinal direction, when stationary

Using the obtained data, it was verified if the theoretical spreading obtained by summing the data of 4 beaters (variant 1 of beaters location in Chapter VI), for which experimental determinations were made with a single beater, is in accordance with the experimental spreading made by the machine.

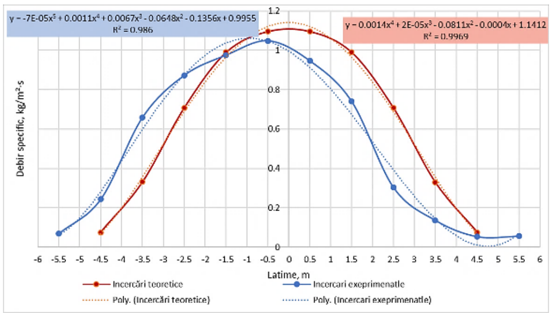


**Fig.7.11.** Comparison of the transverse spreading for *n=540 rpm; theoretical flow q=6 kg/s, theoretical tests-experimental tests*

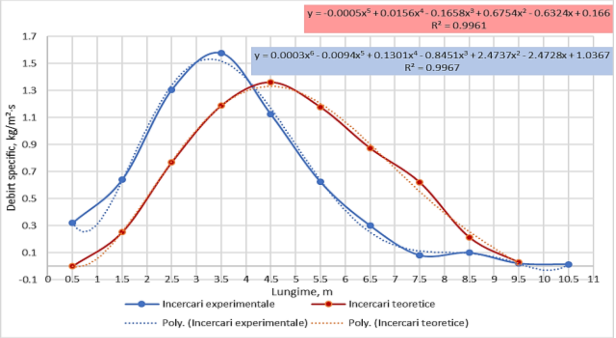


**Fig.7.12.** Comparison of the longitudinal spreading for *n=540 rpm; theoretical flow q=6 kg/s, theoretical tests-experimental tests*

From the graphs it is observed that the calculated theoretical spreading approximates the real spreading obtained when testing the machine.

It can be concluded that, by testing only one rotor, the design of the spreading device can be optimized, so that the best results can be obtained regarding the quality of the fertilization work.

## 7.3. Processing the experimental data obtained in the test of the solid fertilizer spreading machine when operating

### 7.3.1. Determination of the shredding degree of administered material

The determination of the shredding degree is performed by weighing the particles having dimensions smaller than 6 cm and relating their weight to the total weight of the sample.

The shredding degree of the material is suitable if the values of all the samples are over 75%. Samples were analyzed also by size classes, the material being passed through the sieve with hole dimensions of 60, 40, 20, 10 and 5 mm, the results being presented in table 7.7 and represented graphically in fig. 7.15

***Table 7.7.*** The particle size classes of the materials tested at beaters speed n=540 rpm

| Material | Total mass of the sample, [kg] | Size classes [kg] | | | | | |
|---|---|---|---|---|---|---|---|
| | | >60 mm | 40--60 mm | 20-40 mm | 10-20 mm | 5-10 mm | <5 mm |
| Semi-fermented manure | 3.45 | 0.250 | 0.300 | 0.446 | 0.954 | 0.492 | 1.008 |
| Compost | 4.82 | 0 | 0.245 | 0.520 | 0.745 | 1.360 | 1.950 |

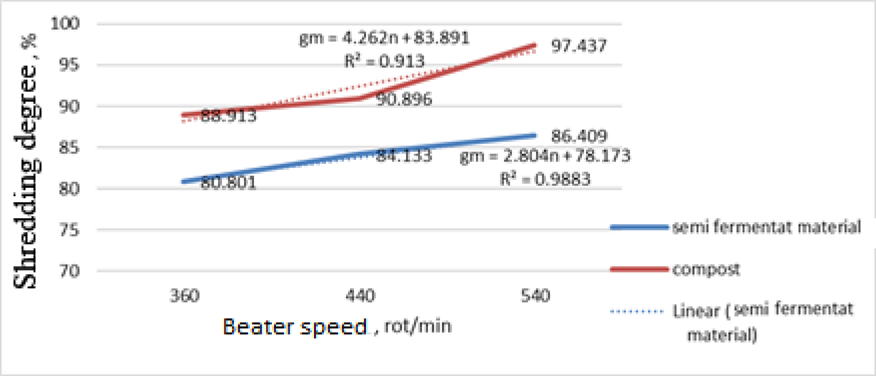


***Fig.7.15.*** Dependence of the shredding degree on the beater speed

If we denote $g_m$, the degree of material shredding and with $n$, the beater speed, then the equations of linear dependencies are written as follows:

$$g_m(n) = 2.804n + 78.173 \tag{7.11}$$

for semi-fermented manure,

$$g_m(n) = 4.262n + 83.891 \tag{7.12}$$

for compost.

### 7.3.2. Determination of multivariable functions for qualitative working indices

#### *7.3.2.1. Algorithm for calculating the coefficients of multivariable functions*

Experimental data processing aimed to obtain multivariable regression functions that have polytropic and/or polynomial form with the help of which to assess the functional and qualitative indices of the organic fertilizer spreading machine.

The form of multivariable functions has the following form:

$$y = f(x_i, a_0, a_i, a_{ii}, a_{ij}) \tag{7.13}$$

which expresses the dependence of the function $y$ on the independent variables $x_i$ and on the constants $a_0$, $a_i$, $a_{ii}$, $a_{ij}$.

**The polynomial regression function**, with three independent variables, has the form [147]:

$$y = a_o + \sum_{i=1}^{3} a_i \cdot x_i + \sum_{i=1}^{3} a_{ii} \cdot x_i^2 + a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3 \tag{7.15}$$

where $x_1$, $x_2$, $x_3$ are the independent variables, $y$ is the dependent variable and $a_0$, $a_i$, $a_{ii}$, $a_{12}$, $a_{13}$ and $a_{23}$ are constants whose value is to be determined.

**The polytropic regression function**, with three independent variables, has the form [147]:

$$y = a_o \cdot x_1^{a_1} \cdot x_2^{a_2} \cdot x_3^{a_3} \tag{7.22}$$

where $x_1$, $x_2$, $x_3$ are the independent variables and $y$ is the dependent variable.

#### *7.3.2.2. Determination of multivariable functions for compost spreading uniformity degree*

In order to determine the uniformity degree of the compost distribution, it was necessary to calculate in advance the working width considered optimal on which the spreading uniformity will be determined. To determine this effective working width, an experiment with successive passes was performed. When spreading the compost (density 510 kg/m³) at the beater speed of n=360 rpm the machine speed $v_m$ = 1 m/s and the flow rate q=26 kg/s, a number of three passes was made.

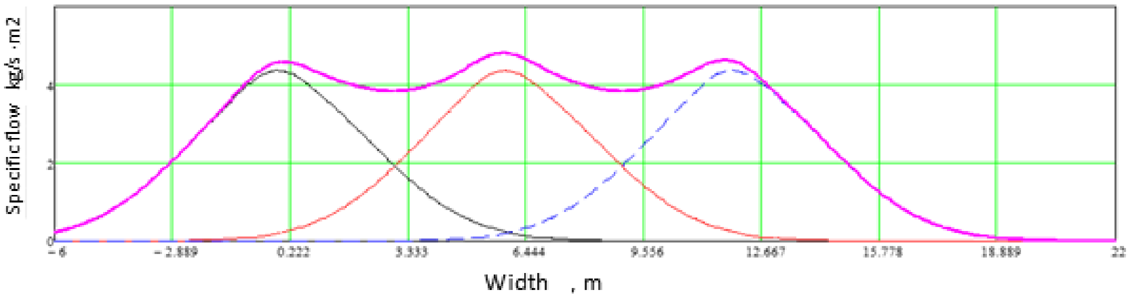


***Fig. 7.19.*** Cross-section distribution of three successive passes for Q=26 kg/s, n=360 rpm, density=510 kg/m³, 6 m between successive passes

***Table 7.9.*** The degree of uniformity achieved for different distances between passes.

| Distance between passes [m] | Average value of the specific flow rate, [kg/m$^2$·s] | Degree of uniformity, [%] |
|---|---|---|
| 9 | 2.858 | 64.13 |
| 8 | 3.118 | 74.69 |
| 7 | 3.266 | 79.63 |
| 6 | 3.811 | 82.69 |

It is observed that as the distance between passes decreases, the uniformity of the spreading increases.

The uniformity degree of the fertilizer spreading according to the working width can be calculated with the relation:

$$G_{ud} = -1.875 \cdot l + 22.063 \cdot l + 17.625 \tag{7.31}$$

where $l$ is the effective width.

To determine the coefficients of the multivariable functions needed to calculate the uniformity degree of compost spreading, three independent variables influencing the dependent variable were chosen, as well as their range of variation:

- *Beater speed: n=360;440;540 rpm;*
- *Beater inclination angle : α=5°, 10°, 15°;*
- *Beater feed flow: Q = 6;15;26 kg/s;*

A minimum, a maximum and a medium level were chosen for each independent variable.

The polytropic function with which the uniformity degree of the spreading can be calculated is:

$$G_{ud} = 68.670694280 \cdot n^0 \cdot \alpha^{0.042717678} \cdot Q^{0.022190391} \tag{7.33}$$

where $G_{ud}$ is the spreading uniformity [%];

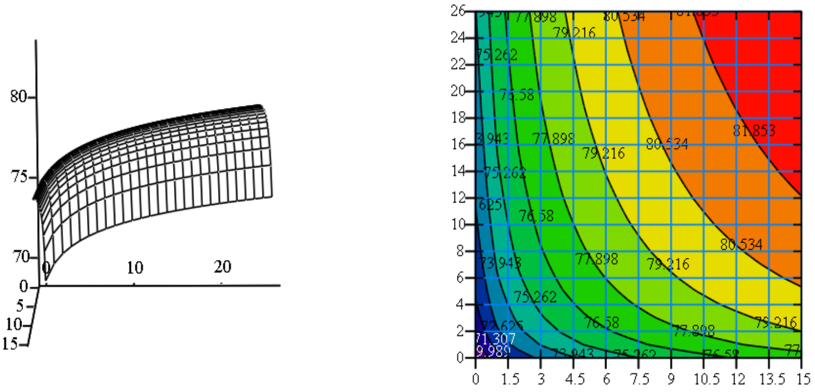
$n$ – beater speed 360-540 [rpm];

$\alpha$ – inclination angle of the beaters 5-15 [°]

$Q$ – beater feed flow 6-26 [kg/s]

It is observed that the deviation between the measured and calculated values is maximum 6.563% which shows that the form of the function is quite precise.

Fig.7.22 shows graphically the uniformity degree depending on the inclination angle of the beaters and the flow of spread compost.



Gu Gu

***Fig.7.22***. Graphical representation of the uniformity degree Gu = f (α, Q) when spreading compost

The function of polynomial form, for calculating the uniformity degree of the compost spreading, is:

$$G_{ud} = 80.285 + 0.013 \cdot \alpha - 0.491 \cdot Q - 2.264 \cdot 10^{-3} \cdot \alpha^2 + 0.023 \cdot \alpha \cdot Q + 0.013 \cdot Q^2 \qquad (7.35)$$

It is recommended that the inclination of the beaters be 15° because it ensures maximum uniformity degree for compost spreading (80.219% -82.972%).

### *7.3.2.3. Determination of multivariable functions for semi-fermented manure spreading uniformity degree*

In order to determine the coefficients of the multivariable functions for semi-fermented manure, the following independent variables were considered that influence the dependent variable, but also the range of their variation:

- *Beater speed: n = 360;440;540 rpm;*
- *Beater inclination angle: α=5°, 10°, 15°;*
- *Feed flow: Q =10;23;40 kg/s*

The polytropic function obtained is:

$$G_{ud} = 62.79787 \cdot n^0 \cdot \alpha^{0.05216} \cdot Q^{0.04832} \qquad (7.42)$$

where $G_{ud}$ is the spreading uniformity [%];
$n$ – beater speed 360-540 [rpm];
$\alpha$ – inclination angle of the beaters 5-15 [°]
$Q$ – beater feed flow 10-40 [kg/s]

It is observed that the deviation between the calculated and measured values of the uniformity degree is maximum 4.294% which shows that the form of the function is quite precise.

Fig. 7.25 shows graphically the uniformity degree of semi-fermented manure spreading.

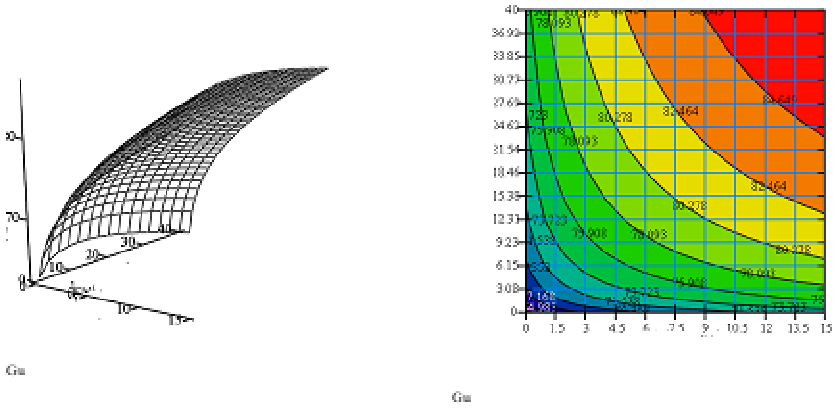


***Fig.7.25.*** Graphical representation of the uniformity degree $G_{ud} = f(\alpha, Q)$ when spreading semi-fermented manure (polytropic function)

The polynomial form of the function for calculating the uniformity degree of the semi-fermented manure spreading is:

$$G_{ud} = 82.037 - 0{,}304 \cdot \alpha - 0.041 \cdot Q + 0.042 \cdot \alpha^2 - 0.022 \cdot \alpha \cdot Q + 6.556 \cdot 10^{-3} Q^2 \qquad (7.44)$$

It is recommended that the inclination of the beaters of the solid fertilizer spreading machine be 15° because it ensures maximum degree of uniformity (82.694% - 86.439%).

#### *7.3.2.4. Determination of multivariable functions for the spread fertilizer rate*

In order to determine the coefficients of the multivariable functions for the calculation of the spread fertilizer rate, the following independent variables and their variation interval were considered:

*Beaters feed flow rate: Q = 6;23;40 kg/s;*
*Tractor working speed: v = 2; 6; 10 m/s;*
*Effective spreading width: L = 6;7.5; 9 m.*

The inclination angle of the beaters was $15^0$ and the speed n=540 rpm.

***Table 7.18.*** Experimental test program to determine the spread fertilizer rate

| Den. no. | Feed flow rate, Q[kg/s] | Working speed [km/h] | Width [m] | Rate [t/ha] |
|---|---|---|---|---|
| 1 | 6 | 2 | 6 | 18 |
| 2 | 40 | 2 | 6 | 120 |
| 3 | 6 | 10 | 6 | 3,6 |
| 4 | 40 | 10 | 6 | 24 |
| 5 | 6 | 2 | 9 | 12 |
| 6 | 40 | 2 | 9 | 80 |
| 7 | 6 | 10 | 9 | 2,4 |
| 8 | 40 | 10 | 9 | 16 |
| 9 | 6 | 6 | 7.5 | 4,8 |
| 10 | 40 | 6 | 7.5 | 32 |
| 11 | 23 | 10 | 7.5 | 11 |
| 12 | 23 | 2 | 7.5 | 55 |
| 13 | 23 | 6 | 7.5 | 15 |
| 14 | 23 | 6 | 7.5 | 23 |
| 15 | 23 | 6 | 7.5 | 18 |
| 16 | 23 | 6 | 7.5 | 20 |
| 17 | 23 | 6 | 7.5 | 19 |

| Den. no. | Feed flow rate, Q[kg/s] | Working speed [km/h] | Width [m] | Rate [t/ha] |
|---|---|---|---|---|
| 18 | 23 | 6 | 7.5 | 17 |

The polytropic function that allows the calculation of the administered rate is:

$$N = 36.7399 \cdot Q^{0{,}9996} \cdot v^{-1} \cdot L^{-1{,}01} \qquad (7.51)$$

where $N$ is the fertilizer rate per hectare [t/ha];

$Q$ – beaters feed flow rate 6 - 40 kg/s;

$v$ – working speed 2 - 10 m/s;

$L$ – working width 6 - 9 m.

It is observed that the deviation of the values of the rate of distributed fertilizer calculated, compared to the experimental values is of maximum 8.126% which shows that the form of the function is precise.

For the optimal working widths (table 7.14), for which the degree of uniformity of the fertilizer distribution is maximum, the polynomial function that allows the calculation of the administered rate is:

$$N = 7.796 + 3.242 \cdot Q - 8.028 \cdot v - 3.156 \cdot 10^{-3} \cdot Q^2 - 0.0279 \cdot Q \cdot v + 0.753 \cdot v^2 \qquad (7.52)$$

The multiple correlation coefficient is $R^2$=0.958.

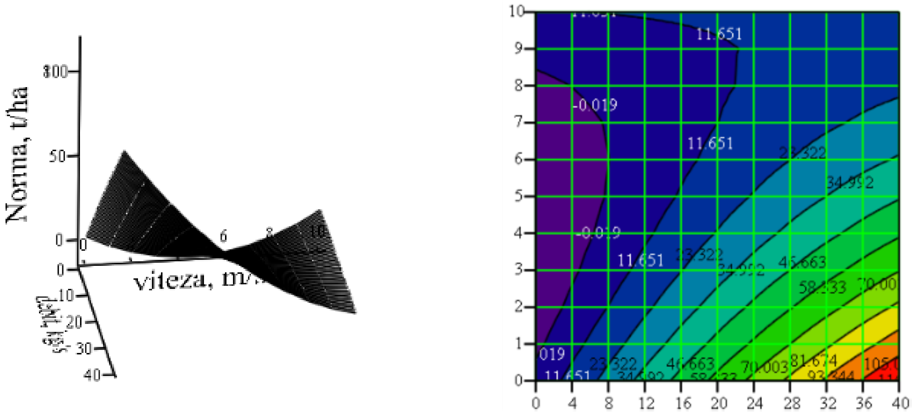


***Fig.7.28.*** Graphical representation of the spread fertilizer rate

Using the relation 7.52 and the graphical representation in fig.7.28, for an imposed rate, the spread fertilizer flow $Q$ and the working speed of the machine $v$ can be determined.

Fig. 7.29 shows graphically the variation of the feed rate $Q$ depending on the speed of the scraper conveyor that feeds the beaters for the two types of fertilizer used in the experimental tests (Annex 7.7).

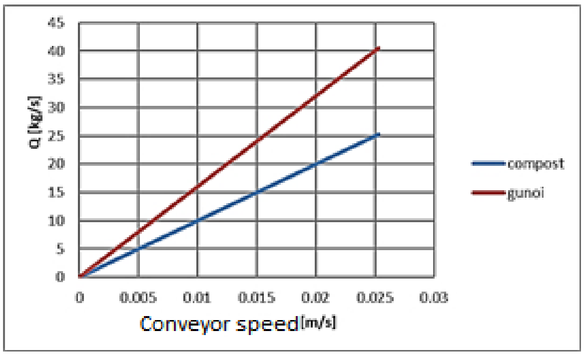


***Fig.7.29.*** Feed rate variation depending on scraper conveyor speed

For a known flow rate *Q* can be determined, from fig.7.29, the speed of the scraper conveyor in case of compost or semi-fermented manure spreading.

### 7.4. Conclusions

Between the theoretical transversal spreading made with the modeling program and the spreading obtained in the experimental tests, for the speed n=540 rpm and the flow rate Q=6 kg/s, there is a great similarity which confirms the hypotheses made when modeling the working process of the beaters.

In the test of solid fertilizer spreading machine when stationary, for the beater speed n=540 rpm and the flow rate Q=6 kg/s, the specific flow rate of the fertilizer spread in the transverse direction has a length of 12 m and the fertilizer spread in the longitudinal direction has a length of 11m, the maximum value being at a distance of approximately 3.5m from the beaters.

The shredding degree of the compost increases from 88.913% at the speed of 360 rpm to 97.437% at the speed of 550 rpm and for semi-fermented manure it increases from 80.801% at the speed of 360 rpm to 86.409% at the speed of 550 rpm.

The multivariable functions obtained for calculating the spreading uniformity degree and the imposed rate are quite accurate because the values of the deviations between the measured and the calculated data are very small.

# CHAPTER VIII
# GENERAL CONCLUSIONS, CONTRIBUTIONS, PERSPECTIVES

### 8.1. General conclusions

- Organic fertilizers used in agriculture are: manure, compost, sewage sludge, poultry manure, biochar, green manure, vegetable waste.
- Within the doctoral thesis, **a mathematical model was developed for the study of the helical beater** arranged in inclined plane, at various angles, in order to determine the constructive, functional and energetic parameters, optimal in terms of achieving the optimal qualitative indices of the fertilization, according to agrotechnical requirements
- From the numerical simulations performed with the presented modeling program, the constructive and functional parameters that directly influence the spreading of organic fertilizers on the soil can be noticed:
  - dimensions of the spreading device (maximum and minimum diameter, helical coil pitch, distance from the ground, beater length);
  - coefficient of friction between the material and the coil;
  - the position of detachment of the material from the coil;
  - beater speed;
  - beater inclination angle;
- Performing **stationary tests of the beater** inclined 15° to the vertical axis: beater speed n=540 rpm, the amount of material spread in 25 seconds was 40.51 kg, which corresponds to a specific flow of 1.6203 kg/s m$^2$. In this case, the spreading width was 9 m, the largest amount of material being in the center of the surface, decreasing towards the extremities.
- In variant 1 of placing the four beaters, the spreading uniformity degree was maximum, this being the recommended variant.
- Between the theoretical transversal spreading, obtained with the modeling program, and the spreading obtained in the experimental researches, for the speed n=540 rpm

and the flow rate Q=6 kg/s, there is a great similarity, which confirms the hypotheses made when modeling the process.

- In the machine test, when stationary, for the speed n=540 rpm and flow rate Q=6kg/s, a total working width of 12 m is obtained in the transverse direction symmetrical to machine axis, and in the longitudinal direction the material is thrown up to a distance of 11m.
- Analyzing the theoretical spreading made by the machine equipped with 4 beaters, for different working speeds of the machine, it was observed that increasing the working speed, the specific flow of fertilizer that reaches the ground decreases.
- It is recommended to incline the beaters of the fertilizer spreader to $15^0$, considering that the research results showed a degree of uniformity between 80.22 ... 82.97%, when distributing the compost and 80.84 ... 86.44 %, when distributing semi-fermented manure.
- The multivariable functions obtained for calculating the spreading uniformity degree and the imposed rate are quite accurate because the values of the deviations between the measured and the calculated data are very small.
- For the spreading of the studied solid organic fertilizers, the following recommendations are made:
    - the optimal beater speed is 540 rpm;
    - the inclination angle of the beaters should be 15°;
    - working flows should be between 6 and 40 kg/s.

## 8.2. Personal contributions

As a result of the theoretical and experimental research carried out in this thesis, the following contributions can be deduced:

- Carrying out a synthesis on the main types of organic fertilizers used in agriculture, highlighting the physical and mechanical properties that influence the spreading process with specific equipment, by studying an extensive bibliography (scientific articles, official documents, books, etc.).
- Carrying out a synthesis regarding the main technical equipment for solid organic fertilizer spreading, identifying the main constructive characteristics and possible adjustments that influence the process of their spreading;
- Realization of a mathematical model and a modeling program of the helical beater working process and of a series of numerical simulations by which it was allowed to determine the influence of the constructive and functional parameters on the qualitative working indices;
- Establishing the constructive and functional parameters of the spreading device, consisting of the beater with helical coil inclined to the vertical axis, the number of beaters, the distance between them, so that the qualitative indices of the working process are optimal;
- Elaboration of the methodology necessary to perform experimental tests on the spreading of several types of solid organic fertilizers;
- Determining the properties of the fertilizers used in experiments and the working conditions;
- Determining the trajectories of fertilizer particles both on the helical coil of the beater and in space up to the intersection with the ground, in different working conditions;
- Determining the stagnation time on the beater, until detachment, but also the time until landing on the ground, of the material particles;

- Determining the specific flows of material that reached the ground tested under various conditions of the working part (helical beater), but also of the fertilizer spreading machine;
- Processing the experimental data and obtaining multivariable regression functions of polynomial and polytropic form that allow calculating the spreading uniformity degree, the degree of material shredding and the possible rate obtained with the tested equipment;
- Following the theoretical and experimental studies, a series of recommendations were made for specialists in the field of designing machines for solid organic fertilizer spreading;
- Theoretical and experimental research, conducted in the field of fertilization, were widely disseminated by developing and publishing a number of 19 scientific papers published in journals, as well as the proceedings of national and international conferences and their presentation, in national and international scientific events, as author and co-author.

### 8.3. Future research

- Knowing the current trend of transition to smart agriculture, it is proposed to equip the spreader machines with variable application fertilization technology, which ensures that the incorporation of fertilizers is made exactly in the areas where it is needed, thus amplifying their effect.
- The mathematical model proposed in the paper can be improved by considering some omitted elements such as: the influence of friction with air, particles' mass or shape;
- Another variant of simulation of the material spreading on the ground can be performed in specific programs of CFD fluid mechanics, the material can be considered light fluid (no weight), ideal fluid (no viscosity), incompressible fluid, where the volume of a determining mass is constant or real fluid (compressible and viscous).
- Optimizing the process of organic fertilizer spreading and obtaining maximum uniformity, using mathematical relations and experimental results in this paper.
- Experimenting with other types of materials used for soil fertilization with other physical and mechanical characteristics than those used in the work.
- Development of a technology for pelletizing organic fertilizers, which would involve pressing and drying them, this way considerably reducing the volume and odors and spreading them on the ground would be simplified.

## SELECTIVE BIBLIOGRAPHY

[57] Thirion F., Chabot F. ,Andler D. "Physical characterization of animal manure," *98-FAO:8th,* pp. 457-468, 1997.

[58] *Lague C., Agnew J., Roberge M., Landry H.,* "Systems Engineering for Handling and Land Application of Solid and Semi-solid Livestock Manure," Department of Agricultural & Bioresource Engineering Prairie Swine Centre Inc., Saskatoon, Saskatchewan, Canada, 2005.

[63] *Landry H., Lague C., Roberge M.,* "Physical and rheological properties of manure products," *Applied Engineering in Agriculture,* vol. 20, no. 3, p. 277-288, 2004.

[64] *Frick R., Heusser J. , Shick M.,* "Technique d'épandage des engrais à base de déchets et de fumier de stabulation libre : Qualité du travail et adéquation de différents systèmes d'épandage.," Rapport FAT No. 560, 2001.

[66] *Landry H.,* Numerical modelling of machine-product interactions in solid and semi-solid manure

handling and land application, PhD. Thesis, Canada: University of Saskatchewan, 2005.

[67] *Malgeryd J., Watterberg C,* "Physical Properties of Solid and Liquid Manures and their Effect on the Performance of Spreading machines," *Journal of Agricultural Engineering Research,* vol. 64, no. 4, p. 289-298, 1996.

[69] *Scripnic V., Babiciu P.,* Agriculural machinery, Bucharest : Ceres Printing House, 1979.

[88] http://mixerfeeders.squarespace.com, [Interactiv].

[89] Babaryka S.F., The substantiation of parameters of machine's working bodies for surface applying the sapropels into the soil, Phd. Thesis, Ukraine: Technical University from Ternopil, 2010.

[102] *Turbin B.G., Lurie A.B., Grigoriev C.M.,Grigoriev C.M., Ivanovici E.M., Melnicov C.B.,* Agriculural machinery.Theory and technological calculation, Leningrad: Mașimostroeni Printing House, 1967.

[107] ***Ștefan V.****, David L., Popa L., Ciupercă R., Zaica A., Nedelcu A., Anghelet A.,* "Study of the particle motion on a manure fertilizer spreader," *UPB Scientific Bulletine,* vol. 81, nr. 4, 2019.

[113] *Landry H., Thirion F., Laguë C., Roberge M.,* "Numerical modeling of the flow of organic fertilizers in land application equipment," *Computers and Electronics in Agriculture,* vol. 51, nr. 1-2, pp. 35-53, 2006.

[118] ***Ștefan V.****, Cârdei P., Vlăduț N.V., Popa L., Ciupercă R., Ungureanu N.,* "Mathematical model for particle motion applied on a manure spreading apparatus used în environmentally friendly technology," *Environmental Engineering and Management Journal, Gheorghe Asachi Technical University, Iași,* vol. 17, pp. 217-227, Impact factor 1.096, 2018.

[119] *Cârdei P.,* ***Ștefan V.****, Matache M.G.,* "Mathematical models for calculating the qualitative parameters of organic fertilizer machines," în *Research people and actual tasks on multidisciplinary sciences*, Lozenec, Bulgaria, 2019.

[143] *Păunescu I., David L.,* "Basics of experimental research on biotechnical systems", Bucharest: Printech Printing House,, 1999.