INFLUENCE OF THE MANURE SPREADING MACHINES' WORKING PARAMETERS ON THE QUALITATIVE PERFORMANCES OF THE FERTILIZATION PROCESS
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INFLUENTA PARAMETRILOR REGIMULUI DE LUCRU AL MASINILOR DE FERTILIZARE ORGANICĂ, ASUPRA PERFORMANŢELOR CALITATIVE ALE PROCESULUI DE FERTILIZARE

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ABSTRACT

This paper presents results regarding the variation of the qualitative parameters of the organic fertilizer machines according to the parameters of the material and control, of the working regime. These results are obtained from mathematical models that interpolate experimental data. The functions thus obtained allow the investigation of the existence of optimal working regimes and, if confirmed, the identification of these operating modes (of the optimal control parameter set: rotational speed, inclination angles, flow rate, etc.). The analysis can be extended to other types of agricultural machinery for the administration of solid organic fertilizers, chemicals or amendments.

ABSTRACT

Această lucrare prezintă rezultatele privind variația parametrilor calitativi ai mașinilor de administrat îngrășăminte organice solide în funcție de caracteristicile materialului și de parametrii regimului de lucru. Aceste rezultate sunt obținute prin modele matematice care interpolează date experimentale. Funcțiile astfel obținute permit investigarea existenței unor regimuri de lucru optime și, dacă se confirmă, identificarea acestor moduri de funcționare (a setului optim de parametri de control: viteza de rotație, unghiurile de înclinare, debitul etc.). Analiza poate fi extinsă la alte tipuri de mașini agricole pentru administrarea de îngrășăminte organice solide, substanțe chimice sau amendamente.

INTRODUCTION

It is well known that the manure and others by-products can be recycled by soil-crop systems, being a valuable source of nutrients and also improve the soil physical structure. Because an uncontrolled fertilization can become a source of diffuse pollution by contamination of groundwater and watercourses, that's why the land application should be as accurate and even as possible *(Ştefan V., Cârdei P., Popa L., 2019; Ştefan V., Ciupercă R., Popa L. et al., 2015)*

The available machines designed to handle and land apply solid and semi-solid organic fertilizers do not have efficient application rate control systems and exhibit uneven longitudinal and transversal product distribution *(Cârdei P., Ştefan V., Matache M.G., 2019; Duhovnik J., Benedičič J., Bernik R., 2004; Landry H., Lague C., Roberge M., 2004)*. The interaction between machine and manure pieces taking into consideration the manure physical and rheological properties were studied and the results are shown in (Landry H., Thirion F., Lague C., Roberge M., 2006; *Ma Yibo, Yu Zhenjun, Zhang Yuanyuan et al, 2018*, *Ştefan V., Ciupercă R., Popa L. et al., 2015).*

The prognosis of the behavior of an agricultural machine in the process of working is one of the major objectives of conception, design and testing activities characteristic of obtaining a good quality product. Within these activities, in their modern vision, the modelling of the agricultural machine in the process of working as a system, is a common work option. This modelling requires parameter inventories (inputs, outputs, control and parameter settings). It is often difficult to choose a set of properties that will make the behaviour of the virtual material similar to that of the physical material. (*Duhovnik J., Benedičič J., Bernik R., 2004*; *Miclet D., Piron E. et al., 2010*; *Ştefan V., Ciupercă R., Popa L. et al. 2015*; *Ștefan V., Cârdei P. et al., 2018).*

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In research done by *Oida A., Schwanghart H. et al. (1998)* a series of parameters were investigated (Young's modulus, friction coefficient, normal and shear strength of the contact bonds as well as normal and shear strength of the contact bonds). All these parameters influenced the apparent cohesion. The methods presented have the potential to be extended to any type of solid organic fertilizers.

In the paper of *Miclet D., Piron E. et al., (2010),* the longitudinal distribution of a vertical manure spreader is optimized by controlling the speed of the scraper conveyor regarding the height of the gate during the hopper unloading. It is technically based on an electronic and automatic adaptation of the scrapper conveyor speed in regard with the alimentation section of the beaters and the spreader velocity into the field.

In *Landry H., Thirion F. et al., (2006)* the authors applied a DEM to describe the manure flow of two types of composts. The first model was capable to predict the ground distribution of the product along with the power requirements of the beaters and discharge conveyor. Scaled numerical models were developed to study the effect of the vertical position of a flow-control gate and the type of compost spread on the discharge flow and energy requirements. The proposed models were validated against experimental results obtained using a full-size manure spreader. along with the power requirements of the beaters and discharge conveyor. Scaled numerical models were developed to study the effect of the vertical position of a flow-control gate and the type of compost spread on the discharge flow and energy requirements. The models were validated against experimental results obtained using a full-size manure spreader.

MATERIALS AND METHODS

The aim of this article consists in linking the mentioned parameters (*rotational speed, inclination angles, flow rate, drive speed*) by mathematical relations that can then be processed in order to control the optimal system (the agricultural machine in the present case). There are some relations between the involved parameters that can be establish theoretically. These relations, however, are often insufficient to solve various problems. For this reason, new relations between system parameters must be deduced, using the experimental pathway combined with statistics and statistical modelling. The results presented in this paper are obtained through the statistical modelling of the experimental results. These results allow the estimation, adaptation and improvement of the quality performance of an agricultural machine - the fertilizer machine with vertical beaters. The experimental results obtained for the MG5 fertilization machine and the working conditions were exposed in *Ştefan V., Cârdei P., Popa L. (2019)*.

To obtain experimental relations through statistical modelling between the quality parameters of the work process of the MG 5 machine and the input and control parameters, we used the experimental data processed in the research of *Ştefan V., Cârdei P., Popa L. (2019)*. Then these data were interpolated by Gaussian functions through which they were found the effective work width and actual effective norm.

Parameters that have been used to achieve the results outlined in this paper are listed in Table 1. Also, in Table 1 are given the physical dimensions of the parameters involved and taken into consideration in the statistical model of the work process of the MG 5 machine *(Miclet D., Piron E. et al,* 2010; *Oida A., Schwanghart H., et al., 1998*; *Popa L., Pirnă I. et al., 2008; Ştefan V., Cârdei P., Popa L., 2019).*

A view from the rear of the fertilizer machine highlights the rotors of the spreading device, Fig. 1.
The aggregate at work, during the experiments, can be seen in Fig. 2.

Fig. 1 - Organic fertilizer spreader MG 5

Fig. 2 - Organic fertilizer spreader MG 5, during work

Table 1

The main parameters of the working process of the organic fertilizer machine

Parameter name	Notation	M	L	T
Rotors speed	ω	0	0	-1
Conveyor flow	q	1	0	-1
The angle of inclination of the rotors	β	0	0	0

Table 1
(continuation)

Parameter name	Notation	M	L	T
Density of scattered material	ρ	1	-3	0
Linear density of scattered material	σ	1	-2	0
Drive speed	v	0	1	-1
Effective working width	B_{ef}	0	1	0
Effective working norm	N_{ef}	1	-2	0

By Gauss interpolation of the linear density of the scattered material, relative to the normal coordinate at the trajectory of the aggregate, functions are obtained which help to find the effective work width and the effective norm applied. There are obtained 18 tables of the type of table 2, resulting in the actual working widths, B_{ef} and the actual norm applied, N_{ef} as functions of the input, ρ and control parameters ω,q,β,v of the working regime.

Table 2

The qualitative functions values (effective work width and effective norm) for various values of the input and control parameters main parameters of the working process of the organic fertilizer machine

ω	β	ρ	q	min (σ)	max(σ)	$mean(\sigma)$	$std(\sigma)$	$kurt(\sigma)$	$skew(\sigma)$
530	5	510	6	0.049	1.347	0.684	0.413	-0.775	0.247
			15	0.056	3.134	1.444	1.297	-2.245	0.091
			26	0.156	3.94	2.379	1.179	-0.322	-0.67

In order to know which independent variables (input and control parameters) have greater influence on the dependent variables (working width and norm), the correlations between the two types of variables are calculated. The correlation values are given in Table 3.

Table 3

The correlation between the output (qualitative) parameters of the system (the fertilizer machine with the material used) and the input and control parameters

Parameter	q	ρ	ω	β
B_{ef}	0.425	0.609	-0.233	-0.219
$\boldsymbol{N_{ef}}$	0.931	0.37	0.088	-0.824
$\boldsymbol{B_{efexp}}$	0.394	0.564	-0.194	-0.194
$\boldsymbol{N_{efexp}}$	0.931	0.357	0.084	-0.835

It can be seen that the effective working width and the effective norm, either calculated by interpolation or directly from the experimental data, are most dependent on the fertilizer flow and mass density of this.

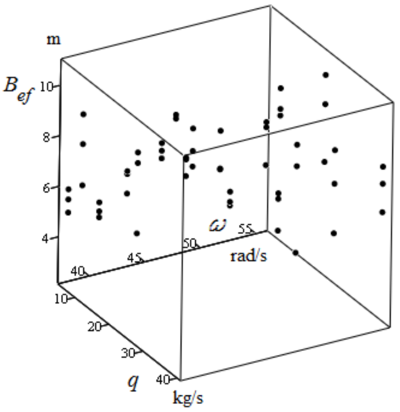

Fig. 3 - Distribution of effective work width values (interpolated variant) in relation to material flow and rotation speed of rotors

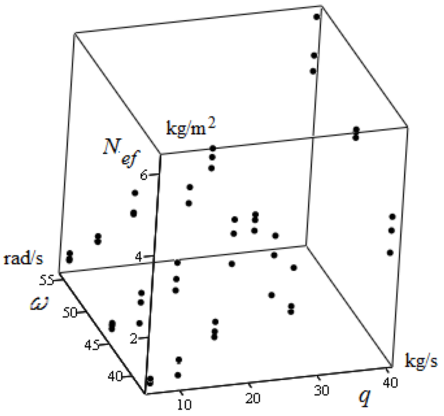

Fig. 4 - Distribution of effective norm values (interpolated variant) in relation to material flow and rotation speed of rotors

RESULTS

Using the polynomial interpolation programs of *MathSoft Engineering & Education, Mathcad User's Guide with Reference Manual Mathcad 2001 Professional,* the expressions of effective working width dependence on independent variables are obtained. First degree polynomial or linear regression has the next explicit form.

$$B_{ef}(q,\rho,\omega,\beta) = 6.958 - 0.024q + 0.007156\rho - 0.051\omega - 8.378\beta \tag{1}$$

The second-degree polynomial which interpolating the effective working width has the explicit form:

$$B_{ef}(q,\rho,\omega,\beta) = 79.48 + 0.07q - 0.227\rho + 0.141\omega - 70.386\beta + 0.0003917q\rho - 0.005054q\omega + 0.164q\beta + 0.0001737\rho\omega + 0.036\rho\beta + 0.117\omega\beta - 0.002775q^2 + 0.0001602\rho^2 - 0.002422\omega^2 + 100.439\beta^2 \quad (2)$$

The graphical representation of the actual working width dependence on the flow and mass density of the scattered material is given in Fig. 3 and 4.

In a similar way, first-degree and second-degree polynomial functions are established modelling the experimental data (previously undergoing a training process). The expressions of the two functions are given in eq. (3) and (4).

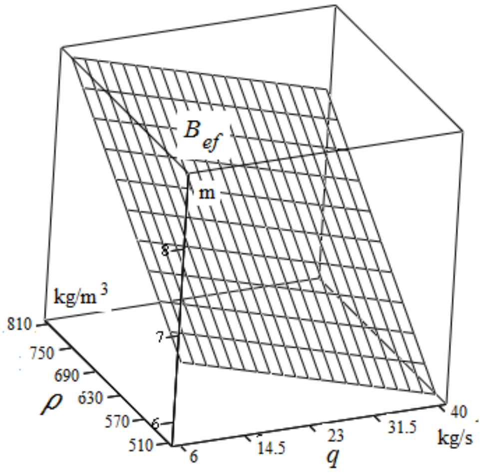

Fig. 5 - Effective work width as a partial function of material flow and material density - first degree polynomial interpolation

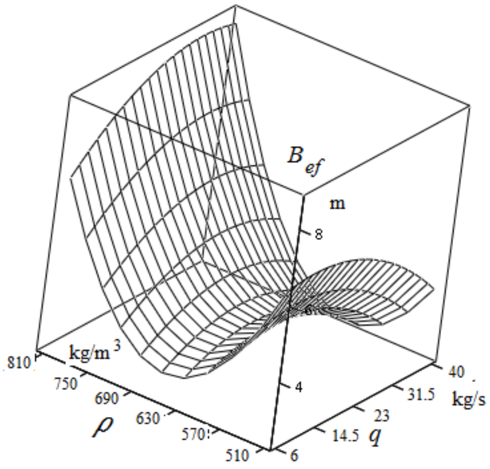

Fig. 6 - Effective work width as a partial function of material flow and material density - second degree polynomial interpolation

$$N_{ef}(q,\rho,\omega,\beta) = -1.535 + 0.144q - 0.0008054\rho - 0.017\omega - 4.888\beta \quad (3)$$

$$N_{ef}(q,\rho,\omega,\beta) = 37.535 - 0.704q - 0.056\rho - 0.196\omega - 79.893\beta + 0.0001992q\rho + 0.012q\omega + 0.083q\beta - 0.000351\rho\omega + 0.019\rho\beta + 1.382\omega\beta + 0.001507q^2 + 0.00005072\rho^2 - 0.0003256\omega^2 - 18.402\beta^2 \quad (4)$$

In Fig. 5 and 6 are given graphical representations of the first degree interpolation polynomials and the second for the effective norm as flow and density functions of the scattered material. The graphic representations of Fig. 3-6, were made for constant rotational speeds of the rotors, $\omega = 46.426\,rad/s$, respectively the angle of inclination of the rotors, $\beta = 0.75\,rad$.

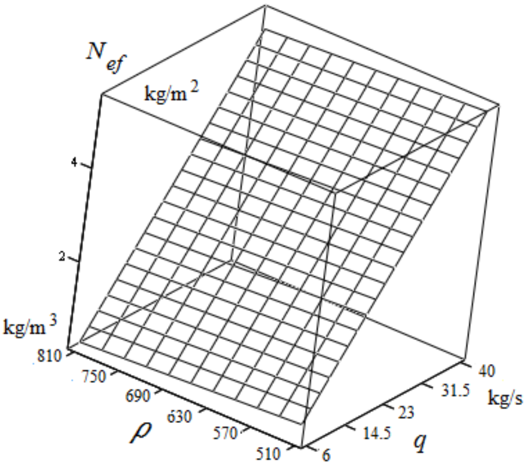

Fig. 7 - Effective norm as a partial function of material flow and material density - first degree polynomial interpolation

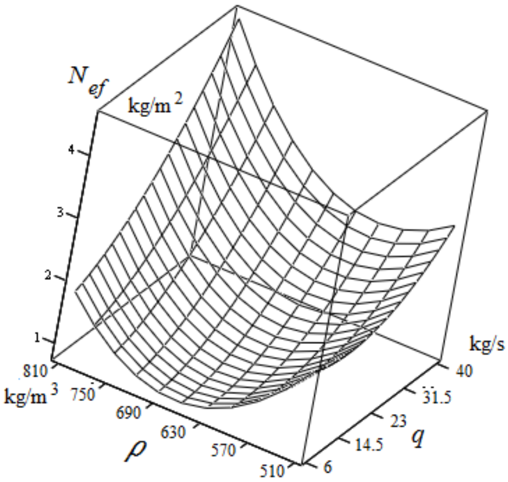

Fig. 8 - Effective norm as a partial function of material flow and material density - second degree polynomial interpolation

For the qualitative and quantitative study of the dependence of the qualitative parameters on the input and control parameters, graphical representations can be made for each separately independent parameter. Such a graphical representation is given in Fig. 7.

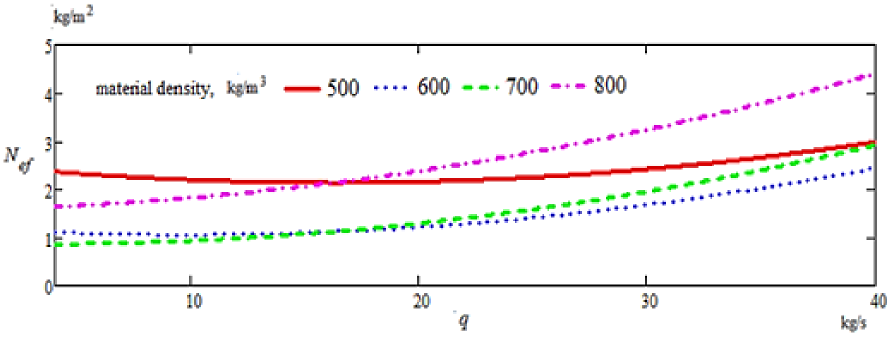

Fig. 9 - Dependence of the effective material flow rate for four different material densities and a constant value of rotation speed and rotor inclination, $\omega = 46.426\ rad/s$, $\beta = 0.75\ rad$.

In Fig. 7 it is observed that for low densities of the scattered material, the effective norm shows a minimum in the experimentally realized range for material flow. As the density of scattered material increases, the critical point leaves the experimental range. In these latter cases, the effective norm is minimal at the lowest and maximum flow rates at the maximum flow rate in the experimental range

CONCLUSIONS

The method of calculating the dependence of the quality parameters of the fertilization machine on the input and control parameters, exposed in this paper leads to sufficiently precise relations that allow not only the evaluation of the results of experimental regimes but also the prognosis and the improvement or even optimization of the working regime.

It is useful and necessary to interpolate the raw experimental data to obtain the quality parameters separately for each experimental work regime. Quality parameters are calculated on the data thus obtained by interpolation and thus receive superior precision.

The quality parameters described by the method presented in this article are the effective work width and effective norm. These parameters depend on the input parameter given by the density of the fertilizer material, and the control parameters of the working regime: rotation speed and rotor inclination as well as the flow of fertilizer material.

The analytical expressions of the fertilizer machine's quality parameters allow the calculation of the effective working width and the effective norm in sets of vales of independent parameters which do not be touch in the experiments, prognosis and improvement of the working regime. Also, the analytical expressions of the quality parameters, based on the input and control parameters, by graphical representations of two parameters, for example, allow visualization of qualitative behavior in certain areas. More accurate are the graphical representations of only one variable. On these representations it is possible to highlight the existence of optimal points and their location.

It remains to approach the interpolation of experimental results, possibly pre-processed, through variables formed with dimensionless combinations of parameters of the model system.

Obviously, the convenient or even optimal working regimes found with the proposed method should be validated experimentally in turn.

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