COMPARATIVE ANALYSIS OF THE OPERATION OF HORIZONTAL SCREW-TYPE DISPENSER WITH AND WITHOUT A COMPENSATING SCREW-CONVEYOR DEVICE

Dean Todorov[1], Bozhidar Kolev[2]

[1]PhD – student, Agrarian and Industrial Faculty, Department of Agricultural Machinery, "Angel Kanchev" University of Ruse, Bulgaria
[2] Assoc. Professor, Eng., PhD, Department of Agricultural Machinery, "Angel Kanchev" University of Ruse, Bulgaria

---***---

Abstract - This report presents the results from the planned multi-factor experiments that have been performed and the comparative analysis of the results of the two different structures.

Key Words: **Dispensers, Auger, Small ruminants, Pelleted feed, Volumetric efficiency;**

1. INTRODUCTION

Based on preliminary studies[1] of a dispenser with a horizontal screw-type auger and of the same dispenser with an added compensating auger, the intervals of variation of the manageable factors and the results regarding their effect on productivity, dispensing error and specific energy consumption have been established. This report presents the results from the planned multi-factor experiments that have been performed and the comparative analysis of the results of the two different structures.

2. EXPOSITION

A summary of the theoretical and experimental values in case of operation with a single auger or two augers is given in table1

Table -1: Summary table of productivity at different rotation speeds

Rotation speed, min^{-1}	6	10	15	20	22.8	25	30	40
Theoretical productivity, kg/h	101.73	169.56	254.34	339.12	386.6	423.9	508.68	678.24
Productivity, 1 auger, kg/h	94.4	140.2	212.1	306.4	320.2	379.2	466.2	560.4
1 trial	94.4	140.21	212.1	306.4	320.2	379.2	466.2	560.4
2 trial	94.42	140.23	212.14	306.5	320.26	379.28	466.29	560.5
3 trial	94.38	140.17	212.06	306.3	320.14	379.12	466.11	560.3
4 trial	94.41	140.21	212.12	306.43	320.23	379.24	466.25	560.45
5 trial	94.39	140.18	212.08	306.37	320.17	379.16	466.15	560.35
Mean value, kg/h	94.4	140.2	212.1	306.4	320.2	379.2	466.2	560.4
Mean quadratic value	0.001	0.0024	0.004	0.0218	0.009	0.016	0.0212	0.025

[1] Todorov, D., et. al. Preliminary studies on horizontal screw-type dispenser with and without a compensating screw-conveyor device.

Productivity, 2 augers, kg/h	98.8	165.4	246.24	325.9	371.3	400	483.25	630
1 trial	98	165.4	246.24	325.9	371.3	403	483.24	633
2 trial	99.5	167.4	249.24	329.9	375.8	404.5	489.25	630
3 trial	97.6	163.4	243.24	321.9	366.8	396.5	477.25	40
4 trial	99.5	166.4	247.74	327.9	373.6	395.5	486.26	6.281
5 trial	99.4	164.4	244.74	323.9	369	400.5	480.25	633
Mean value, kg/h	98.8	165.4	246.24	325.9	371.3	400	483.25	630
Mean quadratic value	0.925	1.581	2.372	3.162	3.574	3.937	4.745	6.281
Coefficient of variation, %	0.00936	0.00955	0.00963	0.0097	0.00963	0.00984	0.009819	0.00997

Summary graph of productivity in case of operation with a single auger and with two augers as compared to the theoretical productivity at different rotation speeds.

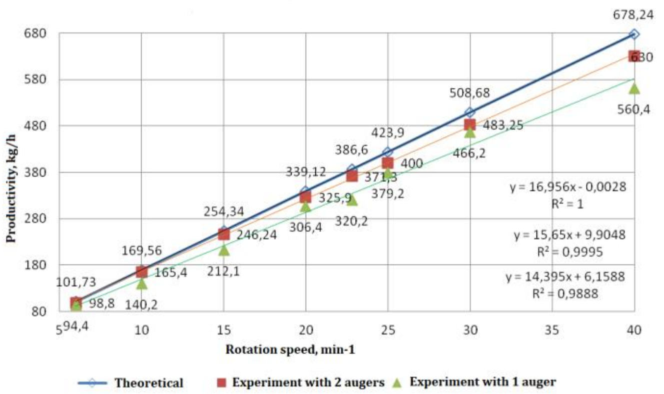

Chart -1: Comparison between theoretical productivity and productivity in case of operation with a single auger or two augers

2.1 Multi-factor experiments

The levels and intervals of variation of the manageable factors have been identified based on preliminary information and single-factor experiments that have been conducted. The natural and coded values of the factors are given in table 2.

Table -2: Natural and coded values of factors

Indicator	Natural values			Coded values		
	x_1,	x_2,	X_3,	$\overset{\circ}{x}_1$	$\overset{\circ}{x}_2$	$\overset{\circ}{x}_3$
	min^{-1}	m	º			
Lower limit of change	20	0.4	-10			
Upper limit of change	30	1.0	+10			

Interval of change	5	0.3	10			
Main level	25	0.7	0	0	0	0
Lower level	20	1.0	+10	-1	-1	-1
Upper level	30	0.4	-10	+1	+1	+1
Interval of variation	5	0.3	10	1	1	1

Table -3: Productivity dependence on rotation speed and the feed level in the hopper

No. of trial	Experiment matrix			Value of the indicator Y_i			Mean value, Y_{av}		Error, %	Volumetric efficiency
	x_1,	x_2,	X_3,				Experimental productivity, kg/h	Theoretical productivity, kg/h	[(theoretical productivity – experimental productivity) /theoretical].100,%	(experimental productivity/ theoretical productivity)
1	30	0.4	+10	490.39	496.2	482.0	489.53	508.68	3.764	0.96
2	30	0.4	+10	338.2	332.0	326.31	332.17	339.12	2.049	0.972
3	30	+1	-10	491.5	488.89	480.7	487.03	508.68	4.256	0.955
4	30	0.4	-10	325.5	330.21	333.3	329.67	339.12	2.786	0.97
5	30	+1	0	482.2	494.48	488.16	488.28	508.68	4.010	0.96
6	30	0.4	0	326.63	335.23	330.9	330.92	339.12	2.418	0.967
7	30	0.7	+10	405.34	411.79	415.42	410.85	423.9	3.078	0.965
8	30	0.7	-10	411.2	410.35	403.5	408.35	423.9	3.668	0.962
9	30	0.7	0	414.5	409.6	404.7	409.6	423.9	3.373	0.965

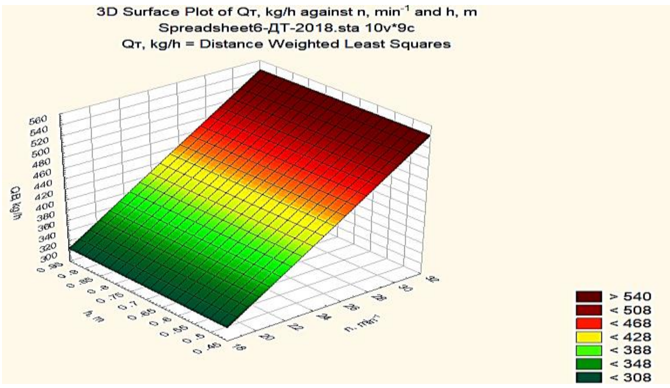

Fig -1: Dependency of productivity Q on the auger rotation speed n, min-1 and the feed level in the hopper h, m

Table -4

	Regression Summary for Dependent Variable: Qт, kg/h (Spreadsheet6-DT-korekcia-2018.sta) R=1.00000000 R?=1.00000000 Adjusted R?=1.00000000 F(2,6)=676E13 p<0.0000 Std.Error of estimate: .00000					
N=9	b*	Std.Err. of b*	b	Std.Err. of b	t(6)	p-value
Intercept			0.00000(	0.000004	0	1.000000(
n, min $^{-1}$	1.000000(	0.000000(	16.95600(	0.000000(	11623596	0.000000(
h, m	-0.000000(	0.000000(	-0.00000(	0.000004	-0	1.000000(

Results from multi-factor regression

Productivity: Qt, kg/h Multiple R = 1.00000000 F = --

R2= 1.00000000 df = 2, 6, No. of cases: 9 adjusted R2= 1.00000000 p = -- Standard error of estimate: .000001787, Intercept: .000000000 Std.Error: .0000045 t(6) = .00000 p = 1.0000

Rotation speed, n, min-1 b*=1.00 feed level in hopper, h, m b*=-.00 (the significant b* are marked in red)

The range of change in productivity is between 300 kg/h and 540 kg/h. The value within this range is 240 kg/h. This is a sufficient value. It is evident that under these manageable factors, productivity changes at a rate that is convenient for the final selection of the productivity the dispenser will operate at.

Based on the multi-factor experiment for identification of the dependency of productivity on the auger rotation speed and the feed level in the hopper it has been established that the level of feed in the hopper is an insignificant factor. The productivity depends solely on the rotation speed.

Qt = 16.965.n, kg/h (1)

This corresponds to the single-factor experiments that have been performed. After increasing the height from minimum to maximum (full load of the hopper), productivity increases by only 2.5 kg/h. At the area of the centre of the experiment plan, productivity is 424.12 kg/h.

2.2 Dependency of the dispensing error on the rotation speed and the feed level in the hopper

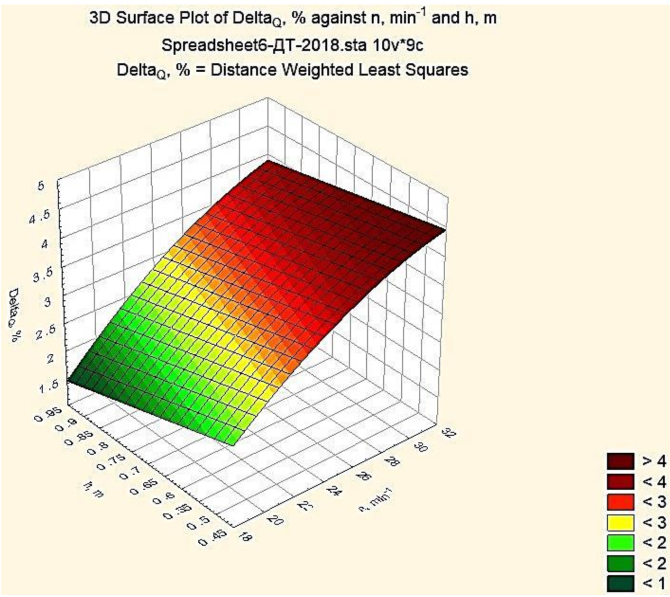

Fig -2: Dependency of the dispensing error Δp % on the auger rotation speed n, min-1 and the feed level in the hopper h, m

Table -5:

Multiple Regression Results

Dependent: DeltaQ, % Multiple R = .99252121 F = 198.3201

R2= .98509835 df = 2,6, No. of cases: 9 adjusted R2= .98013114 p = .000003

Standard error of estimate: .104781165

Intercept: .347138889 Std.Error: .2634042 t(6) = 1.3179 p = .2356

n, min-1 b*=.928 h, m b*=-.35 (the significant b* are marked in red)

Under this model, both factors are significant. Thus, the equation of the dependency of the dispensing error on the auger rotation speed and the feed level in the hopper looks as follows:

ΔQ = 0.347 + 0.159.n – 1.52.h + 18.61.n2 – 7.087.h2, % (2)

Regarding the auger rotation speed, there is a non-linear relationship of second order. This is in contrast to the established linear dependencies both from the single-factor experiments and from the model on productivity in the previous subsection.

This can be explained by the influence of accidental factors, such as change in the grid voltage, different humidity of the batch of the feed used, etc.

Despite this, the range of the error is within the limits of 1.5 % (at the lowest auger rotation speed and the highest feed level in the hopper) to 4.5 % (at the highest auger rotation speed and the lowest feed level in the hopper). These are acceptable values, because they are below the accepted possible values for dispensers of 5 %. This means that under these manageable factors, the error changes insignificantly and this is an indicator of the stability of the dispensing process.

It should be noted that the surface curvature is only significant with respect to the rotation speed and has a lower value.

Nevertheless, the error at the centre of the plan is 2.15 %.

2.3 Dependency of volumetric efficiency during dispensing on the rotation speed and the feed level in the hopper

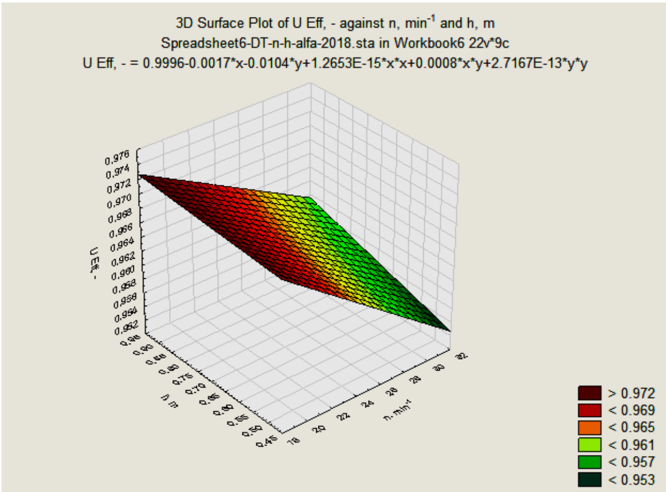

Fig -3: Dependency of volumetric efficiency Vef on the auger rotation speed n, min-1 and the feed level in the hopper h, m

Table -6:

Regression Summary for Dependent Variable: U Eff, - (Spreadsheet6-DT-n-h-alfa-2018.sta)
R= .95819030 R?= .91812865 Adjusted R?= .89083821
F(2,6)=33.643 p<.00055 Std.Error of estimate: .00176

N=9	b*	Std.Err. of b*	b	Std.Err. of b	t(6)	p-value
Intercept			0.986500	0.004434	222.4846	0.000000
n, min $^{-1}$	-0.919255	0.116813	-0.001133	0.000144	-7.8695	0.000223
h, m	0.270369	0.116813	0.008333	0.003600	2.3146	0.059894

Multiple Regression Results

Dependent: U Eff, - Multiple R = .95819030 F = 33.64286

R2= .91812865 df = 2,6, No. of cases: 9 adjusted R?= .89083821 p = .000549, Standard error of estimate: .001763834, Intercept: .986500000 Std.Error: .0044340 t(6) = 222.48 p = .0000

n, min-1 b*= -.92, h, m b*= .270 (the significant b* are marked in red)

The dependency of volumetric efficiency on the auger rotation speed and the feed level in the hopper is an issue of interest.

The coefficient associated to the factor of feed level in the hopper is insignificant.

U Eff = 0.987 – 0.0011.n, % (3)

The range of change in volumetric efficiency is between 0.964 (at maximum productivity and minimum feed level in the hopper) and 0.973 (at minimum auger rotation speed and maximum feed level in the hopper). It is evident that the volumetric efficiency changes negligibly at the values of these manageable factors and does not have effect on the operation of the dispenser.

At the centre of the plan, the volumetric efficiency has the following value

U Eff = 0.987 – 0.025– 0.007 = 0.962 (4)

The low values of the ranges of change both with respect to the error and with respect to volumetric efficiency are noticeable.

This explains the high level of stability of the process of dispensing using the auger device.

2.4 Productivity based on rotation speed and slope

Table -7: Values of productivity at different rotation speeds

No. of trial	Matrix of experiment			Value of the indicator Y_i		Mean value, Y_{av}			Error, %	Volumetric efficiency	Error in g
	x_1,	x_2,	X_3,			Experimental productivity, kg/h		Theoretical productivity, kg/h	[(theoretical productivity – experimental productivity) /theoretical] . 100, %	(experimental productivity / theoretical productivity)	
1	30	0.4	+10	489.3	483.2	477.01	483.17	508.68	5.014	0.971	6
2	30	0.4	+10	331.24	324.88	321.31	325.81	339.12	3.925	0.991	6
3	30	+1	-10	499.4	493.07	487.7	493.39	508.68	3.005	0.95	6
4	30	0.4	-10	329.8	321.8	325.83	325.81	339.12	3.925	0.964	4
5	30	+1	0	482.2	494.48	488.16	488.28	508.68	4.010	0.96	6
6	30	0.4	0	326.63	335.23	330.9	330.92	339.12	2.418	0.976	4
7	30	0.7	+10	409.34	404.71	399.42	404.49	423.9	3.078	0.98	5
8	30	0.7	-10	419.6	414.83	409.7	414.71	423.9	3.668	0.956	5
9	30	0.7	0	414.5	409.6	404.7	409.6	423.9	3.373	0.97	5

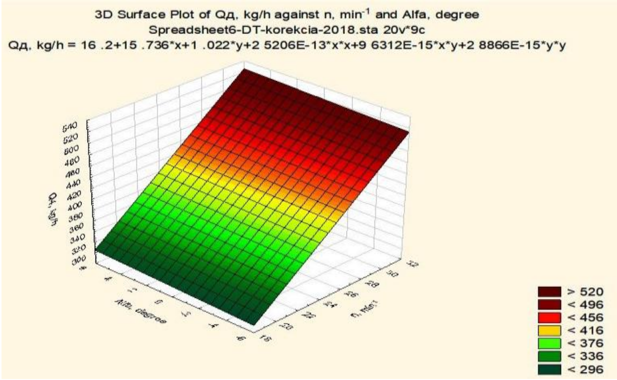

Fig -5: Dependency of productivity Q kg/h on the auger rotation speed n, min-1 and the auger slope, º

Multiple Regression Results

Dependent: Qd, kg/h Multiple R = 1.00000000 F = -- R2= 1.00000000 df = 2.6, No. of cases: 9 adjusted R2= 1.00000000 p = -- Standard error of estimate: .000002056, Intercept: 16.200000000 Std.Error: .0000043 t(6) = 3810E3 p = 0.0000, n, min-1 b*=.998 Alfa, degree b*=.065 (the significant b* are marked in red)

Table -8

Regression Summary for Dependent Variable: Qд, kg/h (Spreadsheet6-DT-korekcia-2018.sta)
R=1.00000000 R?=1.00000000 Adjusted R?=1.00000000
F(2,6)=441E13 p<0.0000 Std.Error of estimate: .00000

N=9	b*	Std.Err. of b*	b	Std.Err. of b	t(6)	p-value
Intercept			16.20000	0.000004	3809512	0.000000
n, min^{-1}	0.997898	0.000000	15.73600	0.000000	93735359	0.000000
Alfa, degree	0.064810	0.000000	1.02200	0.000000	6087795	0.000000

The range of change in productivity is between 300 kg/h and 530 kg/h. It is evident that under these manageable factors, productivity changes at a rate that is convenient for the final selection of the productivity the dispensing unit will operate at.

Based on the multi-factor experiment for identification of the dependency of productivity on the auger rotation speed and the feed level in the hopper it has been established that both factors are significant for the dispensing process. Productivity depends on both factors.

Qd = 16.2 + 15.736.n + 1.022.y, kg/h (5)

This corresponds to the single-factor experiments that have been performed. In case of a change in the auger slope from minimum to maximum, productivity changed by 11 kg/h.

At the area of the centre of the experiment plan, productivity is 400.62 kg/h.

The auger slope with respect to the horizon is a significant factor for productivity. Each degree brings productivity deviation of 1.1 kg/h. The acceptable deviation is up to 2.5 kg/h. This means that the acceptable deviation from the horizon is up to 2.7º.

2.5 Dependency of error on rotation speed and slope

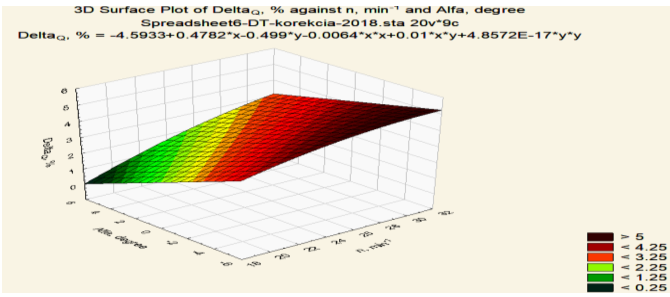

Fig -6: Dependency of error Δp % (based on theoretical model) on auger rotation speed n, min-1 and the feed slope, º

Multiple Regression Results

Dependent: DeltaQ, % Multiple R = .98841603 F = 127.2437

R2= .97696626 df = 2.6

No. of cases: 9 adjusted R2= .96928834 p = .000012

Standard error of estimate: .226109794

Intercept: -.712166667 Std.Error: .4676581 t(6) = -1.523 p = .1786

n, min-1 b*=.534 Alfa, degree b*=-.83 (the significant b* are marked in red)

Table -9

N=9	Regression Summary for Dependent Variable: Delta$_Q$, % (Spreadsheet6-DT-korekcia-2018.st R= .98841603 R?= .97696626 Adjusted R?= .96928834 F(2,6)=127.24 p<.00001 Std.Error of estimate: .22611					
	b*	Std.Err. of b*	b	Std.Err. of b	t(6)	p-value
Intercept			-0.71216	0.46765	-1.5228	0.17862
n, min^{-1}	0.53417	0.06195	0.15916	0.01846	8.6214	0.00013
Alfa, degree	-0.83163	0.06195	-0.24780	0.01846	-13.4223	0.00001

Under this model, both factors are significant. Thus, the equation of the dependency of the dispensing error on the auger rotation speed and the feed level in the hopper looks as follows:

ΔQs = -4.5933 + 0.4782.n – 0.499.h - 0.0064.n2 – 0.01.h. n,% (6)

Regarding the auger rotation speed, there is a non-linear relationship of second order. This is in contrast to the established linear dependencies both from the single-factor experiments and from the model on productivity in the previous subsection.

This can be explained by the influence of accidental factors, such as change in the grid voltage, different humidity of the batch of the feed used, etc.

Despite this, the range of the error is within the limits of 0.2% (at the lowest auger rotation speed and the highest backward slope of the auger, elevation at the outlet) to 4.2% (at the highest auger rotation speed and the lowest forward slope of the auger, lowering of the outlet). These are acceptable values, because they are below the accepted possible values for dispensers of 5 %, which is an indicator of the stability of the dispensing process.

It should be noted that the surface curvature is only significant with respect to the rotation speed, because the error at the centre of the plan is 2.36 %.

2.6 Dependence of volumetric efficiency on the rotation speed and slope

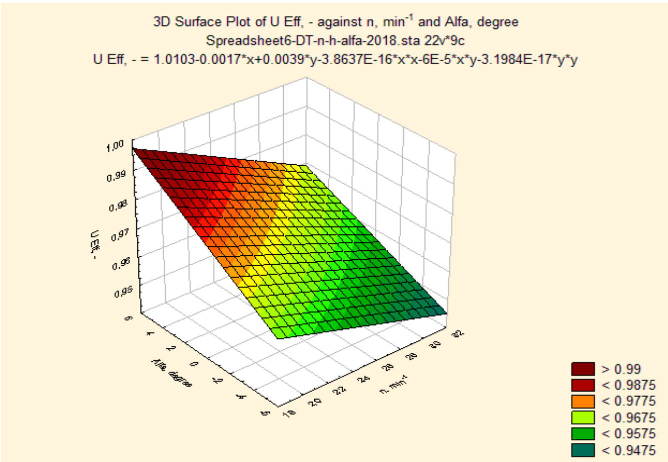

Fig -7: Dependency of volumetric efficiency Vef (based on the theoretical model) on the auger rotation speed n, min-1 and the auger slope, degrees

Table -10

N=9	Regression Summary for Dependent Variable: U Eff, - (Spreadsheet6-DT-n-h-alfa-2018.sta) R= .99483468 R?= .98969603 Adjusted R?= .98626138 F(2,6)=288.15 p<.00000 Std.Error of estimate: .00149					
	b*	Std.Err. of b*	b	Std.Err. of b	t(6)	p-value
Intercept			1.010333	0.003083	327.6890	0.000000
n, min $^{-1}$	-0.567450	0.041441	-0.001667	0.000122	-13.6931	0.000009
Alfa, degree	0.817127	0.041441	0.002400	0.000122	19.7180	0.000001

Multiple Regression Results

Dependent: U Eff, - Multiple R = .99483468 F = 288.1500

R2= .98969603 df = 2.6

No. of cases: 9 adjusted R?= .98626138 p = .000001

Standard error of estimate: .001490712

Intercept: 1.010333333 Std.Error: .0030832 t(6) = 327.69 p = .0000

n, min-1 b*=-.57 Alfa, degree b*=.817

The dependency of volumetric efficiency on the auger rotation speed and the auger slope is an issue of interest.

U Eff = 1.01 – 0.0017.n – 0.0039.h (7)

The coefficient associated with the factors of second order is insignificant like it is for the mixed effects.

The range of change of volumetric efficiency is between 0.946 (at the highest auger rotation speed and the lowest backward slope of the auger, lowering at the outlet) to 0.997% (at the lowest auger rotation speed and the highest forward slope of the auger, elevation of the outlet).

This means that at these values of the manageable factors, volumetric efficiency changes negligibly and does not influence the operation of the dispensing unit, with value of the volumetric efficiency of 0.9675 at the centre of the plan.

3. CONCLUSIONS

Based on the data presented in table 1 and fig. 1, the following conclusions can be made:

1. Experimental productivity is lower than the theoretical one;
2. These differences are the result of different factors related to the nature of the material dispensed, the constructive features of the unit, the kinematic mode of the process, the electrical actuation, etc.
3. It was established that during operation of the dispenser with a single operating auger, the process is unstable and the dispensing precision error exceeds 18% which is the result of the uneven filling of the interturn space.
4. The established volumetric efficiency (between 0.828 and 0.928) has a high dispersion due to the insufficient filling of the auger;
5. The introduction of a second, compensating auger in the dispenser improves the process stability, reduces the dispensing error (3.61% at 22.8 min^{-1}) and increases the volumetric efficiency to 0.971 at 22.8 min^{-1}, i.e. the experimental values for productivity obtained tend to the ones calculated theoretically;
6. Adequate mathematical productivity models have been obtained based on:
   a. the auger rotation speed and the feed level in the hopper,
   b. rotation speed and slope of the unit,
   c. feed level in the hopper and the slope of the unit;

7. Adequate mathematical models of the dispensing error have been obtained based on:
   a. the auger rotation speed and the feed level in the hopper,
   b. rotation speed and slope of the unit,
   c. feed level in the hopper and the slope of the unit;
8. Adequate mathematical models of the volumetric efficiency have been obtained based on:
   a. the auger rotation speed and the feed level in the hopper,
   b. rotation speed and slope of the unit,
   c. feed level in the hopper and the slope of the unit;

REFERENCES

[1] D. Todorov, “Dissertation,” unpublished.

AUTHORS

Eng. Dean Todorov, PhD-student
Major field of study: Agricultural Engineering.

Assoc. Professor Eng. Bozhidar Kolev, PhD
Major field of study: Agricultural Engineering.