MECHANICAL-TECHNOLOGICAL FUNDAMENTALS OF THE FRONT-WEIGHTED HAULM GATHERER ON THE WHEELED TRACTOR

Volodymyr Bulgakov[1], Doctor of Engineering, academician
Evgeniy Ignatiev[2], Engineer
Vladimir Kročko[3], Doctor of Engineering
Pavol Findura[3], Doctor of Engineering

[1]National University of Life and Environmental Sciences of Ukraine
[2]Tavria State Agrotechnological University
[3]Slovak University of Agriculture in Nitra

Sugar beet harvesting is a complex and energy-intensive technological process in the production of this technical crop. At the present time, the process of harvesting sugar beet haulms is carried out on the root and is performed in two steps: firstly a continuous uncopied cut of the main area of green mass and subsequent individual post-cleaning of the root crop heads from the haulm remains. The increased working harvesting rate causes intensive fluctuations of the cutoff apparatus in the longitudinally vertical section that doesn't only reduce the quality of root crops cutting but also causes significant losses of the haulms. The use of haulm gatherers as independent harvesting modules allows aggregating them with various types of row tractors that makes it necessary to determine the compliance of the definite haulm gatherer with the traction and energy characteristics of tractors which will ensure high efficiency of using the proposed machine and tractor units. The purpose of this study is to increase the efficiency of using a front mounted haulm gatherer on the wheeled tractor based on the development of thebasic regulations of the theory of its aggregation and determining the influence of its kinematic and design characteristics on the quality of a continuous cut of the haulm with oscillations of the cutting device in the longitudinal-vertical plane. While making research the methods of the theory of mathematical modeling of agricultural machines and machine aggregates, the theory of the tractor, the foundations of machine use in plant growing, and the compilation of the programs and numerous calculations on the PC were used. Conducted investigations made it possible to develop mathematical models of the movement of a haulm gatherer determining the optimum shear height, and also to justify and select the optimal parameters of machine-tractor aggregates which are made up of a tractor and a front unloaded haulm gatherer. The developed mechanical and technological fundamentals of aggregation make it possible to determine the optimal design and kinematic parameters both of the botting harvester and the aggregates according to the criteria of productivity and energy intensity.

Keywords: sugar beet, rotary cutter, aggregation, tractor, math model, characteristics/specifications, fluctuations, differential equations.

INTRODUCTION

Modern technologies for harvesting sugar beet haulms suggest firstly a continuous, uncopied cut of the main mass of green mass and subsequent individual finishing of the heads of root crops from the remains of the haulms, Bulgakov (2011). At the same time, the first technological operation to cut the main mass of the green foliage assumes the main harvesting of its harvest (continuous uncopied cut, collection of sloping mass and unloading), its transportation for further use for animal feed, as fertilizer or raw material for biogas production. Thus, it is important to establish optimal characteristics of the continuous main cut so that the heads of the root crops are not damaged and it is not too high since in this case the post-cleaning of the heads is complicated by the existing additional cleaning organs of the haulm gatherers. The use of haulm gatherers as independent harvesting modules allows to aggregate them with various types of row tractors. This raises the need to determine the

Contact info: Melitopol, Ukraine, mvz@tsatu.edu.ua

compliance of a haulm gatherer with the traction-energy parameters of the aggregating tractors which will ensure high efficiency of the proposed harvesting machine and tractor units. However, the high efficiency of the harvesting of the agricultural machine and tractor unit is achieved due to the fact that there will be a correct correlation between its technical parameters, operation modes and external production conditions. Therefore, the issues of effective use of haulm gatherers are urgent and require an appropriate scientific substantiation.

ANALYSIS OF RECENT RESEARCH

Questions of the theoretical study of the aggregation of agricultural machines connected with the construction of computational mathematical models for the functioning of various self-propelled and trailed machine aggregates are presented in detail in the scientific works by Vasilenko (1980, 1996). At the same time, the work written by Bulgakov (1980, 2007) is devoted to the construction of computational mathematical models of trailed agricultural machines including sugar beet and flax harvesting machines.

The theory of aggregation of trailed and rear-mounted agricultural machines is widely represented in the fundamental works of Kutkov (2004) and Nadykto (2003).

According to the research results by Boris (2009) and Bulgakov (2011) it is established that there is a definite linear relationship between the height of the placement of the heads of root crops above the soil surface and the dimensional characteristics of the most root crops. However, studies that would affect the analytical determination of the total weight of the cut-off haulage during its continuous cutting with a rotary cutting apparatus have not been carried out sufficiently yet.

Fundamental questions of forecasting the degree of increase in the productivity of sugar beet harvesting machines depending on the specific investment were examined by Pogorely (1984). However, the choice of the optimal parameters of front-mounted bot-harrowing machines according to the performance criteria of the aggregating tractor is not considered here.

Methods for obtaining performance characteristics of various machine-tractor aggregates made up of aggregating tractors and mounted machines and tools are widely represented in the works by Fere (1978) and Pastukhov (2001).

Therefore, on the basis of all the above-stated it follows that the efficiency of the use of aggregated beet harvesters must first of all be evaluated as part of the aggregating tractor and justify this efficiency with the help of quantitative criteria that would accurately display their operational properties and technical excellence. Among these criteria there should be attributed, first of all, the performance of such aggregate, minimum operating costs, specific performance per 1 kW of power of the unit tractor and other performance indicators.

RESEARCH METHODOLOGY.

While conducting research the methods of the theory of mathematical modeling of agricultural machines and machine aggregates, the theory of the tractor, the foundations of machine use in plant growing, and the compilation of programs and numerical calculations on a PC were used.

The purpose of the study is to increase the efficiency of using a front mounted vehicle on the wheeled tractor based on the development of the main provisions of the theory of its aggregation and determining the influence of its kinematic and design parameters on the quality of a continuous cut of the haulm top with oscillations of the cutting device in the longitudinal-vertical plane.

RESULTS AND DISCUSSION.

The use of haulm gatherers as independent technological modules in the harvesting of sugar beets allows to aggregate them with various types of wheeled tractors equipped for this purpose with front attachments and front power take-off shafts. The aggregate tractor must be tilled, i.e. it is equipped with narrow tires set to the corresponding track width, i.e. corresponding rowing of sugar beet root crops. Besides, the haulm gatherers were viewed frontally mounted on an aggregating power tool (tractor).

To ensure these conditions, the design of the haulm gatherers was developed (Ignatiev

(2016)) which carries out a continuous, uncopied cut of the bulk of the tops, the loading of the mown mass in a nearby vehicle and which is front mounted on a wheeled tractor (Figure 1). This botting harvester can be manufactured in various layout designs, i.e. various ranks from two-row to six-row variants.

To develop a new theory of effective aggregation of a front-mounted machine mounted on the wheeled tractor using the well-known dependencies to determine the productivity of the machine-tractor unit the

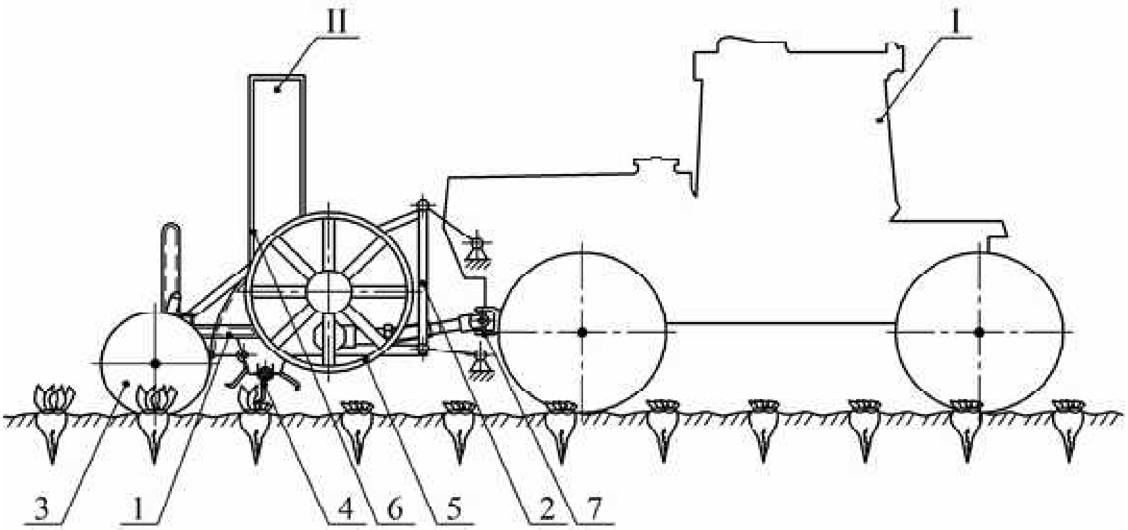

Figure 1. Aggregate for harvesting sugar beet haulms:
I - wheel integral tractor-tractor; II - front mounted hoeing machine:
1 - frame; 2 - hinged device; 3 - copying wheel; 4 - rotary cutter apparatus;
5 - transporting working body; 6 - loading device; 7 – drive.

$$W = 0{,}1B\left\{\frac{3600\cdot\xi\cdot N_e\eta_t\eta_v\left[1+\frac{1}{b}\ln\frac{\left[(mg\cdot\psi+kB)\cdot(mg\cdot\lambda)^{-1}\right]-\varphi}{\alpha}\right]}{(kB+mg\psi)\eta_v+10N_pB\cdot H\eta_t\left[1+\frac{1}{b}\ln\frac{\left[(mg\cdot\psi+kB)\cdot(mg\cdot\lambda)^{-1}\right]-\varphi}{\alpha}\right]}\right\}, \quad (1)$$

where N_e - rated, effective engine power, kW;

ξ - engine load factor;

N_p - the specific energy consumption for the process of harvesting the tops of sugar beet, kW·s· kg^{-1};

H - yield of sugar beet tops, c / ha;

η_t - the efficiency of the transmission of the wheel assembly tractor;

η_v - efficiency of the front power take-off shaft of the tractor;

α - angle of rise, rad .;

m- the mass of the wheeled tractor, kg;

g - acceleration of gravity, m · (s^2)$^{-1}$;

k- specific resistance of the front-mounted haulm gatherer, Н · м$^{-1}$;

ψ - drag coefficient to the movement of the wheel assembly tractor;

φ - utilization factor of the coupling weight;

a, *b* - constant coefficients that depend on the type of wheeled tractor and agrophone on which the sugar beet tops are harvested;

λ - traction factor of the tractor;

B- working width of the gripper front mounted on the wheeled tractor, m.

following expression was obtained (1).

The resulting expression (1) is a mathematical model of the aggregation of a front mounted haulm gatherer on a wheeled tractor using which it is possible to determine the performance of the machine-tractor unit depending on the initial parameters of a particular tractor and haulm gatherers of various ranks and layout.

The technical characteristics that concern universal-tilled and integral wheeled tractors with which it is possible to aggregate a front-mounted haulm gatherer are given according to the data of Pastukhov (2001) in Table 1.

Table 1.Technical characteristics of tractors

Tractor draw bar category, purpose	mg, kg	N_e, kW	φ_m	a	b
0,9 universal, wheeled	3000	36,8	0,6	0,75	8,81
1,4 universal, wheeled	3810	58,9	0,6	0,75	8,81
3 intergratedrow-crop, wheeled	8200	117,7	0,65	0,753	9,52

Based on the analysis of numerical calculations carried out on a PC in the Mathcad mathematical model (1), it can be argued that wheeled tractors of class 0.9 and 1.4 will provide sufficient and stable performance only when three- or four-row haulm gatherers are assembled, and the use of a six-row machines is possible only at low values of resistivity up to 2100 ... 2300 N · m-1. At the same time, a class 3 wheeled tractor will provide a fairly high productivity of 3,3 ... 3,5 ha · h-1 with the addition of a six-row hitch at any resistivity values, and thanks to the power reserve it's possible to use a rear-mounted head cleaner or a haulm gatherer.

To solve the next important issue which concerns the choice of the optimal height of the main continuous cut of the haulms the value of which will directly depend on the height of the protruding heads of the sugar beet root crops above the soil surface, which is a random quantity, we will develop a mathematical apparatus that will predict the loss of the sugar-containing mass.

Let us consider the loss of the sugar content and the remains of the foliage which are determined by the distance from the established cut height h to the top of the head of the root crop bt and the base of the green eye zone bh (Fig. 2).

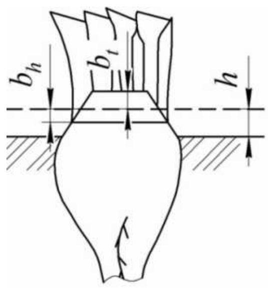

Figure 2. Scheme of root cropping

Setting these parameters and using the geometric calculations let's determine the volume of the cut part of the crop root and the remains of the foliage taking into account their density, and it is possible to determine the mass characteristics of the unknown quantities for root crops of a given height interval (Boris (2009)):

$$M_i = F\left(h_i; b_i\right) \cdot P\left(h_i; h_{i+1}\right) \cdot N_i, \quad (2)$$

where: F - loss of the sugar content or the remains of the foliage, for the root crop;

$$M = \sum_{i=a}^{b} \left[N_i \cdot F\left(\frac{h_i + h_{i+1}}{2}; b_i\right) \cdot \left(\frac{h_{i+1} - h_i}{3m} \sum_{j=0}^{m} c_j \cdot f(h_i)\right)\right], \quad (3)$$

where b_i - cutting height respectively of the tops or heads of the root crop;
F - loss mass of the sugar-containing mass or the remains of the foliage;
H - height of the unpaired cut of the haulms above the soil surface;
M - number of intervals: m = 2U; U = 1, 2, 3, 4, ...;
C_j - coefficient for the values of the integrand at the corresponding points, cj = 1, 2, 3, 4, 2, 4, ..., 2, 4, 1 ...

P - probability of occurrence of the given interval of heights of heads of sugar beet;

N_i - number of root crops of a given interval per unit area.

The determination of the probability of the appearance of root crops of a given interval of protuberant heights is calculated by numerical integration using the Simpson formula. Adding the general remains of the tops and loss of the sugar content for all intervals of protuberance heights we obtain the total remains of the tops and loss of the sugar content per unit area (3)

Using the above dependence it's possible to develop the algorithm and program for computing on a PC. Applying this mathematical apparatus the loss of the sugar content and the remains of the foliage is calculated as a function of the height of the uncopied cut (Fig. 3).

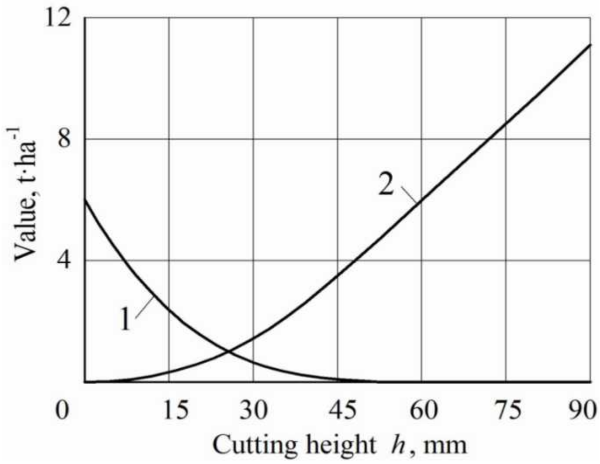

Figure 3. Dependence for determining the rational height of the main continuous cut at mathematical expectation m = 40 mm and mean square deviation σ = 10 mm: 1 - loss of sugar content, t · ha-1; 2 - mass of the remains of the tops, t · ha-1

Therefore, there is a reason to use the obtained mathematical dependence for forecasting losses of sugar-containing mass and haulm residues for different varieties of sugar beet and various technologies for its cultivation. Based on the obtained dependencies which are shown in Fig. 3 it is possible to determine the height of a continuous uncopied cut with the predicted losses of the sugar-containing mass and the remains of the foliage.

To determine the effect of the structural and kinematic parameters of the bot-harvesting machine, which is front-mounted on the wheel integral tractor, on the magnitude of the amplitude of oscillations in the longitudinal-vertical plane of the cutoff apparatus, it is necessary to construct its mathematical model.

To do this, let us analyze analytically the movement of the haulm gatherer only in the longitudinal-vertical plane, that is, we'll construct a mathematical model of the oscillation of the haulm gatherer when moving along the unevenness of the soil surface in only one plane. Based on Vasilenko (1996), we will first of all compile an equivalent scheme for the movement of the front-mounted machine mounted on the aggregating wheel integral tractor in the longitudinally vertical plane (Fig. 4).

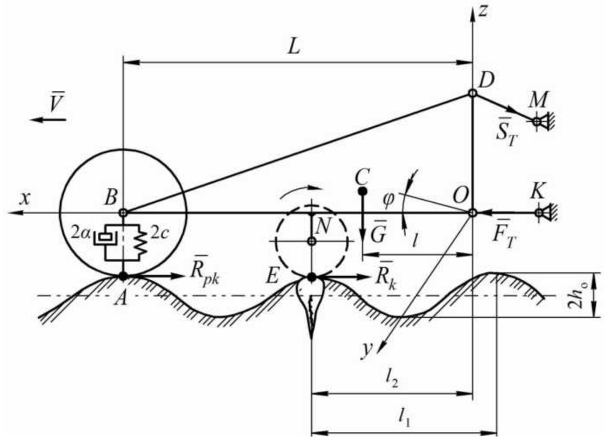

Fig. 4. Equivalent scheme of the front mounted haulm gatherer on the aggregating integrated tractor

Based on this equivalent scheme and determining the potential forces and forces of viscous resistance (Butenin (1985), the following differential equation is obtained:

$$z = e^{-\frac{\alpha}{m}t}\left(-\frac{\frac{\alpha}{m}(N+R)+\frac{2\pi V}{l_1}M}{\sqrt{\frac{\alpha^2}{m^2}-\frac{2c}{m}}}\cdot\sin\sqrt{\frac{\alpha^2}{m^2}-\frac{2c}{m}}\cdot t - (N+R)\cdot\cos\sqrt{\frac{\alpha^2}{m^2}-\frac{2c}{m}}\cdot t\right) + M\cdot\sin\frac{2\pi V}{l_1}t + N\cdot\cos\frac{2\pi V}{l_1}t + R, \qquad (4)$$

where: α - coefficient of damping of the copying wheels, H · s · m^{-1};

m - mass of copying wheels, kg;

t - time, c;

c - coefficient of rigidity of pneumatic tires of the wheels of the copying system, N · m^{-1};

l_1 - step of unevenness of soil surface, m;

V - forward speed of the movement of the botting harvester, m · s^{-1};

R- the coefficient that equals $R = h_o$;

M, N - coefficients which are determined from expressions (6), (7) respectively.

Expression (4) defines the law of translational vertical oscillations of the center of mass of the copying wheels (point B) during the movement of the haulm gatherer along the unevenness of the soil surface given by the analytical expression in the form (Morozov (1969)):

$$h = h_o\left(1 - \cos\frac{2\pi x}{l_1}\right), \qquad (5)$$

where: h- the ordinate of the height of the unevenness of the soil surface, m;

h_o - half the height of the unevenness of the soil surface, m;

$x = Vt$ - current coordinate, m.

Coefficients M and N are determined after use of Cramer's rule:

$$M = \frac{\Delta_M}{\Delta} = -\frac{16\pi^3\alpha V^3 h_o}{ml_1^3\left[\left(\frac{2c}{m} - \frac{4\pi^2V^2}{l_1^2}\right)^2 + \frac{16\pi^2\alpha^2V^2}{m^2l_1^2}\right]}, \qquad (6)$$

$$N = \frac{\Delta_N}{\Delta} = -\frac{\frac{2ch_o}{m}\left(\frac{2c}{m} - \frac{4\pi^2V^2}{l_1^2}\right) + \frac{16\pi^2\alpha^2V^2h_o}{m^2l_1^2}}{\left(\frac{2c}{m} - \frac{4\pi^2V^2}{l_1^2}\right)^2 + \frac{16\pi^2\alpha^2V^2}{m^2l_1^2}} \qquad (7)$$

Therefore, a mathematical apparatus has been developed to determine the optimal design and kinematic parameters of the front mounted haulm gatherer on the wheeled trailing tractor in the form of a final analytical expression. Application which allows determining the vertical movement of any point of its frame (including the lower end of the rotary cutter) with the vibrations of the botting machine during its operation affects the quality of the process.

The analysis of the dependences showed that the amplitude of the natural oscillations of the center of mass of the copying wheels of the haulm gatherer decreases with an increase in the speed of its movement to 3.0 m·s^{-1} and an increase in the design parameter from 1.05 to 2.10 m. This allows us to state that improving the quality of soil cultivation and using wide-swing aggregates allows reducing the oscillations of the cutting device of the haulm gatherer.

It is also determined that the frequency of forced oscillations of the center of mass will not exceed 10 s^{-1} in the whole range of agronomic speeds when using machines with a working width of more than 2.2 m.

Numerical modeling of the oscillatory characteristics of the front mounted hovering aggregate based on the integrated wheel tractor of traction class 3 showed that when choosing the optimal design parameters this oscillating system is capable of extinguishing the disturbing effect from the field surface. Thus, for example, at an aggregate speed of 3.5 m · s^{-1} the amplitude of the natural oscillations of the center of mass of the copying wheels of the haulm gatherer decreases by 2.2 ... 2.7 times in comparison with the height of the unevenness of the field surface equal 0.06 m.

CONCLUSION

1. Conducted analytical studies allowed to close the main issues related to the mechanical and technological fundamentals of the front suspension of the haulm gatherer on the wheeled tractor.

2. On the basis of the developed mathematical model of efficient aggregation of front mounted haulm gatherers on the wheeled tractors, it is determined that wheeled tractors of class 0.9 and 1.4 will provide sufficient and stable performance only when three- or four-row harvesting machines are assembled, and using a six-row machine It is possible with a specific resistance up to 2100 ... 2300 N · m^{-1}. Tractor class 3 provides productivity of 3,3 ... 3,5 hectares · h^{-1} when working with a six-row harvester, and the power reserve is enough for a root harvesting machine.

3. A mathematical model for predicting the loss of sugar-containing mass and remains of tops for different varieties of sugar beet, cultivation technologies and means of harvesting it has been developed. Thus, with a

mathematical expectation of m = 40 mm and a root-mean-square deviation of σ = 10 mm of the arrangement of the beet root heads, the rational height of the main continuous cut is h = 23.6 mm.

4. The dependence for the determination of structural and kinematic parameters of the front mounted haulm gatherer on the wheeled row tractor has been derived that allows to obtain a vertical movement of any point of its frame with the oscillations of the haulm gatherer during its operation. It is determined that when choosing the optimal design parameters and the speed of the unit = 3.5 $m \cdot s^{-1}$, the amplitude of the natural oscillations of the center of mass of the copying wheels of the haulm gatherer decreases by 2.2 ... 2.7 times in comparison with the height of the unevenness of the field surface = 0.06 m.

REFERENCES

Vasilenko P.M., Vasilenko V.P. Metodika postroeniya raschetnyh modelej funkcionirovaniya mekhanicheskih sistem (mashin i mashinnyh agregatov): Uchebnoe posobie. Kiev USKHA, 1980. - 137 s.

Vasilenko P.M. Vvedenie v zemledel'che-skuyu mekhaniku. Kiev Sel'hoz obrazovanie, 1996. - 252 s.

Bulgakov V.M. Metodika postroeniya raschetnoj modeli funkcionirovaniya samo hodnoj korneuborochnoj mashiny. – Moskva, “Doklady VASKHNIL”, 1980, № 7. – S. 27-29.

Bulgakov V.M., Gorbovoj A.YU. Teoriya dvizheniya l'nouborochnyh kombajnov. Monografiya. - L'vov: Izdatel'stvo LvCNTI, 2007. - 115 s.

Kut'kov G.M. Traktory i avtomobili. Teoriya i tekhnologicheskie svojstva. – Moskva: KoloS, 2004. – 504 s.

Nadykto V.T. Osnovy agregatirovaniya modul'nyh energeticheskih sredstv. Mono grafiya. –Melitopol':KP “MMD”, 2003. – 240 s.

Pogorelyj L.V. Industrializaciya agropromyshlennogo kompleksa. – Kiev: Tekh nika, 1984. – 200 s.

Posobie po ekspluatacii mashinno-traktornogo parka./ Pod red. N.E. Fere. Izd. 2-e. – M.: Kolos, 1978. – 256 s.

Pastuhov V.I. i dr. Spravochnik po mashinoispol'zovaniyu v zemledelii. – Har'kov: Vesta, 2001. – 347 s.

Borys N. M. Obgruntuvannia tekhnolo hichnoho protsesu y parametriv robochoho orhana dlia viddilennia hychky tsukrovoho buriaka: avtoref. dys. na zdobuttia nauk.stupenia kand. tekhn. nauk: spets. 05.05.11 / N. M. Borys. – Vinnytsia: VDAU, 2009. – 20 s.

Bulhakov V. M. Buriakozbyralni mashyny / V. M. Bulhakov. – K.: Ahrarna nauka, 2011. – 352 s.

Morozov B.I., Gringauz N.M. Raschet dvizheniya kolesnoj mashiny po nerovnoj doroge. – Mekhanizaciya i elektrifikaciya socialisticheskogo sel'skogo hozyajstva. – 1969. – № 7. – S. 11-14.

Butenin N.V., Lunc YA.L., Merkin D.R. Kurs teoreticheskoj mekhaniki. Tom 2. Dinamika. – Moskva: Nauka, 1985. – 495 s.

Ihnatiev Ye. I. Rozrobka novoi konstruktyvno-tekhnolohichnoi skhemy zbyrannia hychky tsukrovoho buriaku z vykorystanniam orno-prosapnoho traktora / Ye.I. Ihnatiev // Visnyk ahrarnoi nauky. – 2016. – №8. – S. 67-71.