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OPTIMAL POLICY FOR USING A RENTED FARMING MACHINE

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Abstract: This research analyzes the optimal harvesting policy and the optimal timing for ordering a rented self-propelled blueberry harvester for maximizing the total expected profit. The paper proposes a stochastic model that takes into account two types of uncertainties: 1) the exact date when the crop will be ready for harvesting (fruition) is unknown; 2) the exact quantity of the crop in the field is unknown. Another factor that is taken into account is the decreasing price of the crop during the harvesting season.

Keywords: AGRICULTURE MACHINERY, SELF-PROPELLED BLUEBERRY HARVESTER, OPTIMAL HARVESTING POLICY.

1. Introduction

The mechanized agriculture allows farmers to attain high yield of crops with few workers who operate sophisticated farming machines. Unfortunately, most of the farming machines are single purpose machines. A farmer that purchases an expensive farming machine uses it only when the crops need the special task that the machine is capable to do. This means that the machine works only several weeks every year/season. Due to the high cost of owning a single purpose farming machine (purchasing and maintenance), small and medium farms rent machines (with their operational teams) for the period of time the machines are needed. The renting company requires from the farmer to determine in advance the exact date he/she will need the machine. At the time when the farmer must set the due date for the arrival of a harvesting machine, he/she faces two types of uncertainties: 1) the exact date when the crop will be ready for harvesting (fruition) is unknown; 2) the exact quantity of the crop in the field is unknown. If the machine would arrive before the crop fruition, the farmer would pay extra rental fee until the work would begin. If the machine would arrive after the crop fruition, the farmer would have the following three possibilities: 1) wait for the machine arrival; 2) use manual harvest until the machine arrival (slow and expensive in comparison to the machine harvest); 3) mix policy (part of time manual harvest and part of time wait for the machine). Another factor that must be taken into account is the price of the crop. At the beginning of the harvest season the selling price is high and then it gradually decreases. This research concentrates in blueberry harvesting.

Blueberry consumption in the U.S. increased threefold from 2000 to 2010, followed by a fourfold increase in acreage plantings in the Southeastern region (Perez et al. [1]). During this period, machine harvesting technology also improved (Rodgers et al. [2]). Fresh market blueberry harvesting in the Southeastern U.S. is generally characterized by high demand for the large workforces that are needed to hand-pick each ripened blueberry; this takes place over a six to eleven weeks ripening window. Labor costs are estimated to be about 60 percent of the average operating costs (Brown et al. [3]; Safley et al. [4]). Rodgers et al. [2] estimate that the price of a mechanical harvester ranges is between \$100,000 to \$200,000, depending on functionality, and that such a machine has a useful lifespan of approximately 20 years.

Assuming that the distribution functions of the two random variables (the fruition date and the quantity of the crop) and the function of selling price during the harvest time are known, the research analyzes the optimal harvesting policy and the optimal timing for ordering a rented self-propelled blueberry harvester for maximizing the total expected profit.

2. Notation

Let us introduce the following terms:

T - is the time when the product (blueberry) is ready for harvesting (a positive random variable), $T \in (0, A)$; that is, the earliest possible time for starting the harvest season is defined as zero and the latest possible time for starting the harvest season is defined as A , where $A > 0$ is a known deterministic value.

$f_T(x)$ - is the known density function of the random variable T , $0 \leq x \leq A$;

B - is a length of the harvest period (i.e., the time interval $(T, T+B)$) and it assumed to have a known positive deterministic value;

H - is the total amount of the product in the field which is measured in thousands of pounds (a positive random variable);

$f_H(x)$ - is the known density function of the random variable H , $x > 0$;

c_1 - is the booking cost to reserve the use of the machine (a self-propelled harvester) (a one-time payment that guarantees the availability of the machine as well as the option of returning the machine at any point of time), $c_1 \geq 0$;

c_2 - is the machine rental cost per hour, $c_2 > 0$; This includes the cost of the operational team of the machine.

$c(t)$ - is the known function of the selling price of the one thousand of pounds of the product (a continuous decreasing function defined on the range $(0, A+B)$);

q_1 - is the machine capacity per hour (the amount of the product, in thousands of pounds, that can be picked by the machine during one hour, $q_1 > 0$);

q_2 - is the manual capacity per hour (the amount of the product, in thousands of pounds, that can be picked manually by the existing workers during one hour, $0 < q_2 < q_1$);

c_3 - is the cost of harvesting one thousand pounds by harvesting machine, $c_3 > 0$;

c_4 - is the cost of harvesting one thousand pounds by manually (without the assistance of the harvesting machine), $c_4 > c_3 > 0$;

t_b - is a point in time when the machine arrives at the farm and the rental payments begin to be incurred (t_b is a deterministic decision variable that should be determined by the farmer, $0 \leq t_b < A$);
 $B(t_b, H, T)$ - is the farmer's profit (benefit) (a random variable).

3. An analysis of the optimal harvesting policy

This section presents the farmer's optimal working policy that maximizes his profit, given values of the random variables H , T and the decision variable t_b . The assumption is that the farmer does not consider the option of not renting a harvesting machine because the available manual harvesting capacity he has is not enough to pick up all the expected amount of the product during the harvesting period. That is, the booking cost C_1 must be taking into account for any harvesting policy. It is also assumed that for any $0 \leq t \leq A + B$, the cost function $c(t) \geq c_4 > c_3$.

If $t_b \leq T$, the optimal policy is to use the machine during the entire harvesting period. In this case the farmer's profit is $B(t_b, H, T)$

$$B(t_b, H, T) = -c_1 - c_2(T - t_b) + q_1 \int_T^{\min\{T+B, T+H/q_1\}} (c(t) - c_3) dt. \quad (1)$$

If $t_b > T$, then the farmer can start with manual harvesting at time T and he can continue with the manual harvesting for the period $(T, T + t_1)$, where $0 \leq t_1 \leq \min\{t_b - T, H/q_2, B\}$. After that, the farmer stops manual harvesting and waits for the arrival of the machine. Finally, at time t_b , the farmer begins with the machine harvesting and he continues with it until all the available yield is harvested (or until the end of harvesting period). In this case, determining the farmer's optimal working policy is to determine an optimal value of t_1 ($t_1^* = t_1^*(H, T, t_b)$) that maximizes the profit. The farmer's profit is

$$B(t_b, H, T, t_1) = -c_1 + q_2 \int_T^{T+t_1} (c(t) - c_4) dt + q_1 \int_{\min\{t_b, T+B\}}^{\min\{T+B, t_b + \frac{H-q_2 t_1}{q_1}\}} (c(t) - c_3) dt, \quad (2)$$

where $0 \leq t_1 \leq \min\{t_b - T, H/q_2, B\}$. Thus, for this case,

$$t_1^* = t_1^*(t_b, H, T) = \arg \max_{0 \leq t_1 \leq \min\{t_b - T, H/q_2, B\}} B(t_b, H, T, t_1), \quad (3)$$

and the farmer's profit attained by this optimal policy is

$$B(t_b, H, T) = B(t_b, H, T, t_1^*) = \max_{0 \leq t_1 \leq \min\{t_b - T, H/q_2, B\}} B(t_b, H, T, t_1), \quad (4)$$

where $B(t_b, H, T, t_1)$ is defined by Equation (2). The following straightforward proposition guarantees that if the selling price function $c(t)$ is a differentiable function, then for all given values of $H > 0$, $0 \leq T \leq A$, $B > 0$, $0 \leq t_b < A$, $0 < q_2 < q_1$,

$c_4 > c_3 > 0$, there is a unique feasible value of t_1^* that satisfies Equation (3).

Proposition. Assume that the selling price function $c(t)$ is a differentiable function. Then for all given values of $H > 0$, $0 \leq T \leq A$, $B > 0$, $0 \leq t_b < A$, $0 < q_2 < q_1$, $c_4 > c_3 > 0$,

Equation (3) has a unique solution $t_1^* = t_1^*(t_b, H, T)$. This solution is defined as follows:

1. If $t_b \geq T + B$ then $t_1^* = \min\{H/q_2, B\}$.

2. If $T < t_b < T + B$ and

$$QQ = QQ(H, T, t_b, q_1, q_2, B) = \frac{H - q_1(T + B - t_b)}{q_2}, \text{ then:}$$

2.1 If $QQ > t_b - T$ then $t_1^* = t_b - T$.

2.2 If $QQ < 0$ then:

2.2.1 If $c(T) - c_4 \leq c\left(t_b + \frac{H}{q_1}\right) - c_3$ then $t_1^* = 0$,

2.2.2 If $c(T + \min\{t_b - T, H/q_2\}) - c_4 \geq c\left(t_b + \frac{H - q_2 \min\{t_b - T, H/q_2\}}{q_1}\right) - c_3$ then $t_1^* = \min\{t_b - T, H/q_2\}$,

2.2.3 If $c(T) - c_4 > c\left(t_b + \frac{H}{q_1}\right) - c_3$ and

$$c(T + \min\{t_b - T, H/q_2\}) - c_4 < c\left(t_b + \frac{H - q_2 \min\{t_b - T, H/q_2\}}{q_1}\right) - c_3 \text{ then } t_1^*$$

is the unique feasible solution of the equation

$$c(T + t_1) - c\left(t_b + \frac{H - q_2 t_1}{q_1}\right) = c_4 - c_3 \quad (5)$$

and can be found analytically or numerically, depending on the complexity of the selling price function $c(t)$.

2.3 If $0 \leq QQ \leq t_b - T$ then

$$t_1^* = \begin{cases} QQ & \text{if } q_1 \int_T^{T+B} (c(t) - c_3) dt \geq q_2 \int_{T+QQ}^{T+t_1^{**}} (c(t) - c_4) dt, \\ t_1^{**} & \text{otherwise} \end{cases}$$

where t_1^{**} is defined by the following way:

if $c(T + QQ) - c_4 \leq c\left(t_b + \frac{H - q_2 QQ}{q_1}\right) - c_3$ then $t_1^{**} = QQ$,

if $c(T + \min\{t_b - T, H/q_2\}) - c_4 \geq c\left(t_b + \frac{H - q_2 \min\{t_b - T, H/q_2\}}{q_1}\right) - c_3$ then

$$t_1^{**} = \min\{t_b - T, H/q_2\},$$

if $c(T + QQ) - c_4 > c\left(t_b + \frac{H - q_2 QQ}{q_1}\right) - c_3$ and

$$c(T + \min\{t_b - T, H / q_2\}) - c_4 \\ < c\left(t_b + \frac{H - q_2 \min\{t_b - T, H / q_2\}}{q_1}\right) - c_3, \text{ then } t_1^{**}$$

is the unique feasible solution of Equation (5) and can be found analytically or numerically, depending on the complexity of the selling price $c(t)$.

The farmer's profit that incorporates his optimal policy is defined according to Equation (1) for $t_b \leq T$, and in according to Equation (2) with $t_1 = t_1^*$ for $t_b > T$, where t_1^* is stated in the above proposition.

4. An analysis of the optimal start time for the machine rental

This section presents a procedure for determining the optimal value of the decision variable $0 \leq t_b < A$ in order to maximize the farmer's expected profit, $E(B(t_b, H, T))$, assuming that the farmer behaves according to his optimal working policy. The aim is to find t_b^* such that

$$t_b^* = \arg \max_{0 \leq t_b < A} E(B(t_b, H, T)), \quad (6)$$

where $B(t_b, H, T)$ is defined in Equations (1) and (4). Assuming that the random variables T and H are independent, the farmer's expected profit has the form

$$E(B(t_b, H, T)) = \int_0^A \int_0^A B(t_b, h, \tau) f_T(\tau) f_H(h) d\tau dh \\ = \int_0^A \int_0^{t_b} B(t_b, h, \tau) f_T(\tau) f_H(h) d\tau dh \\ + \int_0^A \int_{t_b}^A B(t_b, h, \tau) f_T(\tau) f_H(h) d\tau dh, \quad (7)$$

where $f_T(x)$ and $f_H(x)$ are known density functions of the random variables T and H , respectively. Straightforwardly by Equations (1)-(4), (7)

$$E(B(t_b, H, T)) \\ = \int_0^A \int_{t_b}^A \left(\begin{aligned} & \left(-c_1 - c_2(\tau - t_b) \right. \\ & \left. + q_1 \int_{\tau}^{\min\{\tau + B, \tau + h/q_1\}} (c(t) - c_3) dt \right) \\ & \times f_T(\tau) f_H(h) \end{aligned} \right) d\tau dh \\ + \int_0^{t_b} \int_0^A \left(\begin{aligned} & \left(-c_1 + q_2 \int_{\tau}^{\tau + t_1^*} (c(t) - c_4) dt \right. \\ & \left. + q_1 \int_{\min\{\tau + B, t_b + \frac{h - q_2 t_1^*}{q_1}\}}^{\min\{\tau + B, \tau + h/q_1\}} (c(t) - c_3) dt \right) \\ & \times f_T(\tau) f_H(h) \end{aligned} \right) d\tau dh, \quad (8)$$

where t_1^* is stated by the proposition presented in section 3. Note that in any real life problem, the decision variable t_b , $0 \leq t_b \leq A$, is practically not continuous and can be considered to have a finite number of values (e.g., the values of t_b are the integer numbers of hours after the earliest possible time for starting the harvest season). Therefore, the optimal value of t_b may be attained by examination of all its possible values. That is, the farmer's expected profit $E(B(t_b, H, T))$ can be calculated (with reasonable accuracy in the context of a considered real problem) for all possible values of t_b . Then, the value of t_b that yields the farmer's highest expected profit is the needed solution t_b^* of Equation (6). The farmer's expected profit $E(B(t_b, H, T))$ can be approximated by utilizing a numerical integration of the double integrals in equation (8) or it can be approximated by simulation.

5. Conclusions

This research proposed a stochastic newsvendor-like model to maximize the farmer's expected profit in the context of an unknown (stochastic) fruition date of blueberry crops and an unknown (stochastic) quantity of the yields in the field. Assuming that the two aforementioned random variables are independent, the results of this research enable the farmer to calculate the optimal due date for the arrival of a rented harvesting machine, and then, when the values of the random variables are revealed (fruition date and quantity), to select the optimal harvesting policy. The presented analysis can be adjusted for a situation where the two random variables, the fruition date and the quantity of the yields in the field are dependent random variables.

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INFLUENCE OF THE RECOMBINATION OF IONS ON THE PRODUCTIVE CAPACITY OF THE ELECTRIC CORONA IONIZATION FOR STORAGE OF JUICY PLANT PRODUCTS

ВЛИЯНИЕ РЕКОМБИНАЦИИ АЭРОИОНОВ НА ПРОИЗВОДИТЕЛЬНОСТЬ ЭЛЕКТРОКОРОННОГО АЭРОИОНИЗАТОРА ДЛЯ ХРАНИЛИЩ РАСТИТЕЛЬНОЙ ПРОДУКЦИИ С СОЧНЫМИ ТКАНЯМИ

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Abstract: The works on creation of technique of calculation of the electric corona ionization for storage of products with juicy plant products are summarized. The necessity to determine the effect of recombination of ions on the performance of these devices is proved. The dependence of the concentration of ions from the ionizer uptime, productivity and the recombination coefficient was obtained. It was determined that when calculating performance electric corona ionization for processing of plant products with succulent tissues outside the corona ions recombination can be ignored. Elucidation of the role of recombination in the processing of such products in the inter electrode space further research.

KEYWORDS: JUICY PLANT PRODUCTS, STORAGE, ELECTRIC CORONA IONIZATION, PRODUCTIVE, IONS, RECOMBINATION

1. Introduction

Performance of air ionizers, which are used in industrial processes, in particular the storage of plant products with rich fabrics, is much higher ionizers of industrial and residential premises. Ionizers for rooms where people are, as a rule, do not require calculations, for their performance to ensure comfortable stay of humans is quite sufficient. For processes of ionizer performance should be of maximum resolution. When creating a methodology of calculation of such ionizers it is necessary to determine the effect of recombination of ions on its performance.

2. Preconditions and means for resolving the problem

Aero ions treatment of plants with succulent tissues products can reduce losses during storage, extended shelf life as well as loss of nutrients can also be prevented [1,2,3,4].

The methodology of calculation of such ionizers includes: definition of energy efficiency of the process and on the basis of their study selection processing duration, depending on the workload of the installation [5]; determining the duration and frequency of treatment and the concentration of ions at a predetermined processing efficiency [6]; determination of relation of electric corona ionization performance on its design parameters [7,8,9,10,11]; equipment calculation for the ion processing equipment in storage during transport of ions to the processing facility with an active ventilation system [12] and using feedback from the processing object for timely correction processing modes [13].

Aero ions processing of plant products with rich fabrics can be carried out in the inter electrode space (single treatment for short-term storage) and outside it (intermittent treatment with long-term storage).

Aero ions processing of plant products with rich fabrics can be carried out in the inter electrode space (single treatment for short-term storage) and outside it (intermittent treatment with long-term storage). In the latter case the necessary to take into account the recombination of ions in space and time, as well as their losses during transportation is obtained. In [12] dependencies which allow to determine the concentration of ions at a certain distance from their source, but without taking into account recombination are obtained. Equation of reducing the concentration of ions in time received of empirically derived in [14]. The authors argue that this

reduction corresponds to a linear relationship. It does not correspond to the physical nature of the process.

Approximation of data with an exponent gives constant duration of recombination $\tau_r = 7.65$ min. The correlation coefficient was 0.944 at the same time.

Reducing the concentration of ions in the space was investigated experimentally [14,15,16,17,18].

Research of dynamics of change of aero ionic indoor air gave the analytical relationships that allow determine the concentration of ions in industrial structure [19].

The purpose of work is investigation of the effect of recombination of ions in time for the performance electric aero ionizer for plant products storage with rich fabrics.

3. Results and Discussion

Under the action of an external ionizer considering recombination true first order differential equation [20].

$$\frac{d\eta}{dt} = q - r\eta^2, \quad (1)$$

η - concentration of ions, t - duration of the ionizer, q - ionizer performance, r - recombination coefficient.

After separation of variables

$$d\eta = q dt - r\eta^2 dt. \quad (2)$$

The solution of this equation [21] gives the concentration dependence of the ions from the ionizer work duration, its performance and the recombination coefficient, namely:

$$\eta = \sqrt{\frac{q}{r}} \operatorname{th}\left(t\sqrt{qr}\right). \quad (3)$$

The values of the recombination coefficient are $1.67 \cdot 10^{12} \text{ m}^3/\text{s}$. [22].

Performance ionizer varies from $1 \cdot 10^{12} \text{ m}^3$ to $1.2 \cdot 10^{13} \text{ m}^3$ [7,23].

Consequently, work on the ionizer performance recombination coefficient can be regarded as little more than one. The square root of this product even is more closer to it. Hyperbolic tangent of the general can not be bigger than one. In the end, the concentration of ions in inter electrode spacing interval is directly proportional to the square root of the ionizer performance and inversely proportional to the square root of the recombination coefficient, which is confirmed

by a graphical analysis of the equation (3) with respect to electric aero ionizer for plant products storage of juicy plant products.

Obviously, this function does not have extremum. Further analysis is performed graphically.

The dependence of the concentration of ions on the duration of the ionizer's work and the recombination coefficient of performance of the ionizer $q = 5 \cdot 10^{13} \text{ m}^3 \text{ s}^{-1}$ is shown in Fig. 1.

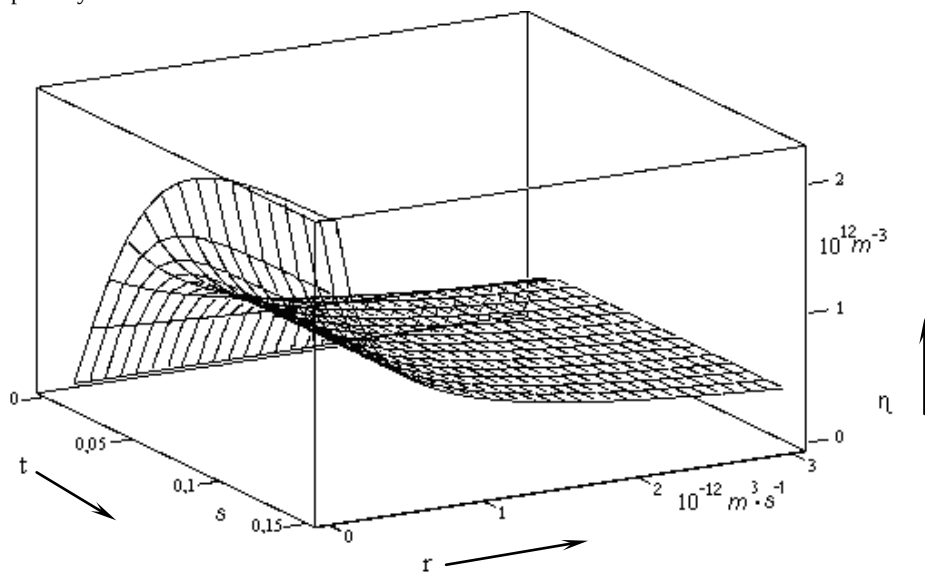


Fig. 1. The dependence of the concentration in the length of the ionizer, of the duration of operation of the ionizer and the recombination coefficient

The dependence of the concentration of ions in the inter electrode space on the duration of operation of the ionizer, and his performance in the recombination coefficient $r = 1 \cdot 10^{-12} \text{ m}^3 \text{ s}^{-1}$ is shown in Fig. 2.

The dependence of the concentration of ions on the performance of the ionizer and the recombination coefficient on the productivity of the ionizer $t = 1 \text{ s}$ shown in Fig. 3.

As you can see, in order to achieve steady-state operation of the ionizer enough 1 sec., so when calculating performance of electric aero ionizer for processing of plant products with rich fabrics is a corona discharge zone recombination of ions can be

ignored. Elucidation of the role of recombination in the processing of such products in the inter electrode space further research.

4. Conclusions

The dependence of the concentration of ions in the inter electrode space of ionizer for storage of plant products with rich fabrics, its performance and the recombination coefficient is received on the duration of the ionizer operation. Its analysis has been performed.

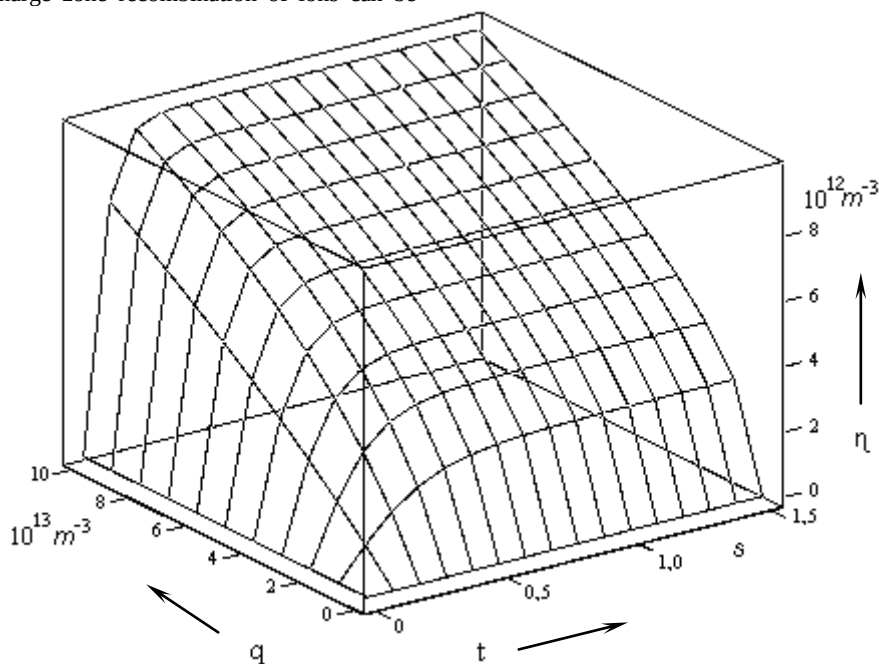


Fig. 2. The dependence of the concentration of ions in the inter electrode space on the duration of operation of the ionizer and his performance.

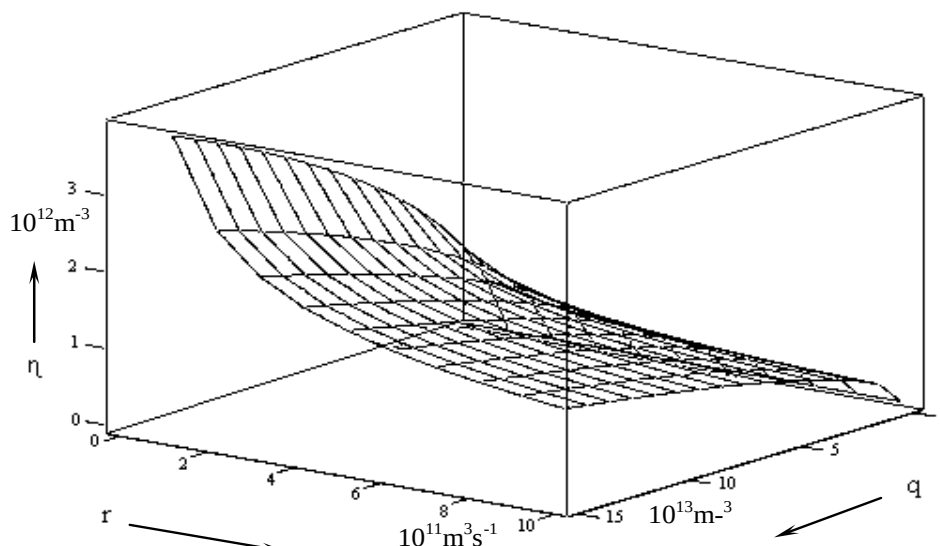


Fig. 3. The dependence of the concentration of ions on the performance of the ionizer and the recombination coefficient

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RESEARCH PNEUMATIC GRAVITY SEPARATION GRAIN MATERIALS

ИССЛЕДОВАНИЕ ВОЗДУШНОГРАВИТАЦИОННОЙ СЕПАРАЦИИ ЗЕРНОВЫХ МАТЕРИАЛОВ

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Abstract: The mathematical description of the motion of particles of grain mixture in the chamber, air separator gravity under the action of a pulsating flow of air of variable speed. An trajectory of particles of different sizes. The resulting equations of motion of particles under the action of a pulsating flow of air to determine the dependence of the velocity of material in grain liquefied air layer of material on a number of factors: the geometric parameters of sieve openings, the angle of presentation, initial the kinematic mode material index kinematic mode sieves and sails share ratio. Theoretically reasonable technological possibilities of the proposed method of separation of grain by the action of air flow and impact on established technological performance parameters: air speed factor with regard to living sectional thickness of material entering the channel.

KEYWORDS: SEPARATOR AIR FLOW, WEEVIL, VARIABLE AIR SPEED, TRAJECTORY, FORCE RESISTANCE, FACTIONS, PULSATING AIR FLOW, WIND FACTOR.

1. Introduction

Air separation (separation and purification of grain mass) is one of the most common methods of postharvest processing of grain mixtures of different cultures. To implement an air separation using pnevmoseparatory those have a simple design and compact and reliable operation. Existing structures pneumatic of the separation job of separating the grain mixture aerodynamic properties of the particles only into two main fractions: heavy and light. Seeds that have high critical rate - has the best biological properties. It is therefore advisable to use air flow to separate seed into several factions.

2. Preconditions and means for resolving the problem

Because they are used for clearing of small impurities, or for re-division of the size or density, when introduced material in the air flow equal density particles are separated by size or same size by density. Thus there is a stable relationship between the critical velocity and their biological properties [1, 10, 11]. Seeds that have high critical rate - has the best biological properties. It is therefore advisable to use air flow to separate seed into several factions. The emergence of new structures air separators [4, 5, 6] with the lower zone of separation and discharge of certain factions allows manner of separating by trajectories [2, 3, 7, 8] and pneumatic gravity canals seed treatment machines is a promising area of improvement.

Review of existing technologies and facilities for grain material separation air flow and analysis of the results of their research [9, 12, 13] revealed the following. Vertical pnevm sifter used for grain processing enterprises are usually separates two fractional material as a mixture of [14, 15, 16] the difference of the resistance of air environment different factions grain material. To separate grain mixture into several factions in the air stream used inclined pnevm chanel [17, 18, 19] and principles pnevm insertion separated by stuffing the grain mass in the cylinder primary suction or airflow. Separation occurs as a result of the difference in air resistance components of the grain mixture (mass), cast with a fairly large initial velocity.

Found that the most influential technological efficiency separation on [19, 20] factors are: the aerodynamic properties of the material and unit load on air channels; air flow characteristics and geometry of the channel; provided input grain mixture in an air stream. But as the experience of the operation [20, 21] defining characteristics pneumatic separating system is the speed and angle of feed grain material in the channel (air flow) and parameters distribution element.

Improving the quality of grain separation materials in vertical air channels can be achieved by improving the way in feed grains and airflow optimization of the flow. The most effective [14, 17, 19] presentation of the material with a thin layer. To realize such a

filing by use of rotary and rotary surfaces (cone, sphere, paraboloid) whose external surface area increases when removed from the top. In the process of movement on such a surface thickness of the grain decreases in airflow may enter individual grains.

In the literature are divergent data on parameters input material in the channel - the angle at which the material is introduced in the channel and speed $\alpha_0 v_0$: $0^\circ - 10^\circ$, $0,2 - 0,5$ m / s [5, 6]; 0° , $0,7$ m / s [11]; $0^\circ - 10^\circ$, $0,2 - 0,8$ m / s [14]; since these parameters, according to experimental data, significantly affect the process of separating the criterion deflection trajectories of particles of material as the top (with respect to the input) and the lower zone of the channel, it is appropriate, based on a single methodological approach to identify the impact of primary traffic conditions and particle separation treatment on the quality of separation.

3. Results and Discussion

Sort grain mixes air flow is known to be based on the ability of individual particles do different opposition air environment at their relative motion, depending on the physical properties. In practice, air separation to characterize the properties of a complex indicator - the coefficient of sails (wind conductivity) having a dimension and is determined from the expression:

$$(1) \quad K = C_x(Re) \frac{\rho_0 \cdot S}{2 \cdot m} = \frac{q}{u_{\text{air}}^2},$$

$C_x(Re)$ - dimensionless drag coefficient is a function of the Reynolds criterion; ρ_0 - air density; m , S - mass and cross section area Midelevoho particles; u_{air} - speed congratulations class of particles.

As a simulation model of the separation process commonly used in the art knowledge [20] differential equations of motion of a particle in a medium with (Nyutonovskym) resistance:

$$(2) \quad \frac{d^2 y(\tau)}{d\tau^2} = g - K \cdot \left(\frac{dy(\tau)}{d\tau} + u \right) \cdot \sqrt{\left(\frac{dy(\tau)}{d\tau} + u \right)^2 + \left(\frac{dx(\tau)}{d\tau} \right)^2},$$

$$(3) \quad \frac{d^2 x(\tau)}{d\tau^2} = -K \cdot \frac{dx(\tau)}{d\tau} \cdot \sqrt{\left(\frac{dy(\tau)}{d\tau} + u \right)^2 + \left(\frac{dx(\tau)}{d\tau} \right)^2},$$

u - air speed in the channel, m / s;

v_0 - velocity when entering the stream, m / s;

α_0 - angle velocity particle stream at the entrance to hail;

y , x - coordinates of a particle, m;

τ - time, s; g - acceleration of gravity, m/s²;

Define the concept of separation efficiency and separation sharpness. If separation of cereal seeds main task exception process or ingress "substandard fractions" (a light, broken, empty, etc.) In selected seed. Therefore, the definition of separation could take a percentage of the number of substandard products in the selected seeds:

$$(4) \quad \eta = \frac{m_H - m_{HT}}{m_H} \cdot 100$$

m_H , m_{HT} - number of selected seeds and the number of substandard grain selected fractions, kg.

To determine rational values of speed and angle of presentation in the channel and air channel in the magnitude of the differences

and trajectories criterion of efficiency, a series of numerical experiments with such variables angle input material.

According to the results of numerical simulations to plan three factorial experiment received adequate mathematical model regression process of separating binary mixtures of grain by weight and speed greetings ($m_1 = 0,04 \cdot 10^{-3}$ kg; $v_{vyt,1} = 7.9$ m / s ; $m_2 = 0,025 \cdot 10^{-3}$ kg; $v_{vyt,2} = 6.2$ m / s):

$$(5) \quad \Delta x(\alpha_0, v_0, v) = -0,088 + 0,003 \cdot \alpha_0 + 0,024 \cdot v \cdot v_0 - 0,001 \cdot \alpha_0 \cdot v_0 + 0,002 \cdot v^2 - 3 \cdot 10^{-4} \cdot v \cdot \alpha_0 - 6,13 \cdot 10^{-5} \cdot \alpha_0^2$$

$$(6) \quad \varepsilon(\alpha_0, v_0, v) = -0,583 + 0,017 \cdot \alpha_0 + 0,158 \cdot v \cdot v_0 - 0,008 \cdot \alpha_0 \cdot v_0 + 0,017 \cdot v^2 - 0,002 \cdot v \cdot \alpha_0 - 4,4 \cdot 10^{-5} \cdot \alpha_0^2$$

According to the mathematical regression models constructed response surface (Fig. 1).

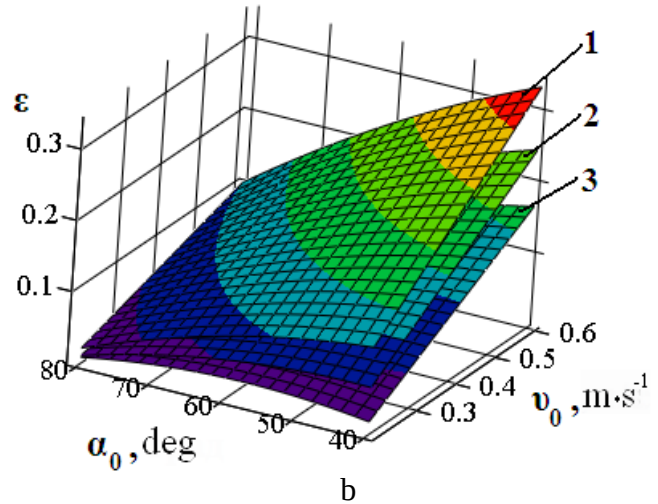
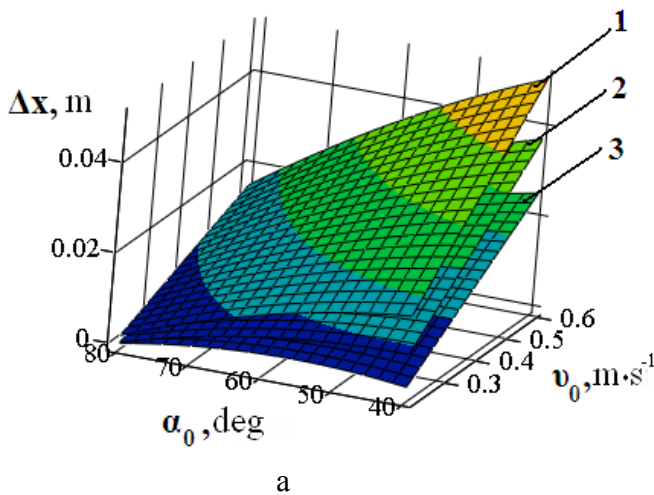


Fig. 1. Surfaces response deviation trajectory fractions in the place of unloading Δx (a) and the criterion of efficiency ε (b): airflow speed 1 – $v = 5,5$ m / s; 2 – $v = 5,0$ m / s; 3 – $v = 4,5$ m / s;

The effect of increasing the difference in the trajectories of output channel is increased by increasing the feed rate of particles in the air flow to the values of 0.5-0.6 m / s air velocity close to the speed of light fraction greetings at an angle of 40 ° -50 °.

The speed of air in the channel in the specified range has little effect on the value of the maximum deviation of the trajectory. For channel radius $R = 0.2$ m value $\Delta x = 0,08$ m, $x_2 = 0.2$ m and to channel radius $R = 0,1$ m: $\Delta x = 0,05$ m, $x_2 = 0,09$ m, respectively equal performance criteria $\varepsilon_1 = 0,4$ and $\varepsilon_2 = 0,55$.

Analysis of the studies revealed major shortcomings and areas for improvement process separation grain materials. Implement the required parameters of presentation of the existing air flow conical distributor [20] is not possible. Therefore, to ensure speed east in a wide range of change (0,4-0,9 m / s) at the corners - 10-80 ° appropriate to apply the distributors in the form of rotating surfaces where generators has the form of variable radius curve. As the velocity of the particles along the bearing surface in the area of East depends on the initial velocity, the latter can be used as a control parameter.

Increase airflow (close to the size of the removal of light particles) have a positive impact on increased efficiency by dividing a deviation trajectories within 4,5-6 m / s almost no effect on the "theoretical" value deviations. But the actual process of separation flux of different sails with increasing air velocity on particles begin to act, the forces that arise due to asymmetrical flow of particles (irregular) - Forces [21] of the "forces of Zhukovsky," rejecting the particle in a random direction, which reduces efficiency division.

To avoid this negative phenomenon advisable to increase the speed zone (input material in the channel), and the bottom of the channel air speed reduced. You can use such a conical annular channel [21].

As the speed of air flow in the direction of the material linearly:

$$(7) \quad v_v = v_m - a \cdot y(\tau)$$

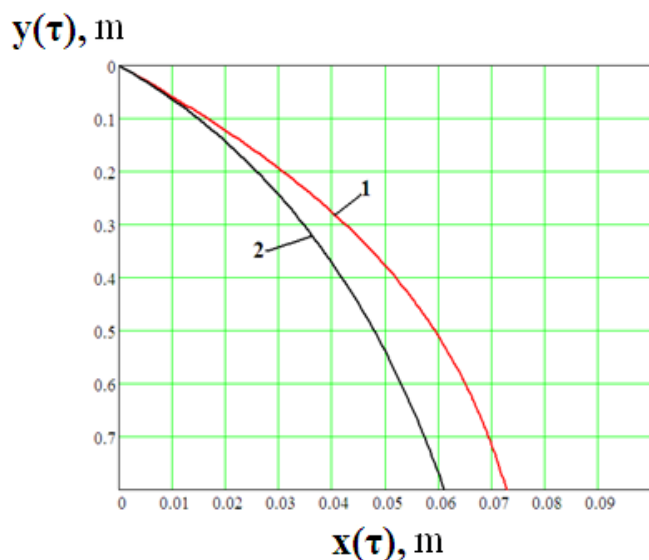
v_v - air velocity, m / s; v_m - air velocity at the beginning of a particle, m / s; a - speed reduction ratio.

Deviations trajectory in the zone of intense separation is much steeper trajectory and the value of splitting this increases, increasing the efficiency of separation.

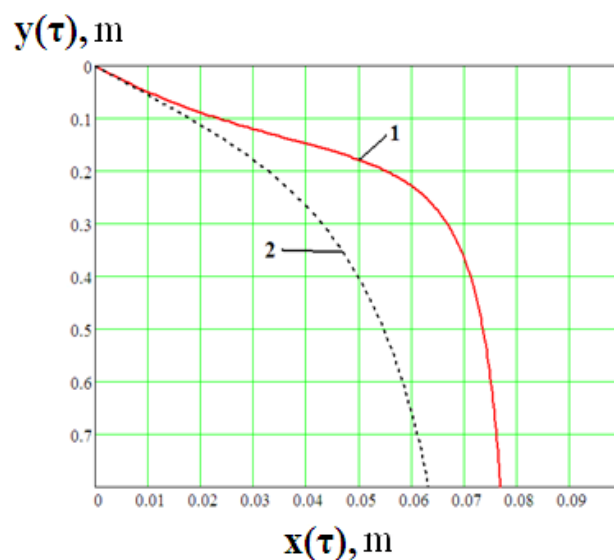
Fig. 2. shows the trajectory of particles of grain material at a constant height channel airflow and at a linear speed reduction along the stream.

4. Conclusions

The analysis of theoretical studies established the possibility of increasing the efficiency of separation grain materials on aerodynamic characteristics and the proportion of particles through intensification and increased efficiency in the separation of the grain mixture application for division of air flow in passive sieve mixes.



a



b

Fig. 2. Trajectory fractions at a constant airflow (a) and linear decrease airflow height (b):
1 – light fraction $v_{vit} = 11.8 \text{ m/s}$; 2 – heavy fraction $v_{vit} = 12.1 \text{ m/s}$;

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THEORETICAL RESEARCH OF CLEANER PRESSURE ON SUGAR BEET ROOT CROP

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Abstract: Technology incompatibility in the sugar beet harvesting process is established. Beet tops removing by follower cutoff with the subsequent root crop heads cleaning is possible at speed no more than $1.5 \text{ m}\cdot\text{s}^{-1}$ whereas beet pullers operate at speeds of 1.2... 1.5 times are higher. At a cutting without copier of sugar beet tops a working speed makes more than $1.5 \text{ m}\cdot\text{s}^{-1}$, however losses of sugar-bearing plant material exceed agrotechnical requirements twice because of unreasonable height of a cut relative to soil surface. The differential equation of bow-shaped copier movement on a root crop head of sugar beet which is the main equation of functioning root crops heads cleaner is worked out. Components of the differential equation are defined and dependence of normal reaction on design parameters of root crop head cleaner is received. Conditions not of knocking-out of root crops are received and rational values of design parameters and operating modes of root crop head cleaner are proved.

KEYWORDS: ROOT CROP, BEET TOPS, ROOT CROP HEAD, CLEANER, WORKING MEMBER, SENSING MEMBER, NORMAL REACTION, DEFOLIATOR

1. Introduction

There is an incompatibility between the operations of harvesting beet tops and digging sugar beet root crops at working speeds, while observing the requirements of the standard for the quality of raw materials (waste of sugar-bearing mass at cut - no more than 2%, and the tops remains on root crops - no more than 1.5%): beet tops separation by sensing cut with subsequent post-cleaning of the residues is possible at a speed of no more than $1.5 \text{ m}\cdot\text{s}^{-1}$, whereas the root-harvesting machines operate at speeds of 1.2...1.5 times higher. However, in the increased operating conditions of the cleaner, dynamic forces arise, causing damage and knocking out the heads of root crops. [1, 3, 4].

Overcoming these contradictions by scientifically justifying the process of non-sensing cutting of beet tops with minimal losses of sugar-bearing content and developing new technical solutions that will improve separation quality of tops residues at speeds close to the working speeds of root harvesting machines is urgent scientific and production task.

The process of interaction of the working element with the heads of root crops is cyclic and therefore the value of the normal reaction in contact point with the root crop head is variable and has a pulsating character. It is necessary to investigate its change and to estimate the peak loads on the root crop in order to prevent the limiting values of heads damage and knocking out of root crops..

2. Preconditions and means for resolving the problem

2.1. Analysis of recent research and publications

Known method of separating beet tops at operating speeds of about $2 \text{ m}\cdot\text{s}^{-1}$ using non-sensing cut the bulk of foliage and subsequent passive topping root crops heads with the remains of leaves, but the losses of sugar-bearing plant materials exceeds the standard requirements and can reach 8%.

Currently working bodies which designed for non-sensing separation of the bulk of foliage, which can operate at speeds higher than speed of root crops digging, but there is no justification for the height of non-sensing cut and designs of working bodies for separation beet tops residues on operating speeds over $1.5 \text{ m}\cdot\text{s}^{-1}$ [1, 3, 4, 13, 14].

2.2. Purpose of the study

Determination of dependence of normal reaction on root crop from constructive and technological parameters.

2.3 Materials and Methods

The object of this research is the process of separating beet tops from sugar beet root crops head by cleaner.

The main provisions of theoretical mechanics and material resistance, as well as previous studies of the physico-mechanical properties of sugar beet roots, were used to conduct research.

A necessary condition for the functioning of the working element and, accordingly, the stability of the process is characterized by the continuity of the cleaning element from the sensor and the sensor from the root crop. Let's compose the calculation scheme fig. 1 and consider the equation of dynamic equilibrium of copier, which will be equation for functioning of this mechanism [2, 5-8, 11, 12]:

$$J_k \cdot \ddot{\phi} = -M_k + M_G + M_L, \quad (1)$$

where J_k – inertia moment of copier relative to the suspension point; M_k – force moment of action root crop head on a sensor; M_G – moment of gravity; M_L – force moment of a blade pressure on sensor.

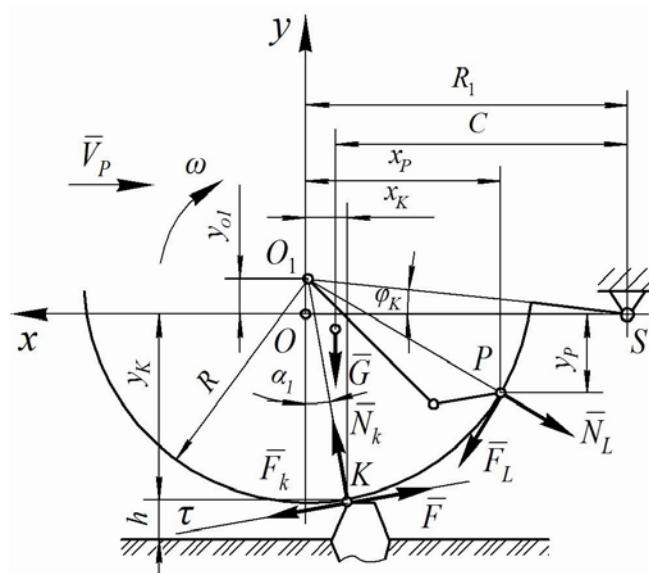


Fig. 1. The equivalent scheme of interaction cleaner with root crops head

Value of equality components have been identified (1) with the following form [5-8, 11, 12]:

$$\ddot{\varphi} = \frac{V^2 \cdot R^2}{R_1 \left(R^2 - \left(Vt - \sqrt{2Rh - h^2} \right)^2 \right)^{2/3}}, \quad M_k = N_k (a + f_1 b),$$

$$M_L = \left(\frac{m\omega^2 r \cdot l \sin \alpha - J \cdot \ddot{\alpha}}{d + fe} \right) (d_1 + fp_1), \quad M_G = G \cdot c,$$

where J, J_k – inertia moments of sensor relative to the suspension points; R_1 – distance from the center of sensor to suspension point; c, a, b and d_1, p_1 – accordingly shoulders of forces G, N_k, F_k and N_L, F_L – with respect to copier suspension axis; d, e – shoulders of forces of normal reaction and friction of sensor on cleaning element with respect to suspension axis of cleaning element.

Substituting value of resulting constituent expressions in equation (1), we determine the normal reaction force which acting in contact between root crop and sensor:

$$N_k = \frac{1}{a + f_1 b} \left[\frac{J_k \cdot V^2 \cdot R^2}{R^1 \left(R^2 - \left(Vt - \sqrt{2Rh - h^2} \right)^2 \right)^{2/3}} + G \cdot c - \frac{d_1 + fp_1}{d + f \cdot e} (m\omega^2 r l \cdot \sin \alpha - J \ddot{\alpha}) \right]. \quad (2)$$

3. Results and discussion

When the copier moves on the root crop head, it is possible knock out from soil and damage the root crop. The condition of not knocking out the root crops is:

$$N_k \leq [N_k] = \frac{[P_G]}{\sin \alpha_1 + f \cos \alpha_1}, \quad (3)$$

where $[P_G]$ – limiting horizontal component of root crop stability in soil; α_1 – angle between the axis Oy and the force N_k , we assume for calculations $\alpha_1 = 38^\circ$, which corresponds to the beginning of the contact between sensor and root crop height $h = 80$ mm. At $[P_G] = 200$ N allowable value of the normal reaction $[N_k] = 172$ N [9, 10].

The minimum value of the force at which the head of root crops destructed – $[P_k] = 200$ N [9, 10].

For the dependencies obtained, calculation programs for PC are compiled and results of calculations are shown in fig. 1-7.

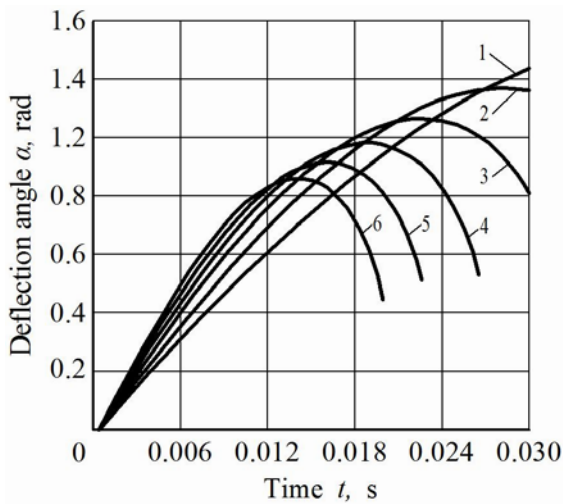


Fig. 2. The deflection angle α cleaning element of the radial position: 1 – $\omega = 60$ deg; 2 – $\omega = 80$ deg; 3 – $\omega = 100$ deg; 4 – $\omega = 120$ deg; 5 – $\omega = 140$ deg; 6 – $\omega = 160$ deg

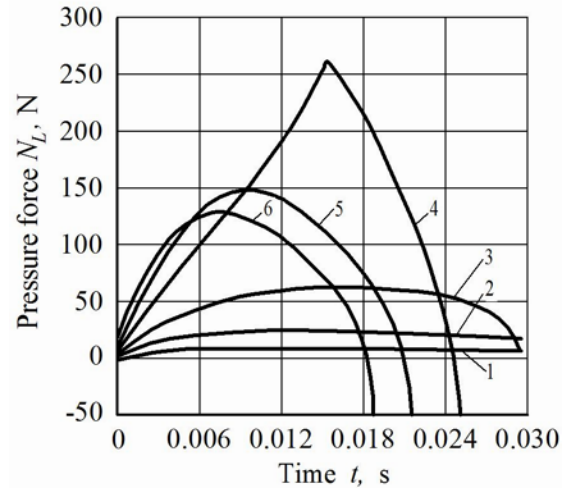


Fig. 3. The pressure force N_L cleaning member for copier: 1 – $\omega = 60$ deg; 2 – $\omega = 80$ deg; 3 – $\omega = 100$ deg; 4 – $\omega = 120$ deg; 5 – $\omega = 140$ deg; 6 – $\omega = 160$ deg

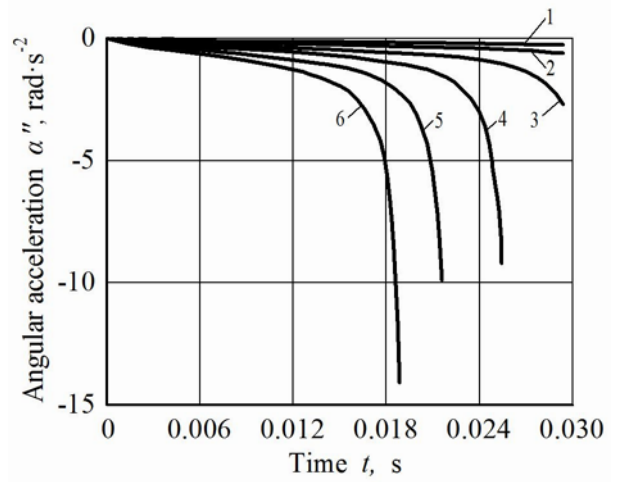


Fig. 4. The angular acceleration of the cleaning member: 1 – $\omega = 60$ deg; 2 – $\omega = 80$ deg; 3 – $\omega = 100$ deg; 4 – $\omega = 120$ deg; 5 – $\omega = 140$ deg; 6 – $\omega = 160$ deg

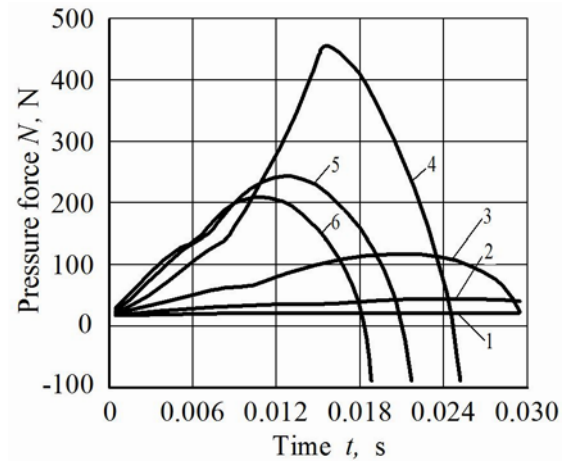


Fig. 5. The pressure force N copier cleaner on a root vegetable at different angular velocities: 1 – $\omega = 60$ deg; 2 – $\omega = 80$ deg; 3 – $\omega = 100$ deg; 4 – $\omega = 120$ deg; 5 – $\omega = 140$ deg; 6 – $\omega = 160$ deg

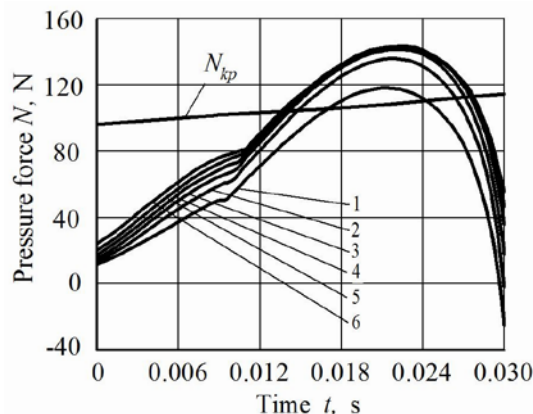


Fig. 6. The pressure force on the copier cleaner N_{kp} root vegetable with angular velocity $\omega = 100 \text{ s}^{-1}$ and different translational velocities: 1 – $V_p = 0.5 \text{ m}\cdot\text{s}^{-1}$; 2 – $V_p = 1.0 \text{ m}\cdot\text{s}^{-1}$; 3 – $V_p = 1.5 \text{ m}\cdot\text{s}^{-1}$; 4 – $V_p = 2.0 \text{ m}\cdot\text{s}^{-1}$; 5 – $V_p = 2.5 \text{ m}\cdot\text{s}^{-1}$; 6 – $V_p = 3.0 \text{ m}\cdot\text{s}^{-1}$

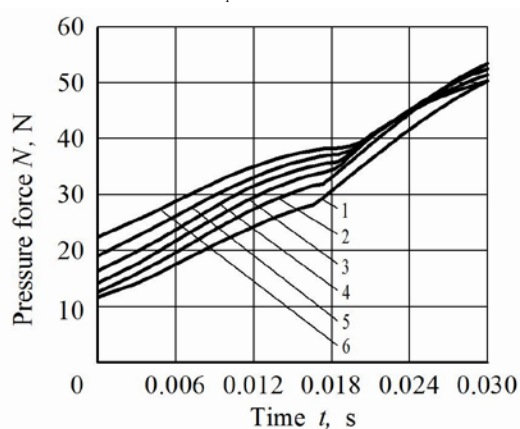


Fig. 7. The pressure force copier cleaner on a root vegetable with angular velocity $\omega = 60 \text{ s}^{-1}$ and different translational velocities: 1 – $V_p = 0.5 \text{ m}\cdot\text{s}^{-1}$; 2 – $V_p = 1.0 \text{ m}\cdot\text{s}^{-1}$; 3 – $V_p = 1.5 \text{ m}\cdot\text{s}^{-1}$; 4 – $V_p = 2.0 \text{ m}\cdot\text{s}^{-1}$; 5 – $V_p = 2.5 \text{ m}\cdot\text{s}^{-1}$; 6 – $V_p = 3.0 \text{ m}\cdot\text{s}^{-1}$

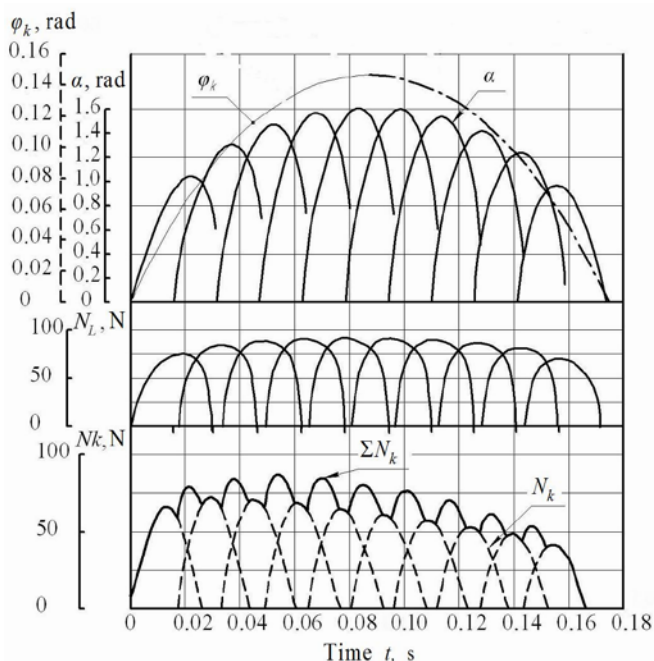


Fig. 8. Dependence of cleaner element rotation angle and normal reaction at machine translational speed $V_p = 2 \text{ m}\cdot\text{s}^{-1}$ and the rotor angular velocity $\omega = 100 \text{ s}^{-1}$.

4. Conclusions

With translational speed $V_p = 1...3 \text{ m}\cdot\text{s}^{-1}$, rotor angular velocity $\omega = 90...105 \text{ s}^{-1}$, number of cleaning elements $z = 4...6$ and diameter of cleaning rotor $D = 0,55...0,65 \text{ m}$ the rational normal reaction force in the contact point of sensor-root crops is ensured at level – $N_k = 60...100 \text{ N}$.

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THE RESULTS OF THE LABORATORY AND FIELD TESTS OF SEEDERS WITH COMBINED PLOUGHSHARES

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According to the developed technique, the laboratory and field research tests were carried out for the experimental installation of the stubble grain seed drill with working organs for separate application of seeds and fertilizers [1, 2]. The test conditions were determined in accordance with SST 20915 [3]. The evaluation of agrotechnical indicators was carried out in accordance with SST 31345 [4].

During the tests, the investigated parameters were the working velocities of the experimental setup- $V = 8; 10$ and 12 km/h , setting depth of coulters - $h = 5; 7$ and 10 cm . The row spacing is 22.8 cm . The repetition of the experiment is four-fold. Determination of the experimental traction resistance of a set of prototypes of the working bodies of the seeder was carried out in accordance with the requirements of SST R 52777 [5] simultaneously with the evaluation of agrotechnical indicators.

To record and process the experimental data, a measurement information system was used with the IS 264 with the module MS-5 of the KubNIITiM [6].

Processing of primary materials of experimental studies was carried out using appropriate software tools in the MathCad, MSExcel and descriptive mathematical statistics. The results of the data are presented in the table.

To determine the traction resistance of the seed drill theoretically, the previously obtained formulas were used:

- With series claw coulters [7]:

$$R = G \cdot f + \sqrt[3]{\frac{D^4}{b \cdot q \cdot d^2}} + h \cdot b \cdot n \cdot (K_m + K_p + K_k), \quad (1)$$

- with coulter for separate seeds and fertilizer introduction [8]:

$$R = G \cdot f + \sqrt[3]{\frac{D^4}{b \cdot q \cdot d^2}} + n \cdot [h \cdot b \cdot (K_m + K_p + K_k) + 2h_1 \cdot b_1 \cdot (K_{1m} + K_{1p} + K_{1k})], \quad (2)$$

Where h_1 - Depth of the horizontal jaw, m;

b_1 - The width of the horizontal jaw, m;

The results of theoretical calculations (R_t) and experimental studies (R_E^1 and R_E^2) are given in the table (field background - stubble). The tiller aggregate tractor Belarus 952 + SZTSS-2.0 seeder with serial claw coulters (R_E^1) and with coulters for separate seed and fertilizer application (R_E^2).

Table- The results of the theoretical calculations (R_t) and experimental studies (R_E^1 and R_E^2)

Experiment No	date	Description	Depth cm	soil Average moisture, %	of Average hardness soil, kg / cm ²	The results of the experiment					Theoretical tractive resistance (R_T), кН
						Velocity km/h	Actual velocity km/h	average traction of central shovel (R_E^1), кН	Ср. тяга Ав traction for separate applica- tion (R_E^2), кН	Av. Fuel consump- tion kg/h	
1	28.09. 2016	Tractor Bela- rus 952 + C3C 2,1 with central shovel ploughshare and coulter for separate application of seeds and fertilizers	4	5,6	138	6	5,57	7,264	7,41	19,09	7
						8	7,9	8,561	8,90	23,443	7,56
						10	9,51	9,33	9,80	17,258	8,35
						12	11,6	11,49	12,18	18,951	10,52
2	28.09. 2016		7	37	267	6	5,74	7,602	7,83	20,196	7,10
						8	7,74	8,65	9,07	23,104	8,49
						10	9,84	8,492	11,29	17,723	10,25
						12	10,91	11,78	12,49	19,156	12,00
3	28.09. 2016		10	49,4	348	6	5,81	8,294	8,54	21,965	8,2
						8	7,78	8,894	10,00	23,365	8,9
						10	9,6	9,187	10,80	19,67	10,3
						12	11,6	12,06	12,90	21,065	12,30

A comparative analysis of the results obtained is presented in Figures 1-3. Thus, analysis of figure 1 shows that with a depth of tillage $a = 4 \text{ cm}$ and a change in the working speed of the

unit from 5.57 km/h to 11.6 m/s , the theoretical traction resistance of the seeder (R_T) increases from 7.0 kN to $10,52 \text{ kN}$. In this case, the value of the working speed of the unit V is increased by

more than 2 times, and the R_t value is increased by 50%. The results of processing the experimental points show that they are approximated by a second-order polynomial dependence (R_E^1 and R_E^2) with $R^2 = 0,99$ reliability. When the working speed of the unit varies within the specified limits, the value of the experimental traction resistance of the seeder with the serial claw coulters (R_E^1) increases from 7.26 kN to 11.49 kN, which is about 60%. Similar data for a seeder with coulters for separate application of seeds and

fertilizers, the value of R_E^2 increases from 7.41 kN to 12.18 kN, which is more than 64%. In general, the percentage of growth in the values of R_E^1 and R_E^2 is the same, and the difference between them is about 4%. We note that with the increasing of the working speed of the aggregate, the difference between theoretical R_t and experimental (R_E^1 and R_E^2) traction resistances increases. Similar results were obtained for soil depth $a = 7$ cm and $a = 10$ cm.

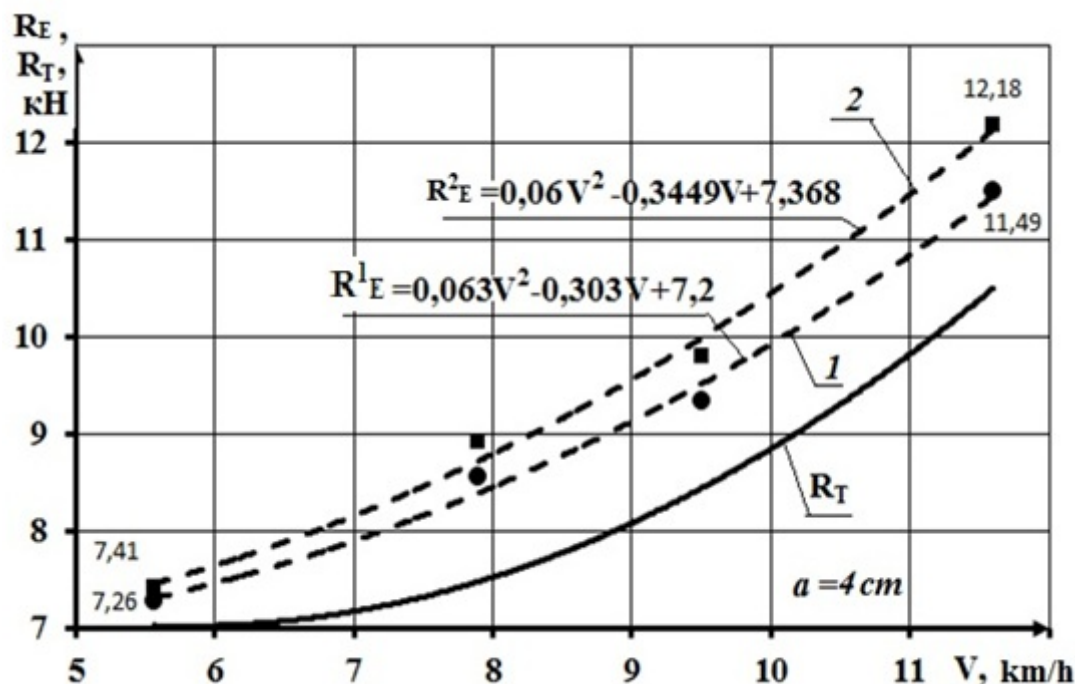


Figure 1- Theoretical (R_t) and experimental dependencies of the traction resistance of the seed drill AGSSS 2.0 with serial central shovel coulters (R_E^1) and coulters for separate application of seeds and fertilizers (R_E^2) from the working speed of the aggregate V at the depth of tillage $a = 4$ cm.

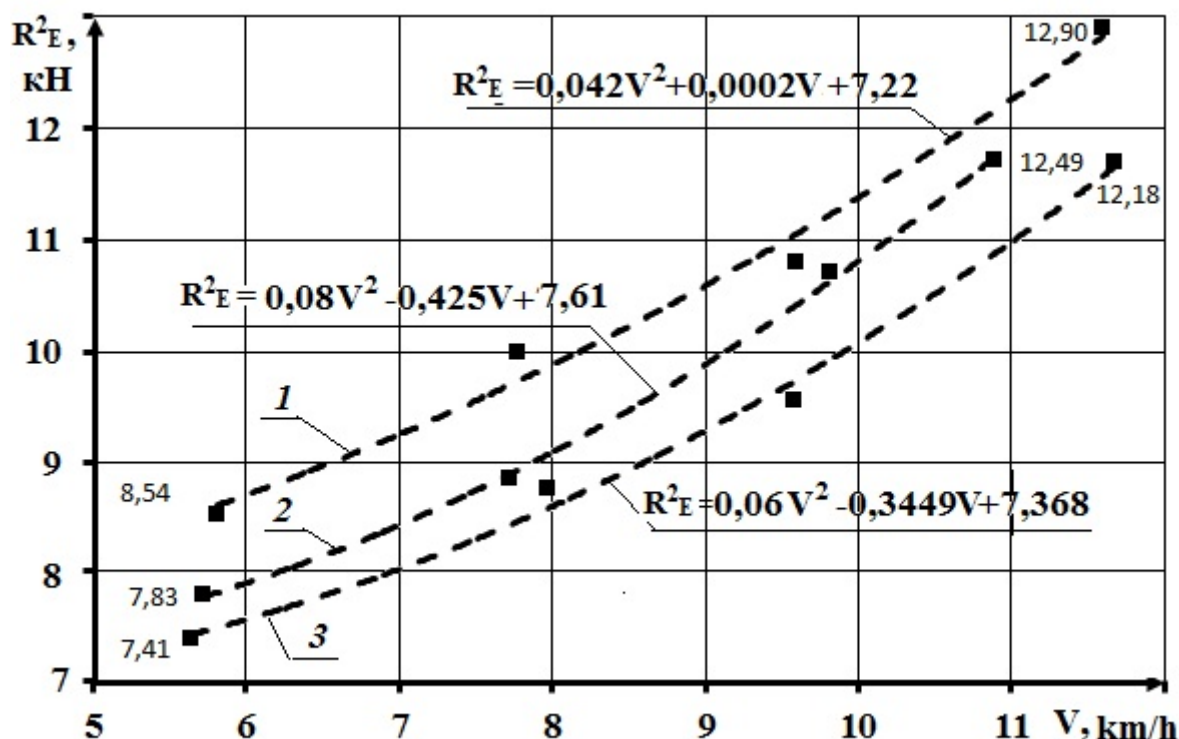


Figure 2 - Experimental (R_E^2) dependence of traction resistance of the seeder with openers for separate application of seeds and fertilizers from the working speed of the aggregate V at various depths of tillage: 1- $a = 10$ cm; 2- $a = 7$ cm; 3- $a = 4$ cm;

Analysis of the results of the experimental dependences of the traction resistance of the seed drill on the working speed of the aggregate V at various depths of tillage a (Fig. 2) shows that when V is changed to a mean of 5.81 km/h to 11.6 km/h, i.e. increases 2 times. At the same time, the value of the R_E^2 curve for curve 1 is increased from 8.54 kN to 12.9 kN, i.e. on the average 50%. From the analysis of figure 2 (curves 2 and 3) it follows that the same pattern is observed when analyzing the

experimental data for the seeder coulters for separate application of seeds and fertilizers (R_E^2).

It is shown more clearly in Figure 3 the effect of depth of tillage on the traction resistance of the seed drill with coulters for separate application of seeds and fertilizers (R_E^1). So, with a depth of tillage $a = 4$ cm, a change in the working speed of the aggregate V from 5.81 km/h to 11.6 km/h leads to an increase in the traction resistances R_T and R_E^1 by 0.25 kN on the average.

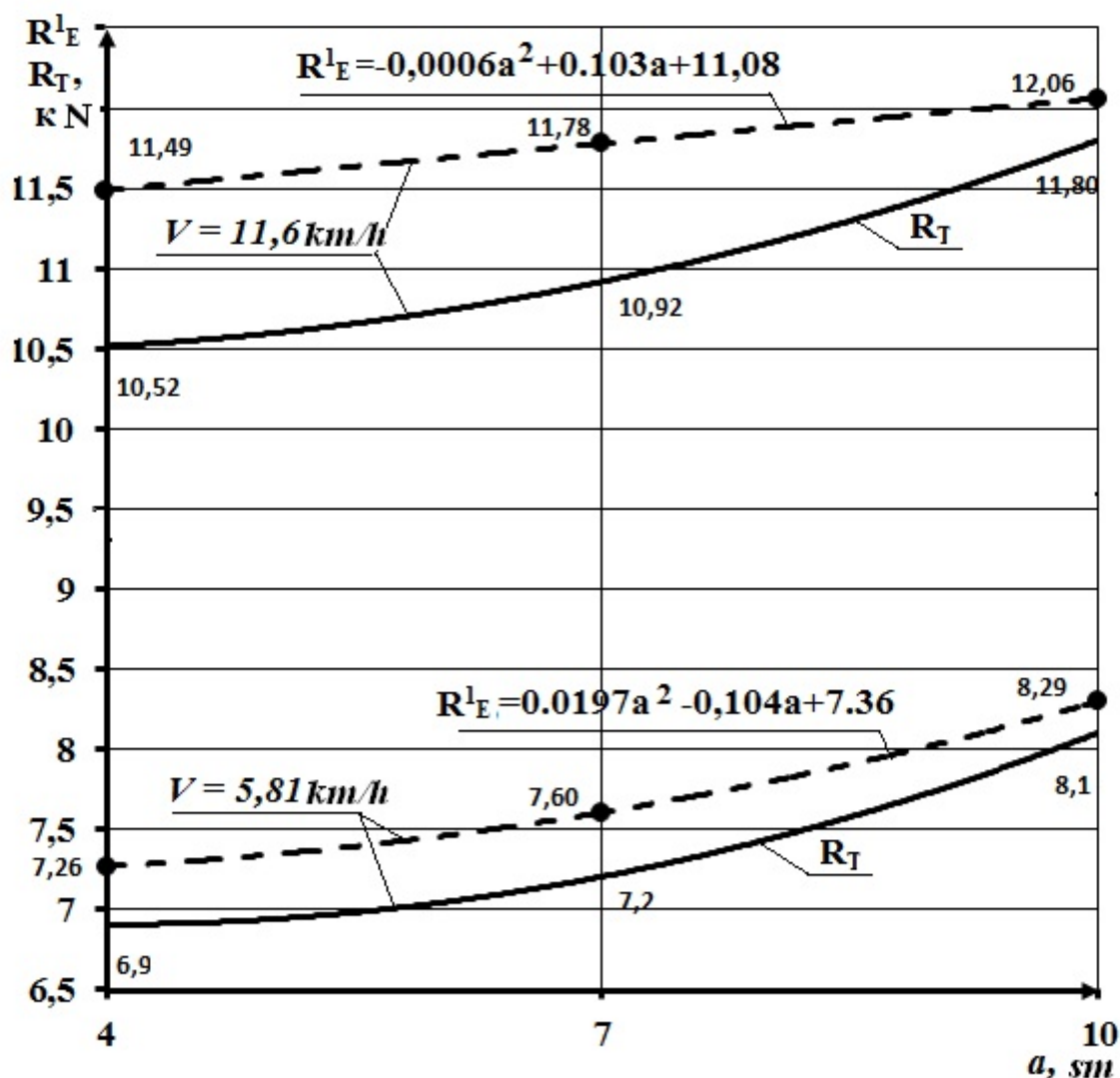


Figure 3- Theoretical (R_T) and experimental (R_E^1) dependences of traction resistance of the seed drill AGTS-2,0 with openers for separate application of seeds and fertilizers from the depth of tillage at various operating speeds of the aggregate V .

Similar results for the depth of tillage $a = 10$ cm show that with an increase in the working speed of the aggregate V , there is a stabilization of the technological process and a share of the increase in the traction resistances R_T and R^1 decreases from 1.2 kN to 0.25 kN.

The results of the agrotechnical evaluation of the experimental set up of the stubble grain seeder with separate application of seeds and fertilizers are recorded in the observation log. Observations of the experimental sites showed that the field germination of seeds in the area sown by the experimental installation of a stubble grain fertilizer seeder with separate application of seeds and fertilizers exceeds the field germination of the control plot by only 1.1%.

An analysis of the agrotechnical evaluation of the experiments shows that, in terms of the quality of the work, the experimental installation of a stubble grain seed drill with separate application of seeds and fertilizers is slightly superior to the serial stubble grain seed drill: according to the uniformity of

seeding 1%; on the distribution of plants in the area of food 1.2%.

The results of the agrotechnical evaluation of the experiments show that the number of productive stems in the experimental area exceeds the number of productive stems on the control plot (306.3 and 274.8), and the mass of grains in the spike on the experimental site is higher than the mass of grains in the spikelet (1, 26g and 1.17g). Accordingly, the yield in the experimental plot is 26.61 kg/ha, and in the control plot 22.94 kg/ha, so the difference is 16%. The increase in yields is due to the fact that this year the month of June was droughty and the roots of plants in the control plot did not use fertilizers located in the same horizon and spread to the depth of the soil. And in the control plot, the experimental coulters laid fertilizers 2 cm deeper than the seeds and the plants effectively used the starting dose of fertilizers.

In the final, based on the above, we can draw the following conclusions:

-Theoretical and experimental dependences of the traction resistance of the experimental seeder plant with coulters for

separate application of seeds and fertilizers from the depth of seeding and working speed were obtained;

- The results of the study show that the traction resistance of the seed drill AGTS-2.0 with openers for separate application of seeds and fertilizers exceeds the traction resistance of the seed drill AGTS-2.0 with serial central shovel claw openers (R^1_E) by 5-10%;

- It is required to clarify the main operating modes of the seeder;

- Further research is needed to justify the rational design parameters of the opener for separate application of seeds and fertilizers, taking into account the agro-technical performance indicators;

- To evaluate the effectiveness of using a seeder with coulters for separate application of seeds and fertilizers, comparative tests of various designs of working elements are necessary.

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DETERMINATION OF THE WATER INFLUENCE ON THE CROP DEVELOPMENT COEFFICIENTS

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ОПРЕДЕЛЯНЕ ВЛИЯНИЕТО НА ВОДАТА ВЪРХУ КОЕФИЦИЕНТИТЕ НА РАЗВИТИЕ НА РАСТЕНИЯТА Митев, Г.В

Abstract: The water is involved in all physiological processes and is extremely important for the growth and development of plants and for the formation of yields. Due to the growing variations in the climate, resulting in intense rainfall, followed by prolonged dry periods, crop-developed sustainable crops can only be achieved by efficient water use. The alternatives for water use have been considered, with the necessary quantities determined in different ways of supplying water.

Keywords: water, plant growth factors, alternatives to water use

Introduction

The ability of the soil to retain water directly addresses the possibilities and retains the water required for the plants in the corn-soaked soil layer. After rainfall or irrigation, the soil reaches its marginal land moisture (FC) and then begins draining, [4, 5, 7, 9]. Soil water balance is a procedure for calculating the incomes and costs of water needed for cultivation of cultivated plants [8, 10, 18]. The main part of the incoming water comes from natural rainfall. Geographer C. W. Thornthwaite (1899-1963) first used the water balance approach in the soil. In order to understand correctly the concept of water balance in the soil, its component components must be elucidated [2, 3, 6].

The growth and development of a culture can be described by the coefficients that represent a stage of development and the equation [12, 16, 33, 40]:

$$K_c = K_s K_{cb} + K_e \quad (1)$$

Where K_c is the coefficient describing the crop under consideration;

K_s - the coefficient describing the stressful conditions under which the crop under consideration is developing;
 K_{cb} - the main coefficient representing the crop under consideration, providing optimal growth and development conditions;

K_e - the coefficient describing the evaporation of water in the soil.

Applying the Double Coefficient Approach The approach to describing the growth and development of plants using double factors requires the daily values for the evapotranspiration in the upper soil layer to be determined.

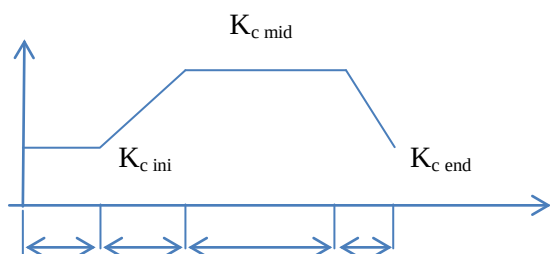


Fig.1. Presentation of the stages of growth and development of plants through the specific coefficient for the respective crop

The more commonly used approach is to use the effect of calculating the evapotranspiration in the upper layer of the soil over a period of several days (seven or ten days), equation (2).

$$K_c = \overline{K_{cb}} + \overline{K_e} \quad (2)$$

Where: K_c is the coefficient describing the development of plants under specific conditions.

This approach is used for precise planning, irrigation design, and typical irrigation management activities. It is used in a number of simulation modeling schemes such as WinISAREG, [31, 37].

The approach for describing the growth and development of plants through the mean values of the coefficient K_c over time is presented in Figure 1, which shows the change of the coefficient values during the vegetation period. At the beginning, when about 95% of the plants have emerged, the values of $K_{c\ ini}$ are low, [43].

There follows a rapid increase in the coefficient corresponding to the stage of rapid growth of plants. The maximum values of the coefficient are observed in the middle of the growing season or at the maximum development of the plants. The period in which $K_c = K_{c\ mid}$ is defined as the period of accumulation of the yield.

When going to the end of the extraction period, the plants pass into the so-called. Technological maturity, i.e there is a moment in which the process of picking can begin. The values of K_c decrease and reach low values at the end of the vegetation period, $K_{c\ end}$, (Allen et al., 1998; Pereira and Allen, 1999; Allen et al., 2005a) [11,13,17].

The evaporation (the loss of water from the soil) is a dominant component in the initial period of plant growth, and therefore the coefficient $K_{c\ ini}$ depends on the frequency of wetting of the soil surface.

The coefficient $K_{c\ ini}$ is calculated by the model in which the equilibrium of the plant (living or plant residue) soil is expressed in two different stages (Allen et al., 1998; 2005b, Pereira and Allen, 1999). In the first stage, the exposure is limited by the available energy in the surface soil layer. In the second stage, the evaporation depends on the available water in the soil. The depth of water evaporation, D_e , is determined by the amount of REW for the first stage and the total TEW for Stage 2 evaporation water.

The coefficient $K_{c\ ini}$ is determined by equation 3 when the water supply interval t_w is less than the duration of the drought stage 1, t_1 , ($t_w \leq t_1$), i.e. when the process Found in the early stages of plant growth, [14, 26, 27,].

$$K_{c\ ini} = \frac{E_{so}}{ET_{o\ ini}} = 1.15 \quad (3)$$

where: E_{so} is the potential evaporation (potential evaporation) of the soil, [mm];

$ET_{o\ ini}$ - the reference equation for the initial period when $t_w > t_1$, [mm].

Under these conditions, for the coefficient $K_{c\ ini}$ the equation can be written[11]:

$$K_{c\ ini} = \frac{TEW - (TEW - REW) \exp \left[\frac{-(t_w - t_1) E_{so} (1 + \frac{REW}{TEW - REW})}{TEW} \right]}{t_w E_{to\ ini}} \quad (4)$$

Where TEW is the total quantity of water available for evaporation in the soil, [mm];

REW - actual water available for evaporation in the soil, [mm];

t_w - the average duration of the time interval in which soil moisture is applied, [h];

t_1 - period of the first stage of plant growth, [h]; The duration of step 1 = t_1 (soil drying) is determined by the equation:

$$t_1 = \frac{REW}{E_{so}} \quad (5)$$

The average duration of the sludge application interval is:

$$t_w = \frac{t_{ini}}{n_w} \quad (6)$$

Where t_{ini} is the length of the start period, [h];

n_w - the number of events in which the soil has entered (ie rainfall count and / or number of irrigations). The depth of evaporation of water from the soil is determined by the percentage of sand and clay, such as:

$$REW_{est} = 0 - 0.15S_a \text{ корато } S_a > 80 \quad (7.a)$$

$$REW_{est} = 11 - 0.6CL, \text{ корато } CL \geq 50 \quad (7.6)$$

$$REW_{est} = 8 + 0.08CL, \text{ корато } S_a < 80 \text{ и } CL < 50 \quad (7. б)$$

Where S_a is the percentage of sand in the evaporable soil layer at depth of [%];

CL - the percentage of clay in the evaporable soil layer at depth, [%];

In the case of the initial soil temperature, $ET_{o\ ini} \geq 5$ mm/d the total quantity of vaporizable water, TEW, is determined by equation (8)

$$TEW_{est} = 1000(\theta_{FC} - 0.5\theta_{WP})Z_e \quad (8)$$

When $ET_{o\ ini} < 5$ mm/d then

$$TEW_{est} = 1000(\theta_{FC} - 0.5\theta_{WP})Z_e \left(\frac{ET_{o\ ini}}{5} \right)^{0.5} \quad (9)$$

The values of REW and TEW should be corrected when the amount of water in the evaporable soil layer is low [11]. In this way, it is possible to determine the depth of absorption of water in the soil supplied by natural rainfall (P_n) and irrigation (I_n) corresponding to the number of irrigations (n_w).

$$P_{mean} = \frac{(\sum P_n + \sum I_n)}{n_w} \quad (10)$$

Where P_{mean} is the depth of water absorption in the soil, [mm]; P_n - the quantity of water supplied by the valves, [mm];

I_n - the quantity of water supplied (by irrigation) artificially, [mm]; n_w - the number of irrigation events, [number].

Each value of P_n and I_n must be limited by the conditions $P_n \leq TEW$ and $I_n \leq TEW$. By establishing the presence of water in the evaporable soil layer on the first day (i.e., the first day after sowing), the values of REW and TEW are determined by equations 11 and 12.

$$REW = REW_{est} \left[\min \left(\frac{P_{mean} + \frac{W_{ini}}{n_w}}{TEW_{est}} + 1 \right) \right] \quad (11)$$

$$TEW = \min \left[TEW_{est} \left(P_{mean} + \frac{W_{ini}}{n_w} \right) \right] \quad (12)$$

Where W_{ini} is the presence of water in the evaporable soil layer on the first day of the reporting period, [mm].

When only part of the soil surface is moistened, such as furrowing, by using drifting systems or drip irrigation, the values of I_n must be corrected only for the part of soil f_w , to which water is supplied

$$I_n = \frac{I}{f_w} \cdot 100 \quad (13)$$

Where f_w is the part of the water to which the water is supplied [%]; Therefore, the values for $K_{c\ ini}$ defined by equations 3 and 4 must be reduced in accordance with f_w , equation 14.

Therefore, the values for equations 3 and 4 must be reduced in accordance with equation 14.

$$K_{c\ ini} = (K_{cc\ ini} \overline{K_{cb} + K_e}) f_w \quad (14)$$

The use of equations (13) and (14) requires further verification and confirmation as TEW is determined by the soil water retention value, Z_e , while REW is determined by the texture characteristics of the soil and can easily be recalculated, [15,30,36]. A methodology for graphical determination of $K_{c\ ini}$, (Allen et al., 1998) was developed and TER values were determined empirically for REW determination

$$REW = \frac{TEW}{TR} \quad (15)$$

In the case of $ET_o \geq 5$ mm d⁻¹, the ratio of TER is expressed by equation 12, but if $ET_o < 5$ mm d⁻¹, an equation should be used, (16).

$$TR = 4 - [0.05 - 0.002(TEW - 15)](P_{mean} - 10) \quad (16)$$

$$TR = 4 \sqrt{\frac{ET_o}{5}} - [0.05 - 0.002(TEW - 15)](P_{mean} - 10) \quad (17)$$

Thus, the mean depth of soil moisture, P_{mean} , (equation 12) and the vaporized TEW, from the surface soil layer, is expressed.

The $K_{c\ mid}$ and $K_{c\ end}$ maturity coefficients are defined by Allen et al. (1998). They correspond to irrigation frequency and rainfall and are characteristic of the subtropical regions where $RH_{min} = 45\%$ and $u_2 = 2$ m s⁻¹. When climatic conditions differ from these values, it is necessary to adjust the values for $K_{c\ mid}$ and $K_{c\ end}$.

The following equations 18 and 19 are used for this purpose.

$$K_{c\ mid} = K_{c\ mid\ (tab)} + [0.04(u_2 - 2) - 0.04(RH_{min} - 45)] \left(\frac{h}{3} \right)^{0.3} \quad (18)$$

$$K_{c\ end} = K_{c\ end\ (tab)} + [0.04(u_2 - 2) - 0.04(RH_{min} - 45)] \left(\frac{h}{3} \right)^{0.3} \quad (19)$$

Where u_2 is the average daily wind speed value for the beginning of the period, [ms⁻¹];

RH_{min} - the average daily moisture value of the soil for the beginning of the period, [%];

h - the height of the plants, [m]. Indicative values of plant height are given by Allen et al. (1998) and Pereira and Allen (1999).

No adjustments to the $K_{c\ end}$ are required when its values do not exceed 0.45, i.e., When the plants are allowed to cease their vegetation and dry out in the fields. In the absence of minimum humidity data RH_{min} , they can be calculated from equation 20 [11]:

$$RH_{min} = \frac{100 e^0(T_{min})}{e^0(T_{max})} \quad (20)$$

Where $e^0(T_{min})$ is the value of the saturated vapor pressure at a minimum temperature;

$e^0(T_{max})$ - the value of the saturated vapor pressure at the maximum temperature.

The amount of water in the soil before the plants are subjected to water stress (p) is defined as the mean value of the water present in the root zone and which can be reduced to such an extent that the plants are subjected to water stress. Consequently, soil water content is a critical point to be taken into account when presenting irrigation recommendations and defining irrigation schedules. Also, the plant water stress factor can be determined in this way [11].

Consequently, the p criterion appears to be fundamental in the simulation models for determining irrigation schedules and irrigation norms. The values for the main crops are also presented.

$$p = p_{tab} + 0.04(5 - ET_c) \quad (21)$$

But is limited to $0.1 \leq p \leq 0.8$.

For the initial period of plant growth, the value of p is taken as $p \leq 0.6$ to ensure good water supply of the plants (Allen et al., 1998) [156].

Exposition

The WINISAREG program (developed by Teixeira and Pereira, 1992, [37]) determines soil water balance by processing a combination of soil, crop and meteorological data (rainfall, air temperature, direction and velocity The wind, the loss of water from

the soil and the plants (evapotranspiration), so it is possible to develop a schedule for use and supply of water for the needs of the plants in the various stages of their growth and development.

The reference (ET_a) is determined by FAO 56 methodology using the Penman-Monteith method (Allen et al., 1998). For this purpose, an EVAP software 56, [11] is used. Plant information was processed using a KCISA software product, [Rodrigues et al., 2000], [43].

The crop development coefficients in their individual periods (Kc) and the factor describing the reduction of water to the stress conditions MAD (p) is determined for the climate in Bulgaria for the period 2012-2016.

Soil, climate and plant data have been collected and systematized for Northeastern Bulgaria [1, 2, 7, 9, 38, 39, 41, 42].

Options for simulating the water consumption of plants.

The WINISAREG program offers two basic simulations aimed at:

Use of water to obtain maximum yield; Delivering water at a specified time and quantity. The first option provides basic information on the presence of water in the surface soil layer as well as in the lower layers of root system development. The presence of water is represented as a percentage of the total amount of water available (% TAW). The limitations are expressed in the number of days before the beginning of the harvest, during which the supply of water is stopped for the purpose of obtaining quality produce.

The second option offers alternatives to fix the time for water delivery and quantity. This wide range of alternatives makes it possible to evaluate the alternatives and the results of the simulations.

Planning the simulation models

Simulation planning is designed to find optimal conditions where maximum yields can be obtained at maximum efficiency of water use. Maximum efficiency of water use is locked in minimizing delivery costs and minimizing deep water penetration below the root system area. I.e. Maximum water efficiency can be obtained in the following cases:

Preservation of water from precipitation in the cornobondable soil layer;

Avoiding movement of water in the lower layers of the soil and becoming unusable;

Reduce the evaporation of water from the surface of the soil.

Comparing strategies to simulate the use of water for plant needs.

In order to obtain practical water use schedules for the needs of plants, several (simulated) alternatives have been developed.

All alternatives refer to crops grown in one place, such as corn, sunflower, soybean and alfalfa.

First alternative: Need for water to maximize yield. By supplementing the "soil reservoir", i.e. the volume of soil occupied by the root system of the plants, up to the level of PPP, water supply can be optimized to maximize yields and maximize water efficiency without Negative phenomena such as surface runoff and / or water penetration below the root system area. In order to determine the optimum yield threshold, the optimal yield line (OYT) is used as the lower limit for the reduction of water in the soil. The upper limit is the capacity of the soil to retain water, i.e., FC.

Consequently, $(TAW = \theta_{FC})$. The water quantity change ranges in the interval between TAW and OYT ($OYT \leq D_{r,i} \leq TAW$). The simulation of data for one year shows the following results, fig. 2. Due to the decrease of the water in the soil in the initial period of the plant development, the delivery must take place on May 10 with a quantity of 35.6 mm. The second water supply is after 23 days with an amount of 42.7 mm, and so on.

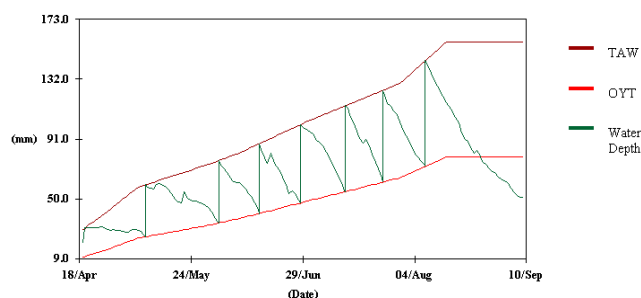


Fig.2. Graphical presentation of a schedule for water supply for plant use, 2015 for maize to maximize yield

The irrigation events are seven (7) and the total amount of water required to deliver (in addition to fallen rainfall) in order to obtain a maximum yield is 373.50 mm. The necessary information that each user should receive is presented in Table 1. Additional information needed to analyze water consumption is presented in Table 2.

Table 1. Needs of plant water presented as a simulation delivery schedule obtained using WINISAREG

No	Date of delivery	Quantity	Deep percolation under the root zone
		[mm]	[mm]
	10/05	35.6	0
	03/06	42.7	0
	16/06	47.7	0
	29/06	53.5	0
	14/07	58.8	0
	26/07	62.8	0
	01/08	72.3	0
O: BЧЧК		373.	0
Average delivery interval, [days]			1
Yields reduction due to the water stress, [%]			2

Table 2 2. Data obtained by the simulation models

No	Parameters	Dimension	Value
1	Really available water, (RAW)	[mm]	10.20
2	Really available water on the season end,	[mm]	0
3	Total available water in the down soil layer at the beginning of the season (drilling)	[mm]	20.40
4	Total available water in the next soil layer at the beginning of the season (drilling)	[mm]	64.20
5	Total available water at the beginning of the season	[mm]	20.40
5	Total available water at the end of the season	[mm]	51.10
6	Deep percolation under the root zone	[mm]	0.00

7	Accumulated rains during the vegetation period	[mm]	92.30
8	Not use water during the season	[mm]	0.00
9	(Max evapotranspiration)	[mm]	507.80
10	Actual evapotranspiration during the season	[mm]	499.30
11	Relationship ETa/ETm	[-]	0.98
12	Underground water contribution	[mm]	0.00
13	Maximum water consumption on the day 22/07	[l. s-1d-1]	0.559

Simulation of water consumption for 4 crops such as maize, sunflower, soybeans and lucerne for the period 2006 - 2016 shows the following results, fig. 3.

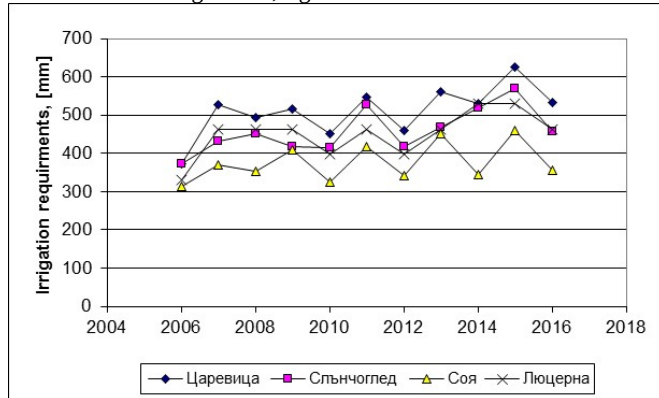


Fig. 3. Annual water requirement for corn, sunflower, soybeans and alfalfa to maximize yield

Alfalfa requires minimum water volumes of 331 mm in 2006 and reaches a maximum of 529 mm in 2015. At the same time, corn needs a minimum of 527 mm of water and rises to 547 mm per year, reaching values of 624 mm over 2015, which is the largest water consumption for this ten-year period. Sunflower needs water in the range of 452 - 568 mm, (see Table 3). Frequency analysis shows that in years with low consumption of 50%, the need for water supply ranges from 356 mm to 527 mm for all crops, fig. 4.

In years with high water consumption (75%) it reaches values from 418 to 547 mm, and in years with very high consumption (90%) (dry years) ranges from 460 to 624 mm.

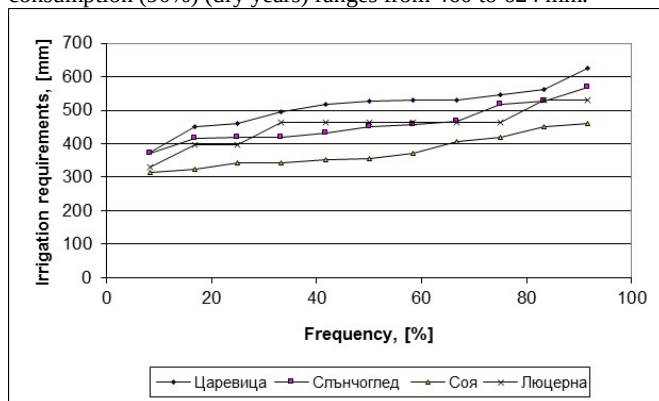


Fig. 4. Frequent analysis of the distribution of the need for water for growth and development of plants in order to obtain maximum yield for the period 2006-2016 for the district of BRS Blachlen, Ruse.

Second alternative: Simulation of water in the root system up to 85% of the total water available (85% TAW)

In this case, the planning of the simulation experiment and the subsequent analysis show that soil moisture should be reduced by 30% of the TAW value and further supplemented to 85% of the TAW value. It can immediately be assumed that the number of water supplies and the total amount of water required for plants is

expected to decrease. At the same time, the yields are expected to decrease by about 9 - 13%, Figure 5.

Compared to the data presented in Table 2, the number of water supplies (irrigation) over the same period of time for maize will be reduced from 7 to 6 and annual water consumption from 527 to 347 mm. At the same time, the reduction in yield due to the lack of sufficient water ranges from 1 to 16% for the selected years with low, medium and high water consumption.

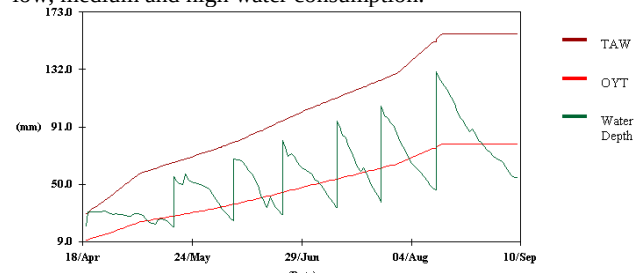


Fig. 5. Simulate a change in the amount of water available to plants when water available to plants decreases by 30% of TAW and the next water supply is to complement 85% of TAW

The comparison for the reduction of the yields between the simulated crops is presented in Fig. 6.

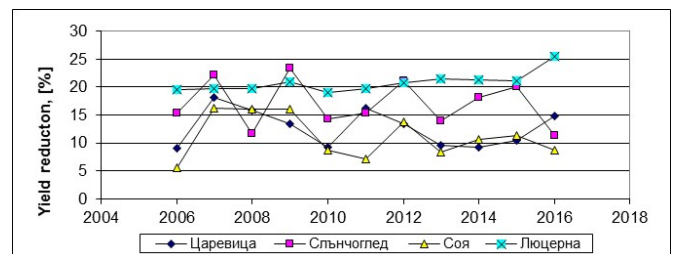


Fig. 6. Loss of yields for simulated cultures at TW reduction to 30% and supplementation to 85% of TAW

Third alternative: Water supply at fixed dates
The supply of water for plant needs at fixed dates as a percentage of TAW has two options:

The first is that the Management Allowable Depletion (MAD) is equal to the p portion of the TAW, which can be reduced in the root system area to the extent before the water stress (MAD = p), Fig. 7.

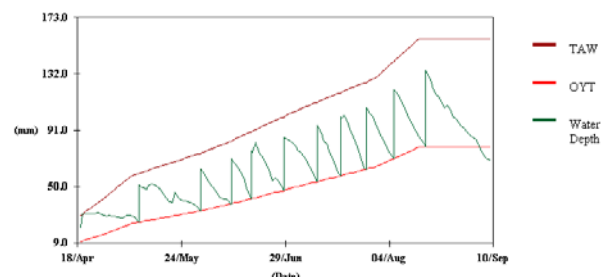


Fig.7. Simulate the net quantities of water to be delivered on fixed dates when MAD = p

The difference between Figures 2 and 7 is within the upper bounds of the set limits. In the first case, (Figure 2), water is supplied to the water to reach PPP (100% FC) and the subsequent delivery is in an amount equal to 85% of the FC. Amounts of water required for plants ranged from 337 mm at the lowest level of consumption to 499 mm for average consumption, 550 mm for high and 574 mm for very high water consumption for corn. Similar results are obtained for other cultures. In the second embodiment, it is required to start supplying water when MAD < p and reaches values that would be set according to the experience of the conducting simulation. The reduction in yields due to the water stress obtained when MAD < p for the crops studied is shown in Fig. 8.

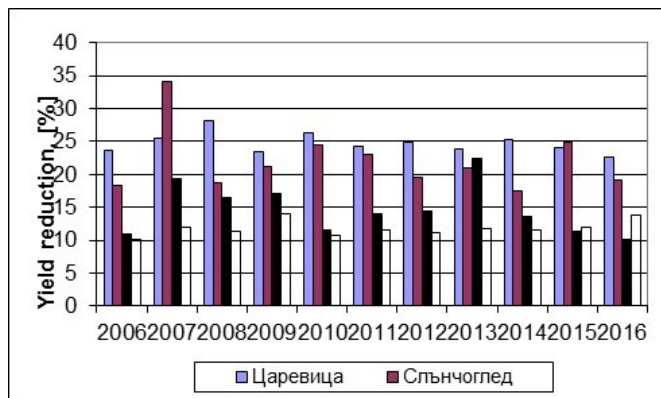


Fig. 8. Reduction in yields due to water stress caused by the use of MAD <p> as a water supply strategy

Fourth alternative: Water supply in fixed quantities Simulation planning was done at 60, 40 and 20 mm. The quantity of water supplied by 60 mm is widely used in practice for the studied crops, fig. The remaining 40mm and 20mm quantities are selected based on mathematical calculations aiming obtaining wide spectrum of possibilities for analysis.

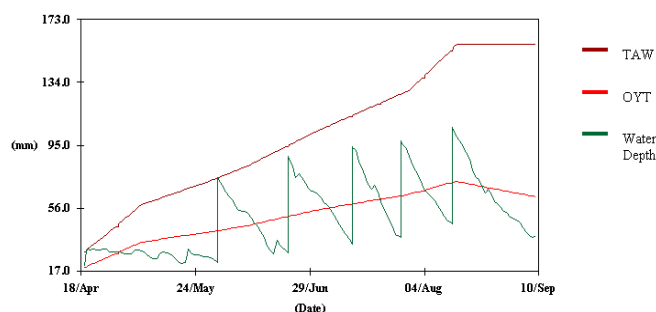
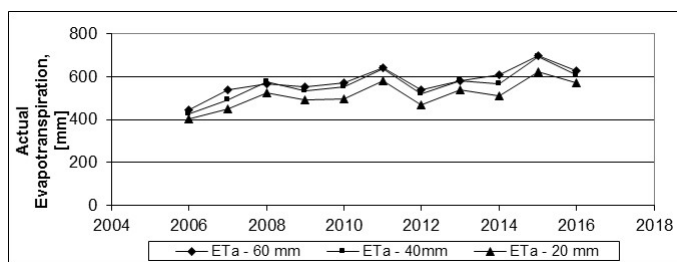
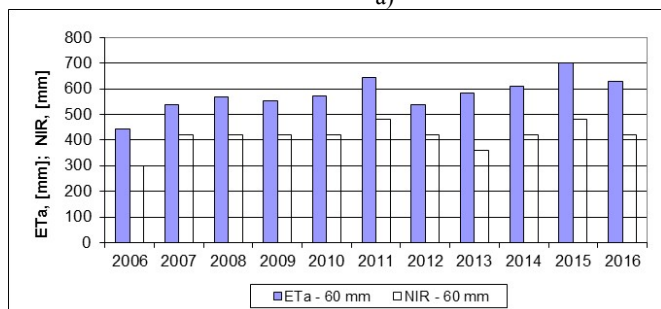


Fig. 9. Simulate supply of water for plants at a fixed amount of 60 mm for maize.

The comparison for the actual evapotranspiration and the water supply recommendations for the 60 mm fixed amount for the maize culture studied is presented in Fig. 10. The simulation procedure performed on other crops shows that the best results are obtained with alfalfa, with yield losses ranging from 8 to 12%. Soybeans should not be irrigated with such large irrigation regulations due to the penetration of water under the root zone. It is logical to observe and inefficient use of precipitation.



a)



b)

Fig.10. Comparison of the simulated actual evapotranspiration when a crop (corn) is irrigated with 20, 40 and 60 mm of water in: (a), actual evapotranspiration; (b) the need for water

In the typical years of this crop, representing 50%, 75% and 90% of the water supply, the quantities of water supplied are between 360 and 480 mm. The optimal amount of water supplied is 40 mm.

Simulating the need for water for soybeans using the intended 20 mm, 40 mm and 60 mm quantities indicates that the minimum required water supply is 240 mm and the maximum 480 mm at the 60 mm delivery rate. The yield reduction ranges from 43% to 7%. The number of water supply events, maximum use rates and evapotranspiration values can be presented in a similar way.

Fifth alternative: Delivery of water at fixed dates and quantities

Due to the simplified procedure for supplying water to plants, this strategy is widely used in practice. The limited water resources and the lack of water during the vegetation of the plants support the application and, Fig.11.

At the same time, there are several hidden obstacles, mainly in delivering too little or too much water. In both cases there is a negative impact such as yield reduction, deep root penetration, surface water runoff, and water efficiency.

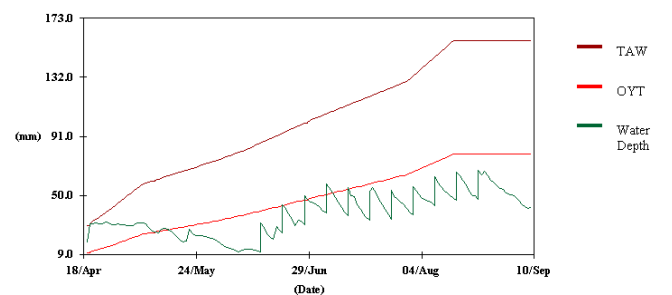


Fig. 11. Strategy for the 20 mm water delivered at a time step of 7 days

Water delivery at 20 mm at 7 day interval requires 220 mm of water to be delivered at 11 events (deliveries). The available water in the soil is between 70 and 85 mm, but the actual yield is below the optimal yield line (OYT). The decrease in yields is in the range of 33%, with its average values being about 30%.

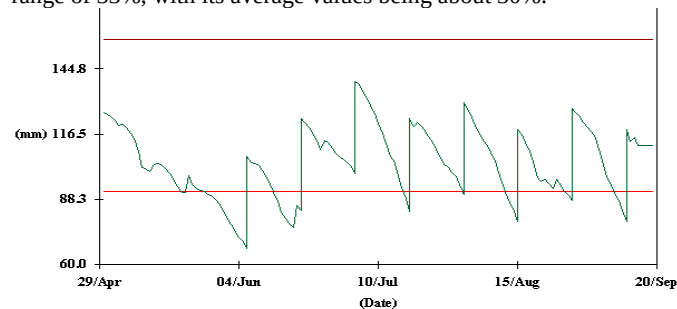


Fig. 12. Strategy for eight-fold delivery of 40 mm water

The situation could be corrected if an irrigation rate of 40 mm was applied to an 8-fold delivery, Fig. 12. The total amount of water delivered is 320 mm, and the increase in water in the soil is in the range of 70 mm minimum and 137 mm maximum. The decrease in yields is within 16% in the years with high water consumption and the efficiency of the use is high, fig.13.

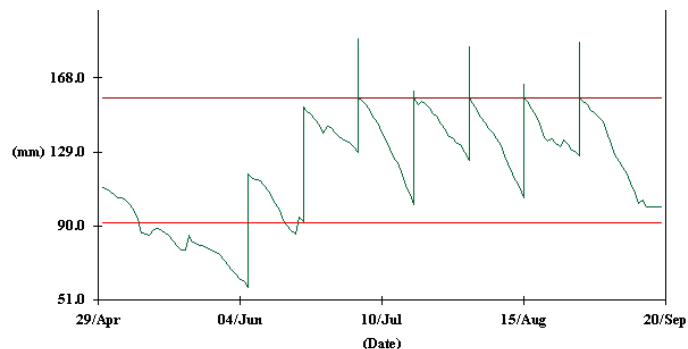


Fig. 13. Strategy for a 14-fold delivery of 60 mm water

The application of a 60 mm irrigation rate at 14 day intervals shows that the excess water reaches 117 mm, the efficiency of water use being reduced to 87% and the yields by 11%, Fig. 14.

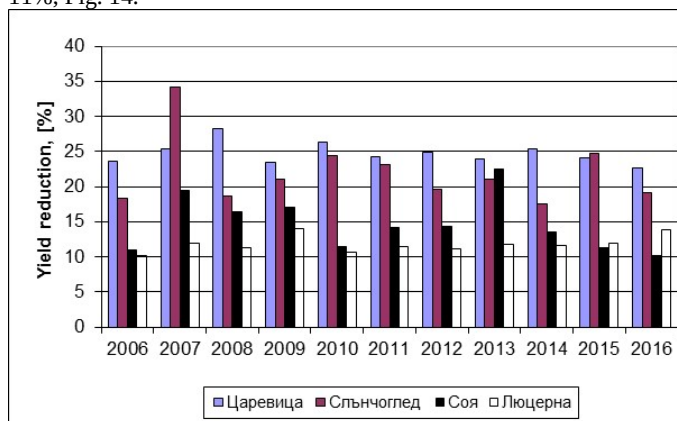


Fig. 14. Comparison of the decrease of yields in the supply of water at fixed quantities and dates

By using the WINISAREG program, the years corresponding to the different probabilities of applying recommendations for the supply of water to plant needs can be determined. The amounts of water and their application time, depth penetration below the root system caused both by precipitation and water supply, the effectiveness of their application, water efficiency, actual evapotranspiration, and relative reductions in yields are being compared to assess the water use strategies. Years representing 50%, 75% and 90% of the probabilities of applying water recommendations correspond to average dry, dry and very dry conditions in which crops are grown. Typical years are selected by frequency analysis of net water needs for plants. The results of the five alternatives considered are summarized in Table 3.

Empirical Probabilities		Year	Rains mm]	Actual ETa[mm]	Reco mmen dation smm]
Awerage water consumpt ion 50%	Maize	2008	141	552	491
	Soybea n			421	308
	Sunflo wer			519	392
	Alfalfa			497	373
Total option 1 (50% probability)					1564
High consumpt ion 75%	Maize	2014	244	578	487
	Soybea n			436	305
	Sunflo wer			555	412

	Alfalfa			519	373
Total option 2 (75% probability)					1577
Very high consumption 90%	Maize	2015	255	645	502
	Soybean			528	404
	Sunflower			588	398
	Alfalfa			555	448
Total option 3 (90% probability)					1752

Table 3. Summary table of simulation of five alternatives for using water for crops for spring crop maize

Condition s		Recom mendat ions	Deep percolation: (DP)		Actual ET (ETa)	Water efficie ncy (IE)	Yiel ds redu ction (IRL)
			Напо я ван е	Вале жи			
		Y1	Y2	Y3	Y4	Y5	Y6
		[mm]	[mm]	[mm]	[mm]	[%]	[%]
Average water consumption							
a)		527	0	0	721	100	2.20
b)		441	0	0	567	100	13.4 0
c)	MAD = p	499	0	0	630	100	1
	MAD < p	443	0	0	551	100	16.4 0
))	60 mm	420	0	0	570	100	12.0 0
	40 mm	400	0	0	550	100	16.0 0
	20 mm	340	0	0	467	100	27.3 0
e)		280	0	0	428	100	38.0 0
High water consumption							
a)		547	0	0	637	100	1
b)		449	0	0	585	100	9.20
c)	MAD = p	550	0	0	732	100	1.00
	MAD < p	494	0	0	518	100	18.1 0
))	60 mm	420	0	0	628	100	17.8 0
	40 mm	440	0	0	577	100	16.3 0
	20 mm	380	0	0	522	100	26.3 0
e)		360	0	0	520	91	28.0 0
Very high water consumption							
a)		624	0	0	812	100	1
b)		545	0	0	747	100	10.40
))	MAD = p	574	0	0	721	100	4.00
	MAD < p	569	0	0	652	100	14.50
))	60 mm	420	0	0	699	100	17.80
	40 mm	480	0	0	694	100	18.00
	20 mm	420	0	0	580	100	26.20
e)		400	< 15	< 5	548	99	19.00

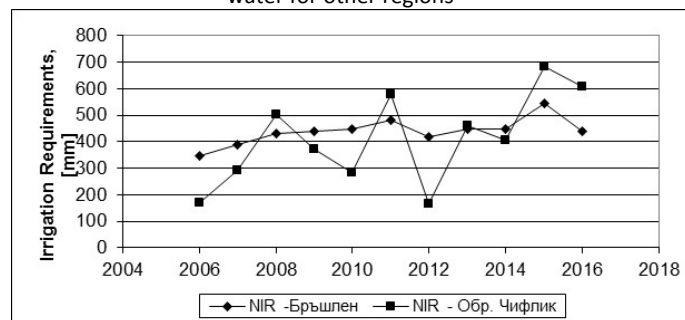
The results of simulation of the above-mentioned crops and alternatives are summarized in Table 4. The presented years differ from those presented as opportunities.

Table 4. Example of balance of water components for typical years determined by frequency analysis for four independent crops sunflowersoybeans and alfalfa at MAD <p

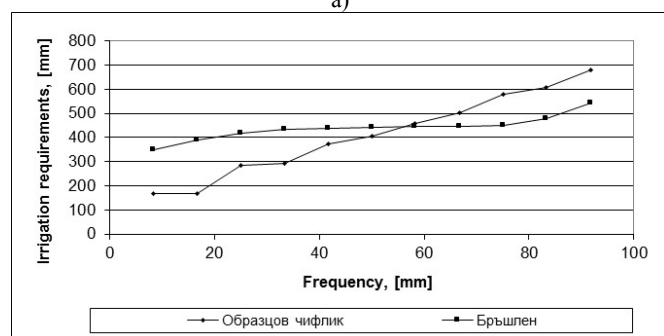
Table 5. Rainfall reported over the monitored period 2006 - 2016, [mm]

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Rainfall [mm]	173	143	141	123	144	241	132	275	244	255	271

Comparison of simulated recommendations for using water for other regions



a)



b)

Fig. 15. Simulation of the water consumption of plants on an annual basis for two different sites, Model Chef and BRS)

Conclusions

Simulation alternatives have been applied for an 11-year period for 3 crops such as corn, sunflower and alfalfa. Due to the reduction of irrigation areas and the changing climatic conditions, it is found that soybeans are not suitable for cultivation, at least until the technology is optimized in their effective use of water, Table 3.

The crops above are grown in many regions of the country but under different soil and climatic conditions and with the application of similar or improved technologies. Consequently, the recommendations for supplying the necessary quantities of water will vary.

It is interesting to compare the consumption of water from the same crops but grown at 25, 50, 75 and 150 km as well as cultivation of the same crops when in the soil are imported water-accumulating materials that retain larger amounts of water in the cornobondable soil layer

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STREAMFLOW TRANSFORMATION UNDER PRESENT CONDITIONS

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ABSTRACT. An estimation of streamflow transformation in rivers of Belarus under present conditions influenced by natural fluctuations of flow and anthropogenic impacts, has been performed. On the whole, no sizeable changes in the annual streamflow have been found. At the time of spring floods, an average decrease in the maximum annual discharge in the territory of Belarus is 43%, while the increase in peak summer-autumn and winter yields are 27% and 36 %, respectively.

KEY WORDS: streamflow, transformation, river, Polesie

1. INTRODUCTION

In general, the streamflow is formed under the influence of natural and climatic factors. However, lately anthropological impacts become increasingly important factors and in a number of situations are even comparable with natural processes of flow formation. The most powerful man-impacted factor, with a substantial influence on river ecosystems, is a large-scale agricultural reclamation started in the mid-60s of the last century (Lishtvan *et al.* 1999; Kalinin and Volchek 2001). At that time, the southern part of Belarus (Byelorussian Polesie) suffered most from extensive drainage reclamation projects that could not but seriously affect the river discharge (Volchek 2004). Besides, there is a recorded significant effect of global warming (Leiserowitz 2006; IPCC, 2007; Dai 2013; Howe *et al.* 2013). This effect will manifest itself in full within the next decade in the form of combined regional changes in river ecosystems — the very sensitive indicators of availability of both natural and human-caused factors (Jeton *et al.* 1996; Cole *et al.* 1997; McMichael *et al.* 2008; Spence *et al.* 2011).

With an indispensable volume of streamflow data on hand, as obtained from permanent stream-gauging stations over a considerable length of time — from 1940 to 2004 — and with the help of state-of-the-art geoinformation systems and technologies, it is now possible to obtain a quantitative assessment of river discharge fluctuations and to identify disturbances in the inner

structure of time-base series plots. An attempt to correlate the impact of these disturbances with particular changes in climatic factors and economic (or business) activity on the river watershed areas certainly offers potential for revealing concrete river courses and territories with altered hydrological regimes and explaining the cause of these transformations. In its turn, this will enable us to resolve issues of importance of drainage reclamation projects in changes in the hydrolycity and comparability of their role with natural historical fluctuations of the elements of hydrologic budget. In the process, it is important to consider all types of streamflow discharge and, thus, to determine the origin of the above changes as a system (complex).

2. MATERIALS AND METHODS

The starting materials were the results of observational evidence on annual water discharges, spring-flood maxima, summer-autumn and winter flows based on data obtained from 164 control sections, available from the Department of Hydrometeorology under the Minprirody (Ministry of Nature Protection) of the Republic of Belarus, for the entire period of instrumental observations.

To correctly assess the amount of discharge, it is necessary to discriminate between human-affected and natural components on the basis of the following expression [1]:

$$M_{nat} = M_{meas} \pm \Delta M_{aper} \pm \Delta M_{cli} \pm \Delta M_{anth}, \quad (1)$$

where M_{nat} is a would-be observed amount of stream flow under stationary process condition; M_{meas} is a measured (actual) value of discharge for the time period in question; ΔM_{aper} are natural fluctuations of discharge due to aperiodic climatic variations; ΔM_{cli} represents changes in discharge induced by the effect of global warming; ΔM_{anth} is a complex estimate of the effect of economic and other land-use activities on the bed and upon the river catchment area upstream.

The complexity of practical implementations of expression [1] arises from assessment errors and a relative uncertainty of its components.

Measured discharge may reflect visual errors in flow rates and section areas, these are the errors of discharge estimation of a momentary water flow. Besides, there are errors in computation of the volume of streamflow for the period under study; in other words, errors in estimation of stream fluctuations between measurements, as well as those due to a likely deformation of the river bed and flow rates profiles.

As a rule, value ΔM_{aper} serves as a correction to the average discharge value for the period based on its annual normal

flow. For the sake of simplicity, ΔM_{aper} can be determined by using standard deviation values for normal yield and its fluctuations. However, it calls for the study of peculiarities of its regime variations (seasonal and annual).

Value ΔM_{cli} may be found from the recorded data, if the above-mentioned correction has been defined with certainty, while element ΔM_{anth} is not available. Another way of its estimation can be achieved when climate changes are perceived as known. Such models have been already developed for a number of river basins in Belarus (Volchek 2004).

Elements ΔM_{aper} and ΔM_{cli} are of an identical concept. However, if natural changes of climate and flow fluctuations caused thereby in the territory are sharply asynchronous, then the climate-induced discharge variations should be characterized by a more universal unidirectional character for a large territory. This opens up new opportunities for identification of their inputs. During the last ten years when the climate influence came into particular prominence, general territorially-common regularities are to be found in the climate and discharge. Then, it will provide an estimate of the ΔM_{cli} value.

Element ΔM_{anth} reflects a combined (multidirectional, compensating inclusive) influence of economic activities in the catchment area on the water yield.

Due to limited utility of instrumental observations for water distribution and for a variety of other objective causes, the estimation of ΔM_{anth} is associated with considerable errors, the result of which represents the contribution of errors from all the components of the water distribution balance. Relation $\Delta M_{anth} / M_{meas}$ may serve as a simplified estimate of changes in the streamflow. If it is less than 1 to 3%, then this quantity is inessential, with no loss in accuracy. Otherwise a detailed analysis of confidence for all the components is required, as well as the exclusion of ΔM_{anth} element by way of recovery of the discharge, using this element in this relation.

Based on the above, we have worked out a method for estimation of the anthropogenic component in discharge fluctuations founded on the analysis of the flow-field statistic structure. The essence of the method is to perceive the subtle differences between space and correlation functions (SCF) built up

$$\sigma_{abth} = (\sigma_{nat}^2)^{0,5} - (\sigma_{meas}^2 + \sigma_{aper}^2 + \sigma_{cli}^2)^{0,5} = \sigma_{\Delta} \dot{M} (R(0) - R(0)^*)^{0,5}, \quad (2)$$

where σ is the standard deviation of hydrological initial values; $R(0)$, $R(0)^*$, are extrapolated values of an empirical SCF implemented on discharge data before and after exposure to anthropogenic actions, respectively.

Significance of the value obtained, σ_{anth} , is assessed using well-known statistical criteria.

If it is established that σ_{anth} is due not to random mistakes that depend on the length of series, then the quantity ΔM_{anth} characterizes anthropogenic component of the territory water flow.

Identification of concrete water catchment areas susceptible to anthropogenic fluctuations is achieved by analyzing changes in pairing correlative coefficients, and catchment areas with statistically different changes of these coefficients are revealed.

A priori, the motivation for solving task [1] has been substantiated by the analysis of uniformity of the initial hydrometrical data series, graphically and statistically. Further, the date of a radical change in the curve of time behaviour of discharge processes has been determined, causes and parameters of fluctuations in time of those anthropogenic factors that could give rise to them.

Variations in discharge caused by the economic activity, ΔM_{econom} , are determined from the following difference:

$$\Delta M_{econom} = M_{nat} - M_{meas}. \quad (3)$$

Appraisal of man-influenced variations may be thought as credible, if their absolute values are well over the computational error:

$$|\Delta M_{econom}| \geq \alpha_p \cdot \Delta M_{econom}, \quad (4)$$

where α_p is the confidence interval for computing errors, expressed in fractions of its root-mean-square value, is a function of the level of confidence, p .

Usually, when evaluating the confidence of computation, it is typical to set $p=0.95$, for which $\alpha_{p0.95} \approx 2.0$.

Statistical computations were preceded by a special analysis of source information, to check the uniformity of data. On instances where violations were detected within the critical statistics limits, standard statistical methods were adopted in the computational procedure, namely:

- chronological charts of variations and integral difference curves were used to identify trends in fluctuations;
- the dynamics of time series was estimated with the help of linear and square-law trends.

on discharge timebased series for the periods of prior to and during the exposure to active man-induced disturbance (Volchek 1988).

The overall standard deviation of initial data can be objectively evaluated with the help of a reflectory empirical correlative function, of space $R(\rho)$ or time $R(\tau)$, using an extrapolated value, $R(0)$, corresponding to a null distance $\rho = 0$ or null shift in time $\tau = 0$.

When measuring hydrological quantities in very small time intervals or division steps ($\Delta \tau$, $\Delta \rho$), that are appreciably less than the period of oscillations of the type of «white noise» ($\Delta \tau^*$, $\Delta \rho^*$), that is, $\Delta \tau \ll \Delta \tau^*$ and $\Delta \rho \ll \Delta \rho^*$, the sampling or digitizing errors are close to zero.

On the basis that different types of errors are independent, the dispersion of total error is equal to the sum of dispersions of these errors. The Root-mean-square error induced by human factors is defined by the following expression:

Student's test and Fisher's variance ratio test (F-ratio test) were applied to estimate differences in statistical parameters.

Following a thorough analysis, the observation time series were broken up into two periods, namely: from the initial date observation was initiated till 1965, inclusive (i.e., commencement of large-scale amelioration projects) and from 1966 to 2004. Therewith, the series with the period of observation less than 15 years, even though only one of the periods was involved, were discarded. Thereafter, discharge fluctuations have been evaluated from the following relation [5]:

$$k_i = (Q_{av2} - Q_{av1}) / \bar{Q}, \quad (5)$$

where Q_{av1} , Q_{av2} , and $\bar{Q}$ are average values of the discharge for the period of up to 1965, from 1966 to 2004, and the annual average discharge value for the entire period of observation, respectively.

3. RESULTS AND DISCUSSION

The major factors of economic activity in the stream catchment areas in Belarus are as follows: marsh and water-logged land drainage, stream-channel regulation, industrial-municipal and agricultural water-supply, agromeliorative and forest reclamation practices.

The analysis of time-series uniformity for discharge fluctuations has made it possible to identify rivers (Tab. 1) with the most severe man-induced effects (fluctuations in the catchment area, redistribution of flow, excessive regulation, etc.) that have not been mapped because of disturbed hydrological regimes. Fig. 1 shows patterns of these fluctuations.

Table 1. Rivers-Sections with Essentially Disturbed Inner Structure of Historical Series

Type of discharge	River-Section	Discharge fluctuations (formula 5)
Annual	riv. Kopayuvka – village Chersk	-0.61
	riv. Vit' – vil. Borisovschina	-0.57
Maximum spring flood	riv. Viliya – vil. Vilejka	-1.03
	riv. Bobrik – control section Parokhonsk	0.14
	riv. Vit' – vil. Borisovschina	0.20
Minimum	riv. Zhabinka – vil. M.	1.42

summer-autumn low-water flow	Zhabinka riv. Vit – vil. Borisovschina	1.20
Minimum winter flow	riv. Rzhavka – vil. Chernaya Virnya riv. Vit' – vil. Borisovschina	1.60 1.34

It is appropriate here to note the curve riv. Vit' – village Borisovschina, the discharge series of which for all types of

discharge demonstrated the most thorough transformation. First and foremost, it can be linked to variations in the water catchment area. The disturbed structure of the spring-flood maximum discharge curve at riv. Viliya – village Vilejka can be explained by a partial accumulation of the flow in water storages basins and its further transfer to the Vilejsko-Minskaya Water System. The rest of rivers presented in this Table are also classified under a category of small watercourses and, as it is known, this kind of streams are most susceptible to man-induced activities.

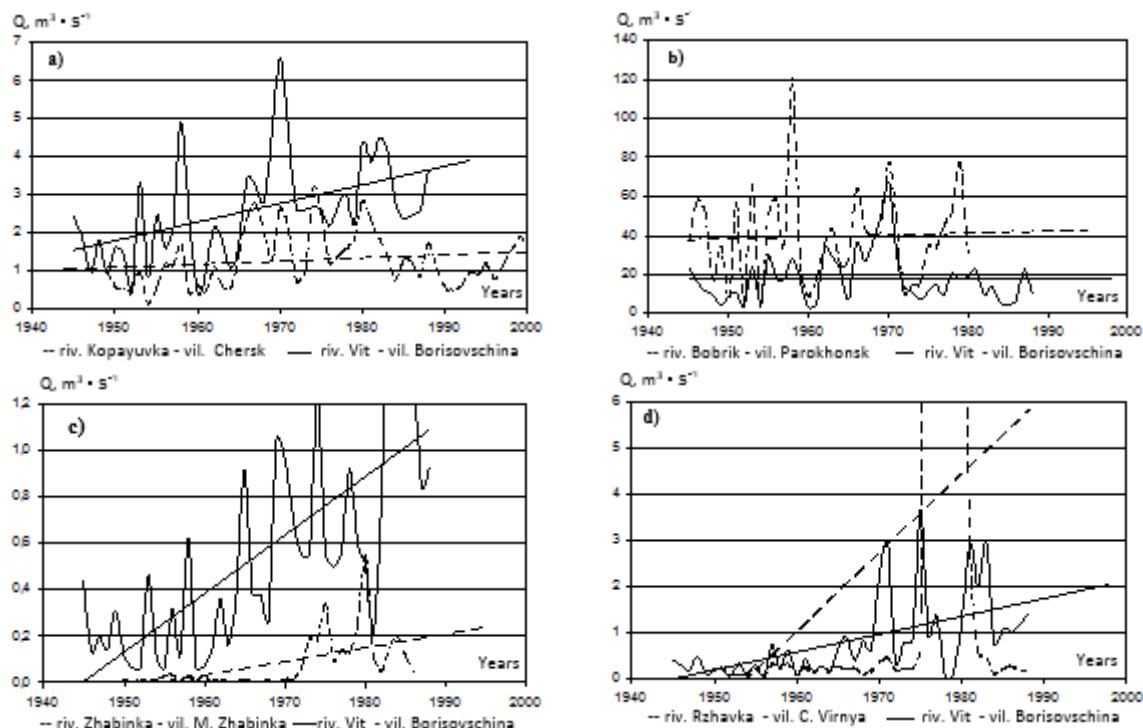


Fig. 1. Chronological charts of, and trends in, discharges for rivers with the most disturbed inner structure of time-series: a – annuals; b – spring-flood maxima; c – summer-autumn low-water minima; d – winter low-water minima.

Values k_i computed with the formula (5) have been gridded (Figs. 2 to 5) using catchment-area coordinates of the river-sections under observation.

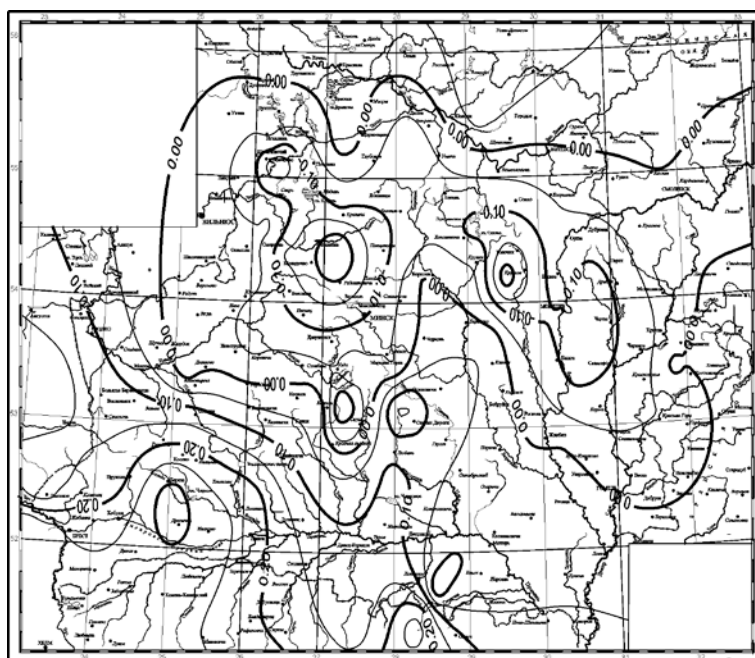


Fig. 2. Spatial structure of fluctuations in annual mean discharges for rivers in Belarus

An analysis of spatial structure for annual discharge fluctuations (Fig. 2) indicates that no variations of annual discharge have practically taken place in the north and central parts of Belarus, less exposed to ameliorative hazards. In the northwest part the discharge of water has insignificantly decreased during the period from 1966 to 2004. Whereas in the south and southwest parts an increase of the annual discharge for the period of 1966 to 2004, as compared to the situation prior to 1965. To summarize, fluctuations in the annual discharge are insignificant – an average value of the fluctuation coefficient was 2.7%, i.e. within the discharge measurement error limits. At the same time, these fluctuations were found more pronounced – the mean value of fluctuation coefficient was equal to 0.201, suggesting a 20-percent increase in the annual discharge. Hence, the large-scale amelioration projects contributed to the increase in annual discharge on small rivers of Byelorussian Polessie through a partial draw-

down of secular storage in earth surface horizons and redistribution of component ratios in the hydrologic budget.

The mean value of the discharge-change coefficient for spring flood maxima was down to -0.425, the same coefficient for summer-autumn low-waters equals to 0.271, and for winter discharge minima amounts to 0.356. In other words, in average, a 43-percent decrease in maximum spring-flood discharges, 27-percent increase in minimum summer-autumn low-waters, and 36-percent increase in minimum winter low-water season are registered in Belarus.

Studies of maximum spring floods, minimum summer-autumn and minimum winter discharges of Belarus rivers form a basis for formulation of the following infringements of the inner structure of time series:

- a decrease in maximum water flow after 1965 (up to 25–40%) over the entire territory of Belarus (Fig. 3);

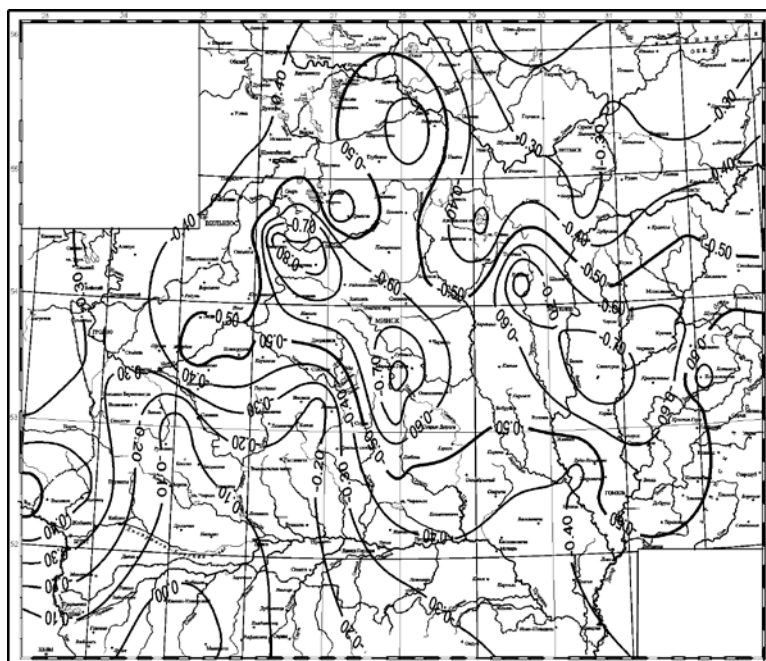


Fig. 3. Spatial structure of fluctuations in discharge maxima during spring floods for rivers in Belarus

- a substantial (up to 50–80%) increase in minimum discharges during the summer-autumn low-water period for the

south and southwest parts of Belarus during the 1966-to-2004 period, as compared to the period before 1965, inclusive, while the stated above variations are not so drastic (10–30%) (Fig. 4);

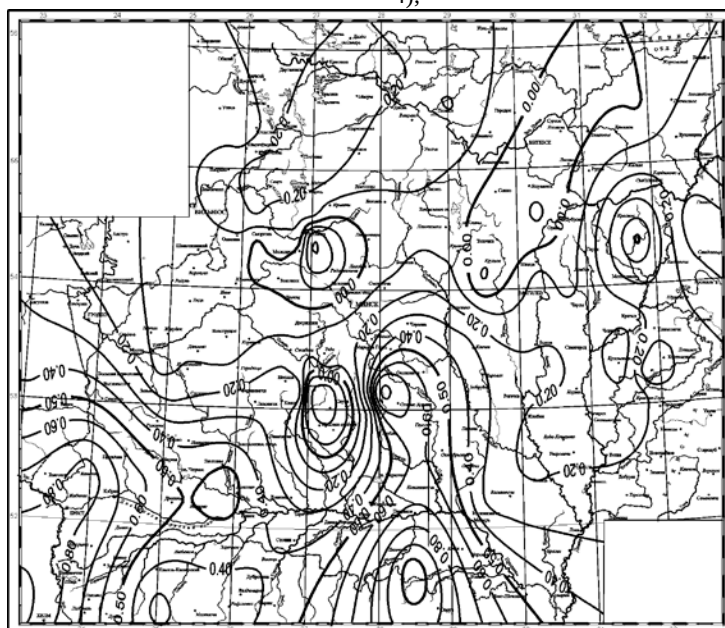


Fig. 4. Spatial structure of variations in summer-autumn discharge minima for rivers in Belarus

– minimum winter yields increased in the aggregate by 20–40 percent, a compared to the prior-to-1965 period, let us mention

in passing that maximum of these variations is specific for Byelorussian Polessie (60–80%) (Fig. 5):

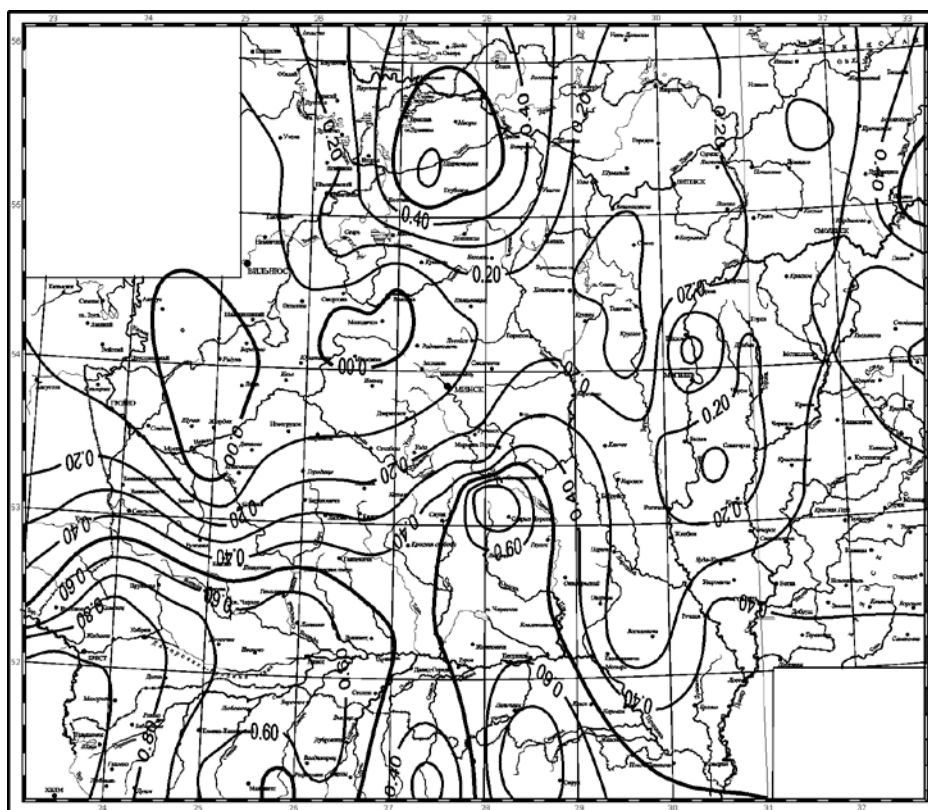
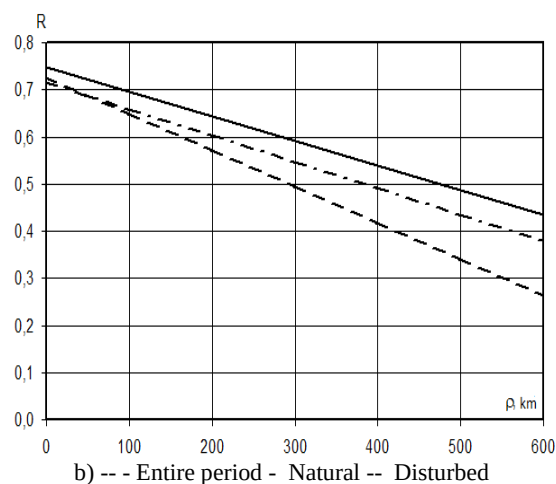
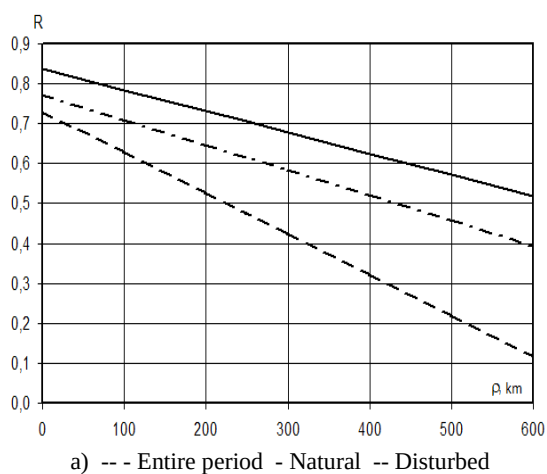


Fig. 5. Spatial structure of variations in winter discharge minima for rivers in Belarus

This increase in winter low-water season is an aftereffect of prolonged thaws which became more frequent recently and are characterized by intensive thawing of snow and replenishment of ground water stocks. As a result, the spring flood discharges decrease, while the summer-autumn low-waters increase.

To estimate the influence of large-scale amelioration projects on the hydrological regime of Byelorussian Polessie, an

analysis of changes in SCFs has been completed for the following periods: from the starting point of observations until 1966, i.e. the time of the onset of large-scale land-reclamation and development projects, and since 1966 to date implemented on data from 26 measuring sections established on rivers with catchment areas from 67 to 2560 km². Computations have been carried out for the three specific-type discharges: maximum spring floods (SF), minimum summer-autumn (S) and annual water debits (A) (Fig. 6).



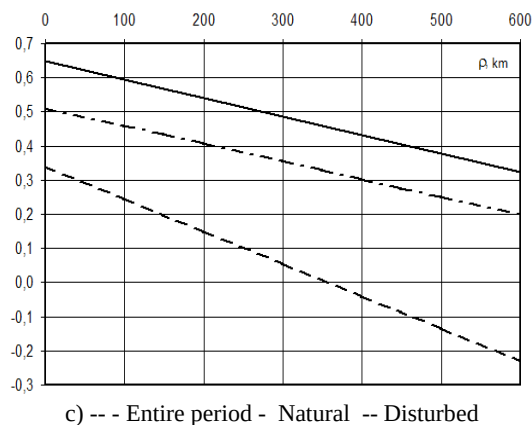


Fig. 6. The space-correlation function of the mean annual (a), springtime flood (b), and minimum summer-autumn low-water (c) total streamflow for rivers in Byelorussian Polessie.

Instances with disclosed statistically distinguishable changes in correlation coefficients indicate the exposure to human-initiated activity. Thus, the comparison of SCFs for the period free from ameliorative effects, ($R(0)_{SF}=0.774$; $R(0)_S=0.687$; $R(0)_A=0.853$), with SCFs like ($R(0)_{SF}^*=0.734$; $R(0)_S^*=0.351$; $R(0)_A^*=0.742$) for the period of building large-scale land-reclamation structures indicates the presence of statistically discernible distinctions between them ($\Delta R(0)_{SF}=0.040$; $\Delta R(0)_S=0.326$; $\Delta R(0)_A=0.111$).

These distinctions are most substantial for the minimum discharge (47.5%); it can be associated with variations in the general water content in rivers, the extent of catchment area,

the size of drained marshes and water-logged land areas, as well as the density drainage channel network and the degree of channelization. Polessie is characterized by the predominance of peat bogs of shallow bedding located on well-filtered sand underlayers; also, a deep drainage patterns and channelized river beds are cut into the bedrock. Hence, a substantial increase in the minimum discharge (approximately by 50 percent) has been noted in this area for the 1966-to-2004 period as compared with the period since the time of commencement of observations and till 1966.

At the early stage of land reclamation projects changes in discharge maxima took an ambiguous route. The water catchment areas where the uniformity of maximum rate of flow and runoff layers had been infringed demonstrated an increase and decrease alike. This is the consequence of amelioration activity in the catchment areas leading to the establishment of an intricate set of various conditions. The latter have appreciable multidirectional effects on the formation of maximum discharge in rivers during spring floods. A pronounced increase in the storage capacity of areas reclaimed by draining in the catchment area results in loss of melt waters and a decrease in maximum discharge intensity, while an artificial expansion of gauging station density coupled with river regulation favours the formation of augmented discharge maxima. In the context of simultaneous combined action of both factors, the pattern, as well as the scale of maximum discharge variations is actually a function of the factor whose effect is more severe.

Following the establishment of equilibrium condition, a certain decrease in the maximum discharge is noted (approximately by 25 %), also, it is more “organized” both, in time and in space, as opposed to processes with an increase in the minimum discharge. Hence, an insignificant decrease in the correlation coefficient $R(0)_{SF}=5.2\%$.

Maximum changes of the yearly streamflow has been registered at the water catchment areas located within flat lowlands, as well as on those with wide water-logged flood plains. The higher the degree of swampiness of the catchment, the greater fluctuations of the yearly runoff subsequent to amelioration. As a rule, it also increases with the added portion of drained swamps and waterlogged-land patches. As the results of our study for the territory of Byelorussian Polessie imply, the yearly runoff augmented approximately by 20% for the period from 1966 to 2004, as compared with the period prior and including 1965. At the same time the parameter $R(0)_A$ came to 13%.

4. CONCLUSION

Thus, the main causes of river flow transformation in Belarus are environmental repercussions due to the global climate changes on the backgrounds of man-made effects in the form of the large-scale reclamation projects in Byelorussian. The influence of the anthropogenic component (for example, amelioration) on different types of flow should be examined individually, on a case by case basis.

Changes in flows demonstrate a varied character, with a certain “intra-annual” transformation of river hydrological regime in Belarus. The observed reduction of maximum spring-flood discharge is made up by an essential increase in minimum discharges during both winter and summer-autumn low-water seasons. In other words, global climatic changes have led to the flow change within the hydrological year, while the yearly normal runoff has not practically changed in quantity, with the exception of the Byelorussian Polessie territory which differs from other regions of Belarus by the conditions of flow formation and man-impacted loads.

Further still, it is not so much the drainage (of marshes), as incompetent servicing and improper operation of the drainage systems and incorrect water usage and economic practices on the territories of water catchment areas that impair the inner structure of flow formation and lead to those quantitative changes of water discharge that have been recorded during this study.

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NATURAL COMPACTION OF PLOWED SOIL: EVOLUTION IN TIME

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Abstract: This paper aims by changes in field soil compaction in dependence on time and weather conditions, like current air temperature, current weather conditions, average monthly air temperature and average monthly rainfall. Experimental data were taken from 11th November to 10th March 2017 nearby České Budějovice, the Czech Republic. The soil compaction was measured by penetrometer up to 80 cm at thirty different places. The average temperature in November was 2.1 °C and in December was -0.9 °C, which are common temperatures in this season in the Czech Republic. Magnitudes of the compaction are almost similar up to the deepness of 30 cm, whereas the soil compaction grows significantly from 20 cm of depth. There is a break-point at about 30 cm of deepness, where the magnitude of soil compaction stops growing and starts falling. The soil compaction from 30 cm and deeper decreased according to elapsed time after tilling. Interpretation of this data could assist in deciding on agricultural machinery passes over plowed soil with minimal undesirable compaction of the subsoil.

Keywords: MONITORING OF COMPACTION, FIELD EXPERIMENT, PENETROMETER, TILTH

1. Introduction

Soil consolidation, in primary plant production, is an undesirable phenomenon, which is the root cause of number of negative phenomena, such as reducing crop yields or worsening water retention in the countryside. The process of pedocompaction is defined by the most of authors as the reduction of air porosity and permeability through the process of physical degradation of soil. Nowadays, one of the most important factors, that influences pedocompaction, is the movement of agricultural technology on a land [1].

Methods of assessing and observing soil compaction are as diverse as individual directions that can be investigated when soil is compacted. Compaction can be detected by visual or laboratory methods (eg [2]). Sandin et al. [3] used X-ray tomography for soil structure and saturation after soil treatment. Naveed et al. [4] used even more modern, computerized, tomography when observing the soil structure. Shahgholi and Abuali [5] measured field soil compaction using potentiometers located in the soil profile. Soil penetrometer resistance measurements can also be used to quickly assess soil compaction. This method was used by Taghavifar and Mardani [6] while they were assessing the effects of speed and load and number of land crossings, on soil compaction. Barik et al. [1] based their observations on uninterrupted soil sampling, after a number of agricultural technology crossings. Then the samples were examined for changes in soil physical properties such as soil aggregate stability, bulk density, total porosity, penetration resistance and moisture content. The biggest changes in these parameters were recorded at a depth of up to 10 cm below the surface.

Radford et al. [7] conducted their observations on a specific sample of agricultural technology. They monitored changes in soil properties, after using harvesting techniques.

Such as other science disciplines, computer models have been recently used for better understanding of the processes which take place in soil, during the transition of agricultural technology. These models allow for example to estimate the decomposition of compressive forces induced by agricultural technology. One of the first models was designed by Lozano et al. [8]. Keller and Arvidsson [9] used computer models to design measures that will lead

to reduction of pedocompaction, using track and half-track chassis. The input parameters of the model are load on the track, track width, track length, number of support rollers, wheel and roller diameter.

Currently the method of permanent tracks is considered to be the best accessible technology, leading to minimization of negative

effects of agricultural technology crossings to soil. Bennett et al. [10] conducted their comparative research of conventional and controlled agricultural technology crossings and its impact on soil sources. Accordingly to their conclusion, there is less plants per hectare in the system of controlled crossings of agricultural technology, when compared with the use of system conventional crossings. Nevertheless the yield from the land is higher. However, the technology of controlled crossings is not sufficiently tested in terms of long-term time.

Natural soil compaction can also be called as soil consolidation. It is the gradual dismantling of the soil and increase of its penetrometer resistance. According to Sabetamala et al. [11], the dynamic porous environment behaves accordingly to Biot's theory, and the solid phase of the soil, if not behaving linearly, is controlled by Mohr-Coulomb theory or Modified Cam-Clay model. The assessment of the methods for predicting volumetric changes of expansive soils per time was performed by Adem and Vanapalli [12]. They concluded that the predictions are based on three methods - consolidation theory, methods of volume moisture, and suction methods.

2. Materials and Methods

Measurement of spontaneous soil compaction was taking place from November 2016 to beginning of March 2017, on the experimental land in České Budějovice, whose position is captured in Figure 1. The area of the experimental land was 0.37 ha. The time before the first and last measurement was 119 days.

The land is located in a slightly warm and slightly humid climatic region, characterized by an average annual temperature of 7-8 °C and an average annual rainfall of 550-650 mm. The land is flat, slightly sloping and is not significantly oriented to some world side. The soil layer on the experimental land is middle-deep (40-60 cm) to deep (> 60cm). The soil on the land is medium-porous, non-skeletal to lightly skeletal and is moderately to lightly inclinable to hardening. The soil type of the land is up to 40 cm of a depth sandy-loam and in deeper layers it passes into loamy soil. The texture of the experimental land in three different layers of the soil horizon is shown in Table 1. The experimental land was ploughed two days before the first measurement. The data was taken from [13].



Figure 1: A photo of the experimental land

Table 1: Percentage representation of individual soil fractions on experimental land depending on depth

	Depth beneath the surface [cm]		
	0-20	20-40	40-60
Sand [%] (particles' diameter >0,05 mm)	52,3	50,7	33,9
Silt [%] (particles' diameter 0,001-0,05 mm)	25,2	23,5	23,8
Clay [%] (particles' diameter <0,001 mm)	22,5	25,8	42,3

Spontaneous compaction of soil was measured through the penetration resistance of the soil against penetrating it with a cone apex of a penetrometer. This device counts the penetrometer soil resistance R_p [MPa] according to:

$$(1) \quad R_p = \frac{F}{S \cdot 100},$$

where F [N] represents the force captured by the device and S [cm²] is surface of the base of the apex used for penetration. During the measurements, the surface of the cone's apex base was 1 cm² and the penetrometer resistance was recorded up to 80 cm of a depth. During all other measurements the surface moisture, air temperature, characteristics of weather and average surface moisture of soil were stated. The measurements took place 2, 9, 16, 37, 114 and 121 days after the soil was ploughed. The received values are presented in table 2.

Table 2: Weather description during measurements

Days after plough	Measurement date	Air temperature [°C]	Weather character.	Average surface moisture of soil [%]
2 days	11.11.2017	2,5	cloudy, drizzling	19,6
9 days	18.11.2017	3	clear	23,7
16 days	25.11.2017	6	cloudy	24,6
37 days	16.12.2016	0	partly cloud	20,6
114 days	3.3.2017	5	clear	18,7
121 days	10.3.2017	4	cloudy, drizzling	25,6

3. Results and discussion

Comparison of the penetrometer resistance recorded during individual measurements is presented in Figure 2. The most significant increase of penetrometer resistance values up to 50 cm of a depth, seen in the figure 2, was recorded during the fifth and sixth measurement. After the first measurement, the soil compaction in less than 40 cm of a depth, was reduced.

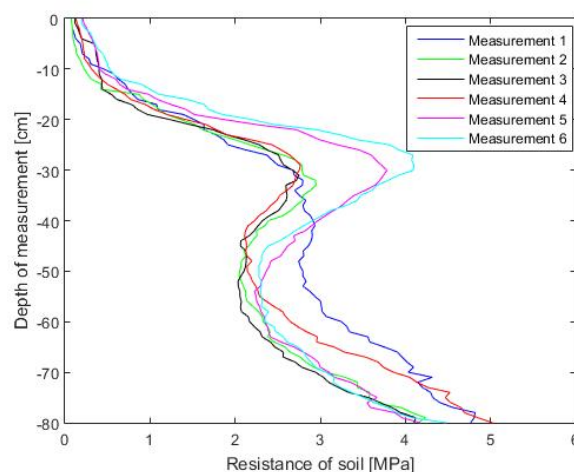


Figure 2: Penetrometer resistance received out of individual measurements

The changes of penetrometer resistance during individual measurements, which took place on different days, are presented in table 3. Table 4 presents percent changes of penetrometer resistance compared to values received during the first measurement.

Table 3: Change of penetrometer resistance after individual measurements (%)

	0-30 cm	31-40 cm	41-50 cm	51-60 cm	61-70 cm	71-81 cm
9 days	-13,62	0,62	-22,98	-26,40	-30,06	-17,12
16 days	39,28	-6,63	-1,55	-3,34	-4,67	-3,89
37 days	2,31	-1,91	-0,56	12,46	28,37	26,74
114 days	43,21	35,34	23,98	-1,03	-15,93	-19,57
121 days	14,80	2,35	-5,49	0,86	1,11	-0,44

The results show gradual increase of the penetrometer resistance (i.e. soil compaction) at a depth of 0-40 cm. The only exception is the second measurement, carried out 9 days after the land was ploughed, where the surface moisture, which was 5% higher, could have affected the results. On the contrary, at a depth of 41-80 cm during the second (November 18, 2016) and the third measurement (November 25, 2016), there was gradual reduction of the penetrometer resistance, which was probably caused by soil regeneration after the soil was ploughed.

The fourth measurement (December 16, 2016), which took place 37 days after the land was ploughed, shows increase of penetrometer resistance in its entire depth, except for a depth of 31-50 cm, where the penetrometer resistance is practically the same as in the previous measurement. This phenomenon can be explained by lowering average daily air temperatures and freezing of the soil. The air temperature at this measurement was the lowest of all measurements. The fifth (March 3, 2017) and the sixth (March 10, 2017) measurements were carried out in the spring, after thaw of the soil. The trend of increasing penetrometer resistance, at a depth of 50 cm and on the contrary, its reduction from a depth of 51 cm, is noticeable in the measured values. The increase of penetrometer resistance at depths up to 30 cm was also noted during the last, sixth, measurement. For depths greater than 60 cm the differences between the measurements are no longer significant.

Table 4: The percent change of penetrometer resistance related to the first measurement (%)

	0-30 cm	31-40 cm	41-50 cm	51-60 cm	61-70 cm	71-81 cm
9 days	-13,62	0,62	-22,98	-26,40	-30,06	-17,12
16 days	12,05	-6,09	-24,20	-28,88	-33,35	-20,30
37 days	9,55	-7,78	-24,67	-20,14	-14,47	0,73
114 days	59,25	24,91	-6,75	-21,12	-28,17	-18,97
121 days	77,12	28,08	-11,80	-20,51	-27,42	-19,32

The table 4 shows changes of penetrometer resistance in upper layers of soil up to a depth of approx. 50 cm. This process is a result of spontaneous compaction of ploughed soil up to borders near to values of natural penetrometer resistance.

Based on the values presented for depths of 41 -81 cm, it can be presumed that during the first days after the crossing, it comes to regeneration of the soil compacted by crossing with agricultural technology. Nevertheless, the percent values presented indicate, that the referential measurement (day 2) was significantly negatively affected by air conditions (rainy weather). That is reflected by decrease of penetrometer resistance already after 9 days since the soil was ploughed, however it can be presumed that values measured as comparable, were affected by moisture or by other effects.

4. Conclusions

In conclusion, it can be said that soil is a constantly changing nature formation formed from the surface residues of the earth's crust under the influence of soil-forming factors and organic remains of dead plants and animals. Soil is the environment of soil organisms and habitat for both crop and weed plants. By human activity the land is transformed into a space, reserved for cultural crops but it is also severely damaged. These negative impacts are, to a large extent, eliminated by the regeneration processes that take place in the soil. The experiment conducted on the lands of the Agricultural Faculty, University of South Bohemia, showed not only the differences in penetrometer resistance between the different layers of soil, but also its changes accordingly to weather and weather conditions. Understanding the regeneration processes can help to improve soil condition and farming on it.

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INVESTIGATION OF MACHINES FOR SOIL PROCESSING AND SOWING BIOENERGETIC CROPS UNDER CONDITIONS OF CHANGEABLE RELIEF

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Abstract: *Problematic issues of tillage on slopes are distinguished and methodological aspects of theoretical analysis and experimental researches and production testing of tillage and sowing machinery under the given conditions, in recognition of preservation of soil fertility, are represented. It is considered that sloping lands can be terraced to reduce water erosion of soil, but it is not always expedient to apply this anti-erosion measure, especially on slopes with low steepness, where the usage of special tools for soil-protective non-moldboard tillage is preferable. The theoretical background to make calculation of sowing machines that are engineered for the system of precise/specific/accurate farming in fields with a complex terrain is presented.*

KEYWORDS: SOIL, CROPS, TILLAGE MACHINES, SLOPES, SOWING EROSION, TERRACING.

1. Introduction

Mechanized technological processes in plant growing on flat, horizontal fields under the optimal values of humidity and firmness of soil by existing agricultural machines are basically conducted satisfactory. Herewith, quality, energy and economic indicators correspond with the norms of agrotechnics and business. Farm scale trial shows that it is not possible to perform technological work properly on sloping lands even with slight steepness.

The main factor that affects work of agricultural units on sloping lands is the terrain, which is characterized by steepness and configuration of the cultivated areas, and state of soils as well. The preparation of fields (terracing of slopes, the organization of anti-erosion facilities, usage of No-Till, Strip-Till technologies, etc.) for carrying manufacturing processes of crop cultivation has great influence/impact on work of agricultural machines. To prevent erosion on the slopes it is preferably to carry out tillage operations, sowing, spacing cultivation horizontally (crosswise the slopes).

In Ukraine, in particularly in some south-western regions, sloping lands/slopes of varying steepness occupy large areas [1]. About 10,5 million. ha (31,7% out of all arable land) are eroded. Among them 7,8 mln. ha (74,2% out of the total area of eroded lands (TAEL)) are poorly eroded; 2,2 mln. ha (21,0% out of TAEL) are mid-eroded; and 0,5 mln. ha (4,8% out of TAEL) are highly eroded lands. Typically/as a rule, the slopes of more than 10° steepness are eroded by more than 60 % [2]. Water erosion starts if the steepness of a slope is 0,5° [3]. Investigations show that intensity of water erosion increases greatly with the increasing of slope steepness. Conditions of lowland and slope agriculture significantly differ in relation to agrotechnics, the specifics of conducting mechanized processes, methods of land development (preparing

lands for reclamation and conducting land clearance operations, regulating moisture regime of soil), etc. [1, 2, 3].

Agricultural crops, that can accumulate solar energy to a large extend/considerably, take/have a special place in the agricultural sector of the Ukrainian economy. These are sugar beet, corn, small grains (wheat, triticale), which are used as primary produce for producing bioethanol, and oil plants (rapeseed, sunflower, soybean, etc.), which are used for the production of biodiesel [4, 5]. The technological process of sowing occupies an important place in the complex of works on growing bioenergetic crops. Erosion processes of soil, following effective mechanized operations and, eventually, the yield of these crops and the profit for agribusiness depend on the correctness and accuracy of sowing processes. Although, growing bioenergetic crops on sloping lands, especially tillage and sowing are not investigated properly, that's why it is an urgent scientific and industrial problem that should be solved comprehensively.

2. Prerequisites and means for solving the problem

Conditions of work of agricultural machines on the same hilly field vary due to the moving direction: uphill, downhill, across a slope or on a hillside. To minimize erosion on sloping lands tillage machines should move across the slope.

Moreover, it should be considered that while moving across the slope spontaneous withdrawal of tires can be caused by the cross-wind component of a machine weight, and the difference of/in rolling resistance of lower and upper support parts of the machine on slopes as well. Alongside the spontaneous withdrawal of tires, sliding of machine wheels and its working parts should be taken into account. It mainly depends on magnitude of a slope angle, wheel load, physical and mechanical characteristics of soil and tire grip. As

the result of side movement and sliding, rectilinear stable moving of agricultural machines on a slope gets interrupted.

While tillage and seeding on sloping lands are in process, both motion stability and quality indicators (especially, agroecological ones) should be taken into consideration. Thus, for example, when plowing slopes of 4° steepness soil shifts up the hill, partial inversion of soil layer by shellboards of a plough bottom; and while working on soil turned to the footslope, soil shifts down the hill that is equal to the soil loss of 12 m³/ha [3, 7].

In general, intensity of soil loss per area unit in a time unit, i.e. t/ha per year or mm/yr., is computed assessing erosion processes. These units are for assessing speed of soil forming, too. Comparing intensity of soil loss and speed of soil forming we can evaluate the level danger of erosion. If the intensity of erosion lower than the speed of soil forming, then the erosion of this field is not dangerous, although it occurs quite rare.

3. *Solution of the examined problem*

According to steepness of slopes conservation cropping system of contour land reclamation intends usage of soil/lands differentially, due to what arable lands are divided into 3 groups. The first group of lands is plains and slopes of up to 3° steepness. These are used for grain and hoed crop rotation. Sowing of hoed crops decreases and sowing of grains and herbs increases on the farmlands with greatly rugged terrain. It is because of different soil-protecting efficiency of these crops. The second group of lands is slopes of 3 to 7° steepness. It is recommended to use them for soil-protective crop rotations with sowing of winter and spring grains, one year and perennial grasses, and not hoed crops. The third group of lands is slopes of more than 7° steepness. They are sown by perennial grasses. The complex of tillers and sowing machines to use depends on the type of crop, sowing of which in turn depends on the slope steepness.

According to the profile of the slopes they are concave, convex and convex-concave. In the concave slope steepness gradually diminishes from the middle to the base. The soil on it becomes more fertile as you approach the valley. On the convex-concave slopes the steepest portion is spaced near the base. Over the steep part of the slope is again a flat area on which is deposited the fine earth, carried from the upper part of the slope.

Cultivation of the soil without turning the soil formation, is widely used in soil conservation technologies of land processing and it includes such operations: metal-cutting blades surface treatment, treatment by combined units, chisel tillage, chisel processing, slotting, milling, deep-hole digging.

Metal-cutting blades tools better perform their function in the light and medium soils. On heavy soils they work worse, form

lumps, don't move steadily. For quality work of metal-cutting blade tools the soil should not be over-wet. On heavy soils and at higher moisture content it is recommended a wider use of rippers and chisel cultivators, gap-makers, narrow holes tools, cutters.

When designing metal-cutting blades, you can implement a large number of options for the location of the working bodies, as the soil formation at work does not move to the side and does not turn around. But because these tools work on stubble backgrounds, containing a significant amount of crop residue on the field surface, it is important that the distance between the steel paws was enough for the free passage of plant debris and carrying out the process without jamming the soil.

Soil treatment without recourse to the reservoir was carried out with a chisel ploughs working bodies in the form of rippers with interchangeable bits of different designs. As a result of deep soil loosening and mixing 20-30% of crop residues with the surface layer 2-3 times increased its water-soaking effect that prevented water erosion. Chisel hoeing to a depth of 50 cm was carried out during the rotation of planting the seeds. Because of the depth of treatment below the arable layer, the energy intensity of the process of loosening the soil increased sharply.

On sloping lands the system of the non-plough tillage included slotting the soil to a depth of 60 cm, with gaps of 3-4 cm in width and the distance between them more than 120-150 cm. Working bodies of the narrow holes maker worked in a cutting blocked mode.

Economically feasible is the use of combined units, which consist of a set of tools and execute within a single pass three or more basic operations – cultivation, disking of the soil, leveling, harrowing, compacting surface, etc. Each of these tools can be used individually for the intended purpose. Needle harrow BIG-3, for example, effectively loosens the soil in the spring to perennial grasses of the 2nd, 3rd year of cultivation.

The most beneficial to have the stabilization of movement for the tillage and sowing machines which is carried out by the lateral soil reaction on the working bodies of the machine and wheels. Dimensions of the running wheels of tillers depend on soil conditions, implement design features, durability requirements.

A wheel experiences a radial load P_r and P_o axial force applied to the bottom of the rim by the gauge. The magnitude of the axial force can be taken as

$$P_o = P_r \varphi_c, \quad (1)$$

where φ_c – friction coefficient. The axial force creates $P_o D/2$ point, which acts on the wheel, causing a bending stress. To increase traction with the ground applied spurs or flanges [10].

Pneumatic wheels mounted on the soil cultivated tools and compared over metal ones have several advantages: they have

somewhat lower traction resistance; they are less damaging to crops. Furthermore, application of pneumatic tires can improve speed and durability of the machine unit, due to the decrease of intensity in shocks and bumps. Besides this a tread of the tire must meet the following requirements: a good longitudinal and lateral grip on the rolling surface, sufficient self-cleaning grooves.

The centuries-old practice of growing different crops on the slopes with the steepness 5 ... 25° shows that these lands cannot get lower yields when you hold the plain and a soil moisture and on a slope.

Effective way to protect the soil from water erosion is terracing slopes [2].

Professor J.K. Kyrtbaya proposed formulae for calculating elements terraces where sizes of terraces set in such a way that the volume of soil excavation is an apparent volume after shrinkage of the soil.

Tilt bandwidth necessary for the construction of terraces set parameters determined by the formula: (2)

$$L = B \frac{\sin(\beta + \gamma) \sin(\varphi - \alpha) + \sqrt{\sin(\beta + \gamma) \sin(\varphi - \alpha) \sin(\varphi + \gamma) \sin(\beta - \alpha)}}{\sin(\beta - \alpha) \sin(\varphi - \alpha) \left[1 + \sqrt{\frac{\sin(\beta + \gamma) \sin(\varphi - \alpha)}{\sin(\varphi + \gamma) \sin(\beta - \alpha)}} \right]} + a,$$

where B – width of the canvas (Fig. 1);

α – steepness of a slope;

β – long well inclined angle of the slope to the horizon;

γ – angle of the angled cross-section to the horizontal position of the canvas;

φ – angle of repose of a bulk;

a – berm width.

The width of the dredging on a canvas

$$b = B \frac{1}{1 + \sqrt{\frac{\sin(\beta + \gamma) \sin(\varphi - \alpha)}{\sin(\varphi + \gamma) \sin(\beta - \alpha)}}}. \quad (3)$$

The width of the excavation of a soil slope [2]

$$c = B \frac{\sin(\beta + \gamma)}{\sin(\beta + \alpha) \left[1 + \sqrt{\frac{\sin(\beta + \gamma) \sin(\varphi - \alpha)}{\sin(\varphi + \gamma) \sin(\beta - \alpha)}} \right]}. \quad (4)$$

For terraces that have an angle cross-section the canvas down the hill, in all formulae before γ should be put a minus sign

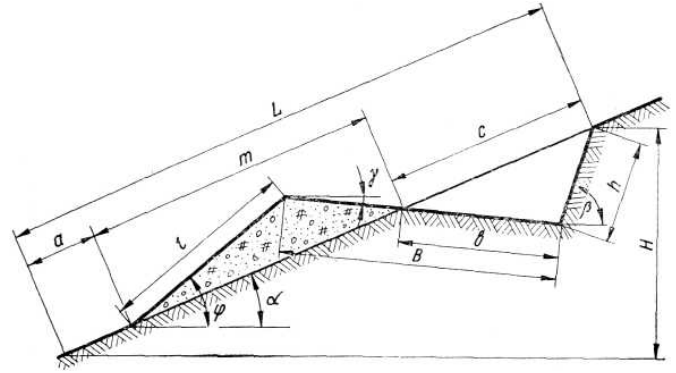


Fig. 1 Scheme of stepped terrace

Bulk of many terraces is being compacted by the tractor tracks during its soil processing. Therefore, when calculating it is appropriate to use the settings that are obtained after shrinkage of the soil, and do not consider the ratio of hollow soil during creating a formula. This ratio is expedient to consider while fulfilling a normalization process for the construction of terraces, where the volume of compacted soil should be multiplied by a factor of availability of the hollow soil.

The movement of particles on rough surfaces of the agricultural machines is analyzed in details in the works by Vasilenko P.M. [8] as well as other sources.

Design of many agricultural machines, their working bodies, including seeding machines, is impossible without the determination of kinematic and dynamic parameters of movement of material on the working surface. [6, 9]

When talking about the sowing machines it is necessary to understand that moving particles can occur without interaction with other seeds, but because the definition of trajectories of individual particles, determining the parameters of its interaction with moving surfaces of the machine is an important scientific task, it is allowing the design phase to ensure high standards for their accuracy.

Let's us consider moving a cone surface of the sowing machine with a casing diameter D_0 in the cylindrical coordinate system $O\rho\theta z$, rotating with angular velocity ω (Fig. 2) [6].

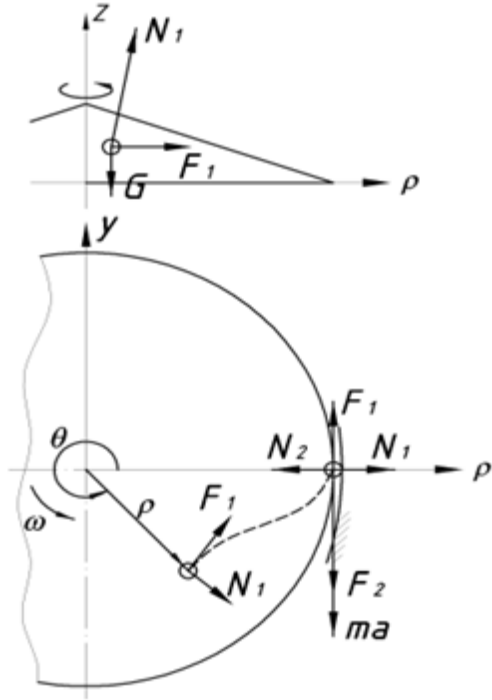


Fig. 2 Estimated traffic pattern of a single seed on the surface of the seed sowing disc

The equation of this surface is in the cylindrical coordinate system

$$\rho_1 = u; \quad \theta_1 = \varphi_1; \quad z_1 = u_1 \operatorname{ctg} \beta. \quad (5)$$

Equation on a cylindrical surface casing:

$$\rho_1 = D/2; \quad \theta_1 = \varphi_1; \quad z_2 = u_2, \quad (6)$$

where u_1 and φ_1 – respectively linear and angular parameters which are independent on each surface.

According to the law of conservation of energy to grains during rolling the equality happens [6]:

$$\frac{m v_c^2}{2} + \frac{I \dot{\varphi}_e^2}{2} + \frac{k_t \dot{\varphi}_e^2}{2} = mg \Delta h, \quad (7)$$

where m – grain weight; V_c – the velocity of the center of mass of grain; I – moment of inertia around the ellipsoid axes around the central axis of rotation; k_t – dissipative energy dissipation rate; Δh – grain level placement for working height range, $\Delta h = -y_{oc}$.

Value of a module angular velocity ellipse:

$$|\omega| = \sqrt{\frac{-mgy_{oc}}{m \sqrt{\left(\dot{x}_{oc}\right)^2 + \left(\dot{y}_{oc}\right)^2} + \frac{I}{2} + \frac{k_t}{2}}}, \quad (8)$$

The changes in angular velocity are according (8) defined linear speed of grains.

Depending on the derived data it enables to determine the trajectory of the center of mass cone surface grain on the sowing

machine and the variation speed of the particles, for which are developed the appropriate algorithms and software.

Using the principle of d'Alembert equation, the flow of grains has the following form:

$$\bar{N}_1 + \bar{F}_1 + \bar{N}_2 + \bar{F}_2 + \bar{G} - m\bar{a} = 0 \quad (9)$$

where $\bar{N}_2$ and $\bar{F}_2$ – are the vectors of force with normal reaction to the cylindrical surface of the housing and the friction force because of its action, $\bar{F}_2 = \mu_2 \bar{N}_2$. Vector resultant in reaction on the disk surfaces ($i=1$) and a cylindrical casing ($i=2$) in a polar coordinate system is similarly recorded as:

$$\bar{R}_i = \bar{N}_i + \bar{F}_i = \{\alpha_{\rho i} N_i; \alpha_{\theta i} N_i; \alpha_{z i} N_i\}, \quad (10)$$

where $\alpha_{\rho i}$, $\alpha_{\theta i}$ and $\alpha_{z i}$ – are the relevant factors (amount of the direction cosines vectors and to the angles on the coordinate system). For the proposed case

$$\alpha_1 = \{\sin \beta; \mu_1; \cos \beta\}; \quad (11)$$

$$\alpha_2 = \{-1; -\mu_2; 0\}.$$

Components of the absolute speed and acceleration of a grain during its movement on the surface of the enclosure under the drive of a disc [6]:

$$v_\rho = 0; \quad v_\theta = u \cdot d\theta / dt; \quad (12)$$

After appropriate transformations and reactions on a disk surface the casing is determined according to defined dependencies:

$$\begin{aligned} N_1 &= mg / \cos \beta; \\ N_2 &= m \left(D_0 / \dot{\theta} / 2 + g \operatorname{tg} \beta \right). \end{aligned} \quad (13)$$

The equation of motion of a particle in expanded form looks like:

$$\ddot{\theta} - 2\mu_1 g / (D_0 \cos \beta) + \mu_2 \left(\dot{\theta}^2 + 2g \operatorname{tg} \beta / D_0 \right) = 0. \quad (14)$$

For the set motion when $\ddot{\theta} = 0$, under the condition that the angular velocity of the circular flow of grains is provided $\dot{\theta} \leq \omega$ is equal [6]:

$$\omega_A = \dot{\theta} = \sqrt{2g(\mu_1 - \mu_2 \sin \beta) / (\mu_2 D_0 \cos \beta)}. \quad (15)$$

As a result of researches the model of a particle seed, which allows determining the kinematic and power parameters when interacting with a conical seed and seeding flat disks. We can obtain the analytical dependence for determining the trajectory of the grains on the surface of a rotating disk, the angular velocity array of seeds and reaction of the surfaces and a drive enclosure. The

described above is a scheme and a principle of work for a mechanical precision seeding machine [5] .

A method of structuring mechanical constructions precision seeding machines and methods to improve them are based on the study of the properties of elements of the structure according to the synthesis theory of hierarchical groups using morphological analysis [5].

The above written scientific principles have important prerequisites for research and development activities of agronomic problems crop on fields with difficult terrain of crops, including promising bioenergetics groups – sugar beet, corn, wheat, triticale [5].

4. Results and discussion

In all soil protection technology is appropriate to include measures which are related to improving soil fertility by application of organic and mineral fertilizers. Therefore, while developing the tillers and seeding machines for work on slopes should be considered an opportunity to add fertilizers, organic mulch, as well as performing terracing of the slopes and develop seeding machines for precision farming in fields with rough terrain.

5. Conclusion

The theoretical and experimental studies have made it possible to clarify certain provisions of the peculiarities of soil cultivation on slopes, and to obtain new scientific results in this direction. In particular, the theoretical substantiation system tillers, their interaction of working organs and working elements running with the soil, taking into account the saving of soil fertility. Slopes terracing of the ground 2-4 times reduces the soil erosion. The model of a particle seed is developed, which allows to determine the kinematic and power parameters when interacting with conical seed and flat seeding disks. Due to all these activities were obtained analytical dependences for determining the trajectory of the grains on the surface of a rotating disk angular velocity array of seeds and reaction of the surfaces and a drive enclosure.

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