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# TRACTION EFFORTS OF THE WORKING BODY OF THE THREE-LAYER CULTIVATOR-FERTILIZER

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**Abstract:** The necessity to accurately place the necessary quantity of nutrients relative to the root system of plants requires an intra-soil layer wise application of site-specific fertilizer doses to different depths. To ensure the full nutrition of plants throughout the growing season, a new technology for intrasoil site-specific three-layer application of mineral fertilizers and a cultivator-fertilizer for its implementation are proposed. The traction force of its working body is determined.

**Keywords:** mineral fertilizers, site-specific application, precision farming, tractive effort, wide-blade tillage.

It is known that soil destruction under the influence of a wedge can occur both by detachment and by shearing (shear), depending on the ratio of the ultimate normal and tangential stresses of the soil, which in turn depend on its moisture and the state of turf grass in top soil layer [1-4]. The strength properties of the soil can be described with sufficient accuracy by the theory of Sh. Kulon and O. Mohr. In this case, for a specific case, the angle of the shift is specified, based on the Zvorykin-Mohr formula.

The soil's resistance to deformed as a whole completely describes the rational formula of V. Goryachkin, consisting of 3 members:

$$P = fG + \kappa ab + \xi a b V^2, \quad (1)$$

where:  $f$ ,  $k$ ,  $\xi$  – are the coefficients,  $G$  – is the weight of the plow;  $a$ ,  $b$  – depth and width of treatment;  $V$  – is the forward velocity.

Later A.P. Osadchiy increased the number of components of the total resistance to 4, NA. Pechertsev, V.I. Vinogradov, G.A. Degraf - up to five, and RA. Martirosov - up to six, which took into account the resistance of the formation to lifting, cutting, compression, installation angle, the type of soil destruction, etc. However, G.N. Sineokov and I.M. Panov noted that theoretical formulas for determining the components of traction resistance, taking into account the deformations of the soil, were not found. Therefore, they believe that in each specific case the traction resistance should be determined empirically [1].

The covering working body of the cultivator-fertilizer being developed is a double-winged share, such as a plain plow [5], figure 1. One wing AB is shown in Figure 2a.

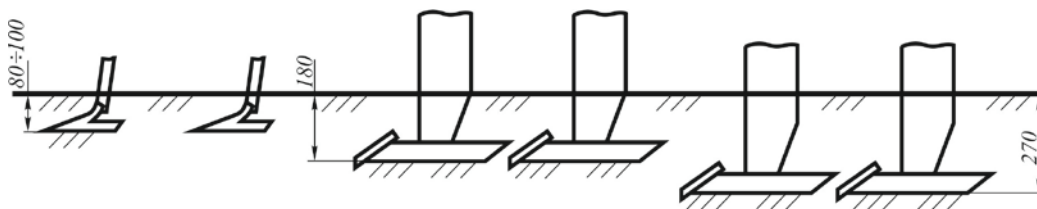


Figure 1 - Technological layout of the working arrangements of a three-layer cultivator-fertilizer

The working part moving in the soil at a speed  $V$  and acting on it with the force  $Q$ . It is the result of the action of the blade by a normal reaction and frictional forces. This, the active force is counteracted by the following resisting forces:

- $R_1$  – the head support of the soil layer displaces the working body in it;
- $R_2$  – the inertial forces of the soil, which it receives from the influence of the working body;
- $R_3$  – oblique support of the formation on the face  $AA_1BB_1$ ;
- $R_4$  – support of the bottom of the furrow;
- $F_3$  – frictional forces on the face  $AA_1BB_1$ ;
- $F_4$  – forces of friction of the bottom of the furrow on the lower edge of the working body.

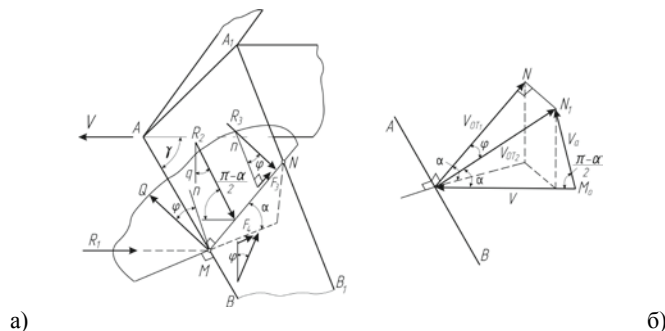


Figure 2 - On the interaction of the covering working body with the soil

In figure 2, the  $MN$  line shows the direction of the largest slope and in the absence of frictional forces, the soil particles would move along it. In this case, the resisting forces  $R_3$  and  $R_4$  deviate from the normals  $n$  to the line  $MN$  by an angle  $\varphi$  in the direction opposite to the possible displacement of soil particles. And the inertial force  $R_2$  also deviates to this side, not only from the normal  $n$ , but from the free fall line  $q$ .

The inertial forces  $R_2$  appear at the initial moment of interaction of the working body with the soil, since at that time the inertia of the rest of the soil is disturbed, its particles acquire certain accelerations and some absolute velocity that do not coincide with the slope line  $MN$ . Obviously, the inertial force  $R_2$  will be directed along the line of absolute velocity of particles, but only in the opposite direction.

A priori, it can be suggested that the soil particles will lag behind the surface of the working body with the same speed with which the working body will be introduced into the soil. Ideally, they are certainly not equal, because due to the crushing of soil particles and gas voids, the speed of the working element should be slightly higher than the speed of the soil. However, this difference, compared to their absolute values, is so small that they can be neglected.

In Fig. 2b, in the absence of frictional forces, the relative velocity will travel along the line  $V_{ot1}$ . Due to frictional forces, the particle  $M$  will not move to point  $N$  after time  $t$ , but will move to point  $N_1$ . The relative velocity of the particle is equal to

$$V_{ot2} = \frac{V_{ot1}}{\cos\varphi} = V. \quad (2)$$

According to the triangle rules of the speed, the relative speed is closed by absolute speed. In this case, from the sine theorem, we have:

$$\frac{V_a}{\sin M} = \frac{V_{ot2}}{\sin M_0};$$

$$\begin{aligned} Q \cos \left[ \frac{\pi}{2} - (\alpha + \varphi) \right] &= R_2 \cos \frac{\pi - \alpha}{2} + R_3 \cos \left[ \frac{\pi}{2} - (\alpha + \varphi) \right] + R_4 \sin \varphi + R_1 \frac{1}{\sin \gamma}; \\ Q \sin \left[ \frac{\pi}{2} - (\alpha + \varphi) \right] &= R_2 \sin \frac{\pi - \alpha}{2} + R_3 \sin \left[ \frac{\pi}{2} - (\alpha + \varphi) \right] + R_4 \cos \varphi. \\ Q \sin(\alpha + \varphi) &= R_2 \sin \frac{\alpha}{2} + R_3 \sin(\alpha + \varphi) + R_4 \sin \varphi + R_1 \frac{1}{\sin \gamma} = 0; \end{aligned}$$

$$Q \cos(\alpha + \varphi) = R_2 \cos \frac{\alpha}{2} + R_3 \cos(\alpha + \varphi) + R_4 \cos \varphi. \quad (7)$$

The inertial forces in (7) can be expressed in terms of the acceleration and mass of soil particles:

$$R_2 = a \cdot m, \quad (8)$$

where:  $a$  – acceleration of soil particles;  
 $m$  – mass of deformable soil.

If we take the initial velocity of the particles equal to  $V_0 = 0$ , the final velocity  $V_a$  and the transit time of the particles the width of the working member ( $L_l$ ;  $V$ ), then the required particle acceleration will be:

$$a = \frac{\Delta V}{\Delta t} = \frac{(V_a - V_0)V}{L_l};$$

We transform the last expression with allowance for (6):

$$a = \frac{V^2}{L_l} \cdot \operatorname{tg} \frac{\alpha}{2}. \quad (9)$$

During the considered time, a soil layer with a mass will pass through the working body:

$$m = L \cdot H \cdot L_l \rho \sqrt{\frac{1}{1 + \operatorname{tg}^2 \alpha}}, \quad (10)$$

where:  $L$  – halfwidth of the sweep of the working body;  
 $H$  – tillage depth;

$$V_a = V_{ot2} \frac{\sin M}{\sin M_0}. \quad (3)$$

Define the angle  $M_0$ :

$$< M_0 = \pi - (< N_1 + < M)$$

As  $V_{ot2} = V$ ,  $< N_1 = < M_0$ . Consequently:

$$< M_0 = \pi - (< M_0 + < \alpha);$$

$$< 2M_0 = \pi - \alpha;$$

$$< M_0 = \frac{\pi - \alpha}{2}. \quad (4)$$

Taking into account (2) and (4) from (3) we obtain:

$$V_a = V \frac{\sin \alpha}{\sin \frac{\pi - \alpha}{2}} = V \frac{\sin \alpha}{\cos \frac{\alpha}{2}}. \quad (5)$$

The transformation (5) gives:

$$V_a = V \frac{2 \sin \frac{\alpha}{2} \cos \frac{\alpha}{2}}{\cos \frac{\alpha}{2}} = V \operatorname{tg} \frac{\alpha}{2}. \quad (6)$$

It follows from the last expression that the absolute velocity of the soil  $V_a$  is directed at an angle  $(\pi - \alpha)/2$  to the direction of the velocity of the working element and to the side opposite to the motion of the particles. Consequently, inertial forces are also directed along the line  $V_a$  in the opposite direction.

To determine the resistance of the soil environment to the working element of the cultivator-fertilizer we will compose the equations of equilibrium of all forces on the horizontal and vertical directions:

$\rho$  – bulk density of soil;

$L_l$  – the path length of the particle along the working member (MN1).

Substituting (9) and (10) into (8) we obtain:

$$R_2 = L \cdot H \cdot \rho \cdot V^2 \operatorname{tg} \frac{\alpha}{2} \cdot \sqrt{\frac{1}{1 + \operatorname{tg}^2 \alpha}}. \quad (11)$$

On the basis of the linear theory, the head support can be estimated by the transverse area of the undeformed formation in front of the working body:

$$R_1 = B \cdot H \cdot \sigma_{\text{сж}} = L \sin \gamma \cdot H \cdot \sigma_{\text{сж}}, \quad (12)$$

where:  $B$  – halfwidth of the working body;

$\sigma_{\text{сж}}$  – ultimate soil crumpling resistance.

It can be determined from figure 1a:

$$R_3 = \frac{L_l \cdot H}{\cos \varphi} \cdot \sigma_{\text{сж}}; \quad (13)$$

$$R_4 = \frac{L_H \cdot H}{\cos \varphi} \cdot \sigma_{\text{сж}}, \quad (14)$$

where:  $L_H = \mu L_l$  – width of the lower cut of the working member;  
 $\mu \approx 0,1 \div 0,2$  – coefficient that takes into account a part of the working width of the sweep.

$$\begin{aligned}\frac{R_1}{\cos \gamma} + R_3 \cos \left[ \frac{\pi}{2} - (\alpha + \varphi) \right] + R_4 \sin \varphi &= Q \cos \left[ \frac{\pi}{2} - (\alpha + \varphi) \right] - R_2 \cos \frac{\pi - \alpha}{2}; \\ R_3 \sin \left[ \frac{\pi}{2} - (\alpha + \varphi) \right] + R_4 \cos \varphi &= Q \sin \left[ \frac{\pi}{2} - (\alpha + \varphi) \right] - R_2 \sin \frac{\pi - \alpha}{2}.\end{aligned}$$

$$Q \sin(\alpha + \varphi) - R_2 \sin \frac{\alpha}{2} = R_3 \sin(\alpha + \varphi) + R_4 \sin \varphi + \frac{R_1}{\cos \gamma}; \quad (15)$$

$$Q \cos(\alpha + \varphi) - R_2 \cos \frac{\alpha}{2} = R_3 \cos(\alpha + \varphi) + R_4 \cos \varphi.$$

Substituting (12), (13), and (14) into (15), we obtain:

$$Q \sin(\alpha + \varphi) - R_2 \sin \frac{\alpha}{2} = \left[ \frac{L_l \cdot H}{\cos \varphi} \sin(\alpha + \varphi) + \frac{\mu L_l \cdot H}{\cos \varphi} \sin \varphi + L \cdot H \operatorname{tg} \gamma \right] \cdot \sigma_{\text{сж}};$$

$$Q \cos(\alpha + \varphi) - R_2 \cos \frac{\alpha}{2} = \left[ \frac{L_l \cdot H}{\cos \varphi} \cos(\alpha + \varphi) + \frac{\mu L_l \cdot H}{\cos \varphi} \cos \varphi \right] \cdot \sigma_{\text{сж}}.$$

From the last system of equations, we determine the normal stresses of the soil crushing:

$$\begin{aligned}\sigma_{\text{сж}} &= \frac{Q \sin(\alpha + \varphi) - R_2 \sin \frac{\alpha}{2}}{\frac{L_l \cdot H}{\cos \varphi} [\sin(\alpha + \varphi) + \mu \sin \varphi] + L \cdot H \operatorname{tg} \gamma}; \\ \sigma_{\text{сж}} &= \frac{Q \cos(\alpha + \varphi) - R_2 \cos \frac{\alpha}{2}}{\frac{L_l \cdot H}{\cos \varphi} [\cos(\alpha + \varphi) + \mu]}. \quad (16)\end{aligned}$$

Equate the right-hand sides of the equalities obtained:

$$\frac{Q \sin(\alpha + \varphi) - R_2 \sin \frac{\alpha}{2}}{\sin(\alpha + \varphi) + \sin \varphi + LH \operatorname{tg} \gamma} = \frac{Q \cos(\alpha + \varphi) - R_2 \cos \frac{\alpha}{2}}{\cos(\alpha + \varphi) + \mu}.$$

We transform the last equation:

$$\begin{aligned}& Q \sin(\alpha + \varphi) \cdot \cos(\alpha + \varphi) + \mu Q \sin(\alpha + \varphi) - R_2 \sin \frac{\alpha}{2} \cos(\alpha + \varphi) - R_2 \mu \sin \frac{\alpha}{2} = \\&= Q \cos(\alpha + \varphi) \sin(\alpha + \varphi) + Q \cos(\alpha + \varphi) \sin \varphi + Q \cos(\alpha + \varphi) \cdot LH \operatorname{tg} \gamma - R_2 \cos \frac{\alpha}{2} \sin(\alpha + \varphi) - R_2 \cos \frac{\alpha}{2} \\&\cdot \sin \varphi - R_2 \cos \frac{\alpha}{2} LH \operatorname{tg} \gamma; \\& Q [\mu \sin(\alpha + \varphi) - \cos(\alpha + \varphi)] - Q \cos(\alpha + \varphi) LH \operatorname{tg} \gamma = \\& R_2 \left[ \sin \frac{\alpha}{2} (\cos(\alpha + \varphi) + \mu) - \cos \frac{\alpha}{2} (\sin(\alpha + \varphi) + \sin \varphi) \right] - R_2 LH \operatorname{tg} \gamma \cos \frac{\alpha}{2}. \quad (17)\end{aligned}$$

We accept the notation:

$$\mu \sin(\alpha + \varphi) - \cos(\alpha + \varphi) = A_1;$$

$$\cos(\alpha + \varphi) = A_2; \quad (18)$$

$$\begin{aligned}\sin \frac{\alpha}{2} [\cos(\alpha + \varphi) + \mu] - \cos \frac{\alpha}{2} [\sin(\alpha + \varphi) + \sin \varphi] &= B_1. \\ \cos \frac{\alpha}{2} &= B_2.\end{aligned}$$

Parameters included in  $A_1, A_2$  and  $B_1, B_2$  for a specific working body are constant. Therefore, for a given tool, they can be considered as constant quantities. In this case, the presentation of the final formula, their calculation and analysis are simplified.

Substituting the notation in (17), we obtain:

$$QA_1 - QA_2 LH \operatorname{tg} \gamma = R_2 B_1 - R_2 B_2 LH \operatorname{tg} \gamma;$$

$$Q(A_1 - A_2 LH \operatorname{tg} \gamma) = R_2(B_1 - B_2 LH \operatorname{tg} \gamma);$$

$$Q = \frac{(B_1 - B_2 LH \operatorname{tg} \gamma)}{(A_1 - A_2 LH \operatorname{tg} \gamma)}. \quad (19)$$

Taking into account (11) and referring to the second half of the body paw, from (19) we have:

$$Q = 2LH\rho V^2 \operatorname{tg} \frac{\alpha}{2} \sqrt{\frac{1}{1 + \operatorname{tg}^2 \alpha}} - \frac{(B_1 - B_2 LH \operatorname{tg} \gamma)}{(A_1 - A_2 LH \operatorname{tg} \gamma)}. \quad (20)$$

Analysis of Eq. (20) shows the direct dependence of the tractive effort on the width of the tillage of the tillage and the depth of treatment and the quadratic dependence on the speed of the cultivator-fertilizer, Fig. 3, 4.

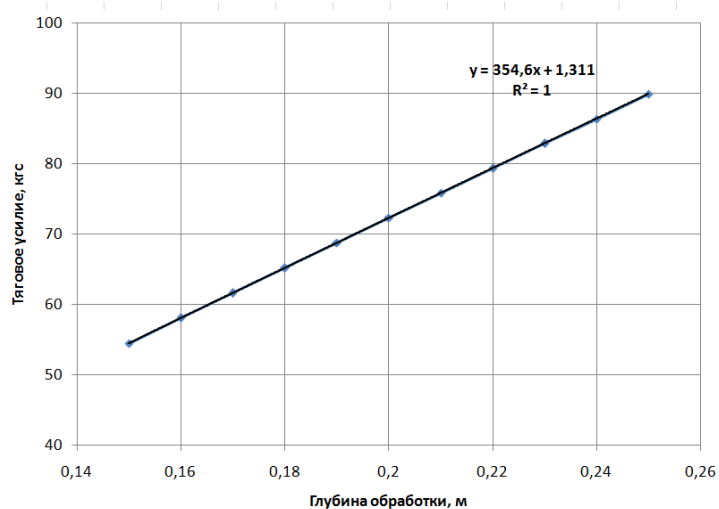


Figure 3 - Traction force versus treatment depth

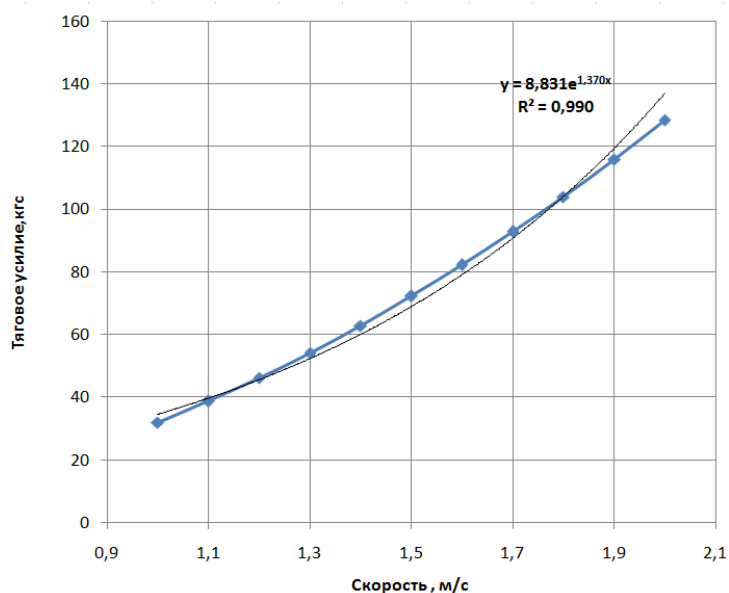


Figure 4 - Traction force versus speed

Increasing the depth of processing from 15 cm to 25 cm and the rake angle of the ploughshare from 15 to 25 degrees increases tractive effort by 40-50%, and increasing the sweep angle in the range from 55 to 65 degrees has a negligible effect on tractive effort, Fig. 5.

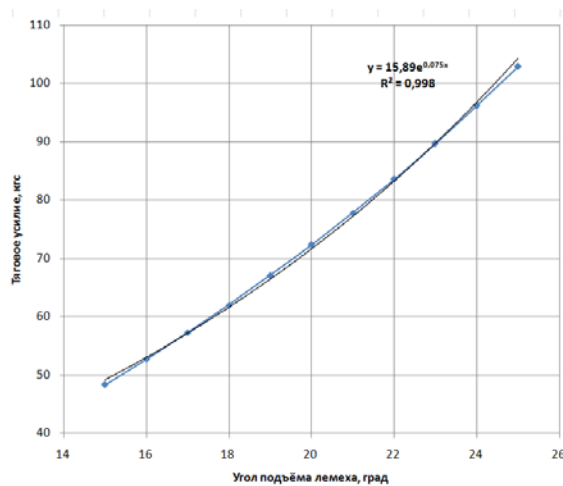


Figure 5 - Dependence of tractive effort on the rake angle ploughshare

For an approximate calculation of the tractive effort of one working body, we take the initial data:

$2L = 0,5$  м - length of share of paws;

$H = 0,2$  м - processing depth;

$\rho = 10^3$  кг/м<sup>3</sup> - soil density;

$\alpha = 20^\circ$  - rake angle;

$\gamma = 60^\circ$  - sweep angle;

$\mu = 0,1$  - the ratio of the lower and upper cuts edge of the share;

$\varphi = 30^\circ$  - angle of friction.

$$Q = 2 \cdot 0,25 \cdot 0,2 \cdot 10^3 \cdot 2,2 \cdot 0,17 \sqrt{\frac{1}{1 + 0,132}} \cdot \frac{(-1,117) - 0,984 \cdot 0,25 \cdot 0,2 \cdot 1,732}{(-0,566) - 0,642 \cdot 0,25 \cdot 0,2 \cdot 1,732} = 70,53 \text{ кгс}$$

$$A_1 = 0,1 \cdot 0,76 - 0,64 = -0,566;$$

$$A_2 = 0,642;$$

$$B_1 = 0,17[0,64 + 0,1] - 0,98[0,76 + 0,5] = 0,125 - 1,234 = -1,117$$

$$B_2 = 0,984.$$

The calculation shows the expected result. A further research program will include laboratory-field experimental testing.

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# MODERN APPROACHES TO QUALITY MANAGEMENT OF AGRICULTURAL TECHNOLOGY

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**Abstract:** The report analyzes the place and role of the problem of quality and reliability of production / agricultural machinery / under the conditions of the market economy is the basis of marketing and business. In a market economy the main driving forces of the business are: marketing, quality and reliability of production and services.

It turns out that we need to change our way of thinking and action. We must get used to the idea that the marketing approach and innovative solutions challenge the consumer to produce and service high quality and reliability.

**KEY WORDS:** MARKETING APPROACH, RELIABILITY, QUALITY, STANDARDS, MANAGEMENT, MODELS, MANAGEMENT SYSTEMS, STANDARDIZATION.

The place and role of the problem of quality and reliability of production under market economy conditions is the basis of marketing and business. In a market economy the main driving forces of the business are: marketing, quality and reliability of production and services.

In a market economy, it is not possible to impose low-quality products, low levels of reliability and low prices. The *non-market economy* elements were: quantity, price and quality. These priorities have to be changed in a market economy and go from reliability and quality, through the supply of spare parts, maintenance, and only then we can talk about the price of the produce or service.

The approaches to changing the quality and reliability management system known so far are related to the names of world-renowned scientists (Figure 1):

A) **Taylor's approach:** specialists are at the heart of managing the quality and reliability of production and services;

B) **Demping and Joran Approach:** Specialists and managers are the main drivers in the system of quality management and reliability of production;

C) **Kaoru Ishikawa's approach:** specialists, managers and workers are at the heart of quality management and reliability.

These approaches can be complemented by another approach, namely: Approach of 21st century: scientists from the research institutes (R & D) and higher education institutions (HEIs) are added to the specialists, managers and workers, but to change the management system Of education services - the labor market. Yes, the labor market is a driving force and HEIs have to take into account the demand for specialists with a certain type of qualification. This requires from HEIs very good marketing and quick re-engineering of its work, opening new specialties and specializations, introducing new courses. There has long been a time when a teacher completes his career by reading the same lectures for 25-30 years. User requirements towards products and services are changing and the HEIs has to keep pace with these changes.

Three strategies for standardization, marketing and innovation are known for managing the quality of products and services.

- Standardization strategy - To market a type of product or service, it must meet the requirements of the country standard;

Marketing strategy - To market a product or service, it is necessary to investigate what product and service are sought and offered on the market;

- Innovation strategy - to offer products and services that consumers did not expect, with better quality and reliability. The consumer must be provoked by quality production and services, and this is achieved by introducing new innovative solutions, new materials, new technologies, and so on.

According to Kaoru Ishikawa, the prosperity of a company depends on the time it will go from standardization to marketing and reach the innovation strategy for quality management of products and services. The rapid transition to the innovation strategy is a guarantee for the company's high business performance.

**Why should we strive to raise the level of quality and reliability of products and services?**

Micro and macro economies are known to be the drivers of demand and supply in a market economy. But only by raising the level of quality and reliability of production, demand increases, hence the volume of production and the profit from the realization of production.

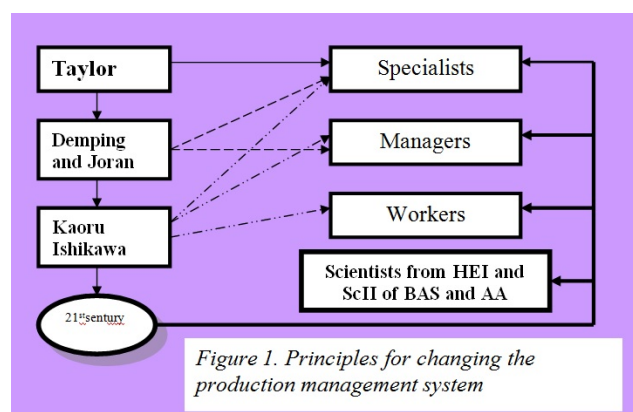
The structure and elements of the theory and practice of product reliability are presented with: a concept of reliability; Mathematical theory of reliability; Physical theory of reliability; Theory of reliability testing methods; Theory of methods for enhancing, ensuring and maintaining the level of reliability; Theory of organizational methods and reliability economics.

The quality of products and services is a combination of properties that meet the needs and / or requirements of consumers and the reliability-complexity of maintaining the quality level within established limits, time, mode and conditions

**The properties of quality and its characteristics** are reflected in the starting point, i. When production is ready for market placement, and reliability as a complex property is manifested in the process of using the products and services. It is known that not always a high level of quality is a guarantee of a high level of reliability during the use of the product or service. The quality and reliability of production are expressed by a large number of properties, features and characteristics. Their use without systematized grouping and classification is associated with certain difficulties. In the literature and in the normative and technical documentation, the properties, performance and quality and reliability indicators and characteristics are not systematized and are not related to each other, and the indicators and characteristics are mixed and expressed only as indicators.

**Quality** is a combination of properties that meet consumer needs and / or requirements, and reliability is a complex feature to maintain quality levels within established limits, time, mode and conditions. The main elements of the conceptual definition of quality are properties, needs and requirements. Quality properties are expressed by specific and complex indicators, and indicators with numerical and functional characteristics.

**Consumers' needs** are diverse and complex. Depending on the cultural level, they are expressed by different needs that can be



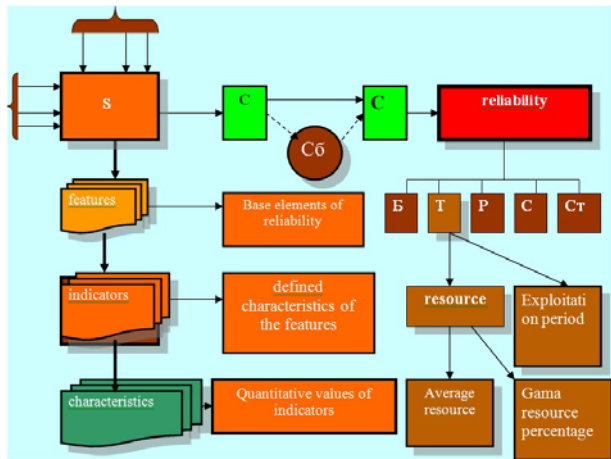
established or suspected. Established needs are recorded in contracts or normative documents, presumed needs of the market and / or the development of the needs of the people and the society.

**Consumers' requirements** are very diverse and can be expressed differently (in procurement and supply contracts, regulatory documents, etc.) or remain latent. In general, these requirements are formulated in modern quality management systems: the ISO-9000: 2000 series of standards and the Total Quality System (TQM).

Reliability is a change in the quality characteristics in function of time, i. Reliability is a manifestation of quality over time. It is the "dynamics" of quality.

The low level of quality of production and services means low competitiveness and return, high operating costs and leads to the scattering of national resources. Improving the quality and reliability of production is a prerequisite for better use of production capacities, saving raw materials, materials, fuels and ultimately boosting labor productivity. Therefore, striving must be at the optimum level of product reliability.

Figure 2 gives the relationship between properties, indices, characteristics, states and events in the theory and practice of product reliability. This formulation is fundamental in theory and must always be respected, as otherwise absurd situations where attributes are mixed with indicators, and practitioners are in fact misleading.



**Fig.2** Relationship between features, indicators, characteristics, and states: C-states; C<sub>0</sub>-events; B - flawlessness; T-durability; P-repairability; C-shelf life; Cm-stability.

Depending on the type of production (object) and the nature of the tasks, one or other features, indicators and characteristics are selected

In order to ensure a consistent level of quality and reliability of production, it is necessary to implement and certify a quality management system, complying with the requirements of the international standard ISO 9001: 2015.

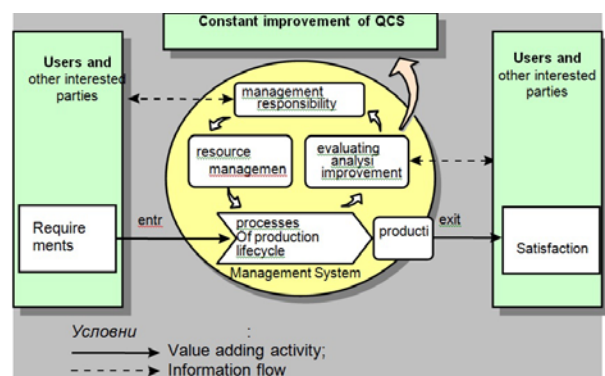
**A quality management system is not a mountain of unnecessary documents but a way to fully realize the principles of quality management in the organization's activity**

The Quality Management System is a system of procedures, rules, information, resources, people, etc. that interact within the organization to identify and achieve quality objectives. According to the contemporary perspectives, the management of quality implies the availability of a number of elements that allow the full quality management to be realized. These elements include:

- quality policy;
- quality planning system (setting quality objectives, identifying the necessary resources, etc.);
- process model of the organization (description of processes, block-schemes, procedures, instructions, etc.);

- quality control system (of incoming resources, semi-finished products, productions, processes, etc.);
- User satisfaction monitoring system;
- internal quality assurance system;
- system for management of process and production quality information (quality records);
- quality analysis system by management;
- Continuous improvement of quality system;
- management of discrepancies;
- corrective impacts;
- Warnings;
- external impact management system.

The architecture of the quality management system and the specific ways of using its elements in the particular organization depend on its scale, profile, structure, culture, style of management, goals and other factors. Therefore, we can speak that there is a formulated summary model of A quality management system that has also been reflected in international ISO 9000 standards (Figure 10).



**Fig.3** The main scheme of the quality management system and the interconnection requirements of the users and their satisfaction with the level of the quality of the products and services

Quality management system certification is a non-organization action. It is called upon to demonstrate the ability of the organization to provide and continually improve quality.

Once established a quality and service management system and certification should not be considered as something that cannot be changed. The requirements of the ISO 9000 series standards provide for continuous improvement and quality improvement to meet the needs of consumers, To meet ever-changing requirements. This requires continuously implementing the Deming principle: Plan; Perform; Check; Act.

An important role in maintaining and improving the quality of production is also the proper and regular implementation of the quality management system audit.

One of the main elements of the quality management system is the application of modern statistical methods for control and management of the level of quality. In Bulgaria there is a lack of confidence in the use of statistical methods for control and management of the level of production quality.

## Conclusions:

**First**, product development, in particular, agricultural machinery and quality management system certification, does not take into account that achieving a high level of quality does not mean a high level of reliability over time.

**Secondly**, the problems of reliability in our country are not discussed and are not studied in HEIs thoroughly enough. In a HEI where reliability is taught, they are separated for several hours, at the end of the curriculum, in different disciplines, and usually there

is no time to study them. The International Standardization Organization introduces ISO 31000 standards that address the risk of design, construction, production, operation, and process risk, workplace risk, food risk and planet health. The entire set of standards is based on probability theory, mathematical statistics and reliability theory.

**Thirdly**, we need to change our way of thinking and acting. We have to get used to the idea that there is no mass production where everything is done on demand, where three kits dominate: time,

money and repeatability. We need a marketing approach and innovative solutions to push the user to products and services with high quality and reliability.

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

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We have developed direct seeding seeders based on the AGTS-2,0 stubble drill with the following coulter combinations [1, 2]:

- Disc and chisel openers installed in at least two rows, in one of the rows there are chisels, and in the other - disk, which provide high throughput and low traction resistance when working on stubble untreated backgrounds;
- Disc and cultivator claws with seed spreaders for sowing with a wide belt (band-sowing seed), providing high throughput, low traction resistance and increasing yield.

If the theoretical traction resistance of the seed drill with serial claw coulters was determined by the following formula [3],

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

Then traction resistance of seeders with different combinations of working organs was found in the following dependencies:

- For working bodies: Central shovel → Double-disc → Central shovel:

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

- For working bodies: chisel → double-disc coulter → chisel:

$$R = G \cdot f + \sqrt[3]{\frac{D^4}{b \cdot q \cdot d^2}} + m \cdot (B_c \cdot h + h_{sp}^2 \cdot \operatorname{tg} \psi_{ck}) (K_{qT} + K_{qp} + K_{qK}) + n \cdot h \cdot b \cdot (K_{xm} + K_{xp} + K_{xk}), \quad (3)$$

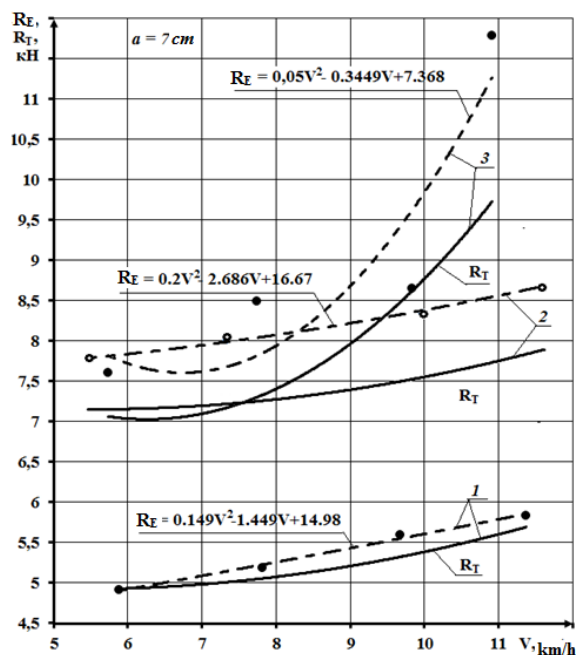
where **m** - is the number of central shovels or chisel openers;

**n** - is the number of disc coulters

The technique of carrying out laboratory and field tests is developed to determine the dependencies of the agrotechnical and energy parameters of the experimental setup of a seeder with combined coulters on its technological parameters.

The evaluation of agrotechnical indicators was carried out in accordance with SST 31345 [4, 5]. Determination of the traction resistance of experimental seeders with disc, claw and chisel coul-

ters was carried out in accordance with the requirements of SST R 52777 [6] simultaneously with the evaluation of agrotechnical indicators. The evaluation of agrotechnical indicators was carried out in accordance with GOST 31345 [4, 5]. The figure shows the theoretical ( $R_T$ ) and experimental ( $R_E$ ) dependences of the traction resistance of the seed drill with various working elements.



**Figure** - Theoretical ( $R_T$ ) and experimental ( $R_E$ ) dependences of the traction resistance of the seed drill with various working organs on the working speed of the aggregate  $V$ , with the depth of tillage  $a = 7\text{ cm}$  (1 - seeder with openers: chisel-disk-chisel, 2-seeder with openers: claw → disks → claw, 3-seeder with serial claw coulters).

The theoretical ( $R_T$ ) and experimental ( $R_E$ ) dependences shown in the figure show that the lowest value of the traction resistance of the seed drill from the working speed of the aggregate  $V$  at different depths of tillage ( $a$ ) is observed for seedlings with coulters according to the scheme chisel  $\rightarrow$  disk  $\rightarrow$  chisel. Moreover, the discrepancy between the  $R_T$  and  $R_E$  dependences is insignificant. At the same time, as the working speed of the aggregate increases,  $V$  the theoretical ( $R_T$ ) and experimental ( $R_E$ ) dependences for a seeder with serial claw coulters increase intensively, on average by a factor of 1.5. This tendency is strengthened with a further increase in the depth of processing.

In the analysis of agrotechnological indicators, it was established that the highest field seed germination was found on the site sowed with an experimental plant with chisel and disk coulters 94.3%, then on the site sown with an experimental setup with claw and disc coulters 93.7%, and at the control site field germination was 91.4%. This is explained by the superiority in the uniformity of the seeding depth of the experimental coulters in comparison with the standard claw coulters.

The analysis shows that the seeding depth with the chisel and disc openers exceeds the serial seeding by 5.1% (respectively 12.5% and 17.6%), by the uniformity of the depth of seeding of the experimental setup, and the experimental plant of the seeder with claw and disc coulters exceeds the production seeder by 2.4% (15.2% and 17.6% accordingly).

Experimental settings of seeders with combined coulters are superior to the series seeder in terms of the number of seeds embedded in the layer of the average actual depth and two adjacent layers. Thus, this parameter is equal to 92% in the experimental setup of the seeder with chisel and disc openers, the experimental setup of the seeder with the claw and disc openers is 90%, and in the series seeder with the claw coulters -87%. In experimental seeder plants with combined coulters, power is higher than in the series seeder. Thus, in the experimental setup of a seeder with chisel and disc openers, the coefficient of variation, which determines the uneven distribution of seeds is 65%, in the experimental setup of a seeder with claw and disc openers is 67%, and for a series seeder with claw coulters is 96.8%.

Harvesting in the experimental plots showed that the highest yield is 21.22 centners / ha in the plot planted with the experimental plant of the seeder with the claw and disk working bodies, then on the site seeded with the experimental plant of the seeder with chisel and disk working organs is 20.35 centners / ha and on the control plot the yield is 19.38 centners / ha.

Conclusions:

- Theoretical and experimental dependences of the traction resistance of the experimental setup of a seeder with combined coulters on the depth of seeding and working speed were obtained;

- The smallest value of the traction resistance of the seed drill from the working speed of the aggregate at different depths of tillage is observed for the seeder with coulters according to the scheme chisel  $\rightarrow$  disks  $\rightarrow$  chisel. Moreover, the discrepancy between the  $R_T$  and  $R_E$  dependences is insignificant. However, with an increase in the working speed of the aggregate, the theoretical ( $R_T$ ) and experimental ( $R_E$ ) dependences for a seeder with series claw coulters increase intensively, on average by a factor of 1.5. This tendency intensifies with further increase in the depth of processing and further research is needed to clarify the main regimes and parameters of the seeding machine.

- To evaluate the effectiveness of using a seeder with different openers, further research is needed;

- It is necessary to justify a seeding unit made up of seeders with combined coulters for tractors of various traction classes.

- High agrotechnological indices with an experimental setup with chisel and disc openers, and then with claw and disk coulters.

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# THEORETICAL RESEARCH AND DEVELOPMENT OF NEW DESIGN OF BEET TOPS HARVESTING MACHINERY

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**Abstract:** Beet tops harvesting machines designs working out is actual scientific and technical task for beet industry. Development of beet tops harvesting machine with technical and operational indicators of work on the level of the best world analogs is research objective. In the research used the methods of design and construction of agricultural machinery, methods of creation calculation mathematical models based on higher mathematics, theoretical mechanics, as well as programming and numerical calculations on the PC. Theoretical researches of technological process sugar beet tops cutting by the rotor mechanism are conducted. The mathematical model of interaction beet tops bunch with arc-shaped blade of knife which pivotally mounted on a power horizontal shaft is constructed. New analytical dependence of full cutting beet tops bunch of a given diameter on constructive, kinematic and power parameters of this design of beet tops harvesting machines is obtained. The dependence for speed definition of beet tops cutting device which providing effective cutting of tops bunches from sugar beet root crops which are in the soil is found. Carried out on the PC, numerical calculations, made it possible to determine the design parameters of the new rotary beet tops harvesting device. Tests of the beet tops harvesting machine in different zones of sugar beet cultivation showed that technical and operational indicators of its work correspond to the level of the best world analogs

**KEYWORDS:** SUGAR BEET, BEET TOPS CUTTING, ROTOR, MATHEMATICAL MODEL, UNSUPPORTED CUTTING, DESIGN PARAMETERS.

## 1. Introduction

Ukraine belongs to the highly developed beet-growing countries of Europe where sugar is one of the main strategic products that is produced by agriculture. Therefore, domestic agricultural machinery must produce sugar beet harvesting machines, the functional and operational parameters of which must meet the level of the best world analogues. The improvement of qualitative indicators of the sugar beet harvesting process is a complex scientific and technical problem, the solution of which must be based on the search for new constructive solutions to the working organs and design scheme of machines, the theoretical substantiation of their design and technological parameters, the experimental verification of theoretical studies carried out with ultimate goal of analysis and synthesis their optimal parameters. Further comprehensive production trials of new designs for sugar beet harvesting machines must finally resolve the issue of their production.

## 2. Preconditions and means for resolving the problem

### 2.1. Analysis of recent research and publications

The design of the first in our country sugar beet harvesting machines began in the 30th of the last century thanks to the fundamental (by that time) theoretical and experimental research A.A. Vasilenko [1]. In the future, the numerical group of scientific workers, under the guidance of academicians P.M. Vasilenko and L.V. Pogorelogo [2-5] at the end of the last century, basically formulated the main theses of theory and calculation of beet harvesters, which were widely used by design bureaus of combine plants during development domestic sugar beet harvesting equipment. However, despite significant successes (including in the world of scientific and design practice) in creation, production and operation of high-performance beet harvesting equipment, to this day there are still many unsolved major problems that are of global significance and a number of unresolved issues that are directly connected with sugar beet harvesting in Ukraine. One of the problems is improving the quality of beet raw materials, especially if it is produced under difficult harvesting conditions (high hardness of the soil or its excessive humidity, unevenness and non-straightness of crops row, excessive weediness, etc.), which is widespread in the production of this technical crop. Therefore, the search for new theoretical developments and design solutions in the world is now continuing with no less intensity than at the beginning of the creation of the first samples of sugar beet harvesting equipment [6-12]. In addition to improving the quality of raw materials, scientists in Europe and the world are making

considerable efforts to find the conditions for a significant reduction in the specific energy intensity of the process of digging out root crops, increasing the productivity and reliability of machines, and also significantly reducing the contamination of the heap by ground impurities, according to the environmental requirements are not allowed to take out fertile soil from the fields together with root crops.

What has been said above relates, first of all, to the harvesting machines, the high-tech and high-quality work of which determines the high quality of beet tops harvesting, which is now effectively used as raw material for biogas production. An important indicator is the degree of root crops damage and the minimum loss of their upper parts – heads of sugar beet root crops, as a sugar-bearing plant material.

### 2.2. Purpose of the study

The development of a new design of beet tops harvesting machine, technical and operational performance of which would be at the level of the best world analogues, using the results of theoretical studies of technological process of its operation.

### 2.3 Materials and Methods

During the research, methods of designing and constructing agricultural machines, methods of constructing computational mathematical models based on higher mathematics, theoretical mechanics, as well as programming and numerical calculations on the PC.

## 3. Results and discussion

Based on the new theories of sugar beet harvesters [10], the basic design and development of rotary type rotary harvesters has been developed. A computational mathematical model of a continuous, non-sensing cut of beet tops bunch by rotary cutting unit has been constructed. The cutting device has located horizontally drive shaft with arched knives, rotates at a certain speed and moves translationally at a specified speed of translational motion. The equivalent circuit of this technological process, used in theoretical studies, is shown in Fig. 1 and Fig. 2.



Numerical calculations of the obtained theoretical dependences made it possible to design a rotary beet tops cutting unit with new design parameters for which obtained patents of Ukraine [11, 12]. There was developed an ultra-light, highly reliable rotary-type beet tops harvesting unit, structural-technological scheme of which is shown in fig. 3 [13]. In this case, the beet tops harvester of this design is frontally mounted on wheeled tractor of drawing class 1.4 - 3.0 (There is a specific tractors' classification which is based not on the engine power, but on the draft force of the tractor measured by 1000 N. It is called 'Drawing Class'). In fig. 4 is given a general view, of the beet tops harvester, which is mounted on a wheeled tractor of drawing class 1.4. At the combine plant, a beet tops harvesting machines of this design was manufactured and successfully passed production tests in different areas of beet-growing.

The technical characteristics of new beet tops harvester unit are such: working width – 1.35 m (or 3 row of sugar beet root crops); working speed up to –  $2.1 \text{ m}\cdot\text{s}^{-1}$ ; weight – 850 kg; performance of the machine for 1 hour of pure time – 1.0...1.2 ha. The rotor speed of beet tops cutting unit must be within 650...850 rpm (if harvesting machine is used for mowing grasses and other thick-stemmed plants, the rotor speed should be within 1200...1600 rpm). The beet tops harvesting machine can be used in almost all weather conditions. The use of tractor of drawing class 3.0 is necessary in case of also mounting with it a root harvester machine.



Fig. 4. Universal beet tops harvesting machine in working with tractors of drawbar category 1.4

The results of production trials of beet tops bottom harvesting machine showed significant reduction in the number of tops residues on the heads of sugar beet roots – up to 1.5...3.0%; reduction of beet tops losses by 5...7%; decrease in energy parameters of process of sugar beet tops cutting by average of 1.5...1.8 times in comparison with the harvesting machines that are now serially produced in the world [14].

#### 4. Conclusions

1. The use of modern theories of the working organs of sugar beet harvesters has the ability to design and manufacture beet harvesters, the technical level of which is at the level of the best foreign analogues, and according to conditions of Ukraine it exceeds the specified level. This concerns, first of all, the harvesting machines, the high quality of which determines the high quality of harvesting (for later use as a source of biogas), minimal losses and damage of heads of sugar beet root crops, as a sugar-bearing plant material.

2. The developed mathematical model of technological process of the unconstrained and non-sensing cutting of beet tops bunch made it possible to obtain analytical expressions for determining the main design parameters of the rotary cutting units. Analytical condition for the complete cutoff of tops bundle of given diameter, depending on the structural and power parameters of the rotary cutter apparatus is obtained. Analytically new expression for determining the minimum rotational speed of the rotor of cutting unit, which performs tops cutting and width of cutting knife is obtained. The numerical calculations of the analytical expressions obtained on the PC made it possible to determine the concrete values of these kinematic and design parameters.

3. The results of the conducted production tests of new design of a beet tops harvesting machine in a three-row version show that the achieved technical and operational indicators are at the level of the best world machines, and some of them exceed this level.

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# MATHEMATICAL MODEL OF INTERACTION OF THE FLEXIBLE CLEANING BLADE WITH ROOT CROP HEAD

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**Abstract:** Modern technologies of harvesting sugar beet tops provide solid preliminary cutting and collecting its harvest at the increased altitude and subsequent additional root crops heads cleaning from tops residues on a root. This last operation also defines quality of root crops of beet before their digging up. Objective of this research is improvement quality of root crops heads cleaning from tops remains, by development of interaction theory of flexible cleaning blade with a spherical surface of root crop head. In the theoretical study were used methods of modeling, higher mathematics and theoretical mechanics, as well as programming and carrying out numerical calculations on the PC. As a result of the conducted theoretical research the interaction theory of flexible cleaning blade with a root crop head surface in the course of its cleaning from tops remains is developed. On the basis of the received differential equations of blade movement which is pivotally mounted on the drive shaft with a horizontal axis of rotation, new mathematical dependences which justify basic parameters of this technology process are given.

**KEY WORDS:** SUGAR BEET, BEET TOPS, HARVESTING, TOPS RESIDUES, CLEANING FLAIL, EQUIVALENT SCHEME, FORCE, VELOCITY, DIFFERENTIAL EQUATIONS.

## 1. Introduction

Cleaning of the root crops heads from the remains of the tops is an important operation of the technological process of harvesting sugar beet. In [1], the theory of the blade cleaner of the beet root heads with a horizontal axis of rotation is considered, and the main analytical dependences describing the impact of the cleaning blade on the head of the root crop are presented.

The next stage of the investigation is the compilation of differential equations of motion of the point of contact of the blade on the head of the root crop in the process of combing the remains of the foliage from it, assuming that this process will occur in the longitudinally vertical plane, that is, when the plane of rotation of the blades is located along the row.

## 2. Results and discussion

We depict the force interaction of the blade with the root of the root crop during the main process of combing the remains of the leaves, i.e. When the blade moves along the head surface of the root crop (Fig. 1).

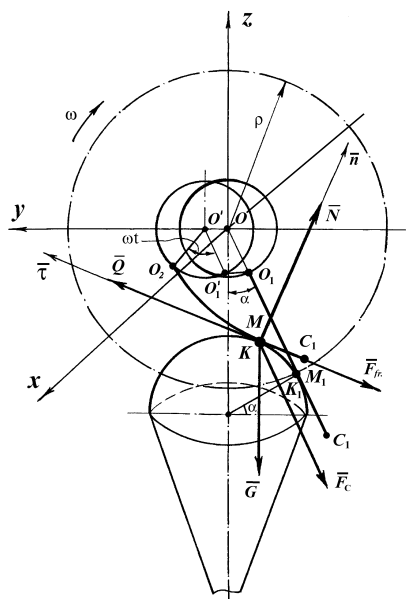


Fig. 1. – Scheme of force interaction of the blade with the root of the root in the process of combing the remains of the foliage

At the contact point  $K$ , the following forces will act:  $\bar{F}_c$  – the centrifugal force of inertia, which is directed along the radius  $OK$  of rotation of the blade about the axis  $O$ ;  $\bar{G}$  – the weight of the blade, which is directed vertically downwards;  $\bar{N}$  – normal reaction of the interaction of the blade with the root of the root, is directed along the normal to the head of the root crop, conducted through the given position of the point of contact;  $\bar{F}_{fr}$  – the frictional force that arises when the blade moves along the root of the root  $\bar{n}$  is directed in the direction opposite to the direction of the absolute velocity  $M$  vector of the point of the blade, which coincides with the point of contact  $K$ ;  $\bar{Q}$  – the force of combing the remains of the leaves from the surface of the head of the root crop, which is directed towards the vector of the absolute velocity of the blade point  $M$ .

Let us find the value of these forces. To determine the centrifugal force  $\bar{F}_c$  at any point of contact  $K$ , it is necessary to consider the kinematics of the motion of the blade  $O_1C_1$  along the head of the root crop after impact contact at a point  $K_1$ . Since the impact occurs in a very short period of time, then at the moment of impact, the blade does not move through the head of the root crop. Therefore, the initial position of the blade on the head of the root crop after the impact can be considered as the position of the impact contact  $K_1$ .

For a more accurate study of the motion of the blade along the head of the root crop, it is necessary to compile the differential equations of motion of the point  $M$  along the head of the root crop, since in this investigation the forces that cause such motion are taken into account.

It should be noted that the main role in forming the combing force  $\bar{Q}$  is played by the centrifugal force of inertia  $\bar{F}_c$ , the traction force  $\bar{P}$  and the rotational moment of the blade  $M_{ob}$ . It is thanks to the action of these forces that the blade is pressed to the root of the root crop and the deformation of the blade is bent. Indeed, immediately after impact, the centrifugal force of inertia is directed along the blade and tries to straighten the blade along the radius  $\rho$ .

If this force was absent, then under the action of the translational motion of the cleaner and the rotational motion of the blade around the axis  $O$ , the blade, when in contact with the root of the root, would simply deflect to some angle in the direction

opposite to the rotational motion, and without any effort slip through the root of the root without changing its Rectilinear form, since the suspension  $O_1$  is hinged.

After all, under the influence of centrifugal force  $\bar{F}_c$ , upon reaching the root of the root, the blade remains straightened along the radius  $\rho$ , and therefore, as a result of further translational and rotational movements, the blade slides over the root of the root, while experiencing a certain deformation of the bend, which creates a scratching force of the remains of the foliage.

The value of the centrifugal force of inertia  $\bar{F}_c$  at the initial point of contact  $K_1$  (point  $M_1$ ) is:

$$F_{c1} = m\omega^2 \rho, \quad (1)$$

where:  $m$  – mass of the blade.

Determine the centrifugal force  $\bar{F}_c$  of the point  $M$  at any point of contact  $K$  between the blade and the root of the root. This strength will be equal to:

$$F_c = m\omega^2 \cdot O'K, \quad (2)$$

where:  $O'K$  – distance from point  $K$  to point  $O'$ .

As can be seen from the circuit in Fig. 1, this distance is approximately equal to

$$O'K \approx OK_1 - K_1K + OO', \quad (3)$$

where:  $OK_1 = \rho$ .

Then, taking into account that  $OO' = V_p \cdot t$  and  $KK_1 \approx V_p \cdot t$  and (3), we obtain:

$$O'K \approx \rho. \quad (4)$$

Thus, the centrifugal force  $\bar{F}_c$  of inertia at each point of contact  $K$  approximately remains constant in magnitude and direction and is equal to:

$$F_c \approx m\omega^2 \rho. \quad (5)$$

In this case, the mass of the blade  $m$  is considered to be concentrated on the working part of the blade. The centrifugal force of inertia that arises from the rotation of the mass of the blade closer to the axis  $O_1$  of suspension causes tension of the blade and is balanced by the reaction in the hinge  $O_1$ .

The deformation of the blade bending results from the pressing of the blade at the point of contact  $K$  by the forces of inertia  $\bar{F}_c$  and the weight of the blade  $\bar{G}$  under the action of the traction force  $\bar{P}$  of the translational motion of the cleaner and the rotational moment of the blade  $M_{ob}$ .

The force of the deformation of the bend will be equal to the force of combing  $\bar{Q}$ . After all, the force  $\bar{P}$  of the translational motion of the cleaner and the rotational moment of the blade  $M_{ob}$  enter into the component of the force  $\bar{Q}$ , and therefore they are in Fig. 1 are not shown.

The frictional force is known to equal to:

$$F_{fr} = f N, \quad (6)$$

where:  $f$  – coefficient of friction of the blade surface along the surface of the head of the root crop;  $N$  – normal reaction at the contact point  $K$  of the blade with the root of the root.

Thus, the differential equation of motion of the point of contact  $K$  over the root of the root in a vector form will have the following form:

$$m\bar{a} = \bar{F}_c + \bar{G} + \bar{N} + \bar{F}_{fr} + \bar{Q}, \quad (7)$$

where:  $\bar{a}$  – absolute acceleration of the movement of the point of contact  $K$  along the head of the root crop;  $m$  – mass of the blade.

Since in this case we have a plane system of forces that is located in the plane  $yOz$ , the differential equation of motion (7) reduces to a system of two second-order differential equations of the following form:

$$\left. \begin{aligned} m\ddot{y} &= F_{cy} + G_y + N_y + F_{fr,y} + Q_y, \\ m\ddot{z} &= F_{cz} + G_z + N_z + F_{fr,z} + Q_z, \end{aligned} \right\}, \quad (8)$$

where:  $F_{cy}$ ,  $G_y$ ,  $N_y$ ,  $F_{fr,y}$ ,  $Q_y$  – projections of the vectors of forces on the axis  $Oy$ , respectively  $F_{cz}$ ,  $G_z$ ,  $N_z$ ,  $F_{fr,z}$ ,  $Q_z$  – the projections of the vectors of the mentioned forces on the axis, respectively.

Taking into account the value of the projections of the force vectors that enter into the system of differential equations (8) and expressions (5) and (6), the mentioned system acquires the following form:

$$\left. \begin{aligned} m\ddot{y} &= -m\omega^2 \rho \sin \alpha + N \cos(y, \bar{N}) - fN \cos(y, \bar{V}) + Q \cos(y, \bar{V}), \\ m\ddot{z} &= -m\omega^2 \rho \cos \alpha - mg + N \cos(z, \bar{N}) - fN \cos(z, \bar{V}) + Q \cos(z, \bar{V}), \end{aligned} \right\}, \quad (9)$$

where:  $\cos(y, \bar{N})$ ,  $\cos(z, \bar{N})$  are the direction cosines of the force vector  $\bar{N}$  to the axes  $Oy$  and  $Oz$ , respectively;

$\cos(y, \bar{V})$ ,  $\cos(z, \bar{V})$  – the direction cosines of the velocity vector of the contact point on the head of the root crop to the axes and, respectively;  $\dot{y}$ ,  $\dot{z}$  – the projection of the velocity vector  $\bar{V}$  on the coordinate axis  $Oy$  and  $Oz$ , respectively.

From the source [2] it is known that these directing cosines are equal to:

$$\left. \begin{aligned} \cos(y, \bar{N}) &= \frac{\partial f}{\partial y} \frac{1}{\Delta f}; \quad \cos(z, \bar{N}) = \frac{\partial f}{\partial z} \frac{1}{\Delta f}; \\ \cos(y, \bar{V}) &= \frac{\dot{y}}{V}; \quad \cos(z, \bar{V}) = \frac{\dot{z}}{V}, \end{aligned} \right\} \quad (10)$$

where:  $f(y, z) = 0$  is the coupling equation (the surface along which the material point moves);  $\Delta f$  – modulus of the function gradient  $f(y, z)$ ;  $V$  – the modulus of the velocity vector of a point.

Since it was initially assumed that the head of the root crop has a spherical shape, the coupling equation is a sphere that has the following equation:

$$f(x, y, z) = x^2 + y^2 + z^2 - R^2 = 0, \quad (11)$$

where:  $R$  is the radius of the spherical head of the root crop.

For the plane  $yOz$   $x = 0$ , and therefore the equation of the sphere (11) goes over into the equation of the circle:

$$f(y, z) = y^2 + z^2 - R^2 = 0. \quad (12)$$

According to the source [2], the modulus of the function gradient and the velocity modulus will be:

$$\Delta f = \sqrt{\left(\frac{\partial f}{\partial y}\right)^2 + \left(\frac{\partial f}{\partial z}\right)^2}, \quad (13)$$

$$V = \sqrt{\dot{y}^2 + \dot{z}^2}. \quad (14)$$

Substituting (10) into (9) and adding the coupling equation (12) to the system of differential equations (9), we obtain the following system of differential equations:

$$\left. \begin{aligned} m\ddot{y} &= -m\omega^2 \rho \sin \alpha + \frac{N}{\Delta f} \frac{\partial f}{\partial y} - fN \frac{\dot{y}}{V} + Q \frac{\dot{y}}{V}, \\ m\ddot{z} &= -m\omega^2 \rho \cos \alpha - mg + \frac{N}{\Delta f} \frac{\partial f}{\partial z} - fN \frac{\dot{z}}{V} + Q \frac{\dot{z}}{V}, \\ y^2 + z^2 - R^2 &= 0. \end{aligned} \right\} \quad (15)$$

We calculate the partial derivatives and the gradient of the function that enter the system of equations (15). Will have:

$$\frac{\partial f}{\partial y} = 2y, \quad \frac{\partial f}{\partial z} = 2z. \quad (16)$$

Then, according to (13):

$$\Delta f = \sqrt{(2y)^2 + (2z)^2} = 2R. \quad (17)$$

We substitute the expressions (16), (17) into (15). Then the system of differential equations (15) takes the following form:

$$\left. \begin{aligned} m\ddot{y} &= -m\omega^2 \rho \sin \alpha + \frac{y}{R} N - fN \frac{\dot{y}}{V} + Q \frac{\dot{y}}{V}, \\ m\ddot{z} &= -m\omega^2 \rho \cos \alpha - mg + \frac{z}{R} N - fN \frac{\dot{z}}{V} + Q \frac{\dot{z}}{V}, \\ y^2 + z^2 - R^2 &= 0. \end{aligned} \right\} \quad (18)$$

The system of equations (18) is a system of three equations with three unknowns  $y$ ,  $z$  and  $N$ . Therefore, it is definite and has a unique solution.

We eliminate the unknown quantities from the obtained system of equations (18) and, thus reducing the given system to one differential equation with one unknown function,  $y(t)$ . To do this, it is necessary to differentiate twice  $t$  according to the constraint equation (12). If we differentiate this equation once, then we get:

$$2y\dot{y} + 2z\dot{z} = 0. \quad (19)$$

From where we find:

$$y\dot{y} + z\dot{z} = 0. \quad (20)$$

If we differentiate equation (20), then we have:

$$y\ddot{y} + \dot{y}^2 + z\ddot{z} + \dot{z}^2 = 0, \quad (21)$$

or

$$(y\ddot{y} + z\ddot{z}) + (\dot{y}^2 + \dot{z}^2) = 0. \quad (22)$$

Since,  $\dot{y}^2 + \dot{z}^2 = V^2$  we get:

$$V^2 = -(y\ddot{y} + z\ddot{z}). \quad (23)$$

We multiply the first equation of system (18) by, the second on and add them term by term, we obtain:

$$\begin{aligned} m(y\ddot{y} + z\ddot{z}) &= -(m\omega^2 \rho y \sin \alpha + m\omega^2 \rho z \cos \alpha) - mgz + \\ &+ \frac{N}{R}(y^2 + z^2) - f \frac{N}{V}(y\dot{y} + z\dot{z}) + \frac{Q}{V}(y\dot{y} + z\dot{z}). \end{aligned} \quad (24)$$

Whence, taking into account expressions (20) and (23), we have:

$$-mV^2 = -m\omega^2 \rho (y \sin \alpha + z \cos \alpha) - mgz + RN. \quad (25)$$

From expression (25) we find a normal reaction. It equals:

$$N = \frac{1}{R} [m\omega^2 \rho (y \sin \alpha + z \cos \alpha) + mgz - mV^2]. \quad (26)$$

We make further transformations. From the expression (20) we obtain:

$$\dot{z} = -\frac{y\dot{y}}{z}, \quad (27)$$

then

$$\dot{z}^2 = \frac{(y\dot{y})^2}{z^2}, \quad (28)$$

or

$$\dot{z}^2 = \frac{(y\dot{y})^2}{R^2 - y^2}. \quad (29)$$

Thus, for the magnitude of the speed of motion  $V$ , we can obtain the following expression:

$$V^2 = \dot{y}^2 + \dot{z}^2 = \dot{y}^2 + \frac{(y\dot{y})^2}{R^2 - y^2}. \quad (30)$$

Substituting expression (26) into the first equation of system (18), we obtain:

$$\begin{aligned} m\ddot{y} &= -m\omega^2 \rho \sin \alpha + \left( \frac{y}{R} - f \frac{\dot{y}}{V} \right) [m\omega^2 \rho (y \sin \alpha + z \cos \alpha) + \\ &+ mgz - mV^2] + Q \frac{\dot{y}}{V}. \end{aligned} \quad (31)$$

Since,  $z = \sqrt{R^2 - y^2}$  then, taking into account expression (30), finally:

$$\begin{aligned} m\ddot{y} &= -m\omega^2 \rho \sin \alpha + \left( \frac{y}{R} - \frac{f \dot{y} \sqrt{R^2 - y^2}}{\sqrt{(R^2 - y^2) \dot{y}^2 + (y\dot{y})^2}} \right) \times \\ &\times \left\{ m\omega^2 \rho (y \sin \alpha + \sqrt{R^2 - y^2} \cdot \cos \alpha) + mg \sqrt{R^2 - y^2} - \right. \\ &\left. - \frac{m [(R^2 - y^2) \dot{y}^2 + (y\dot{y})^2]}{R^2 - y^2} \right\} \left\{ \frac{1}{R} + Q \frac{\dot{y} \sqrt{R^2 - y^2}}{\sqrt{(R^2 - y^2) \dot{y}^2 + (y\dot{y})^2}} \right\}. \end{aligned} \quad (32)$$

### 3. Conclusions

Thus, we have obtained a second-order differential equation (32), in which only one function  $y$  is known, i.e. a differential equation is obtained in the so-called normal form, when the higher derivative is expressed in terms of the lower derivatives and the desired function.

The unknown force  $Q$  that enters into equation (32) must be found from the deformation conditions of the blade bending.

Therefore, to solve this equation, you must first find the force  $Q$ , or express it through known quantities.

Since equation (32) is non-linear, it can be solved only by numerical methods on a personal computer with given initial conditions, which will be the subject of the next study.

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# BIOTROPIC PARAMETERS OF ELECTROMAGNETIC RADIATION FOR REGENERATION OF ANIMAL DAMAGED BONE TISSUE

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**Abstract.** The development of effective medication-free treatment and means of animal injuries treatment is urgent task. The optimal parameters of electromagnetic field of ultra-high frequency range interacting with the bone tissues of animals have been determined. The aim of the work is to identify the high-frequency range of the electromagnetic field parameters in interaction with animal tissues using the developed mathematical model. The dependence of electric component amplitude of magnetic frequency field was investigated. It has been proved that the dimensions of the limbs and internal tissues significantly affect the internal distribution of the electromagnetic fields. The results of experimental studies have made it possible to determine the optimal frequency, power and radiation source arrangement for the injury treatment of different animal species. The application of electromagnetic radiation with optimal parameters intensifies metabolism on the diseased cells membrane level and assists more rapid recovery of the injured bone tissue.

**KEYWORDS:** INJURIES, ULTRA-HIGH FREQUENCY, PARAMETERS, MATHEMATICAL MODEL, METABOLISM, CELLS MEMBRANE

## 1. Introduction

Nowadays, one of the important tasks facing Ukraine's agrarian complex is increase of livestock farming productivity while keeping heard expansion of domestic animals, which depends on efficient animal disease treatment, in particular traumatism.

Animal traumatism is the common group of diseases among all non-contagious diseases amounting to 50% of total disease rate [1].

Now medicaments are mainly used for treatment of animal injuries. In most cases application of antibiotics and other medicated things is not efficient enough and unsafe, it blocks the disease symptoms. Getting into the human organism via livestock products, antibiotics have negative influence on it, suppress the immunity, contribute to mutated virus replication causing various diseases [1,2].

Therefore, the development of efficient medicament-free treatment and development of technical means for animal injury treatment is actual one.

## 2. Results and Discussion

The data analysis of numerous researches and publications [2] has allowed to state that one of the prospective ways of medicament-free treatment of animal injury is the impact of electromagnetic field (EMF) of LHF-range.

The research aim was on the basis of the developed mathematical model [3, 4] to define the biotropic parameters of electromagnetic field of LHF-range during its interaction with animal tissues.

Applying the obtained [3,4] mathematical expressions, the numeric computations of the biotropic parameter values of the electromagnetic field in animal limbs of different geometric dimensions have been made; the optimal frequency of impact which allows to give the appropriate recommendations on technical features of the developed therapeutic apparatus has been defined.

The fundamentals of the computations were the mathematical values [3, 4], which describe the distribution of electromagnetic wave of LHF-range on a biological object of cylindrical shape with layered structure by radius:

$$\dot{E}_{z\text{pad}}^i + \dot{E}_{z\text{otr}}^i = \sum_{m=0}^{\infty} \left[ \dot{B}_m^i J_m(k_i r) + \dot{C}_m^i H_m^{(2)}(k_i r) \right] \cos(m\varphi)$$

where  $\dot{E}_{z\text{pad}}^i$  – tangential component of incident electromagnetic wave for the i-layer, W/m;  $\dot{E}_{z\text{otr}}^i$  – tangential component of reflected electromagnetic wave for i-layer, W/m;  $J_m(k_i r)$ ,  $H_m^{(2)}$  –

according to Bessel function of the first kind and Hankel function of the second kind of m-harmonic;  $k_i$  – wavenumber for i layer,

$k_i = \omega \sqrt{\varepsilon_i \mu_0}$ ;  $\varepsilon_i$  – dielectric permittivity of i layer;  $\omega$  – angular frequency of given radiation, s<sup>-1</sup>;  $\mu_0$  – magnetic permeability of the air, Gn/m;  $r$  – the coordinate on the cylinder radius ( $0 < r < R$ );  $\dot{B}_m^i$ ,  $\dot{C}_m^i$  – fixed coefficients [4];  $\cos(m\varphi)$  – Legendre polynomial.

According to the obtained expressions the amplitudes of inner fields are complex values which change their phasing depending on animal limb dimensions, incident frequency, electro-physical characteristics of biological tissues and their location inside a limb.

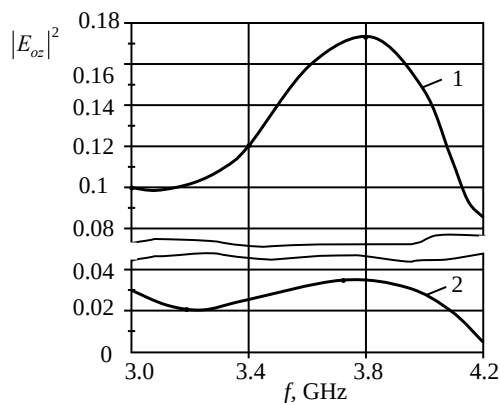
The zeroth harmonic of incident electromagnetic field (the amplitude of harmonics with numbers  $m > 1$  is significantly lower than the zeroth one) makes the major influence on an animal limb, which is connected with low resonance characteristics of biological objects being exposed to radiation.

Electromagnetic characteristics of all five layers taken into account [4] were chosen according to reference data. The intensity of the incident field electrical component equals one, which allows going to any concrete value  $E_0$  in calculations, at the same time the case of E-polarization is considered.

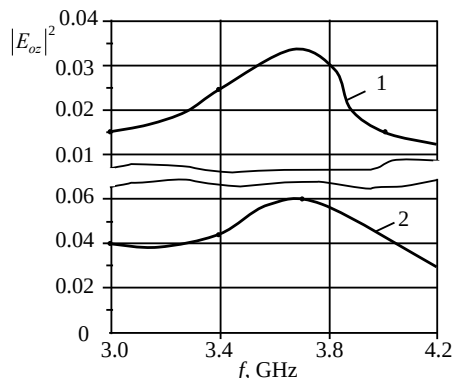
The mentioned review of literature data [2] indicates that the main curative effect of electromagnetic radiations in case of bony pathologies is connected with their effect on cell membranes and the activation of ion movement of different microelements through them. At the same time characteristic resonance frequencies of these processes are within the range of 10<sup>9</sup>-10<sup>11</sup> Hertz.

Taking into account that during passing of electromagnetic radiations of decimeter and centimeter range through an animal limb, on the one hand, there is the radiation absorption, on the other hand, there is their resonance re-scattering on different biological inhomogeneity; first of all, it is necessary to determine at what frequencies the electromagnetic field component strength will be maximum in bone marrow of bony tissue.

According to the aim we have studied the dependence of EMF electric component amplitude on frequency in the area of bone marrow and bony tissue of a limb. To obtain the more universal animal treatment methods the limbs of large animals (a horse, a cow) as well as small ones (a pig, a sheep) were examined. It was done due to the fact that both cross-sectional geometric shapes of limbs and sizes of their internal tissues differ significantly, so this could affect the distribution of inside electromagnetic fields in them.



**Fig. 1** – The square of amplitude of EMF electric component  $|E_{0z}|^2$  versus frequency response  $f$  for a pig leg: 1 – in bone; 2 – in bone tissue area marrow area



**Fig. 2** – The square of amplitude of EMF electric component  $|E_{0z}|^2$  versus frequency response  $f$  for a cow leg: 1 – in bone marrow area; 2 – in bone tissue area

In picture 1 there are the results of calculations performed within the range of 3.0-4.2 GHz for a pig leg. Picture 1 (curve 1) shows that in the area of bone marrow the maximum value of the electric component is at a frequency of 3.8 GHz. At frequency shift to the left and right from the identified frequency there is the amplitude loss. The same has to be said about the curve 2, where the same response is presented but for the area of bony tissue. In this case the maximum amplitude is at a frequency of 3.7 GHz. However, the shift into more longwave range affects the field value less than the shift into more shortwave range.

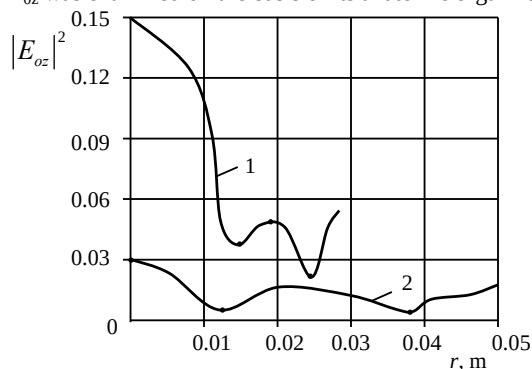
In picture 2 there are curves corresponding to frequency dependence of square for inside field electric component amplitude for a cow leg. It should be mentioned that in this case in the area of bone marrow as well as in the area of bone tissue of a leg the maximum is weaker than for a pig. This is explained by large sizes of a leg and correspondingly the length of incident electromagnetic wave. Therefore, resonance phenomena are weaker. However, in this case the electric component reaches its maximum at the range of frequencies of 3.6 – 3.7. GHz.

According to the obtained results we can conclude that the most acceptable value for radiation of injured legs of farm animals is the frequency within 3.7 GHz from the view of electrodynamics. In addition, the proper location of maximum of effecting field allows to choose the radiation sources with less power flows that is very important for treatment.

It should be emphasized that in the present graphs along the axis of ordinates there is a dimensionless value indicating which part of incident electromagnetic radiation strength reaches the particular area of an injured leg.

Having identified the most acceptable radiation frequency of electromagnetic field, the examination of its distribution in cross-section cut of an injured limb was carried out; it was necessary to determine how efficient was the field affecting the proper injured areas of legs.

In order to get the result, the radius of cross-section cut of leg versus  $E_{0z}$  was examined on the basis of its anatomic organization.



**Fig. 3** – Distribution of amplitude square of electric component of electromagnetic radiation inside animal limbs at a frequency of 3.7 GHz: 1– for a pig; 2– for a cow

In picture 3 (curve 1) there is the dependence of amplitude square of longitudinal component of electric field on a leg cross-section cut radius inside a pig limb. The chosen radiation frequency was equal to 3.7 GHz. According to the picture in the both areas of bone marrow and bony tissue the electric field is more powerful than in other areas. Thus, we have to conclude that radiation at this frequency will have maximum effect on the injured bony tissue and assist its fast recovery.

According to figure 3 (curve 2) illustrating the distribution of electric component  $|E_{0z}|^2$  in cross-section cut of a cow leg at a frequency of 3.7 GHz there is the similar result. In this case density of the field is located in the areas of bone marrow and the injured bony tissue.

Thus, despite an animal size (a pig, a cow) the radiation at identified frequency in particular has the maximum stimulating effect on cambio-genetic hardness, cortical layer of bone and soft tissues around the fracture.

The similar results obtained after calculations for limbs of other farming animals (a horse, a sheep) indicate that the most acceptable value of electromagnetic field applied for therapeutic reason during the treatment of limb injuries of different animals is the range from 3.7 to 3.8 GHz. This range is acceptable from the view of obtaining the optimal amplitudes of EMF inside the objects exposed to radiation as well as from the view of optimal distribution of inner field.

Taking into account the above calculations it may be concluded concerning the flow density strength of radiation for an injured limb. According to literature sources, radiation strength at 0.1 mW/cm<sup>2</sup> causes the appearance of membrane cells of the identified potentials, which has positive influence on the transmembrane ion movement. In other words, there is an intensive recovery process for diseased and injured cells. Thus, the radiation source has to create the exact flow density strength in the places of injury.

Taking into account the results (see pics. 1-3) demonstrating which part of radiation strength reaches the injured area (0.005-0.01) and the identified above the necessary strength level for curing effect, it may be defined that the radiation source has to radiate approximately at 100 W/m<sup>2</sup>.

### 3. Conclusions

On the basis of proposed theoretical model, the performed computations have indicated that the most acceptable frequency of electromagnetic radiation for limbs of different farming animals is 3.7-3.8. GHz. In this case the field distribution by limb cross-section cut and its amplitude are the most optimal ones.

According to the results the radiation has to be of 100 W/m<sup>2</sup>. This intensifies the metabolism in membranes of sick cells and encourages the fastest recovery of injured bony tissue.

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# TECHNOLOGICAL RELIABILITY OF GRAIN DRYERS OPERATION AND PROCESSES

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**Abstract:** A mathematical model of the heat transfer during grain drying has been developed. To estimate qualitative parameters of a technological process, the theory of the tolerance control is used. Control criteria for the drying process in rhomb-shaped aggregates have been determined. The obtained results allow increasing the technological reliability of grain dryers operation.

**Keywords:** grain post-harvest care, technological reliability, probability, optimization.

## Introduction

The flow line limiting section of grain post-harvest care is a dryer; the efficiency of its operation determines the pace of harvest work fulfillment and the quality of grain-harvesting complex operation as a whole. When analyzing the operating regimes of grain dryers, the effect of control parameters on various criteria of efficiency is evaluated. A control action should not out the internal temperature field formed by the heat-carrier  $\theta_c$  beyond the set level  $\theta_s$ . Another criterion for the drying process optimization is ensuring a minimum deviation of the grain moisture from the standard value at the dryer outlet. The non-uniformity of the material at the dryer outlet determines the time spread  $t$  of a grain stay in the drying unit by this index and is characterized by the function of distribution in dependence to  $t$ . These criteria are agricultural and engineering tolerances for the grain drying technological process execution.

## Background

The main condition for the optimum drying process control lies in the need to identify factors affecting the specified process and determining the heat-mass exchange and hydrodynamic characteristics of drying. In order to ensure the stability of controlled parameters of the technical equipment quality, it is required to develop an adequate mathematical model which establishes a relationship between these parameters and the factors affecting them.

In order to create a complete theoretical picture of processes which proceed in a dryer, it is necessary to formalize the corresponding regularities. The number of factors, which are taken into account, also determines the number of connections which allow for obtaining a closed system of kinetic equations.

The technological process under consideration is stationary and is characterized by three-dimensionality of fields of velocities, temperature, pressure, grain humidity and air humidity. Since drying is carried in the volume with fixed geometric parameters, the material shrinkage, which takes place during the gradual removal of the osmotic moisture from grains, has a significant effect on the technological process.

A complete system of equations characterizing the external heat-mass exchange (heat-mass exchange in the flowing around stream) and the internal heat-mass exchange (heat-mass exchange in the solid phase), during grain drying, includes:

- equations of flow dynamics (Navier–Stokes equations):

$$\rho_r \left( \frac{\partial \vec{v}}{\partial \tau} + \vec{v} \Delta \vec{v} \right) = q \rho_r - \nabla p + \mu_r \nabla^2 \vec{v} \quad (12)$$

$$\frac{\partial \rho_r}{\partial \tau} + \nabla (\rho_r \vec{v}) = 0 \quad (13)$$

- an equation characterizing the energy of the air flow in the filling channels:

$$\rho_r C \rho_r \left( \frac{\partial t_r}{\partial \tau} + \vec{v} \Delta t_r \right) = \lambda_r \nabla^2 t_r \quad (14)$$

- an equation taking into account diffusion of water vapors in the air:

$$\frac{\partial \rho_v}{\partial \tau} + \vec{v} \Delta \rho_v = D \nabla^2 \rho_v \quad (15)$$

- an equation of the heat conductivity for a filling layer:

$$\rho_T C \rho_T \frac{\partial t_T}{\partial \tau} = \lambda_T \nabla^2 t_T + \varepsilon \frac{\partial U}{\partial \tau} \rho_d r \quad (16)$$

- an equation characterizing the moisture conductivity of a filling layer:

$$\frac{\partial U}{\partial \tau} = \alpha_n (\nabla^2 U + \delta \nabla^2 t_T) \quad (17)$$

Accepted designations are as follows:  $\rho_r$  is the moist air density;  $\rho_v$  is the vapor density;  $\vec{v}$  is the vector characterizing the air flow rate;  $\tau$  is the time;  $\vec{q}$  is the vector characterizing the acceleration of the gravity;  $p$  is the gas pressure;  $\mu_r$  is the factor characterizing the air dynamic viscosity;  $C \rho_r$  is the moist air heat capacity;  $\lambda_r$  is the air thermal conductivity;  $D$  is the factor characterizing water vapor diffusion in the air;  $t_r$  is the temperature of the grain weighed portion;  $\rho_T$  is the density of the grain weighed portion;  $\rho_d$  is the density of the absolutely dry grain;  $r$  is latent heat of vaporization;  $\varepsilon$  is the phase transformation criterion;  $\alpha_n$  is the factor characterizing the moisture conductivity;  $\delta$  is the factor characterizing the thermal moisture conductivity;  $\nabla$  is the Hamiltonian operator;  $\nabla^2$  is the Laplace operator.

The following functions were accepted as criteria for assessment of the grain dryer operation quality, characterizing:

- deviation of the heat-carrier temperature in the dryer from the set value, i.e.

$$m(t) = m\{\theta_c, \theta_3\} \quad (18)$$

- deviation of the grain moisture content at the dryer outlet from the standard value, i.e.

$$b(t) = b\{W_c, W_k\} \quad (19)$$

## Results

In order to determine probabilistic characteristics of overranges and build the area of admissible values of  $O$ , let us represent equations (18) and (19) in the form of a two-dimensional vector process:

$$K(t) = \{m(t), b(t), t \in T\} \quad (20)$$

Components of this equation are continuous and differentiable random functions of time  $b(t)$  and  $m(t)$ ,  $t \in [t_0, t_0 + T]$ . Values of the vector  $K(t)$  vary on the real axis, i.e.  $K(t) \in (-\infty, \infty)$ .

The geometric interpretation of the tolerance problem - lies in the following. The plane  $(b, m)$  is the phase space; components  $b(t)$  and  $m(t)$  of the two-dimensional random process are viewed as coordinates of some point of the phase space. Changes in values of the two-dimensional vector process  $K(t)$  are described by the motion of a point with coordinates of  $b(t)$  and  $m(t)$  in the phase space.

Borders of the area of O admissible values are determined from the condition:  $m(t) \in [-\theta, \theta]$ ,  $b(t) \in [-W, W]$ .

Overrange of the two-dimensional process  $K(t)$  trajectory beyond the limits of the O area are the consequence of the overrange of the function  $b(t)$  beyond the limits  $\pm W$ , provided that the second function  $m(t)$  remains within the borders  $[-\theta, \theta]$ . The

mechanism of the function  $m(t)$  overrange beyond the limits of  $\pm \theta$  is similar, provided that the function  $b(t)$  remains within the borders of  $[-W, W]$ . The average number of overranges of the two-dimensional random process under consideration from the set area is determined by the following equation:

$$N_{k(t)}(O, T) = [N_w^+(W, T) + N_w^-(-W, T)] \cdot P\{m(t) \in [-\theta, \theta]\} + [N_o^+(\theta, T) + N_o^-(-\theta, T)] \cdot P\{b(t) \in [-W, W]\} \quad (21)$$

Here  $N^\pm(\pm W, T)$  is the number of positive or negative overranges of the one-dimensional process  $b(t)$  beyond the border ( $\pm W$ ) on the interval  $[t_o, t_o+T]$ ;

$N^\pm(\pm \theta, T)$  is the number of overranges (positive or negative) of the one-dimensional process  $m(t)$  beyond the border ( $\pm \theta$ ) on the interval  $[t_o, t_o+T]$ .

If the trajectory of the two-dimensional process  $K(t)$  does not overrange the area of O limits, then the following conditions are fulfilled:

$$\begin{aligned} b(t) &\in [-W, W]; \\ m(t) &\in [-\theta, \theta] \end{aligned} \quad (22)$$

The average value of the relative stay duration of the vector process  $K(t)$  in the area of admissible values is calculated according to the following equation:

$$T_{k(t)}(O) = P\{k(t) \in O\} = P\{b(t) \in [-W, W], m(t) \in [-\theta, \theta]\} \quad (23)$$

## Conclusions

The mathematical model of the drying process in rhomb-shaped aggregates and formulation of the numerical algorithm for calculating the temperature field and the moisture field for the grain by the volume of the dryer allow representing this algorithm in a computer program and carrying out a series of calculations. The information, obtained in such way, is the basis for developing a calculation procedure and substantiation of the parameters of grain dryers.

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# TECHNOLOGY AND MEANS FOR MECHANIZATION FOR THE RATIONAL AND SAFE APPLICATION OF PESTICIDES

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**Abstract:** *The paper analyzes the results of research in the sector of mechanization for the evaluation of efficiency of deposition of dispersed drops of fluid on the treated surface when using conventional hydraulic nozzles and rotating disk atomizers, mesh or perforated drums with the forced deposition of small drops. The necessity of using forced deposition of small droplets when creating new working bodies to the spraying technique on the basis of the rotating disc atomizers, mesh, or perforated.*

**Keywords:**

DROPLET DEPOSITION, THE DEMOLITION OF DROPS; THE SPRAY; THE FINENESS OF THE SPRAY; GRAVITATIONAL DEPOSITION; THE DEPOSITION RATE; THE PHYSICAL LOSS OF THE WORKING FLUID.

## 1. Introduction

In view of the continuous growth in the use of pesticides and agrochemicals, the world is becoming increasingly concerned about the reduction of their potential danger to public health as one of the main sources of pollution of the environment and food products. It is known that 75% of pesticides are applied by spraying. In this regard, work is underway in our country and abroad to improve agricultural technologies and, technical means for the rational and safe application of plant protection products.

The main areas for improving spraying technology are improving the quality of application of the working fluid to the surface being treated, reducing the consumption rates of the preparation and working fluid, reducing the unproductive loss of the preparation to the environment due to the drift of small droplets and the dripping of large drops from the treated surface to the soil.

## 2. The subject of the research and ways to solve it

The implementation of spraying technology requires significant material and energy costs. The analysis of the energy consumption of full-scale, low-volume and ultra-low-volume spraying technology showed that with ultra-low-volume spraying, the energy intensity of the process is reduced by 35%, and with low-volume spraying by 15.1% compared to the basic technology of full-scale spraying. In field rod sprayers for low-volume and full-volume spraying technologies, two types of spray guns are generally used: standard slotted flat and injector slotted flat-spray nozzles. When using standard slit nozzles, the spray contains droplets in a very wide range of sizes, while the fraction of small droplets (up to 50  $\mu\text{m}$ ), subject to evaporation and drift from the treatment zone, varies from 1 to 2 depending on the size of the sprayers %. For standard flat-face slot nozzles, the median-mass diameter (MMD) is 200-300  $\mu\text{m}$ . In order to reduce the risk to the environment due to the drift of small drops from the treatment zone, field rod sprayers are equipped with a new generation of injected slotted flat-spray nozzles of various sizes. Due to the air ejection, more sprays of large and medium size are contained in the spray spectrum in these sprayers, while the fraction of small droplets subject to demolition does not exceed 0.4-0.6% of the volume of the sprayed working fluid. In this case, the median mass diameter Drops in these sprayers is 400-600 microns, depending on the size of the sprayer. In this regard, to reduce the drift of small droplets into the environment when working with herbicides, it is advisable to use injector slotted flat-nozzle diffusers such as IDK or IDKN when operating at low pressures. The increase in the spray spectrum of the proportion of large and medium drops, according to a number of specialists, should lead to an increase in soil contamination with pesticide residues due to the dripping of large droplets from the leaf surface.

Another area of research on advanced energy-saving spraying technologies. Cultures against harmful objects with low rates of flow of working fluid and reduced rates of drug consumption is the technology of introducing pesticides with the

help of spraying equipment with rotating disc atomizers, perforated or reticulated drums.

Rotating disk atomizers in comparison with traditional hydraulic sprayers for pesticide application have a number of undeniable advantages, namely:

- provide dispersion of the working fluid into a more uniform, near-monodisperse, spectrum of spray droplets with a polydispersity coefficient in the range 1.4-2.2;
- possibility to adjust the size of the main drops in the range from 40 to 400  $\mu\text{m}$ ;
- allow small application rates of working fluid per hectare;
- provide a greater density of the coating with drops of the upper and lower sides of the leaf surface of the treated plants;
- allow to obtain a high-quality spray when supplying working fluid at low pressures of less than 1 bar or gravity, which excludes the use of high-pressure pumps in spraying technology.

To obtain a more uniform with a narrow spectrum of spray droplets, various designs of rotating disc atomizers (mesh or perforated drums) have been developed. Their wide application, as working bodies in spraying technology, for spraying plant protection products is restrained for a number of reasons. When spraying working fluids of plant protection products, rotating spray disks form a horizontal spray torch, the spray spectrum of which contains the main uniform droplets and small drops of satellites [Dunsky et al., 1982]. In this case, the deposition of droplets on the surface being treated occurs under the action of gravitational forces. Due to the low rate of gravity settling (for the 20 micron droplets, the settling velocity is 0.012 m/s, for 60  $\mu\text{m}$ -0.103 m/s), drifts of small droplets outside the treated area by wind and incoming air flow occur during the movement of the sprayer. Demolition of small droplets from the treatment zone leads to environmental contamination, and also causes burns of other crops and plants near the treatment zone when using herbicides. With a horizontal flame spraying of these sprayers, the uneven distribution of the working fluid at the effective capture width, expressed by the coefficient of variation, is 20% according to the test data, which does not correspond to the requirements of the European norm for this indicator - 7-9%.

## 3. Materials for Production of Prototype Parts<sup>1</sup>

To address these shortcomings, we conducted studies to develop a new rotating sprayer design with forced deposition of small droplets onto the surface being treated and the possibility of adjusting the size of the droplets formed for different spraying regimes.

Figure 1 shows a constructive diagram of a new rotating disk atomizer protected by the RF patent [Lysov et al., 2016]. In the case of the atomizer 1, an electric motor 2 with two shaft outputs is installed, at its lower outlet, there is a spraying disk 3 which can be made in the form of a mesh or perforated drum, a tube 6 supplying a working fluid. At the upper output of the motor shaft between the impeller of the fan 5 to create a directional air flow, a cone-shaped

fairing 4 is installed. The body of the atomizer 1 is made in the form of a truncated cone with an open upper and lower surfaces. The sprayer body is vertically movable, to the motor, the body of which is provided with guides 7 and is assembled with the impeller of the fan 5, the fairing 4 and the spray disk located at the lower shaft outlet. The diameter of the base of the fairing 4 is equal to the diameter of the spraying disk 3. The tube for feeding the liquid 6 is located on top of the spraying disc.

When the working fluid is fed through the tube 6 to the rotating disk 3, due to the centrifugal force, the liquid is dispersed into the main and small droplet-satellites. The air flow created by the impeller of the fan 5, thanks to the installed fairing 4 and its conical shape, provides directional forced deposition of small droplets directly at the outlet from the edge of the spraying disk 4, thereby eliminating their demolition from the treatment zone. The housing of the atomizer 1 is made in the form of a truncated cone, which allows to change the volume of the airflow created by the fan, due to the possibility of its movement relative to the electric motor 2, in combination with the fan impeller and the spray disk 4, downwards. For this purpose, guides 7 are mounted on the motor housing 2. As the housing is moved downwards, due to the conicity of the housing of the atomizer 1, the annular gap between its inner surface and the impeller of the fan 5 is increased, which makes it possible to vary the volume of the air flow for effectively precipitating the droplets of the dispersible liquid and increasing the density uniformity Distribution of droplets on the surface to be treated. In addition, it is possible to adjust the effective spray grasp width from 0.8 to 1.2 meters, as well as the density of the surface to be treated, depending on the pesticide treatment regimes used, which should be at least 20-30 drops per cm for herbicides. Sq., Insecticides-30-40 drops per 1 cm<sup>2</sup>, fungicides -50-70 drops per 1 cm<sup>2</sup>.

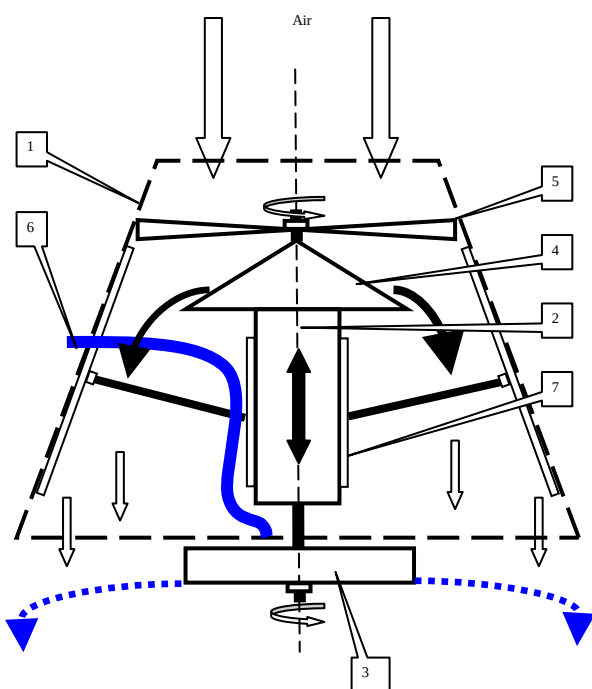


Fig.1 Sprayer with forced droplet deposition

#### 4. Results and discussion

Stand tests were performed on a new atomizer with a disk diameter of 52 mm, a rotation speed of 6080 rpm and a median mass of droplets of 52 µm at a temperature of 21 ° C and a relative humidity of 68%. In the case of forced droplet deposition Fan casing of 4.1 m / s), the amount of settled fluid along the width of the nebulizer increases by 24.51% compared to the operation of a similar atomizer without the application of droplets of a forced drop. In the presence of a side wind with an allowable wind speed of 3 m / s during the spraying process, the amount of settled fluid in the treatment zone was 39% higher than when the sprayer was

operated without precipitation due to a forced drop. . On the basis of the results of bench tests, it can be concluded that due to the forced deposition of droplets of the atomizer of the rotating disk atomizer, the density of the working fluid in the processing area is increased by reducing the unproductive losses due to the demolition and evaporation of the droplets of the dispersible liquid. An assessment was made of the biological effectiveness of spraying technology with the forced precipitation of droplets of working fluid. The biological effectiveness of ATC spraying technology in the case of forced droplet dropout was determined by the introduction of herbicides into crops and potato planting to suppress weed vegetation, and against pests in cabbage plantations. The evaluation of the effectiveness of the technology included the determination of the following parameters: the biological effectiveness of the use of pesticides; Ecological indicators: dynamics of residual amounts of herbicides in the soil at 1, 3, 7 and 21 days after treatment; Contamination with residual amounts of pesticides of plant vegetative organs; Possible reduction in the level of pesticide consumption for various technologies for the introduction of plant protection products.

For comparison, spraying technology was used at a spraying rate of 200 liters/ha using standard slotted flat nozzles, flat nozzles and spraying of UVO with forced release of fine droplets at a rate of 10 liters / ha of working fluid. Conducting pilot experiments included the introduction of complete norms of drug consumption and a reduction in consumption by 25 and 50 percent in experiments with pesticides.

Determination of micro-quantities of pesticides in the soil and green mass of plants with different technologies for their application was carried out by gas chromatographic analysis of the samples taken. Brief description of pesticides

In comparative tests of various technologies for the introduction of pesticides into crops, the herbicide was used as a herbicide of the postemergence systemic action of Diphezan AD to control dicotyledonous weeds in grain crops of cereals.

Active substance: 344 g / l of dicamba (diethylethanolamine salt) + 18.8 g/l of chlorosulfuron (diethylethanolamine salt). The presence of a mixture of the two components allows us to control more than 200 species of weeds, including species resistant to 2,4-D and Dielen.

Preparative form: aqueous solution.

To compare weeds with potatoes in comparative tests, selective herbicide Zino SP Was used to control dicotyledonous and gramineous weeds when planting tilled and vegetable crops. The preparation provides protection of crops from weeds within 1-2 months depending on weather conditions and soil type

Active substance: metribuzin, 700 g/kg.

Preparative form: wettable powder. The biological effectiveness of various technologies for the introduction of herbicides on cereals and potatoes is presented in Tables 1 and 2.

Table 1. Biological efficiency of herbicide application Diphezan BP on cereals, depending on the technology of application

| Variant                                      |                | Total number of weeds, ind./m <sup>2</sup> | Number of annual weeds, ind./m <sup>2</sup> | Total biological efficiency, % | Efficiency against annual weeds, % |
|----------------------------------------------|----------------|--------------------------------------------|---------------------------------------------|--------------------------------|------------------------------------|
| Technology MO (standard Slot sprayer 120 03) | 50% (0,2 l/ha) | 34                                         | 23                                          | 50                             | 60,3                               |
|                                              | 75% (1,5 l/ha) | 27                                         | 20                                          | 60,3                           | 65,5                               |
|                                              | 100% (1, l/ha) | 22                                         | 17                                          | 67,6                           | 70,7                               |
| Technology MO (Injector slot sprayer 120 03) | 50% (0,2 l/ha) | 23                                         | 20                                          | 66,2                           | 65,5                               |
|                                              | 75% (1,5 l/ha) | 21                                         | 19                                          | 69,1                           | 67,2                               |
|                                              | 100% (1, l/ha) | 20                                         | 16                                          | 70,6                           | 72,4                               |

|                                                       | l/ha           |    |    |      |      |
|-------------------------------------------------------|----------------|----|----|------|------|
| UMO technology sprayer with forced droplet deposition | 50% (0,2 l/ha) | 17 | 12 | 75   | 79,3 |
|                                                       | 75% (1,5 l/ha) | 18 | 9  | 73,5 | 84,5 |
|                                                       | 100% (1, l/ha) | 13 | 7  | 80,9 | 87,9 |
| Control                                               |                | 68 | 58 |      |      |

Table 2. Biological efficiency herbicide application of Zino, DP on potato depending on the application technology

| Variant                                               |                | Total number of weeds, ind./m <sup>2</sup> | Number of annual weeds, ind./m <sup>2</sup> | Total biological efficiency, % | Efficiency against annual weeds, % |
|-------------------------------------------------------|----------------|--------------------------------------------|---------------------------------------------|--------------------------------|------------------------------------|
| Technology MO (standard Slot sprayer 120 03)          | 50% (0,2 l/ha) | 36                                         | 20                                          | 25                             | 44,4                               |
|                                                       | 75% (1,5 l/ha) | 24                                         | 16                                          | 50                             | 55,6                               |
|                                                       | 100% (1, l/ha) | 20                                         | 16                                          | 58,3                           | 55,6                               |
| Technology MO (Injector slot sprayer 120 03)          | 50% (0,2 l/ha) | 32                                         | 24                                          | 33,3                           | 33,3                               |
|                                                       | 75% (1,5 l/ha) | 28                                         | 20                                          | 41,7                           | 44,4                               |
|                                                       | 100% (1, l/ha) | 16                                         | 12                                          | 66,7                           | 66,7                               |
| UMO technology sprayer with forced droplet deposition | 50% (0,2 l/ha) | 16                                         | 12                                          | 66,7                           | 66,7                               |
|                                                       | 75% (1,5 l/ha) | 12                                         | 8                                           | 75                             | 77,8                               |
|                                                       | 100% (1, l/ha) | 8                                          | 4                                           | 83,3                           | 88,9                               |
| Control                                               |                | 48                                         | 36                                          |                                |                                    |

## 5. Conclusion

As the results of the experiments of 2014 and previous years show, the most effective technology for applying herbicides to potatoes and cereals is the technology of ultra-low-volume spraying with forced droplet sedimentation. With this technology, water resources are reduced by 20 times, pesticide consumption rates are 25% higher than traditional spraying technologies. In the course of several years, the residual amount in the soil and vegetation of herbicide Gezagard 50 SP was estimated for various technologies for its application. It was found that the residual amounts of herbicide in the soil on the third day after treatment at the full application rate of the preparation for ultra-low-volume spraying technology was - 0.6656 mg/kg, low-volume spraying with slot injectors - 0.6015 mg/kg, with standard slot-sprays - 0,6405 mg/kg. On the seventh day after the treatment, the dynamics of decomposition of herbicide residuals by technologies was as follows: ultra-low volume spraying with forced droplet deposition of 0.5758 mg/kg, low-volume spraying with slot injectors of 0.4010 mg/kg, with standard slotted sprays of 0.2637 mg/kg. At day 28, the residual amounts of the herbicide in the soil were practically the same and amounted to 0.0374 mg/kg with an ultralow volume spraying, 0.0375 mg/kg with slot injectors, 0.0371 mg/kg with standard slit nozzles. A similar dynamics of decomposition of residual amounts of the drug was observed even with reduced rates of drug consumption by 25 and 50%. Evaluation of the decomposition dynamics of herbicide Gezagard 50 SP in the green mass of potatoes showed that the residual quantities of the preparation at the full application rate on the third day are: for ultra-low-volume spraying technology with positive droplet precipitation of 0.7481 mg/kg, a low-volume spraying technology with a slot

injector atomizer, 5355 mg/kg, and a slotted standard sprayer of 0.3561 mg/kg. At day 28, the residual amounts of the preparation in virtually all variants are the same: with the technology of ultra-low volume spraying with the forced precipitation of drops of 0.0338 mg/kg, low-volume spraying with a slit injector atomizer of 0,0281 mg/kg and slotted standard atomizer - 0.0295. In this case, the remnants of the drug in the crop were not detected. A similar dynamics of the decomposition of the drug was observed at reduced dosage rates of the drug by 25-50% (3).

## 6. Recommendations

Technologies with forced droplet deposition are recommended for application of herbicides and insecticides in field crops with reduced by 25% and more consumption rates of preparations.

A sprayer with forced droplet sediment provides a reduction of unproductive losses of pesticides to the environment up to 40%.

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# MEASUREMENT OF EXHAUST EMISSIONS FROM FARM MACHINERY UNDER ACTUAL OPERATING CONDITIONS WITH THE PEMS EQUIPMENT – SELECTED ISSUES

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**Abstract:** The paper discusses the problem of exhaust emissions from farm machinery. The paper presents selected results of the measurements of exhaust emissions (CO, HC, NOx, PM) from farm machinery under actual operating conditions, during fieldwork. For the tests, the authors used a portable exhaust emissions analyzer (PEMS) for the measurement of gaseous exhaust emissions and for the measurement of the emissions of particulate matter. The analyzers provide an on-line measurement of the concentrations of the exhaust components under actual operating conditions. The tests performed under actual operating conditions provide invaluable information regarding the exhaust emissions. In the paper, the authors analyzed the relations between the engine operating parameters and the exhaust emissions. Despite differences in the methodology, the authors also presented a comparison of the obtained results with the currently applicable exhaust emission limits in order to draw attention to this issue.

## Introduction

Engines of non-road applications are a group of extremely wide scope of application that includes: engines for hand-held equipment (mowers, handheld chainsaws etc...), power generator engines and engines of non-road mobile machinery (NRMM). The NRMM group includes farm tractors and construction machinery. The engines of the NRMM vehicles are currently the largest group of all

non-road vehicles, and according to forecasts, their share will grow [6] (fig. 1).

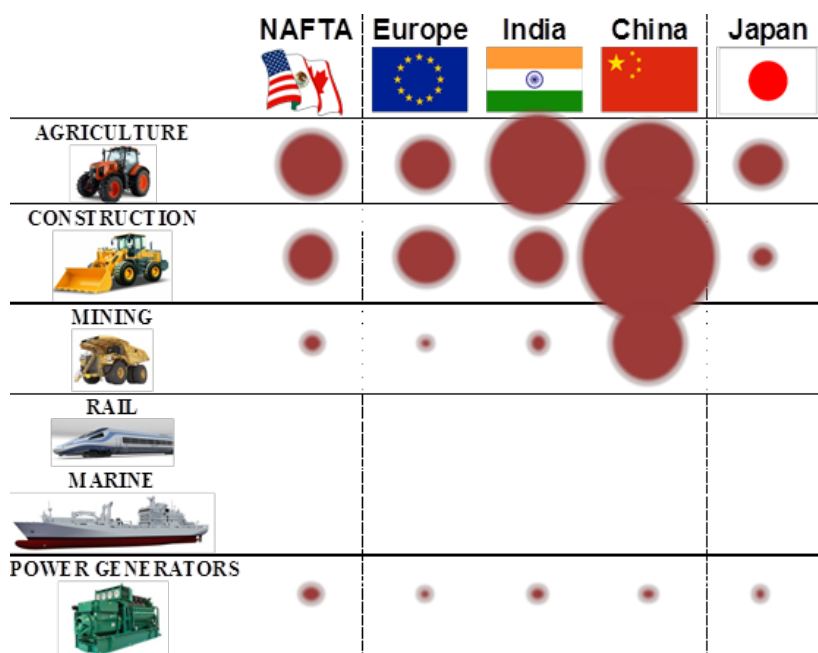


Fig. 1. Share of non-road engines in selected regions of the world [6]

The ecological aspects and the reduction of the production costs combined with the quality of the agricultural products are today the main factors that spur on the advancement of farm production technologies. In Europe, classic plowing system of production prevails, which is an energy consuming technique but ensures high efficiency and high quality of products. A very important aspect of all fieldworks is the fuel consumption/CO<sub>2</sub> emission (energy consumption) and the exhaust emissions. The question of environment pollution by tractors and farm machinery during fieldwork becomes increasingly significant. The engines driving the tractors and other farm machinery are, of course, subject to homologation tests for compliance with the exhaust emissions standards, but the current advancement of the measurement techniques provides new measurement possibilities. Engines of NRMM (Non-Road Mobile Machinery) vehicles such as farm

tractors and farm machinery are tested on engine tests beds in stationary and dynamic tests. Today much attention is drawn to testing under actual conditions of operation (RDE – Real Driving Emissions). Such tests are being introduced to the homologation procedures and, in the coming years, will cover all vehicle categories. European homologation procedures will eventually include RDE tests. That will also be the case for the NRMM engines. Tests under actual operating conditions of farm tractors and farm machinery as well as other NRMM have been carried out for a few years now [4, 5, 9,]. In these works, attention is drawn to the fact that the exhaust emissions under actual conditions of operation are usually higher than the admissible limits determined in laboratory tests [5, 10, 11]. According to the authors, the problem results from the non-representativeness of the engine operating parameters in the tests. In the exhaust emissions tests, it is desired

that the testing conditions reflect the actual conditions of operation, which renders the results most reliable. The reproduction of the actual conditions of engine operation in laboratory tests was a subject of investigations and analyses in many works [1, 3, 7, 8, 10-12]. The conclusions from the literature published thus far, clearly confirm that the engine operating parameters (load and speed) in the laboratory tests for both the road and non-road vehicles, diverge from the parameters of actual operation. This problem, despite numerous research and analyses, has not yet been resolved. Therefore, in recent years, we can see a dynamic advancement of PEMS equipment and methodology of testing under actual conditions of operation. This type of research is novel and the results of such research are highly demanded.

RDE tests are introduced to homologation procedures of vehicles of all categories, including NRMM. In the Stage V legislation, an ISM (In-Service Monitoring) procedure is introduced requiring tests performed with the use of PEMS under actual operation. The final version of the procedure is not yet fully developed and accepted but all agree that RDE tests are necessary and should be included in the homologation procedures [2].

### RDE equipment and methodology

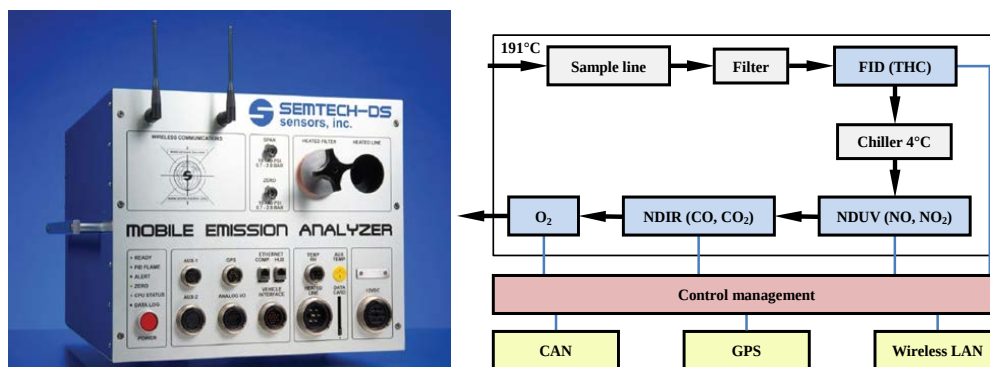
Currently applicable homologation legislation for heavy-duty vehicles (Euro VI) and the heralded proposal of future test procedures for this as well as other vehicle groups included the application of tests performed under actual driving conditions. This type of research however, requires technologically advanced equipment (PEMS) that is increasingly often proposed by automotive measurement equipment manufacturers in their portfolio (AVL List GmbH, Horiba Ltd. And Sensors Inc.). This type of equipment can be used for testing machines and vehicles fueled with different fuels such as gasoline, diesel fuel, CNG, LPG or oxygenated fuels. This also requires the application of special filters or exhaust gas diluters. Besides, the discussed equipment is characterized by high sampling frequency – a minimum of 1 Hz up to 500 Hz (e.g.: EFM-HS – High Speed Exhaust Flow Meter).

Due to the fast varying parameters of engines under actual conditions of operation and the advancement of aftertreatment systems, the equipment must be characterized by high measurement

accuracy. The recording of ambient conditions is also necessary (pressure, temperature, humidity) as they have great impact on the measured values, which is why additional corrective calculations are necessary. Therefore, the said measurement equipment often includes solutions (sensors, algorithms) that perform such procedures. What is more, the equipment must be characterized by low energy consumption, low weight and size, let alone high reliability. In order to perform a full analysis of the impact of a given type of powertrain and the motion parameters of city buses on the environmental indexes the following were utilized: SEMTECH DS (exhaust component concentration, oxygen content exhaust gas mass flow) as well as AVL MSS (used to determine the concentration of PM).

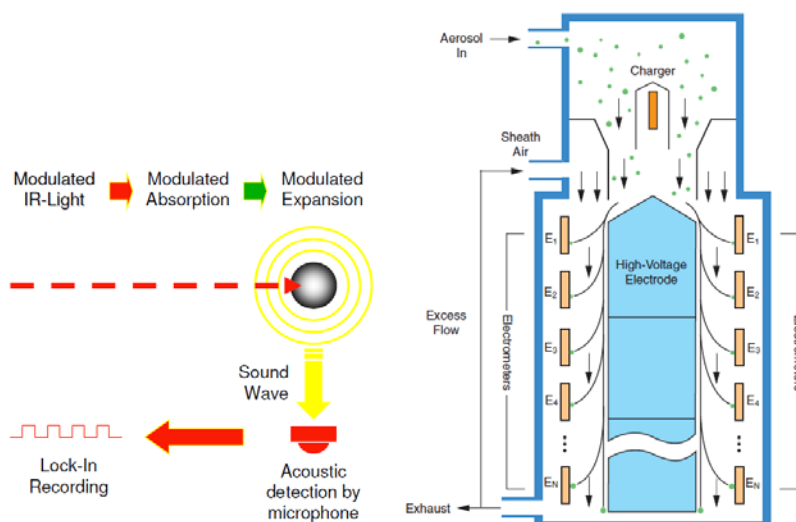
The presented measurement equipment is a unique set of analyzers allowing the determination of energy consumption and environmental performance of vehicles under actual conditions of operation:

- SEMTECH DS (Fig. 2) – designed for the testing of gaseous exhaust components: NDIR: CO [%], CO<sub>2</sub> [%]; FID: THC [ppm]; NDUV: NO [ppm], NO<sub>2</sub> [ppm] and O<sub>2</sub> [%] electrochemical;
- AVL MSS (Micro Soot Sensor – Fig. 3) – used to calculate the concentration of PM [mg/m<sup>3</sup>] with the photo-acoustic method;
- TSI 3090 EEPST<sup>TM</sup> (Engine Exhaust Particle Sizer<sup>TM</sup> Spectrometer – Fig. 3) – allows determining of the size distribution of PM [nm];
- SEMTECH ECOSTAR – allows measurement of both gaseous components and particulates (mass and number);
- AVL OTR (On The Road) OPACIMETER – used to test the exhaust gas opacity [%];
- SEMTECH LASAR – allows determining of the content of the exhaust gas including NH<sub>3</sub>, N<sub>2</sub>O, CH<sub>4</sub> [ppm].



**Fig. 2.** Semtech DS analyzer used for the measurement of gaseous exhaust components under actual conditions of operation





**Fig. 3.** Measurement Equipment for PM measurement: a) AVL MSS analyzers for the measurement of PM and b) TSI 3090 EEPS™ equipment for PM size distribution under actual conditions of operation

Exhaust emissions measurements under actual operation of farm tractors and machines were performed during regular fieldwork. During the measurements, the tractor was coupled with a seed drill, the harvester collected rye, and the beet-harvesting machine collected sugar beet. The test cycles during the measurements were not different from typical working conditions during the said activities,

which is why one can state that the obtained results represent the actual exhaust emissions during fieldwork. The results of the emission measurements were analyzed as performed on the tractor with the seed drill, the combine harvester, and the beet-harvesting machine. The investigated machines and their technical specifications have been presented in table 1.

Table 1  
Machinery and measurement equipment during the test

|  |                                                                                                                                                                                                                                                                                                             |
|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | <p>displacement: 7.1 dm<sup>3</sup><br/>architecture: straight 6, 4 valves per cylinder<br/>bore, stroke: 115×149 mm<br/>maximum power output: 198 kW/2300 rpm<br/>maximum torque:<br/>1050 Nm/1400 rpm<br/>fitted with VGT intercooled turbocharger, EGR, common rail,<br/>Tier 3/Stage IIIA compliant</p> |
|  | <p>displacement: 9.3 dm<sup>3</sup><br/>architecture: straight 6, 4 valves per cylinder.<br/>bore, stroke: 115×149 mm<br/>maximum power output: 230 kW/2200 rpm<br/>maximum torque:<br/>1550 Nm/1400 rpm<br/>fitted with VGT intercooled turbocharger, EGR, common rail Tier 3/Stage IIIA compliant</p>     |
|  | <p>displacement: 16.0 dm<sup>3</sup><br/>architecture: V8, 4 valves per cylinder<br/>maximum power output: 444 kW/1800 rpm<br/>maximum torque:<br/>2800 Nm/1080 rpm<br/>fitted with: intercooled turbocharger, EGR, pump nozzle injection system<br/>Tier 3/Stage IIIA compliant</p>                        |

## Results and analysis

The performed investigations determined the following exhaust emissions: CO, HC, NO<sub>x</sub> and PM as well as fuel consumption (the emission of CO<sub>2</sub>). It is noteworthy that the obtained results depend on a variety of factors such as type of soil, terrain conditions, driver skills, ambient conditions as well as the machine itself and its technical condition. The analysis of the exhaust emissions from all investigated vehicles was performed for the entire measurement

cycle i.e. the measurements initiated when the machine started fieldwork and were finished when the machine completed fieldwork. In order to assess the emissions of individual exhaust components an emission index was defined:

$$k_j = \frac{e_{rzecz,j}}{e_{dop,j}}$$

where:  $j$  – exhaust components, for which the emission index was determined,

$e_{rzecz,j}$  – unit emission measured under actual operation [g/kWh],

$e_{dop,j}$  – admissible emission (depending on the applicable standard for each engine standard, *Stage, Tier*) [g/kWh],

The adopted emission index is a measure of emission changes of individual exhaust components against the applicable European and American standards. The index may assume a value from  $(0; \infty)$ . If its value is greater than 1, it signifies a higher emission under actual operation compared to the admissible limit and when its value is lower than 1, it signifies a lower emission under actual operation compared to the admissible one. If the index equals 1, the emission under actual operation is tantamount to the admissible one.

For all tested machines, the PM emission index was greater than 1 (Fig. 4). The lowest value of this index was recorded for the combine harvester – 1.95 and its highest value for the beet-harvesting machine – 1.45. Also, the  $\text{NO}_x + \text{HC}$  emission index for all tested vehicles was greater than 1 (Fig. 5). The highest value of this index was recorded for the combine harvester (1.95). Aside from the collective emission of  $\text{NO}_x$  and HC (as per the guidelines of Stage IIIA and Tier 3), the emission of  $\text{NO}_x$  alone was also presented. From this comparison it results that it is  $\text{NO}_x$  that had the significant share in the total  $\text{NO}_x + \text{HC}$  emission. Based on the performed research, it was observed that the emission of the most troublesome exhaust components for diesel engines (PM and  $\text{NO}_x$ ) under actual operation is higher than the admissible values set forth in the homologation procedures.

The performed research confirms that for the NRMM vehicle category, the main problem in actual operation is still the emission of  $\text{NO}_x$  and PM. The advancement of the engines of these vehicles should aim at limiting of these particular exhaust components. In this respect, the potential is great, which is confirmed by solutions applied in on-road vehicles that can be easily transferred to the NRMM vehicles



Fig. 4. PM emission index for the tested machines

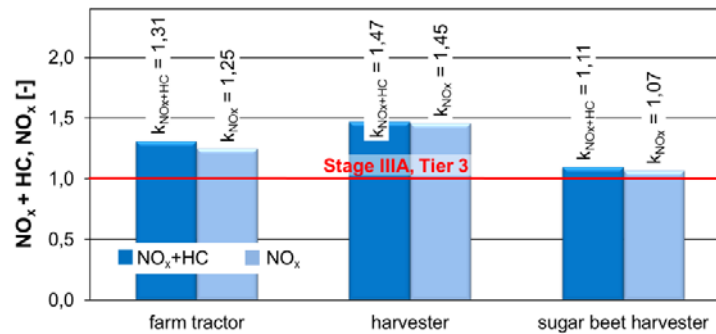


Fig. 5.  $\text{NO}_x + \text{HC}$  ( $\text{NO}_x$ ) emission index for the tested machines

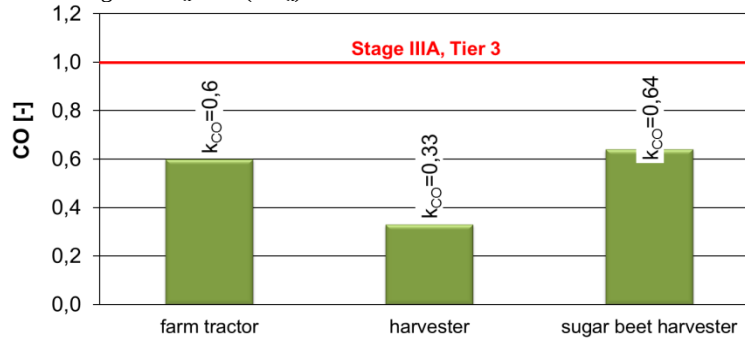
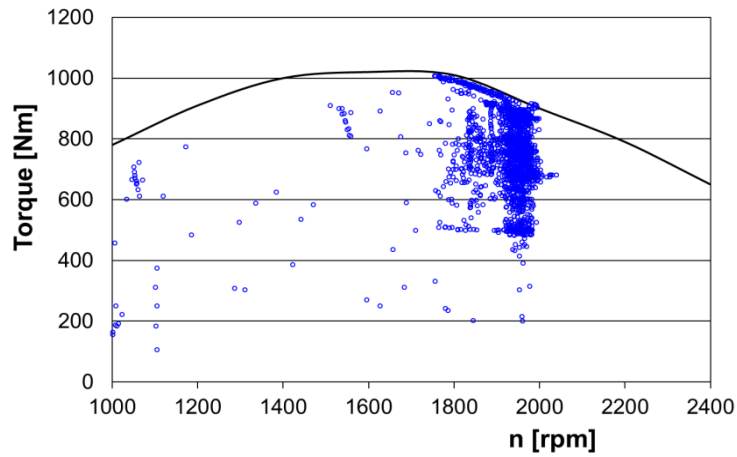


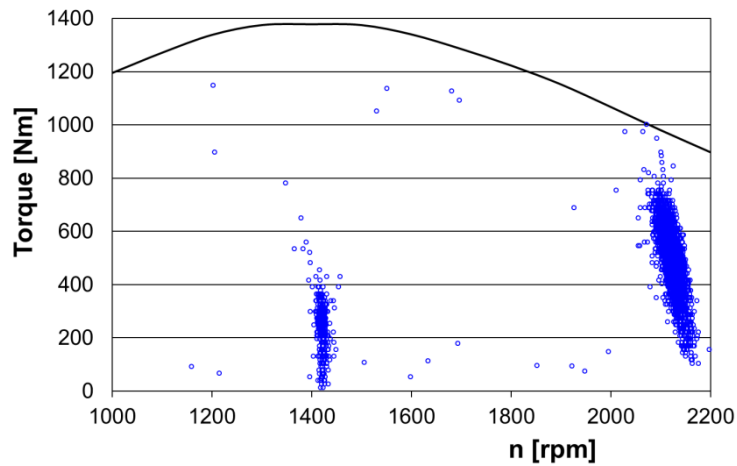
Fig. 6. CO emission index for the tested machines

The performed tests also allowed an analysis of the engine operating parameters during fieldwork. The performed analysis enabled identification of the most frequently used engine work areas and determining the operating time share of these areas (Fig. 7–9). The operation of the tested engines is characterized by a very narrow operating area (range). The limitation of this area mainly results from the range of applied engine speeds, not the torque range. Compared to the on-road vehicles, where a wide range of

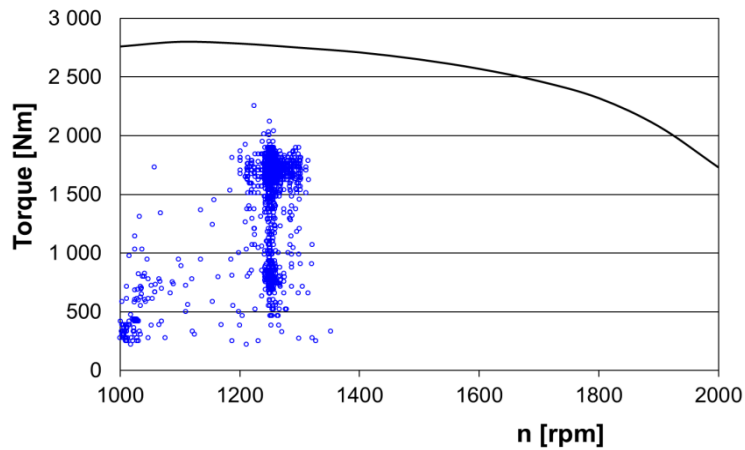
engine speeds and torques is used, farm tractors and machinery during fieldwork use a narrow range of engine speeds. For the investigated cases, more than 90% of the operating time, the tractor operated in the range  $1950 \pm 50$  rpm, the combine harvester  $2100 \pm 50$  rpm and the beet-harvesting machine  $1250 \pm 50$  rpm. For the investigated machines, the range of load was much wider (the widest for the combine harvester). For a given engine speed it varied from approx. 10 to 80% of the maximum torque.



*Fig. 7. Operating parameters of the farm tractor coupled with the seed drill during actual operation*



*Fig. 8. Operating parameters of the combine harvester during actual operation*



*Fig. 9. Operating parameters of the beet harvester during actual operation*

Such specific operating conditions of engines are not yet allowed for in the applicable exhaust emissions and fuel consumption tests for farm tractors and farm machinery. This is particularly the case for the NRTC (Non-road Transient Cycle) test [13], where the range of engine speed variations is very wide and it should be noted that it is more suitable for on-road engines. This is, most likely, one of the main reasons for the divergence of the emission results between laboratory tests and tests performed under actual operation.

## Conclusions

Reducing the exhaust emissions requires a continuous search for new solutions in the area of construction and design of combustion engines and methods of their testing. The paper has shown selected aspects of testing of exhaust emissions from farm tractors and machinery under actual operating conditions. The results obtained in the research confirm that RDE tests are, by all means, necessary, as they provide invaluable information impossible to obtain under laboratory conditions. The advantage of RDE tests is the fact that they include factors that are difficult to reproduce in the laboratory (driver's or machine operator's

behavior, ambient conditions, terrain etc.), but heavily influence the exhaust emissions. It is therefore fully justified to introduce RDE testing to homologation procedures. It is important, however, that these procedures must be developed and adapted to the specificity of operation of engines fitted in farm tractors and farm machinery. This specificity is much different from the on-road engine applications. A factor stimulating this advancement is appropriate exhaust emissions legislation. The advancement of exhaust emissions measurement technology has created new possibilities in terms of the methods used in RDE. One may suppose that it is this particular method that will be further improved and will gain in importance. The aim of the legislators and the manufacturers should be the acknowledgement of measurements under actual operating conditions to be one of the main methods in homologation testing. Proper works in this respect should finish without delay and the introduced legislation should have global outreach.

The performed research confirms that for the NRMM vehicle category, the main problem in actual operation is still the emission of NO<sub>x</sub> and PM. The advancement of the engines of these vehicles should aim at limiting of these particular exhaust components. In this respect, the potential is great, which is confirmed by solutions applied in on-road vehicles that can be easily transferred to the NRMM vehicles.

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# CRITICAL PERIOD METHOD - INNOVATIVE METHOD FOR SIZING OF THE IRRIGATION SYSTEMS: CASE KOSOVO

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**Abstract:** Systematic approach and sustainable use of water and energy is the key point for human existence. Irrigation systems are one of the main directions for the development of the economy. Renewable energy sources, especially solar photovoltaic (PV) energy are suitable as input energy for the irrigation systems. By using the original and innovative scientifically sizing method named Critical Period Method, the irrigation systems are sustainable, given the economic, environmental and social indicators. This method includes design elements of the solution by subsystems: Photovoltaic generator + inverter - PV, pump station - PS and water reservoir - WR based on the critical period of operation of each one. Critical Period Method is different from the usual sizing methods because instead of a single critical period, which relates to the maximum daily water consumption, this method considers three critical periods (for subsystems PV, PS, and WR) due to the different balancing days. Each of the critical periods is determined with regards to a certain balance period. Critical day/period for subsystem PV is determined by statistical minimization, with regards to the difference between over pumped and demand quantity of water. For the subsystem, WR critical day/period is the day with maximum water demand and the shortest duration of solar radiation suitable for the operation of the pump station. A critical day/period for the subsystem PS also coincides with this critical day. Pumps use electric energy produced by using solar photovoltaic energy and causing water pumping into the water reservoir, which with its usual hydraulic role of storing water also has the function of energy reservoir. This concept is adaptable and can be implemented in the previously constructed systems, as well as for the new ones. Application of Critical Period Method replaces the installation of long energy supply lines and associated energy losses, and additionally reduces greenhouse gas emissions. Application of Critical Period Method is suitable for rural areas because of locations where classical power network is not available or has limited availability, i.e. remote areas and on islands. In order to prove this innovative method, a practical application is predicted to perform in irrigation of agriculture field in Dečan, Kosovo.

**Keywords:** CRITICAL PERIOD METHOD, IRRIGATION, WATER PUMPING, RENEWABLE ENERGY SOURCES, SOLAR PHOTOVOLTAIC ENERGY, PUMP STATION, WATER RESERVOIR, SUSTAINABLE DEVELOPMENT

## 1. Introduction

Usage of solar photovoltaic (PV) energy, not only in urban water supply systems but also for irrigation systems has special importance for the entire human population of the world. Even if the location has a sufficient quantity of water, it should be noted that electricity supply for its abstraction, further distribution, and use can be a problem. PV energy is particularly suitable for energy supply for irrigation and water supply systems in rural areas because there are locations where classical power network is not available or has limited availability. In this situation, especially in remote areas and on islands, PV energy solves the problem of distribution with water and energy.

In doing so, the emphasis is not only on the use of PV energy but also on the improving the performance of pumping stations and reservoirs, as well as the remaining parts of the water supply system (for the most part that refers to pipelines). The above-mentioned solution is sustainable, given the economic, environmental and social indicators, which is achieved by using original and innovative scientifically method, i.e. Critical Period Method (CPM), which was presented and explained in details in doctoral dissertation (PhD thesis) from 2014, titled "Sustainability of the urban water supply system operating" and many other published scientific papers (Đurin, B., 2014, Đurin, B., J. Margeta, 2014, Borisov B., B. Đurin, J. Matin, 2016, Margeta, J., B. Đurin, 2016, Đurin, B., L. Baić, 2016, and many others). Such kind of methodology (CPM) so far hasn't been applied anywhere in the world. This concept was presented in London at the international scientific conference "World

Congress on Sustainable Technologies" in 2015, where it was declared for the best work on this conference. Furthermore, it was presented at the International Exhibition of Innovations (ARCA), held in Zagreb in 2016, where it was given a bronze medal for this innovative method. In November 2016, this project was presented at the Faculty of Geotechnical Engineering, which was proclaimed the best student presentation for the City of Varaždin, which as one of seven partners, has been included in the EU project "CENSE 2020 - Circular Economy from North to South Europe 2020", co-funded through the 'Europe for Citizens' program - European Executive Education, Audiovisual and Culture Agency (EACEA). Accordingly, this methodology was also presented at the CENSE 2020 conference in Campulung in Romania in April 2017. Nevertheless, this methodology was chosen to present the Faculty of Geotechnical Engineering at the University Fair in Zagreb, held in November 2016. Also, the same concept was presented at Open Door Day of Faculty of Geotechnical Engineering in Varaždin, University of Zagreb, held in April 2017.

There is a plan to apply CPM on the existing irrigation filed at location in Prapačan, Municipality Dečan, Kosovo. This project is predicted to be financed by Ministry of Education, Science and Technology, Republic of Kosovo in cooperation between University of Prishtina and University of Zagreb.

## 2. Innovative methodology for sizing of the irrigation systems – Critical Period Method (CPM)

### 2.1. Description of the mathematical model

Critical Period Method (CPM) includes design elements of the solution: subsystem “PV”, subsystem “pumping station” and subsystem “water reservoir”, based on the critical period of operation of each one. By using of solar photovoltaic energy, electric energy is produced and used for operational work of the pumping station. Pumping station pumps water into the water reservoir. From the water reservoir, water is distributed to the irrigation machine or to the irrigation pipelines on the green areas. The balancing period  $t_b$  of water pumping and water consumption (water and energy balance) is usually at least one day and may be several days, usually no more than five ( $t_b = 1$  till 5 days). Moreover, it has been proved that the reservoir with its usual hydraulic role of storing water also has the function of energy reservoir through the proven functional connection with the source of energy, which is in this case subsystem PV. This relationship between stochastic input energy and deterministic output energy is expected because larger reservoir volume reduces the influence of some extreme time series values of the input solar radiation intensity (solar energy). CPM is different from the traditional (common) methods as a single critical period, which relates to the maximum daily water consumption, this method considers three critical periods due to the different balancing days (periods). These are critical periods for sizing of subsystems such as: PV, pumping station and water reservoir.

The minimum required power for the subsystem PV is determined from established differences  $\Delta V_{tb,i}$  between pumped water amount  $\Delta V_{PS,tb,i}$  and required water amount  $\Delta V_{daily,tb,i}$ :

$$\Delta V_{tb,i} = V_{PS,tb,i} - V_{daily,tb,i} \quad (1)$$

where  $i$ , are days in the year;  $i = 1, 2, \dots, 365$  days.

The critical day/period for PV generator design (subsystem WR)  $t_{Pel,PV,tb,i}^*$  is determined by statistical minimization, where  $\Delta V_{tb,i}$  is a difference, which is typically equal to 0:

$$\min \Delta V_{tb,i} \Rightarrow t_{Pel,PV,tb,i}^* \quad (2)$$

In general, the critical day/period for the designing of the volume reservoir is the day with the maximum water demand  $V_{max,daily,tb,i}$  and the shortest daily duration  $T_{S(i)}$  of solar radiation suitable for pump station operation, providing that on the available day insolation  $E_{S(i)}$  is sufficiently high. Based on the above mentioned, the required water reservoir volume  $V_{tb,i}^*$  for each alternative  $t_b$  is obtained using statistical maximization, with the associated critical day  $t_{V,tb,i}^*$ :

$$V_{tb,i}^* \geq \max V_{tb,i} \Rightarrow t_{V,tb,i}^* \quad (3)$$

As a rule, this critical day refers to the day in which the daily duration of solar radiation  $T_{S(i)}$ , which is suitable for pumping, is the shortest duration of the analyzed year.

The same situation applies to the capacity of pump stations (subsystem PS)  $Q_{PS,tb,i}^*$  where the critical day  $t_{PS,tb,i}^*$  is defined by the following expression:

$$Q_{PS,tb,i}^* \geq \max Q_{PS,tb,i} \Rightarrow t_{PS,tb,i}^* \quad (4)$$

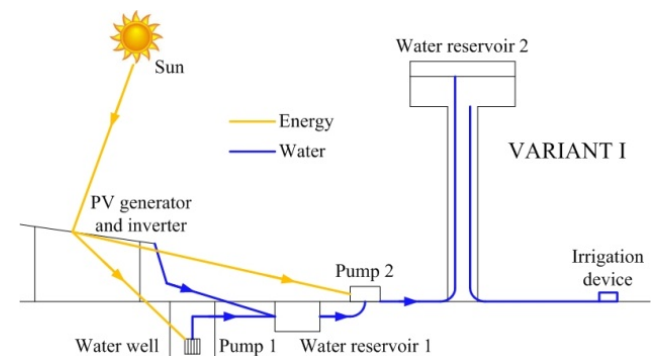
The application of the mentioned sizing methodology of the irrigation system (CPM) is resulting in more rational sizing of the entire irrigation system i.e. in achieving the sustainability of systematic use of water and energy. It is a deterministic approach, which accommodates a large range of possible conditions. It is also a conservative approach because the elements of the solution are potentially oversized. Such approach provides a reliable irrigation system. Such this kind of methodology (CPM) so far hasn't been applied anywhere in the world. Currently, “State of the Art” shows that other procedures, models, and techniques for sizing of the PV irrigation systems (and also a PV water pumping systems) didn't reach CPM, with regards to the mutual relationship of all subsystems sizes.

Based on the obtained values, the minimum required size of the PV system is determined, which provides the necessary inflow of water in the critical period. The results obtained from the scientific research show that the acceptability of the solution grows when the balancing period used for sizing of the system is longer. Lower PV generator power is obtained by applying an extended balancing period. Presented solution is more reliable and safer, regarding operational work of each subsystem (PV system, pump station, and water reservoir) of the entire irrigation system, comparing to the usual water supply systems, which uses conventional or renewable energy.

### 2.2. Presentation of the solar photovoltaic (PV) irrigation system sized by Critical Period Method (CPM)

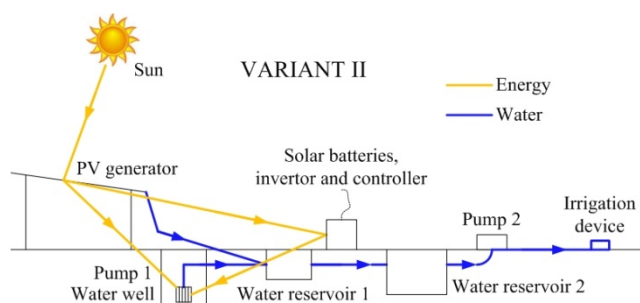
This paper analyses two possible variants of an autonomous water supply system using PV energy to drive the pump station by pumping the water into the water reservoir; Variant I which uses PV generator & inverter while Variant II uses batteries, Figure 1 and Figure 2.

In Variant I, PV cells (forms the PV generator) are used for the conversion of solar radiation into direct current power, which is converted by inverters into alternating current necessary for pump drive. In case the pump station is powered by direct current pumps, the inverter is not required. Available insolation  $E_s$ , i.e., electric energy  $P_{el,PV}$  determines the period of the pump station operation  $T_s$  with uniform rate during the daily work period.



**Fig. 1** Schematic representation of the observed irrigation system for Variant I

Variant II has the same working principle; the difference is that water is stored in the surface water reservoir and pumped over to the irrigation device using electrical energy stored in solar batteries.



**Fig. 2** Schematic representation of the observed irrigation system for Variant II

In both variants, it is necessary to set up minimum two pumps. A first pump (pump 1 in a well) is used to pump water from a well and deliver it to the water reservoir 1. Rainwater (precipitation water) is collected in this water reservoir. Rainwater is collected from the existing roofs and PV cells via grooves for water discharge into the water reservoir 1. If the roof or the solar cells are at a sufficient height, the rainwater is drained by gravity (free fall). In case such gravitational flow is not possible, it is necessary to install a "booster" pump for pumping over. It should be noted that this water reservoir does not function as a pumping tank or conventional water reservoirs for flow and consumption equalization since both pumps operate when the intensity of solar radiation is at its optimal operating level. This implies that the hourly, as well as daily input, is the same as hourly/daily output from this water reservoir, so there is no need to provide for the volume equalization. In Variant I, water is drawn by surface pump 2 from the water reservoir 1 into the water reservoir 2 where water is collected and distributed to the areas being irrigated. Variant II has the same working principle; the only difference is that the water from water reservoir 1 is coming into surface water reservoir 2 in most of the cases by gravity or by "booster" pump if it is not possible to provide flow by gravity. These types of irrigation can be also used for enclosed areas (greenhouses). Typically, water is pumped over into a water reservoir during the day while the irrigation takes place at night, which is more suitable for the vegetation, with the reduced evapotranspiration as well. The distribution of water from the water reservoir to the crops is mainly gravitational in Variant I since the water reservoir is situated at a certain height above the ground surface thus achieving the required water pressure. In Variant II water is distributed by pump 2.

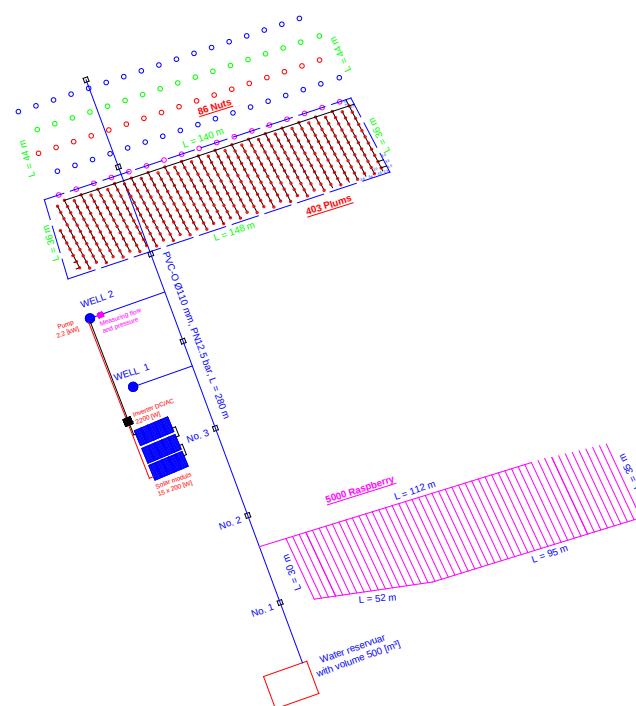
In any case, it is necessary to provide the required volume of the water reservoir 2, namely the water required to meet the irrigation needs. Primarily this need will be provided by pumping groundwater, with a certain amount obtained from rainwater. However, an additional volume of rainwater will not be foreseen for the water reservoir 2, since it is assumed that this quantity of water will be considerably lower than the planned amount of water drawn from the well. Rainwater has an additional purpose of mixing with underground water, which makes it more suitable for the irrigated vegetation. In addition, this amount of water to some extent also relieves the underground aquifer layer.

The last part of the observed system includes the output pipelines from the water reservoir. In this case, one can predict the irrigation of an area based on the installed connected pipelines or irrigation devices.

### 3. Implementation of the methodology

#### 3.1. Case study

Momentarily, there are a couple of possible locations for construction of the presented innovative irrigation system. Most important and the biggest location is existing irrigation field at a location in Prapaqan, Municipality Deçan, Kosovo. Existing irrigation system consists of PV power plant with power of 3000 W (15 modules with 200 W of peak power for each of them), water reservoir with capacity of the 500 m<sup>3</sup> and submersible water pump with power of 2200 W, Figure 3. With the listed main parts, irrigation system also includes all required equipment (pipelines, electronic and mechanical devices). Irrigation area has size of 8.9 ha, wherein planted agricultural crops are 1.8 ha of raspberries which are irrigated with  $\Phi 16$  mm drip irrigation system, 1.6 ha of nuts also with  $\Phi 16$  mm drip irrigation system, 2.0 ha of pumpkins with  $\Phi 110$  mm flat irrigation, 1.0 ha of white bean also with  $\Phi 110$  mm flat irrigation, 0.5 ha of plum with  $\Phi 16$  mm drip irrigation system and 2 ha of meadow with  $\Phi 110$  mm flat irrigation.



**Fig. 3** Schematic representation of the irrigation system in Deçan

Groundwater, which is situated at a depth of 25 m, is used for irrigation and the usage of the existing well shows that its capacity is sufficient. There is a plan to apply presented innovative methodology (CPM) on this location.

#### 3.2. Implementation plan

The main task of the presented project ideas is to construct, describe, and present the solar photovoltaic (PV) irrigation system, which will be sized by using of the CPM. There will be a couple of stages after this. The first stage will be testing of the proposed innovative methodology. This means comparison of the measured and calculated values, i.e. comparison of the subsystem

sizes, which are calculated by using the mathematical model/calculated data (included within CPM) and by using the data measured on the location of the built project.

Next stages will be a comparison of CPM method with other methods for sizing of the PV irrigation systems, which can possibly be applied. This will be very valuable due to a comparison of the mathematical model and real situation model for all possible sizing methods. Also, measured values of the input meteorological parameters will be compared with modeled/calculated values and values obtained from meteorological services or other available sources, i.e. internet sources.

There will be a possibility of using the excess of the produced electric energy or pumped water for many purposes, as is stated in this project proposal. Measured output values will be compared with the calculated values. Based on this, the possible excess will be adopted with bigger reliability. Unfortunately, using only mathematical model doesn't provide this accuracy. Such analysis will contribute to the techno-economic analysis of the entire project and also to the "cost-benefit" analysis. Determination of the possible differences or discrepancies of the input parameters, calculated subsystems sizes, and output values are directly related to the reliability of the PV irrigation system. Possible over-sizing means big reliability, but here is a possibility for decreasing of the particular subsystem size. On the other hand, under-sizing means decreased reliability.

After detection of such kind of the occurrences, recommendations for their removal should be provided. For this (last) stage, these recommendations cannot be proposed beforehand, because assumed nonlinear connections and dependencies between all subsystems will be exactly determined after field measuring and final analysis. Normally, strong SWAT analysis will be provided.

#### **4. Conclusion**

The use of PV electric energy for water pumping in urban water supply system can contribute to the sustainability objectives of the urban areas and urban water system. It represents a realistic alternative energy. PV pumping is applicable to different settings of pump stations in the urban water system and suitable for smaller water supply systems where pumping stations are quite distant from the power supply lines. The local application replaces the installation of long energy supply lines and associated energy losses, and additionally reduces greenhouse gas emissions. The impacts of the application of sustainability objectives depend on the local climate and characteristics of the water supply system. The proposed concept is adaptable and can be implemented in the previously constructed systems, as well as new ones.

Given that the primary energy source (Sun) is inexhaustible and free of charge, energy supply essential for the operation of water pumping system is sustainable. It should be noted that the cost of energy from conventional sources is increasingly raising (i.e. electric energy in this case). Currently, the Life Cycle Costs (LCC) of PV systems is bigger than LCC of conventional (classic) energy systems. However, LCC of the PV systems is becoming smaller due to PV cell price decreasing. The above is also supported by the current trends of decreasing the quantity of fossil fuels.

The proposed innovation can be used as a stand-alone power system or in combination with electric energy from the regional network, other local energy sources as well as with other

renewable energy sources. That solution can be used to cover the needs of daily and seasonal peak energy. It is important to bear in mind the fact that the price of PV generator is significantly decreasing and production is increasing, as well as the efficiency of cells. This means that the cost of application will be lower, more reliable and more productive. It is not difficult to conclude that the environmental and social criteria are largely met, due to the fact that the system as a whole has the function of sustainable development.

Ecological criteria such as CO<sub>2</sub> reduction can also be economically evaluated, by revenue, through Renewable Obligation Certificates, ROCs. The use of mentioned concepts/solutions may contribute to the EU 20-20-20 Target by 2020 because it increases the share of renewable energy, increases energy efficiency and reduces greenhouse gas emissions. In almost all countries in the world, regardless of the climate, this solution can be successfully implied. In other climate areas and urban areas the result would be slightly different; nevertheless, the basic features of the presented solution would be the same. The surplus of produced electric energy can be used for other needs (different electric devices) or can be sold to the electric companies. In addition, energy surplus can be used for water pumping to the other consumers (for irrigation of green areas, gardens, orchards, nursery-gardens, etc.). With regards to the irrigation systems, groundwater in combination with rainwater could be used for irrigation water demands. Purified wastewater can be also used for mentioned purpose.

#### **Acknowledgements**

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# EFFECT OF MULCH ON SOIL PROPERTIES UNDER ORGANIC FARMING CONDITIONS IN CENTER OF SAUDI ARABIA

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## Abstract:

The mulch application on top of soil surface may effect on soil physical conditions by reducing evaporation losses, soil moisture and soil temperature which in turn affect the distribution of soil elements through soil profile. This work presents a study of the effects of mulch on movement and distribution of soil properties including pH, soil salinity and major nutrition plant available N, P and K in organic palm farming by use different irrigation rates. The decreasing in soil pH more pronounced in surface layer compared to subsurface layers. Soil salinity of surface layers were lower than sub surface layers in mulched treatments for both tow time samples, under organic farming system, Soil moisture and mulch were shown to have a strong indirect influence on the amount of available soil nitrogen, phosphorus and potassium. The highest value of total nitrogen in the soil was recorded in the presence of mulch with the availability of 100 % of the recommended irrigation, where the conditions are very suitable for the mineralization N process. With respect of available phosphorus and potassium, it has given highest values in the presence of mulch with the availability of moisture up to 70% and 85% of recommended irrigation, respectively.

**KEY WORDS:** ORGANIC FARMING, PALM, MULCHING, MOVEMENT MAJOR NUTRITION NUTRIENT

## 1. Introduction

Using mulch on top of the soil surface may improve soil moisture conditions. Mulch benefits crop yield by improving soil physical conditions, including improved structural stability in the topsoil (De Silva and Cook, 2003). A variety of types of mulch leads to an increase in soil moisture content as a result of decreased evaporation from the soil surface compared to that of un-mulched soil (Maged, 2006). Generally, mineral mulch is impervious to water vapour and is thus expected to conserve soil water more efficiently than organic mulch (Lei *et al.*, 2004). Also, the combination of mulching with tillage increased conservation of soil moisture (Grevers *et al.*, 1986; Bhagat and Acharya, 1987). The higher moisture content was always in the 0-60 cm soil layer of the mulched compared to bare soil (Ramakrishna *et al.*, 2006). Diaz *et al.* (2005) reported the greatest reduction in soil moisture content in the case of mulched soil at 10 cm (92%), followed by soil moisture content at 5 cm (83%), and at 2 cm (52%). Some studies instigated the effect of gravel mulch on evaporation by comparing cumulative evaporation rate from soils mulched by gravel with a bare soil surface in the laboratory (Mellouli *et al.*, 2000; van Wesemael *et al.*, 1996; Groenevelt *et al.*, 1989; Modaihsh *et al.*, 1985). The covering of surface soil by gravels and coarse sand can reduce evaporation by 10-20% of that occurring from a wetted un-mulched soil surface (Fang *et al.*, 1993; Unger, 1971; Lemon, 1956). The gravel mulch decreases the area of soil surface available for evaporation (Nachtergaele *et al.*, 1998). Effect of mulching on conserving moisture and increasing productivity had been reported for many crops (Zhang *et al.*, 2005; Verma and Acharya, 2004a,b; Li *et al.*, 2005; Huang *et al.*, 2005; Rahman *et al.*, 2005; Araki and Ito, 2004; Incalcaterra *et al.*, 2003; Tariq *et al.*, 2001; Kumar *et al.*, 2003; Haq, 2000; Kar and Singh, 2004). While weed growth controlling by potential of mulch has been studied by Erenstein (2002). Using irrigation system combined mulch is advocated for better uptake of water by wheat (Liet *et al.*, 2004). During the first stage of evaporation, the mulch on top of the soil decreases capillary diffusion, and water moves from the soil surface to the mulch surface mostly in the vapour phase (Li, 2003). Furthermore, the mulch reduces evaporation of soil water by shading the soil surface from the sun; shading is most effective during the first stage of evaporation when the soil surface is wet (Tolk *et al.*, 1999). On the other hand, Effect of mulching on soil temperature depends on the type of the mulch. Heat storage in the mulch layer is small, but the available energy at a mulch site will be affected by the heat storage in the mulch layer, see e.g. Price *et al.* (1998). Several researchers have found that the mulch influenced on soil temperature (Epstein, 1966; Hay and Allen, 1978; Bristow, 1988; Kar, 2003; Kar and Singh, 2004). The impact of mulching on bulk density depends on soil properties, climate and type of mulch. While some study explained the mulch reduced soil bulk density (Unger and Jones, 1998), and some of them not found any effect of

mulch on soil bulk density (Acosta *et al.*, 1999; Duiker and Lal, 1999). Whilst (Bottenberg *et al.*, 1999) reported that the mulch increased bulk density of soil. On the other hand, addition the organic mulch above soil surface influence soil properties and may affect the movement of some plant nutrient, for example mulching at rate low then 2.25 Mg/ha from crop residue reduced losses of NO<sub>3</sub>-N, P, K, Ca and Mg, additional to increased soil organic matter (Rees *et al.*, 2002), beside that there are relationship between crops residue amount and soil organic matter principally in soil surface (Reicosky *et al.*, 1995). (Kar and Kumar, 2007) reported that the mulch increased available phosphorus, potassium and organic carbon might have enhanced crop growth and yield production especially in the mulched treatments. Therefore, the objective of this research is to study the effects of mulch on soil properties including pH, soil salinity, available N, P, and K through different soil depths in organic palm farming by use different irrigation rates.

## 2. Materials and methods

### 2.1 Study area

A field experiment was conducted at Oukaf Al Rajhi Al khairiah between April and October 2014. The study area is located in Albaten (26°17' 47" N, 44°09'30" W), Buraydah, Saudi Arabia at an altitude of approximately 26m. The texture of the soil was sandy loam (sand 79.17%, silt 8.33% and clay 12.5%) with date palm crop. The soil (0-30 cm) has bulk density 1.58 g/cm<sup>3</sup>. Fifty kg Organic fertilizer (residues cow) was applied for every palm mixed with 0-30 cm soil surface in January 2013. Chemical analysis of organic fertilizer was showed in Table 1. Three irrigation treatments were applied start from first of March 2014 at 100%, 85% and 70% from the recommended water requirements for palm. Water salinity was 2.31 dS/m. Two layers mulch treatments were applied above soil surface, first layer from gravel rock 10 cm (1.14 g/cm<sup>2</sup>) and second layer 5cm palm leaves (0.17 g/cm<sup>2</sup>) starting from soil surface.

### 2.2 Soil analysis

Soil samples (0-30, 30-60 and 60-90 cm) were collected in early of season (April 2014) and end of season (October 2014) for analysis. Each sample was dried at laboratory room temperature (25 °C) to a constant weight and sieved (2 mm) to eliminate coarse soil particles. Electrical conductivity, EC (dSm<sup>-1</sup>), and pH of soil samples were determined in saturated soil-pastes extract, by EC and pH meter, respectively. Total N was determined using the macro-Kjeldahl distillation method, available potassium was determined using a flame photometer and available phosphorus was extracted using 0.5 M NaHCO<sub>3</sub> solution and measured calorimetrically using ammonium molybdate procedure by spectrophotometer according to Chapman and Pratt (1961) and Jackson (1973).

**Table: 1** Chemical analysis of organic fertilizer (residues cow )

| EC dS/m | pH   | Moist. % | C%    | OM%   | TN%  | C/N Ratio |
|---------|------|----------|-------|-------|------|-----------|
| 6.43    | 7.95 | 9.33     | 19.88 | 34.27 | 1.28 | 15.53     |

### 3. Results and discussion

Under organic farming conditions compost is considered the main source of nutrients, especially in dry areas. Therefore, the available nutrient concentration in the soil affected by any process, which will influence the decomposition process of organic fertilizers. In fact, it is noticed that the soil mulching maintains on the soil moisture and temperature, both of which affect the microorganism activity and microbial degradation of organic matter in the soil, as well as nutrient release from organic matter. Consequently, soil mulching has an indirect effect on soil chemistry and fertility. The data in table (2) showed response of soil pH for irrigation levels and mulch at different soil depths. There slightly decrease in soil pH for mulched treatments compared to unmulched treatment in all soil depths either in the beginning or end season. The data were non-significant in the beginning season. However, The decreasing in soil pH more pronounced in surface layer compared to subsurface layers. In the beginning season, the changes in soil pH between (With out-M+100%I ) and (M+85%I) treatments were 0.15, 0.09 and 0.06 for depths 0-30, 30-60 and 60-90 cm, respectively. Also, in the end season, soil pH values in treatment (With out-M+100%I) increased by 0.65, 0.28 and 0.19 for depths 0-30, 30-60 and 60-90 cm, respectively. Many studies have shown that soil pH decreases when organic mulches are used and that this decrease is proportional to the depth of these mulches (Tukey and Schoff, 1963; Billeaud and Zajicek, 1989 and Duryea et al., 1999). Also, data showed that application of compost in arid land cause decrease in soil pH. Mulvaney et al. (1997) and Xia Zhu et al. (2013) observed that lower soil pH was in 50% WHC (water hold in

capacity) compared with in 100% WHC treatment, which suggests that nitrification is stronger in drier conditions, as nitrification contributes to increases soil acidity (reduces pH). Also, other researchers reported that organic mulches cause reduce pH of the underlying soil (Billeaud and Zajicek 1989; Himelick and Watson 1990; Hild and Morgan 1993). Mulch induced pH reduction results from the addition or retention of organic matter, with organic acids produced from decomposition of plant-derived materials accumulating or leaching into the soil (Himelick and Watson 1990). On the other hand, soil pH value in surface layer were lower than sub surface layer with all irrigation levels. While, highest pH values recorded at deep layer. In fact, under organic farming, soil reaction (soil pH) is the result of two processes, ammonification and nitrification. With high soil moisture content, soil air percentage will decrease, so ammonification process will be dominant and soil pH will increase. In contrast, with low soil moisture content, soil air percentage will increase, so nitrification process will be dominant and soil pH will decrease. Reichman et al. (1966) reported that ammonification and nitrification of soil N were almost directly proportional to soil water content. Also, Yu-lin et al. (2013) added that net ammonification rate of soil N reached the maximum at the moisture of 15.2%. Net nitrification rates and net mineralization rates of soil N, however, reached their maximums at the moisture of 11.8% and decreased at the moisture of 15.2%. As expected that the aeration in deep layer (60-90 cm) less than those in surface layer. Consequently, soil pH in surface layer was less than that in deep layer.

**Fig. (2):** Response of soil pH for irrigation levels and mulch treatments at different soil depths.

| Soil Depth, cm | End season            |          |         |         | Beginning season      |          |         |         |
|----------------|-----------------------|----------|---------|---------|-----------------------|----------|---------|---------|
|                | Treatments            |          |         |         | Treatments            |          |         |         |
|                | With out-M+100% I (C) | M+100% I | M+85% I | M+70% I | With out-M+100% I (C) | M+100% I | M+85% I | M+70% I |
| 0-30           | 8.15                  | 7.50     | 7.34    | 7.57    | 7.96                  | 7.81     | 7.86    | 7.92    |
| 30-60          | 8.11                  | 7.83     | 7.47    | 7.94    | 8.05                  | 7.96     | 7.94    | 7.91    |
| 60-90          | 8.30                  | 8.11     | 8.38    | 7.61    | 8.11                  | 8.05     | 7.97    | 7.96    |
| P              | 0.003                 | 0.002    | 0.001   | 0.002   | 0.367                 | 0.174    | 0.958   | 0.710   |

M=mulching C=control I=Recommended irrigation

Soil salinity was significantly affected by presence of mulch ( $p \leq 0.05$ ). Soil salinity of surface layers were lower than sub surface layers in mulched treatments for both two time samples. The results in table (3) showed that treatment of (M+100%I) in the end season had indicated maximum reduction in soil EC, 2.36 dS/m compared to unmulched treatment (With out-M+100%I). The interpretation for this result was accordingly to Pakdel et al. (2013) who suggested that mulch can reduce soil EC in two ways, A: mulches reduced water evaporation of soil and so lead to reducing salt accumulation in soil; and B: water-soluble salts may be absorbed by mulch layer and lead to reducing of water EC when it reaches to the soil layer. Moreover, Hild and Morgan (1993) reported that the greatest effect of mulches on soil EC was observed in the surface of soil layer (0 to 5 cm) below the mulches. They also found that using mulch reduces water evaporation and maintains soil moisture. Therefore lead to reducing the accumulation of soluble salts in the soil surface and so electrical conductivity of soil can be reduced. Also, data showed that soil salinity values in different soil depth were affected by

different irrigation levels. Soil salinity of treatment (M+100%I) recorded less value, 2.26 and 2.46 dS/m in the beginning and end season respectively, compared other treatments.

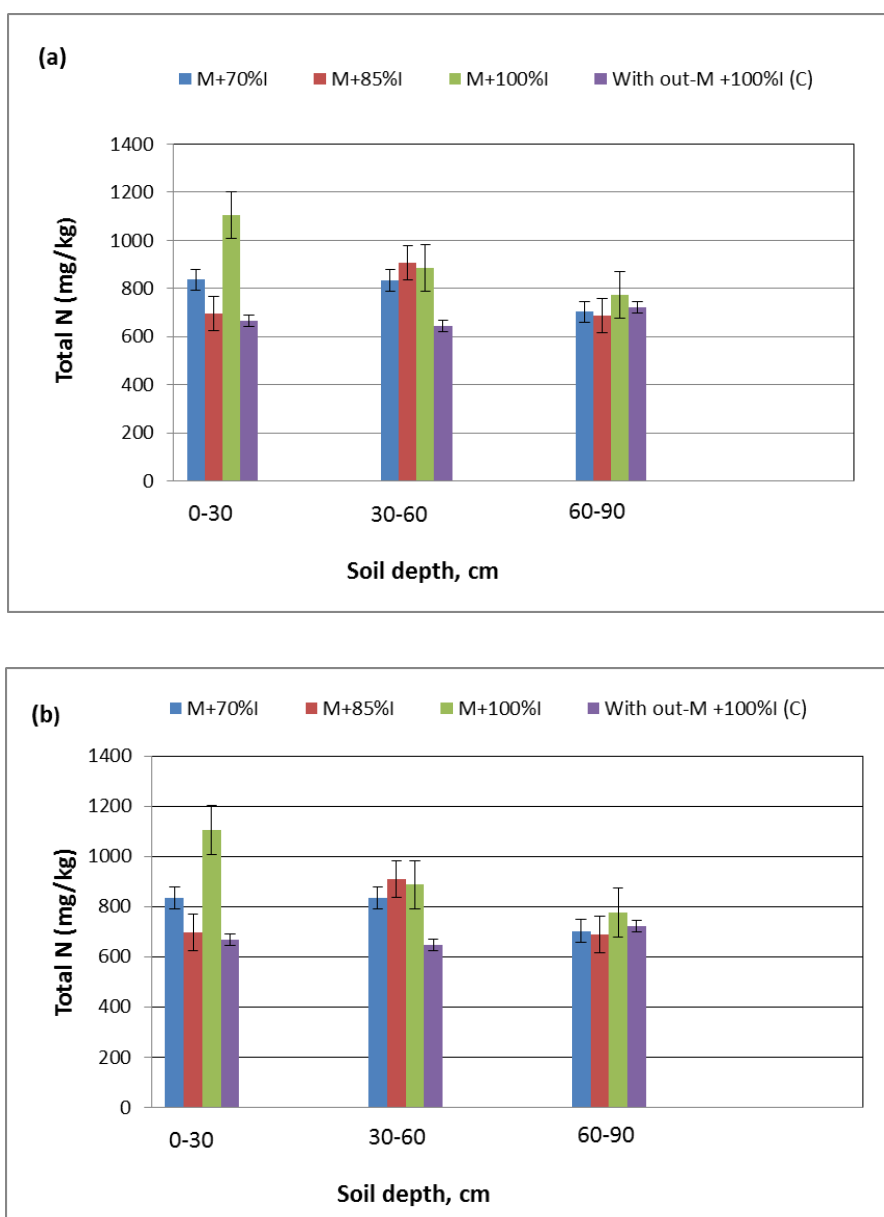
It could be attributed to the increase effect of irrigation water volume for treatment (M+100%I) on the top soil surface depth (0-30 cm) compared to other treatments, (M+ 85% I) and (M+70% I). Where, by increasing the water volume applied in each irrigation treatment, the soil salinity may be reduced as a result of the increased volume of water percolated the surface layer and then accumulated in deep layers. In similar study, Wang et al. (2011) reported that, at the end, salt leaching occurred during the growing season for each treatment as a result of the frequent irrigation, which resulted in the ECe value increasing with depth. However, the difference in soil salinity value between treatment of (M+100%I) and (M+ 85%I) was 0.12 dS/m, 5.3% compared to treatment of M+100%I. This decrease in soil salinity level indicated that the soil salinity was improved and this may be due to that the amount of water irrigation in treatment (M+ 85% I) was suitable.

**Table (3):** Response of soil EC (dS/m) for irrigation levels and mulch at different soil depths.

| Soil Depth,<br>cm | End season                       |         |            |            | Beginning season                |         |            |            |
|-------------------|----------------------------------|---------|------------|------------|---------------------------------|---------|------------|------------|
|                   | Treatments                       |         |            |            | Treatments                      |         |            |            |
|                   | With out<br>-<br>M+100%<br>I (C) | M+100%I | M+85%<br>I | M+70%<br>I | With out<br>-<br>M+100%I<br>(C) | M+100%I | M+85%<br>I | M+70%<br>I |
| 0-30              | 4.62                             | 2.26    | 2.38       | 2.92       | 3.3                             | 2.46    | 2.78       | 3.35       |
| 30-60             | 3.46                             | 2.45    | 2.86       | 5.43       | 2.69                            | 4.09    | 2.95       | 3.00       |
| 60-90             | 4.72                             | 6.70    | 4.32       | 8.46       | 4.17                            | 4.08    | 3.26       | 3.01       |
| <b>P</b>          | 0.001                            | 0.001   | 0.001      | 0.001      | 0.001                           | 0.001   | 0.013      | 0.002      |

M=mulching C=control I=Recommended irrigation

Results, also, showed that soil N significantly affected by mulching process ( $p \leq 0.05$ ) (**Fig.1**). Total N in surface layer in mulched treatment (M+100%I) was higher than unmulched treatment (Without-M+100%I) by 31.0 and 65.9 % in the beginning and end season, respectively. These results were confirmed by Tisdale et al. (1985) and Watt et al. (2010) who reported that mineralization capacity of nitrogen was higher at the soil surface while that mineralization and availability of nitrogen decreased with deeper layer.



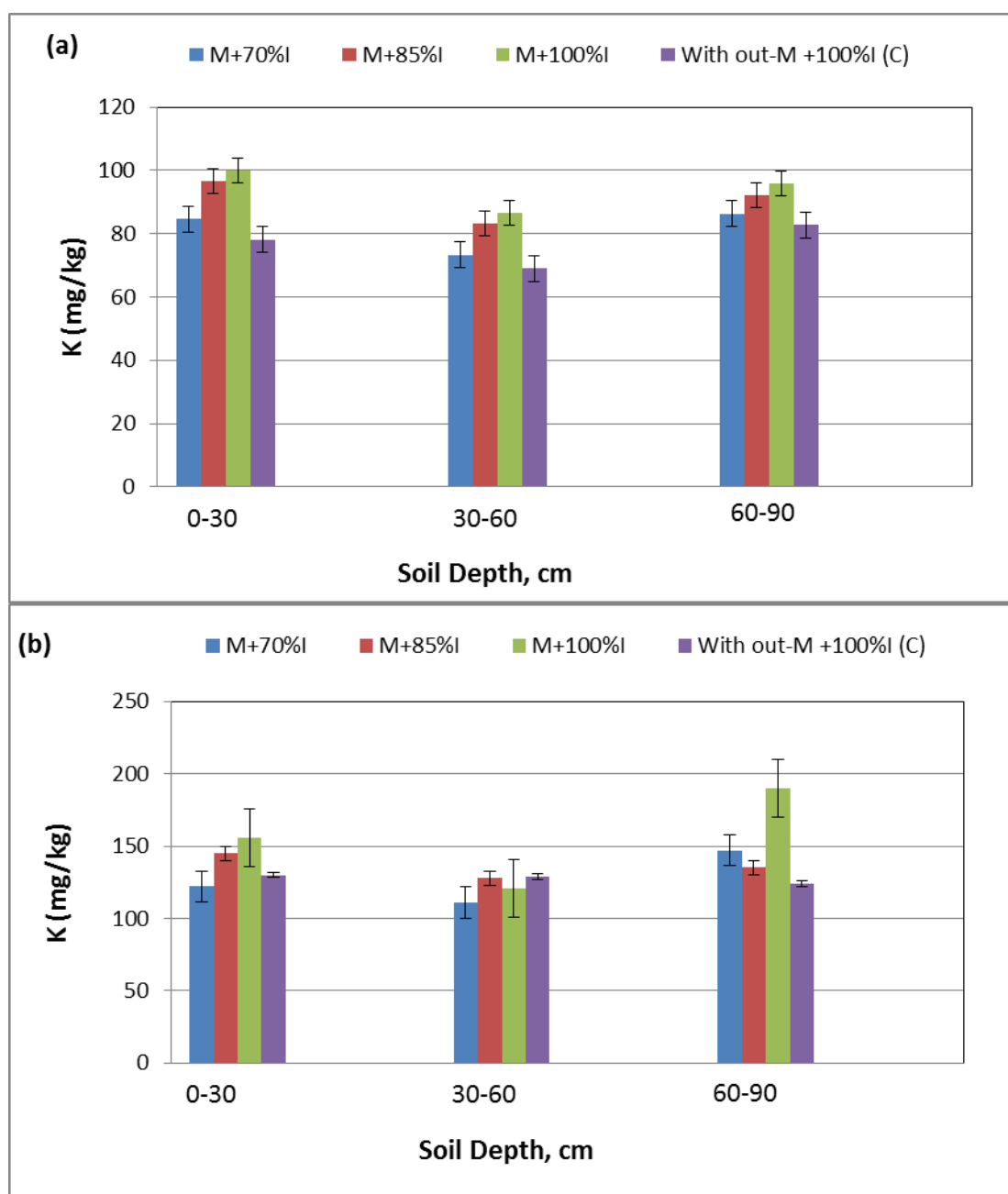
**Figure (1):** Response of total N (mg/kg) in soil for irrigation levels and mulch at different soil depths in (a) the beginning season, (b) the end season. M=mulching, C=control, I=Recommended irrigation

The addition of compost to the soil either increases the  $\text{NH}_4^+$  level from ammonification or leads to a shift in soil pH, which promotes the growth of the nitrifying bacteria population. This may explain the higher nitrate concentration in mulched plots (Engel, 1934 and Pakdel et al. 2013). In addition, Myers (1975) demonstrated that nitrification had a distinct temperature optimum between 25 and 35°C, whereas ammonification reached its maximum at 50 to 70°C. Hence, unfavorable microclimatic conditions in the topsoil of no-mulched plots reduce the number and/or the efficiency of the nitrifying soil microorganisms.

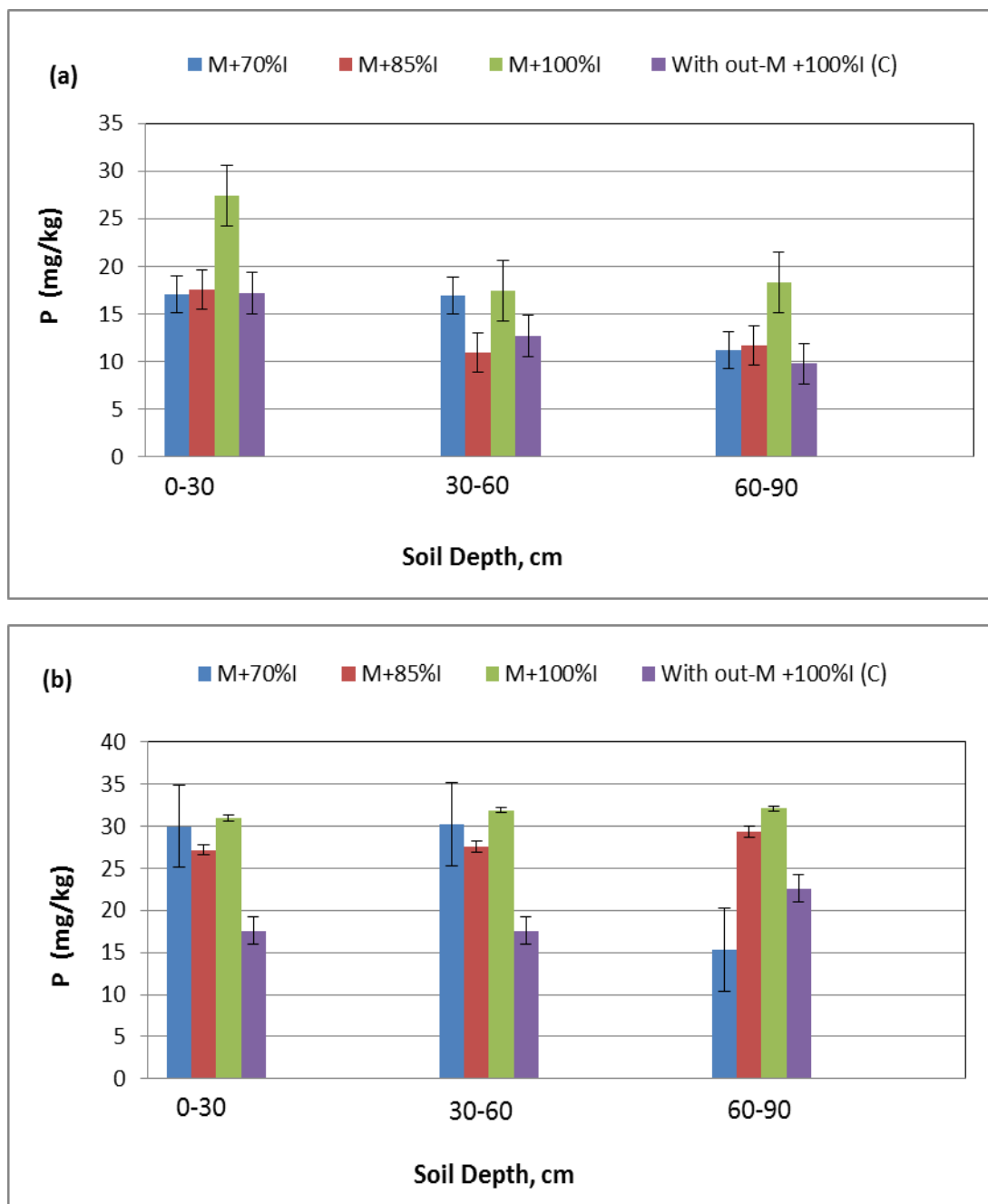
The data in (Fig.2) indicated that available potassium concentrated in surface layers. While, the medial layers had lowest concentration of potassium. Results showed that soil K significantly affected by mulching process ( $p \leq 0.05$ ). Available potassium in surface layer for mulched treatment (M+100%I) was higher than unmulched treatment (With out-M+100%I) by 27.6 and 20 % compared to unmulched treatment in the beginning and end season, respectively. With respect of availability phosphorus, at soil surface

layer for mulched treatment (M+100%I), it was higher than unmulched treatment (With out-M+100%I) by 76.1 and 59.3 % compared to unmulched treatment in the beginning and end season, respectively (Fig.3). Similar results were obtained by Green lee and Rakow (1995) who mentioned that potassium and phosphorus availability under mulch treatment increased in comparison with no-mulched treatment. Tukey and Schoff, (1963) observed increasing amounts of available soil P and K under mulches. They suggested that the release of nutrients from decomposing mulches (rapidly and slowly decomposing) might have a positive effect on the soil.

Presence of mulch caused adjusting soil temperature and maintaining soil moisture that helped better phosphorus available condition in soil. Plots mulched with organic materials had significantly higher soil K concentrations than no-mulched plots (Broschat, 2007). Other possibility, the organic acids produced during the decomposition of soil organic matter complexes the metal cations Ca, Al and Fe, hereby helping in solubilization of native P and reduction in P sorption (Dahiya and Malik, 2002).



**Figure(2 ):** Response of available K (mg/kg) in soil for irrigation levels and mulch at different soil depths in(a) the beginning and (b) the end season. M=mulching, C=control, I=Recommended irrigation



**Figure(3):** Response of available P (mg/kg) in soil for irrigation levels and mulch at different soil depths in(a) the beginning season,(b) the end season . M=mulching, C=control, I=Recommended irrigation

It may be worth to mention that the concentrations of nutrient in the end season were higher than those in the beginning ones. It may be due to mineralization process for compost during the season. Cambardella et al. (2003) reported that the composting process affects the availability of nitrogen and other nutrients when the compost is applied to the field.

#### 4. Conclusion

There slightly decrease in soil pH for mulched treatments compared to unmulched treatment in all soil depths either in the beginning season or end season. The data were non-significant in the beginning season. However, The decreasing in soil pH more pronounced in surface layer compared to subsurface layers. Soil salinity was significantly affected by presence of mulch ( $p \leq 0.05$ ). Soil salinity of surface layers were lower than sub surface layers in mulched treatments for both two time samples, treatment of (M+100%I) in the end season had indicated maximum reduction in soil EC, 2.36 dS/m compared to unmulched treatment (With out-M+100%I). Total N in surface layer in mulched treatment (M+100%I) was higher than unmulched treatment (With out-M+100%I) by 31.0 and 65.9 % in the beginning and end season,

respectively. Available potassium in surface layer for mulched treatment (M+100%I) was higher than unmulched treatment (With out-M+100%I) by 27.6 and 20 % compared to unmulched treatment in the beginning and end season, respectively. In soil surface layer for mulched treatment (M+100%I), available phosphorus was higher than unmulched treatment (With out-M+100%I) by 76.1 and 59.3% compared to unmulched treatment in the beginning and end season, respectively.

Finally, under organic farming system, Soil moisture and mulch were shown to have a strong indirect influence on the amount of available soil nitrogen, phosphorus and potassium. The highest value of total nitrogen in the soil was recorded in the presence of mulch with the availability of 100 % of the recommended irrigation, where the conditions are very suitable for the mineralization N

process. With respect of available phosphorus and potassium, it has given highest values in the presence of mulch with the availability of moisture up to 70% and 85% of recommended irrigation, respectively.

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