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Comparative evaluation of various approaches to the foundation of parameters of agricultural drainage

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Abstract

The traditional and optimization approaches to substantiation ~~of~~ the parameters of agricultural drainage and the results of their comparative effectiveness are considered. The results of calculation of the defined yields of crops grown at appropriate levels of drainage efficiency show that in given conditions the optimal distance between the drains at the lowest level of the hierarchy of crop performance varied from 20 m for potatoes in peat up to 38 m for cereals on sand at the appropriate change of calculation of the drainage runoff module across the entire spectrum of efficiency from ecological drainage of 0.4 $m^2 \cdot day^{-1}$ to the economic one of 0.85 $m^2 \cdot day^{-1}$.

Key words: *agricultural drainage, approaches, evaluation, justification, parameters*

INTRODUCTION

For today massive development of reclamation associated with significant investments are very significant for the economy of any country, but the received effect is thus at best 60–70% of the project. One of the major reasons is the imperfection of existing methods of design and calculation of drainage systems [SHUMAKOV 1996; SMEDEMA *et al.* 2004; VAN DER MOLEN *et al.* 2007].

In addition, together with necessity of increase the economic efficiency of drainage reclamation, today there is an extraordinarily acute problem of validity of reclamation activities by ecological requirements [MIODUSZEWSKI *et al.* 2010; ROKOCHINSKIY 2010; VAN DER MOLEN *et al.* 2007].

That is, construction projects and reconstruction of reclamation facilities should provide immediate ameliorative effect of all aspects of its implementation. Therefore it requires new approaches and advanced methods substantiation of, especially construction and agricultural drainage parameters as defining regulatory element drainage system [ROKOCHINSKIY 2010].

Theoretical foundations of the science of soil drainage works were laid by H. Darcy, J. Dupuis, J. Boussinesq and others. Subsequently, at different stages of development of melioration science, known scientific schools were identified two basic methods of calculating the parameters of agricultural drainage: hydromechanical based on theoretical principles of the movement of water in natural and technical systems, empirical that based mainly on statistical data processing of numerous natural investigations. Each of them has its advantages and disadvantages.

Should be noted that the hydromechanical method for determining the distance between drains is the most reasonable in theory, but it does not consider economic, environmental, and some regime-technological aspects of drainage.

There are many received based on this method formulas, that do not take into account the presence of the initial pressure gradient which determines water movement [SHKINKIS 1981]. Excluding this condition error of distance between drains can range from 3% to 40%, depending on the length of the period of drying.

A major disadvantage of hydro-mechanical formulas is also ignoring the conditions of formation of the drainage flow in the phase of raising the level of groundwater that is more intense compared with the phase of recession [SHKINKIS 1981].

However, as the most grounded theoretically, this method makes it possible to carry out a qualitative analysis of hydrological factors of action drainage, hydrodynamic processes that taking place in soils. Hydromechanical formulas have also great importance in the compilation of the field studies data of drainage, in this regard, their role cannot be overemphasized.

MATERIALS AND METHODS

The most widely in practice of designing of drainage on drained lands were DBN V.2.4-1-99 formulas based on development of O.J. Oleinik and A.I. Murashko for homogeneous and layered soils under conditions of atmospheric and soil nutrition.

These formulas sufficiently take into account the structural features of material horizontal drainage and implemented:

a) in the case of shallow confining layer when $m_D \leq E/4$

$$E_i = 4\left(\sqrt{L_{fi}^{\,2} + \frac{HT}{2q_i}} - L_{fi}\right), \quad i = \overline{1, n_i} \tag{1}$$

b) in the case of deep confining layer when $m_D > E/4$

$$E_i = \frac{2\pi k_f H}{q_i\left[\ln(2E_i / \pi D_i) + f_i\right]}, \quad i = \overline{1, n_i} \tag{2}$$

where: m_D = distance from the axis drains to the confining layer, m; E = distance between drains, m; L_f = total filtration resistance of the degree and nature of disclosure reservoir, m;

$$L_f = \frac{m_D}{\pi}\left[\ln\left(\frac{2m_D}{\pi D}\right) + \frac{2h_0}{m_D}\ln\left(\frac{4h_0}{\pi m_D}\right) + \left(1 + \frac{2h_0}{m_D}\right)f\right] \tag{3}$$

$h_0 = 0.5H$, m; H = calculated pressure, m; T = water conductivity of layer, m^2·day^{-1}; q = intensity of infiltration power, m·day^{-1}; k_f = soil filtration coefficient, m·day^{-1}; D = outer diameter of drains, m; f = filtration resistance of the nature disclosure of the reservoir depending on the design of drains.

In the practice of design drainage systems also is widespread an empirical method by which the distance between drains installed according to one or more factors of affecting the intensity of drying (grain size, physical and chemical properties of the soil, the intensity of rainfall, permeability rocks, etc.). It is based on the assumption that the heavier soils are and lower their filtration properties – the smaller should be the distance between drains.

Thus PISARKOV [1955] provides correlation between distance B and depth determined in function of hygroscopic moisture capacity of soil:

$$\frac{B}{w} = 23.6 - 14 l_g W \tag{4}$$

and PISARKOV [1955] by the following formula:

$$B = N\frac{w - H_p}{\sqrt{5P}} \tag{5}$$

where: B = distance between drains, m; w = depth of drainage, m; P = the average rainfall intensity, mm; N = coefficient that depends on the granulometric composition of soil.

For the humid zone of Ukraine KUBYSHKIN [1981] recommends to determine the distance between the drains (B_p) due to their optimal values for a certain type of soil, which are adjusted experimentally, determined correction factors, namely

$$B_p = B_{on}{\cdot}K_c{\cdot}K_e{\cdot}K_n{\cdot}K_d{\cdot}K_i{\cdot}K_k \tag{6}$$

where: B_{on} = the optimum distance between drains, defined by the table depending on the genetic soil type, filtration coefficient and slope of land; K_c, K_e, K_n, K_d, K_i, K_k = correction factors that take into account the appropriate height of bias above its sole, exposure bias, pressure of groundwater depth laying drains, the degree of moisture territory, the nature of the economic use of drained area.

But, in practice, empirical method requires considerable expenses for its implementation and at the same time has a very limited scope of application, by the terms of zonal location of the object.

Therefore today is considered to be most perspective economic-mathematical method that combines the advantages of hydro and empirical methods and is based on the realization of complex prediction-optimization calculations.

At one time this method has been improved by M.O Lazarchuk and V.G. Muranov, that offered, particular, in the calculation of the optimal parameters of the drainage to consider minimizing of the criterion reduced costs of the technical decision and appropriate them to possible losses of agricultural crop harvest rejecting the water regime of drained land in the settlement of the optimal (seed) period [LAZARCHUK *et al.* 1989; ROKOCHINSKIY 2010]:

$$ZP_i + \Delta Y_i \to \min \tag{7}$$

where: ZP_i = presented unit cost; ΔY_i = expectation reduce of agricultural yield by crop rotation design-relevant and that variant.

Using this method, the distance between drains determined by formulas (1)–(3), depending on complex soil and hydrogeological conditions, the design features of the drains, the structure of the rotation, the depth of laying drains. The distance between drains determine with achievement of only maximum economic benefit from land drainage in given conditions.

However, in the transition to a market economy, this method, in the form in which it is implemented, will not allow differentially determine optimum parameters of the drainage on different productivity levels of cultures grown in compliance with the current economic and environmental requirements in the variable nature of agro-reclamation (soil, geological, climatic, agronomic, economic and environmental) conditions of real object and requires further improvement.

The essence of improving of the optimization method is to develop complex model of optimization of parameters of drainage, which, unlike existing economic and mathematical method takes into account both economic and environmental aspects of drainage and allows determination of economically viable and environmentally acceptable design solutions (PR) [FROLENKOVA *et al.* 2007]:

$$\begin{cases} ZP_0 = \min\limits_{\{i\}} \sum\limits_{n=1}^{n_p} ZP_{ip} \cdot \alpha_p, i = \overline{1, n_i} \\ q_0 = \min\limits_{\{i\}} \sum\limits_{n=1}^{n_p} | q_s - q_{ekol} | \alpha_p, i = \overline{1, n_i} \end{cases} \quad (8)$$

where: ZP_0 = the optimal value of the criterion by the i-th set of option PR $\{i\}$, $i = \overline{1,n_i}$, $m^2 \cdot day^{-1}$; α_p = known (defined or set) the value of shares or recurrence of typical meteorological condition possible modes of settlement during the growing season together $\{p\}$, $p = \overline{1,n_p}$, within the project lifetime of the object, $\sum\limits_{p=1}^{n_p} \alpha_p = 1$; q_0 = optimal design value module by drainage runoff and PR-order option, $m^2 \cdot day^{-1}$; q_s = weighted average of drainage runoff module within the system and project lifetime of the facility and by i-order option of PR, $m^2 \cdot day^{-1}$; $\hat{q}_{ekol}$ = limit value of the module of drainage runoff, corresponding ecological level of efficiency of the drainage in the studied conditions, $m^2 \cdot day^{-1}$; i = set of the PR options $\{i\}$, $i = \overline{1,n_i}$, on the type, design parameters and the drainage.

As the economic criteria and optimization of parameters of the drainage conditions in the model (8) accepted minimization of reduced costs totality ZP_i with due regard to weather and climate risk R_i at a deviation of water regime of drained land in the optimal settlement in the spring (seeds) and vegetative periods of the drainage for the implementation of the relevant options of PR totality $\{i\}$, $i = \overline{1,n_i}$

$$ZP_i + R_i \rightarrow \min, i = \overline{1, n_i} \quad (9)$$

For the general economic optimization criterion are accepted presented costs Z, reduced to comparative view ZP by the volume (value) V of received products by the relevant options draft decision $\{i\}$, $i = \overline{1,n_i}$

$$ZP_i = \frac{C_i^{cg} + C_i^{m} + A_i + E_n K_i + R_i}{V_i}, i = \overline{1, n_i} \quad (10)$$

where: C_i^{cg} = agricultural inputs in growing crops for the i-th version of PR, USD·ha^{-1}; C_i^m = and reclamation costs or operating costs by i-th version of PR, USD·ha^{-1}; A_i = depreciation expense by i-th version of PR, USD·ha^{-1}; E_n = regulatory factor economic efficiency of capital investments in the arrangement of the drainage, E_n = 0.015; K_i = capital investments in the construction by i-th version of PR, USD·ha^{-1}.

Weather and climatic risk is defined as the difference between the value of gross output of the actual yield obtained by i-th version of PR, and the value of gross output by the potential yield on the object

$$R_i = \sqrt{(V_i - \hat{V}_i)^2}, i = \overline{1, n_i} \quad (11)$$

where: V_i = the value of gross output the actual yield, received by i-th version of PR, USD·ha^{-1}; $\hat{V}_i$ = the value of gross output for the potential yield on the object, USD·ha^{-1}.

The distances between the drains by a given method also determined with the formulas (1)–(3).

Optimality criterion for environmental PR for the construction and the drainage parameters in complex optimization model (8) is the deviation of the average value of the module of drainage flow within the system for calculated years and designed lifetime of the object q_s from the limit value of the module of drainage flow $\hat{q}_{ekol}$, which corresponds to the level of environmental efficiency of the drainage.

Thus the implementation of complex optimization model (1) allows determining the relevant criteria of economically viable and environmentally acceptable PR for the construction and parameters of the drainage of drained land of the real object.

Principles and implementation of integrated optimization model based on interconnected structurally, technological forecasting, simulation and optimization models for the substantiation of blocks of optimum construction and parameters of drainage, their impact on the yield cultivated crops and created economic and environmental effects [FROLENKOVA *et al.* 2007; ROKOCHINSKIY *et al.* 2013].

RESULTS AND DISCUSSION

Comparative characteristics of and application of traditional optimization approaches to the substantiation of agricultural the drainage parameters to comply with the current requirements in its calculations presented in Table 1.

Example of the application of traditional and optimization approaches to substantiation of agricultural

Table 1. Comparative characteristics of traditional and optimization approaches to substantiation of parameters of the drainage

Specification	Methods for calculating the parameters of the drainage			
	the empirical method	DBN V.2.4-1-99	economic and mathematical method	an integrated optimization method
1. Integration of multiple variables natural and agro-reclamation facility conditions	–	–	partially	+
2. Definition and verification of the module of drainage flow rate: – for economic demands – for ecological requirements	 – –	 – –	 + –	 + +
3. Rationale by the drainage parameters of: – for economic demands – for ecological requirements	 – –	 – –	 + –	 + +
4. Consideration of design features on the drainage, type, material by production, different diameter pipes, filters the drainage design, the design scheme of the drainage	–	–	+	+
5. Justification of design variables and determine crop yield losses of (weather and climatic risk)	–	–	+/–	+
6. Comparison of options *PR* volume and quality of the products	–	–	–	+
7. Differential determine the optimal parameters of the drainage on various productivity levels produced crops	–	–	–	+
8. Determination of parameters the drainage system relative levels of hierarchy (culture, soil, soil reclamation difference and the whole system)	–	–	–	+
9. Assess the effectiveness of the drainage of the defined parameters in the given conditions	–	–	–	+
10. The investment project evaluation reconstruction of the drainage areas	–	–	–	+

Source: own elaboration.

Table 2. Comparative evaluation of the effectiveness of traditional and economic-mathematical methods for determining the parameters of the drainage

Soil	The distance between drains (m) acc. to		
	the empirical method	DBN V.2.4-1-99	economic and mathematical method
Sod-medium podsolic meadow gley sandy	24.0	30.0	28.0
Sod meadow gley loamy	22.0	28.0	26.0
Peatlands powerful medium to medium spread	18.0	22.0	20.0

Source: own study.

the drainage parameters of we considered on lands farm "Svitanok" in Rokytne district of Rivne region.

Research area is the total area of 410 hectares. Soils in the area are sod-medium podsolic meadow gley on sandy with a coefficient of filtration- $k_f = 1.2$ m·day^{-1} and equity share ($f_{gm} = 0.1$), sod-sandy ($k_f = 1.0$ m·day^{-1}, $f_{gm} = 0.3$) peat medium and powerful medium unfolded ($k_f = 0.4$ m·day^{-1}, $f_{gm} = 0.6$). The area reconstruction plastic embedded with a round perforated drainage and sand and gravel filling diameter of 63 mm. Crop rotation on the array represented by the following crops – oats yield is 3.6 t·ha^{-1} and equity share ($f_k = 0.12$), perennial grasses for hay 4.2 t·ha^{-1} ($f_k = 0.25$), winter wheat 3.0 t·ha^{-1} ($f_k = 0.12$), corn for silage 32.0 t·ha^{-1} ($f_k = 0.13$) and potatoes 21.0 t·ha^{-1} ($f_k = 0.13$).

The calculations were obtained following distance between drains to the terms of this facility are systematized in Table 2.

Summary results of optimization calculations on hierarchical levels of culture – soil – soil melioration difference – the system for the object being studied by complex optimization method presented in Table 3.

The table presents a comparative estimation of three methods for calculating distances between drains for three different soils.

CONCLUSIONS

The results of calculation of the defined yields of cultures cultivated on appropriate levels of efficiency the drainage show that in given conditions the optimal distance between the drains at the lowest level of the hierarchy of performance culture – the way of change 20 m for potatoes in peat up to 38 m for grain on sand at the appropriate change calculation of the module of drainage runoff by the entire spectrum efficiency levels of ecological the drainage $q_{ekol} = 0.4$ m^2·day^{-1} to the economic $q_{ekon} = 0.85$ m^2·day^{-1}.

Thus, a comparative evaluation of different approaches to the substantiation of agricultural the drainage parameters of by the technique and the results strongly suggest that an integrated optimization method determines to be reasonable under the terms of the distance between multiple drains that further enhances the validity of design decisions in the construction and reconstruction of drainage systems.

Table 3. Summarized results of the calculation parameters of by complex the drainage optimization method in variable nature of agro-reclamation conditions studied object

Type of soil g_m	Culture k	At the level of culture $v = 1$		At ground level $v = 2$		At the level of soil melioration difference $v = 3$		At the system level $v = 4$	
		q_0	B_0	q_0	B_0	q_0	B_0	q_0	B_0
Sod-medium podsolic meadow gley sandy	oats	0.4	38.00						
	winter wheat	0.5	32.00						
	perennial herbs	0.6	30.00						
	corn for silage	0.5	32.00						
	potatoes	0.85	26.00	0.85	26.00	0.85	26.00		
Sod meadow gley loamy	oats	0.45	35.00						
	winter wheat	0.55	30.00						
	perennial herbs	0.5	28.00						
	corn for silage	0.5	28.00						
	potatoes	0.8	24.00	0.8	24.00	0.8	24.00		
Peatlands powerful medium to medium spread	oats	0.4	30.00						
	winter wheat	0.45	26.00						
	perennial herbs	0.55	22.00						
	corn for silage	0.5	24.00						
	potatoes	0.6	20.00	0.6	20.00	0.6	20.00	0.6	20.00

Explanations: in this case, the terms of the object studied the results of optimization calculations for hierarchical levels soil-soil reclamation differences coincide; q_0 = drainage module flow, B_0 = distance between drains.
Source: own study.

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Porównawcza ocena różnych podejść do ustanawiania parametrów drenażu rolniczego

STRESZCZENIE

Analizowano tradycyjne i optymalizacyjne sposoby ustalania parametrów systemu drenarskiego na obszarach rolniczych oraz oceniono ich względną skuteczność. Rozpatrywano wielkość plonu wybranych upraw rosnących na terenach z różnymi rozstawami drenów. Oceniono, że w danych warunkach glebowych optymalny rozstaw drenów na najniższym poziomie wydajności zmieniał się od 20 m dla ziemniaków uprawianych na torfie do 38 m dla zbóż uprawianych na piaskach. Moduł odpływu z sieci drenażowej wahał się od wydajności ekologicznej 0,4 $m^2 \cdot dzień^{-1}$ do ekonomicznej 0,85 $m^2 \cdot dzień^{-1}$.

Słowa kluczowe: *drenowanie rolnicze, optymalizacja drenowania, parametry systemu drenarskiego*