OBSERVAÇÕES DE CAMPO DA ÁREA DE IRRIGAÇÃO DE BAIXA PRESSÃO, IRRIGADA PARA FERTILIZAÇÃO COM CAMA DE FRANGO

FIELD SURVEY OF LOW-HEAD IRRIGATION AREA WITH FERTILIZING POULTRY LITTER APPLICATIONS

НАТУРНЫЕ ИССЛЕДОВАНИЯ НИЗКОНАПОРНОГО УЧАСТКА ОРОШЕНИЯ С УДОБРИТЕЛЬНЫМИ ПОЛИВАМИ ПТИЧЬИМ ПОМЕТОМ

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RESUMO

Este estudo visa resolver problemas associados ao desenvolvimento de uma rede local de irrigação de baixa pressão com um sistema tecnologicamente fundamentado de misturar excrementos de aves com água de irrigação e fornecer esta mistura para a irrigação fertilizante de culturas hortícolas em condições de solo protegido. Os resultados teóricos foram obtidos usando métodos conhecidos para o cálculo de sistemas de recuperação, usando os resultados da pesquisa de campo realizada de acordo com as recomendações do acadêmico S. I. Litvinov e a teoria do planejamento experimental de V. A. Voznesensky. Com base em materiais de estudos experimentais, foi desenvolvida uma base teórica para o cálculo de uma rede de irrigação de baixa pressão e elementos de um misturador para as condições de solo protegido, destinados à irrigação fertilizante de culturas vegetais com uma mistura de água de irrigação e cama de frango. Os resultados da pesquisa podem ser usados no cultivo de hortaliças em estufas e em áreas abertas quando uma rede local de baixa pressão e um misturador para irrigação de fertilizantes estiverem disponíveis.

Palavras-chave: *cama de frango, misturador a jato, bomba centrífuga, rede de irrigação de baixa pressão, fertilizantes minerais.*

ABSTRACT

This survey is focused on the solution of the problem related to the development of local irrigation network with a technically reasonable system of mixing poultry litter with irrigation water and of mixture transportation for fertilizer application of vegetable crops under conditions of the protected soil. Theoretical results are obtained with the help of well-known calculation methods of amelioration systems by means of materials of field survey carried out according to academician S. I. Litvinova's recommendations and V. A. Voznesenskii's theory of experimental design. Theoretical foundations of calculation of low-head irrigation network and mixer elements for the conditions of protected soil, in case of fertilizer application of vegetable crops with a mixture of irrigation water and poultry

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litter, are developed on the basis of materials of the experimental survey. The results of surveys can be employed in vegetable production in greenhouses and on the open ground with available local low-head network and a mixer for fertilizer application.

Keywords: *poultry litter, jet mixer, centrifugal pump, low-head irrigation system, mineral fertilizers.*

АННОТАЦИЯ

Данное исследование направленно на решение проблем, связанных с разработкой локальной низконапорной оросительной сети с технологически обоснованной системой смешения птичьего помёта с поливной водой и подачи смеси для удобрительных поливов овощных культур в условиях защищённого грунта. Теоретические результаты получены с помощью известных методов расчёта мелиоративных систем с использованием материалов полевых исследований выполненных согласно рекомендациям акад. С.И. Литвинова и теории планирования эксперимента В.А. Вознесенского. Разработаны теоретические основы расчёта низконапорной оросительной сети и элементов смесителя для условий защищённого грунта, при удобрительных поливах овощных культур смесью поливной воды и птичьего помёта, на основе материалов экспериментальных исследований. Результаты исследований могут быть использованы при выращивании овощных культур в теплицах и открытом грунте при наличии локальной низконапорной сети и смесителя для удобрительных поливов.

Ключевые слова: *птичий помёт, струйный смеситель, центробежный насос, низконапорная оросительная сеть, минеральные удобрения.*

INTRODUCTION

At the end of XX[th] century, the main type of fertilizers put in soil was mineral ones. Poultry litter and livestock wastewaters receded into the background. Nowadays, unfairly forgotten fertilizers are being used more frequently in agriculture (Lipkovich *et al.*, 2016; Bondarenko *et al.*, 2017; Bondarenko *et al.*, 2018; Bondarenko and Kachanova, 2016b; Krylatykh *et al.*, 2015; Lima *et al.*, 2018). Among all the kinds of organic fertilizers, poultry litter is considered to be the most nutritionally valuable, it well dissolves in water and is easily assimilated by plants.

With the view of determination of poultry litter flow rate when growing tomato in the first cycle and cucumber – in the second one (for the conditions in small farm), the real survey was carried out, with account of recommendations (Bondarenko and Kachanova, 2016a; Bondarenko, 2010; Kachanova and Bondarenko, 2014), in two beds of protected soil (575 plants of tomato and 400 plants of cucumber) with an area of 0.029 ha (Figures 1, 2).

The scheme of the equipment assembled in the research and production department of Biryuchekutskaya vegetable selection station (Novocherkassk, Rostov region) is shown in Figure 3 (Chaika *et al.*, 2012; Korolenko, 2008).

MATERIALS AND METHODS

The experimental survey and empirical data manipulation were carried out with the help of V.A. Voznesenskii's theory of experimental design (Voznesenskii, 1981).

When growing tomato in the first cycle and cucumber in the second cycle, mixer-inlet head from the side of the induced poultry litter flow rate H_0, mixer-inlet head from the side of centrifugal pump H_1, and mixer-outlet head in head pipeline H_2 are considered as factors (Petrov *et al.*, 2018; Gladilin *et al.*, 2004; Gladilin *et al.*, 2013).

The induced by mixer litter flow rate at the mixer inlet Q_1 is considered as a criterion. During the survey, two groups of experiments were carried out: the first group is aimed to determine the degree of impact of every factor H_0, H_1, H_2 on the flow rate Q_1 and the second one is aimed to determine the relationship between Q_1 and the most influential factors. Manometers H_0, H_1, H_2 record pressure head in pipelines 2, 10, 15, 18. Piezometer 20 records mixture level in low-head tank 21. The litter flow rate Q_1 and total flow rate Q_2 (litter-and-water mixture) were defined with the volumetric method. In terms of measured quantities, the following was calculated:

– the induced by mixer flow rate (Equitation 1).

The experiments were carried out in the

following sequence. Tank 11 is filled with 6-days fermented poultry litter diluted with water one-to-one. Gate valves 4, 19 open, centrifugal pump 1 turns on, the gate valve 12 open. The mixture of water and poultry litter goes through the head pipeline to low-head tank 21, and then through distribution pipeline 15 – to irrigation area. The following is calculated:

– the mixing ratio (Equitation 2)

– operating flow rate of centrifugal pump (Equitation 3)

The first group of experiments was carried out for the preliminary estimation of factor impact on the induced flow rate. Coding and variables variation are shown in Table 1, the planning matrix and results are shown in Table 2.

RESULTS AND DISCUSSION:

As a result of the received data manipulation, such an empirical equation was derived: $Q_1 = f(H_0, H_1, H_2)$ (Equitation 4), where $b_0 = \frac{\sum_{i=1}^{n} Q_1}{N}$ – constant term; N – number of experiments.

The regression coefficient is calculated using the formula:

$$b_i = \frac{\sum_{i=1}^{N} x_{in} \cdot Q_{in}}{N} \quad (5)$$

where: x_{in} – number of an experiment; Q_{in} – criterion of an experiment

The substitution of calculated values b_0 and b_i in equation 4 leads to Equation (6). The impact of every factor on litter flow rate Q_1 within the studied variation interval is estimated with the sign and absolute double regression coefficient of the studied factor (Troeh and Thompson, 2005). In accordance with the received equation, a ranked curve, which characterizes the degree of impact of every factor on flow rate Q_1, was built (Figure 4).

The rank curve shows that pump head H_1 makes the most impact on flow rate Q_1 in the studied field – up to 36%, and mixer-inlet head H_0 makes the least impact – up to 6%.

In the face of the aforementioned and the analysis of the first group of experiments, the second group of experiments was carried out for the further search of optimal factor values, which impact litter flow rate Q_1, pump head $H_1(x_2)$ and mixer-inlet head $H_2(x_3)$ with different variation intervals (Table 3). Planning matrix and rthe esults of the second group of experiments are shown in Table 4.

The results manipulation of the second group of experiments enabled to receive such an equation $Q_1 = f(X_2, X_3)$ that in total is Equitation (7)

Experimental error $S_э^2$ and standard deviation were calculated with the formula (Equitation 8), where: $Q_{1,0}$ – the average value of the induced flow rate in central experiments; $Q_{1,i}$ – the induced flow rate in *i* experiment.

Coefficients of equation 6 are statistically significant in that case, when $b_i \geq b_{kp} = t_\alpha \cdot S(b_i)$, where b_i – coefficient of *i* factor, b_{kp} – critical coefficient. t_α = 3.182 – Student’s t-test at significance level 5%. $S\{в_i\} = t_\alpha S_э$ – error of coefficient estimate is acceptable for b_0, b_i, b_{ii}, b_{ij}, consequently – 0,4787; 0,2357; 0,6212; 0,2500.

In order to have the equation with statistically significant coefficients, their values were determined according to the relation: $b_i \geq b_{kp}$. (Volkova, 2014).

The value of critical coefficients and equation form with an account of statistical significance are shown in Table 5 (Degtiareva, 2013). Equation 9 is canonized by methods of linear algebra (Golovina, 1985) Equitation (9) on the basis of which contours of equal induced flow rates are built depending on pump head H_1 and mixer head H_2 (Figure 5).

With the received experimental relations, there is a possibility to determine the value of litter flow rate in areas of mixer heads, almost from 0 up to 7 m, and of operating pump head from 5 up to 30 m at stable (almost without impact on flow rate Q_1) mixer-inlet head H_0 (X_1).

At any acceptable nitrogen content in litter flow rate (Q_1), for instance, 0.4%, it is possible to identify by curves (Figure 5) the number of input nitrogen, and other nutrients (phosphorus or potassium), which impact the planned yield, the number of bedding plants and the corresponding area. Based on the carried out calculation, Table 6 was compiled (Alley and Vanlauwe, 2009; LeBlanc *et al.*, 2005). It enables to determine within head values, which are used currently by small farmers, the amount of necessary poultry litter, regardless of its nutrition content, estimated and planned yield, the area of bedding of tomato, cucumber or any other crops.

Thus, within the studied variation intervals and possible heads, H_1 up to 30 m and H_2 up to 7 m, there is a possibility to grow 5600 plants of tomato and cucumber with simultaneous fertilizer application. In case of step irrigation schedule, the bedding of either tomato or cucumber on the bigger area is possible.

CONCLUSIONS:

Based on the empirical surveys, for calculated amounts of nutrients, which are necessary for crop growing and are eligible for the conditions of small farms, there is estimated the possibility of setting up heads of poultry litter in mixer-inlet H_0 (up to 0.9 m), centrifugal pump H_1 (up to 30 m) and mixer H_2 (up to 7 m).

In addition to this, the estimated maximum of simultaneously fertilized plants amounts to 5600 with fertilizer application 5 kg/h/plant. Similarly, the calculation for another necessary number of growing crops within 5600 units is carried out. In case of step irrigation schedule, fertilizer applications, which are determined by application time and standard of nutrients supply, may be carried out for a significantly bigger number of bedding plants.

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$Q_1 = Q_2 - Q_0$ (Eq. 1)

$\alpha_0 = \frac{Q_2}{Q_0} - 1$ (Eq. 2)

$Q_0 = \frac{Q_1}{\alpha_0}$ (Eq. 3)

$Q_1 = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3$ (Eq. 4)

$b_i = \frac{\sum_{i=1}^{N} x_{in} \cdot Q_{in}}{N}$ (Eq. 5)

$Q_1 = 0{,}8 + 0{,}048 x_1 + 0{,}28 x_2 + 0{,}18 x_3$ (Eq. 6)

$Q_1 = 3{,}69 + 0{,}3 X_2 - 0{,}37 X_3 - 0{,}41 X_2^2 + 0{,}20 X_3^2$ (Eq. 7)

$S_{\text{Э}}^2 = \sum_{i=4}^{4} (\bar{Q}_{1,0} - \bar{Q}_{1i})^2$ (Eq. 8)

$Q_1 - 3{,}57 = -0{,}41 X_2^2 + 0{,}2 X_3^2$ (Eq. 9)

Figure 1. *Spring multi-span greenhouse before the tomato harvest in the first cycle (the 2nd decade of June)*

Figure 2. *Spring multi-span greenhouse during the cucumber harvest in the second cycle (2nd-3rd decades of September)*

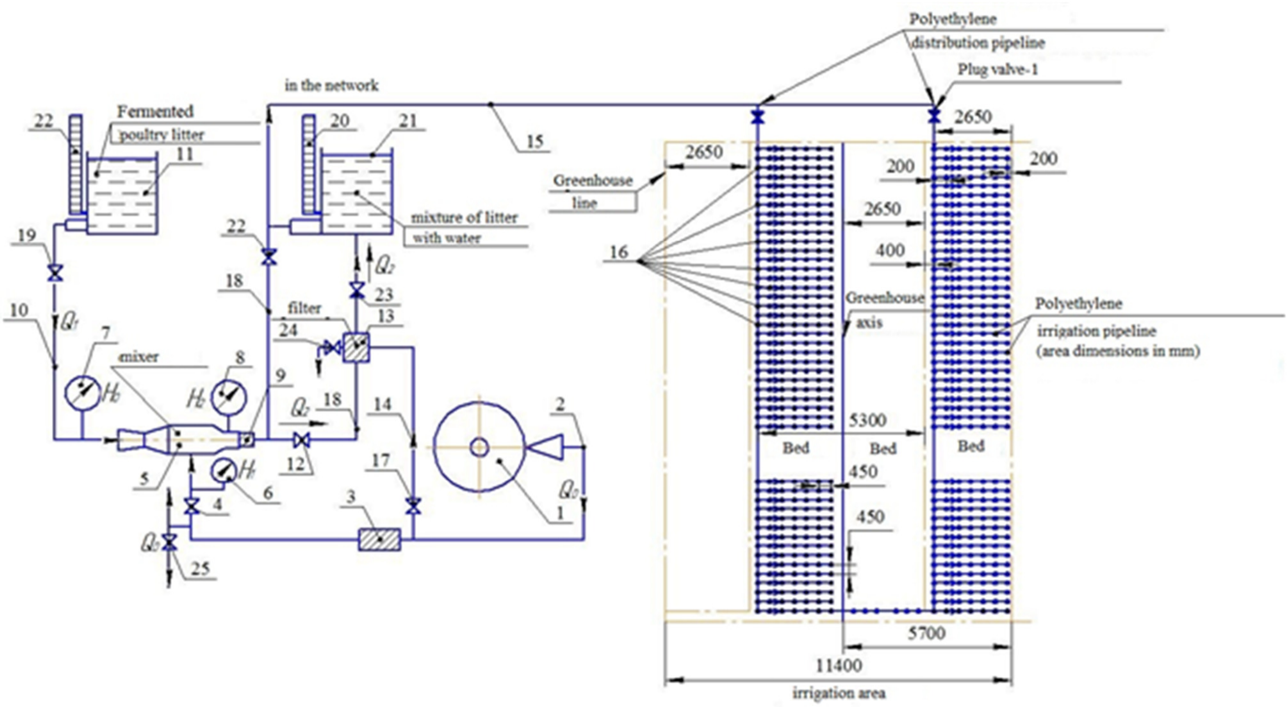

Figure 3. *The scheme of local low-head irrigation network with fertilizer equipment: 1 – centrifugal pump; 2 – head pipeline for water supply to mixer; 3,9 – flow meters; 4,12,17,19,22,23,24,25 – gate valves; 5 – mixer; 6,7,8 – manometers; 10 – pipeline for poultry litter supply to mixer; 11 – poultry wastewater tank; 13 – filter; 14 – filter washing line; 15 – main pipeline; 16 – irrigation pipeline; 18 – pipeline for mixture supply to low-head tank; 20,22 – piezometers; 21 – low-head tank.*

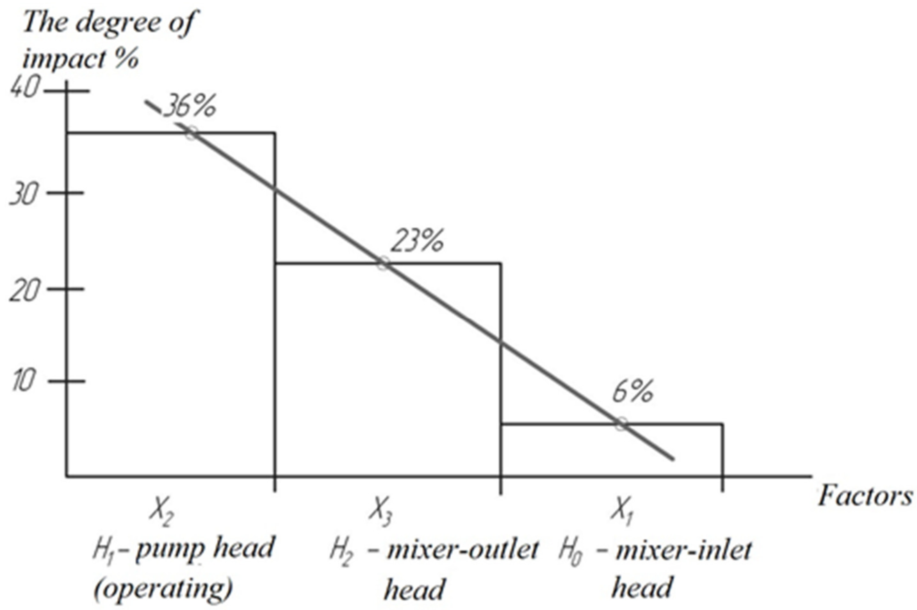

Figure 4. *The relation between the degree of impact of every studied factor on the induced flow rate Q_1*

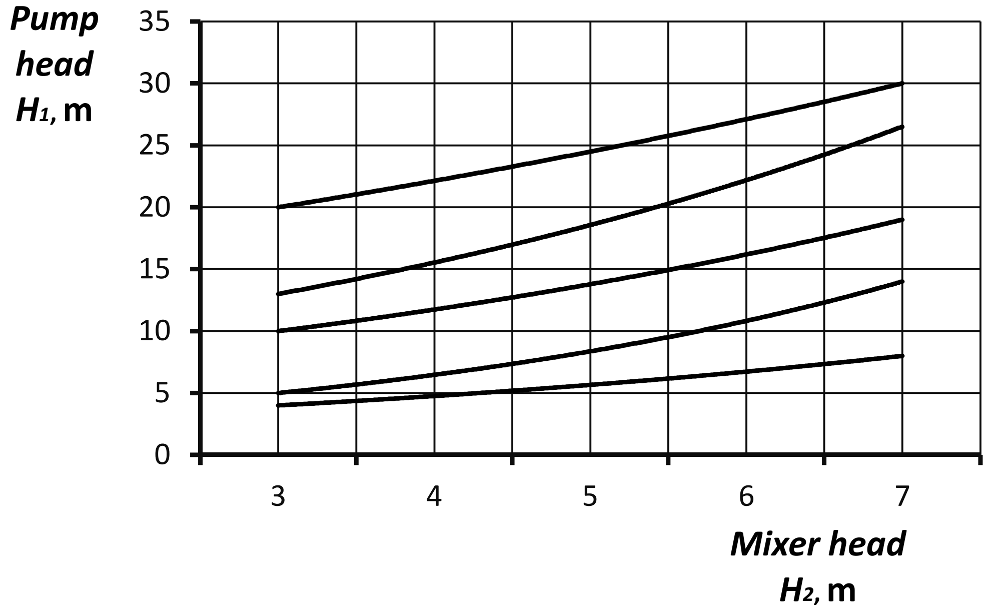

Figure 5. *Centrifugal pump head H_1 and mixer head H_2 vs litter flow rate Q_1 – curve*

Table 1. *Coding and variables variation in the first group of experiments.*

Factors	Code	Basic level, m	Interval, m	Lower level, m	Upper level, m
Mixer-inlet head from the side of the inducing mixer nipple, m (H_0)	X_1	0.7	0.2	0.5	0.9
Mixer-inlet head from the side of centrifugal submersible pump, m (H_1)	X_2	20	5	15	25
mixer-outlet head in head pipeline, m (H_2)	X_3	2.0	0.5	1.5	2.5

Table 2. *Planning matrix and results of the first group of experiments.*

No. of experiment	Mixer-inlet head X_1/H_0 *(code)*	Operating pump head X_2/H_1 *(code)*	Mixer head X_3/H_2 *(code)*	Actual values of factors, m			The induced by mixer litter flow rate Q_1, kg/s
				H_1,m H_0, m	H_1, m	H_2, m	
1	+	+	0	0.9	25	2.0	2.8
2	+	-	0	0.9	15	2.0	1.4
3	-	+	0	0.5	25	2.0	2.6
4	-	-	0	0.5	15	2.0	2.0
5	+	0	+	0.9	20	2.5	1.4
6	+	0	-	0.9	20	2.5	2.3
7	-	0	+	0.5	20	2.5	1.3
8	-	0	-	0.5	20	1.5	1.6
9	0	+	+	0.7	25	2.5	3.0
10	0	+	-	0.7	25	1.5	4.1
11	0	-	+	0.7	15	2.5	1.0
12	0	-	-	0.7	15	1.5	1.7
13	0	0	0	0.7	20	2.0	2.2
14	0	0	0	0.7	20	2.0	2.2

Table 3. *Coding and variables variation in the second group of experiments (two-way layout)*

Factors	Code	Basic level	Interval, m	Lower level, m	Upper level, m
Pump head, $H_1(X_2)$	X_2	25.0	5.0	20	30
Mixer head, $H_2(X_3)$	X_3	5.0	2.0	3.0	0.7

Table 4. *Planning matrix and results of the second group of experiments*

No. of experiment	Operating pump head, m $H_1(X_2)$	Mixer head, m $H_2(X_3)$	Actual values of factors, m		The induced by mixer flow rate Q_1 kg/s
			H_1	H_2	
1	+	+	30	7.0	3.25
2	-	-	20	3.0	2.85
3	+	-	30	3.0	5.00
4	-	+	20	7.0	3.00
5	0	+	25	7.0	3.80
6	0	-	25	3.0	3.85
7	0	0	25	5.0	3.90
8	0	0	25	5.0	3.92

Table 5. *Values of critical coefficients and equation form with account of statistical significance*

Critical coefficients				Equation in total	Equation with account of statistical significance
b_0	b_i	b_{ii}	b_{ij}		
0,52	0,15	0,20	0,24	$Q_1 = 3,69 + 0,3X_2 + 0,37X_3 - 0,41X_2^2 + 0,20X_3^2 - 0,16X_2X_3$ (8)	$Q_1 = 3,69 + 0,3X_2 - 0,37X_3 - 0,41X_2^2 + 0,20X_3^2$ (9)

Table 6. *Relation of litter flow rate and head values H_1 and H_2*

Mixer-inlet litter flow rate Q_1, kg/s	Centrifugal pump head H_1, m		Mixer head H_2, m		Acceptable pump flow rate Q_0 t/h (accepted within characteristics)	Total mixer-outlet flow rate $Q_2=Q_1+Q_0$ (t/h)	The possibility of simultaneous irrigation of bedding plants based on application of $5\frac{kg}{h}$/plant	Nitrogen flow rate t/h at content of 0,4% in flow rate Q_1
	min	max	min	max				
3.6	4.0	8.0	3.0	7.0	10.0	13.6	2720	1.44
7.2	5.0	14.0	3.0	7.0	10.0	17.2	3440	2.88
10.8	10.0	19.0	3.0	6.1	10.0	20.8	4160	4.32
14.4	13.0	22.0	3.0	6.0	10.0	24.4	4880	5.76
18.0	20.0	30.0	3.0	4.5	10.0	28.0	5600	7.2