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TÍTULO: El aumento de los indicadores cualitativos durante el riego con múltiples aspersores de soporte.

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RESUMEN: Se desarrollaron dispositivos avanzados para el riego de superficie (DSW) para los rociadores de la granja, que permiten aumentar el ancho del área de riego, reducir la intensidad promedio de la lluvia y ajustar la altura de un rociador sobre la superficie del suelo a medida que crecen las plantas agrícolas. Desarrollaron una boquilla de aspersión con el deflector de "cono inverso", que forma una pequeña gota de lluvia. El uso de DSW y rociadores desarrollados en el rociador "Kuban-LK" reduce el impacto energético de la lluvia en el suelo, mejora la uniformidad del riego en el viento, reduce las pérdidas de agua debido a la evaporación y demolición, y aumenta la tasa de riego a la escorrentía.

PALABRAS CLAVES: rociadores, intensidad de lluvia, tamaño de gota, riego cerca de la superficie.

TITLE: The increase of qualitative indicators during watering with Multiple Support Sprinklers.

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ABSTRACT: Advanced devices for surface watering (DSW) were developed for the farm sprinklers which allow to increase the width of watering area, to reduce an average rain intensity, and adjust a sprinkler height above the soil surface as the agricultural plants grow. They developed a sprinkler nozzle with the "reverse cone" deflector, which forms a small-drop rain. The use of developed DSW and sprinklers on "Kuban-LK" sprinkler reduces the energy impact of rain on soil, improves the uniformity of watering in the wind, reduces water losses due to evaporation and demolition, and increases the irrigation rate to runoff.

KEY WORDS: sprinkler, rain intensity, droplet size, near-surface watering.

INTRODUCTION.

The stability of agricultural production and the growth of crop yields in Russian arid zones is largely determined by the level of irrigation development. At present, the most perfect are the multipurpose domestic sprinklers of the circular action "Kuban-LK", "Cascade", "NEVA", "ORSIS", "Kazanka" types and "T-L", "Bauer", "Valley" foreign types, etc.

The sprinklers of circular action, on which short-jet sprinkler nozzles are used, characterized by significant increases of water consumption by sprinklers at the end of a pipeline and rain intensity (up to 1.2 mm/min and more), which leads to watering rate reduction up to the drain and does not allow to provide optimal irrigation rates without runoff. This causes the redistribution of rain in the lowered areas of the field and infiltration losses. The rain of great power compacts and destroys the soil top layer considerably. All this causes the variegation and shortage of crops.

The sprinkling units use pressure regulators mainly, which provide a small pressure before sprinkler nozzles - about 0.1 MPa, which leads to the development of a rain cloud with large drops.

Numerous studies of Russian scientists -Shwebs (1974), Abdrazakov (2005), Abramov (1987) and the studies of foreign scientists – Hudson (1974), King and Bjorneberg (2010) and others have shown that water absorption into the soil during irrigation by sprinkling should be considered as the process that varies in time, which is determined by irrigation technology, soil and relief conditions, cultivation technology, an agricultural crop type, etc.

The main factors are the type and the mechanical composition of soil, the soil moisture before irrigation, the soil density, the type of crop, and the technological and energy characteristics of rain.

The equations for the irrigation norm calculation to runoff are taken into account first of all: the mean rainfall and an average droplet diameter (Yerkhov, 1966); an average and an instantaneous rain intensity and an average diameter of drops; the force of impact drops; rain power (Abramov, 1987); the kinetic energy of drops and rain intensity (Hudson, 1974, King and Bjorneberg, 2010, etc.). The conducted analysis shows that the equations during the calculations of the irrigation norm to drain take into account only the main factors, and the influence of additional factors is not taken into account sufficiently. Therefore, the studies of irrigation quality and irrigation rate improvement to the drain of multi-support sprinklers are relevant.

DEVELOPMENT.

Study methodology

In order to justify the improvement of sprinklers to improve the quality of irrigation, we conducted the analysis of experimental and theoretical studies on irrigation rate increase to runoff.

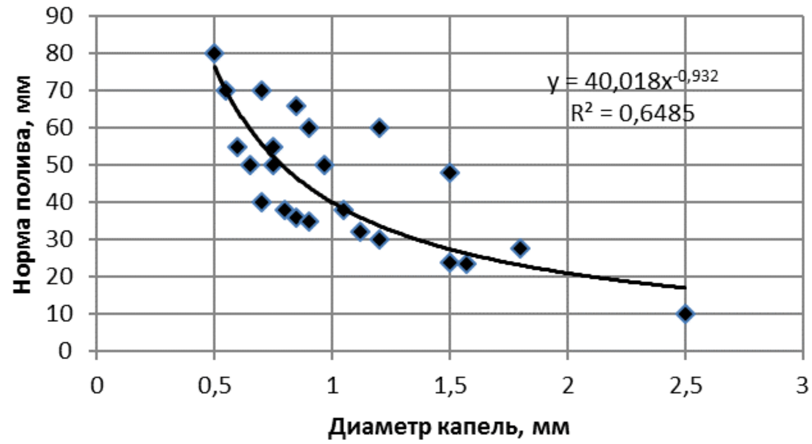
One of the main factors affecting the rate of irrigation to drainage is the irrigation technology, which is determined by sprinkler type - long-jet, medium-jet or short-jet one, by irrigation type - in motion or positional, by the way of irrigation water supply - in one or several passes, etc. The main characteristics of irrigation technological process is an average and an instantaneous rain intensity, an average diameter of rain drops and the rate of their fall, the rain power, the rain layer per one pass of a device or a machine, the coefficient of uniform irrigation water supply during irrigation, an intermittent rain, etc. (Table 1).

Tabl. (1). Irrigation characteristics of different types of sprinklers

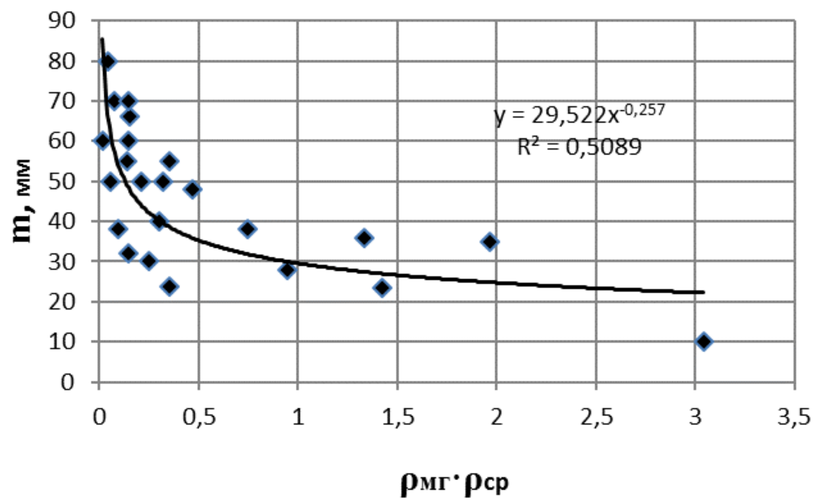
Sprinkling device	Water consumption, l/s	ρ_c, mm/min	$\rho_м$, mm/min	$d_к$, mm	h, mm	$V_п$, m/s	K_H	m, mm
DKSH-64	1,0	0,275	1,7	1,5	0,14	6,0	1,0	52,5
Dnieper	3,5	0,32	2,95	1,8	1,0	8,0	1,0	27,8
Frigate No. 1	0,14	0,10	1,52	0,85	0,145	3,5	1,7	65,0
Frigate No. 4	3,8	0,59	2,54	1,57	0,245	6,8	3,0	23,5
DDA-100	100	0,10	3,5	1,5	4,0	6,0	3,0	23,8
DDN-70	70	0,36	8,45	2,5	1,64	9,0	1,0	10,0
ADP-350	0,7	0,50	0,70	0,75	1,0	3,2	1,0	65,0

Note ρ_c, $\rho_м$– an average and an instantaneous rain intensity, mm/min; $d_к$– an average droplet diameter, mm; h– a layer of rain per pass of a sprinkler mm; $V_п$ – the speed of rain drop fall; K_H – the coefficient of uneven irrigation water supply during irrigation; m – the irrigation rate to runoff.

The processing of experimental data (Figure 1) showed that the highest correlation coefficient and the closest relationship is observed between the irrigation norm to the runoff and instantaneous rain intensity (r = -0.606); an average diameter of rain drops (r = -0.741); the product of mean and an instantaneous rain intensity (r = -0.662); the speed of rain drop falling (r = - 0.757); a single layer of rain per sprinkler pass (r = -0.327); an average rain intensity (r = -0.418).



a) Норма полива – watering standard / Диаметр капель, мм – Drop diameter, mm



б)

Fig. (1). Irrigation rate change to runoff from sprinkle drop size (a) and from the product of average and instantaneous nozzle intensity on sprinkling units (b)

The equation for the calculation of watering rates to runoff is determined by mathematical processing of field research data:

$$m = \frac{31{,}5 \cdot K_1 \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5 \cdot K_6}{\rho_{cp}^{0{,}24} \cdot \rho_{\text{мг}}^{0{,}24} \cdot d^{0{,}3} \cdot h^{0{,}085} \cdot K_{\text{н}}^{0{,}2}} \qquad (1)$$

Where ρ_c, $\rho_м$ – an average and an instantaneous rain intensity, mm / min;

$d_к$ – an average diameter of drops, mm;

h – rain layer from a sprinkling unit pass, mm;

$K_Н$ – the coefficient of irrigation water supply non-uniformity during irrigation period.

K_1 = 1+ 0,0147 (70-W) – the coefficient taking into account the soil moisture before sprinkling, W - soil moisture percentage of the lowest moisture capacity, %;

K_2 = 1-15,11·i – the coefficient that takes into account a field surface slope.

I – the slope of field surface (i =0…0,1);

K_3=e $^{п(ao- a)}$– the coefficient that takes into account the soil density (a) before watering (Abramov, 1987); a_o – the initial soil density before sowing; n = 1,42…2,95.

K_4 – the coefficient, that takes into account the presence of soil crust (in the absence of the crust K_4 = 1, in the presence of the crust K_4 = 0.57);

K_5 – the coefficient that takes into account the field soil fertility, the degree of an irrigation plot coverage by plants (Abramov, 1987). Coefficient K_5 varies with the growth of plants: for cabbage - from 1 to 1.4; for soybeans - from 1 to 1.7; for corn - up to 1,9.

K_6 – the coefficient, which takes into account the intermittence of rain, K_6 = 1,1.

The coefficient of equation (1) multiple correlation makes R^2 = 0.89, calculated by P.I. Kuznetsov's formula - R^2 = 0.68, and according to N.S. Erhov's formula (Yerkhov, 1966) - R^2 = 0.39.

On the basis of the performed analysis and obtained equation (1), it is determined that the main technological trends of irrigation rate to runoff increase are the decrease of an average and an instantaneous rain intensity, the droplet size, the drop rate and the rain power.

Taking into account the performed researches, we carried out the substantiations (Pat, 2017) and the constructive developments of the improved devices for near-surface sprinkling (DNSS) for multi-bearing sprinkling machines of farm design (Fig. 2). Several options have been developed to increase the width of the rain by:

- the replacement of sector attachments mounted on the pipeline of "Kuban-LK" sprinkler at a height of 5 m, to the sprinkler nozzles with the "reverse cone" deflector installed on the truss rods of trusses at the height of 2.7 m from the soil surface (var. 1);

- the installation of sprinkler nozzles at the height of 0.8 ... 1 m on truss rods of trusses using hoses (var. 2), fixed brackets or swivel bars (var. 3). Advanced DNSS increase the distance between the nozzles up to 2.5 m (var. 2) and up to 5 ... 6 m (var.3).

In order to determine DNSS parameters and irrigation characteristics, we took into account the following conditions. The length of a pipe or DNSS sleeve between soil and the truss rods of trusses is determined from the following condition: $\ell_т = h_ш - h_н = 3 - 1 = 2$ m.

where $h_ш$ and $h_н$ – the height from soil surface to a truss rod and a sprinkling nozzle, m.

The width of the sprinkler nozzle placement ($B_н$) perpendicular to a pipeline is the following one:

$B_н = B_ф + 2\ \ell_т$. (2)

where $B_ф$ is the truss width, m;

$\ell_т$ – the length of a rotary rod or a bracket, m.

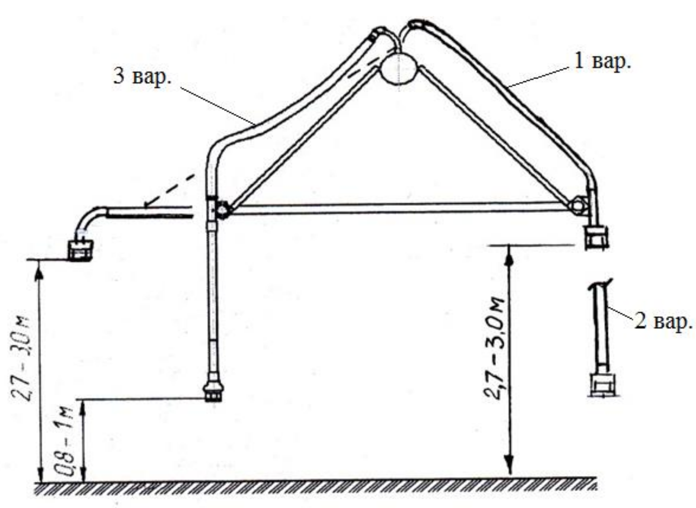


Fig. (2). The schemes of near-surface sprinkling device variants and the photos of sprinkling unit "Kuban-LK" and "T-L" prototypes

The width of the rain coverage on the i-th section of a unit pipeline is determined by the following formula:

$B_{дi} = B_{н} + 2\ R_{нi}$, (3)

Where $R_{нi}$ is the watering radius of the i – th watering nozzle, m.

An average rain intensity with the increase of attachment arrangement width on the truss span of a device is determined by the following formula:

$\rho_{c} = 60 \cdot q/a(B_{н} + 2R_{н})$, (4)

Where q – the consumption of water by sprinkling nozzle, l/s;

a - the distance between sprinkling nozzles along a pipeline, m.

When the irrigation radius of sprinkling nozzles is changed $R_{н} = 3 \ldots 7$ м, the area of rain coverage increases to: $B_{н} + 2R_{н} = 11 \ldots 20$ m, which is 1.3 ... 1.6 times greater than that of "Bauer" sprinkler and 1.4 ... 2 times more than the sector nozzle of the sprinkler "Kuban-LK". The rain intensity will be decreased by the same value.

A sprinkler nozzle with a "reverse cone" deflector (Figure 3) was developed, which consists of the body 1 with a conical deflector 2, made in the form of an inverse cone. The deflector 2 is installed on two legs 3. In order to adjust the rain nozzle to the required water flow and high-quality spraying into the housing 1, the adapter 4 with a calibrated hole 5 is inserted under some stretch.

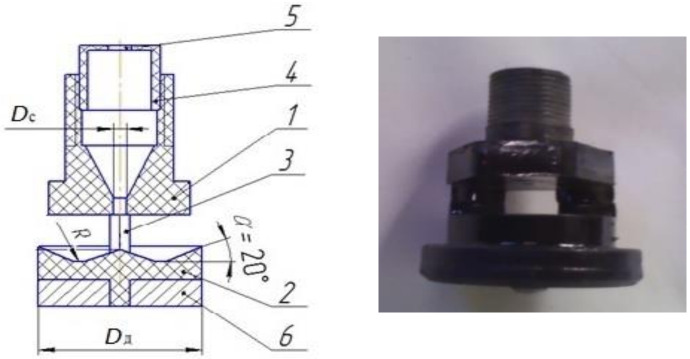


Fig. (3). Sprinkler nozzle with "reverse cone" deflector

The lower part of the body has a tapered thread, which allows the nozzle to be fitted into the clutch of a near-surface sprinkler.

Study results and discussion.

The researches of sprinkler nozzles with a conical cone found that with a nozzle diameter and pressure increase, the flow of water and the range of jet flight increase.

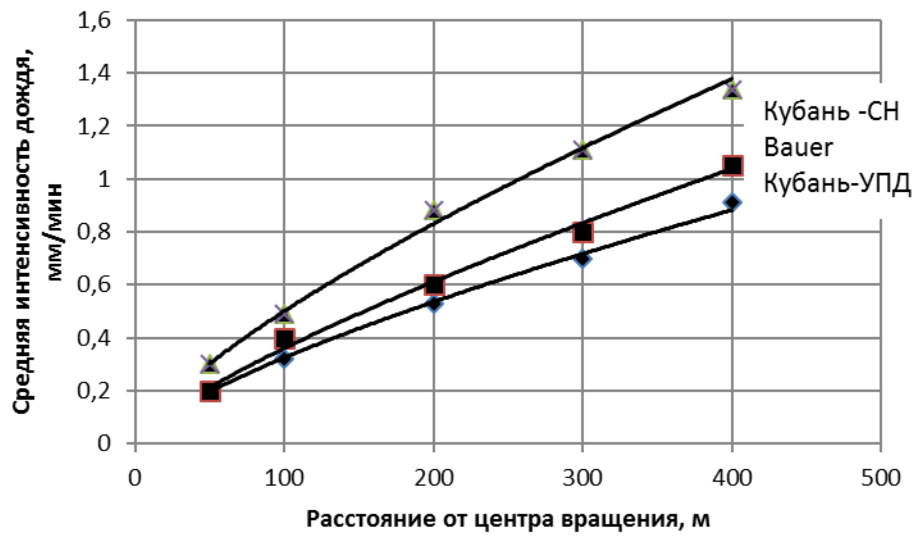
When the height of a sprinkler attachment is reduced, the irrigation radius (R, m) decreases. The range of the jet (R, m) is calculated according to the formula (Ryzhko, 2016) depending on a nozzle diameter (D, mm), an operating pressure (H, m of water column) and a sprinkler nozzle height:

$$R = \frac{(0{,}96+0{,}02h)H}{1{,}073+0{,}746\cdot {H}/{D}} \qquad (5)$$

where h is the height of a sprinkler nozzle installation (varies from 1.0 to 2.5 m).

On the basis of experimental data, they established that at a nozzle diameter change from 2 to 12 mm and a nozzle inlet pressure is changed from 0.1 to 0.3 MPa, the irrigation radius of a sprinkler nozzle with the "reverse cone" deflector increases from 2.3 to 10.8 m. In order to ensure good uniformity of irrigation by sprinkler nozzles, DNSS should be installed along a pipeline at a distance no more than 5 ... 6 m.

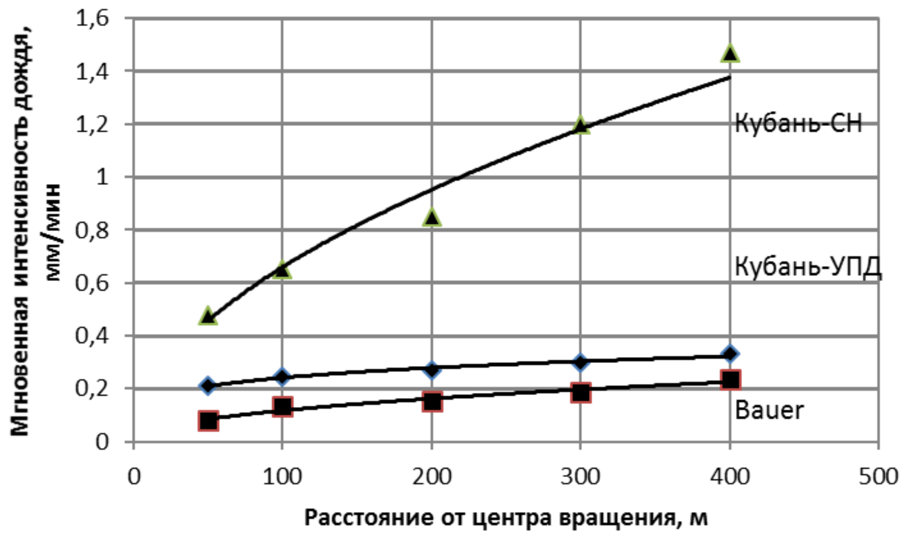
The studies showed that DNSS placement width increase with rainfall nozzles on the sprinkler "Kuban-LK" leads to an average rain intensity decrease by 1.5, as compared with standard sector nozzles (1.3 mm/min) and in 1,15 times as compared with i-Wob "Bauer" nozzles during their installation in a line along a device pipeline (Fig. 4).



Средняя интенсивность дождя, мм/мин – Average rain intensity, mm/min / Расстояние от центра вращения – The distance from rotation center

Fig. (4). The distribution of average rain intensity along the pipeline of multi-bearing devices "Kuban-LK" and "Bauer"

An instant rain intensity of the sprinkler "Kuban-LK" has the maximum values for sector attachments (1.47 mm/min), and when sprinkler nozzles are used on a DNSS it is decreased by 4.4 times, down to 0.33 mm/min (figure 5). Also, a small instantaneous intensity of rain along a pipeline is observed on "Bauer" sprinkler.



Мгновенная интенсивность дождя, мм/мин - Instantaneous intensity of rain / Расстояние от центра вращения, м - The distance from rotation center

Fig. (5). The distribution of instantaneous rain intensity along the pipeline of multi-support unit "Kuban-LK" and "Bauer".

The studies have determined that the sprinkler nozzles develop a shallow rain. The change of droplet mean diameter along the irrigation radius by rainwater nozzles is shown on Figure 6, from which one can see that at the beginning of the irrigation radius d_{min} = 0.1 ... 0.3 mm, in the middle - d_c = 0.5 ... 0.6 mm; at the end - d_{max} = 1.0 ... 1.6 mm.

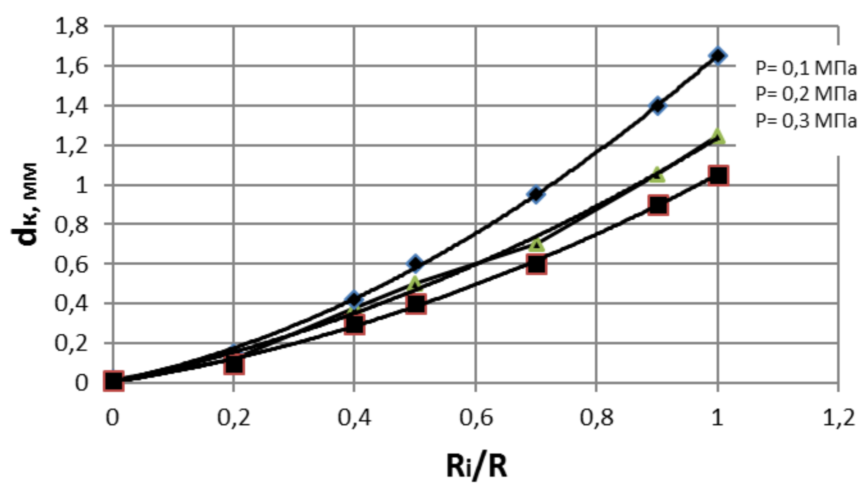


Fig. (6). The change of drop average diameter along the irrigation radius by sprinkling nozzle of 6 mm in diameter.

The experimental data processing showed that the minimum size of droplets at the beginning of the irrigation radius depends on the nozzle diameter (D, mm) and the pressure (P, MPa) and it is described by the following equation:

$d_{min} = 0{,}01(100P)^{-0{,}21}D^{0{,}70}$; (6)

The maximum size of drops at the end of the sprinkler nozzle irrigation radius also depends on the nozzle diameter and pressure:

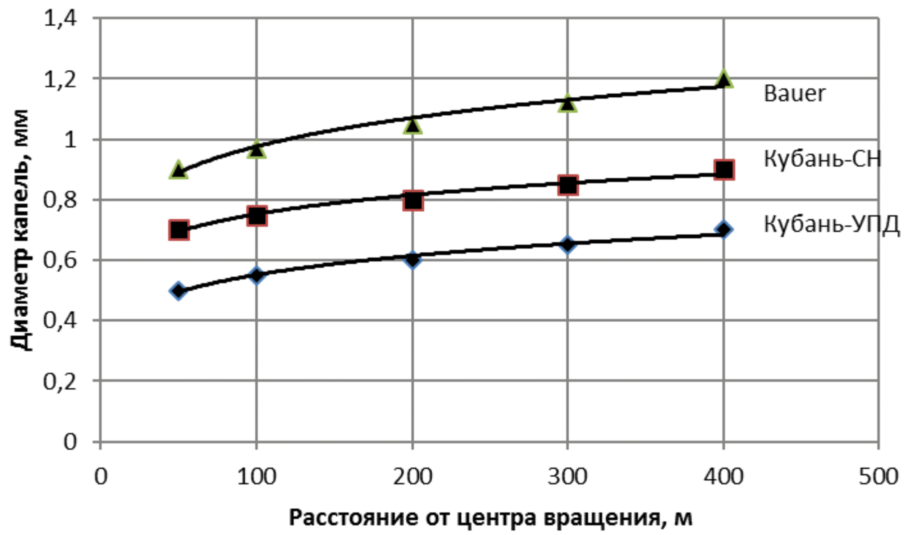
$d_{max} = 1{,}38(100P)^{-0{,}27}D^{0{,}44}$; (7)

The dependence determining the fineness of raindrops along irrigation radius with a sprinkler nozzle (Ryzhko, 2012):

$d_i = d_{min} + (d_{max} - d_{min})(X_i/R)e^{-0{,}75(1 - Xi/R)}$, (8)

where (X_i/R) is the relative radius of a jet range, $0 \leq X_i/R \leq 1$; d_{min}, d_{max} is the minimum and the maximum size of rain drops with a sprinkler, mm.

The change of drop average diameter of the serial sector nozzles and the DNSS with the sprinkling nozzles along the pipeline of various sprinklers is shown on Fig. 7. The use of sprinkler nozzles with a "reverse cone" deflector on the sprinkler "Kuban-LK" instead of sector attachments leads to the droplet size decrease from 0,7 ... 0,9 mm to 0,5 ... 0,7 mm or 1,3 times, and 1,7 times as compared with i-Wob and "Nelson" attachments. The increase of pressure at the output of the sprinklers i-Wob and "Nelson" from 0.1 to 0.17 ... 0.2 MPa makes it possible to reduce the droplet size by 20-30%.



Диаметр капель, мм - Droplet diameter, mm / Расстояние от центра вращения, м - The distance from rotation center

Fig. (7). The change of rain drop average diameter along the pipeline of multi-support units "Kuban-LK" and "Bauer".

An average (an instantaneous) power of rain is determined by Shwebs formula (Shwebs, 1974) taking into account the speed of rain drop fall:

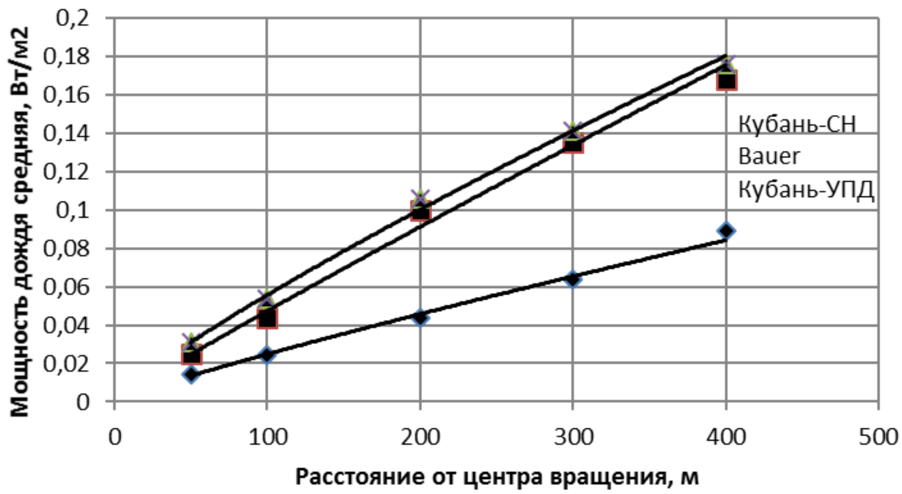
$$N_y = 0{,}0083 \cdot \sum(n_i \cdot V_i)^2 = 0{,}14 \cdot \rho \cdot d_к \qquad (9)$$

where N_y - the rain power (an average or an instantaneous one), W/m^2;

ρ – rain intensity (an average or an instantaneous one), mm/min;

$d_к$ – an average diameter of drops, mm; V – the speed of raindrops fall, m/s.

The increase of the sprinkler nozzle arrangement width and the reduction of droplet size on the sprinkler "Kuban-LK" lead to the average rain power decrease by 1.97 times as compared to the sector nozzles and i-Wob nozzles of the sprinkler "Bauer" (Figure 8).



Мощность дождя средняя, Вт/м2 - Average power of rain, W/m2 / Расстояние от центра вращения, м - The distance from rotation center
Fig. (8). The changes of the average rain power along the pipeline of multi-bearing units "Kuban-LK" and "Bauer".

The increase of the sprinkler nozzle arrangement width and the decrease of the droplet size on "Kuban-LK" sprinkler leads to the reduction of the instantaneous rain power by 5.6 times as compared to the sector nozzles.

The studies have established that devices of near-surface irrigation on "Kuban-LK" sprinkler provide watering uniformity increase during wind from 0.55 ... 0.72 to 0.7 ... 0.88 (by 20 ... 27%) due to rain cloud height decrease from 5 m to 1 ... 1.5 m; wind load reduction and the demolition and the optimization of jet spraying in comparison with the sector nozzles installed in a sprinkling unit (Figure 9).

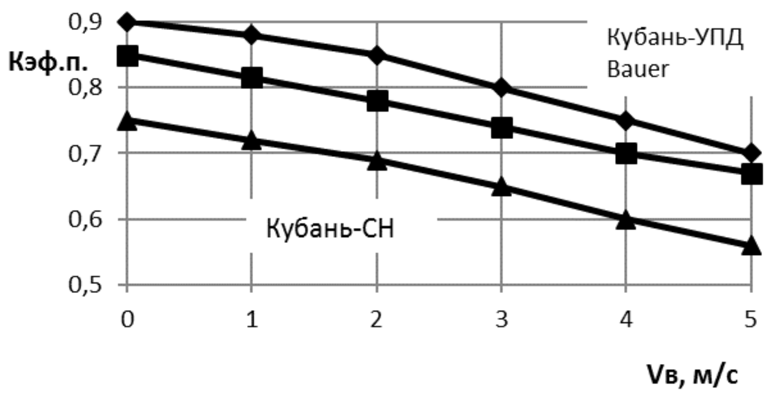


Fig. (9). The uniformity of watering by the sprinkling unit "Kuban-LK" and "Bauer" depending on wind speed.

The uniformity of watering by "Kuban-LK" sprinkler with DNSS is at the level of foreign sprinkler uniformity and it is improved slightly, as the impact of jets decreases as the result of the distance increase between nozzles (in comparison, if they were placed in a line along a pipeline).

On the basis of mathematical processing, the formula for water loss calculation from evaporation and the drift by the wind ($E_{и.у}$, %), with a single sprinkler, a sprinkling nozzle and a machine or unit watering (Ryzhko, 2016):

$$E_{и.у} = 1{,}22\frac{h^{0{,}6}(n+1)^{0{,}08}}{d^{0{,}6}\rho_c^{0{,}2}\rho_м^{0{,}1}}\left[t\left(1-\frac{\varphi}{100}\right)(v_в+1)\right]^{0{,}5}K_\alpha \qquad (10)$$

where h is the height of the rain drops above the soil, m; n - the rotational speed of units, min^{-1}; t - air temperature, ^0C; φ – relative air humidity, %; $\upsilon_в$ – wind speed, m/s; K_α – the coefficient that takes into account the change of evaporation and rainfall values depending on the angle α between a unit pipeline and the wind direction; d – an average diameter of drops, mm; ρ_c, $\rho_м$ – an average and an instantaneous intensity of rain, mm/min.

According to King and Bjorneberg (2010) the coefficient of meteorological tension of climate (F) is calculated by the following formula: $\Phi = t\cdot(1-\varphi/100)\cdot(\upsilon_в+1)$.

During the mounting of DNSS with deflector nozzles on "Kuban-LK" sprinkler, it is ensured that the loss of water from evaporation and demolition decreases from 12 ... 20% to 6 ... 10% or 1.5 ... 2

times, as compared to sector nozzles, due to rain height reduction from 5..6 m to 1.5 ... 2.5 m, the reduction of wind load and the optimization of sprinkler spraying (Figure 10). The loss of water from the evaporation and demolition of "Kuban-LK" sprinkler with DNSS is at the level of the sprinkler "Bauer" losses - within 6 ... 10%.

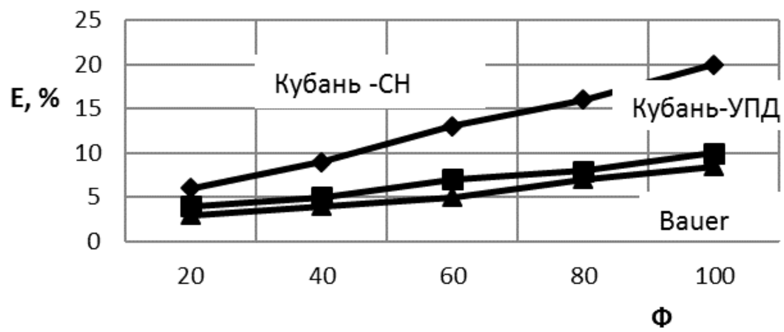
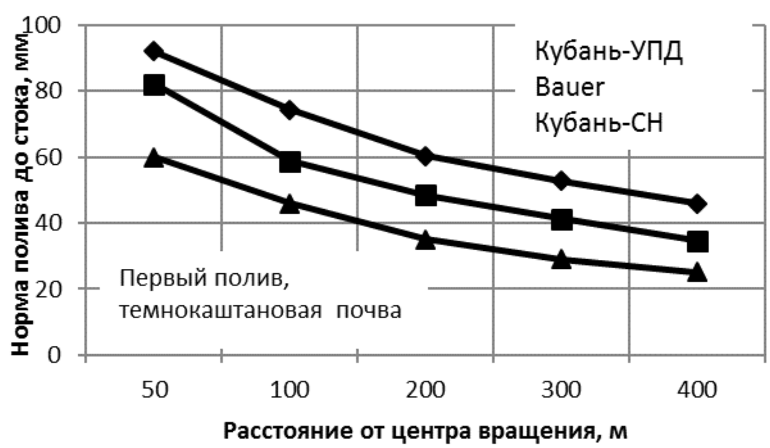


Fig. (10). Water losses from evaporation and demolition depending on the sprinkling machines and the meteorological climate tension Φ.

The studies showed that the increase the width of rain coverage by the sprinklers mounted on the DNSS of Kuban-LK sprinkler and the decrease of the average rain intensity, the size of droplets, and rain power leads to a higher watering rate to drainage (Figure 11).



Норма полива до стока, мм - Watering rate to drain, mm / Первый полив - First watering / Тёмно-каштановая почва - Dark chestnut soil / Расстояние от центра вращения, м - The distance from rotation center

Fig. (11). The change of watering rate to runoff along the pipeline of multi-bearing units "Kuban-LK" and "Bauer".

During the first watering of dark chestnut soils at the end of the Kuban-LK machine (with DNSS deflector nozzles), the watering rate to drain makes 460 m^3/ha, which is 75 ... 80% more as compared to the sectoral nozzles (252 m^3/ha) and 30 ... 35% more as compared to i-Wob nozzles of DM Bauer sprinkler (340 m^3/ha). During the watering of slope areas, the watering rate to runoff is reduced down to 328, 180 and 242 m^3/ha, respectively.

CONCLUSIONS.

The studies have established that the norm of irrigation to drainage during the irrigation by sprinkling machines has the closest correlation with an average and an instantaneous rain intensity, an average droplet diameter, the rate of their fall and the rain power. The equation has been established to calculate the irrigation norm to runoff, depending on the technological parameters of irrigation and soil-relief conditions.

They developed improved near-surface sprinkler devices for rainwater sprinkling units that increase the rain width, reduce an average rain intensity and adjust a sprinkler nozzle height above the soil surface as the agricultural plants grow. A sprinkler nozzle with a "reverse cone" deflector has been developed, which forms a small droplet rain within 0.5 ... 0.9 mm and provides the irrigation radius within 2.3 ... 9 m with a nozzle diameter of 2 ... 10 mm.

During the operation of "Kuban-LK" sprinkler with the developed DNSS and sprinkler attachments reduces an average rain intensity is reduced in comparison with the serial sector nozzles, and the rain power is decreased. The uniformity of irrigation of the sprinkler "Kuban-LK" irrigation with the developed DNSS is increased by 20 ... 27% as compared to the serial machine, and the water losses from evaporation and demolition are reduced from 12 ... 20% to 6 ... 10%, the irrigation rate to runoff is increased to 460 m^3/ha or 75 ... 80% during the first watering at the end of a unit as compared to the sectoral nozzles (252 m^3/ha) and by 30 ... 35% as compared to the i-Wob attachments of the sprinkler "Bauer" (340 m^3/ha).

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