Experience shows that for the irrigation of intensive gardens, various types of equipment and technologies are used, such as continuous irrigation (invasive), drip irrigation, subsurface irrigation and other methods. All irrigation options have some shortcomings, such as water evaporation, high water consumption, high consumption of mineral fertilizers and energy. (Research purpose) To develop an automated system for subsurface irrigation of intensive gardens with groundwater using electric pumps and solar panels, and to create a mathematical model of soil moisture distribution. (Materials and methods) Special devices shaped as pegs were designed to supply water with dissolved mineral fertilizers directly into the root system of intensive gardens. The authors investigated the pegs’ geometric parameters and the criteria for their placement in the soil, taking into account the consumption of water and nutrients. The authors examined soil mechanical composition and salinity as well as its physical and mechanical, technological properties. (Results and discussion) It was found out that the installation of the peg facilitates soil moisturizing through the central pipeline within the radius of 1.55-1.75 meters at the depth of 0.7-0.9 meters. Three-four pegs, being equidistant from each other and inclined in relation to the vertical axis by 20-30 degrees, were placed around a tree. Water consumption was determined for various irrigation methods: for furrow irrigation (control) – 1125.7 cubic meters per hectare, for continuous irrigation (invasive) – 1812.3 cubic meters per hectare, for drip irrigation – 618.6 and subsurface irrigation – 506.4 cubic meters per hectare. (Conclusions) Based on the results of the experimental study carried out in farms with intensive gardens using various irrigation methods, continuous irrigation (invasive), drip irrigation and subsurface irrigation were compared in terms of water consumption. The results show that drip irrigation and subsurface irrigation ensure less water consumption than flood irrigation, by 46 per cent and 57 per cent respectively. It was found out that subsurface irrigation ensures 57 per cent water and 25-35 per cent mineral fertilizer economy, in comparison with the other methods of providing trees with water and nutrients.

Keywords: intensive gardening, garden irrigation, water filters, pipelines, water flow, nutrient solution.

For citation: Zhuraev F.U., Karimov G.K. Oborudovanie i tekhnologiya dlya vnutripochvennogo orosheniya intensivnykh sadov v Bukharskoy oblasti Respubliki Uzbekistan [Equipment and technology for subsurface irrigation of intensive gardens in the Bukhara Region of the Republic of Uzbekistan] Sel skokhozyaystvennye mashiny i tekhnologii. 2021. Vol. 15. N2. 4-8 (In English). DOI 10.22314/2073-7599-2021-15-2-4-8.

Equipment and Technology for Subsurface Irrigation of Intensive Gardens in the Bukhara Region of the Republic of Uzbekistan

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Abstract.

Conclusions

For citation.

Оборудование и технология для внутрипочвенного орошения интенсивных садов в Бухарской области Республики Узбекистан

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Реферат. Показали, что для обеспечения интенсивных садов водой применяют различные технологии: бороздковый полив, капельное или внутрипочвенное орошение. Отметили среди недостатков во всех вариантах большой расход воды, минеральных удобрений и энергии. (Цель исследования) Разработать автоматизированную систему внутрипочвенного орошения интенсивных садов грунтовыми водами с помощью электронасосов и с использованием солнечных батарей, а также создать математическую модель распределения почвенной влаги. (Материалы и методы) Создали специальные устройства в виде колышков для подачи воды с растворенными в ней минеральными удобрениями прямо в корневую си-
Структура интенсивных садов. Исследовали их геометрические параметры и критерии размещения в почве с учетом расхода воды и питательных веществ. Изучили физико-механические, технологические свойства, механический состав и засоленность почвы. (Результаты и обсуждение) Показали, что при установке разработанного колышка обеспечивается увлажнение почвы через центральный трубопровод в радиусе 1,55-1,75 метра на глубине 0,7-0,9 метра. Разместили вокруг дерева 3-4 колышка, равнодоемленных друг от друга, с наклоном по отношению к вертикальной оси на 20-30 градусов. Определили расход воды при различных способах орошения: при бороздковом поливе (контроль) - 1125,7 кубометра на гектар, при капельном орошении - 618,6 и внутрипочвенном - 506,4 кубометра на гектар. (Выводы) Определили, что внутрипочвенное орошение, при сравнении с другими способами обеспечения деревьев водой и питательными веществами, способствует экономии воды на 57 процентов, минеральных удобрений на 25-35 процентов.

Ключевые слова: интенсивное садоводство, орошение садов, фильтры воды, трубопроводы, расход воды, питательный раствор.

Для цитирования: Жураев Ф.У., Каримов Г.Х. Оборудование и технологии для внутрипочвенного орошения интенсивных садов в Бухарской области Республики Узбекистан // Сельскохозяйственные машины и технологии. 2021. Т. 15. Н2. С. 4-8. DOI 10.22314/2073-7599-2021-15-2-4-8.

И в Республике Узбекистан, в связи с увеличением, и сельское хозяйство испытывает особое недостаток этого ресурса: 85% воды, используемой в промышленной продукции, обеспечивается за счет иностранных государств. В таких условиях, важно оптимизировать водопотребление в сельскохозяйственном производстве. В зарубежных странах, положительные результаты были получены при использовании внутрипочвенного орошения интенсивных садов. Они подтверждены экспериментально и теоретическими исследованиями, а также математическими моделями. Экспериментальные образцы были созданы и успешно прошли испытания [5, 6].

The research purpose is to develop new equipment and technologies for intensive garden irrigation in the soil and climatic conditions of the Bukhara region in Uzbekistan, as well as to create a mathematical model of the soil moisture distribution.

Materials and methods. In the region, meadow-allovoluvisols are widespread, which texture is represented by light, medium and heavy sands. The groundwater level is at the depth of 1.5-2.0 m, the salinity is 1.0-1.2 g/l. Field experiments were carried out in 2016 at the Zodabek farm in the Kagan district of the Bukhara region. Six hectares are covered by an intensive orchard, represented by medium-sized Golden Delicious apple trees.

In accordance with the structure of the soil, the irrigation pegs were made from a polyethylene pipe with the diameter of 16-25 mm and the length of 30-80 mm.

We used systematic analysis, mathematical planning of experiments, modern methods for determining the water and energy consumption and conducting field experiments at the Research Institute of Agricultural Technology of Cotton Seed Production.

Results and discussions. The proposed irrigation technology provides for the use of groundwater in areas with water scarcity.

The automated groundwater irrigation system employs solar-powered electric pumps (Fig. 1). From a solar panel sized 4 × 5 = 20 m², a voltage of 6-60 V is supplied to the controller generating 12 V, charges the storage battery powered through an inverter (a device for converting direct current into alternating current with a voltage value of 24 V). Upon switch-on, the automatic control panel starts the pump, which, depending on the selected control mode, is partially or fully immersed in the groundwater level.
change) under a voltage of 220 V. A pump, capable of pumping 0.5-0.7 m³ of water per hour from the ground, takes water from a single 10-15 m depth well at the flow rate of 84.6 m³/day and fills a 100-ton cistern, from where the water is sent through a transport pipeline.

If the level of groundwater mineralization exceeds 0.085% in terms of chlorine ion, it is diluted with river water in appropriate proportions. Through a system of automatic control valves installed in the outlet of the tank, the water is treated with a water purifier. The main irrigation flow is directed to the pegs along the main pipes, distribution pipes and a thin pipe to provide the required amount of water (Fig. 1a) [7-12].

Three-four pegs intended for subsurface irrigation are placed in the soil equidistantly around the tree. They are inclined by 60-70° in relation to the horizon (Fig. 1b).

In the upper part, the pegs are connected by means of tees with pipes for supplying and discharging water. With the help of an additional segment, it is possible to increase the depth of the device. The lower part of the peg ends with a pointed cylinder.

During the operation, the water flows from top to bottom. A rubber diaphragm is installed in the peg cavity, which regulates the water flow uniformity. It expands and contracts depending on the pressure of the fluid (Fig. 2).

On average, 1.8-2.5 liters of water flows through each hole in an hour, and the seedling’s entire root system is irrigated by the moderate moistening of the soil with a mixture of mineral fertilizers. As a result, water savings amount to 55% compared to the local flood irrigation.

In addition to the flow compression, it tends to reveal inversion, that is, a change in the shape of the lateral motion along its length. For example, a square shape can take the shape of a cross or another shape. The liquid outflow through the irrigation peg hole was determined parametrically (Fig. 3).

Theoretical, the water flow can be calculated from the pipeline to the pipe distribution network.

The average duration of the between-irrigation period is:

$$ N_1 = \frac{m}{h}, $$

where $N_1$ is the average interval between the watering time periods, days;

$$ h = \frac{V}{N}, $$

where $N$ is the duration of the growth period, days.

The time required to supply the amount of water corresponding to the irrigation rate was determined experimentally depending on the structure of the irrigation network, the irrigation rate and the soil properties [13].

For the subsurface irrigation, the watering time is determined by the formula:

$$ t = \frac{m \cdot 1000}{q \cdot n_1 \cdot n_2}, $$

where $t$ is the watering time, h;

$$ q $ – water consumption by one peg, l/h;

$$ n_1 $ – the number of pegs around one tree, pcs;

$$ n_2 $ – the number of trees per hectare, pcs;

$$ \Delta l $ is the distance between the drops of the peg irrigation system, m.

$$ k = \frac{V}{m}, $$

where $k$ is the number of watering time periods;

$$ V $ – irrigation rate for the entire period, m³/ha;

$$ m $ – one-time irrigation rate, m³/ha.

The seasonal irrigation periods were determined by the generally accepted graphic-analytical method for monthly and ten-day water balance deficit based on tabular analysis.

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$$ \Delta l $ is the distance between the drops of the peg irrigation system, m.
During the intra-soil watering of fruit trees, only a part – 0.1-0.2 of the area is moistened, not the whole garden. This indicator usually depends on the plant type and variety, its age, planting density, soil and climatic conditions. In this case, the following expression is used to calculate the irrigation rate:

\[
V = \left( R - Q \right) \frac{W_k \cdot r}{\sqrt{0.3 \cdot \left( 1 - W_k + W_k^2 \right)}} ,
\]

where 
- \( R \) is evaporation from the surface of open water during the growing season, m³/ha;
- \( Q \) is the amount of precipitation during the growing season, m³/ha;
- \( r \) – coefficient of proportionality between evaporation from the surface of open water and water consumed by plants through the moisture circuit;
- \( W_k \) is the moisture contour coefficient representing the wetted part of the plant nutrition zone.

For the surface irrigation of agricultural crops, the seasonal rate can be determined taking into account the bioclimatic coefficients of crops [14, 15]:

\[
V = \frac{\left( W \Sigma d - Q \right) W}{\sqrt{0.3 \cdot \left( 1 - W_k + W_k^2 \right)}} ,
\]

where \( W \) is the bioclimatic coefficient for different climatic zones and crops;
- \( \Sigma d \) is the average daily moisture deficit during the growth of agricultural crops, mm.

For the subsurface irrigation, a one-time irrigation rate is calculated using the expression [15, 16]:

\[
m = \frac{100 \cdot h \cdot g \cdot W_k \left( \varphi_y - \varphi_a \right)}{\sqrt{0.3 \cdot \left( 1 - W_k + W_k^2 \right)}} ,
\]

\[
H = \frac{m \cdot \sqrt{0.3 \cdot \left( 1 - W_k + W_k^2 \right)}}{100 \cdot h \cdot g \cdot W_k \left( \varphi_y - \varphi_a \right)} ,
\]

where \( H \) is the depth of the moistened soil layer, m;
- \( g \) – the volumetric weight of the reference soil layer, t/m³;
- \( y \) – the upper limit of the average soil layer moisture content, %;
- \( q \) – the lower limit of the average soil layer moisture content, %.

To calculate the one-time and seasonal irrigation rates, the \( R, Q \) indicators can be found in the databases of hydrometeorological observations for the region [3, 5, 7].

Experimental studies were carried out in 2017-2019. An intensive garden of dwarf varieties covering the area of 6 hectares was divided into three 2-hectare plots.

The first plot is a reference one for the continuous irrigation, the second plot is for the drip irrigation, and the third one is for the subsurface irrigation.

The interval between the watering periods is 9-17 days.

Water consumption during the continuous irrigation was determined during the irrigation using a Chipoletti water meter, and in the other two options – during the drip and subsurface irrigation – this indicator was calculated based on the pump performance per unit time [12-14].

The boundaries of the water distribution were studied in the laboratory when organizing pile irrigation for various texture soils (Fig. 4).

In the laboratory experiment, at the end of the first hour the water absorption rate was 0.079 m/h in the medium sandy soils, at the end of the fourth hour it was 0.05 m/h, and the filtration coefficients were 0.018 and 0.013 m/h, respectively.

**Fig. 4.** The pile method for studying the water distribution boundaries: a – determining the peg angle when installed at an angle; b – initial soil moisture; c – complete soil moistening

**Table: Water consumption depending on the irrigation method**

| Irrigation methods   | Number of waterings | Irrigation rate, m³/ha | Number of waterings | Irrigation rate, m³/ha | Number of waterings | Irrigation rate, m³/ha | Water consumption on average for 3 years, m³/ha |
|----------------------|---------------------|------------------------|---------------------|------------------------|---------------------|------------------------|-----------------------------------------------|
| Furrow irrigation    | 11                  | 1080                   | 12                  | 1111.9                 | 11                  | 1185.2                 | 1125.7                                        |
| Drip                 | 15                  | 594                    | 19                  | 610.7                  | 18                  | 651.1                  | 618.6                                         |
| Subsurface           | 13                  | 486                    | 14                  | 500.2                  | 15                  | 533                    | 506.4                                         |
The experiments were carried out according to the following system: the first option (the reference one) – furrow irrigation, the second option – drip irrigation, the third option – subsurface irrigation (Table).

Compared to the reference plot, water consumption during the drip irrigation was 507.1 m³/ha (45%), during the subsurface irrigation – 619.3 m³/ha (55%). As you can see, the subsurface irrigation is more efficient in terms of water saving. Compared to the reference option, the water consumption during the drip irrigation was reduced by 45% (507.1 m³/ha), and during the subsurface irrigation – by 55% (619.3 m³/ha).

**Conclusions.** For the irrigation of intensive gardens with a moisture deficit, ground waters can be used supplemented with river water. The equipment and technology for the subsurface irrigation have been developed. Water consumption was as follows: for the furrow irrigation – 1125.7 m³/ha, for the drip irrigation – 618.6 and for the subsoil irrigation – 506.4 m³/ha. The subsurface irrigation, in comparison with other methods of providing trees with water and nutrients, increases water saving by 57%, mineral fertilizer saving by 25-35%. Excessive post-irrigation drainage and filtration losses were avoided while the topsoil was retained soft. Seasonal irrigation rates depend on rainfalls.

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**Conflict of interest.** The authors declare no conflict of interest.