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RESEARCH ARTICLE

Determination of soil moisture depth in a mountainous region of Uzbekistan

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Abstract. The conservation of water resources, their wise usage, and consumer access continue to be major and relevant issues nowadays. Regulating the system of effective use of the existing water resources is crucial for addressing the issue of water scarcity. The goal of the article is to create irrigation technologies and techniques for viticulture, which is growing and expanding year after year in the context of a growing water shortage, that are acclimatized to the soil and climatic conditions of the mountainous area of Uzbekistan. A study on drip irrigation of vineyards using local runoff was conducted in the foothills of Kashkadarya province in Uzbekistan on gray soils and few water supplies. In addition, irrigation was done using a 2-3-2 system with irrigation norms of 170-200 m^3/ha and seasonal irrigation norms of 1300-1900 m^3/ha while pre-irrigation soil moisture was kept at 70-75-65% relative to LFMC. By yielding 20.8 tons/ha of grapes, which was shown to be 5.6 tons/ha or 24% more than the control alternative, which is a standard furrow irrigation, 33% of water resources were conserved.

Keywords Vineyards • Irrigation • Drip irrigation • Uzbekistan • Water saving

Introduction

Development of horticulture and viticulture in the foothills of Uzbekistan in all sectors, including increasing fruit yield and improving quality, meeting the population's demand for fruit products, expanding exports, efficient use of irrigated land and other resources, and increasing soil fertility plays an important role in improving living standards and developing the country's economy [1, 2]. Raising horticulture and viticulture to a higher level, creation and placement of fruit tree species, and grape varieties suitable for soil climatic conditions are considered as a national priority in agriculture [3]. The use of new and advanced agro-technologies with high efficiency in the cultivation of grapes, thereby expanding the share of fruit growing, fully satisfying the demand of the population for fruit, and grape products is one of the most important and topical issues today in Uzbekistan [4].

It has been almost nine years since the introduction of foreign technologies for the development of horticulture, the introduction of small, and fast-growing (deaf and dumb) fruit seedlings and grafts in Uzbekistan [5]. The placement and maintenance of these seedlings in different soil and climatic conditions of the republic are also yielding positive results nowadays.

To realize the efficient use of ridges and foothill lands, it is necessary to establish adequate cooperation between science, technology and industry [6]. Now, despite the shortage of water, there is a need to improve the use of irrigated lands and the adoption of optimal and convenient methods to ensure the restoration of ecological balance [7]. It is especially important that attention is paid at the level of state policy to improving the reclamation of lands and increasing soil fertility [8]. In the current conditions of Uzbekistan, which organizes the development of its economy in the agro-industrial direction, to study the legal problems of soil fertility protection and to develop solutions and conclusions is vital based on in-depth scientific and theoretical observations based on practical materials.

For this reason, many challenges surrounding the protection of water resources, their rational use and access to consumers remain relevant and important. To solve the problem of water shortage, regulating the system of efficient use of available water resources is important [9, 10]. That is, it will be possible to contribute to the solution for the problem of water scarcity through the efficient use of available water resources. Considering the issues of saving water, using economical methods and technologies in irrigation, proper distribution of water, and its calculation in areas where there are sufficient water resources is nationwide crucial [11]. In areas where there is a shortage of water, it is necessary to supply water, find additional sources of water, and increase the efficiency of irrigation networks [12]. In addition, great attention should be paid to the organization of water distribution, the implementation of agro-technical measures that retain moisture in the field, the structure of crop placement and the correct placement of varieties [13,14].

The aim of the research is to carry out an investigation on the development of orchards and vineyards in the foothills, the reproduction of high-yielding fruit tree species, and the care in different soil-climatic conditions. The main purpose of the paper is to develop irrigation techniques and technologies suitable for the soil and climatic conditions of the mountainous region of Uzbekistan in viticulture, which is developing and expanding year by year in the context of increasing water scarcity.

Materials and methods

In the experiments, we conducted surveys on the development of standards for irrigation of orchards and vineyards in the conditions of gray soils of the field of “Guldorasoy” Water Consumers Association appertain to Kashkadarya province in Uzbekistan (Figure 1). According to the granulometric composition of the soil, the area is medium sandy, meadow gray, non-saline soils. The level of groundwater is 2-3 m and the mineralization is 1-3 g/l.

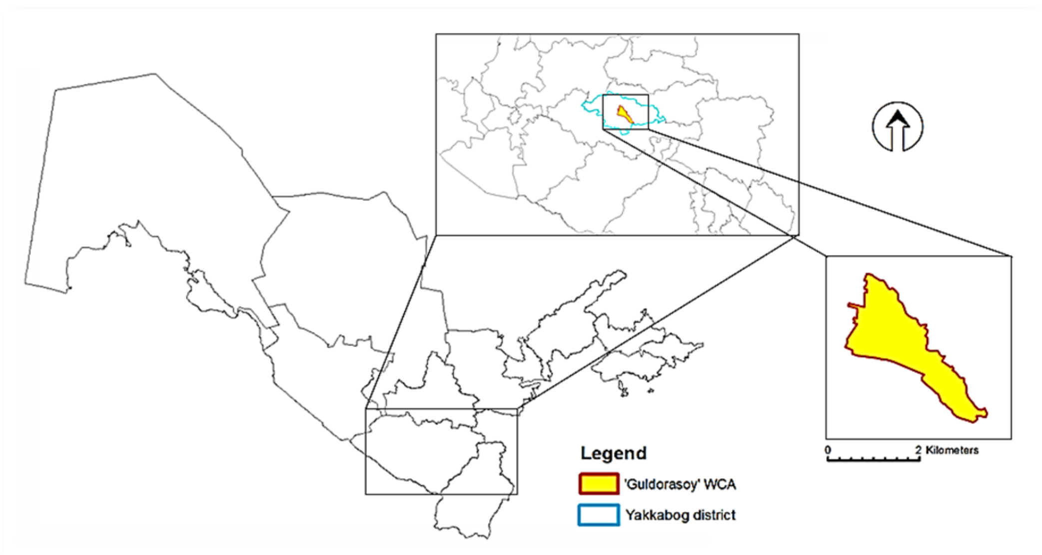

Figure 1. Location of the study area (source: Jumanov et al. [9]).

The experimental plot is a 3 x 2 m, located in the conditions of foothills and has field paths. Fieldworks on improving the technology of drip irrigation, studying of the order of irrigation of grapes, the number of irrigations, and the norms of seasonal irrigation on the basis of "Modern technologies of viticulture and raisin drying" methodology [15] were undertaken at the Tashkent Institute of Irrigation and

Agricultural Mechanization Engineers and the Research Institute of Irrigation and Water Problems, and the Scientific Research Institute of Horticulture, Viticulture and Enology named after Academician Mahmud Mirzaev.

Table 1. Experimental system of the fieldwork.

Irrigation methods	Moisture-supplied soil layer, m	Pre-irrigation soil moisture, in % of the limited field moisture capacity (LFMC)
Drip irrigation	0.3	70-75-65
	0.5	
	0.7	

In the cultivation of orchards and vineyards in the foothills, the constant supply of moisture to the layer where the main root part of the soil is located plays an important role in the development of seedlings. This adapts more quickly to soil conditions, creating conditions for good formation of the root system. Besides, this also alternates the process of nutrient and air exchange in the soil. In order to maintain the biological structure of the vineyards in the foothills, it is necessary to ensure the nutrition of the root part of the soil at a depth of 50-70 cm. This requires frequent moistening of the soil at low rates. In this regard, first of all, taking into account the mechanical composition of the soil, the depth of groundwater, and their level of mineralization, as well as the relief of the site is deemed.

According to Rybakov and Ostroukhova [16], regarding the irrigation regime of grapes, the moisture content of grape varieties and leaves was 71-73%, in buds 80-85%, in the body 30%, in rust up to 40%, and in the roots up to 50-55%. The bulk of water is used for transpiration and respiration, and that only a certain portion of water was used directly to produce organic matter, had been assessed [16].

Nurjanov [17] developed theoretical and field experiments on the effects of surface slope on irrigated lands in different geomorphological, natural and economic conditions. According to the experiment of drip irrigation of grapes in the study of Yasonidi [18] on the effectiveness of the method, the yield of grapes for three years was 87.0 tons/ha and 85-95% of the limited field moisture capacity (LFMC) by maintaining the average soil pre-irrigation moisture 75% relative to LFMC [18].

This of course follows these norms when irrigated over conventional land. When using drip or other water-saving irrigation methods, when irrigating young intensive apple orchards, it is recommended to moisten the soil layer by 60-80 cm, setting irrigation standards at 170-200 m^3/ha. According to Mallaev [15], who conducted research in this field, high efficiency has been achieved by drip irrigation. The use of seasonal irrigation water decreased by 2.0-2.5 times, with a 1.5-fold increase in grape yield, and improved crop quality and an increase in cotton yield by 5-7 quintals (q)/ha. Furthermore, using and improving resource-saving technologies in the irrigation of orchards and vineyards is crucial to organize irrigation based on the biological requirements of each type of crop and to focus on the introduction of automated irrigation technologies.

Results and discussion

One of the main factors determining soil fertility is its water-physical properties. Here, mainly soil density, volumetric and specific mass, total porosity, water permeability, and moisture capacity are of great agronomic importance [7]. The water-physical properties of the soil vary depending on the type of soil, mechanical composition, structure, amount of organic and mineral substances, structure, culture, and level of tillage [12]. Pasture soils are soils with naturally favorable water-physical properties. In this case, this type of soil determines the air, heat, nutrients, water regime and the activity of microorganisms, as well as the growth and development of plants. This is considered as one of the main factors determining the methods and irrigation regime of vineyards.

The soil of the experimental field is light gray, grazing, medium mechanical sandy soil, with a small amount of humus, and the absorption of mineral colloids is considerably fast [9]. In the upper layers, their variation varies from 8 to 9 mg.equiv. (per 100 g of soil). The primary data on the water-physical properties of the experimental field soil density, solid phase density, soil porosity, maximum hydroscopic, and moisture reserve are given in Table 2.

Table 2. Water-physical properties of experimental field soils.

Soil layer, cm	Density, ton/m^3	Solid phase density, ton/m^3	Soil porosity, %	Maximum hydroscopicity soil mass, %	Possible moisture reserve, m^3/ha
0-20	1.33	2.61	52.9	5.2	400
20-40	1.39	2.72	50.7	5.3	410
40-60	1.45	2.73	48.8	5.4	410
60-80	1.44	2.68	48.1	5.2	410
80-100	1.35	2.66	47.7	5.3	410
0-60	1.37	2.68	50.7	5.3	410
0-80	1.45	2.68	50.0	5.2	410
0-100	1.39	2.68	49.6	5.4	410

To calculate the amount of water used in drip irrigation networks for irrigation of orchards and the cost of irrigation to determine the net income from the garden at the end of the year is important. In the experimental field conducted in the conditions of the soils of this study area, 0.3–0.5 and 0.7 m layers of vineyard soil were irrigated by drip irrigation system with moisture supply.

In this case, the control option provided 0.7 m layer of soil with moisture and irrigated in the order of 70-75-65% relative to LFMC. Fertilization norms used on the farm to feed the orchards and vineyards were 120 kg of nitrogen, 90 kg of phosphorus and 30 kg of potassium fertilizers per hectare.

Depending on the level of soil moisture, the capillary pores up to the lower layers of the soil to be high or low depend on the soil layer to be filled with water, and to be low in winter and high in autumn in sudden changes in air temperature. LFMC of the soil is understood to be the ability to retain water in layers that have been absorbed into the soil to varying degrees [8]. The higher the moisture capacity of the soil at the site of the experiment, the more moisture is provided in the soil for the plant.

Table 3. Experimental field LFMC (%) obtained relative to the dry weight of the soil.

Soil layer, cm	LFMC% according to soil layers (three-year-average)			
	2015	2016	2017	Avg. for 2015-2017
	Avg.	Avg.	Avg.	
0-10	22.2	21.9	22.4	22.5
10-20	21.7	21.7	21.6	21.7
20-30	21.7	21.6	21.3	21.5
30-40	21.6	22.2	21.7	21.8
40-50	22.5	22.1	22.4	22.3
50-60	21.7	21.6	21.6	21.7
60-70	20.7	21.5	20.4	21.5
70-80	20.3	20.5	20.3	20.3
80-90	19.5	19.6	19.8	19.7
90-100	20.3	20.1	20.4	20.3
Avg.				
0-70	21.6	22.1	21.7	21.8
0-100	21.4	21.5	21.1	21.2

Irrigation regime was carried out in the order of 60-65-60% and 70-75-65% relative to LFMC, soil moisture relative to its absolute weight. In the spring, i.e. at the beginning of the growing season, when moisturizing the 0-70 cm layer of the field area where the grapes are grown, the moisture content in the soil should be around 18.2% by weight and 19.7% in the 0-100 cm layer. The exact level of irrigation (m_H) was determined by the following equation (1):

$$m_H = (W_{MMC} - W_{OI}) \cdot h\Delta \cdot 100; \quad (1)$$

Where, W_{MMC}-W_{OI} - minimum moisture capacity and optimal irrigation humidity, % of dry soil mass; h - calculated wetting layer, m; Δ - volumetric mass of the calculated wetting layer, g/cm^3.

The amount of irrigation water required was calculated based on the amount of moisture present in the soil before each irrigation, using the following equation (2) depending on the water-physical properties of the soil and the depth of wetting:

$$M = 100 \cdot h \cdot d \cdot (W_n - W_m) + K \quad (2)$$

Where, W_n - limited field moisture capacity relative to soil weight, %; W_m - absolute moisture before irrigation relative to soil weight, %; h - moisture depth of the irrigated area, m; d - volume mass in the calculated layer of the irrigated area, g/cm^3; K - coefficient of water consumption for evaporation during irrigation (10-15% of the lack of moisture in the calculated layer).

The water supplied to the plant during the growing season is also vital in determining the yield of each study. Therefore, in the process of maintenance of grape varieties, the standard of seasonal irrigation in 2015 was 1800 m^3/ha in the order of 60-65-60% of soil moisture relative to LFMC before irrigation. Pre-irrigation soil moisture was observed to be less than 1120 m^3/ha in drip irrigation in the order of 60-65-60% relative to LFMC or 680 m^3/ha compared to the control option (furrow irrigation).

The pre-irrigation soil moisture in the grapes was 70-75-65% relative to the LFMC. It was found that the pre-irrigation soil moisture was 1530 m^3/ha, or 420 m^3/ha less than the control option, when drip irrigation in the order of 70-75-65% relative to LFMC. Similar data were observed in 2016 and 2017 as well. In the process of maintenance of grape varieties, the average seasonal irrigation rate for three years was 1910 m^3/ha in the order of 60-65-60% relative to the soil moisture LFMC. Pre-irrigation soil moisture was 60-65-60% lower than LFMC in the drip irrigation order which accounted for 1283 m^3/ha or 627 m^3/ha less than the control option. The average seasonal irrigation rate for 20 years was 2037 m^3/ha in the control option in the order of 70-75-65% relative to LFMC. Pre-irrigation soil moisture was observed to be less than 1680 m^3/ha or 357 m^3/ha compared to the control option when drip irrigation in the order of 70-75-65% relative to LFMC (Figures 2 and 3).

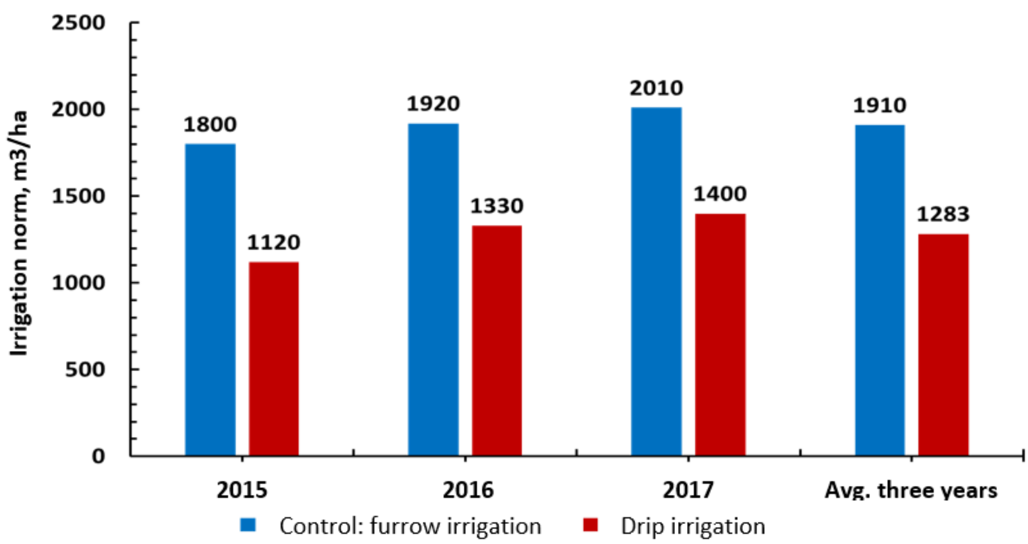

Figure 2. Irrigation methods and norms of irrigation procedures for grape varieties, 60-65-60% compared to LFMC.

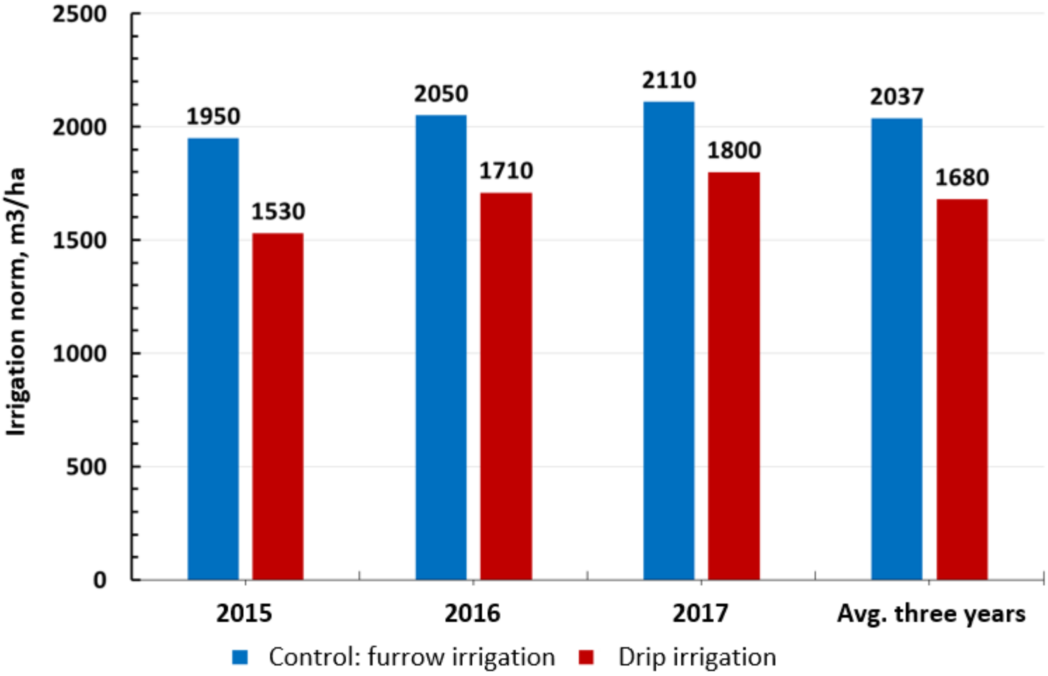

Figure 3. Irrigation methods and norms of irrigation procedures for grape varieties, 70-75-65% compared to LFMC.

The scheme of transition from the artificial pool for water saving from atmospheric rainfall to the next branches in the vineyards, which provides efficient use of irrigation water, was discussed. Understanding the agrophysical properties of soils in irrigated and rainfed viticulture conditions is important to improve soil and increase productivity. After calculating the number of grapes in the vineyard, we calculated the evapotranspiration rate from a single vineyard using the following equation (3).

$$ET_0 = k_p E_0 \quad (3)$$

Where, K_p - coefficient, taking into account the design of the evaporator, the value of which is the coefficient corresponding to the position of the evaporator (0.4 for low biomass; 0.8 for dense biomass); and, E_o - evaporated water, mm.

The amount of evapotranspiration from the area covered by agricultural crops was determined as follows (Equation 4):

$$ET_C = k_C E\mathrm{T}_0 \quad (4)$$

Where, k_c - coefficient, taking into account the plant type and growth stage.

The evolutionary evaporative variability of grape varieties by months is shown in the following graph (Figure 4).

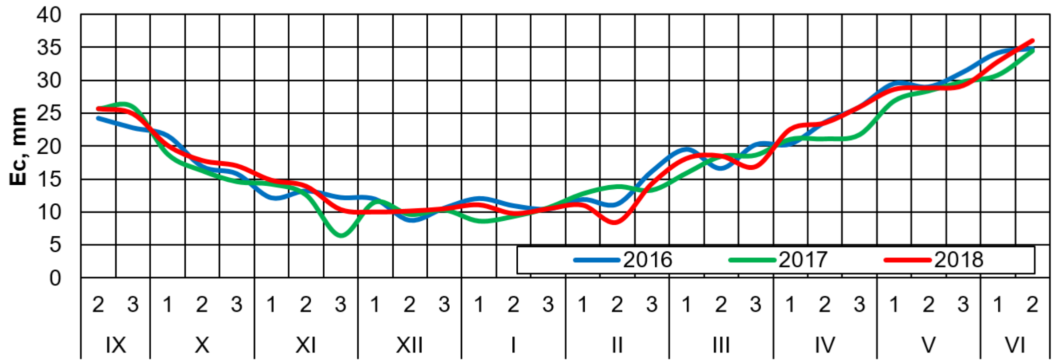

Figure 4. Evapotranspiration variability of grape varieties by months from 2016-2018

Figure 4 above shows that the amount of evapotranspiration varied with temperature during 2016-2018. That is, there was less in December-February and more in September-June. Reducing the soil moisture depth to 0.5 m can provide higher yields than the control option. However, the 0.8 m layer resulted in a significant reduction in moisture content (Figure 5).

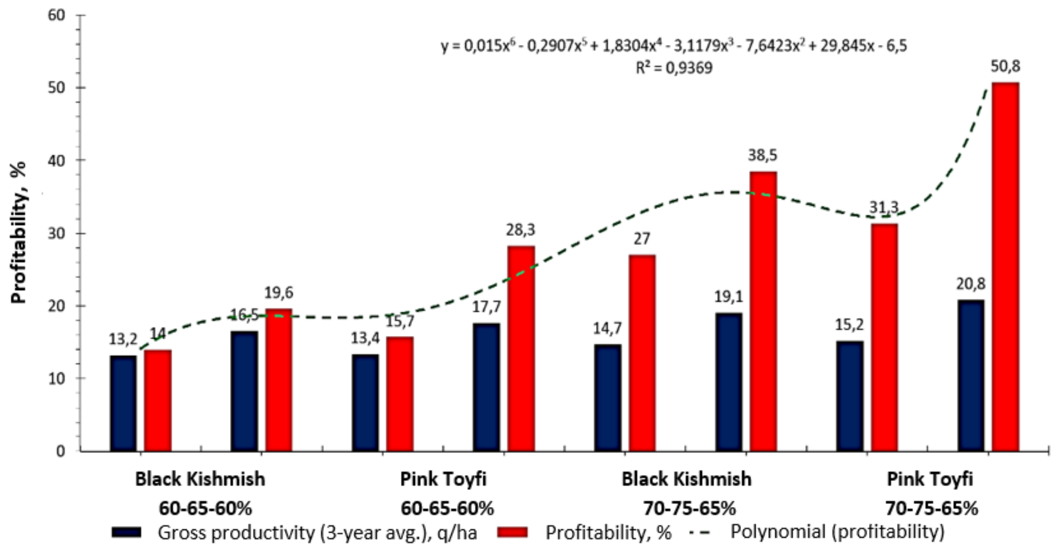

Figure 5. Average three-year yield and profitability of drip irrigation of grape varieties.

Conclusions

In the conditions of gray soils and limited water resources in the foothills of Kashkadarya province in Uzbekistan, an investigation on drip irrigation of vineyards with local runoff was carried out. At the same time, pre-irrigation soil moisture was maintained at 70-75-65% relative to LFMC, irrigation was carried out in 2-3-2 system with irrigation norms of 170-200 m^3/ha, and seasonal irrigation norms of 1300-1900 m^3/ha. As a result, 33% of water resources were saved, yielding 20.8 tons/ha from grapes, which was found to be 5.6 tons/ha or 24% higher than the control option that is a traditional furrow irrigation.

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