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Land suitability assessment for grapevines via laser level in water-scarce regions of Uzbekistan (in the case of Kashkadarya province)

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Abstract. The most suitable arable land for viticulture is mainly located in the rain-fed areas such as in the foothills and mountainous regions of Uzbekistan where vineyards reach the acme point of the yield productivity. Irrigating with rainwater in the vineyard has a great potential for obtaining stable yields at the low cost of irrigation water which is proven by experimental and theoretical studies. This paper aims at implementing and testing the advantage of sustainable irrigation methods in water-scarce regions of Uzbekistan by scrutinizing the hydraulic characteristics of irrigation water and slope of the study area. We considered the maximum evapotranspiration rate in general for all phases to calculate the amount of irrigation water required per one vine tree since considering the water scarcity in the maximum growing season is important. We firstly aimed at constructing the pool to store raindrops. To perform this, we used the laser level for checking land suitability and a standardized 20 Ø irrigation pipe to deliver rainwater from the pool to the furrows of the vineyard. The results of the geodetic survey showed that the average slope of the pilot area was equal to 0.022 and enabled to implement the rainwater irrigation.

1. Introduction

Water is the source of life for every living organism, especially a primary resource that plant requires to thrive [4]. The plant organism is an integral part of the internal plant structure and its growth, development, productivity and potential yield, complex physiological processes such as photosynthesis, transpiration, and respiration go normal and intense if the plant organism consists of sufficient water [8]. Some plants such as grapevines are relatively drought-tolerant, so if vineyards are watered, when needed, they can be well developed and an increased amount of yield can be harvested [10].

According to Saidkhodzhaeva and Abdumutalipova [20], Smirnov et al. [24], and Smirnov et al. [25], around 71-73% of the grape leaves, 80-85% of the grape shoot, roughly 30% of the grape body, 40% of the grape rust and nearly 50-55% of the grape roots contain water molecules. Based on these



researchers' results, it was proven that most of the water located in the rain-fed areas such as in the foothills and mountainous regions of Uzbekistan where vineyards reach the acme point of the yield productivity.

When choosing an appropriate place for vineyards in mountainous and foothill areas, the following should be taken into account [6, 11, 16]:

- The area, in which the vineyard is planted, should not be less than 10-15 hectares and should be able to be expanded further;
- To mechanize grape planting and maintenance, the area should not be more than 10 degrees slanted, and if it is highly sloping, the land should be adjusted and leveled;
- Areas where the foothills are less dense and more humid in during summer period;
- Grapes need to be sowed and planted on the southern slopes of a higher zone so that the grapes ripen early and have relatively high sugar content;
- The vineyard area must be well-cultivated prior to the grape sowing period;
- To make efficient use of rainwater (mudflows), the rows of grapes should be located horizontally. On the condition that the slope of the vineyards accounts for 5-10 degrees, the rows of grapes are recommended to plant horizontally, and if the slope is more than 10 degrees, the prospective vineyard is leveled first;
- The deep cultivation is recommended before planting vine grapes since the deep cultivation enables the viticultural crop seedlings to grow stronger over time.
- The amount of grape seedlings per hectare in the foothills and mountainous areas is determined by considering the sort of grape and local abiotic conditions.

After having located the appropriate place for viticulture, formulating proper procedures for water delivery to the field is the weak point of most studies. While conducting research on choosing an appropriate approach to water delivery to the irrigation water-scarce regions to irrigate, the main objective of irrigation should always be considered. This aims at generating higher yields with minimum water costs to create a production unit [1, 13].

This problem can be solved reasonably by contributing to the introduction of new sustainable irrigation methods, for instance, efficiently using the actual soil moisture in a combination with advanced furrow irrigation (storing rainwater) [9, 21]. For the development of irrigated viticulture, the implementation of automatized irrigation is important, which is not possible without managing the soil-water regime [5, 18]. Unlike surface irrigation, it is only used to moist the root zone of vine grapes. According to the theoretical justification for surface irrigation method, as evidenced by several experimental studies, advancing this conventional irrigation method requires further deep scientific study on the one hand [1, 12, 22]. On the other hand, irrigating with rainwater, using local stream waters as an irrigation water source, in the vineyard has a great potential for obtaining stable yields at a low cost of irrigation water which is proven by experimental and theoretical studies [15, 19].

Considering all the above, this paper aims at implementing and testing the advantage of sustainable irrigation methods in water-scarce regions of Uzbekistan by scrutinizing the hydraulic characteristics of irrigation water and slope of the study area.

2. Materials and methods

2.1 Study area

Uzbekistan is a land-locked country which is located in Central Asia between the Syr Darya and the Amu Darya rivers. The total territory of the republic is 447,400 km², in which just less than 43,000 km² is used for agricultural purposes. Large valleys and deserts, foothills, and mountain regions characterize the landscape of Uzbekistan. Due to the geographical location of Uzbekistan, dry and continental weather can be observed at any time of the year and it is considered as a (semi-)arid zone [23]. Uzbekistan has a unique climate condition consisting of long, dry and extreme summers, cool and wet autumns and chilly winters with thaws [7]. The average temperature during the peak

summertime (July) is 28°C while the mean temperature is 1°C in peak winter time (January). The mean annual sum of precipitation is 424 mm [2].

The most productive vineyards are located in foothills and mountainous areas such as Kitab, Shahrisabz, and Yakkabag administrative districts of the Kashkadarya province and Ahangaran, Parkent and Chirchik administrative districts of the Tashkent province in Uzbekistan [6]. Therefore, the study area selected for this research is the ‘Guldorasoy’ Water Consumers Association (WCA) oriented to viticultural farming located in the Yakkabag administrative district in the Kashkadarya province (37°58’39’’N and 64°23’42’’E) (Figure 1).

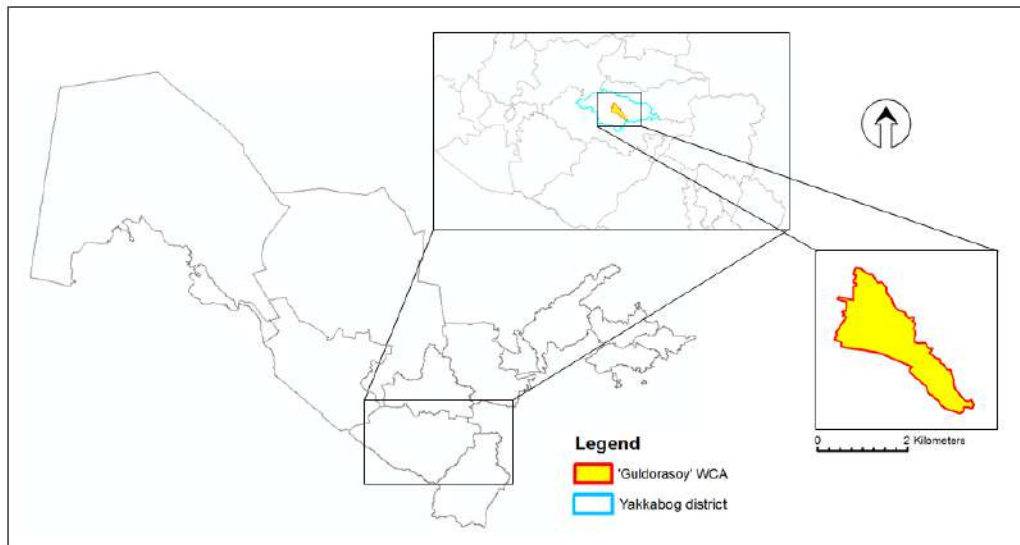


Figure 1. Location of the study area

The climate of the Kashkadarya province is moderately continental and at the same time with hot summers and cold winters. The cold winter air in the northern part of the Arctic causes a significant reduction in temperature. In January, average temperatures may drop from 0 °C to + 2 °C, sometimes from -15 °C to -25 °C in winter. Summer is hot and dry and lasts for a long time and in July, average daytime air temperatures sometimes range from + 44 °C to + 47 °C. By the second half of the summer, windy weather dominates and significantly damages agricultural crops. The sum of the average long-term amount of precipitation is: in the plains 290-300 mm; in the hills 320-550 mm; in the mountains 550-650 mm. Winter and early spring are the precipitation seasons of the study area. The long-term average sum of precipitation calculated by the Kashkadarya provincial station is demonstrated in Figure 2 below. All climate data were derived from the Uzhydromet Service [26] and these data assisted us to determine the period when the rainfall water could be stored in pools for the purpose of the implementation of sustainable irrigation.

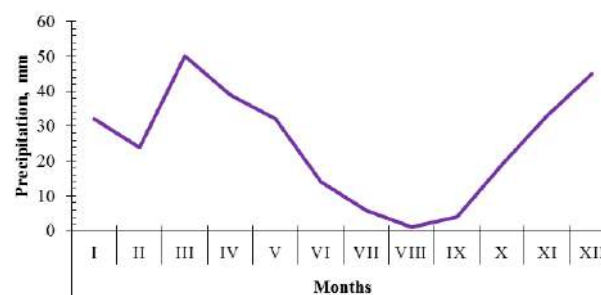


Figure 2. Long-term average sum of precipitation in the Kashkadarya province

As can be seen from Figure 2, the high distribution of precipitation is expected in the beginning and at the end of the year, while during the remaining months, a lack of precipitation mainly occurs. The mountainous and foothill zones, considering their soil-climatic and relief conditions, are fundamentally different from the plain zone [13]. Therefore, the selection of an appropriate area for viticulture and the maintenance of vine grapes require special attention for water delivery and the improvement of yield.

2.2 Materials

For this research, we mainly collected our data based on the secondary data and fieldwork results derived from the experimental field. To calculate the vine grape water consumption, the reference evapotranspiration rate of vineyards is required. This rate is gradually different according to the phases of the growing season (Table 1) [6, 11, 24, 25]. But here, we used the maximum evapotranspiration rate in general for all phases to calculate the amount of irrigation water required per one vine tree since considering the water scarcity in the maximum growing season is important.

Table 1. Growing phases of grapevines

| Phases | Dormancy | Bud break | Blooming | Fruit set | Veraison and fruit maturation | Post-harvest |
|--------|----------|-----------|----------|-----------|-------------------------------|--------------|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Days | 10-15 | 40-45 | 8-14 | 30-60 | 20-60 | 30-60 |

In order to determine the slope of the study area, we used the laser level ‘Johnson Level Tool 99 006K’. This rotary laser level is capable to project a 360-degree beam of light. The laser itself can self-level on the horizontal plane while the vertical plane can be manually operated. The lasers’ split beam feature is used to set up a 90-degree angle where needed. All results of the laser leveling were transferred to the ArcGIS software to manually plot the research area’s slope and its mini Digital Elevation Model (DEM). Determination of the slope and mini-DEM of the study area enabled us to decide on the appropriate place where the proposed pilot area should be located.

We used a standardized 20 Ø irrigation pipe, produced for the purpose of water delivery in the drip irrigation system. In total, 205 meters of plastic pipe were used in our experiment for transferring water from the water source and ensuring ‘furrow-to-furrow’ transition of rainwater.

2.3 Methods

The selected viticultural area is located in the foothills of the Khantag (Khantakhta) ridge, west of the Khisar rangeland. The vineyards on the ‘Normumin ota’ farm in ‘Guldorasoy’ WCA were cultivated under the cultivating viticultural Uzbek standard scheme ‘3 x 2’. In this standard scheme, three (3) denotes the distance between rows, while two (2) stands for the gap between two bushes (in meters) in one row (Figure 3) [12].

Once we have chosen an appropriate study area to conduct this research, to implement the irrigation with rainwater, considering its hydraulic aspects in steep slopes, the actual value of the vineyard’s slope in the ‘Guldorasoy’ WCA has to be first determined. To examine the natural capability of our research area’s geomorphological condition to ensure us to efficiently use hydraulic parameters of irrigation water, we calculated the average slope of the study area using the following Equation 1 [13, 14].

$$i_{average} = \frac{i_1 + i_2 + \dots + i_n}{n} \quad (1)$$

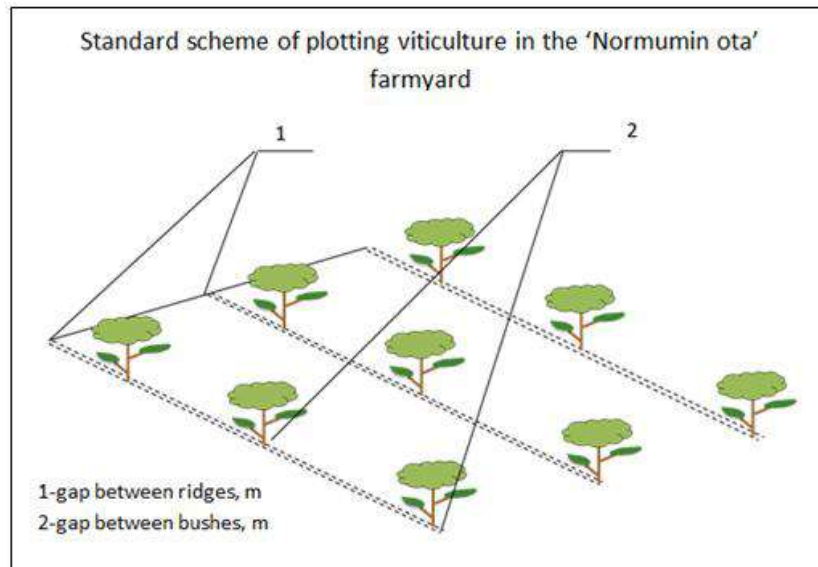


Figure 3. Visualization of the standard scheme in viticulture

Where i_1 is the record of land level derived from the first checkpoint, i_n is the record of land level derived from the last checkpoint, and n is the number of checkpoints.

As far as we proved the suitability of the study area's slope for promoting rainwater irrigation, the number of grape seeds to be sown in the area ($10,000 \text{ m}^2$) had to be determined by the Equation 2 below [27]:

$$X = \frac{10000}{a \times b} \quad (2)$$

Where X is the number of bushes per one hectare, a is the distance between rows, and b is the distance between bushes in one row.

After having calculated the number of bushes in the vineyard, we then needed to calculate the reference evapotranspiration rate out of one grapevine. The following Equation 3 determines the evapotranspiration rate of one grapevine [3]:

$$ET_c = K_c \times ET_0 \quad (3)$$

Where K_c is the factor of water requirement of grapevines (0.4 for low biomass; 0.8 for full biomass) and ET_0 is the cost of initial evapotranspiration.

Based on all these materials and methods above, we derived the results on the promotion of sustainable rainwater irrigation that contributes to the solution of making proper decisions on choosing irrigation types in water-scarce regions.

3. Results and Discussion

As from the 'Guldorasoy' WCA's viticultural farmyard, we conducted our experiment in around 400 m^2 (9 meters x 44 meters) pilot area. This is because simultaneous experimentation on one hectare ($10,000 \text{ m}^2$) requires economic and technical resources, and materials.

Referring to Equation 1 above, we carried out the calculations to determine the actual slope of the pilot area allocated from the selected farmyard. We installed 12 checkpoints per every four meters to improve the accuracy of the outcome, whilst results, derived from the GIS software, provide only with the percentage value of the actual slope after analyzed the digital elevation models (Figure 4) [17]. Each value of 12 checkpoints was obtained from the laser level via a geodetic survey. All leveled data were given in Table 2.

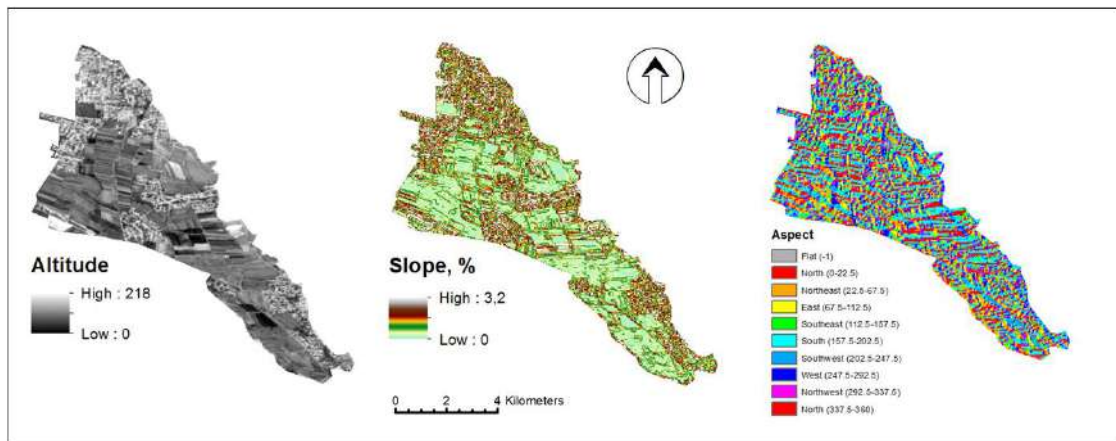


Figure 4. GIS-based analysis of land suitability in the ‘Guldorasoy’ WCA

The results of the geodetic survey showed that the average slope ($i_{average}$) of the pilot area was equal to 0.022. This enabled rainwater to be delivered by the pipes to the vineyard furrows, taking into account rainwater’s hydraulic parameter: transferability in steep slopes without human factor.

Using the Equation 2 above, we calculated the number of shoots per hectare according to the standard scheme (3x2) (Figure 3) that was proposed in our circumstance and 1,667 grape trees can be planted per hectare. For the selected pilot area, 67 grape seedlings were planted, accordingly. Regarding the Table 1, the current water consumption and evapotranspiration rate for each grapevine seed were determined using Equation 3.

Table 2. Results of geodetic survey in the pilot area

| Name of checkpoints | Length of the field | | Land level |
|---------------------|---------------------|------------------|------------------|
| | <i>in meters</i> | <i>in meters</i> | <i>in meters</i> |
| CP1 | 0 | 0 | 292.65 |
| CP2 | 4 | 4 | 292.34 |
| CP3 | 4 | 8 | 292.20 |
| CP4 | 4 | 12 | 292.06 |
| CP5 | 4 | 16 | 291.93 |
| CP6 | 4 | 20 | 291.89 |
| CP7 | 4 | 24 | 291.85 |
| CP8 | 4 | 28 | 291.81 |
| CP9 | 4 | 32 | 291.78 |
| CP10 | 4 | 36 | 291.71 |
| CP11 | 4 | 40 | 291.68 |
| CP12 | 4 | 44 | 291.66 |

Grapevines in the dormancy period of the growing season require significantly less water, around one liter per day due to evapotranspiration, and this rate considerably grows by 5.5 liters per day in the ending phases of the growing season. In this paper, we simulated the crop water demand in this pilot study area considering the maximum reference water consumption in the growing season. In total, we planted 67 grapevines for 400 m² of our pilot area and the amount of water consumed per day accounted for 368 liters based on Equation 2. To fulfill the crop water demand, we proposed to construct a volume, serving to save rainfall during the rainy season for each pilot area (Figure 5).

Figure 5 is a pool area with natural rainwater harvested on the farms, belonging to the ‘Guldorasoy’ WCA. The length of the rainwater pool is 3.8 m, 2 m deep, and 2.2 meters wide. Taking into account the pool capacity, 17 m³, we determined that the rainwater, transferring through the chosen irrigating

pipes, can be used to intensively irrigate the 400 m² vineyard for 46 days without considering the actual soil moisture content in the peak water stress period.



Figure 5. Proposed volume (pool) for saving rainwater

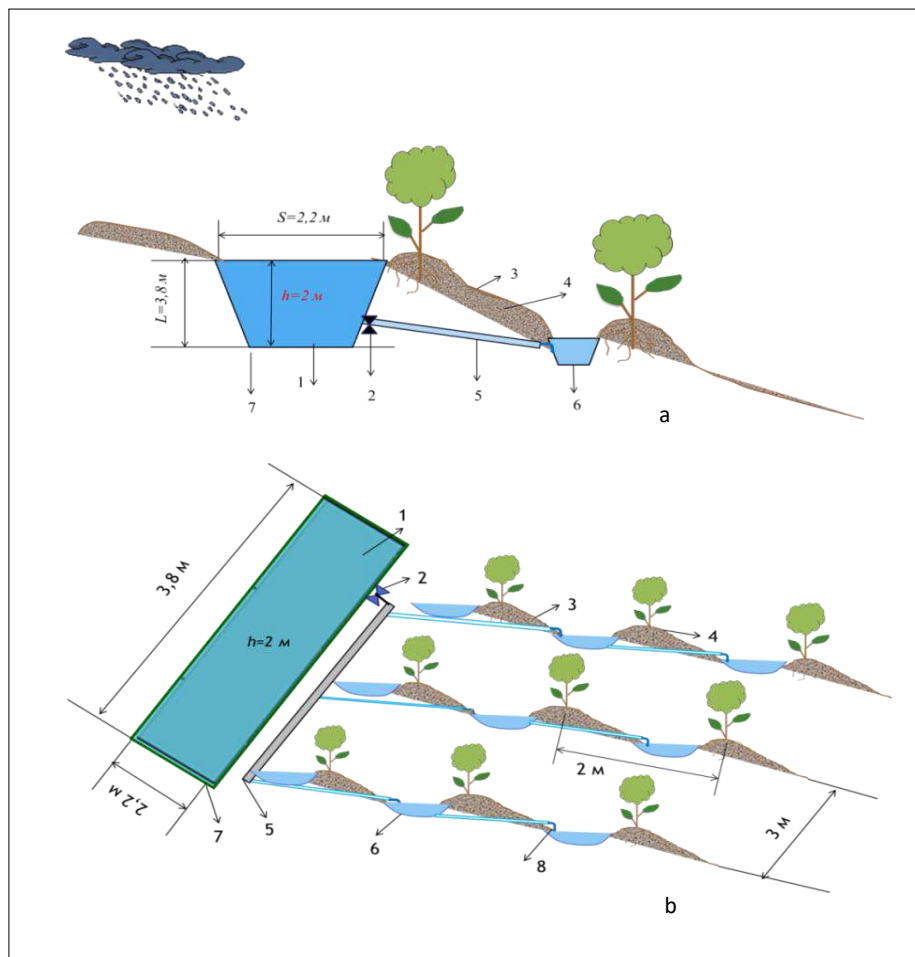


Figure 6. The plot of localized water collection and transition: a-cross sectional view; b-horizontal view (1-rainwater storing pools; 2-management bulb; 3-standardized slope of ridges with reference to the actual slope of the field; 4-surface of the terrace; 5-main pipeline; 6-furrows; 7-plastic film; 8-water faucet)

The harvested rainwater transition scheme from the pool to the subsequent furrows in vineyards, ensuring the efficient use of irrigation water is shown below in Figure 6. In the case of the rainwater transition process, the harvested water is firstly used in the first furrows and then transferred to the next furrows.

Prior to storing raindrops, the surface of the empty pool is covered by plastic film and after having filled out the pool with rainwater, the plastic film is also placed on the surface of rainwater in the pool over to prevent absorption and evaporation processes.

Soil moisture accumulated by rainfall in plain areas of Uzbekistan is not sufficient for grapevines to grow well. Soil moisture is regulated by irrigation at certain periods of growth and where annual precipitation is 450-500 mm. In mountainous and foothill areas, not only pre-irrigation measures but also the timely and qualitative treatment of wineries, weed removal, mulching, planting of protective trees and other agro-technical measures are important in regulating soil-water regimes. Under the conditions of irrigated and rain-fed viticulture, the knowledge of the agrophysical properties of soils is important for improving land and yield productivity [13, 18, 21].

All findings above, based on the selected study area, rendered reasonable patterns to promote the implementation of the proposed sustainable approach to irrigate the vineyards, using the rainwater source in the foothills or mountainous areas of water-scarce regions in the case of Uzbekistan. On the condition of constructing 25 rainwater storing pools that we discussed above, one hectare of the vineyard can naturally be watered by raindrops in the peak growing seasons without squandering efforts to take the irrigation water from down to up, using pumps which require additional energy.

4. Conclusion

The new irrigation technology to mitigate the demand for water is characterized by relatively small contours, complex relief, and high slopes. The main disadvantages of conventional furrow irrigation are the uneven distribution of moisture along the length of the furrow and the high irrigation water loss for discharge and filtration. Therefore, it is necessary to recommend economically inexpensive, easy-to-use irrigation systems that will prevent resource-saving, irrigation erosion, and soil erosion.

The irrigation techniques and technology we recommended include pipelines that allow for a stable production process and the accuracy and regularity of water demand for today's crop-water needs.

Non-traditional irrigation techniques that we also recommended for use in gardens and vineyards are based on the principle of "Local water collection and distribution". Irrigation is carried out at very short distances (1.5-4.0 m) from the beginning to the end of the furrows along the rows of seedlings, with the distribution of the same amount of water consumption. New irrigation technologies have been used to irrigate the grapes at a time of scarcity by collecting local stream rainwater. When harvesting vineyards of the 'Guldorasoy' WCA in June and July prior to the experiment, the yields were lower because of a lack of moisture caused by water scarcity, while using stored rainwater for irrigation resulted in relative changes in the yield of grapes.

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