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Calculation of Humidification Contours upon Drip Irrigation of an Intensive Apple Orchard in Zhambyl Region

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ABSTRACT

Based on the increasing efficiency and productivity of water resources by improving the technique and technology of intensive drip irrigation of apple orchards, calculations were presented on the formation of a moisture contour by drip irrigation for apple seedlings and seedlings of low-growing fruit-bearing apple orchards in the conditions of the foothill zone of the Zhambyl region, the justification of the intensity and time of water supply, the placement of the number of droppers providing moisture to the root layer of apple trees grown to maintain humidity in accordance with 0.8 MC in the foothill zone of the Zhambyl region on light grey soils with insufficient natural humidity. As the apple trees grow and develop, the need to moisten the root layer along the drop line increases until the wet contour is completely covered. It is established that during mass watering of apple orchards, the regularities of the process and dynamics of soil moistening are established depending on the value of the irrigation rate. With drip irrigation, the root layer of the soil is compacted.

1. INTRODUCTION

In Kazakhstan, the industry of intensive gardening is beginning to develop rapidly. A distinctive feature of intensive gardening is agronomic support for a period of one to three years. The level of provision of the population with high-quality apple products in the Republic of Kazakhstan is currently characterised by a very low level of development. The year-round consumption of fresh apples in the Zhambyl region is an important factor in maintaining the health of the local population, children and adolescents, especially the vitamins and nutrients contained in apples. In addition, the issue of full-fledged water supply of gardens and the efficiency of reclamation of irrigated lands is relevant. The arid climate, the lack of natural groundwater and fresh water stimulate the development of small-scale irrigation of gardens in the Republic of Kazakhstan. The biggest task in the design of low-pressure drip systems is to determine the mathematical parameters of the humidification circuits in the root system area, the volume and size of which are determined by the norms and the amount of water supplied by the drops. The study of the parameters of the moisture contours for different irrigation standards is carried out by calculation, considering many factors: the initial degree of moisture content of the site, soil type, soil water permeability, porosity, salinity, density of the soil profile. When choosing varieties and seedlings of apple trees, their requirements for the temperature and humidity regime of the region were considered, which determines the duration of the growing season, the technology of tillage, the timing of harvesting and garden care. Also, to determine the needs and efficiency of the market in the varietal composition of apple products.

Recently, due to the development of irrigation of crops and gardens in agriculture, one of the most promising effective irrigation methods is the low-pressure drip irrigation method. It is obvious that this approach allows creating the most favourable conditions for plant species, to carry out direct water supply to the roots of plants, to automate the irrigation process during irrigation. At the same time, the drip irrigation method is one of the localised irrigation methods. However, when choosing a method of irrigation of fruit-bearing intensive apple orchards, it is necessary to evaluate not only the economic efficiency, but also the environmental feasibility. With drip irrigation, the yield of fruit crops increases by 1.3–1.8 times compared to furrow irrigation, and the saving of irrigation water reaches 60–80% [1].

When the yield of the orchard is reached, the payback of capital expenditures does not exceed 1–2 years. The formation of a favourable water regime by drip irrigation of fruit plantations is achieved by maintaining a high level of soil moisture before watering. For an intensive apple orchard, at least 75–80% of the minimum moisture capacity in the root layer of the soil is approximately 0.2–0.8 m. At the same time, the local moisture content does not exceed 0.1–0.3 of the area, depending on the tree planting scheme, the type, variety of culture and the water-physical properties of the soil. Increasing the high efficiency of this irrigation method is the basis for obtaining maximum production with a minimum amount of irrigation water and labour costs of fields [2].

Artificial irrigation was first used in the 1980s of the 20th century as a way to enhance food production, but for many years traditional systems' water consumption efficiency did not reach 30%. A proactive shift to drip irrigation, also known as trickling irrigation, micro-irrigation, or localized irrigation, was observed in response to the traditional irrigation techniques' low efficacy (sprinkling, furrow irrigation) [3]. Through a system of pipelines, valves, drip lines, and emitters, the drip irrigation system enables to conserve water and nutrients (dispenser-droppers). Directly reaching plant roots or the soil's surface, water moves slowly. The adoption of drip irrigation technology is crucial since it guarantees that water consumption efficiency in the range of the 80% [4]. The state of innovative technology implementation will determine the prospects for the growth of irrigated agriculture. Despite some encouraging trends in recent years, irrigated agriculture still needs large expenditures in regeneration and modernization.

However, the methods of implementing the drip irrigation are currently hampered by insufficient theoretical research on the use of such systems and technologies of specific irrigation regimes and irrigation methods [5]. In this regard, research on the preparation and improvement of drip irrigation systems in long-term intensive apple orchards in arid zones with insufficient precipitation is of scientific and experimental-practical interest from the point of view of rationing and water supply to plants. In this context, the yield of agricultural crops increases by 30–50% compared to other irrigation methods [6]. Despite this, the issues of improving the technique and technology of drip irrigation directly for intensive apple orchards remain insufficiently studied. Large-scale studies on drip irrigation of fruit plantations were carried out mainly in the southern part of the Republic of Kazakhstan in the foothill and steppe zones. Although such studies are carried out practically for the southern part, there are not enough materials confirming scientifically based recommendations for its use. Therefore, this study is aimed at developing the technology and modes of drip irrigation of intensive fruit-bearing apple orchards on grey soils of the Zhambyl region.

2. MATERIALS AND METHODS

For research and practical work, drip irrigation facilities were selected, built in the "Gardens of the East AGRO" LLP, located in the foothill zone of the Zhambyl region in the village of Kulan of T. Ryskulov district. The climatic conditions were determined according to the results of the research of the weather station "Zhambyl", located in the city of Taraz. It has a long growing season in the north (145–160 days) and in the south (165–175 days) of the Zhambyl region. In this regard, the average daily positive air temperature during the growing season in the north and south is above +10°C. Furthermore, these thermal reserves are sufficient for the maturation of various agricultural crops.

In this area, only 140 mm of precipitation falls during the warm period, and at the onset of the growing season, the amount of precipitation is 80 ... 100 mm. At the evaporation rate of 1000 mm, the average annual precipitation in the Zhambyl region ranges from 250 to 330 mm. It is obvious that not enough precipitation falls in the region, and most often these precipitations are of a strong nature. Most of the precipitation flows down from the site, does not have time to absorb into the soil surface, because of this, it has a slight effect on the increase in soil water reserves.

Analysing the average annual climatic data of the Zhambyl region, it can be noted that the greatest amount of precipitation falls in spring (28.9%) and autumn (25.9%). The smallest share of them is in summer (17.3%) and in winter (22.6%) [6]. In general, the annual amount of precipitation in the region is low, especially in its flat part (140-220 mm per year). A negligible amount of precipitation (135 mm per year) is observed in the north-east of the region near the coast of Lake Balkhash. In the foothill areas, the amount of precipitation increases to 210-330 mm. To regulate the degree of moisture availability of the territory, including the lack or excess of moisture, the hydrothermal coefficient is used as an indicator, which is given by G.T. Selyaninov. This coefficient is the ratio of the amount of precipitation during the growing season of plants with an average daily temperature above +10°C to the number of positive temperatures increased by 10 times over the same period. When the hydrothermal coefficient changes in the range from 0.4 to 0.7, the moisture supply of the territory is characterised by a dry climate. At the level of 0.15 – a low level of natural moisture [7].

Analysing the climatic conditions of the region, it can be concluded that the Zhambyl region is sharply continental. It is characterised by long, hot and dry days of summer and cold days of winter with little snow. The average annual temperature is 5.6–8.6°C. According to the indicators, July is the hottest month, the average monthly air temperature is +21.0°C + 25.0°C. During the years of research, the average monthly air temperature in 2018 and 2020 was above the norm by + 1.2°C, and in July 2019 it corresponded to the average annual norm.

In summer, on some days the air temperature is close to +40°C. In 2018 and 2019, the maximum temperature was +33.9°C and +37°C, respectively. These indicators are +2.7 and +3°C higher than those of the long-term average. In three years of research, 2019 was the hottest year. The maximum temperature in June, July and August was +36.6°C, +37°C and 39.9°C, respectively (Figure 2). Especially with insufficient humidification of the air and soil, such high temperatures in some years can damage the leaves, fruits and the trees themselves [7].

3. RESULTS AND DISCUSSION

According to the data, the coldest month of the year is January. In January, the air temperature is -7.1, -15.1°C, in some years it decreases to -28, -32°C. In recent years, snowfall in December and January is less noticeable. In winter, there is a rise in air temperature, snow melts, as a result, the snow cover becomes unstable. The annual average of days with snow cover is 35–100 days, and its thickness is very small. When the thickness of the fallen snow varies between 15–25 cm, its maximum thickness is 30–40 cm. The fallen snow does not lie in the zone for a long time. The first snowfall in the region falls in the second decade of November, sometimes in the third decade of December. Precipitation is observed in the winter months. The average duration of frost-free days is 114 days. The average depth of soil freezing is 1.25 m.

The soils of the studied zone are medium-loamy grey soils. During the study, soil samples were taken from three places. The soil of the study area 0.02–1.42% is characterised by a small amount of black rot, has a lumpy-block structure, that easily breaks down under the influence of mechanical action and moisture. The soil structure is light to medium loam, the content of physical clay is 27.1–29.0% (Table 1). The mechanical composition and water permeability of the calculated soil layer are the same. The filtration coefficient of the calculated layer is 0.2–0.4 m per day. The porosity of the soil of the study area is 48.61–55.64%, the density is 1.21–

1.35 g/cm^3. At a depth of 0.2m, there is a significant compaction of the soil of 0.6 m, the density increases to 1.42 g/cm3, the porosity decreases to 46%. The maximum field moisture capacity is 27.9–30% and the maximum molecular moisture capacity is 10.3–12.12% of the soil volume. According to the results of chemical analysis, the water extracts of the soil of the study area are not saline. The dry residue of a meter thickness is 0.1–0.72% of the mass of dry soil [8].

When studying the soils of the experimental site, special attention was paid to determining their water-physical properties. Table 1 shows the characteristics of the soils used in the calculations of the water balance, when determining the elements of irrigation equipment and the dynamics of moisture in the calculated soil layer, when calculating the irrigation regime.

The research conducted in the Zhambyl region is primarily aimed at studying the features of irrigation of lands in this region and their classification. During the study, the water-physical properties of the soils and the relief conditions of the irrigated experimental site were considered, based on these data, an experimental site was selected and experimental field studies to achieve this goal were conducted. Field experiments were carried out on four varieties of apple trees: Golden Delicious, Gala, Idared and Fuji. The distance between planting trees is 4x1.5 m. Fruit-bearing (apple-bearing) garden is a 5-year-old intensive trellis-dwarf apple orchard. The beginning of experimental work is in the spring of 2019. During the study period, logging was carried out in early spring (March). Fertilisers were applied in the form of top dressing and irrigation water. Fertilising with irrigation water was divided into two stages: the first lasted 35 days, and the second – 20 days (calendar from May 21 to July 20 and the beginning of August). Irrigation of the experimental area of the study was carried out by the "TALGIL DREAM 2" drip irrigation system and the production of drip tapes by the Israeli company "Matzerplatz". This system provides water supply and is equipped with semi-compensated drops. Droppers with a flow rate of 2.2-2.5 l/h have a hole with a diameter of 1 mm. The working pressure of drip systems is 5–40 m [9].

According to the scheme of field experimental practice, 4 irrigation options were adopted (Figure 1):

Option No. 1 – drip irrigation with soil moisture retention of at least 90% MC;

Option No. 2 – drip irrigation with soil moisture retention of at least 80% MC;

Option No. 3 – drip irrigation while maintaining soil moisture of at least 70% MC;

Option No. 4 – furrow irrigation with soil moisture retention at the level of 80% MC (control)

The test plots were rectangular. The experiment was repeated 3 times. The drip strips were 130 m long.

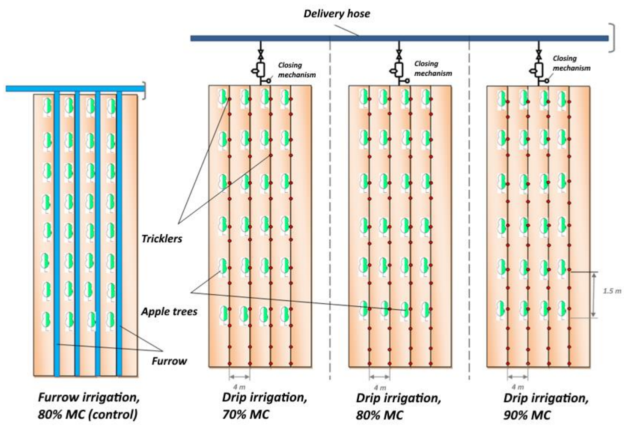

Figure 1. Scheme of placement of variants of the field experimental practice on the irrigated area with the use of drip irrigation

Table 1. Mechanical composition of the soils of the experimental site

No.	Horizons, cm	Fraction content, %								Physical clay, %
		>1.0	1.0–0.25	0.25–0.10	0.10–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
1	0–20	2.2	4.1	8.1	10.1	48.2	6.6	9.1	11.6	27.3
	20–40	2.4	3.8	6.3	10.6	49.7	9.1	6.3	11.8	27.2
	40–60	2.1	3.9	5.8	8.3	51.6	9.3	10.1	8.9	28.3
	60–80	3.0	2.7	5.3	8.2	52.1	9.5	10.8	8.4	28.7
	80–100	2.5	1.8	2.5	12.4%	51.8	8.5	9.6	10.9	29.0
	0–100	2.4	2.7	5.9	11.4	49.3	8.6	10.3	9.4	28.3
2	0–20	2.3	3.5	3.6	15.7	47.5	9.8	8.5	9.1	27.4
	20–40	2.4	3.8	5.8	11.1	48.6	8.8	9.4	10.1	28.3
	40–60	2.7	4.6	5.2	12.4	47.6	7.3	11.1	9.1	27.5
	60–80	2.9	2.7	6.3	10.8	49.3	9.2	113	7.5	28.0
	80–100	2.5	3.8	4.9	17.3	42.5	8.9	10.3	9.8	29.0
	0–100	2.7	4.2	5.3	11.4	47.6	7.9	10.3	10.6	28.8
3	0–20	2.4	4.8	7.5	11.1	46.3	9.3	12.5	6.1	27.9
	20–40	2.3	4.9	6.3	11.7	47.4	9.8	10.2	7.4	27.4
	40–60	2.1	18.2	11.9	10.9	28.7	10.1	7.3	10.8	28.2
	60–80	2.7	12.5	8.6	10.2	37.4	12.7	9.5	6.4	28.6
	80–100	2.5	9.2	9.3	6.4	44.8	11.9	6.1	9.8	27.8
	0–100	2.8	7.4	9.4	14.7	38.6	10.6	9.3	7.2	27.1

The results of various studies prove that there are some differences in the watering of fruit-bearing orchards. It is known that in the case of irrigated agriculture, the water consumption of intensive apple orchards is almost completely determined by the irrigation regime of irrigated plantations. In this case, it is necessary to consider the density, age and biological characteristics of perennial fruit trees. Therefore, when determining the watering of an apple orchard, it is necessary to consider such factors as the depth of the moistened soil layer, humidity, density, precipitation, minimum soil moisture [10]. Thus, the number of pre-irrigation and irrigation norms was determined by the formula,

[11] (1):

$$m = \gamma \cdot H \cdot 100 \cdot (\beta_{MC} - \beta_{TMC}), \quad (1)$$

where, m is the irrigation rate, m^3/ ha; γ is the soil density, t/m^3; H is the power of the calculated soil layer, m; β_{MC} is the soil moisture; β_{TMC} is the soil moisture on the site before watering.

Notably, this formula is suitable when it is necessary to achieve complete moistening of the irrigated area. With the local irrigation method, part of the irrigated area remains non-irrigated, so this formula does not consider the features of local drip irrigation. When determining the irrigation standards in the case of local irrigation, it is necessary to consider the optimal contour of the amount of moisture. The system of plants in the soil horizon corresponds to the placement of the main mass of roots. Based on the above, the area of the humidification circuit when irrigating an apple orchard for the structure under study depends mainly on the number of drops installed directly for watering one plant. Then the calculated irrigation rate for one plant (contour) takes the following form [12] (2):

$$m = 10 \cdot F \cdot h \cdot \gamma \cdot (\beta_{MC} - \beta_{TMC}), \quad (2)$$

where, F is the area of plant nutrition, m^2; h is the depth of the soil, m.

The area of the moisture contour varies considerably for different soils, so the number of droppers per tree depends on the type of soil. Experimental studies are characterised by the transfer of different irrigation standards when watering with one, two and four drip installations located near the trunk of trees [10].

Since the question of the area of moisture distribution in the soil is of great importance, the authors studied the size of the soil moisture contour depending on the irrigation rate for drip irrigation. The parameters of the moisture contour at different irrigation rates in the zone of moisture distribution in the soil after irrigation were estimated by comparing the values of the efficiency coefficient, i.e., the optimal water distribution. Thus, the closer the data is, the more effective drip irrigation can be considered. The efficiency coefficient can be defined as the ratio of the height of the humidification circuit to the width, then [8] (3):

$$K_{HC} = \frac{H}{L}, \quad (3)$$

where, H and L are the height and width of the humidification circuit, m.

To determine the dynamics of humidity, soil samples were taken 0.5 days before and after watering, as well as 1.5, 2.5 and 4.5 days after watering. In addition, the most important elements of the technology for drip irrigation are the main parameters of the humidification circuit, their maximum width, depth, vertical and horizontal zones, as well as humidity. These values depend mainly on the water-physical properties of the soil, the structure of droplets, the characteristics of pressure and flow of droplets and the biological characteristics of agricultural crops. The results of the humidification contour formation studies are presented in Table 3 [13].

In the field conditions and all changes in the dynamics of soil moisture were studied on water-balance plots. These are special sections of the experimental research site, placed diagonally across each section at a distance of 10 m from the beginning, in the centre, and also at a distance of 10 m from the end of the section. When using different irrigation standards, funnel-shaped pits are cut out, which measure the shape and size of the humidification contour. Soil moisture during drip irrigation before each irrigation and after each irrigation in 3 repeated forms, drilling was carried out at a depth of 1.5 m and soil samples were determined by sampling from pits.

The results of the indicators obtained during the analysis revealed that the distribution of moisture in the soil and its humidity contour mainly depend on the volume of the irrigation norm. The indicators of studies with the placement of one, two and four drops were obtained under the conditions of determining the optimal volume of moisture in the area of the root system of apple trees. In general, when installing one dropper at the base of the tree trunk by drip irrigation, with a single watering, water should be given to plants with a volume of no more than 50–70 litres. At a watering rate above 70 l/tree. The water consumption for filtration increases, that is, a deep discharge is formed. The analysis of the obtained data shows that in this volume the water mainly reaches the depth of the main distribution of the root system of the tree, and with an increase in soil moisture to 0.8m, the yield of apple trees practically does not change. At the same time, regardless of the irrigation rate, the highest moisture consumption falls on the upper (0–0.5 m) soil layer, since it is in this layer that the main part of the root system of the apple tree is concentrated, that is, about 80–85% [14].

Considering the results of studying the distribution of soil moisture during single-drop irrigation, the authors began to conduct research using two-drop irrigation. In addition, the main task of the study was to characterise the contours of soil moisture during water supply in the zone of maximum root distribution of no more than 50–70 l/tree. Considering this, one dropper was installed at a distance of 0.5 m from the tree trunk, and the other at the same distance from the other side. At the same time, at a depth of 0.6–0.8 m above the soil surface, the length of the moisture zone increased to 1.6 m, and the width of the soil moisture zone was equal to the maximum diameter of 0.8m (Table 2) [15]. A programme in the visual programming language Delphi 10 was developed and used to automate calculations. The calculations were visualised in the Golden Software Surfer 15 environment [6]. The calculation algorithm consisted in choosing the flow rate of the drop and the time of its operation to moisten the required layer when closing the humidification circuits. Thus, at a dropper flow rate of 2.2 l/h for 20 hours, the 0.8 m layer was moistened to 80% MC along the entire length of the drip line. The calculations performed by the programme mentioned above are shown in Figure 2 [16].

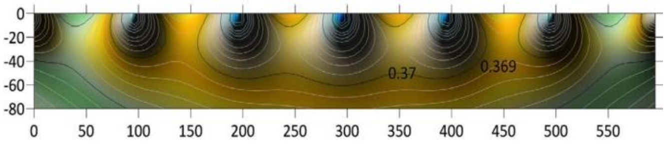

Figure 2. Humidification contours along the line when two droppers are installed every 0.5 m from the tree trunk

Table 2. Distribution of soil moisture during drip irrigation due to the installation of one dropper near the tree trunk

Indicators	Irrigation rate, l/tree		
	70	90	110
1. Maximum humidification depth h, m	1.0	1.15	1.3
2. The maximum width of the humidification, m	0.96	0.98	1.12
3. The maximum length of humidification, m	0.96	1.04	1.19
4. Diameter of the moistened zone, m	0.98	1.06	1.22
5. The maximum value of the ratio, d/h	0.97	0.96	0.90
6. The maximum volume of soil moisture, m^3	0.77	1.48	2.02
7. The ratio of the maximum volume of moist soil to the selected plant, %	10.2	19.6	28.1

Table 3. Formation and dynamics of parameters of the contour soil moistening depending on the irrigation rate and drip irrigation time

	Irrigation rate, m^3/ha											
	(200 m^3) 70% MC				(150m^3) 80% MC				(110m^3) 90% MC			
	0.5	1.5	2.5	4.5	0.5	1.5	2.5	4.5	0.5	1.5	2.5	4.5
Height *H*, m	1.34	1.42	0.79	0.37	1.08	1.17	0.58	0.29	0.85	1.08	0.43	0.23
Width *L*, m	0.69	0.80	0.42	0.17	0.62	0.71	0.32	0.15	0.47	0.58	0.20	0.10
Area *S*, m^2	0.86	1.02	0.31	0.04	0.73	0.77	0.16	0.02	0.37	0.53	0.08	0.01
Efficiency coefficient	1.80	1.68	1.85	1.91	1.66	1.62	1.68	1.72	1.71	1.61	1.81	1.73

During drip irrigation, four droppers were used around the trunk of an apple tree to increase the moisture contour [17, 18]. Drippers were installed around the tree trunk at a distance of 0.5 m from all four sides to supply water around the tree. The results of studies using this method showed a significant increase in the area of soil moisture. For example, if the value of more than 2.0 m to a depth of 0.6–0.8 m, the ratio of the width of the soil moisture, then the area of wet soil increases by 2–3 cm, and the percentage ratio is 35% or more. Notably, this amount of moisture is located in the zone of maximum development of the root system of plants [19, 20].

And it should also be emphasized that in the zone of distribution of the root system of trees, it is possible to increase the amount of moistened soil area by installing four droppers around the tree trunks. This increases the number of droppers per unit of irrigated area, which is the most unreliable element of the drip irrigation system. That is, with drip irrigation, the regularities of moisture distribution in the soil profile and the formation of moisture contours at different volumes of water supply were determined [21, 22].

The obtained data show that with an increase in the irrigation rate, there is a significant increase in the area of the humidification contour. This increases the height and width of the humidification contour. Thus, the height of the humidification circuit at the rate of 200 m^3/ha after 10 hours of irrigation is 1.34 m, and when the irrigation rate is reduced to 150 and 100 m^3/ha, respectively, it is 1.08 and 0.85 m. During the study of irrigation rates, the maximum area of the moistening contour is observed 1.5 days after the end of irrigation. After 2.5 days after irrigation, a decrease in the contour of humidification is observed in all parameters, and if after 4.5 days the nature of the change in the parameters of the contour at different watering rates is assessed, fluctuations in the contour area from 0.02–0.05 m^2 can be observed.

4. CONCLUSIONS

With drip irrigation, the main factor determining the quantitative and qualitative side of the intake and redistribution of moisture into the soil is the irrigation rate. The performed studies on the formation of a humidification contour during irrigation have shown that at high irrigation rates of 200 m^3/ha, compared with low rates of irrigation rates, water penetrates deeper. However, watering at a rate of 150 m^3/ha over the entire soil profile ensures uniform humidity. The study also showed that when watering an apple tree with one dropper of water with a volume of 50 litres/tree, the moistened area of the soil layer where the roots are located is only 4.9% of the amount of allocated soil. If you increase the water supply to the tree to 110 litres, the soil moisture will increase to 28.1%. Consequently, this growth leads to a deep outflow of water, that is, to filtration. Thus, despite the established intensity of research on the successful implementation of land reclamation projects by drip irrigation, there are a number of unresolved issues that make it difficult to further increase the area with this progressive and environmentally friendly method of irrigation.

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