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ON SPECIFIC INFLUENCE OF THE AGROECOLOGICAL CONDITIONS OF HUMID SUBTROPICS OF RUSSIA ON PRODUCTIVE POTENTIAL OF *Actinida deliciosa* (kiwifruit)

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Abstract

Actinida deliciosa (kiwi), recognized for its delicious taste and health-promoting properties, is successfully cultivated in the subtropical regions of the planet. The peculiar climate of the humid subtropics of Russia influences the actinidia plants, in particular, the onset of phenological phases. During fruit formation (June-September), actinidia plants need irrigation depending on the amount of precipitation and temperature conditions. Here we show that in the humid subtropics of Russia, the periods of kiwi fruit formation differ from year to year for precipitations, which coincides with the moisture deficit in the soil. For the first time, we have developed a simple physiological indicator to promptly estimate water status of kiwi plants for timely irrigation based on the cell sap concentration in petioles which correlates with soil moisture in the 0-60 cm layer. Purpose of this work is to determine the complex of agroecological factors affecting the moisture supply and productivity of *A, deliciosa* in the changing weather conditions of the humid subtropics of Russia. The study was performed on late-ripening cv. Hayward planted in 1988 (a 5×4 m scheme, the total site area of 5.5 ha, three-tiered palmette shaping; the Adler experimental station of the Vavilov FRC All-Russian Institute of Plant Genetic Resources, Krasnodar Territory, 2016-2020). The average daily and maximum temperatures were recorded from May to October, the http://www.pogodaiklimat.ru data were used for precipitation. Moisture content of the soil, taken in 10-cm layers along the depth of the root layer (0-60 cm), was measured by the thermostat-weight method. The concentration of cell sap (CCS, %) in the leaves was measured refractometrically from May to September in ten plants (for 3 decades of each month). The yield of each bush (n = 30 in total, three replicates) was recorded. Annually, the average weight of a berry was determined using 100 berries. The weather conditions of the growing seasons significantly differed and showed abnormal precipitations and extreme temperatures (above 30 °C), affecting the water regime of plants and productivity. In May-June 2016-2020, the water content of leaf tissues was high (CCS 4.96-5.25 %), therefore, during the periods of budding, flowering, and fruit setting, the moisture supply of the plantings was optimal. In August, fruits began to grow actively and the initiation of the next-year generative organs occurred. However, high insolation and the temperature rise above 30 °C increased evaporations, while the atmospheric precipitations were minimal. The soil moisture reserves from May to October were optimal and ranged from 80 to 90 % of the least moisture capacity over the entire depth of the soil profile. However, the CCS increased from mid-September and exceeded 10 % at the end of the month despite the complete soil saturation with moisture. Tension in the environment and the peak of physiological processes caused water deficit in the leaves up to the CCS > 7 % which irrigation still could level. At the end of August or at the beginning of September (depending on weather conditions), the CCS steadily rose above 8 %, regardless of irrigation. During this period, a redistribution of water fractions from bound to free ecologically active form occurs. The earlier the transition of water and assimilation from the leaves of kiwi plants to fruits begins, the higher their weight and yield. Thus, our findings show that in the humid subtropics of Russia, the studied agroecological factors have the greatest effect on the water regime and performance of *A. deliciosa* cv. Hayward plants during the period of fruit formation (in August-September).

Keywords: actinidia (kiwi), cv. Hayward, water regime, productivity, heat supply, moisture supply, humid subtropics

Actinidia deliciosa (A. Ghev.) C. Fliang & A.R. Ferguson (kiwi fruit) is naturalized in world production since 1970. In 2019, the number of kiwi fruits produced in the world reached 4,274,870 tons / year, and the planting area was over 268 thousand hectares [1]. The leading positions in this industry are held by China, Italy, New Zealand, Iran, and Chili [2]. The culture was successfully mastered in the subtropical regions of the planet, and its industrial cultivation became important due to its high nutritional and biological value [3-5]. The agrocenosis of *Actinidia deliciosa* is distinguished by the duration of fruiting (40 years or more). For instance, kiwi fruit plantations at the Adler experimental station of All-Russian Institute of Plant Genetic Resources were established in 1988 [6, 7].

This subtropical fruit and berry crop contains dry substances, sugars, acids, vitamins, polyphenols, amino acids, aromatic and mineral substances, and is used in the production of functional food that is of great importance in the prevention of diseases. Berries of *Actinidia deliciosa* serve as a natural concentrate of multivitamins and mineral elements and retain their valuable properties in their natural state for up to six months [8-10].

In New Zealand, where the kiwi crop was bred, three important climate determinants for its cultivation have been identified: optimal cooling (temperature 11 °C and below), 1100 degree-days above 10 °C during the growing season, and annual rainfall of 1250 mm or more [11].

The influence of temperature factors and precipitation on the yield of five *Actinidia argute* cultivars was studied in Poland, in the northeastern regions [12]. Along with climatic factors, soil conditions are important, including the physical state and biological properties of soils (content of enzymes, trace elements, etc.) [13]. Beginning of the growing season is due to the increased sap flow in the stems and roots of plants. Within days, the roots begin to extract water from the places of moisture [14]. In Italy, one of the leading countries in the production of kiwi in plantations, crops optimize irrigation regimes for the full development of plants and ripening of fruits [15]. Water supply to plants is one of the key factors determining the size and quality of the crop [16-18].

The peculiar climate of the humid subtropics of Russia influences the actinidia plants, in particular, the onset of phenological phases. Bud differentiation occurs from the 3rd decade of December until the 2nd decade of February, growing season begins in March, and budding and flowering occurs in April-May. Fruit formation lasts until September, ripening – from October until November, depending on variety. For actinidia, as well as for subtropical crops, the basic sum of active temperatures (more than 10 °C) up to 4000±100 °C is determined [8].

The reaction of actinidia plants to the timing of watering during the day, which affects the biological parameters of the culture, has been shown [19]. Researchers note a higher stem-to-fruit water gradient at half-day/early noon, which favors fruit growth, but not significantly [20]. In Spain, the effectiveness of drip irrigation was studied in fruit crops in comparison with irrigation (in terms of the effect on soil and plants) [21]. High temperatures, solar insolation, and increased transpiration activity aggravated the environmental conditions in the afternoon. In kiwi, watering at this time improves the moisture supply of the soil, increases the gas exchange of leaves and the flow of assimilation products to the fruits [22, 23].

Over the past 20 years, due to climate warming, the sum of temperatures above 10 °C in the humid subtropics of Russia began to vary from 4559 to 4870 °C, while earlier it was 3735-4258 °C [24, 25]. During fruit formation (June-September), actinidia plants need irrigation depending on the amount of precipitation and temperature conditions. If the moisture supply of plants and, therefore, the water content of leaf tissues decreases, the concentration of cell sap in the leaves increases [26].

This work, for the first time, revealed an uneven distribution of precipitation in combination with a deficit of soil moisture during the period of actinidia fruit formation, which occurs in the humid subtropics of Russia over the years. For the first time, we suggest a physiological indicator (concentration of cell sap in actinidia petioles) for timely diagnosing and establishment of the optimal water regime, contributing to an increase in the productivity of actinidia.

Purpose of this work is to determine the complex of agroecological factors affecting the moisture supply and productivity of actinidia in the changing weather conditions of the humid subtropics of Russia.

Materials and methods. The studies on late-ripening *Actinidia deliciosa* cv. Hayward were performed during 2016-2020 at the Adler experimental station of the Vavilov FRC All-Russian Institute of Plant Genetic Resources (Krasnodar Territory). It was planted in 1988 according to a 5×4 m scheme, with three-tiered palmette shaping and the total site area of 5.5 ha. The soil under the culture is alluvial meadow low-humus. Content of humus in a layer is 0-20 cm was 5.67%, labile phosphorus 48.16 mg/100 g of soil, labile potassium compounds 18.3 mg/100 g of soil, pH_{wat}. 7.16-7.30. Drip irrigation was applied. The experimental design included three modes of prethreshold irrigation with soil moisture capacity (MC) of 90, 80 and 70%.

The average daily and maximum temperatures were recorded in dynamics each year from May to October, with using the precipitation data (according to http://www.pogodaiklimat.ru).

The moisture content in 10-cm soil layers along the depth of the root zone (0-60 cm), was measured by the thermostatic method (a 2V-151 drying chamber, Odessa Experimental Plant of Medical Equipment, Ukraine) and laboratory electronic scales (VSLT-300/3A Pioner, Ohaus Instruments (Shangha) Co., Ltd., PRC). The figures present a percentage of the soil moisture capacity (MC), which characterizes the greatest amount of water remaining after abundant moistening and draining of its excess in the absence of upward groundwater. The optimum moisture content in the soil for actinidia was 80% MC [26].

The concentration of cell sap (CCS, %) in the leaves was measured refratometrically from May to September in ten plants for three decades of each month [26, 27].

The yield was recorded for each bush (in three replicates, total number of bushes in a replicate n = 10). Annually, the average weight of a berry was determined using 100 berries.

Data were statistically processed according to Dospekhov [28] using Microsoft Excel and Statistica 10 (StatSoft, Inc., USA). Using F-test, a correlation analysis of the relationship between soil moisture in the root zone of soil and the concentration of cell sap was performed depending on the drip irrigation regime. Mean values (M), standard errors of means (±SEM) and coefficients of variation (Cv,%) were calculated [28].

Results. In the humid subtropics of Russia, three agroclimatic regions with regard to the heat and moisture supply have been identified [24, 29, 30]. Two of them (I and II) in terms of the sum of temperatures > 10 °C (3800-4300 and 3600-3800 °C) meet the needs of subtropical crops, but due to the recorded absolute minimum temperature reaching –14...–15 °C (I) and –17...–18 °C (II), it is required to take into account the microlandscape when planting crops,. The amount of annual precipitation in the regions is 1600 and 2100 mm, respectively, the duration of the frost-free period is 250-300 and 200-250 days. With the introduction of GIS (Geographic Information System) in the Sochi National Park, it was established that the humid subtropical climate remains up to 300-400 m above sea level. The tropical and continental climates are characterized by significant fluctuations in weather factors, increasing to anomalous values.

The optimal placement of crops and a systematic analysis of the complex of factors affecting the productivity of agrophytocenosis contribute to an increase in the productive potential of the culture. One of the methods for optimizing conditions in agrophytocenosis is drip irrigation [31-33]. Optimization of abiotic conditions in agrocenoses leads to a significantly higher yield of economically valuable products per unit area compared to natural phytocenoses [33].

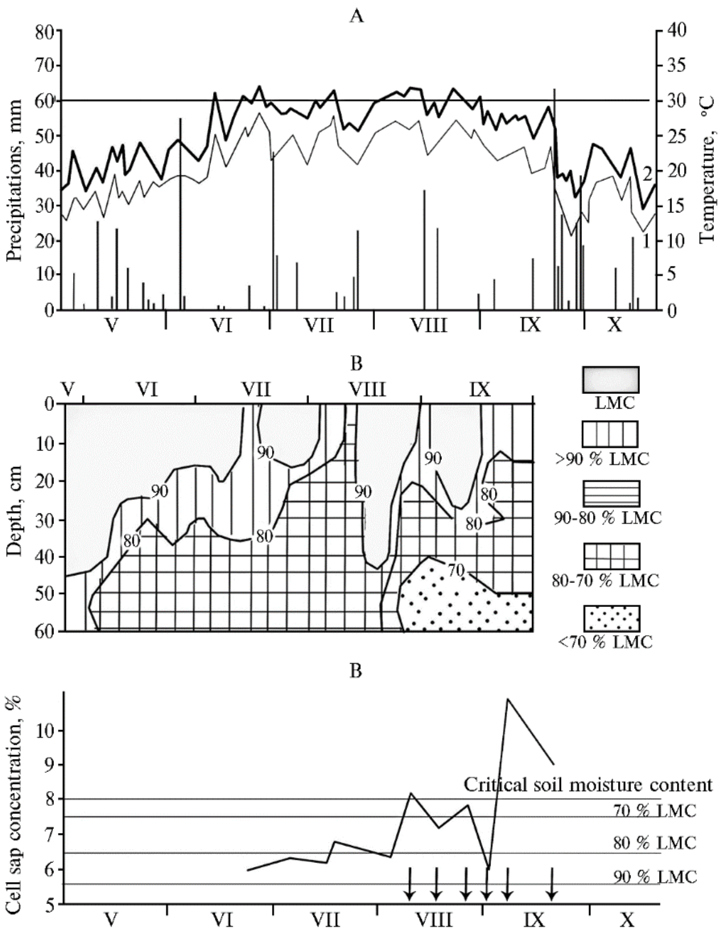

Fig. 1. Mean (1) **and maximum** (2) **ambient temperature** (A)**, soil moisture (%** MC) (B)**, and concentration of cell sap** (CCS) **in petioles** (B) **of** ***Actinidia deliciosa*** **(A. Ghev.) C. Fliang & A.R. Ferguson cv. Hayward in 2016, May-October**. MC is the minimum soil moisture capacity. Annual precipitation is 1682.0 mm; average annual temperature is 14.7 °C. Arrows indicate watering times (Adler Experimental Station VIR, Krasnodar Territory).

In this article, a detailed and comprehensive analysis of the influence of environmental factors (whether and soil) on the dynamics of water regime of Hayward kiwi plants and their productivity is given for 2016, 2019 and 2020, which differed in precipitation distribution and temperature regime.

Figure 1 shows data on the components of the weather-soil-water regime of plants in 2016. The observations of water regime of actinidia plants in 2016 starting from June showed that water content of leaf cells was high until August 8, but at the end of the 1st decade of August, the CCS exceeded 8%, and only subsequent watering in August contributed to its decrease (see. Fig. 1).

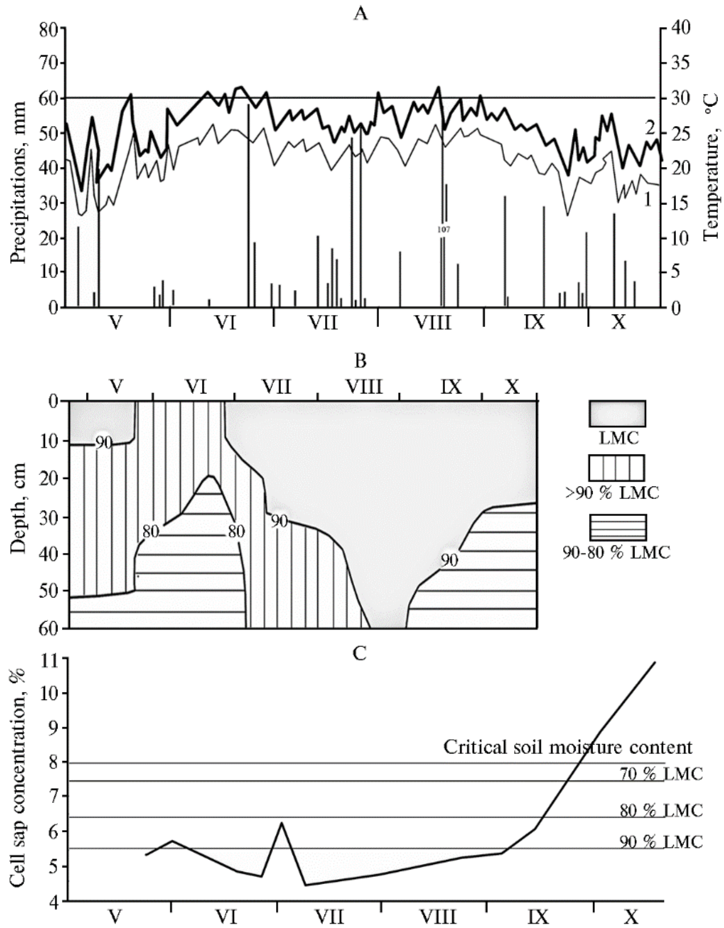

Fig. 2. Mean (1) **and maximum** (2) **ambient temperature** (A)**, soil moisture** (% MC) (B)**, and concentration of cell sap** (CCS) **in petioles** (B) **of *Actinidia deliciosa* (A. Ghev.) C. Fliang & A.R. Ferguson cv. Hayward in 2019, May-October**. MC is the minimum soil moisture capacity. Annual precipitation is 1420.4 mm; average annual temperature is 15.7 °C. Arrows indicate watering times (Adler Experimental Station VIR, Krasnodar Territory).

The thermal regime of 2019 was characterized by low temperatures and significant precipitation during the growing season (Fig. 2). The air temperature in July decreased by 0.8 °C compared to the long-term average values, while precipitation exceeded long-term data by 27%, and in August by 37%. The maximum temperatures (above 30 °C) were episodic in summer. Moisture reserves from May to October 2019 were optimum (80-90% MC) over the entire depth of the soil profile, while irrigation was not carried out. Nevertheless, the concentration of cell sap began to increase from mid-September, and at the end of the month, it was above 10% when the soil was full-saturated (see Fig. 2).

The sum of active temperatures in the driest 2020 reached 5164 °C. The average annual temperature was 15.8 °C, that is, it increased by 1.6 °C in comparison with the long-term average. The maximum air temperatures have been recorded since May. During the year, 1003 mm of precipitation fell, which comprised

59% of the norm (1703 mm). June, August and September were extremely dry. The drought worsened from March to the end of the year (Fig. 3). The intensity of the water regime in the soil profile was traced from the third decade of August in a layer of 30-60 cm. Irrigation in early September optimized the moisture regime in the layer of 50 cm. The water regime of actinidia plants was optimal until the first decade of August. Irrigation in early September could not improve the water regime of the crop (see Fig. 3).

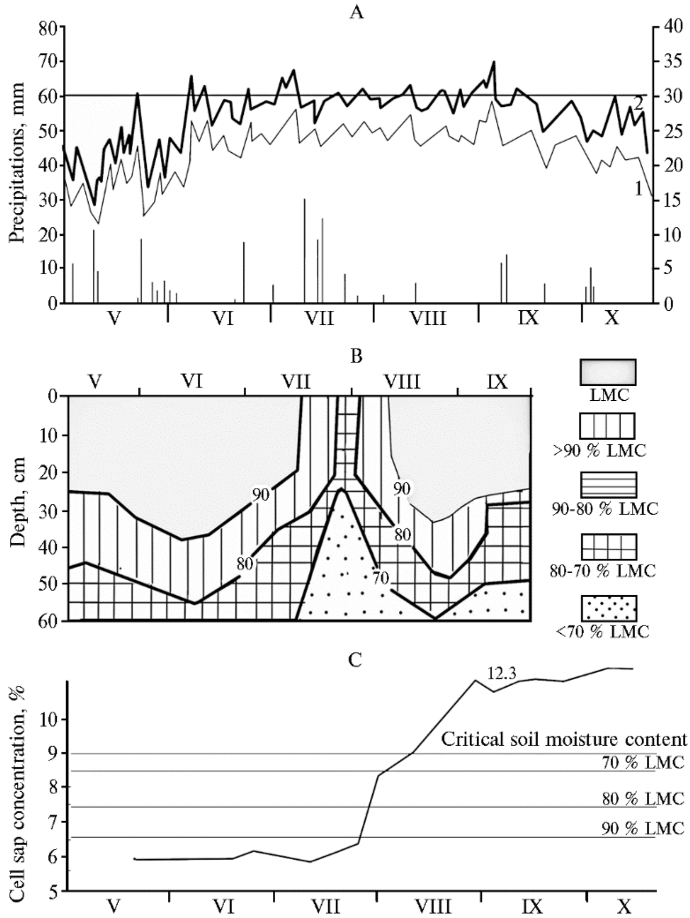

Fig. 3. Mean (1) **and maximum** (2) **ambient temperature** (A)**, soil moisture (**% MC) (B), **and concentration of cell sap** (CCS) **in petioles** (B) **of *Actinidia deliciosa* (A. Ghev.) C. Fliang & A.R. Ferguson cv. Hayward in 2020, May-October**. MC is the minimum soil moisture capacity. Annual precipitation is 1003.0 mm; average annual temperature is 15.8 °C. Arrows indicate watering times (Adler Experimental Station VIR, Krasnodar Territory).

1. Concentration of cell sap (CCS, %) **in petioles of *Actinidia deliciosa* (A. Ghev.) C. Fliang & A.R. Ferguson cv. Hayward vs. soil moisture during vegetation period in the Russia humid subtropics** (n = 30, N = 3, M±SEM, Adler Experimental Station VIR, Krasnodar Territory, 2016-2020)

Parameter	Month					
	V	VI	VII	VIII	IX	X
CCS, %	4.96±0.43	5.25±0.09	5.73±0.11	7.14±0.17	8.80±0.30	9.87±0.35
Cv, %	8.8	11.3	16.5	17.8	23.6	15.5
Soil moisture, %	27.50	27.04	26.20	24.01	21.35	19.67

N o t e. For kiwi plants, the optimal soil moisture is 25% (80% MC), soil moisture level close to stress is 22%.

According to data obtained in August-September 2016-2020, concentration of the cell sap in actinidia leaf tissue increased significantly during these months (Fig. 4, Table 1).

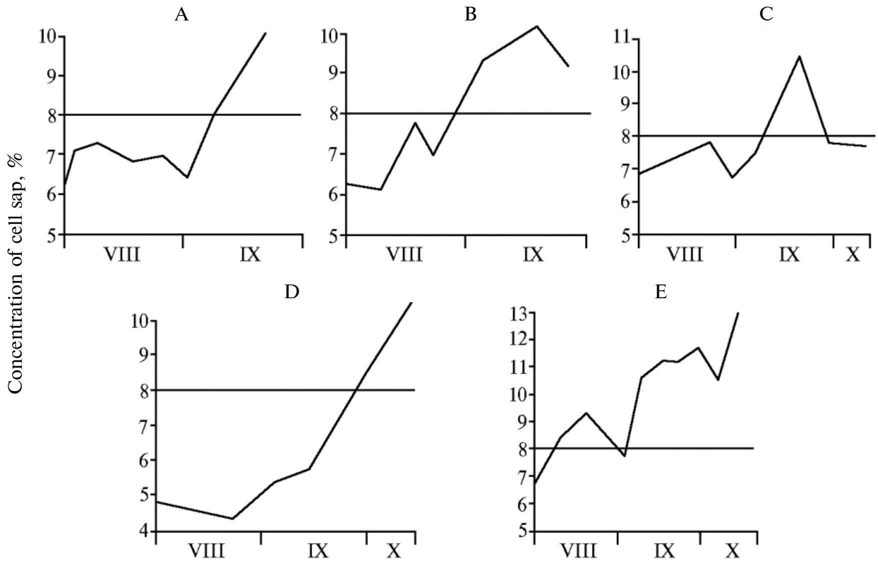

Fig. 4. Concentration of cell sap (CCS) **in petioles of *Actinidia deliciosa* (A. Ghev.) C. Fliang & A.R. Ferguson cv. Hayward at kiwi fruit maturity (August-October) in 2016** (A), **2017** (B), **2018** (C), **2019** (D), **and 2020** (E). The horizontal line marks the value of the CCS corresponding to the critical value of the water supply of plants (Adler Experimental Station VIR, Krasnodar Territory).

Correlation analysis of the relationship between soil moisture in the root layer of actinidia and the concentration of CCS in leaf petioles showed their close dependence. The correlation coefficient *r* was equal to 0.71885 at $F_{exp.} = 9.6236$, $F_{0.5} = 5.12$, which indicates a close statistically significant relationship between the analyzed factors. The mathematical model is as follows: Y = 35.43 – 1.599x, where Y is the soil moisture in the 0-60 cm layer, %; x is CCS, %.

High water content of leaf tissues in May-July was typical for the phases of budding, flowering, and setting. The increase in CCS in August over 7.14±0.17% coincided with the active growth of fruits. During this period, there is a redistribution of water fractions from bound to a free ecologically active form [34]. The content and ratio of water forms in the actinidia plant is in close correlation with agroclimatic factors in humid subtropics]35]. Goncharova [36] believes that the redistribution of water forms and products of assimilation from leaves to fruits can be considered self-regulation of transport flows by a plant organism, which has significant biological expediency under extreme conditions. Such self-regulation, in our opinion, based on long-term indicators of the change in the value of CCS in August-September, is also specific for actinidia.

The most unfavorable year in terms of yield and weight of actinidia cv. Hayward was 2019 due to high temperatures (> 30 °C) during the flowering phase (Table 2). Moisture provision during the ripening period was optimal without irrigation. However, the outflow of water with assimilates occurred at the end of September under moisture in the soil within 90% of the MC and along the entire depth of the root layer.

The minimum weight of the Hayward variety for 2016-2020 was 87 g, the maximum 135 g. On average, this fruit size corresponds to the characteristics of Hayward variety. The productivity of the Hayward variety in 2020, which was characterized by an acute lack of moisture and an early period (from the 2nd decade of August) of the outflow of water with metabolic products from leaves into fruits, was about 82% of the average productivity over 5 years. In a favorable

2018 (with drip irrigation) in the conditions of the Russian subtropics, a yield of 105.8 c/ha was obtained (see Table 2). The average yield of kiwi in the world in 2018 was 160 kg/ha (https://www.global-trademag.com/global-kiwi-fruit-market-2019-new-zealand-and-italy-are-the-leading-exporters-of-kiwi-fruits/).

2. Yield of *Actinidia deliciosa* (A. Ghev.) C. Fliang & A.R. Ferguson cv. Hayward in the Russia humid subtropics (n = 30, N = 3, M±SEM, Adler Experimental Station VIR, Krasnodar Territory)

Parameter	Year					
	2016	2017	2018	2019	2020	M±SEM
Yield, kg per bush	7.3	8.6	23.5	4.6	8.6	10.5±3.3
Yield, c/ha	32.8	38.7	105.8	20.7	38.7	47.3±6.4
Of mean yield, %	69	82	224	44	82	100

N o t e. The yield was assessed based on the average yield per bush according to the total number of female plants per hectare (450 plants).

The cultivation of the Hayward actinidia variety in the Republic of Abkhazia showed a similar influence of agroclimatic factors on the crop yield. Depending on the duration of the period of maximum temperatures and the amount of precipitation during the formation of fruits, the yield of the Hayward variety averaged from 50 to 130 c/ha [9].

In the countries of Western Europe, active selection work is being carried out on various types of actinidia in order to increase their productivity [37-39], fruit quality [40-42] and adaptability to local conditions [42, 43]. The greatest attention in the research is paid to the temperature factor [44, 45].

In the humid subtropics of Russia, as shown by multiple correlation analysis, the factors limiting the productivity of actinidia of Hayward variety are the amount of precipitation and air humidity during flowering and fruit ripening phases (excessive precipitation during flowering, its deficit during ripening). The amount of precipitation during the flowering phase is highly variable and uncontrollable, because of which this period becomes critical. The deficit of precipitation during the ripening period can be leveled by watering.

It should be noted that in the zones of traditional cultivation (New Zealand, Italy, China), much attention is paid to the issues of the influence of water scarcity and the methods and timing of irrigation on actinidia plants, the efficiency of the use of water resources by the culture [22, 46, 47]. It can be expected that under conditions of aridization of the climate and a shortage of water resources, the relevance of such studies will increase. The time of the onset of water stress (at the beginning of the season or at a later date) affects not only the yield, but also the content of biologically significant nutrients in fruits [47]. Therefore, it is believed that by choosing the timing of irrigation, it is possible to purposefully change some indicators of the quality of fruits in actinidia [47].

Since watering effectiveness of actinidia depends on its timing, it is important to have a simple and affordable way to assess the water status of plants. Many studies discuss the timing, methods, and effect of watering on the productivity and quality of actinidia fruits [23, 26, 43, 47]. However, in the available literature, we did not find data on how the optimal watering time for a plant was determined. The concentration of cell sap in the leaf petiole, which we proposed as such a criterion, has a significant advantage, since, firstly, it is a physiological indicator, and secondly, it is easy to determine it by a refractometric method. A mathematical model has been established for a close and significant relationship between CCS in leaf petioles and soil moisture in the root layer (0-60 cm). The optimal pre-threshold irrigation period for the crop is revealed (80% MC).

The mountain terrain and the variegation of the soil cover of the humid subtropics of Russia, as well as the varietal specificity of actinidia, determine the possibilities of agroecological zoning of this young crop based on its adaptability. The study of the physiological status of actinidia when grown on the northern borders of the industrial cultivation area is of interest for understanding the genetic potential of the crop. The development of crop agroecosystem models can be of great importance for expanding the cultivation area and increasing the productivity of actinidia in the humid subtropics of Russia [48].

Therefore, a long-term study of the complex of agroecological factors of the humid subtropics of Russia during fruit formation (August-September) phase of *Actinidia deliciosa* cv. Hayward showed the effect of the amount of precipitation, soil moisture, and the concentration of cell sap in leaf petioles on plant productivity. High water content of leaf tissues during May-July was typical for budding, flowering, and setting phases. The increase in CCS in August over 7.14±0.17% coincided with the active growth of fruits. During this period, there was a redistribution of water fractions from bound to a free, ecologically active form. The earlier the period of the transition of the transport flow of water and assimilates in the actinidia plant from leaves to fruits begins, the higher their mass and yield. The increase in the CCS above 8% indicates the full technical ripening of the actinidia fruits. The parameters of the moisture content of crop were determined according to CCS values from 5 to 8%. An express method for refractometric measurement of the concentration of cell sap in actinidia leaves is proposed. The method provides rapid and reliable determination of the timing for watering actinidia in the field.

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