Perspective method for construction of drying and watering network for growing potatoes

N Martinova[1,*], and *K* Shavazov[2]

[1]Russian State Agrarian University named after K.A. Timiryazev, 127550, Moscow, Russia
[2]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, Tashkent, Uzbekistan

Abstract. In the Central region of the Russian Federation, precipitation is uneven both during the growing season of plants and during the calendar year. Therefore, to obtain sustainable yields and ensure the optimal water-air balance of the soil, agro-reclamation measures are required, including the organization of additional irrigation. During the winter period, a significant amount of snow accumulates, which during the melting period does not have time to soak into the soil, forming surface runoff. The construction of a drainage and water supply network will make it possible to accumulate excess moisture in reservoirs to moisten the soil during the rainless period. The joint use of the drainage network and the drip irrigation system is recommended. Using such a system will allow at the estimated time to supply or divert water to a specific area, removing excess moisture from the soil by drainage to storage tanks and then directing irrigation water to the drip irrigation system during the dry period. The calculation of the irrigation rate, taking into account the semi-elliptical shape of the humidification contour, showed that the required volume of water could be accumulated in special storage tanks. Drip tape laying can be carried out mechanized using a special stacker based on a ridge former.

1 Introduction

The climate in the Moscow region is characterized by an uneven distribution of precipitation both in the annual cycle and for many years of observation; that is, there is an alternation of years with excessive moisture and moisture deficiency during the growing season of plants [1]. So, the average monthly rainfall in the spring and summer ranges from 20 to 85 mm.

The same picture is observed in the winter period; however, snow masses accumulate, and evaporation in this period is minimal. In the spring, the soil that has not had time to thaw does not absorb moisture well; the water goes into surface runoff. In this case, washing out of the upper fertile layer is observed.

In the period of snowmelt, the soils are very waterlogged. This, in some years, is the reason for the delay in sowing, which leads to a shift in agro-technical terms [2]. The solution to the problem is the construction of a drainage network. This will allow the timely

*Corresponding author: yourim2@rambler.ru

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removal of excess moisture from the root layer and increase soil aeration [3]. The maximum load on the drainage network occurs during snowmelt [4]. If the discharge is carried out in a special pond - drive, then in the future, this water could be used for irrigation during a period of moisture deficiency [5].

Therefore, to ensure optimal values of water-air balance throughout the growing season, it is necessary to build a drainage and watering network [6]. This will allow irrigation during a period of precipitation deficit and remove excess moisture in the event of over-moistening of the soil [7]. The drained water should be stored to ensure the next watering.

2 Method

To ensure optimal values of the water-air balance, the inflow and outflow of moisture during the growing season should be predicted. Precipitation is unstable both throughout the growing season and according to long-term observations (Table 1).

Table 1. The average daily rainfall during the growing season

Year of research	Daily rainfall, mm / day.			
	May	June	July	August
2016	3.37	2.56	3.86	4.43
2017	1.58	2.34	3.12	2.46
2018	0.65	1.82	2.74	0.74

In the summer, rainless days and even weeks alternate with rainy ones. Rains at this time are often torrential in nature - a significant amount of precipitation falls in a short time, which, without having time to soak into the soil, goes into surface runoff [8].

Plant water consumption, particularly potatoes, is also uneven during the growing season [9]. In the early development period, potatoes' daily consumption is small since there is enough moisture in the mother tuber. But during this period, the soils are waterlogged, as they are filled with melt water. Water consumption reaches its maximum value at the end of the growth of tops and flowering; in the future, it decreases slightly (Table 2).

Table 2. Potato daily water intake

Vegetation period	Daily water consumption, m3 / ha
Landing - seedlings	16
Shoots - the beginning of budding	28
Start of budding - full bloom	32
Full bloom - the end of the growth of tops	35
The end of the growth of tops - technical ripeness of tubers	27

As seen from the tables, the moisture received by the plant from atmospheric precipitation is not enough for normal development. And the period of greatest water consumption - from the beginning of flowering to the end of the growth of tops - is the driest time of the year (Fig. 1).

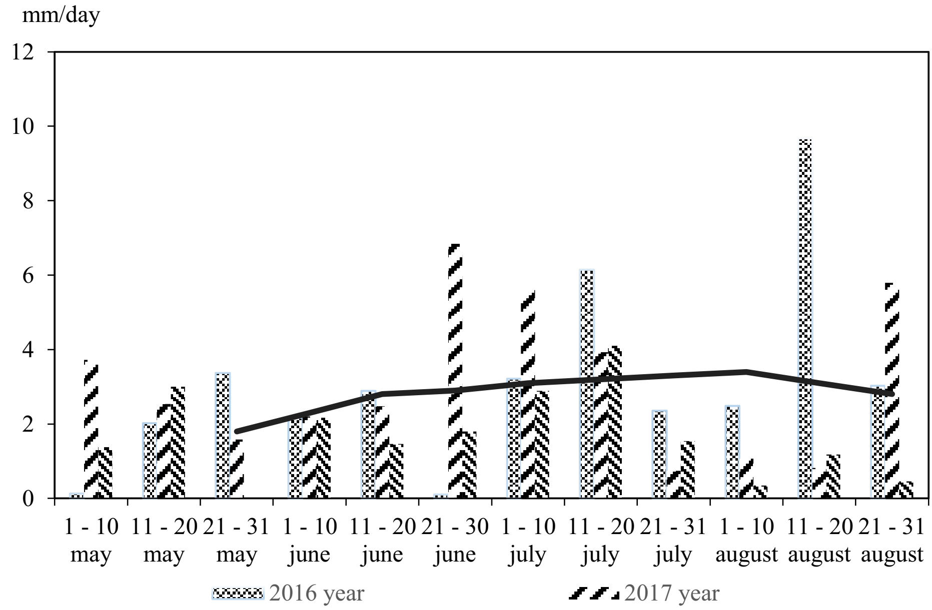

Fig. 1. Precipitation dynamics during the growing season of potatoes

It is during this period that the highest values of average annual temperatures are observed, and as a result, the highest volatility [10]:

$$V = 0.0018 \cdot (25 + t)^2 \cdot (100 - \omega)$$

where t is the average monthly temperature, ω is the average monthly humidity.

The dynamics of changes in evaporation during the growing season are shown on the graph (Fig. 2).

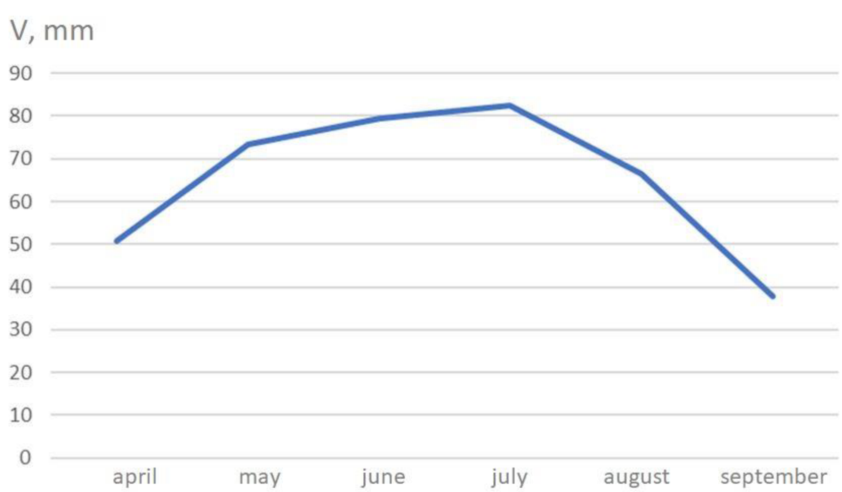

Fig. 2. Values of volatility during the growing season

As seen from the above data, during the period of maximum water consumption, there is a steady deficit of moisture, which can be replenished with the help of irrigation.

Therefore, having excessive moisture at the beginning of the growing season and a moisture deficit during the greatest water consumption, one should choose a method for accumulating water in the spring and in the future during precipitation and spending moisture as needed [11].

There are several ways to build drainage systems. A network of channels - drives with a gateway system is used. This construction has a high cost and can be used only at large reclamation sites; moreover, this scheme cannot exclude soil waterlogging [12].

It is also known the design of a drainage and watering system using ponds - storage tanks, where pumps supply water. This method is energy-consuming and drives the earth out of agricultural circulation and impeding the operation of agricultural machinery.

It is supposed to moisten the developed territory using subsoil irrigation or sprinkling. The first disadvantage is the shallow depth, which prolonged use during freezing and thawing of the soil, will lead to high-altitude deformations and a decrease in the water supply volume.

The use of sprinkling equipment will lead to an increase in operating costs, as well as difficulties in the passage of sprinkler machines among the objects of the reclamation system.

3 Results and discussion

To ensure optimal water consumption regimes and improve water supply and removal of excess moisture depending on external conditions, it is proposed to use a drainage network as a drainage system and a drip irrigation system as a humidification system (Fig. 3). Water for drip irrigation can be obtained from storage collectors.

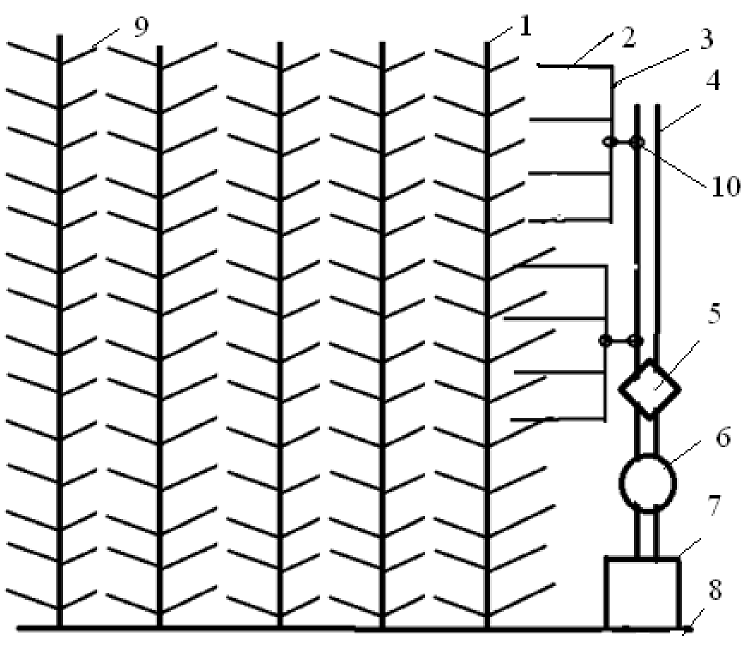

Fig. 3. Drainage and watering system: 1 is collector drainage network; 2 is drop line; 3 is way line; 4 is way manifold; 5 is filtration station; 6 is pump station; 7 is drive; 8 is trunk channel; 9 is drain; 10 is valve.

During snowmelt, water from the main canal is partially supplied to the drive, where it settles and partially clarifies. Then it is transported by a pump to a distribution manifold and, after filtration, enters the drip line by irrigation.

For timely removal of excess moisture and filling wells for subsequent watering, it is necessary to determine the required drain flow rate [13]:

$$Q_m = q_m \cdot F_m, \tag{2}$$

where q_m is estimated intensity of groundwater withdrawal, F_m is drained area, m

The optimal distance between drains is determined by the formula [14]:

$$B = 2 \cdot (h_d - a) \cdot \sqrt{\frac{2 \cdot k \cdot \alpha}{q_m}\left(1 + \frac{T - h_d}{2 \cdot (h_d - a)}\right)}, \tag{3}$$

where k is soil filtration coefficient; T is distance to the aquiclude, m; h_d is the drain depth, m; a is design depth of the groundwater level between drains, m; α is coefficient.

The advantage of drip irrigation is the ability to deliver water directly to the root zone, virtually eliminating the loss of filtration into deeper layers and evaporation.

To compensate for the lack of moisture, it is necessary to determine the irrigation rate. With drip irrigation, the humidification contour has a semi-elliptical profile since the horizontal movement of water is determined by the action of capillary forces, and the vertical movement is determined by the action of capillary and gravitational forces.

The boundary of moisture distribution in the vertical plane should be determined from the equation [15]:

$$\frac{\partial \mathrm{W}}{\partial \mathrm{t}} = \frac{\partial}{\partial \mathrm{z}}\left(\mathrm{D(W)}\frac{\partial \mathrm{W}}{\partial \mathrm{z}} + A\frac{\partial^2 \mathrm{W}}{\partial \mathrm{t}\,\partial \mathrm{z}}\right), \tag{4}$$

where D(W) is coefficient of diffusivity of soil moisture; A is correction factor; W is the relative humidity of the soil; t is time, s.

The vertical coordinate separating the watered and unwatered zones is determined by the formula [16]:

$$\mathrm{z} = 2\mathrm{A}^{-0.5}\sqrt{\mathrm{Dt}} \tag{5}$$

Soil moisture diffusivity coefficient should be determined from the equation [17]:

$$D(W) = D_0 \cdot e^{\beta(W - W_0)}, \tag{6}$$

where β is a parameter depending on soil and humidity; D_0 is diffusion coefficient at initial humidity W_0.

The numerical value of the spread of water in the horizontal direction is determined from the equation [18]:

$$\frac{\partial \mathrm{W}}{\partial \mathrm{t}} = \frac{\partial}{\partial \mathrm{x}}\left(\mathrm{D(W)}\frac{\partial \mathrm{W}}{\partial \mathrm{x}}\right) \tag{7}$$

After the transformations, we find the coordinate of the irrigation contour radius:

$$x = \sqrt{\frac{2tD_0 e^{\beta(W-W_0)} \cdot \sqrt{A}}{\sqrt{A} - \beta(W - W_0)\sqrt{2D_0 e^{\beta(W-W_0)}}}} \qquad (8)$$

After the horizontal and vertical coordinates of the humidification circuit have been determined, the flow rate per dripper should be calculated. Taking into account that the contour has a semi-elliptical profile, we determine the required flow rate [19]:

$$Q_r = \frac{2 \cdot 3{,}6 \cdot 10^{-3} \pi z x^2 (W_1 - W_0)}{3t} \qquad (9)$$

After the required flow rate per dripper has been determined, the drip tape should be selected from the condition that the hourly flow rate of the tape per dripper must be greater than or equal to that obtained from the calculations.

Knowing the consumption of the tape, it is necessary to determine the irrigation rate [20]:

$$m = \frac{2.7 \cdot Q_k \cdot t}{l \cdot b} \;, \qquad (10)$$

where l is the distance between droppers, m; b is the distance between adjacent ridges, m.

According to the results of the calculations, a drip tape was selected with a flow rate of 1.6 liters per hour per dropper, with a distance between droppers of 0.3 m. The drip tape was laid mechanized using a Grimme GR-75/4 comb former, modified to a drip tape stacker (tab. 3).

Table 3. Technical characteristics of the drip tape stacker based on the Grimme GF-75/4 comb former.

Working body weight, kg	2150
Working body width, m	3
Working speed, m / s	0.9…1.4
Productivity, ha / hours	0.51…0.97
Drip tape diameter, mm	16
Water consumption, liters per hour	1.6
Distance between droppers, mm	300

Mechanized laying was carried out at the experimental site of the Field Experimental Station of the RGAU-MSHA, named after K.A. Timiryazev (fig.4).

Fig. 4. Mechanized method using a Grimme GR-75/4 ridger modified for drip tape

A drip irrigation system was installed on the experimental site. Irrigation was carried out with the calculated irrigation rate upon reaching the threshold moisture content of 70% of the maximum field moisture capacity with adjusting the time between irrigations (fig. 5).

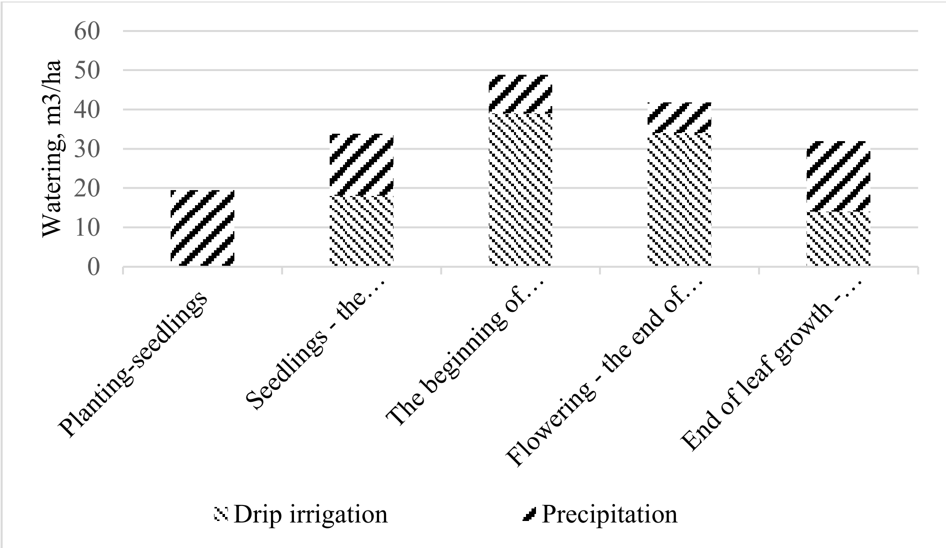

Fig. 5. Water consumption of potatoes at different stages of development.

Thanks to drip irrigation, the yield increased by 28%. A dehumidifying and humidifying system made it possible to start planting work 2-3 weeks earlier.

4 Conclusions

The construction of a drainage and irrigation network makes it possible to take excess moisture from waterlogged areas, accumulate it in a storage collector and distribute it during a period of precipitation deficiency, creating optimal conditions for the growth and development of plants. Calculations have shown that the missing volume of moisture in the rainless period can be accumulated during the snowmelt period in special reservoirs of the drainage network. The calculations established the optimal distance between the drains and, calculated the parameters of the drip system, determined the irrigation rate, taking into account the semi-elliptical shape of the humidification circuit. The use of drainage to remove excess moisture during the snowmelt period made it possible to plant 2–3 weeks earlier, and the use of mechanized laying of the drip tape with a special stacker based on the Grimme GR-75/4 ridge former reduced energy costs by 16%. The increase in potato yield with drip irrigation was 28%.

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