Justification of the parameters and operating modes of the disinfecting system

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Abstract. Increasing yields is an important task for our country. This is possible due to removing the tip of the shoot, which stimulates the potential of the plant itself, and such products can be sold as organic since no other chemicals are used to increase yields. When the shoot tip is removed, a wound is formed through which pathogens can enter. To reduce the likelihood of plant contamination, the device provides a system for applying a disinfectant solution (hydrogen peroxide) to the knife blade. The settings of the injector are taken into account. When choosing a spray gun, it is necessary to take into account the average working pressure, equal to P = 0.28 MPa, which provides a solution flow rate Q = 0.8 l • min⁻¹ with a nozzle diameter of 0.1 mm. These requirements can be met by spray guns of caliber 04 or 05. At a spray angle of 800, the recommended spray angle is 300; the mounting distance is 0.3 m below the plane of rotation of the cut-off wheel. The initial flow rate of the liquid of 17.33 m • s⁻¹ will provide stable droplet formation, providing the recommended dispersion of the solution of 150-200 microns.

1. Introduction
The potato is one of the most important agricultural crops for versatile use. First of all, it is a valuable food product for all categories of the population. By importance in terms of consumption, the potato is the third crop after rice and wheat. More than a billion people eat the potato [1]. It plays a huge role in the food security of any country, including ours. Potatoes yield 2 ... 4 times more nutrients per unit area than cereals do [2]. Despite this, the demand for the product continues to grow, as it is used not only for nutrition, but also for processing and for technical purposes.

In recent years, organic farming has been gaining popularity and its steady growth is observed (from 18 to 97 billion US dollars). The consumption market is growing, especially in European countries, and Russia can be an importer of this valuable culture in the EU. Therefore, increasing crop yields by stimulating the potential of the plant itself is important and interesting. A reserve for increasing productivity is the implementation of various technological methods. One such technique is decapitation. When removing the apical shoot, the plant stimulates the awakening of the lateral shoots on which the leaves develop. The total leaf surface increases, where photosynthesis takes place and organic substances are formed, which later flow into tubers, which ultimately affects the yield [1, 2].
In a production environment, it is necessary to have a mechanized device to carry out the technological process; however, there are currently no industrial designs [2]. A device diagram is proposed by us that can be used to carry out the indicated work [2]. Its design takes into account the characteristics of both the plant and the work performed. So, to increase the degree of coverage of shoots by decapitation, it was proposed to use a pneumatic-type stem-lifting device, which makes it possible to move the maximum number of plant shoots to the knife working area without friction on the surface [3, 4]. In addition, it was taken into account that when the shoot tip is removed, a wound is formed through which pathogens can penetrate, which will lead to a decrease in yield and degeneration of the variety [2]. To reduce the likelihood of plant infection, the device provides a system for applying a disinfectant solution to a knife blade.

As a disinfecting solution, you can use any disinfecting drug (potassium permanganate, alcohol-containing solution, hydrogen peroxide) [2]. The most appropriate and easily prepared means is hydrogen peroxide, a concentrated solution of which is diluted with water in the required proportion.

2. Materials and methods

The agrotechnical requirement for decapitation is the mandatory disinfection of the cut site, since this is the place of penetration of pathogens, especially viral diseases. Coverage is not less than 90% [2]. As a disinfectant, it is recommended to use an aqueous solution of hydrogen peroxide at the rate of 10 l per ha. The device for decapitation is equipped with a system for applying a disinfectant solution to the cutting disk (Figure 1).

![Figure 1. System for applying a disinfectant solution to the disc knives:](image)

1 - tank; 2 - pump; 3 - shutoff valves; 4 - nozzle; 5 - air channel; 6 - cutting; 7 - aerial fan

The level of coverage with a solution of blade knives depends on the following indicators: characteristics of the disinfecting-air mixture, speed of air flow, cutting disc rotation frequency and cutting knife area, parameters and location of the spray head and working pressure in the system.

The geometry diagram for the installation of the spray gun is shown in Figure 2. The position of the spray gun is determined by the spray torch α, nozzle installation angle β, tip nozzle offset relative to the cut plane Sy and disk diameter D. The air flow rate ω of the air gun will affect the flow of the aerosol mixture (Fig. 2).
Figure 2. Geometric reference of the spray head: $\alpha$ — spray angle; $S_y$ — nozzle displacement in vertical flatness; $S_x$ — nozzle offset relative to the wall of the air channel; $\omega$ - air flow rate from the pneumatic stem lifter

To save the solute, the point of intersection of the right boundary of the spray torch B must coincide with the axis of the knife. Then we take $AB$ equal to 0.5D. The left boundary of the spray torch should coincide with point A. The trajectory of the droplet flow will be affected by the air flow moving at a speed $\omega$ created by the fan of the stem lifter 7 (Fig. 1).

To clarify the sprayer installation parameters, we consider the trajectory of the solution droplets. The process of fluid outflow from a nozzle depends on its diameter $d$, pressure in the system $P$, hydromechanical characteristics of the liquid and air (Table 1), velocity and direction of the air flow $\omega$, dispersion of the solution (number and diameter of drops) [2].

| Environmental Characteristics | Air       | Water    |
|-------------------------------|-----------|----------|
| 1. Kinematic viscosity, $m^2\cdot s^{-1}$ | $15.06 \cdot 10^{-6}$ | $1.006 \cdot 10^{-6}$ |
| 2. Dynamic viscosity, $Pa\cdot s$ | $18.1 \cdot 10^{-6}$ | $1004 \cdot 10^{-6}$ |
| 3. Density, $kg\cdot m^{-3}$ | $1.205$ | $1000$ |
| 4. The surface tension of the liquid, $N\cdot m^{-1}$ | - | $0.0725$ |

The process of movement of solution particles is determined by the ratio of dimensionless criterion characteristics: Reynolds criterion $Re$, Weber $We$ (formulas 2-3):

$$Re = \frac{\nu_0 d \rho_w}{\mu_w};$$

$$We = \frac{\nu_0^2 d \rho_w}{\sigma},$$

where $\nu_0$ — speed of fluid outflow from the nozzle, $m\cdot s^{-1}$; $d$ — diameter of the drop, m; $\rho_w$ — water density, $kg\cdot m^{-3}$; $\mu_w$ — dynamic viscosity of water, $Pa\cdot s$; $\sigma$ — surface tension of the liquid (for water $0.0725$, $N\cdot m^{-1}$); $g$ — celeration of gravity, $m\cdot s^{-2}$.

3. Results and Discussion

For a given flow rate of solution $Q$ and pressure in the system $P$ for a continuous flow, we determined the cross-sectional area $F_0$, and nozzle diameter $d_c$ by the formulas:

$$F_0 = \frac{Q}{\nu \sqrt{P}};$$

$$d_c = \sqrt[4]{4 \cdot \frac{F_0}{\pi}}.$$


where $\mu = \varepsilon \cdot \varphi$ - nozzle flow coefficient depending on the jet compression $\varepsilon$ (0.60…0.64) and the velocity coefficient $\varphi = \frac{1}{\sqrt{\alpha + \zeta}}$ ($\alpha$ – Coriolis coefficient; $\zeta$ – local resistance coefficient) [5].

An important indicator of the atomizer is the initial velocity $v_0$ of the outflow of the jet from the nozzle along the axis of movement of the airborne mixture:

$$v_0 = \varphi \sqrt{\frac{2P}{Pw(1+\zeta)}}. \quad (5)$$

For the spraying mode, the fluid velocity $v_0$ must be greater than the critical $v_{crit}$, determined by the dependence [6]:

$$v_0 \geq v_{crit} = 245 \frac{\mu^{0.6} \varepsilon^{0.2}}{q^{0.6} p_{air}^{0.2}}. \quad (6)$$

Subject to condition (8), the liquid stream is crushed into droplets. The average droplet diameter $d_0$ is determined by the formula [6]:

$$d_0 = \frac{1.436 d_c}{\left(1 + \frac{3 \mu e^{0.5}}{Re} \right)^{1/6}}. \quad (7)$$

For a known droplet diameter is obtained, its mass $m$ and the number of droplets are formed $n$ by the known formulas:

$$m = \frac{p_{air} \cdot \pi \cdot d_0^2}{6}; \quad (8)$$

$$n = \frac{c}{m}. \quad (9)$$

The flow of the solution exits the nozzle with an initial velocity $v_0$ at an angle $\beta$ to the horizon and breaks up into droplets. A feature of the process under consideration is that the stream of the jet is directed from the bottom to the top in a closed space and injection is carried out in an upward flow of air. Due to the small size of the droplet, it is considered as an elementary particle of a spherical shape [5, 6, 7, 8, 9]. Getting into the ascending air flow moving with the speed $\omega$, the drop is exposed to the resistance force of the air flow $R$, gravity $m \cdot g$ and the lifting force $F_n$, communicated to the particle by the air flow (Fig. 3).

**Figure 3.** Scheme of movement of a drop of solution

The motion of a drop as a material point falling into the air at a certain angle with an initial speed $v_0$ by a system of differential equations [8].

To draw up the equation of motion for the point, we located the origin $O$ in the initial position of the point (center of the nozzle), directed the $Oy$ axis vertically, and the $Ox$ axis horizontally relative to the initial position. The initial conditions for the motion of the point: $t=0; x_0=0; y_0=0$, the projections of the initial velocity on the axis are equal: $v_{0x} = v_0 \cdot \cos \beta; \ v_{0y} = v_0 \cdot \sin \beta$.

We consider the forces acting on the drop as a material point of a spherical shape: the gravitational force $G=m \cdot g$ is directed downward, the air resistance force is determined by the formula [5, 8]:

$$R = C_x \cdot F_m \cdot p_{air} \frac{v^2}{2}. \quad (10)$$

where $C_x$ - coefficient of resistance to particle motion; $F_m$ – mid-section, m²; $p_{air}$ – air density, kg⋅m⁻³; $v$ – speed of movement, m⋅s⁻¹.
The coefficient of resistance to particle motion depends on the shape of the droplet, the speed and properties of the gaseous medium. Given there is a spherical shape and low speeds, the empirical formula is used to determine $C_x$ [5, 6]:

$$C_x = \frac{24}{Re} + \frac{2.5}{Re^{0.25}}. \quad (11)$$

The constant parameters of dependence (12) are denoted by $\lambda$, which is a proportionality coefficient for the resistance force $R$ and for a spherical drop of mass $m$ is obtained:

$$\lambda = C_x \cdot \frac{\pi d_0^2}{4} \cdot \frac{p_{air}}{2} = k \cdot m. \quad (12)$$

For low speeds (less than the speed of sound), the force of resistance to the movement of the drop is assumed proportional to the speed $R = \lambda \cdot \nu$.

The lifting force $F_p$ will be proportional to the relative velocity of the droplet $(v_y - \omega)$.

The projections of the forces on the coordinate axes will be equal to:

$$R_x = -\lambda \cdot \nu_x = -\lambda \cdot \frac{dx}{dt} \quad (13)$$

$$R_y = -\lambda \cdot \nu_y - mg + k_n \cdot m \omega = -\lambda \cdot \frac{dy}{dt} - m(g - k \omega) \quad (14)$$

where $k_n$ – coefficient of proportionality equal to:

$$k = \frac{C_x \cdot \frac{p_{air}}{m} \cdot \pi d_0^2}{4}. \quad (15)$$

In view of (13) and (14), we composed the differential equations of motion of the drop:

$$m \frac{dx^2}{dt^2} = -mk \nu_x \quad (16)$$

$$m \frac{dy^2}{dt^2} = -m \cdot k \cdot \nu_y - m(g - k \omega). \quad (17)$$

After the transformation, we obtained a system of second-order differential equations:

$$\frac{dx}{dt} + k \frac{dx}{dt} = 0; \quad (18)$$

$$\frac{dy}{dt} + k \frac{dy}{dt} = k \omega - g. \quad (19)$$

As a result of solving equations with constant coefficients [10, 11] taking into account the initial conditions, we obtained the following equations of motion of a solution drop:

$$x(t) = \frac{v_x}{k} (1 - e^{-kt}); \quad (20)$$

$$y(t) = \frac{v_y}{k} (1 + e^{-kt} - \frac{k \omega - g}{k}). \quad (21)$$

**Figure 4.** The trajectory of the drop motion in the center of the spray jet

Calculation results: at a pressure in the system $P = 0.28 \, \text{MPa}$ and a flow rate $Q = 13.33 \cdot 10^{-6} \, \text{m}^3\text{s}^{-3}$, the nozzle diameter will be $d_n = 0.001 \, \text{m}$ and the initial velocity of the solution will be $v_0 = 17.33 \, \text{m} \cdot \text{s}^{-1}$.

Since the critical velocity is less than the initial velocity of the fluid flow $v_{crit} = 16.67 \, \text{m} \cdot \text{s}^{-1}$, then when the jet expires, crushing into droplets will occur. The average droplet diameter will be $d_0 = 0.002 \, \text{m}$.
(200 μm). The coefficient of resistance to droplet movement will be \( C_x = 0.436 \) and the proportionality coefficient \( k = 2.47 \).

For a time \( t = 0.006 \) s with an angle of atomizer installation \( \beta = 30 \) deg., the drop will go horizontally \( x(t) = 0.09 \) m and vertically \( y(t) = 0.297 \) m, which corresponds to the distance \( OA = 0.303 \) m according to geometric calculation. The axis of the spray torch intersects with the plane of rotation of the cutting disc at a point approximately equal to the middle of the knife, which meets the requirements of the geometrical reference of the sprayer.

4. Conclusion
1. When choosing a spray gun, it is necessary to take into account the average working pressure equal to \( P = 0.28 \) mPa, which ensures the flow rate of the solution \( Q = 0.8 \text{l}\cdot\text{min}^{-1} \) with a nozzle diameter of 0.1 mm. Spray guns of caliber 04 or 05 can meet the listed requirements.
2. At a spray angle of 80°, the recommended spray angle is 30°, the installation distance below the plane of rotation of the cutting disc is 0.3 m. Subject to the specified requirements, the center of the spray pattern will direct the aerosol stream to the middle of the cutting part of the circular knife.
3. The initial velocity of the fluid outflow of 17.33 m·s\(^{-1}\) will provide stable droplet formation, providing the recommended dispersion of the solution of 150-200 μm.

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