VINEYARD FLOOR MANAGEMENT WITH NOVEL FREE-ACTIVE INTER-ROW TILLER

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Abstract. Vineyard floor management is a mandatory agricultural method for cultivating this kind of crop. In order to develop a strong root system and the portion of the plant that is above the ground, the soil must contain not only the required nutrients, but it should also be sufficiently humid, well-aerated, and have good thermal conductivity. The soil must be free from weeds that compete with grapevines for nutrients and moisture and aggravate the thermal conditions of the soil by shading it. The means for weed control depend on the soil and weather conditions, the thickness of weed vegetation, the irrigation system, and whether there is an underlying principle of using chemical agents for fighting weeds. In this article we considered widespread methods and techniques for weed control, improving the structure of soil and the methods of cultivating the areas between the plants in the vineyards, the comparison and justification of such methods from the financial perspective, and also the provision of necessary agrotechnical parameters of cultivating this kind of crop. The conducted comparative analysis has shown that the climate, anatomic and physiological peculiarities of grape varieties cultivated in Armenia are an important aspect that is being taken into consideration in developed countries upon choosing the machines for cultivating the areas between the plants in the vineyards. The purpose of this article is to develop to the vertical inter-row tiller of vineyards developed at the Armenian National Agrarian University (ANAU) an alternative variant for rocky soils and without power drive, or, in other words, with the principle of free-active spin-harrow for the inter-tillage of plant rows.

Keywords: agricultural machinery, viticulture, vineyard cultivation, weed control, inter-tillage, spin-harrow, product development.

Introduction

Fertility is the most valuable property of the soil, and its level depends on the chemical composition and physical and mechanical properties of the soil as well as on productive activities of people. Soil management assumes the creation of the best possible conditions for proper grape plant growth. The proper and timely soil cultivation facilitates the creation of conditions for improved microbiological processes in the soil, the accumulation and preservation of moisture, and nutrient enrichment [1]. This is why the selection of the proper method of soil cultivation and its appropriate implementation serves as the foundation of further yield.

Agriculture is a strategically important branch of Armenian economy. Viniculture is one of the leading branches in the agro-food sector, but it is also partly mechanized. The main reserve for boosting the efficiency of grape cultivation is mechanization of the most time- and labour-consuming technological cultivation operations, one of which is soil cultivation with the destruction of weeds around the trunk. As a rule, the area between the bushes in the vineyards is cultivated manually; it is mulched, cover cropped or kept clean of weeds by using herbicides and cultivating the area with the help of machines and equipment [2-4]. However, because of the distinctive features of the soil in Armenia, the serial equipment, machines and methods used in the manufacturing sector abroad do not have widespread application. In addition, the equipment and machines for cultivating the soil between bushes in the vineyards do not have a well-justified selection of parameters of their operating elements. They are mainly meant for operating in non-irrigated areas and do not satisfy the agricultural needs that are imposed on them in irrigated vineyards, which are mainly located on heavy fragmental soils. According to the data obtained in 2015, the total surface area of vineyards in Armenia is 17,500 ha. The main regions of viniculture are located on semi-arid and dry steppe soils. The vineyards are mainly covered and irrigated, and stand out by having vertical zonation, hot summers and harsh winters, specific features of grape varieties and the area, and their system of cultivating, the density of vegetation, and the pruning and shaping of bushes. The presence of medium-sized and large stones (with the diameter from 10 to 30 cm) and the soil capacity for hardening have a negative effect on mechanization of the operations aimed at the soil cultivation in areas between the rows and bushes. According to the data provided by the Armenian State Hydrometeorological and Monitoring Service, all territories of grape cultivation, with a few exceptions, have an average annual rainfall below 500 mm [5], and the relative air humidity is below normal, which means that in such conditions the vineyards definitely need additional (artificial) irrigation. These factors, as well as many others, determine a low level of mechanization of viniculture and a comparatively high labour intensity [6].

The high level of mechanization of the grape cultivation processes in the leading winemaking countries, especially the cultivation of the areas between the bushes, is explained by a comparatively simple mechanical structure of soil and favourable weather conditions in the area, which rules out the technological processes of covering and digging.

Taking into consideration all of the above-mentioned peculiarities creates the need for developing a set of machines that take into account the zonal peculiarities, the modern aims of resource and energy economy, and soil environmental safety [7]. Nowadays, these problems are especially urgent, since the current economical, energy, and environmental situation requires carrying out very diverse tasks: obtaining a sustainable yield, saving material and energy resources, preserving the fertility of soils, protecting them from erosion and negative consequences of the anthropogenic impact.

State of the art of vineyard cultivation

Depending on the type of the soil, climate, geographical area and the adopted method of cultivation the weeds that grow in vineyards are completely different. Consequently, the methods of weed control will vary with the region. The widespread methods of vineyard floor management are mechanical cultivation, which can include the management of spaces between the rows and bushes, chemical, cover cropping, mulching [4; 8-11].

Soil mulching is an old method of fighting weeds and soil erosion and preserving the soil moisture structure. Different plastic and organic materials are used for mulching, such as polymer films, tar felt, hay, straw, manure, compost, saw dust, cut vegetation, etc. [3; 11; 12]. Mulch blocks the light and prevents the weed growth, but at the same time it creates a favorable environment for insects and worms as well as rodents. Developed winemaking countries dedicate a lot of work to the application of this method and its advantages, but the zonal and climate-related peculiarities, and the necessity of covering and digging of the grape vines set some limits on the widespread use of this method.

Chemical methods of weed control mean using herbicides and fumigation. Weed control in vineyards includes using soil-applied (contact) herbicides as well as systemic products. Soil-applied herbicides mainly destroy annual weeds through their root system, but perennial weeds are resistant to them [4]. In order to destroy perennial weeds, systemic herbicides that penetrate into the plants through the leaves and other above-ground organs, and then, through tissues, reach the roots, destroying the plants' metabolism and leading to their death are used during vegetation.

Cover cropping is another famous method, which has a beneficial effect on soil, plants, and on the general ecological system [2]. It can be managed with different plants depending on the soil texture, climate, planting density. However, they compete for water and nutrients, and the other important problem of this method is they do not cover spaces between the bushes. Considering the features of Armenian grape varieties, this is a very important limit for the expansion application.

Several studies were conducted to compare different weed control methods and find the best solution [4; 9; 13-16], but each of these methods has specific limitations in vineyards. The toxicity of some methods, their high cost, the need to use special equipment as well as insufficient efficiency limit the application of these methods, at least in Armenia. These problems contribute to develop a simple and cheap management system that must be also environmental friendly. In this case, effective weed control and good soil properties are provided by mechanical cultivation [2].

Depending on the interaction between the operating elements and the soil, the machines and devices for cultivating areas between the bushes can be divided into two groups: machines with progressive motion and rotating machines [17].

The leading companies in developed countries (Italy, the Czech Republic, the USA, New Zealand) produce special machines, both with progressive and rotating motion, for cultivating the spaces between the bushes and rows in vineyards. The machines with progressive motion (Rinieri, Ostratický, Calderoni) cultivate the areas between the bushes with the help of flat cutters (blades). The flat blade cuts the soil from below at a certain depth without loosening it, and virtually does not displace the soil, leaving it in the same location. As a result, the root systems of weeds are not destroyed properly, and the mechanical structure of the soil does not improve. At the same time, in some cases, the blade can go deeper into the soil than required, thus increasing the traction resistance of the machine.

Numerous research results have proved that, from the point of view of efficiency of soil cultivation, the rotating soil-cultivating machines rank second to none when it comes to meeting all of the relevant agrotechnical requirements [18]. Depending on the supply of energy to them, they can be passive or active. The technological process of soil cultivation can be done with the help of rotating soil cultivating machines with horizontal and vertical rotation axis.

The cultivators with passive operating elements and the cutters with horizontal rotation axis do not provide the appropriate and adequate cultivation quality. The former are not efficient enough for combating low weeds and have high tractive resistance. The latter scatter and dry the soil too much, the weed stems reel on the shaft of the milling drum, the area under the reduction unit is not cultivated, the energy consumption ratio is high, etc. [19]. Regardless of the principle of implementing the technological process by either using a passive or an active operating element, modern machines and equipment for cultivating the spaces between the bushes in the vineyards bypass (Rinieri, Ostratický, Calderoni, Boisselet, FMR) the obstacles by using a sensor that is connected to a hydraulic system, which bypasses a vine or some other obstacle with the help of a sensitive probe, which transmits the signal to the hydraulic system when it comes across an obstacle, so the operating element is taken out of the space between the bushes with the help of a hydraulic cylinder, and it returns into the operating position when the sensor is in the neutral position. This system makes the structure of the machine more complex, improves its metal intensity, reliability, operation, and further maintenance and repairs. The next very important reason for low technological efficiency of these machines is the distinctive feature of Armenian grape varieties – the vine branches off at the bottom and there is no clear and high trunk part. Taking this peculiarity into consideration, the probe can transmit false signals to the hydraulic system, thus affecting the efficiency of the process [17]. Such machines are mainly meant for European grape varieties, where the vine branches and forms at some height, which allows the cultivating equipment to do the cultivation freely and without any obstacles. The hydraulic vine bypass sensor is appropriate and can be used in vineyards like that. Another important factor is the price policy of such machines, since by virtue of using information technologies and electronic equipment, such machines are quite expensive, while large investments can be unjustified and may lead to financial problems for smaller farming enterprises and the developing branches of industry.

The purpose of inter-tillage between the plant bushes in vineyards is to create as favourable soil conditions as possible in terms of aeration, watering, temperature and nutrients for the normal growth and development of plants during the whole growth period [18; 20]. The loosening of the upper layer of soil reduces water evaporation from the soil and improves the aeration of plant roots. Another important task in ensuring normal growth conditions for the plant is the destruction of weeds. Inter-tillage must ensure that weed is completely cut or torn out of soil. Weed control should not be delayed. These tasks stipulate that the treatment level of the upper layer of soil must be sufficient and continuous; however, the depth of the working unit of the inter-row tiller may vary to some extent. In order to achieve a higher level of soil treatment, inter-row tillers with an active working unit should be taken into use, or more precisely, active harrows with rotary vertical axes. As we mentioned, these can be divided in two groups by distinctive features: according to active drive into free active (ground driven) and power driven active harrows, and by construction into disc harrows and helical spin-harrows. Power driven spin-harrows are sometimes called vertical tillers.

Description of prototype

The following is a short description of the inter-row tiller developed at ANAU, Armenia. The inter-row cultivator consists of a П-shaped frame, attached to a tractor, with two hydraulic power driven circular tillers with a vertical rotating axis. The working elements are knives, whereas both of the circular tillers are equipped with 6 knives (Figure 1), depending on the density of a vineyard contamination with weeds and stones, the number of L-type blades attached to the cutter varies from 3 to 6 [21]. The diameter of circular links is 450 mm.

Fig. 1. **General view of ANAU spinharrow**

Unlike similar machines listed above, the developed machine does not have a hydrosensor that is used for bypassing a vine. In this case, vines are bypassed with the help of a rubber bezel, which upon coming into contact with an obstacle or a vine rolls down it freely and guides the operating element out of the space between the bushes. After bypassing the obstacle using a spring of appropriate stiffness and the reactive force of the blades, generated as the result of cutting soil, the operating element gets back into the space between the bushes.

An important fertility factor is the soil density, which depends on the number of the machine operating cycles in the field. Rotating machines and equipment provide the minimum number of operating cycles, within which it is possible to cultivate the soil. Bearing this in mind, this machine fully meets the requirements.

Besides the high level of soil treatment provided by this machine, it has several disadvantages that can be described as follows:

1. Due to power drive the machine energy consumption is higher compared to passive inter-row tillers.
2. When working with power driven machines, the intensive loosening and mixing of soil is accompanied by destruction of soil grits, which may lead to dusting of soil and risk of erosion.
3. Power driven machines are not suitable for rocky fields as surface rocks in the upper layer of soil result in a high risk of mechanical faults. The size of surface rocks is 10-30 cm.

Materials and methods

In vineyards with a high rock content it is rational to use a machine with an alternative concept, which features a spin-harrow, or free-active machine, or ground driven harrow with vertically rotating circular links, equipped with working elements [22]. It is reasonable to use spikes instead of knives as working elements in a free-active machine. The circular links are attached to a free-active spin-harrow in a way that their axis of rotation has a 1...3° slantwise tilt to the vertical axis. Such a tilt results in one side of the circular link having a greater working depth, which, in turn, results in higher soil resistance. This creates momentum towards the circular link axis of rotation, which makes the circular link rotate when the machine is moving; whereat the paths of the spin-harrow spikes represent geometric cycloids with rolling circle having the diameter of $r_l$and a straight line as the directrix. Therefore, the outer spikes of the circular link move along intersecting curves, working through the soil layer in all directions. The illustration of the working principle of a free-active spin-harrow circular links in an inter-row tiller has been presented in Figure 2.

The technological parameters that need to be determined for the spin-harrow are the suitable number of spikes and circular link's tractive resistance, taking into account the geometric parameters of the chosen spike.

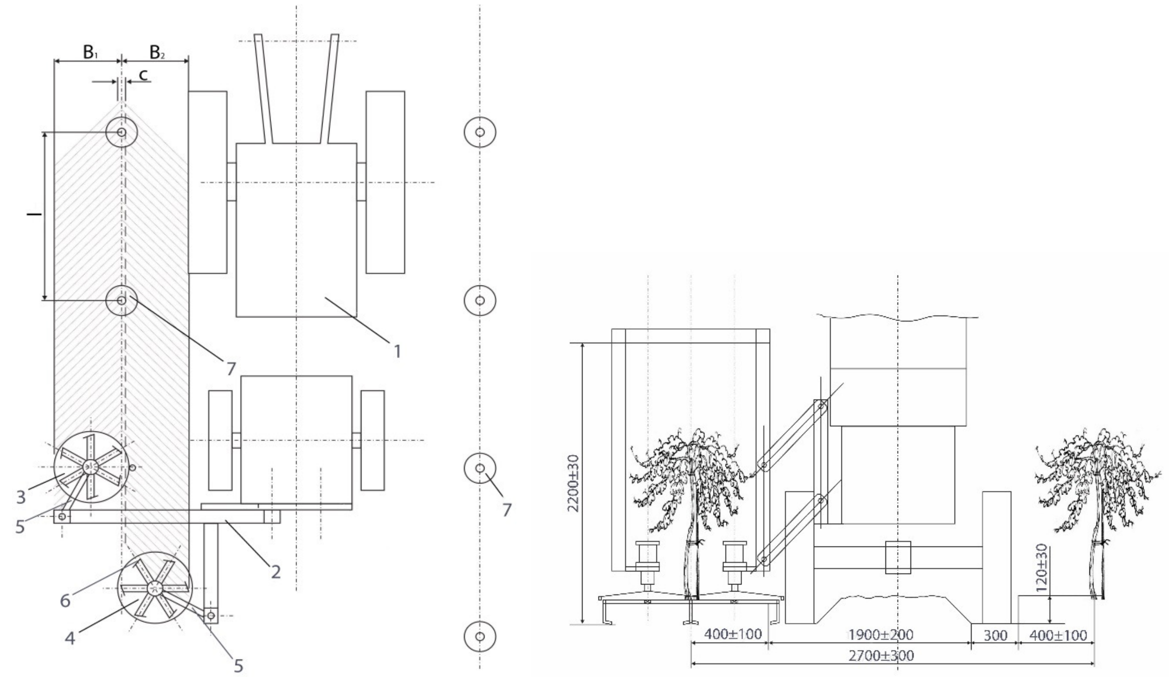

Fig. 2. **Illustration of the working principle of inter-row tiller:** 1 – tractor; 2 – П-shaped frame; 3 and 4 – circular link; 5 – connecting device; 6 – spike; 7 – grape vine

Soil treatment level

The soil treatment level can be determined on the basis of the abovementioned experimental study results and according to the technological parameters of the spin-harrow. As the paths of spikes overlap, the minimal distance between the neighbouring rows equals zero; the maximum distance is determined by the technological parameters.

The difference between the paths drawn by spikes on one link towards the $s_x$movement direction (x axis) is a constant, or $s_x = -r_l \cdot \theta$, or when taking into account the absolute value, $s_x = r_l \cdot \theta$, in which

$$\theta = \frac{b}{r_l}, \tag{1}$$

where θ – angle of displacement of spikes, *i.e.* the angle between the radius vectors;
b – working width of the spike, mm;
r_l – radius of the spin-harrow circular link, mm.

The number of spikes z_1 of the spin-harrow circular link can be determined by $z_1 = 2\pi/\theta$. Taking into account that the working width of one spike can be determined by the relation $b = 2h\tan\rho$, where ρ is an angle characterizing the range of soil deformation (in our case $\rho = 45°$), we can now determine the number of spikes z_1 on the spin-harrow circular link as follows:

$$z_1 = \frac{\pi r_l}{h \tan \rho}, \tag{2}$$

where h – average working depth of the spike; in our case $h = 120$ mm.

As we replace the equation (2) with numeric values, the calculated number of spikes will be $z_1 = 5.84$. In order to avoid clogging, we choose $z_1 = 6$ as the actual number of spikes. A simple calculation will show that the chord between the circular link spikes will have the length of $L = 264$ mm, according to which we can say that there is a risk of clogging for the circular link. As the circular link is rotating, we shall presume that it is self-cleaning and there shall be no problems in its exploitation.

Spike tractive resistance during movement in soil

As the spikes of a spin-harrow move in soil, resistance of motion is created, which is favourable tractive resistance for the tractor implements. Taking into account that the gross width B of the area treated by the circular links of the inter-row tiller can be expressed as:

$$B = \frac{R}{k}, \tag{3}$$

where R – circular link tractive resistance, N;
k – specific resistance, Nm^{-1}.

We can express the resistance of motion R_x for one spike as follows:

$$R_x = \frac{B \cdot k}{z} = \frac{d_l \cdot k}{z_l}, \tag{4}$$

where d_l – diameter of the circular link $d_l = B/n$, mm;
z – number of spikes in the machine $z = z_l n$;
z_l – number of spikes in one circular link;
n – number of circular links in the machine.

Analytically, the tractive resistance $R_{x,a}$ of one spike can be determined as:

$$R_{x,a} = ab\left[\gamma_0\left(K_a ag + K_v v_m^2\right) + K_c C\right], \tag{5}$$

where a – working depth;
b – spike working width;
γ_0 – soil bulk density, $\gamma_0 = \rho_c(1 - \Pi)(1 + w)$, $Mg \cdot m^{-3}$;
ρ_c – density of soil skeleton, $Mg \cdot m^{-3}$;
Π – soil general porosity;
w – soil's moisture level;
v_m – machine's speed, ms^{-1};
C – soil cohesion, kPa;
g – gravitational acceleration, ms^{-2};
K_a, K_v and K_c are generalised factors, whereby:

$$K_a = \left(K_1 + K_2\right)\frac{1}{\sin\alpha_0}, \tag{6}$$

where α_0 – spike working angle, in this case $\alpha_0 = 90º$;

$$K_1 = \frac{\left(1 + \tan\frac{\alpha + \varphi}{2}\tan\frac{\varphi_0}{2}\right)\left(1 + \tan\frac{\alpha + \varphi}{2}\right)\cos^2\frac{\alpha + \varphi}{2}}{1 - \tan\frac{\varphi_0}{2}},$$

where φ_0 – soil internal angle of friction, in this case $\varphi_0 = 15º$; $\varphi = 40º$;

$$K_2 = \left(\tan\alpha\tan\varphi_{xy} + \tan\beta\tan\varphi_{xz} + \frac{1}{2}\sin 2\alpha\tan\varphi\right)\cot\alpha,$$

where β – working unit slant angle in cross vertical plane; in this case $\beta = 90º$;
φ_{xy} and φ_{xz} – angles of friction in different directions, whereby for practical calculations $\varphi_{xy} = \varphi_{xz} = \varphi$.

As $\alpha = 90º$, then $\cot\alpha = 0$, and $K_2 = 0$.

The generalised factor K_v is expressed as

$$K_v = \left(1 - \cos\gamma\right)\left(1 + K_3\right), \tag{7}$$

where $K_3 = \tan\alpha \tan\varphi_{xy} + \tan\gamma \tan\varphi_{xz} + \frac{1}{2}(\sin 2\alpha + \sin 2\gamma)\tan\varphi$;

and the generalised factor K_c is:

$$K_c = 1 + \tan\frac{\varphi_0}{2}\left(\frac{1+\tan\frac{\alpha+\varphi}{2}}{1-\tan\frac{\alpha+\varphi}{2}\tan\frac{\varphi_0}{2}} + \frac{1+\tan\frac{\gamma+\varphi}{2}}{1-\tan\frac{\gamma+\varphi}{2}\tan\frac{\varphi_0}{2}}\right). \quad (8)$$

As can be seen from equations 1 to 4, the tractive resistance of the circular link of a free-active spin-harrow depends only on the constructive parameters of the soil being treated and the working unit, and the speed of the inter-row tiller.

Testing of the spin-harrow

The tasks of the testing works were the following:

1. Checking the test piece's working capacity and suitability;
2. Determining the spin-harrow resistance of motion and specific resistance.

The general parameters of the test were the following: soil – moderate loam soil, moisture content 19 %; bedding density 1.31 $Mg \cdot m^{-3}$; length of the test run 100 m; average working depth 12 ± 1 cm. The harrow tractive resistance was measured on the basis of the power generated by the tractor engine. A power indicator was used to measure the power generated by the engine. The test results have been presented in Table 1.

Table 1

Test results for the spin-harrow

Machine speed, V_m, ms^{-1}	Slippage, δ, %	Average tractive resistance, R_m, N	Circular link specific resistance, k, Nm^{-1}
2.240.03	8.31.0	2848.5	355
2.500.06	10.31.9	58617	732
2.670.04	11.11.1	1349	1686
3.280.05	15.51.3	16522.3	2065

Results and discussion

If $\gamma_0 = 2$ $Mg \cdot m^{-3}$, $v_m = 4$ m s^{-1} and $C = 20$ kPa, then we can determine the tractive resistance of the circular link $R = R_{x,}a \cdot z_l$, and inter-row tiller tractive resistance $R_m = R \cdot n$. This result is one of the parameters for choosing the towing machine for operating the free-active spin-harrow. In comparison to a power driven spin-harrow, it must be noted that the resistance of motion of a circular link, and thereby the power demand and fuel consumption, are significantly affected by the cutting resistance, which is illustrated by the cinematic indication parameter λ.

Experimental studies of the spin-harrow give a reason to make the following conclusions:

1. A free-active machine is a suitable technical instrument for full length cultivation and inter-tillage of soil.
2. A spin-harrow is capable of replacing a row cultivator and passive spike-tooth harrow and ensures higher quality work compared to the latter.
3. The spin-harrow does not clog because a difference in the resistance forces is created when weed or surface rocks accumulate, which causes the circular link to rotate and clean itself.
4. A spin-harrow is effective in levelling the soil surface.
5. The rotation speed of the circular link depends on the circular link angle, soil type and moisture.

Conclusions

The article has pointed out the methodology and explanation for the selection of the most important part of the free-active inter-row tiller – the constructive and kinematics parameters of the spin-harrow. The constructive parameters of the prototype of the spin-harrow (Fig. 2) are the following:

- the diameter of the circular link $2r_l$ = 450 mm;
- the length of the spikes of the circular link L = 264 mm;
- the number of spikes z_1 = 6.

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