VOL. 14, NO. 22, NOVEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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THE CHOICE OF TECHNOLOGY OF AGRICULTURAL CROPS CULTIVATION ON THE BASIS OF THE MANUAL LABOR COSTS INDICATOR OPTIMIZATION (FOR THE EXAMPLE OF VEGETABLE AND MELON CROPS CULTIVATION)

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ABSTRACT

Modern economically advantageous technologies for cultivation of melons and gourds provide unconditional application of manual labor. Such operations include: weeding out protective zones and row spacing during the treatment of seedlings of plants, various types of harvesting of melon fruits, and also sorting them according to certain characteristics. The main task in the choice of technologies is to find the most labor-intensive operation that is performed manually and, taking into account the agro-technical conditions, determine the maximum allowable treatment area per person. These calculations were performed on the basis of the methodology for estimating energy consumption.

Keywords: network graph, graph theory, melons, specific energy intensity, energy efficiency factor, production rate, allowable area, vegetable crops, labor productivity.

INTRODUCTION

Agricultural production at the modern level, based on mechanized and automated processes, cannot do without the use of manual labor, the largest part of which falls on the field of field crop cultivation. It should take into account indirect use of manual labor when filling seeders grain, service trucks and other operations of the manual labor associated with the implementation of operations in the technology itself.

Until now, in the technologies of cultivation and harvesting of vegetable and melon crops, manual labor is used when weeding the crops and harvesting the fruits. For the theoretical determination of the maximum allowable area per employee engaged in manual operations, an appropriate analysis was carried out. It is based on the methodology for assessing the operation based on the energy cost criterion. The maximum allowable area is determined on the basis of specific energy inputs, taking into account agrotechnical and other factors. And to find out the most labor-intensive and energy-intensive operations, a graph model of the technology of cultivation and harvesting of melons has been used, based on the network schedule of the technology.

In modern conditions of agricultural production, special attention should be given to the most economical methods, techniques and technologies, which, at relatively low costs, can have a significant economic effect. However, the farms involved in vegetable growing and melon growing, selection of possible variants of cultivation and harvesting is not determined by obtaining the maximum effect, and most of the available technical means and human resources.

To be able to scientifically make the most rational choice of different technologies of cultivation of melons, it is necessary in specific circumstances to evaluate and compare the different options transactions, causing those or other consequences.

In addition, since there can be very many variants of these, and their individual, and even more so the combined effect, is very difficult to determine, it is necessary to choose a criterion that most fully responds to the influence of both individual factors and their total impact.

Naturally, this generalized indicator should most objectively and comprehensively assess the possible options for production, meet the requirements of the task. This indicator should be based on a number of particular criteria, which are not constants, but are dynamic, since all production of agricultural products, including melon and vegetable growing, is under the influence of constantly changing environment.

MATHERIALS AND METHODS

The assessment system is very complex and diverse, as it must take into account all the diversity and interconnection of natural and climatic conditions, especially the biology of melon and vegetable crops plants and their fruits, the impact of the working organs of agricultural machines and other factors [5].

It is known that the interaction of factors can be represented in the form of a material system closed along

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the contour. Such a closed system is called an absolute material system by a number of scientists. However, more often in mathematical constructions the concept of a complex material system consisting of a finite number of subsystems is used [4]. The main quality of this system is that its constituent elements are considered only in interaction with each other. Therefore, if at least one of the elements changes qualitatively, this immediately affects the entire system. The most complex are various technological processes and, first of all, connected with the production of agricultural products with considerable labor costs. Proceeding from this, the processes of cultivation and harvesting of vegetable crops can be considered as a complex material system, divided, conditionally, into a number of subsystems. Each of them is an interaction of constantly moving artificial and natural material objects that have a common feature. Movement or movement is represented by a quantitative and qualitative change in the system in time and space.

In real production conditions, all this is done with constantly changing external influences at different stages of plant growth and development, the main indicator of all activities. In this case, in the system of "vegetable slaughter plants - the external environment", located in a differentiated dynamic state, it is possible to distinguish elements of organizational management: the control object, the environment, devices affecting the control object [2].

RESULTS AND DISCUSSIONS

Based on the general representation of this system, a network schedule for the cultivation of melons (Figure 1) was developed based on long-term observations of plants. It allows you to more fully imagine not only possible operations, but also take into account the conditions, timing, qualitative change of objects when cultivating melons. The graph of objects is represented by four interrelated blocks, differing interrelated successive goals. The network graph is in absolute accordance with the graph model of cultivation of melons (Figure-2) and is its basis.

From the point of view of carrying out agrotechnical measures and using technical means for cultivating crops, we propose to conduct appropriate studies on the phases: sowing - shoots, shoots - the appearance of the first real leaf, the first leaf - the shed, the shed - the lapping, then - according to the scheme. These additional phases of plant development make it possible to more accurately study the possibilities of carrying out crop and harvesting treatments in time to ensure the least damage to melon and fruit plants [1, 7].

As can be seen from the graph, it includes "on an equal footing" as operations that directly depend on the person, taking into account the work of machines (cultivation, seeding, processing of rows, etc.), and the operations accompanying these works (compaction and warming the soil to certain temperatures, germination and development of weeds). The network schedule also indicates the time during which this or that operation can be performed.

The critical path of the presented network schedule passes through operations denoting phenological phases of development of melons and melons, and its value is determined by the duration of the growing season. The order of operations depicted in the graph allows you to quickly determine the operations of the same name and their approximate quantitative indicators.

Typical for the network graphics is the presence of operations, the accomplishment of which purposefully predetermines the flow of all processes. Of course, plants are differently sensitive to previous operations, but by the time of the onset of "special" operations, all the previous ones must be performed. To denote "special" operations, one resorts to the method of reference points of the complex of operations. For the purposes set in this paper, such points will be the emergence of seedlings, the formation of the first real leaf, the phase of the marquee, and the formation of whorls.

It is characteristic that all operations at these reference points are limited to carrying out measures for inter-row cultivation of crops and weeding of weeds in rows. These reference points serve as the main reference point in the performance of the work, but they themselves cannot be equivalent in the phenological phases.

In order to select the most appropriate technologies for growing and harvesting melons, the graph theory was used [4, 6]. To this end, a systematic approach has been applied, involving the development, the energy assessment of the complex model and the decomposition of a complex technological system into simpler subsystems, resulting in a graph model (Figure-2), with the tops of the graph corresponding to the beginning or end of one of the operations in cultivation technology.

The peculiarity of the model is that it takes into account only the operations relating directly to the technology of cultivation and harvesting of vegetables from the vegetables on the bog.

Since the technologies of cultivation of vegetable and melon crops are very close to carrying out operations, subsequent studies will be carried out for the technological process of cultivation of melons and gourds. This process most fully reflects the set of technological operations of cultivation of a highly labor-intensive crop with pronounced technical processes performed manually [3].

The main purpose of the graph model of the technology of cultivation and harvesting of fruits of melon crops shown in Figure-2 is to perform a comparative assessment of various technologies based on energy analysis.

Energy analysis in crop production allows us to identify the least energy-intensive technologies by comparing the costs of energy resources to the performance of each technological process (operation). It avoids the introduction of technical means and technologies in agricultural production with a higher level of material and energy costs than the minimum level already achieved [8, 9].

Determination of specific energy intensity is possible under the condition of calculating energy costs, as well as knowledge of the duration of the phenological

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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phases of melons and accompanying operations for harvesting.

Using the graph model of the technology of melon cultivation together with the network schedule makes it possible to determine the energy indicators for the entire technology or individual operations in melon growing. The obtained results make it possible to recommend the acquisition of the most rational machine-tractor units.

The dates indicated by the phenological phases of melons and gourds apply not only to calculations of works, but also to the rational use of necessary equipment, as well as the availability of labor resources [3].

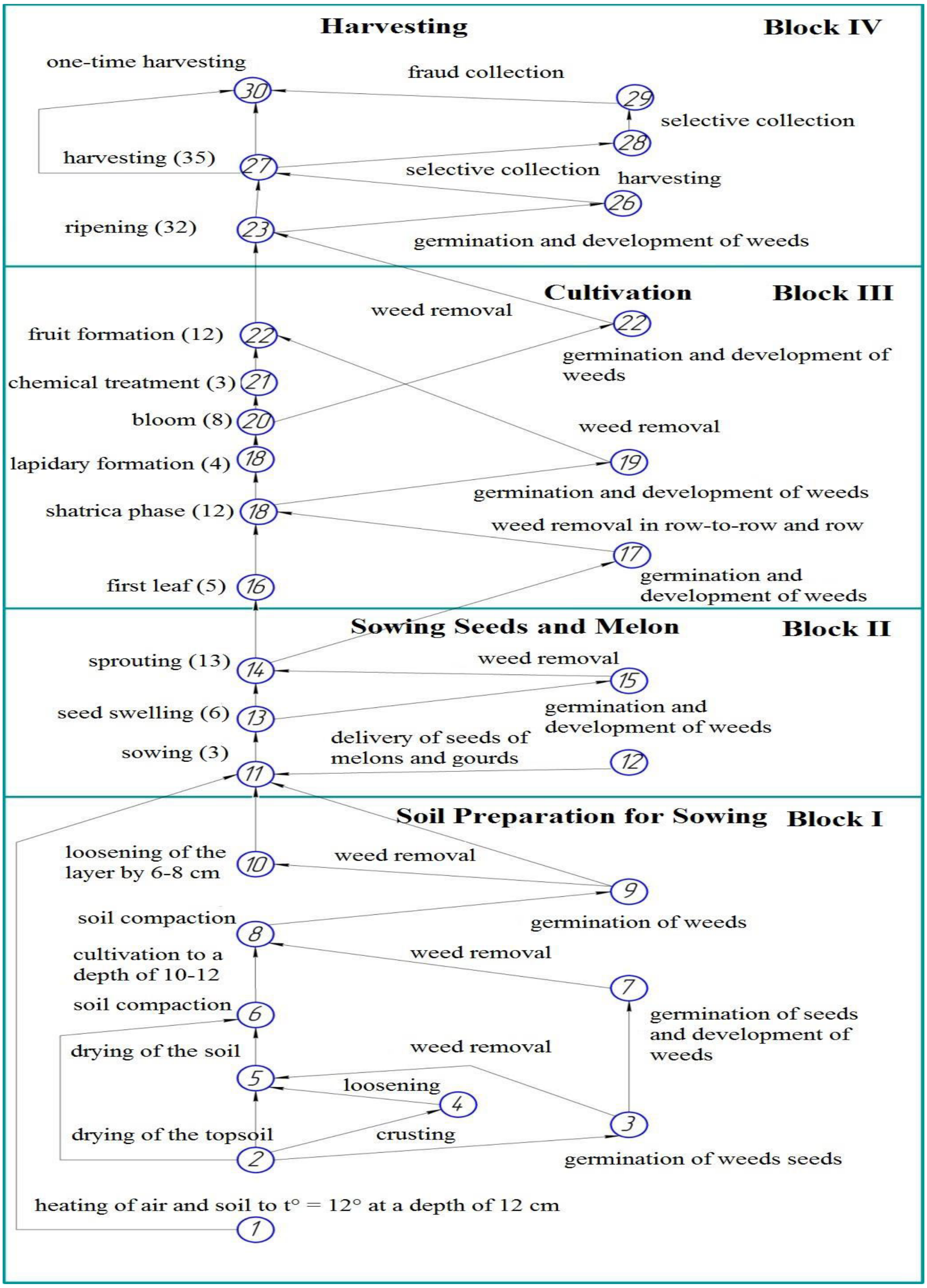

Figure-1. Network schedule for cultivation and harvesting of melons and gourds.

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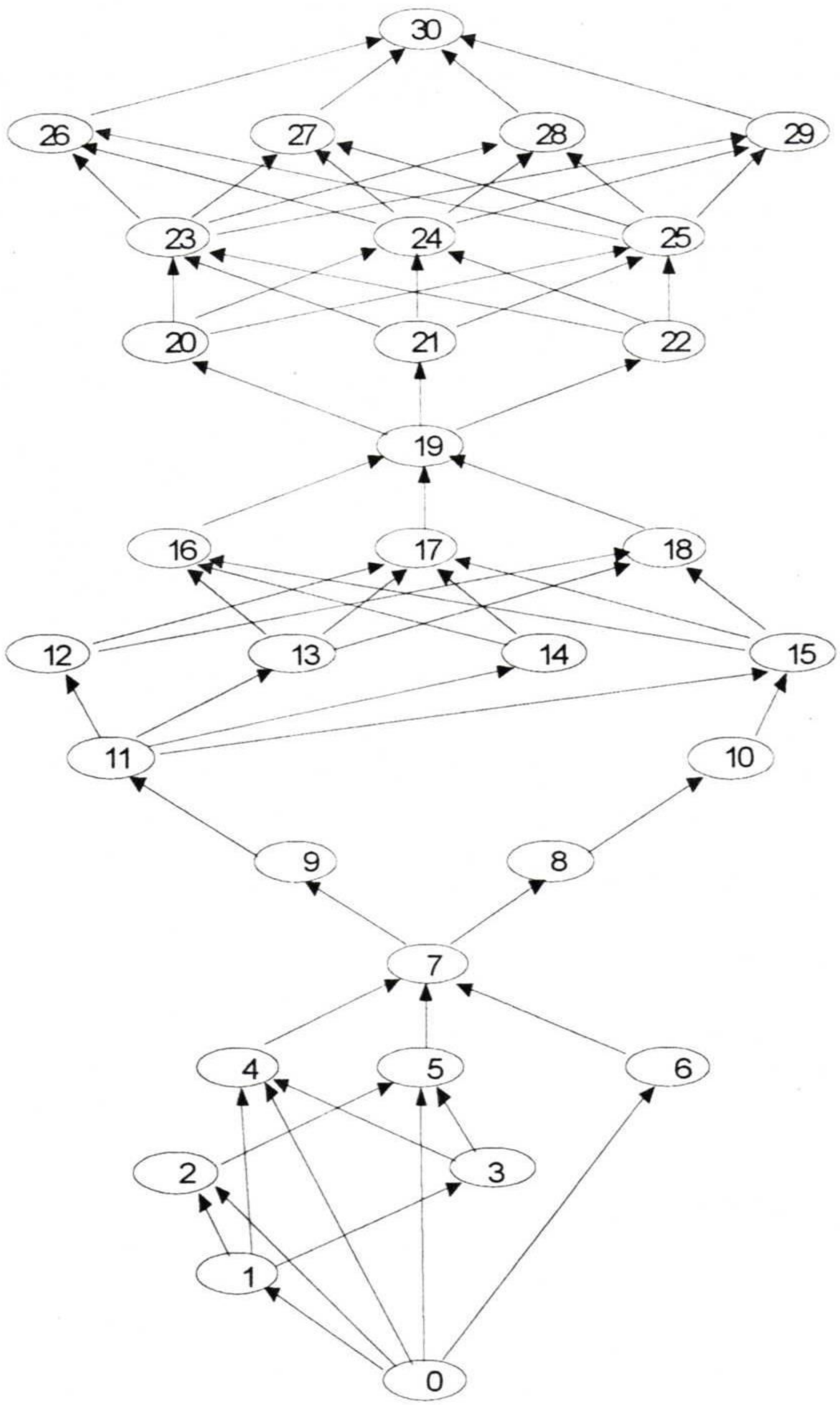

Figure-2. Graph model of technology for cultivation and harvesting of melons and gourds.

VOL. 14, NO. 22, NOVEMBER 2019 ISSN 1819-6608
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Table-1. The operations shown on the graph model of the technology of cultivation and harvesting of melons.

Designation	Operations and tools
0-1	Peeling of stubble: LDG-15
1-2	Application of organic fertilizers: PRT-16
1-3	Application of mineral fertilizers: POU-5
0-4, 1-4, 2-4, 3-4	Plowing: PLN-5-35
0-5, 2-5, 3-5	Loosening by the harrow BDT-3M
0-6	Steaming without waste: KPG-2.2
4-7, 5-7, 6-7	Snow retention
7-9	Cover harrowing: ZBZS-1 + SP-16U
7-8	Surface treatment: BIG-3
9-11, 10-15	Cultivation: KPM-4.0
8-10	Loosening of the soil: KPSh-5.0
11-12, 11-13, 11-14, 11-15	sowing: SUPN-8.0; SBN-3.0; SUPN-8V
12-16, 13-16, 14-16, 15-16	Inter-row processing with manual weeding: KRN-5.6
12-17, 13-17, 14-17, 15-17	Inter-row processing: KNB-5.4 with tool PPR-5.4
12-18,13-18, 14-18, 15-18	Inter-row processing: KRN-5.6 with mechanized treatment of the protective zone
16-19, 17-19, 18-19	Treatment of crops with pesticides
19-20, 19-21	Selective collection of fruits
19-22	Selective machine harvesting of fruits
20-23, 21-23, 22-23	Solid collection of fruits manually with stacking in heaps or rolls
20-24, 21-24, 22-24	Solid fruit harvesting with the use of mechanisms and devices, with laying in rolls or heaps
20-25, 21-25, 22-25	Forming of rolls: UPV-8.0
23-26, 24-26, 25-26	Loading of fruits into the vehicle manually
23-27, 24-27, 25-27	Picking up the fruits with a pick-up with stowage in the vehicle
23-28, 24-28, 25-28	Loading of fruits with a pick-up with stowage in a vehicle with sorting on a combine
23-29, 24-29, 25-29	Loading fruit in containers
26-30, 27-30, 28-30, 29-30	Transportation of fruits to the intermediate point, followed by sorting and packing in containers, storage, etc.

Thus, the whole process of cultivation and harvesting of melons is reduced to two interconnected systems: agrobiological and technical. The agrobiological system is characterized by yield, commodity output, production losses, the maximum allowable treatment area, and the technical system is the set of machines and tools used, and the total energy intensity of cultivation and harvesting of melons. Hence, we can determine the specific energy intensity of the process using the following relationships:

a) the specific energy intensity of the process for mechanized cultivation:

$$E'_{Mj} = \frac{(\sum_j E_{dj} + \sum_j E_{0j})}{\sum_j U_j \cdot S_j} \quad (1)$$

Where

E'_{Mj} is the specific energy expenditure for the j-th process, MJ/t; E_{dj} is the direct energy expenditure for the j-th technological process, MJ; E_{0j} is energy costs, materialized in the production of energy carriers and other resources, MJ; U_j - productivity, t/ha; S_j is the area of cultivation of melons, ha

the specific energy intensity of manual labor during the j-th process:

VOL. 14, NO. 22, NOVEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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$$E'_{Hj} = \frac{\sum_j N_{ij} \cdot a_j \cdot t_{st}}{\sum_j U_j \cdot S_j} \quad (2)$$

Where

E'_{Hj} is the specific energy intensity of manual labor during the j-th process; a_j is the energy equivalent of living labor, MJ/person · h; N_{ij} - number of people involved in the process, people; t_{st} - shift time, h

As follows from the presented formulas, if the denominator increases, that is U_j, S_j → max, and the numerator decreases accordingly, when E_{dj}, E_{0j}, N_{ij}, a_j, t_{st} → min, then the specific energy intensity of the process decreases. The most advantageous option is if E'_{Hj} and E'_{Mj} → min.

Similarly, the determination of specific energy inputs for the output of marketable products is carried out. For this, in the denominator instead of U_j (yield, t/ha), you need to substitute T_p (output of commodity output, t/ha).

The optimal variant is determined by the main criteria of energy efficiency of technological processes. For this purpose, the generalized energy cost coefficients U_{Ej}, U_E.

$$K_{MEj} = \frac{E_{Mjn}}{E_{Mjk}}, \quad (3)$$

$$K_{HEj} = \frac{E_{Hjn}}{E_{Hjk}}, \quad (4)$$

$$I_{MEj} = (1 - K_{MEj}) \cdot 100\%, \quad (5)$$

$$I_{HEj} = (1 - K_{HEj}) \cdot 100\%, \quad (6)$$

Where

K_{MEj}, K_{HEj} - the generalized coefficients of power inputs at comparison n-th and k-th the machine and manual operation (technologies) accordingly; I_{MEj}, I_{HEj} - levels of intensification in machine and manual operations (technologies), respectively [10]

Therefore, analyzing the generalized (for the whole technology) and private (for individual operations or specific energy inputs) coefficients, determine the feasibility of the application of technology, manual labor, a fundamental change in technology as a whole. However, it should be noted that the presence in the technologies of cultivation and harvesting of melons and gourds significantly reduces the efficiency of production, productivity and, as a consequence, leads to a rise in the cost of production.

Therefore, all subsequent studies should be aimed at reducing its share. To determine the actual values of the evaluation criteria for the energy efficiency of technological processes, the denominators of formulas 3 and 4 should be substituted with the numerical values of energy consumption using existing technologies.

Research of operations of technologies of cultivation of melons has shown, that in each case there is a certain optimum period of performance of those or other agrotechnical receptions. However, there are operations in which time is not strictly regulated, since their different duration does not lead to significant changes in yield. Such processes include basic soil cultivation, snow retention, application of organic fertilizers, etc.

At the same time, there are operations and techniques that must be performed at certain times, and changing them can lead to the loss of not only the part but the entire crop. Such operations include the sowing of melons, the destruction of weeds, the processing of plants with pesticides, harvesting, etc. In order to determine the maximum possible area for cultivation of melons and gourds in a particular farm, it is necessary to establish which of the above operations are decisive in melon growing. The production of melons and gourds in the Lower Volga region is carried out in peasant farms, in which their area does not exceed 50 hectares, as well as in larger joint-stock companies where the areas can be up to 100 hectares.

If we turn to labor costs in the production of melons, then most of them are for processing - weeding out melon crops in rows and for harvesting grown products. And if you consider that these operations are performed manually, it is obvious that they will be decisive when finding areas for melons. Therefore, in general, the area under the melon crops can be determined by the formula:

$$S = S_1 + S_2, \quad (7)$$

Where

S is the total area of sowing of melons, ha; S_1 - area processed before the most favorable moment (appearance of the first real sheet); S_2 - the area processed after the onset of a favorable moment, but not exceeding the allowable for agricultural demand

$$S_1 = W_1 \cdot t_n, \quad (8)$$

Where

$W_1 = W_M$ - labor productivity in the performance of mechanized works in the period before the onset of a favorable moment (unit capacity); t_n - the optimal time for performing the work in relation to the most favorable moment

The speed of mechanized work does not depend on the changing conditions of plant development. Therefore $W_M = W_1 = W_2$.

$$W_M = \frac{(E_p + E_w)}{E_a}, \quad (9)$$

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Where

E_p - power consumption of the power machine, MJ/h; E_w - energy intensity of the working machine, MJ/h; E_a - actual energy intensity, MJ/ha.

When carrying out the operation of cultivating crops and harvesting melons the full or partial application of manual labor is envisaged. This will depend on the technology of cultivation and the ultimate goal of using the crop. The use of manual labor will reduce the productivity of work and it will be determined by the expression:

$$W_H = \frac{E_H}{E'_S}, \tag{10}$$

Where

E_H - power consumption of manual labor costs, MJ/h; E'_S - specific energy consumption per 1 hectare area, MJ/ha

If you substitute the value in the specified formula:

$$E_H = N_w \cdot a_H, \tag{11}$$

Then it has the form:

$$W_H = \frac{N_w \cdot a_H}{E'_S}, \tag{12}$$

Where

a_H - the energy equivalent of the cost of living labor to one worker, MJ/h; N_w - pure workers

Then

$$S_2 = W_H \cdot t_g = \frac{N_w \cdot a_H \cdot t_{st}}{E'_S} \cdot t_g,$$

Where

t_g - time allowed for agro-processing for seeding treatment

To reduce the energy costs allows, first of all, the use of machines in labor-intensive manual operations.

The second way to reduce the specific energy intensity is to increase the yield and increase the area under the melons and crops at the equivalent costs of the total energy.

The size of the area of sowing gourds is limited by the rate of production and the possible duration of the period of the most intense type of work. First of all, it is the weeding of crops and harvesting of fruits, the fulfillment of which is associated with the use of manual labor. If we compare the rates of production for weeding crops and harvesting fruits on the boron by hand, taking into account the average conditions, they are approximately equal, as in mechanized technologies. And then the most significant for the size of the maximum allowable area is the time factor. It is known that harvesting of melon fruits can last for a month and more from the ripening of the first fruits. Considering that two selective collections are held on watermelons, and the pumpkins are cleaned before their full ripeness (it is proved that they ripen during storage), the allowable harvest area per person is greater than on the weeding. Therefore, the weeding operation is decisive.

The speed of the weeding operation when using the mechanisms and manually will depend on the damage to the plants, as well as on the presence of weeds. Apparently, an increase in the productivity of machines will cause increased damage, and the weakening will reduce the speed with manual operations.

In the test reports of the experimental sample of the cultivator KNB-5.4, the limiting values of losses in the processing of crops with the use of mechanisms are presented. Let us take these values as permissible and continue to orientate ourselves in their studies. If we take into account that the permissible damage values for weeding $[\varepsilon_p]$%, then the actual value thereof will be equal to ε_p, respectively. The labor productivity for weeding out shoots per shift is:

$$W_M = \frac{(E_p + E_w)}{E_a} \cdot \left(\frac{[\varepsilon_p]}{\varepsilon_p}\right)^{\varphi_n}, \tag{13}$$

Where

$[\varepsilon_p]$ is the permissible damage to the plants on weeding,%; ε_p - actual damage of plants on weeding,%; φ_n is an exponent that depends on damage to plants and cropping of weeds

In general, the expression $\left(\frac{[\varepsilon_p]}{\varepsilon_p}\right)^{\varphi_n}$ represents a decrease in processing performance, so it is more convenient to present it as:

$$\left(\frac{[\varepsilon_p]}{\varepsilon_p}\right)^{\varphi_n} = (K_w)^{\varphi_n}. \tag{14}$$

Subsequent studies of the operation of the weed aggregate determined the value of K_w, representing the ratio of the permissible processing speed to the maximum possible when using the unit.

When processing crops manually the rate of production per shift depends on the degree of contamination and in general is equal to:

$$W_a = W_H \cdot \left(\frac{c_{\min}}{c_a}\right)^{\mu_n}, \tag{15}$$

Where

W_a - actual labor productivity of one employee, ha/h; W_H - theoretically the necessary labor productivity of one employee with minimal contamination; c_a - the actual

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number of weeds at the time of weeding; c_{min} - minimum number of weeds at the beginning of weeding; μ_n is an exponent, determined experimentally and depending on the dynamics of weed development.

Hence the labor productivity during weeding will be determined:

$$W_a = \frac{N_w \cdot a_H}{E'_S} \cdot \left(\frac{c_{\min}}{c_a}\right)^{\mu_n}. \qquad (16)$$

The obtained expression allows, if necessary, to determine the number of workers, if the performance of the work at the beginning is indicated.

It is known that it is possible to start weeding of melons and gourds at a mass emergence, and the most favorable for weeding is the phase of the first real leaf of the plant. Therefore, the labor productivity during weeding in the same phase will somewhat decrease due to the germination of more weeds. Consequently, labor productivity will continue to change constantly and in the general case can be described by a function of the degree of weediness of crops, and its average value is:

$$W_{average} = \frac{\sum (W_a \cdot t_j)}{\sum t_{ij}}, \qquad (17)$$

Where

Σt_{ij} is the number of weeding days; t_j - time of one shift, h

If we consider weeding, then the speed of reaching the most favorable moment from the optimal period should be no less than the rate of appearance of weeds before the development phase of melons, when their growth essentially ceases.

The time of cultivation is determined by the dependence:

$$\sum t_{ij} = t_{\max} + t_{spr} + t_{sh} + t_m, \qquad (18)$$

Where

t_{spr} is the time from the beginning to the mass emergence of sprouts, days; t_{sh} - time of appearance of the first sheet, days; t_m - the time from the phase of the first sheet to the phase of the marquee, h

Hence the maximum allowable area is defined by the expression:

$$S_{\max} = W_{average} \cdot \sum t_{ij} = \frac{\sum \left(\frac{N_w \cdot a_H}{E'_S}\right) \cdot \left(\frac{c_{\min}}{c_a}\right)^{\mu_n}}{t_{spr} + t_{sh} + t_m} \qquad (19)$$

If we reduce the costs of hand ore due to the increase in the volume of mechanized operations, then the maximum allowable area of crops will increase.

CONCLUSIONS

When considering various modern technologies for the production of agricultural products, it is necessary to take into account the most important indicators of their evaluation. Technologies for the cultivation and harvesting of vegetable and melon crops include operations related to the use of manual labor. These operations, taking into account the time limit for their implementation, require the attraction of substantial labor resources. The main indicator in their conduct is the maximum permissible area of cultivation. When determining it, it is necessary to take into account a multitude of factors related to agricultural needs, biological and physiological properties of both cultivated plants and weeds. These factors are taken into account the network schedule of cultivation and harvesting of melons. It is represented by four blocks, including: preparing the soil for sowing; sowing seeds; cultivation of crops; harvesting. In each block, not only operations are indicated, but also the calendar terms for their implementation. On its basis, a graph model of these technologies was developed. They take into account the conduct of various operations and the use of machines to achieve the ultimate goal.

Theoretical calculations of the indicators of the evaluation of various technologies by the method of finding energy inputs are the criterion for choosing the least energy-intensive technologies, and also allow the calculation of specific energy inputs for the application of manual labor.

The indicator of actual productivity per worker when weeding the crops, expressed in terms of the number of workers involved, takes into account the dynamics of the change in the number of weeds and the specific energy intensity, which is the most important quantity in the calculations. This indicator, taking into account the maximum allowable processing time, is most likely to find the maximum permissible speed.

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