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Methods for efficiency evaluation of MX-1.8 GV cotton pickers in horizontal-spindle design

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Abstract. The article is devoted to determining the economic profitability of MX-1.8 GV cotton pickers in comparison with handpicking. The article presents the results of field tests of a horizontal-spindle design of MX-1.8 GV cotton harvester performance, compared with the results of numerical studies obtained using a computer program. The results obtained were used to further determine the economic efficiency of machine harvesting. The costs of machine and handpicking are determined. On the basis of numerical studies, it was proved that machine harvesting using MX-1.8 GV cotton picker is economically profitable at an open crop yield of more than 2.75 t/ha.

1. Introduction

Mechanized cotton harvesting is based on a system of machines, in which cotton pickers with horizontal spindle (with high cotton yield) and vertical spindle (with medium and low cotton yield) designs are recommended to harvest the crop of open cotton bolls [1].

JSC "Tekhnolog" has developed a combined cotton harvester MX-1.8 GV with replaceable harvesting devices for selective cotton picking [1]. At total opening of cotton bolls, the machine works with horizontal-spindle devices, and at incomplete opening of cotton bolls, it works with vertical-spindle devices.

At present, a one-time harvesting technology is mainly used at machine harvesting of open bolls of cotton crop. With the one-time harvesting technology, machine harvesting is carried out when the amount of open cotton bolls is over 90% of the yield and the completeness of machine harvesting should be over 90% [2]. For the widespread introduction of mechanized harvesting, it is necessary to improve the quality of the harvested raw cotton and reduce the costs of machine harvesting as compared to hand harvesting.

In this regard, studies were carried out by Kh. Kh. Usmanhodzhaev, N. D. Ivanenko, by a number of organizations, and by foreign authors [3-5]; these studies were devoted to the influence of the degree of opening of cotton bolls on the performance of cotton harvester; practically, determining the quantitative and qualitative indices of the harvested raw cotton, fiber and seeds. The studies of A. D. Glushchenko and his students [6-8] were devoted to the modeling of dynamic processes in the harvesting devices of a cotton-harvesting machine (CHM) of various designs. Foreign scientists [9-10] carried out studies of the influence of the spindle diameter and its rotation speed on the cotton impurity in a horizontal spindle apparatus.

The authors of [11] proposed to use the MX-1.8 cotton picker equipped with a single-row vertical-spindle apparatus for picking raw cotton in conditions of the Syrian Arab Republic, the MX-1.8 cotton harvester was produced in a small batch at the Vladimirovsk Tractor Plant (Russian Federation).

In [12-14], various options for the effective use of a cotton picker were considered.

An increase in the efficiency of cotton harvesting machines due to the improvement of the pneumatic transport system was considered in [15-17]. There are many recommendations for the widespread use of mechanized harvesting of raw cotton. However, the economic efficiency of machine harvesting compared to handpicking should be ensured.

The economic efficiency is influenced by many initial factors: open cotton bolls yield, machine speed, picking width, the completeness of machine harvesting, the length of furrow, the reliability of the CHM, the cost of machine, and so on. However, the methods for calculating the influence of these factors on the economic profitability of the CHM operation in comparison with handpicking have not been developed.

2. The aim of the work

Development of methods for the economic assessment of the effectiveness of a combined cotton harvester of horizontal-spindle design for a one-time cotton harvesting.

3. Methods

To assess the efficiency of the MX-1.8 GV cotton harvester of horizontal spindle design, the authors used the methods developed for the numerical determination of the productivity of cotton harvesters and empirical formulas for determining direct operating costs in accordance with the state standards (UzDSt 32252017). To determine the performance of the CHM, a calculation method was developed based on a computer program [18]. Direct operating costs of machine picking were determined by empirical formulas given in the state standards (UzDSt 32252017) [2]. In this regard, it is necessary to determine the adequacy of the results obtained using the computer program [18], with the experimental data according to the Protocol [19].

The following initial data are presented for a numerical study using a computer program [18] considering [19]:

- the yield of open cotton bolls is determined on the basis of an assessment of the agricultural background and equals to $G_p = 2.27 \cdot 10^3$, *kg/ha*;
- completeness of raw cotton machine picking is determined on the basis of experimental data. The coefficient of cotton picking completeness is $P = 0.93$;
- the row width spacing is $B = 0.9m$;
- the length of furrow of the fields is determined on the basis of measurements and is $\ell = 500$ *m*;
- the number of rows during machine harvesting is set in the design and equals to $n = 2$;
- the time of one turn on the headland is determined by the timing and amounts to $t_{\Pi 1} = 1 \cdot 60$ seconds;
- Time for the turn depends on device parameters, type of turn, travel method, steer velocity and type of device.
- the time of unloading of one hopper of raw cotton, taking into account the moving at the workplace, is determined by the timing and equals to $t_{P1} = 2.23 \cdot 60$ sec;
- Hopper unloading time refers to maintenance. The duration of unloading depends on the skills of the tractor driver and the CHM design features:

- the hopper capacity, taking into account the automatic ramming, is determined experimentally and is $G_b = 1000$ kg;
- the hopper filling factor according to the timing is $k_b = 0.817$ (with a gasket);
- total shift time spent on raw cotton harvesting is $t = 7 \cdot 3600$ *sec;*
- the total time when the cotton picker is in a non-working technological mode per shift is $t_{ost} = 2.42 \cdot 3600$ *sec*;
- the speed of machine is $V_м = 1.06$ *m/s;*
- area for picking cotton (1 ha $=10^4$) m^2.

Based on the Protocol [19], the balance of the unit operation time was obtained; it is shown in table 1.

Table 1. The balance of the unit operation time for the standard shift duration.

	Time indices	Value of indices according to test data	
		h	%
1	Main work time	3.79	54.11
2	Time for the turn	0.48	6.81
3	Time for moving at the workplace (for unloading raw cotton and driving back)	0.14	2.05
4	Time to unload raw cotton	0.12	1.75
5	Time for other auxiliary operations	0.00	0.00
6	Time for shift maintenance	0.21	3.0
7	Time for preparation and completion of work	0.00	0.00
8	Time for setting and adjustment	0.24	3.46
9	Time for elimination of technological faults	1.13	16.06
10	Time to rest	0.65	9.29
11	Time for idle moving	0.24	3.47
12	Time for every shift maintenance of the machine aggregated with the tested one	0.00	0.00
	Total: shift time (1 + 12)	7.0	100.0

Based on the numerical study and the balance of time from table 1, the results obtained are presented in table 2.

Table 2. Comparison of the results obtained on the basis of the CITT Protocol No. 00-2021 and a numerical experiment based on computer program No. DGU11966.

Indices		According to computer calculations No. DGU 11966	According to Protocol CITT No. 00-2021
Main work time (t_0), hour		3.89	3.79
Time to unload raw cotton and travel to the workplace (t_P), hour		0.26	0.14+0.12=0.24
Time to turn($t_П$), hour		0.48	0.48
Shift capacity	W_m	5.65	0.84·7=5.88
	W_{ha}	2.66	0.37·7=2.59

The analysis of table 2 shows that the results obtained by the developed calculation method with high accuracy agree with the experimental data.

The maximum error is 3.9%. In this regard, for further computational studies, the authors used computer program [18]. Based on the above initial data, table 3 is filled in depending on the change in open bolls yield using computer program [18].

Table 3. Change in shift performance indices depending on the open bolls yield (G_P).

Indices	G_p=2.5 t/ha	G_p=3.0 t/ha	G_p=3.5 t/ha	G_p=4.0 t/ha
Machine speed V_m, m/s	1.06	1.06	1.06	1.06
Completeness of machine harvesting %	0.93	0.93	0.93	0.93
Main time per shift, t_0, hour	3.78	3.73	3.69	3.64
Shift capacity W_{ha}	2.59	2.56	2.54	2.51
Shift capacity W_T	6.03	7.14	8.25	9.3

To calculate the economic efficiency of machine harvesting, using the calculated data from table 3, we additionally introduce the following initial data.

- the cost of CHM MX-1.8 GV - 80.0 thousand US dollars or 80.0 · 10,700 = 856,000 thousand Uzbek sums according to the data from the tractor plant.
- the cost of a tractor separately - 350,000.0 thousand sums;
- annual time rate T_t= 120 hours;
- the payback period for CHM is 7 years;
- consumption of fuel (diesel fuel) per hectare - 16.97 kg/ha [19];
- the cost of one liter of diesel fuel is 9.409 thousand sums [20];
- Payment to the tractor driver is 50.0 thousand sums per one ton of machine-harvested cotton [22].

4. Results

According to republican standards UzDSt 32252017 [2], the authors have determined the direct operating costs *I*, for one shift, by the following formula:

$$I=Z+G+R+A \tag{1}$$

where: Z is the cost of work payment to a tractor driver, thousand sums per shift;
G is the cost of fuels and lubricants, thousand sums per shift;
R is the cost of maintenance and repair, thousand sums per shift;
A is the allowance for depreciation, thousand sums per shift;
We determine the cost of wages for the maintenance personnel (tractor driver) per shift:

$$Z=W_T \cdot C_{xl}, \text{ thousand sums} \tag{2}$$

where: W_T– is the amount of raw cotton harvested per shift according to table 3;
C_{xl}– is the payment to the tractor driver for one ton of harvested cotton (C_{xl}=50,0 thousand sums);
for: G_P=2,5 t/ha $З$=6.03·50=301.5 thousand sums;
G_P=3,0 t/ha $З$=7.14·50=357.0 thousand sums;
G_P=3,5 t/ha $З$=8.25·50=412.5 thousand sums;
G_P=4,0 t/ha $З$=9.3·50=465.0 thousand sums.
We determine the cost of fuels and lubricants per shift:

$$Г=W_{ga} \cdot q \cdot C_d, \text{ thousand sums} \tag{3}$$

where: W_{ga}–is the area treated per shift according to table 3;

q – is the specific fuel consumption per hectare according to [19], it equals to 20.36 l/ha;
C_d–is the cost of diesel fuel [20] 1l = 9.409 thousand sums.
for: G_P=2.5 t/ha Γ=2.59·20.36·9.409=496.16 thousand sums;
G_P=3.0t/ha Γ=2.56·20.36·9.409=490.41 thousand sums;
G_P=3.5 t/ha Γ=2.54·20.36·9.409=486.58 thousand sums;
G_P=4.0t/ha Γ=2.51·20.36·9.409=480.83 thousand sums.
We determine the costs of maintenance and repairs per shift:

$$R = \frac{B \cdot 0.12}{T_{cm} \cdot t_t}, \quad \text{thousand sums} \tag{4}$$

where: B – is the cost of CHM MX-1.8GV - 856000.0, thousand sums;
0.12 – is the norm coefficient;
T_{cm}– is the number of days of standard shifts per year.

$$T_{\text{cm}} = \frac{120}{t_{cm}} = \frac{120}{7} = 17 \text{days}$$

where: 120 –is the standard time per year, hour;
$t_{см}$ = 7 - shift time, hour;
t_t is the payback period of a CHM, t = 7 years.

$$R = \frac{856000 \cdot 0.12}{17 \cdot 7} = 863.2 \text{ thousand sums}$$

We determine the deductions for depreciation per shift:

$$A = \frac{Б}{T_{cm} \cdot t_t} - \frac{Б'}{T'_{cm} \cdot t_t}, \text{ thousand sums} \tag{5}$$

where: $Б'$ - is the cost of the tractor separately - 350,000.0 thousand sums;
1100 –is the standard time per year for a separate tractor, hour;
$T'_{см}$ - is the number of working days per year, $T'_{cm} = \frac{1100}{7} = 157$ days

$$A = \frac{856000.0}{17 \cdot 7} - \frac{350000.0}{157 \cdot 7} = 6874.8 \text{ thousand sums}$$

For G_p = 2.5 ÷ 4.0 t/ha A = 6874.8 thousand sums.
Operating costs depending on the yield of open cotton bolls according to expression (1) per shift are:
For: G_P=2.5t/ha $И_1$=301.5+496.16+863.2+6874.8=8535.6 thousand sums;
G_P=3.0t/ha $И_2$=357.0+490.41+863.2+6874.8=8585.4 thousand sums;
G_P=3.5 t/ha $И_3$=412.5+486.58+863.2+6874.8=8637.1 thousand sums;
G_P=4.0t/ha $И_4$=465.0+480.83+863.2+6874.8=8683.8 thousand sums.
We determine the costs of machine harvesting per one ton (Z_T) according to table 3.

$$Z_T = \frac{I}{W_{ha} \cdot G_p \cdot 0.93}, \text{ thousand sums} \tag{6}$$

For: G_P=2.5 t/ha $Z_{T1} = \frac{8536.6}{2.59 \cdot 2.5 \cdot 0.93} = 1417.6$ thousand sums;
G_P=3.0 t/ha $Z_{T2} = \frac{8585.4}{2.56 \cdot 3 \cdot 0.93} = 1202.0$ thousand sums;
G_P=3.5 t/ha $Z_{TZ} = \frac{8637.1}{2.54 \cdot 3.5 \cdot 0.93} = 1044.6$ thousand sums;
G_P=4.0t/ha $Z_{T4} = \frac{8683.8}{2.51 \cdot 4.0 \cdot 0.93} = 930.0$ thousand sums.
We determine the costs of machine harvesting per one hectare (Z_{mga}) according to table 3.

$$Z_{mha} = \frac{I}{W_{ha}}, \text{ thousand sums} \tag{7}$$

For: G_P=2.5t/ha Z_{mha}=8536.6 : 2.59 = 3295.9 thousand sums;
G_P=3.0 t/ha Z_{mha} =8585.4 : 2.56 =3353.7 thousand sums;
G_P=3.5 t/ha Z_{mha} =8637.1 : 2.54 = 3400.4 thousand sums;
G_P=4.0 t/ha Z_{mha} =8683.8 : 2.51 = 3459.7 thousand sums.
We determine the costs of handpicking:
Payment for handpicking is calculated as [21]:

- for the first time picking - 1200 soum per one kg.
- for the second time picking- 1500 soum per one kg.

We assume that 70% of open cotton bolls yield refers to the first time picking, and 30% - for the second time picking. Let us determine the average price for one goof picked raw cotton.

$$C_p=0.7*1200+0.3*1500=1290.0 \text{ sum}=1.29 \text{ thousand sums} \tag{8}$$

The costs for one ton of handpicked raw cotton are:
$Z_p = 1000 \cdot C_p$, thousand sums
We take the mass of the handpicked raw cotton, depending on open cotton bolls yield, as equal to the mass of the machine-harvested cotton.
So, to determine the cost of hand-picked cotton from one hectare, we define:

$$Z_{pha}=Z_p \cdot G_p \cdot P, \text{ thousand sums} \tag{9}$$

where: P is the completeness of machine picking (P = 0.93);
G_p–open cotton bolls yield t/ha.
for: G_P=2,5 t/ha Z_{pha}=1290 · 2.5 · 0.93=2999.2 thousand sums;
G_P=3.0 t/ha Z_{pha} =1290 · 3.0 · 0.93=3599.1 thousand soums;
G_P=3.5 t/ha Z_{pha} =1290 · 3.5 · 0.93=4198.9 thousand soums;
G_P=4.0 t/ha Z_{pha} =1290 · 4.0 · 0.93=4798.8 thousand soums.
Table 4 is filled in based on the above results.

Table 4. Change in indices of cotton-picking costs depending on open cotton bolls yield.

Indices	Open cotton bolls yield, G_p t/ha			
	2.5	3.0	3.5	4.0
Direct operating costs of machine picking per shift (I), thousand sums	8535.6	8585.4	8637.1	8683.8
Costs of machine picking per ton (Z_T), thousand sums	1417.6	1202.0	1044.6	930.0
Costs of machine picking per hectare (Z_{mha}), thousand sums	3295.9	3353.7	3400.6	3459.7
Costs of hand picking per one ton (Z_p), thousand sums	1290.0	1290.0	1290.0	1290.0
Costs of hand picking per one hectare (Z_{pha}), thousand sums	2999.2	3599.1	4198.9	4798.8

Based on the data from table 4, the graphs of cost changes depending on open cotton bolls yield were plotted in figure 1.

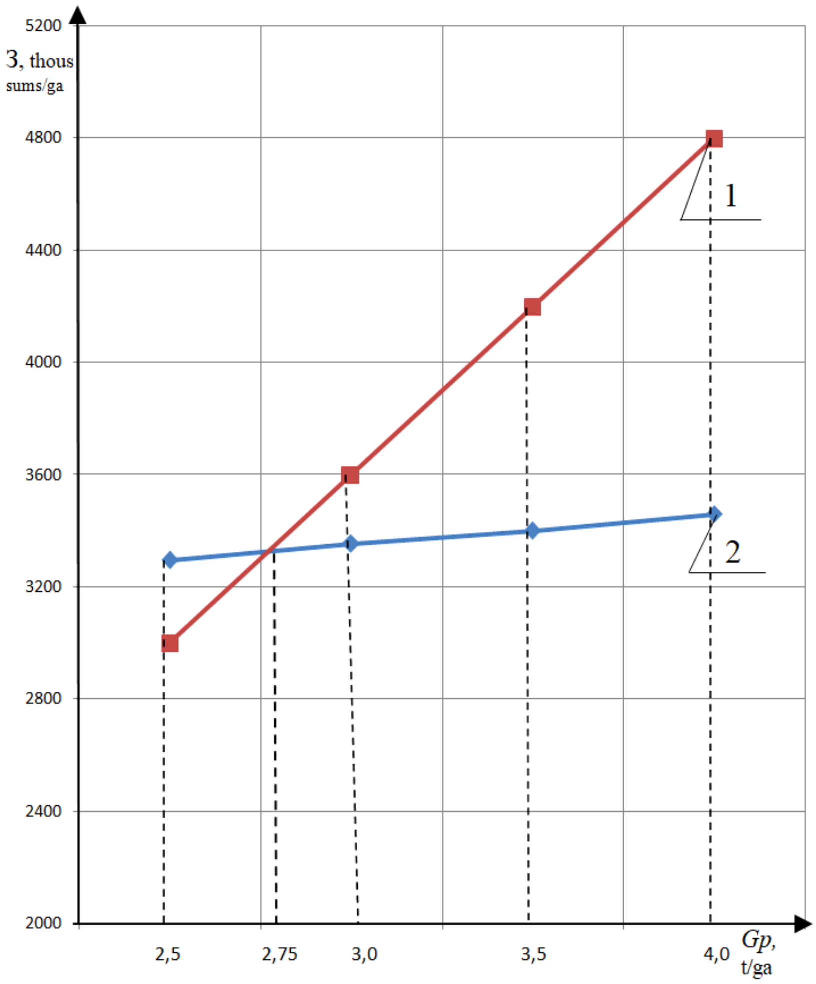

Figure 1. Change in costs of hand and machine picking per hectare depending on open cotton bolls yield.
1- change in costs of handpicking; 2 - change in costs of machine picking.

5. Analysis and discussion

The analysis of data from table 3 shows that with an increase in open cotton bolls yield $G_p = 2.5 \div 4.0$ t/ha, with the remaining parameters unchanged, the shift productivity of machine W_T increases from 6.03 t/ha to 9.3 t/ha. The treated area $W_{га}$ decreases insignificantly, i.e. from 2.59 hectares to 2.51 hectares.

The analysis of data from table 4 shows that with an increase in open bolls yield $G_p = 2.5 \div 4.0$ t/ha, direct operating costs per shift of machine harvesting slightly increase, from 8535.6 thousand sums to 8683.8 thousand sums. However, the costs of handpicking per hectare increase significantly, i.e. from 2999.2 thousand sums to 4798.8 thousand sums.

From figure 1 we can see that starting with a cotton yield of 2.75 t/ha, machine picking has a clear advantage. Hand picking cotton becomes economically unprofitable.

For example, with open bolls yield $G_p = 3.5$ t/ha, the harvesting profitability of machine MX-1.8 GV in comparison with hand picking during a season is:

$E_g = (1290–1044.6) \cdot 8.25 \cdot 17 = 34417.0$ thousand sums.

6. Conclusions

The proposed principle for calculating the efficiency of the MX-1.8 GV combined cotton harvester with horizontal spindle devices at a one-time cotton picking allows for an instrumental assessment of the machine design taking into account the main technological and operational factors, including cotton yield, completeness of cotton harvesting and harvesting productivity.

The use of the MX-1.8 GV cotton harvester of a horizontal-spindle design is economically feasible in comparison with handpicking at open bolls yield of more than 2.75 t/ha.

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