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Evaluating Torque Moment Dependence of the Soil-Tiller Drum on Soil Loosening Depth and Drum Rotation Number

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ABSTRACT

In the result of field experiments on the soil-tiller with self-vibrating (mobile) and fixed blades, the regression equations $y=f(X_1,X_2)$ of the torque moment dependence (M_t, y) in the soil-tiller's drum on the drum's rotation numbers (n_d, X_1) and soil loosening depth h (X_2) have been derived and the set of curves describing the aforementioned dependences have been designed.

The results of research experiments have stated that the torque moment is reduced parallel to the increase of rotation numbers in the drums with self-vibrating (mobile) and fixed blades, while it grows up together with the increase of soil loosening depth.

Introduction

Selected methods of mechanical soil cultivation greatly affect the soil technological properties, its fertility improvement, as well as water and nutritional regimes of the plants. Among various soil cultivating machines used in the agricultural production the soil-tillers are of particular significance, the application of which enables to implement several technological activities simultaneously during a single stroke. The soil-tillers not only loosen the soil at the depth of 0.6-18 cm, but also flatten it; besides, when cultivating the fields covered with the remnants of forage and thick-stemmed plants, they crush and mix the soil (Panov, 1998). Thus, due to the aforementioned peculiarities the soil-tillers are widely used in the agricultural production and fully meet the main agro-technical requirements.

The efficiency of soil-tiller's application is apparent, nevertheless, the great values of power, traction resistance and dynamical load obstruct their efficient work throughout the soil cultivation. The upgrading of structural and technological parameters of the soil-tillers with vibratory axial hinge blades (Tarverdyan, Petrosyan, Hovhannisyan, 2018) will enable to reduce the traction resistance and the required power for the soil cultivation with tiller.

Materials and methods

The efficient work of the soil-tiller in different soil conditions is mainly related to the accurate selection of the structural parameters and working regimes for the working parts of the tillers, as well as to the evaluation of the dependence of the torque moment in the tiller's drum on its rotation numbers and the soil loosening depth.

The theoretical research on the tiller's structure and the drum with self-vibrating blades is introduced by a number of authors (Petrosyan, Khazhakyan, 2019).

The scientific-research experiments have been conducted to evaluate the machine's energetical and agro-technical indices in the cultivation process and the effect of variations on the torque moment of the soil-tiller with the drums containing self-vibrating (mobile) and fixed blades. When describing the energy consumption rate and quality of the implemented activities during the soil cultivating activities by using soil-tillers, the torque moment of the working part, rotation numbers and moving velocity of the aggregate are considered to be the most relevant parameters.

The aim of the current research work is to determine the torque moment M_t (Nm) of the tiller's drum and the drum rotation number n_d (R/m). The imlemented research experiments enable to describe the technological process of the tiller with self-vibrating and fixed blades in different soil conditions and to select such working regimes, which will promote the reduction of traction resistance, specific fuel cost and the increase of the tiller's productivity.

The experiments were carried out through the soil-tiller with self-vibrating blades designed and developed by our research group in the arable lands owned by Anushavan Karapetyan at the village of Kotayk in Kotayk region.

The designed working part with the mobile blades is developed in a way, so as the latter are possible to attach fixedly as well, depriving them of moving capacity. The soil-tiller has been aggregated with China tractor series "JINMA-254", in a way that the torque moment is transferred from bevel gear speed reducer to the tiller's drum through chain-driven transmission, enabling to change the drum's rotation number. Due to the transmission of the chain wheels the rotation number of the drum is modulated within the range of 140-280 (R/m).

For recording the technical parameters of the field experiments the resistance strain gage of TRA-50K series, mercurial current collecting gear TRA-50K, algorithm converter Zet-210 and analog-to-digital signal booster Zet-410 have been applied.

TRA-50K resistance strain gage is designed for measuring the torque moment of the drum, which is installed between the tractor power take-off shaft and bevel gear speed reducer shaft of the tiller (Figure 1).

Figure 1. TRA-50K resistance strain gage installed between the tractor PTO shaft and bevel gear speed inducer shaft of the tiller.

The research experiments aimed at the determination of the drum torque moment (M_t) dependence on the drum rotation number (n_d) were conducted in two variants: through discs with fixed and self-vibrating (mobile) blades. Each experiment was carried out thrice $n=3$ upon different numbers of drum rotation – $n_d=140\ r/m$, $n_d=210\ r/m$, $n_d=280\ r/m$ and different soil loosening depths - $h=0.08\ m$, $0.012\ m$ and $0.16\ m$.

During the research trials the experimental site was divided into 15 m-length sectors. At the start of the experiment the values for M_t and n_d in the idle state of the tiller were recorded, then the drum was provided with appropriate rotation number and the blades were installed in the experimented depth. The trials were repeated according to the blades in their fixed and self-vibrating variants.

The results of the experiments were recorded through computer (Tables 1, 3, 4) and analyzed by the method of multi-factorial experiment planning theory.

Results and discussions

The dependence of the torque moment of the soil-tiller's drum with fixed blades (y_1) and that of with self-vibrating (mobile) blades (y_2) on the drums rotation numbers (X_1) r/m and soil loosening depth (X_2) cm was studied through the methods of experiment planning theory. For the description of the drum's torque moment a second order mathematical model was selected.

$$y = b_0 + b_1 X_1 + b_2 X_2 + b_{12} X_1 X_2 + b_{11} X_{12} + b_{22} X_{22}. \quad (1)$$

To derive such a regression equation in the research experiments the factors varied in three levels. Two-factor central composite orthogonal design of second order was selected as a plan matrix for implementation of the experiments (Petrosyan, Grigoryan, 2001).

The research results on the dependence of tiller's torque moment (M_t) on the drum rotation number (n_d) and plowing depth (h) are presented in Table 1.

Table 1. Values of factors determination domain and variation ranges*

Matrix parameters	Encoded value	Drum's rotation numbers X_1 (r/m)	Loosening depth X_2 (cm)
Variation range	-	70.0	2.0
Lower level	-1	140	8.0
Main level	0	210.0	10.0
Upper level	+1	280.0	12.0

*Composed by the authors.

In the plan matrix the value of the α – chain wheel arm has been selected $\alpha=1$, hence, in that case the new variables have been determined: X_1 and X_2 have been identified:

$$X_1' = X_1^2 - \frac{2}{3}, \quad X_2' = X_2^2 - \frac{2}{3}, \tag{2}$$

For the two factors the second-order orthogonal design looks as described in Table 2.

Coefficients of regression equation based on the planning matrix orthogonality have been determined through the following formulae:

$$b_j = \frac{\sum_{j=1}^{N} X_{ij}\overline{y_j}}{\sum_{j=1}^{N} X_{ij}^{\ 2}}, \quad b_0 = \frac{\sum_{j=1}^{N} X_{0j}\overline{y_j}}{\sum_{j=1}^{N} X_{ij}^{\ 2}},$$
$$b_{ii} = \frac{\sum_{j=1}^{N} X_{ij}'\overline{y_j}}{\sum_{j=1}^{N} X_{ij}'^2}, \; b_{iu} = \frac{\sum_{j=1}^{N} X_{ij}X_{uj}\overline{y_j}}{\sum_{j=1}^{N} (X_{ij}X_{uj})^2}, \tag{3}$$

where i and u are the numbers of columns (factors) in the matrix, j is the number of experiment terms, X_{ij} and X_{uj} are the elements of the appropriate columns in the matrix, $\overline{y_j}$ is the average value of the torque moment for the experiment terms. The research experiments have been carried out upon repetitions $n=3$ and per experimental terms repetition $n=3$ the average torque value has been determined.

$$\overline{y_j} = \frac{1}{n}\sum_{i=1}^{n} y_{ij}. \tag{4}$$

The research results with three repetitions are introduced in Table 3.

Table 2. Second-order orthogonal design*

The number of experiment	n_d (r/m) X_1	h (cm) X_2	X_1X_2	$X_1^2 - \frac{2}{3}$	$X_2^2 - \frac{2}{3}$	M_t y
1	+1	+1	+	$+\frac{1}{3}$	$+\frac{1}{3}$	$\overline{y_1}$
2	-1	+1	-	$+\frac{1}{3}$	$+\frac{1}{3}$	$\overline{y_2}$
3	+1	-1	-	$+\frac{1}{3}$	$+\frac{1}{3}$	$\overline{y_3}$
4	-1	-1	+	$+\frac{1}{3}$	$+\frac{1}{3}$	$\overline{y_4}$
5	+1	0	0	$+\frac{1}{3}$	$-\frac{2}{3}$	$\overline{y_5}$
6	-1	0	0	$-\frac{2}{3}$	$-\frac{2}{3}$	$\overline{y_6}$
7	0	+1	0	$-\frac{2}{3}$	$+\frac{1}{3}$	$\overline{y_7}$
8	0	-1	0	$-\frac{2}{3}$	$+\frac{1}{3}$	$\overline{y_8}$
9	0	0	0	$-\frac{2}{3}$	$-\frac{2}{3}$	$\overline{y_9}$

*Composed by the authors.

Table 3. Plan of experimental results on the torque moment of the drum with fixed blades*

The number of experiment	Π_d (r/m) X_1	*h (cm)* X_2	X_1X_2	X'_1	X'_2	y_{1j}	y_{2i}	y_{3i}	$\overline{y_j}$	S_{j2}	S_j
1	+1	+1	+1	$+\frac{1}{3}$	$+\frac{1}{3}$	64.25	65.25	61.75	63.75	6.50	2.55
2	-1	+1	-1	$+\frac{1}{3}$	$+\frac{1}{3}$	129.3	125.6	129.1	128.0	8.66	2.943
3	+1	-1	-1	$+\frac{1}{3}$	$+\frac{1}{3}$	42.0	45.0	44.25	43.75	4.875	2.208
4	-1	-1	+1	$+\frac{1}{3}$	$+\frac{1}{3}$	90.5	89.0	83.0	87.5	31.5	5.612
5	+1	0	0	$+\frac{1}{3}$	$-\frac{2}{3}$	53.75	50.75	53.0	52.5	4.875	2.208
6	-1	0	0	$+\frac{1}{3}$	$-\frac{2}{3}$	106.75	101.25	102.5	103.5	16.625	4.077
7	0	+1	0	$-\frac{2}{3}$	$+\frac{1}{3}$	82.37	78.87	81.25	81.25	81.25	2.9
8	0	-1	0	$-\frac{2}{3}$	$+\frac{1}{3}$	52.25	55.75	57.0	55.0	12.125	3.482
9	0	0	0	$-\frac{2}{3}$	$-\frac{2}{3}$	62.5	67.0	69.25	66.25	23.625	4.86

*Composed by the authors.

Table 4. Plan of experimental results on the torque moment of the drum with mobile blades*

The number of experiment	X_1	X_2	X_1X_2	$X_1^2-\frac{2}{3}$	$X_2^2-\frac{2}{3}$	$\overline{y_j}$	$\hat{y}_j$
1	+1	+1	+1	$+\frac{1}{3}$	$+\frac{1}{3}$	47.5	44.1
2	-1	+1	-1	$+\frac{1}{3}$	$+\frac{1}{3}$	106.5	105.06
3	+1	-1	-1	$+\frac{1}{3}$	$+\frac{1}{3}$	26.25	26.22
4	-1	-1	+1	$+\frac{1}{3}$	$+\frac{1}{3}$	82.5	84.43
5	+1	0	0	$+\frac{1}{3}$	$-\frac{2}{3}$	30.0	33.84
6	-1	0	0	$+\frac{1}{3}$	$-\frac{2}{3}$	93.5	92.99
7	0	+1	0	$-\frac{2}{3}$	$+\frac{1}{3}$	51.25	56.46
8	0	-1	0	$-\frac{2}{3}$	$+\frac{1}{3}$	38.75	37.205
9	0	0	0	$-\frac{2}{3}$	$-\frac{2}{3}$	48.75	45.09

*Composed by the authors.

Based on the results of the experiments the values of the regression equation coefficients have been determined:

$$b_0 = 75.72,\ \ b_1 = -26.5,\ \ b_1 = 14.46,$$
$$b_{11} = -5.13,\ b_{12} = 12.33,\ b_{22} = 2.46,$$

according to the obtained values for coefficients, the regression equation looks as follows:

$$y_1 = 75.72 - 26.5X_1 + 14.46X_2 - \\ - 5.13X_1X_2 + 12.33X_1^2 + 2.46X_2^2. \qquad (5)$$

The regression equation for the dependence of torque moment (y_2) of the drum with mobile blades on the drum's rotation numbers (X_1) and soil loosening depth (X_2) looks as follows:

$$y_2 = 58.33 - 29.79X_1 + 9.625X_2 - \\ - 0.6875X_1X_2 + 18.12X_1^2 + 1.75X_2^2. \qquad (6)$$

The homogeneity of the results of scientific trials, significance rate of the regression equation coefficients and compatibility degree of the investigated procedures with the regression equation have been tested by means of dispersion analysis. The fact of experimental results deviations $\left(y_{ij} - \overline{y_j}\right)$ found in multiple other parallelly conducted experiments in the same terms testify on the variability of the results in the experiments. In this case the dispersion of the experimental results has been calculated through the following formula:

$$S_j^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(y_j - \overline{y}\right)^2. \tag{7}$$

The reproductivity dispersion for the optimization parameters is estimated through the following formula:

$$S_2\{y\} = \frac{1}{N(n-1)}\sum_{i=1}^{n}\;\sum_{i=1}^{n}\left(y_{ij} - \overline{y_j}\right)^2, \tag{8}$$

where n is the number of parallel experiments and N is the number of experimental terms.

The homogeneity of dispersions for all terms (N) of research experiments has been tested by Fisher's criterion in case of $\alpha=0.05$ significance degree or $p=0.95$ probability in reliability:

$$F_z = \frac{S_{max}^{\;2}}{S_{min}^{\;2}}, \tag{9}$$

where $S_{max}^{\;2}$ and $S_{min}^{\;2}$ are respectively the maximum and minimum dispersions of the experimental terms.

All coefficients of the regression equation

$$b_0 = 75.72,\ b_1 = -26.5,\ b_2 = 14.46,$$

$$b_{12} = -5.13,\ b_{11} = 12.33,\ b_{22} = 2.46$$

describing the torque moment of the drum with fixed blades are significant, since $|b_i| > \Delta b_i$.

If we drop out the coefficient of regression equation $b_{12}=-0.6875$ ($\Delta_{12}<1.47$ in case of Student's t-test) describing the torque moment of the drum with fixed blades, the equation will look as follows:

$$y_2 = 58.33 - 29.79X_1 + 9.625X_2 + + 18.12X_1^2 + 1.75X_2^2. \tag{10}$$

The set of curves (Figures 2, 3) describing the results of the torque moments in the drums with fixed (y_1) and mobile (y_2) blades have been designed by means of the derived regression equations, which are actually curves of extremum.

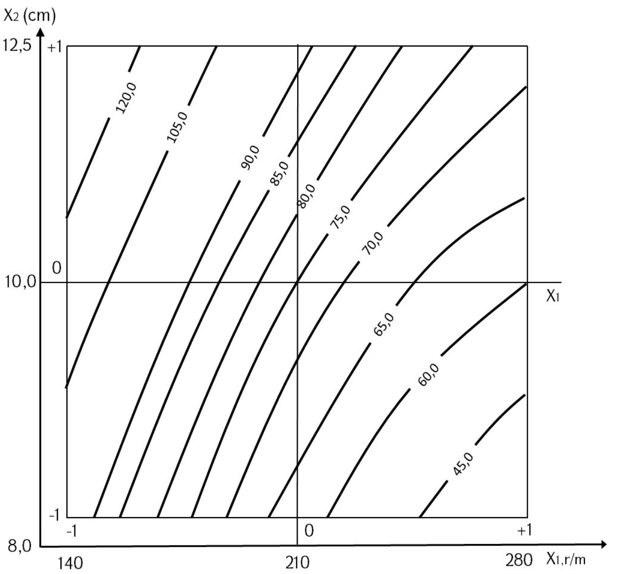

Figure 2. Set of curves describing the effect of the drum's rotation numbers (X_1) and soil loosening depth (X_2) on the torque moment (y_1) of the soil-tiller's drum with fixed blades (*composed by the authors*).

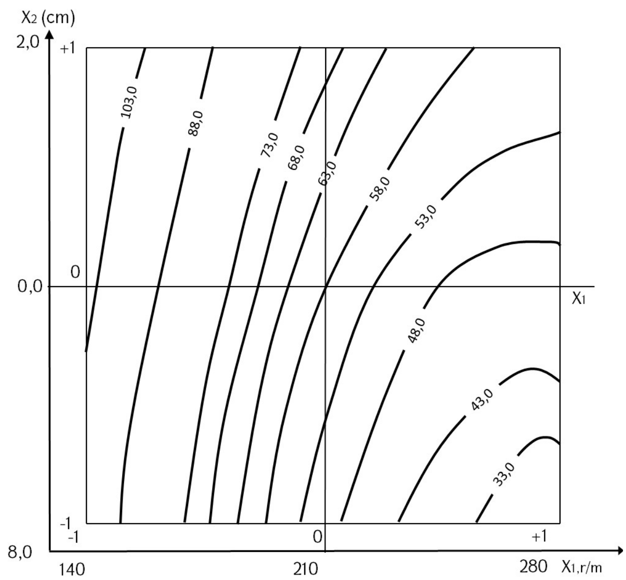

Figure 3. Set of curves describing the effect of the drum's rotation numbers (X_1) and soil loosening depth (X_2) on the torque moment (y_1) of the soil-tiller's drum with self-vibrating (mobile) blades (*composed by the authors*).

Conclusion

Based on the results of the conducted researches, the following conclusions have been drawn:

1. The torque moment of the soil-tiller's drum with both fixed and mobile blades is considerably influenced by all main effects of the regression equation: thus in case of y_1, b_1=-26.5 (drum's rotation number), b_2=14.46 (loosening depth), in case of y_2, b_1=-29.79, b_2=9.625, besides in both cases the torque moment decreases parallel to the increase of drum's rotation numbers, while it grows up together with loosening depth increase.
2. The drum's torque moment is greatly influenced by the interactive effects of the regression equation b_{12}=-5.13 (y_1), while in case of the drum with self-vibrating (mobile) blades b_{12}=-0.6875 (y_2), it is insignificant and has been excluded from the regression equation.
3. The drum's torque moment is considerably affected only by the second-order effects b_{11}=12.33 (with fixed blades) and b_{11}=18.12 (with mobile blades) related to drum rotation number in the regression equation; the torque moment grows up parallel to the increase of drum's rotation numbers in both variants, while the variations of the second-order effects (b_{22}) characterizing the soil loosening depth are insignificant.
4. The desired values of the drum's rotation numbers for the soil-tiller are chosen from the set of the introduced curves (Figures 2, 3) in line with the size of soil loosening depth.

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