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Power need of an implement for removing polymer residues from the soil surface in Kazakh horticulture

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Abstract

Polymeric materials are largely used in horticulture for mulching and irrigation, but their long degradation time causes various environmental and agronomic problems, hence should be removed at the end of the crop cycle. Among different mechanised techniques for collecting polymer residues from the field, the single-phase one is the most effective, since the plastic film and irrigation tape lifting, cleaning, and collection operations are done in a single pass, though, in most cases, the implements used in Kazakhstan still need an operator to manage the winding mechanism. The authors, who developed a completely automatic plastic retriever based on a hydraulic drive with a friction clutch for winding up the plastic materials, assessed the power need of the implement in order to compare it with the power need of similar implements, where the winding mechanism is hand-operated. Consequently, power consumption is high due to the need to stop and start the engine many times.

In this study, the parameters of the hydraulic drive were determined by analytical calculation, starting from pressure and speed data measured on the hydraulic line and velocity and traction resistance of the implementation measured during the field tests. The maximum power needed to drive the winding mechanisms resulted in 1.86 kW at a forward speed of the unit of 1.8 $m \cdot s^{-1}$. Secondary, the operation costs were broadly assessed, finding that they were about 43% less than when using man-driven equipment.

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Introduction

Since the second half of the last century, synthetic polymer materials have been used as a mulching cover for growing vegetables. The use of plastic mulch on the soil surface improves the microclimatic and physical conditions for the growth and development of the plant as it prevents the growth and development of weeds and, in average weather conditions, also controls the moisture regime of the soil by preventing heat transfer and evaporation of moisture from the surface.

Interaction of plastic mulch with solar radiation directly affects the temperature of the covered soil because of its heating properties, such as absorption, reflection, and flow capacity (Khazimov *et al.,* 2014; Khazimov *et al.,* 2018a; Urmashev *et al.,* 2021).

In cold regions, mulching reduces soil temperature decrease at night, contributing to rapid germination, hence allowing the planting of seedlings 2-3 weeks in advance, while in hot weather protects the stems and leaves of the plant from the hot moisture evaporating from the soil surface (Khazimov *et al.,* 2018b).

Polymer technology has also allowed the use of flexible tapes for drip irrigation, which ensures high-quality, cost, and water-saving irrigation (Khazimov *et al.,* 2019).

The combined use of plastic mulch and flexible irrigation tapes has made it possible to increase crop yield, saving water in various kinds of cultivations, especially in horticulture (Biswas *et al.,* 2015).

However, the spreading of this technology, along with very positive effects, has led to the contamination of many cultivated areas with plastic waste: residues of polymers in the soil can persist for a long time (50-100 years), hindering the supply of water to the plant roots and affecting the composition of the soil layers (Astner *et al.,* 2019; Shah and Wu, 2020); moreover, plastic mulching is suspected to be a significant source of microplastics contamination in terrestrial environments (Yi *et al.,* 2020). To tackle this problem, not biodegradable plastic residues must be removed after the cultivation cycle, and various methods are used that can be classified as indicated in Figure 1 (Khazimov *et al.,* 2020a and 2020b).

The authors classify the methods for removing polymer residues in a one-phase, two-phase, and three-phase system according to the number of passages needed.

The one-phase removal, where all operations are done in one passage, can be carried out in two ways: in the first case, all operations are carried out simultaneously, while in the second case, the vegetable residues and polymeric materials are burned directly on the ground (Kasirajan and Ngouajio*,* 2013; Kennco, 2018), though this practice is unadvisable and even illegal in many countries since, among others, it can release carcinogenic substances, such as dioxin, and other toxic particles into the air (Valavanidis *et al.,* 2008). Furthermore, single-phase removal is the most complex and expensive because a multifunctional technique is needed.

Also, the two-phase removal of polymer residues can be done in two ways: if the plant stems are removed during harvest, the plastic mulch is removed in the first phase, and the drip tape in the second one (Ablikov *et al.,* 2019). On the other hand, if the plant residues are left in place, they must be removed with the first passage, while plastic mulch and drip tapes are removed simultaneously with the second one (He *et al.,* 2017).

In the three-phase polymer removal,, the stems are trimmed first, the plastic mulch is removed later, and the drip irrigation tape is collected (Garthe*,* 2004).

Removing plastic mulch and drip irrigation tapes can be done manually and mechanically. Mechanised removal can be carried out with stationary or moving equipment.

Concerning the plastic mulch, the operation can be partially or fully mechanised and done with specialised or non-specialised equipment. Incineration of vegetation and polymer materials is done using a burner.

The simultaneous removal of plastic mulch and drip irrigation tape can be done manually or in a semi-mechanised or fully mechanised way. The manual method is very time-consuming, while the partially mechanised one still needs manual work.

The mechanised method is based on specialised machines, the most complex of which can do the lifting, cleaning, and collection of the plastic mulch in a single pass, though still requiring the help of an operator to control the winding up of the mulch while, the unit is moving (Kennco, 2018; Rocca, 2006).

These units have a very high cost, up to 20k euro (about 10M KZT, when converted into the national currency), and in the Kazakh agricultural economy, their purchase is not sustainable, even for wealthy farmers. Therefore, the manual method is preferred, which requires high labour and time inputs.

To address this problem, Khazimov *et al.* (2021a) and Khazimov *et al.* (2016, 2019, 2020a, and 2020b) developed various prototypes for separate and joint collection of mulch film and flexible drip irrigation tapes in vegetable cultivation after harvesting. In particular, a version where the rolling mechanism was driven by a hydraulic motor (Khazimov *et al.*, 2021a; Khazimov *et al.*, 2021b) has shown to be effective, fail-safe, and usable for large areas.

The scope of this work is to calculate the power need of this device, including the calculation of the hydraulic drive mechanisms for winding up the plastic mulch and drip irrigation tape, to assess its performance better.

Materials and methods

Description and working principle

Figure 2 shows the constructional layout of the implementation used in this study that was first designed in 2016 (Khazimov *et al.,* 2016).

This implementation for removing and collecting the flexible irrigation tape and the plastic mulch after harvesting, at the end of the cultivation cycle, first eliminates the residues of the plants that protrude above the mulch and then winds up the freed plastic mulch and the irrigation tape onto a drum mounted on a rotating shaft. The plant residues are scattered behind, onto the soil surface, as a natural mulch to favour moisture retention in the soil and fast humification of organic matter.

The modified implementation used in this work is semi-mounted, which means connected to the tractor's three-point hitch and supported by two wheels (1). The whole device is raised during transportation, and all working bodies are lifted off the ground. In the working position, the support wheels, like those of the tractor,

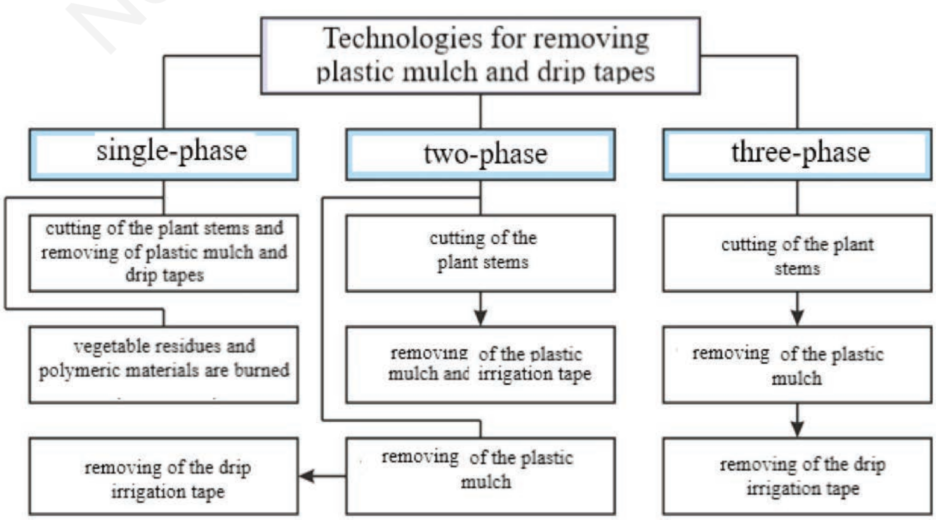

Figure 1. Classification of methods for removing polymer residues from the crop surface.

run along the edges of the plastic mulch, while the cutting unit (3) rests on the mulching surface through special shoes. When proceeding, the stems of the plants protruding above the mulch are mowed by the mowing mechanism (3) driven by the tractor's PTO, connected through a gearbox (4). Behind the mower, 2 dumps dig out from the soil the edges of the plastic mulch (2), and a conveyor (5) transports it (6) towards the back end of the machine, together with the mowed mass, which is dumped behind onto the surface of the field (5). During work, the velocity of the cut mass and the plastic mulch, relatively to the ground, along the horizontal plane, is zero. At the end of the conveyor, a drum (11) winds up the plastic sheet while the flexible irrigation tape (12) is collected underneath the conveyor and rolled on the tape winder (7) through the guide mechanism (10). The conveyor belt, the plastic sheet drum, and the tape winder are moved by a system of pulleys and belts (9) driven by a hydraulic motor (8) powered by the tractor's hydraulic system. The drums' speed is set to ensure a tight winding of the film to produce a dense reel and tearing of the film or the tape is prevented by a friction clutch placed on the rotation shaft.

In the early designs of prototypes for plastic mulch removal, the movement of the winding unit was derived from a support wheel (Khazimov and Khazimov, 2011; Khazimov *et al.*, 2016, 2019; Masheng and Shang 2014; Shilo *et al.,* 2009), but its slippage, due to the variation of density or moisture of the soil, caused poor-quality operational results, so the mechanical transmission was substituted by a hydraulic system, and a structural diagram was drawn up, and a graphic-analytical calculation was performed to determine the characteristics of this hydraulic drive (system pressure, length of the main line, torque, power, *etc*.) (Masheng *et al.,* 2014).

The advantage of a hydraulic drive is to maintain even the chosen shaft speed at any angle and reduce the acoustic pressure.

To increase the efficiency of the winding system, an intermediate friction mechanism is provided, triggered before the film tearing limit is reached; this also eliminates the need for manual adjustments during the work (Khazimov *et al.,* 2021a).

Calculation of the hydraulic drive mechanisms for winding up the plastic mulch and the drip irrigation tape

The hydraulic drive system, which includes a hydraulic pump, a reversible hydraulic motor, and appropriate piping, accessories, and control components, is described in the diagram in Figure 3A.

The pump (2) drives the working fluid from the reservoir tank (1) to the hydraulic motor (4) through the throttle (3) and back again to the tank through the filter (5). The output shaft (7) of the hydraulic motor drives the plastic sheet drum (8), the irrigation tape winder (9), the rolling ring tape guide mechanism (10), and the conveyor belt (6), through a series of pulleys and belts, with the protection of friction clutches (11) that are deactivated when the set torque value is reached on the drive shafts in order to avoid tearing of the plastic mulching sheet.

The hydraulic system diagram was schematised as shown in Figure 3B (Bashta, 1982; Lepeshkin *et al.,* 2003).

The power needed by the hydraulic drive was calculated considering the tangential velocity of the primary pulley (7) and the efficiency of the hydraulic system.

Table 1 shows the values of the single parameters that were used, chosen based on the technical characteristics of the tractor and of the attached unit.

The calculations followed the sequence: i) selection of the scale and the characteristics of the pumping unit; ii) drawing up the equations for the characteristics of each one of the two parts of the

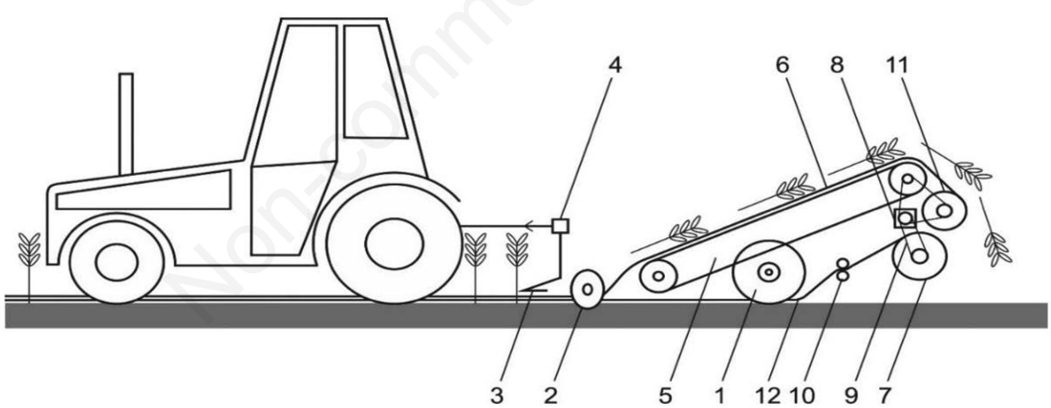

Figure 2. Hinged device for mechanised removal of polymer residues: 1 - frame with support wheels; 2 - blade; 3 - segment mechanism for cutting of plants; 4 - reducer; 5 - conveyor; 6 - plastic mulch; 7 - winder for drip irrigation tape; 8 - hydraulic motor; 9 - belt drive system; 10 - tape guide mechanism; 11 - drum for plastic mulch; 12 - drip irrigation tape.

Table 1. Data for calculations.

Density of the fluid, ρ (kg.m^{-3})	Pump displacement, $W_{p.max}$ (cm^3)	Rated speed of the pump shaft, n_p (rev·s^{-1})*	Volumetric Leak Rate, K_{vol}, (MPa^{-1})	Hydraulic line dimensions: Length, $l_1=l_2$ (m)	Hydraulic line dimensions: Pipe diameters, d_1 d_2 (mm)	Filter resistance coefficient, ξ_f	Hydraulic throttle parameters, S_{th}, (mm^2)	Flow coefficient, μ_{ap}	Displacement of motor, W_p, (cm^3)	Kinematic viscosity, ν (cm^2·s^{-1})	Minimum pressure in the system, P_{Hmin} (MPa)
900	32	25	0.03	5	8	5	0.14	0.7	30	0.14	5

The ratio between the actual consumption and the theoretical consumption without the unit: μ=Q_ac/Q_th.

pipeline and determination of their coefficients; iii) matching the characteristics of the two parts and obtaining the overall characteristic of the entire pipeline; iv) determination of the operating point, performing additional graphical constructions and analytical operations.

The equivalent hydraulic drive diagram is a pipeline that comprises sections 1 and 2, each of which is a series-connected element.

Considering the linearity of the characteristics of the pump and a pumping unit with a working volume regulator, the construction of each is sufficient at two points AA´ and BB´. The ABC characteristic is obtained as a result. The general equation for the characteristics of the pipeline is represented in the following form (Bashta, 1982):

$$P_\Sigma = \Delta P_d + \Delta P_{l_1} + \Delta P_h + \Delta P_{l_2} + \Delta P_f, \tag{1}$$

The coefficients are determined for each section in the following way:

- for the 1st section – $\Delta P_1 = \Delta P_{l1} + \Delta P_d$ considering Darcy and Blasius friction factor formula:

$$\Delta P_1 = \lambda \frac{8 \cdot l_1 \cdot \rho}{\pi^2 \cdot d_1^5} \cdot Q^2 + \frac{\rho}{2\mu_d^2 \cdot S_d^2} \cdot Q^2 = K_1 \cdot Q^2, \tag{2}$$

- for the 2nd section – $\Delta P_2 = \Delta P_{l2} + \Delta P_f + \Delta P_h$ considering the Weisbach formula:

$$\Delta P_2 = \lambda \frac{8 \cdot l_2 \cdot \rho}{\pi^2 \cdot d_1^5} \cdot Q^2 + \xi_\Phi \frac{8 \cdot \rho}{2\pi^2 \cdot d^4} \cdot Q^2 = K_2 \cdot Q^2, \tag{3}$$

- for the hydraulic motor, considering the displacement of the hydraulic motor (W_h):

$$\Delta P_\Gamma = \frac{2\pi \cdot M}{W_h \cdot \eta_h}, \tag{4}$$

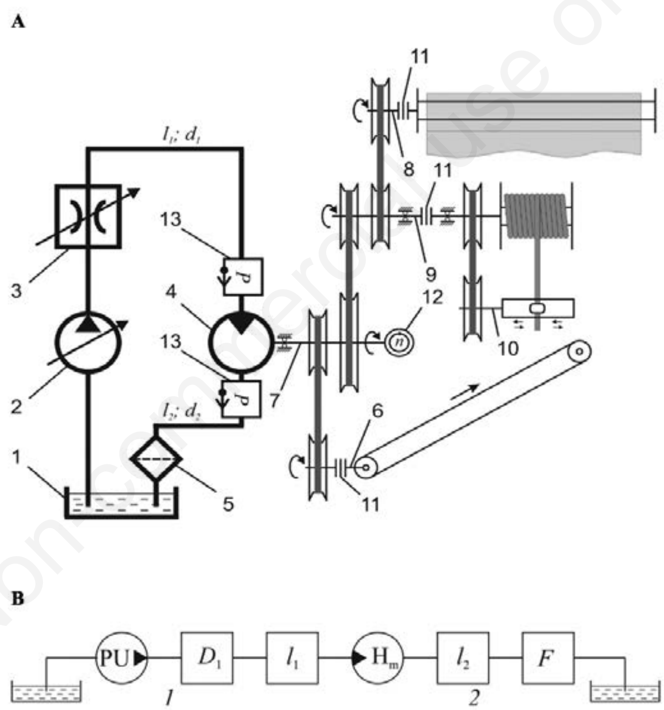

Figure 3. A) Simplified diagram of the hydraulic drive mechanisms for winding of the plastic mulch and flexible drip irrigation tapes: 1 - reservoir tank; 2 - hydraulic pump; 3 - throttle; 4 - hydraulic motor; 5 - filter; 6 - shaft of the conveyor; 7 - shaft of the hydraulic motor; 8 - shaft of the mulching film rewinder; 9 - shaft of the irrigation tape winder; 10 - shaft of rolling ring tape guide for even distribution of the tape on the winder; 11 - safety clutches; 12 - tachometer; 13 - pressure sensors; l1, l2 - length of the pipeline before and after hydraulic motor; d1, d2, - diameter of the pipeline before and after hydraulic motor. B) Simplified diagram of the hydraulic drive: PU=pump; D1, l1=pipe diameter and length in the first part of the circuit; Hm=motor; D2, l2=pipe diameter and length in the second part of the circuit; F=filter.

Table 2. Pipeline sections and their coefficients.

Sections	Coefficients		Formulas for determining coefficients
ΔP_1	K_1	$4.503 \cdot 10^{12}$	$\lambda \frac{8 \cdot l_1 \cdot \rho}{\pi^2 \cdot \alpha_1^5} \cdot Q^2 + \frac{\rho}{2\mu_d^2 \cdot S_d^2}$
ΔP_2	K_2	$4.503 \cdot 10^{12}$	$\lambda \frac{8 \cdot l_2 \cdot \rho}{\pi^2 \cdot d_1^5} \cdot Q^2 + \xi_\Phi \frac{8 \cdot \rho}{2\pi^2 \cdot d^4}$

Coefficient characteristics are resumed in Table 2.

The equation of characteristics of the pumping unit at $P_p > P_{Pmin}$ is determined by the formula:

$$Q_{pu} = - K_p \cdot (P_p - P_{p\,min}), \quad (5)$$

Pressure at point C at a flow rate equal to zero is:

$$P_c = P_{Pmin} + \frac{Q'_{pu} - Q}{K_p}, \quad (6)$$

for the 2nd section, the application of Eq. 1 results in:

$$\Delta P_2 = K_2 \cdot Q^2 + \Delta P_h, \quad (7)$$

Determination of the power need

GOST (former USSR interstate standard) methodology was applied to determine the characteristics of the experimental machine (GOST, 2020a) and the power need (GOST, 2020b).

The field tests were carried out after harvesting tomatoes. Data were collected with the use of a data logger PR200-24.4.2.0 (OWEN, Moscow, Ru) with PC Interface ETG-CP-070 7″ (ONI series, IEK, Moscow, Ru) with permanent memory for processing and storing the collected data (Figure 4) and sensors for: i) forward velocity, measured with the use of inductive sensors (Figure 4C), ISB A4A-31P-5-LZ (TEKO, Chelyabinsk, Ru); ii) traction force for the displacement of the unit, measured separately with the use of a traction dynamometer DPU 50–1-U2 (Budenberg Gauge Co. Ltd, UK) with a maximum pulling force of 30 kN; iii) the rotational speed of the hydraulic motor, measured with a tachometer (Figure 4B) TX01-224.SCH2.R (OWEN, Moscow, Ru); iv) pressure in the hydraulic system line measured with pressure sensors PD100-DI40.0-111-0.5 and PD100-DI25.0-111-0.5 (OWEN, Moscow, Ru), sending an impulsive signal to a central processor located before and after the hydraulic motor (Figure 3A, n. 13 and Figure 4A).

The power at the drive shafts for idling and working phases was calculated automatically from the data logger as the pressure difference measured by the two sensors.

The software for programming the PR200-24.4.2.0 data logger was designed and developed with the FBD language (according to IEC 16131-3 standard) using the OwenLogic (OWEN, Moscow, Ru) programming environment; the flowchart is drafted in Figure 5A.

The data logger was connected to the ETG-CP-070 7″ operator panel, and a specific application was created using ONI Visual Studio (ONI, IEK, Moscow, Ru) for setting and managing the main parameters (Figure 5B).

For determining the prototype's traction resistance, the tractor-implement set, with the tractor gearbox in a neutral position, was towed by a second tractor connected by a dynamometer with a maximum pulling force of 30 kN (Figure 6). Traction resistance was measured for mulch and pipe removal operations and the coasting tractor alone.

Field tests

The experiments were conducted in a 200×100 m test field in the Almaty Region, Kazakhstan. The average soil top layer (150 mm) density, hardness, and moisture content were 1.3 g×cm^{-3}, 2.9 MPa, and 25%, respectively.

The test protocol considered 50 passages that ran parallel to the main plot side (200 m) in order to cover the whole plot surface. Out of these, 5 were selected randomly in the middle of the field section for data analysis. During the tests, the connected complex of instruments measured and recorded the forward speed of the

Figure 4. Sensors installed on the experimental unit: A) pressure sensor; B) sensor of the hydraulic motor speed; C) sensor of unit forward velocity; D) data logger with PC Interface.

unit, the frequency of rotation of the driving hydraulic motor, the energy needed for driving the drive shafts (calculated by the PR200-24.4.2.0 data logger), and the pressure variations in the hydraulic system line driving the working bodies. In addition, the traction force for moving the unit and the device was measured with a traction dynamometer,

Statistical data processing

Statistical processing of experimental data results is presented in Tables 3-7.

Results and discussion

Power consumption

The theoretical characteristics $\Delta P_1(Q)$, $\Delta P_2(Q)$, and $\Delta P_\Sigma(Q)$ resulting from the previous calculations (2), (7), and (2) + (7) are shown in Figure 7A.

The intersection of the curve $\Delta P_\Sigma(Q)$ with the line characterising the pumping unit determines the operating point of the hydraulic system (point R in Figure 7A).

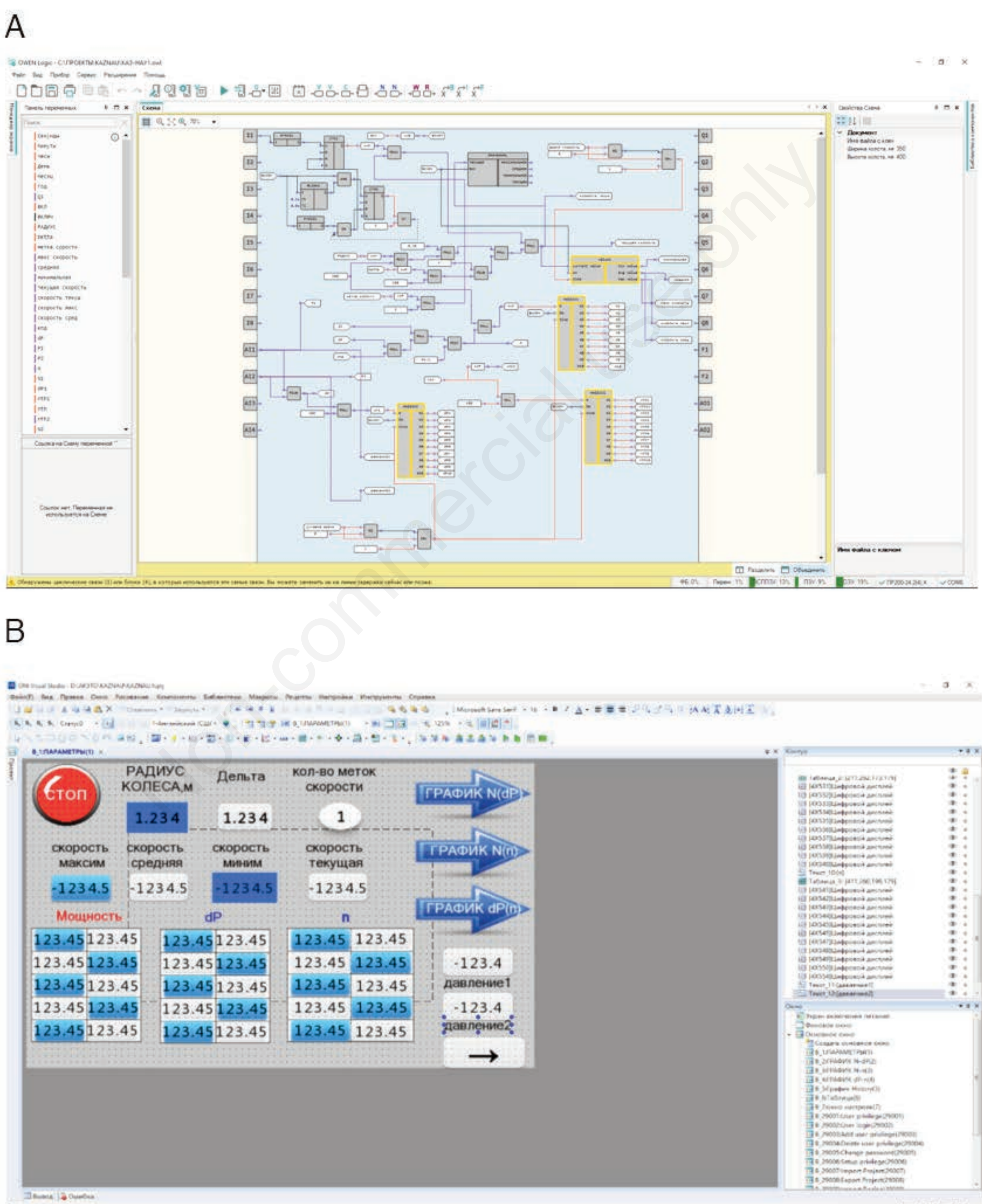

Figure 5. A) Data logging flow chart developed with the OwenLogic software. B) ONI Visual Studio software: the work algorithm and the graphical operator panel.

To obtain the power needed by the hydraulic drive (N) and its' efficiency (η), the tangential velocity of the pulley of the winding devices was measured.

The main parameters of the hydraulic drive were determined experimentally.

Figure 7B and C shows the power need and the speed of the hydraulic motor at different velocities. The average velocities of the unit were 0.52 m·s^{-1}, 0.96 m·s^{-1}, 1.58 m·s^{-1}, and 1.8 m·s^{-1}, while the power needed ranged from 1.55 to 1.90 kW. The power need increases with an increase in the pressure drop and the speed of the hydraulic motor. The variation of the power consumption at various values of the forward velocities of the unit is shown in

Table 3. Initial data and function values.

N	Initial data		Function values		
	Translational velocity of the unit (m·s^{-1}) X_1	Speed of the hydraulic motor (rpm) X_2	Power need (kW) $Y(X_1,X_1)$ Measured	Calculated*	Variation
1	0.49	156	1.88	1.81214	6.786001E-02
2	0.5	156	1.88	1.81	6.999993E-02
3	0.5	156	1.86	1.81	4.999995E-02
4	0.51	156	1.86	1.80786	0.05214
5	0.52	157	1.86	1.80772	5.227995E-02
6	0.52	157	1.86	1.80772	5.227995E-02
7	0.53	158	1.85	1.80758	4.242003E-02
8	0.53	159	1.85	1.80958	4.041994E-02
9	0.55	160	1.85	1.8073	4.269994E-02
10	0.55	161	1.85	1.8093	4.069996E-02
11	0.94	154	1.71	1.71184	–1.840115E-03
12	0.94	154	1.71	1.71184	–1.840115E-03
13	0.94	155	1.71	1.71384	–3.83997E-03
14	0.95	155	1.72	1.7117	8.300066E-03
15	0.95	156	1.72	1.7137	6.299973E-03
16	0.96	157	1.72	1.71356	6.440044E-03
17	0.98	157	1.72	1.70928	1.072002E-02
18	0.98	158	1.72	1.71128	8.720041E-03
19	0.99	158	1.73	1.70914	2.085996E-02
20	0.99	158	1.74	1.70914	3.085995E-02
21	1.56	151	1.6	1.57316	2.683997E-02
22	1.55	152	1.6	1.5773	2.269995E-02
23	1.56	152	1.6	1.57516	0.02484
24	1.57	152	1.61	1.57302	3.697991E-02
25	1.57	153	1.61	1.57502	3.497994E-02
26	1.58	154	1.61	1.57488	3.511989E-02
27	1.59	155	1.61	1.57474	3.526008E-02
28	1.6	155	1.62	1.5726	4.740012E-02
29	1.61	155	1.62	1.57046	4.953993E-02
30	1.61	155	1.62	1.57046	4.953993E-02
31	1.79	148	1.54	1.51794	2.205992E-02
32	1.79	149	1.55	1.51994	3.005993E-02
33	1.79	149	1.55	1.51994	3.005993E-02
34	1.8	150	1.56	1.5198	0.0402
35	1.8	151	1.56	1.5218	0.0381999
36	1.8	151	1.56	1.5218	0.0381999
37	1.8	151	1.56	1.5218	0.0381999
38	1.81	152	1.57	1.52166	4.833997E-02
39	1.81	152	1.57	1.52166	4.833997E-02
40	1.81	152	1.58	1.52166	5.833996E-02

*The regression equation for Y is: $Y=1.605-0.214\ X1+0.002\ X_2$.

Figure 7C. It can be seen that with an increase in the unit's forward velocity, the drive's power consumption decreases from 1.86 kW to 1.56 kW, which is 18% less than at an average velocity of 0.52 m·s^{-1}. When winding plastic mulch and flexible drip tapes, the friction clutches of the unit drive mechanism work depending on the forward velocity of the unit. Thus, with an increase in the unit's forward velocity, and the clutches' response time is reduced, which leads to a decrease in the drive's power consumption. Such a control scheme for the winding processes allows the use of lower power motors, which positively affects the machine's cost.

The results of the traction tests are shown in Table 8, which shows that the mean traction resistance of the developed device was 1.96 kN.

From the results, it appears that the power need data for the winding mechanisms and for the movement of the unit itself are reliable.

The power needed to move the unit at minimum ($v_{\min}$) and maximum ($v_{\max}$) velocities results, respectively, 1.019 kW and 3.528 kW (GOST, 1988). Consequently, the maximum power needed to drive the winding mechanisms is 1.86 kW. This is about 1.9 times lower than the power needed to move the unit at a steady forward velocity.

Table 4. Statistical parameters of initial data.

Variable names X and Y	Average	Squared deviation	Coefficient of variation	Asymmetric relation	Excess
X_1	1.22	0.51	41.6	–0.2	–1.57
X_2	154.43	3.13	2	–0.08	–0.73
Y	1.69	0.12	6.9	0.43	–1.29

Table 5. Pair correlation coefficients.

Variable names	X_1	X_2	Y
X_1	1	–0.825	–0.987
X_2	–0.825	1	0.833
Y	–0.987	0.833	1

Regression parameters: b_0=1.605164; b_1=-0.2141075; b_2=2.2181445 E-03.

Table 6. Analysis of variance table.

Source	Sum of squares	Degrees of freedom	Mean square
Regression	0.5208882	2	0.2604441
Residual error	1.365006 E-02	37	3.689205 E-04
Total	0.5345383	39	

R-squared: R^2=0.974; coefficient of multiple correlation: R=0.987; residual standard error: O_t=0.0192073; MSE of multiple correlation coefficient Gr=4.198122 E-03; Student's T-test: t_d= 235.1407; approximation error: e=1.998529; residual dispersion: S_{res}=1.60252E-03; F-Statistic criterion for assessing the degree of approximation of multiple regression: F=8.339213; regression equation for Y: Y=1.605-0.214X_1+0.002X_2).

Table 7. Table of private factors.

Factors	BETA odds	Partial coefficients of elasticity	Partial odds determination
X_1	–0.937	–0.154	0.924
X_2	0.054	0.183	0.045

Figure 6. Measuring the traction resistance.

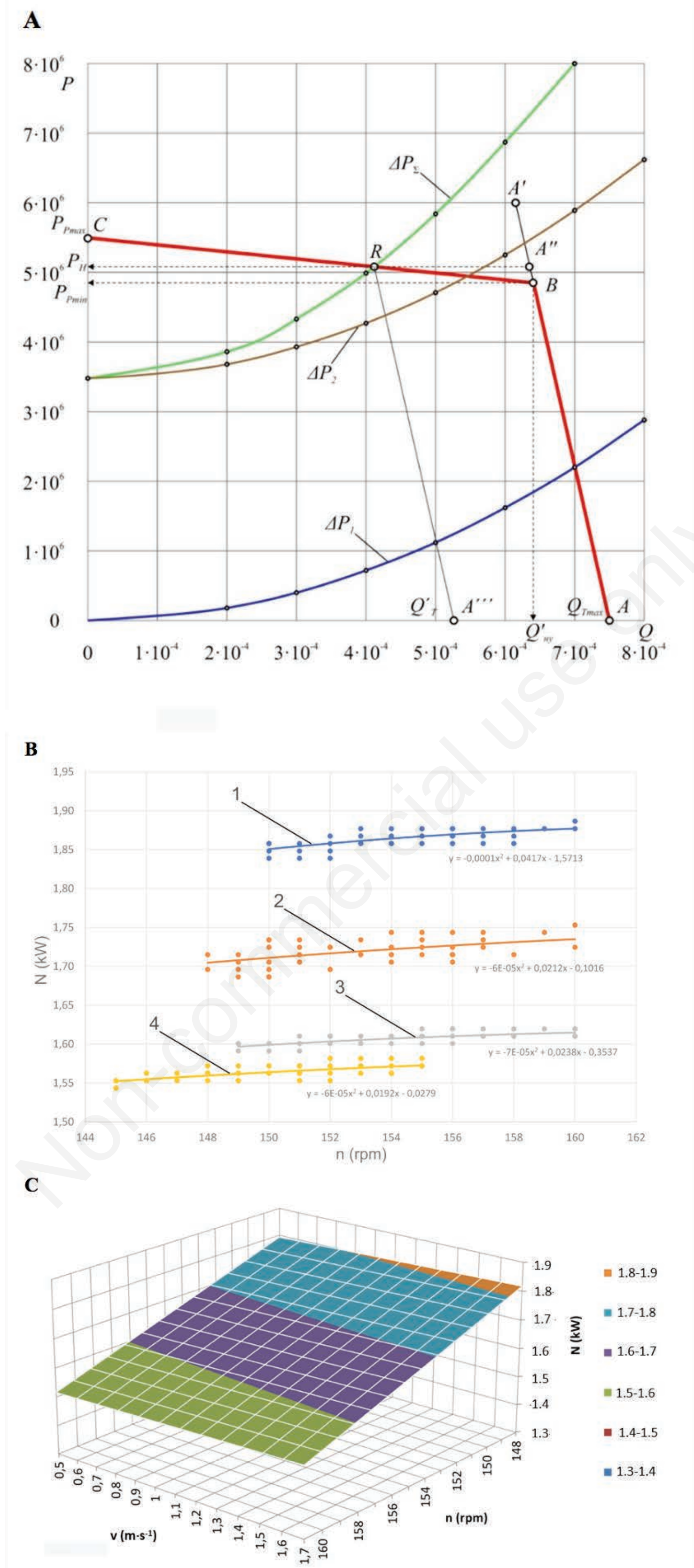

Figure 7. A) Graphic representation of the calculation results: ΔP_1- characteristics of the 1st section; ΔP_1- characteristics of the 2nd section; R- operating point of the pumping unit; ABC- characteristics of the pumping unit. B) Power need (N) of the hydraulic motor at different speeds (n) and forward average velocities (V_{aver}): 1 - V_{aver}=0.52 m·s^{-1}; 2 - V_{aver}=0.96 m·s^{-1}; 3 - V_{aver}=1.58 m·s^{-1}; 4 - V_{aver}=1.8 m·s^{-1}. C) Power need (N) of the hydraulic motor at different motor speeds (n) and forward velocities (v) of the unit.

The power consumption of the hydraulic drive of the winding mechanisms is low because the friction clutch on the drive shaft makes the winding smooth and continuous with no need for frequent stop and start. At the same time, the film is wrapped up more tightly, which makes the bundle easier to manage. However, the implements available in the Kazak market instead need an operator to constantly manage the functioning of the hydraulic motor, stopping and starting it again when needed hence much more power and energy are required; moreover, the film is not rolled up evenly, and the resulting bunch is challenging to remove and to handle.

Cost analysis

A comprehensive cost analysis was also done comparing the performances of the prototype with a PMR-01 Plastic Mulch Retriever (Rocca Industries Pty Ltd, Australia) according to the State Standard 34393-2018 (GOST, 2018). The economic indicators were labour costs and direct operating costs. The labour cost for machine operators and support personnel resulted in being 50% lower with the modified implementation, while direct operating costs per hectare were more than 43% lower (14,631.27 KZT against 25,891.58 KZT). The results of this analysis will be published separately.

Table 8. Values of traction resistance of the unit.

Measurement	Test number					Average	Coefficient of variation
	1	2	3	4	5		
$R_{t.u.}$, (kN)	6.35	6.39	6.36	6.37	6.38	6.37	0.002482
$R_{t.t.}$, (kN)	4.42	4.41	4.39	4.43	4.4	4.41	0.003585
R_{m}, (kN)	1.93	1.98	1.97	1.94	1.98	1.96	0.023452

Formulas used for calculations

The power needed for idling and working phases was calculated with the expression:

$$N = \frac{Q_t \cdot \Delta P}{61{,}2} \cdot \eta_{hm}, \text{kW} \quad (8)$$

where:

Q_t - theoretical pump flow, l·min^{-1};

ΔP - hydraulic motor pressure drop, MPa;

η_{hm} - hydraulic motor hydromechanical efficiency rate.

The traction resistance of the unit was calculated by the formula:

$$R_{M} = R_{t.u} - R_{t.t}, \text{kN} \quad (9)$$

where;

$R_{t.u.}$ - traction resistance of the tractor with the implement during mulch and pipe removal, kN; $R_{t.t.}$ - traction resistance of the tractor alone, kN.

The power need was obtained with the formula:

$$N_{in} = \frac{P_p \cdot Q'_{pu}}{\eta_{pp}}, \quad (10)$$

while the net power output from the hydraulic drive with the formula:

$$N_{out} = F \cdot \upsilon, \quad (11)$$

So the hydraulic drive efficiency is:

$$\eta = \frac{N_{out}}{N_{in}}, \quad (12)$$

The power needed to move the unit at minimum ($\boldsymbol{v}_{\mathbf{min}}$) and maximum ($\boldsymbol{v}_{\mathbf{max}}$) velocities was calculated applying the power calculation formula:

$$\mathbf{N = R_m \times v}, \quad (13)$$

to the measured data

$R_{t.t.}$ - traction resistance of the tractor alone, $R_{t.u.}$ - traction resistance of the tractor with the implement during mulch and pipe removal, $R_{m.}$ - traction resistance of the implement calculated according to (13)

Conclusions

The power consumption of a plastic mulch and irrigation tape retriever can be calculated theoretically, starting from some basic data measured during the use of the implement.

The methodology proposed in this study was applied to a prototype developed by the authors, where a hydraulic motor drove the rolling mechanism. Moreover, a friction clutch made the operation automatic and continuous and showed a considerable reduction in power consumption hence showing that the control system used in most of the machines available on the Kazak market (Khazimov *et al*., 2021a) can be simplified by installing a hydraulic motor with low power need. This also makes the operation easier and eliminates the need for an operator to manage and control the winding operation.

The proposed methodology is quite simple and can be applied and also adapted to other similar cases, and the data obtained from the tests carried out can be used to develop models describing a unit's movement and its operation.

The reduction of power consumption and labour time implicates a cost reduction that was broadly assessed and should be investigated more in-depth.

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