Platform-maker for preparing stumps for lowering below the surface of the soil with a variable boom of the hydraulic manipulator

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Abstract. The technology of continuous lowering of stumps below the soil surface throughout the area of cutting is proposed to reduce the loads on the working bodies and frames of tillage tools and ensures complete mechanization of the reforestation process. A technological process has been developed to prepare stumps for lowering below the ground surface, which consists in creating platform-deepenings around stumps and cleaning their lateral surface from the soil within the depth of the platform. An aggregate for its implementation consisting of a tractor, a hydraulic manipulator, a screw rotator and a platform-maker with flexible working bodies has been designed. A mathematical model of the aggregate operation has been created. It enables to evaluate the efficiency of the manipulator placement of platform-maker and to determine the influence of the parameters of the hydraulic manipulator on the performance of the aggregate. The influences of the stump distribution density, the boom of the manipulator and the maximum angle of its rotation on the performance of the platform-maker have been determined. It was revealed that the productivity of the aggregate increases with an increase in the density of stump distribution on the cutting and the main geometrical parameters of the hydraulic manipulator.

1. Introduction

Existing technologies in forestry, many of which are based on the continuous onward movement of aggregates, have significant drawbacks. They include large energy and material costs. In addition, there is a violation of the natural environment: deep rutting from the propulsion means is removed, the ground cover is removed, the structure of the soil changes, and the undergrowth of valuable wood species is destroyed. The aggregates with hydraulic manipulators transporting the working parts during various technological operations are becoming more common in order to eliminate these drawbacks in logging operations, as well as during reforestation and afforestation. Thereby the technology provides a discrete way to carry them out [1].

Hydraulic manipulators are used in the aggregate with logging machines [2, 3], equipment for cutting, crushing and milling stumps [4, 5], cutting off of secondary hardwood, forming crowns, collecting seeds, preparing seats and platforms [6, 7], digging seedlings [8] and others. It is also proposed to prepare stumps for lowering below the soil surface. It consists in creating platform-deepenings around stumps (removing soil around stumps and cleaning them from contamination...
within the depth of a platform) using a hydraulic manipulator.

The continuous lowering of stumps below the soil surface makes it possible to turn the felling into an area that, in many ways, is close to agricultural areas, free from the aerial part of the stumps, with the preserved fertile soil layer. When using this technology, there are opportunities to increase the speed of aggregate movements, reduce the dynamic loads on the working bodies of the tillage machines and, as a result, reduce metal intensity of the structures and material costs for their manufacture, create strictly parallel rows of forest plantations with predetermined row spacing. These enable to mechanize the whole technological process of the cultivation [9].

In addition, this operation will lead to an increase in the volume of energy raw materials. It is obtained as a result of crushing and collecting chips, which, unlike other traditional fuels, is renewable and the safest material for the environment. Removing the soil around the stump, for example, to a depth of 15-20 cm and a diameter of about 1.5 m, depending on the type of wood, will increase the raw material by 40-70%.

The purpose of the study is to determine the dependencies of the platform-maker performance to prepare stumps for lowering below the soil surface on the overhang and angular range of the hydraulic manipulator boom, as well as on the stump distribution density in the cutting area.

2. Materials and methods

2.1. The design and technological process of the platform-maker to prepare stumps for lowering below the soil surface

A special aggregate was developed to prepare stumps for lowering below the soil surface (figure 1). It includes a tractor 1, a telescopic hydraulic manipulator 2, a screw rotator 3, and a platform-maker for creating platform-deepenings around the stumps 4.

![Figure 1. Aggregate for preparing stumps to lower below the soil surface.](image)

The platform-maker (figure 2) consists of frame 1, rotary working bodies (rotors) 2, and two-piece hydraulic cylinder 3 for changing the distance between them, hydraulic motors 4 for driving the working bodies, hydraulic system and controls. The rotor is a shaft on which four sections are installed, consisting of disks 5 with fragments of cable 6 attached to them, designed to create platform-deepenings around the stumps and clean their side surfaces from the soil and other contaminants. In order to eliminate the rapid wear of the cables, their ends are hardened and covered by collars 7.
The technological process of preparing stumps for lowering below the soil surface is as follows. The platform-maker is mounted above the stump with the help of a hydraulic manipulator and lowered to contact with the soil, after which the rotors are set in rotation by means of hydraulic motors, and the cables contacting the stump clean it. The profile of the platform-deepening (figure 3) - a depth of 15-20 cm and a radius of 60-90 cm - is provided by reversing rotation of the rotator, carried out simultaneously with the rotation of the rotors. After completion of the operation, the device moves to another stump, and the process repeats. Depending on the diameter of the stumps, the distance between the rotors is adjusted using a two-piece hydraulic cylinder.

After cleaning the stumps can be crushed below the soil surface by machines for lowering, crushing and milling the aerial part of the stumps [10].

The use of a hydraulic manipulator for positioning the area of the distributor significantly improves the performance of the aggregate compared to the option of mounting the machine directly on the mounted mechanism of the tractor. The hydraulic manipulator reduces the number of crossings of the tractor on the felling due to the fact that at each stop of the aggregate it is possible to create platform-deepenings for -10 stumps (depending on the density of their distribution).
2.2. Simulation of the technological process of the aggregate for the preparation of stumps to lower below the soil surface with a variable boom of the hydromanipulator

To evaluate the effect of the manipulator placement of the platform-maker and determine the dependence of its performance on the parameters of the hydraulic manipulator, a mathematical model of the operation of the aggregate for cutting is developed.

The proposed model allows to calculate the number of tractor moves on cuttings with different stump density distribution (from 200 to 1200 stumps/ha). Modeling is performed in the two-dimensional space XY, and the modeling plane is a “top view” of the cutting. Initially, a model cutting is generated with a given density of stump distribution \( \sigma_{st} \) (figure 4).

\[
\begin{align*}
\| i \| & = 1 \ldots \| \sigma_{st} L_x L_y \|; \\
\chi_i & = F_1^i L_x; \\
\gamma_i & = F_2^i L_y,
\end{align*}
\]

where \( i \) – stump number in model;
\( \| \ldots \| \) – rounding operator;
\( \sigma_{st} \) – specified stump distribution densities;
\( L_x \) and \( L_y \) – the length and width of the cutting piece;
\( (\chi_i, \gamma_i) \) – the coordinates of the \( i \)-th stump in the cutting;
\( F_1^i \) and \( F_2^i \) – realizations of random variables distributed according to a uniform law in the interval (0,1).
The main objective of the simulation is to determine the number of moves tractor $N_t$ when processing a specified number of stumps $N_{st}$. To solve this problem, the model simulates the movement of the tractor along a straight line of the rut and periodically checks the stumps surrounding the aggregate into the working area of the hydraulic manipulator, which is a sector of the ring and is determined by the range of the boom angles $\varphi_1-\varphi_2$ and the range of its departure $R_1-R_2$ (figure 5).

![Figure 5. The working area of the hydromanipulator and its geometric parameters.](image)

In accordance with the design scheme, the condition for entering the $i$-th stump into the working area of the hydromanipulator can be written as follows:

$$\begin{cases} R_1 \leq R_i \leq R_2; \\ \varphi_1 \leq \varphi_i \leq \varphi_2; \\ R_i = \sqrt{(x_i - x_t)^2 + (y_i - y_t)^2}; \\ \varphi_i = \begin{cases} \arctan \frac{y_i - y_t}{x_i - x_t}, & x_i - x_t \geq 0; \\ \arctan \frac{y_i - y_t}{x_i - x_t} + 180^\circ, & x_i - x_t < 0, \end{cases} \end{cases}$$

(2)

where $R_1$, $R_2$ – minimum and maximum outreach of the boom of the manipulator;

$\varphi_1$, $\varphi_2$ – limit angles of rotation of the boom of the manipulator;

$x_t$, $y_t$ – coordinates of the manipulator column;

$R_i$ and $\varphi_i$ – polar coordinates of departure and angle of rotation of the boom of the hydraulic manipulator for the $i$-th stump in the coordinate system associated with the axis of rotation of the rotary column $(x_t, y_t)$.

At the beginning of the computer experiment, a model tractor with a hydraulic manipulator and a platform-maker is placed on the model cutting so that the working area of the hydraulic manipulator does not extend beyond the cutting area $L_x \times L_y$. After counting the number of stumps that have fallen into the working area, the aggregate is moved along the OX axis to such a distance that the stump does not pass past the working area in the treated strip. Thus, the model reproduces the move of the tractor from one processing position to another, resulting in a gradual shift of the working area. In this case, each time the number of stumps caught in the work area is calculated. When reaching the total number of treated stumps, equal to some given value $N_{max}$ (in most experiments $N_{max} = 1000$ stumps, so that the random error is small enough), computer experiment is completed, and the total processing time
The most important indicator determined by the model is productivity $P$ of the platform-maker, that is, the number of stumps processed per unit of time:

$$P = \frac{N_{st}}{t_{proc}}$$

The developed model makes it possible to find out how the productivity of the platform-maker with manipulator positioning depends on the basic geometrical parameters of the hydraulic manipulator: the minimum and maximum boom $R_1$ and $R_2$ and limiting angles of its rotation $\phi_1$ and $\phi_2$.

To study the model, a special computer program was written in Object Pascal in the programming environment Borland Delphi 7.

3. Results

Figure 6 shows examples of the operation of the aggregate: the sequence of processing areas is shown with the aggregate gradually moving along the rut line. In the case of a small number of stumps per unit of cutting area (up to 200-400 stumps/ha) (figure 6, a), the platform-maker at each stop of the tractor processes approximately 1-3 stumps and makes long journeys (about 10 m). With a larger number (600-800 stumps/ha) (figure 6, b), the number of stumps processed during one stop increases to 3-5, and crossings between stops are reduced to 5 m.

![Figure 6](image-url)
Using the model, we studied the effect of the density of stump distribution $\sigma_{st}$ on cutting and the main geometrical parameters of the hydraulic manipulator ($R_2, \Delta \varphi = \varphi_2 - \varphi_1$) on the performance of the platform-maker (figure 7).

**Figure 7.** Dependencies of the productivity $P$ of the platform-maker’s placed on the hydraulic manipulator: (a) – on the density of stump distribution $\sigma_{st}$ in the cutting; (b) – from the maximum boom distance $R_2$; (c) – from the angular range of the boom rotation $\Delta \varphi$.

Since the productivity of the platform-maker increases with an increase in the density of stump distribution at the cutting site (figure 7, a), it can be concluded that the hydraulic manipulator positioning of the area of the landlord is reasonable at high density (more than 600 stumps/ha): in this case, it is possible to process from 3 to 5 stumps at each stop of the unit. With a low density (less than 400) stumps are located far from each other, and from one tractor stop it is rarely possible to process more than one stump. Therefore, in this case, it is advisable to place the platform-maker directly on the tractor hitch mechanism.

With an increase in the maximum boom reach $R_2$, the productivity (calculated for $\sigma_{st} = 600$ stumps/ha) increases almost linearly (figure 7, b). Therefore, it is advisable for a platform-maker to choose a hydraulic manipulator with the boom as large as possible, but with simultaneous consideration of the mass and cost parameters, as well as the power characteristics of the tractor.

An increase in the angular range of boom rotation leads to an increase in the working area of the manipulator, and, accordingly, to an approximately linear increase in productivity (figure 7, c). Therefore, it is advisable to install the hydraulic manipulator on the tractor so that the angular range of boom rotation is as large as possible.

4. Conclusions

Thus, the dependencies of the performance of the platform-maker for preparing stumps for lowering below the soil surface on the departure and angular range of the boom of the hydraulic manipulator, as well as on the density of stump distribution at the cutting site, are determined. It has been established that the manipulator placement of the platform-maker is necessary with 600 or more stumps per 1 hectare of logging. Otherwise, it is advisable to place it on the rear hitch of the tractor. In turn, an increase in the departure and angle of rotation of the boom of the hydromanipulator causes an approximately linear increase in the productivity of the platform-maker.

References

[1] Bartenev I M, Emtel Z K, Tatarenko A P, Drapalyuk M V, Popikov P I, Bukhtoyarov L D 2011 Hydraulic manipulators and forest processing equipment (Moscow: Flint: Science) p 408
[2] Spinelli R, Nati C, Magagnotti N 2005 Harvesting and transport of root biomass from fast-growing poplar plantations Silva Fennica 39(4) 539-548
[3] Andersson J, Eliasson L 2004 Effects of three harvesting work methods on Harwarder productivity in final felling Silva Fennica 38(2) 195-202
[4] Lindroos O, Henningsson M, Athanassiadis D, Nordfjell T 2010 Forces required to vertically uproot tree stumps Silva Fennica 44(4) 681-694
[5] Kärhä K 2012 Comparison of two stump-lifting heads in final felling Norway spruce stand Silva
[6] Rantala J, Harstela P, Saarinen V-M, Tervo L 2009 A techno-economic evaluation of Bracke and M-Planter tree planting devices *Silva Fennica* **43**(4) 659-667

[7] Laine, T, Saarinen V-M 2014 Comparative study of the Risutec Automatic Plant Container (APC) and Bracke planting devices *Silva Fennica* **48**(3) article id 1161.

[8] Harris J R 2007 Transplanting large trees *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 2 024

[9] Sukhov I V, Kostrikin V A, Kazakov V I 2004 *Technologies of silvicultural works on logging (recommendations)* (Moscow: VNIILM) p 152

[10] Bartenev I M, Pozdnyakov E V 2014 Platform-maker around stumps *Forest Engineering Journal* **13** 156-158