Evaluation of an Autonomous Hole-Drilling Robot in Afforestation Operations

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ABSTRACT

Over the past several decades, agricultural mechanisation has advanced rapidly, and most Hungarian crop producers now have access to modern machinery. In contrast, the machinery fleets of forestry enterprises and contractors – with only a few exceptions – still consist largely of ageing equipment. The technological sophistication of forestry machinery continues to lag far behind that of other agricultural sectors. Yet the strengthening and competitiveness of forestry enterprises are inconceivable without the adoption of modern machines and technologies. A further serious challenge is the growing labour shortage affecting the sector. For these reasons, the integration of digital technologies, automated machinery, and robotics into forestry operations has become inevitable. In recent years, a family of horticultural robots has been developed in Hungary. Last autumn, our research team tested one member of this machine family in an oak afforestation project within the Nagykanizsa Forestry District of Zalaerdő Plc. This paper presents operational experience from field tests and provides an economic evaluation of the machine's performance.

Keywords: autonomous self-propelled robot, autonomous navigation software, precision forestry, GPS-based positioning, performance and cost analysis

1. INTRODUCTION

Technological development is indispensable for modern, efficient, profitable, and competitive agricultural production. Over the past few decades, agricultural mechanisation has advanced rapidly, and Hungarian crop producers generally have access to modern machinery fleets (Popp et al., 2018). In contrast, a significant proportion of the machinery fleets of domestic forestry enterprises and contractors consists of ageing equipment, and the forestry sector has fallen far behind agriculture in technological sophistication. This represents a significant obstacle to strengthening and modernising the forestry service sector. Given the current labour shortage, mechanisation is vital, as the implementation of planned forestry operations – silvicultural and timber-harvesting activities –

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requires a stable base of reliable forestry enterprises (Major & Kovácsevics, 2023). These factors – particularly the observable labour shortage in the sector – clearly indicate that mechanisation levels in individual silvicultural and forest utilisation activities must increase, thereby improving operational efficiency. For these reasons, the integration of digital technologies, automated machines, and robots into forestry operations is inevitable.
Information technology (IT) has now reached the forestry sector, and robotisation has become an integral part of forestry machinery development. Numerous experiments and machine-development projects are underway worldwide, with manufacturers continuously introducing new autonomous machines applicable to various areas of forest management (Czupy, 2023; Horváth, 2016; Horváth & Czupy, 2022).
Moreover, promising domestic developments have emerged.

2. MATERIALS AND METHODS

2.1 Background

In Hungary, among other domestic developers, Hári Tech Kft. began designing and manufacturing specialised small-scale, custom-built self-propelled robots in 2019. The company continuously develops and refines its machines, which are tested and optimised on a 50-hectare family horticultural farm (Hári, 2021). Currently, four types are produced, all equipped with Kubota diesel engines offering rated outputs of 18 kW (24 hp) and 48 kW (65 hp). The robots feature rubber-track undercarriages with hydraulically adjustable track widths, enabling adaptation to various terrain types and operational conditions.
A wide range of implements can be attached, including – but not limited to – auger drills, sprayers, fertiliser spreaders, mulchers, cultivators, and mowers.
Robot operation is supported by the company's proprietary "hariPilot" autonomous control software. The latest models include onboard cameras, allowing operators to monitor the work process in real time and intervene when necessary. Positioning relies primarily on GPS, with correction data supplied by commercial services (e.g., Lechner, Corrigo) or a local base station, achieving an operational accuracy of approximately ± 2 cm.
The robots are equipped with multiple safety features, including automatic shutdown in the event of a malfunction, tilt sensors, and collision-avoidance systems, ensuring safe operation even under demanding conditions.

2.2 Description of the Examined Machine

Among the machines manufactured by Hári Tech Kft., the haRiBOT V3 self-propelled robot – which has already proven its efficiency under horticultural conditions – was selected for testing in a forestry environment (*Figure 1*). The experiment aimed to assess the robot's performance under the specific operational and environmental conditions typical of forest management.
The haRiBOT V3 is equipped with 180 mm-wide rubber tracks, and its track gauge can be continuously adjusted hydraulically between 70 cm and 110 cm. Implements can be attached to both the front and rear of the machine. The front hydraulic lift has a lifting height of 200 mm and a load capacity of 100 kg, while the rear hydraulic lift offers a lifting height of 600 mm and a load capacity of 150 kg. To counterbalance heavy rear-mounted implements, additional front ballast weights can be installed.

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The robot has a maximum travel speed of 4.5 km/h and a total weight of 800 kg, which allows convenient transport on a trailer (*Figure 2*).

Figure 1: The haRiBOT V3 self-propelled robot at work

Figure 2: The haRiBOT V3 self-propelled robot – transportation

The control interface is located on the left side of the machine and includes the start button, ignition switch, throttle control, display panel, and emergency stop button. (An emergency stop button is also located on both sides of the robot and on the remote control.) The display panel shows operational parameters such as travel speed, engine revolutions per minute (RPM), and fuel level, and allows adjustment of related settings (*Figure 3*).
A waterproof tablet interface mounted on top of the robot enables the operator to configure work parameters – including boundary coordinates, row spacing, and plant spacing – and to monitor the work process in real time (*Figure 4*). The machine's operation can be mastered quickly thanks to the control software's logical, user-friendly design.
The robot is equipped with several safety features. In the event of a malfunction, it automatically shuts down to prevent accidents. The collision detection sensor provides a 270° field of view;

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upon detecting an obstacle, the robot first slows down and then stops. A tilt sensor prevents overturning by continuously monitoring the machine's inclination.

Figure 3: Control panel of the haRiBOT V3 self-propelled robot

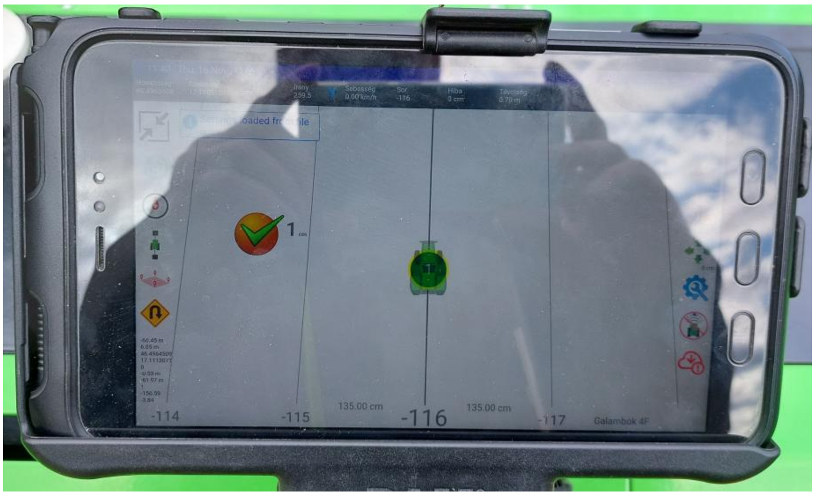

Figure 4: User interface of the hariPilot autonomous navigation software

2.3 Description of the Field Test

Since Hári Tech Kft. is located in Pötréte (Zala County), our research team conducted testing of the haRiBOT V3 robot under forestry conditions within the operational area of Zalaerdő Plc., Nagykanizsa Forestry District. The trials took place during the autumn afforestation season. The robot, equipped with an auger drill attachment, was used to dig planting holes for seedling establishment.

The forestry company proposed three forest subcompartments for the trials. Stump grinding had been carried out in two of them, while the third contained unground stumps, making it unsuitable for robot operation. The selected site was subcompartment Galambok 4F, where afforestation was planned using manual wedge-spade planting. Before planting, soil preparation was performed with a furrow-opening plough following stump grinding. The plot covered a total area of 3.02 hectares and was fenced to prevent wildlife damage.

Before commencing operation, the following input data were provided to the control software: EOV (Hungarian National Projection System) coordinates of the field boundaries, row spacing, plant spacing, and driving direction.

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The haRiBOT V3 self-propelled robot can be equipped with one, two, or three auger heads, depending on the desired row spacing. To improve operational efficiency, the work was performed with three auger heads operating simultaneously, with the robot moving perpendicular to the planting rows (*Figure 5*). The row spacing was 2.2 m, the plant spacing 45 cm, the auger diameter 13 cm, and the drilling depth 30 cm.

Once started from the defined initial point, the robot operated fully autonomously: it stopped at each predefined position, drilled the planting hole, retracted the auger head, and moved automatically to the next drilling position. Upon reaching the end of a row, it turned toward the next row and continued its operation. The turning radius at the field ends was approximately 3 m. The operator could take over manual control at any time using the remote controller. In this particular test, the robot was able to perform automatic turning at the end of the rows on only one side. Because the fence did not always follow the exact forest boundary, there was insufficient space for a full automatic turn in some sections. In such cases, control was temporarily switched to manual mode using the remote control to complete the turn. Afterwards, control was returned to the robot, which then automatically repositioned itself and resumed autonomous operation.

Figure 5: Application of three auger heads operating perpendicular to the rows

3. RESULTS

3.1 Evaluation of Work Quality

The self-propelled robot prepared the planting holes according to the specified row and within-row spacing, achieving high precision thanks to its ± 2 cm positioning accuracy.

Minor deviations of a few centimetres occurred occasionally when the robot tilted on uneven surfaces. This resulted from the drilling position (coordinate) being defined at the auger mounting point rather than at the drill bit tip. Consequently, depending on the auger length and the degree of tilt, small positional deviations of a few centimetres were observed.

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In certain spots, despite prior stump grinding, residual stump fragments in the soil prevented the robot from reaching the required drilling depth or from forming a planting hole at all (*Figure 6*). On one occasion, the auger became jammed in a thick root, requiring manual intervention to free the machine. The excavated soil was deposited next to the planting hole, providing enough material to cover the seedlings during planting. The ejection distance of the soil depends on soil cohesion and moisture content and can be adjusted by varying the auger's rotational speed.
In some cases, solar flares can noticeably affect the ionosphere, making precise (geodetic-level) positioning difficult or even impossible. Therefore, a local reference base station is recommended under such conditions.

Figure 6: Drilled planting holes

3.2 Performance Characteristics

Accurate knowledge of machine operating costs is indispensable for sound decision-making by forest managers and service providers. These costs represent a substantial share of total production expenditures and fundamentally influence operational profitability (Erdeiné Késmárki-Gally et al., 2022). As the technology improves, an increasing number of new machines are being introduced (Horváth, 2000; Horváth & Czupy, 2022), yet practical data on their operating costs under specific conditions are often unavailable. The haRiBOT V3 self-propelled hole-drilling robot is a case in point. For this reason, we analysed its performance and cost parameters.
The field performance of the haRiBOT V3 depends primarily on:

- row spacing (a),
- within-row spacing (b),
- the machine utilisation factor (K03).

Performance is also affected by:

- plot length (L) (since the machine moves perpendicular to the rows, this corresponds to plot width),
- inter-hole travel speed (v),
- turning time at plot ends (tf).

Row spacing can be chosen arbitrarily. However, when drilling two or three rows simultaneously, it is advisable to operate perpendicular to the intended planting rows (see *Figure 5*). The analysis considered typical values used by the Nagykanizsa Forestry District: 1.8 m, 2.0 m, 2.2 m, 2.4 m, and 2.5 m. Within-row spacing – that is, the distance between adjacent holes in a row – can be freely selected (starting from the minimum defined by the hole diameter) when drilling a single row. When drilling two or three rows simultaneously (moving perpendicular to the intended planting rows), the minimum and maximum within-row spacing depend on the beam length and

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the number of mounted auger heads, while still being limited by the minimum spacing defined by the hole diameter. The analysis used values typical for the Nagykanizsa Forestry District: 40 cm, 45 cm, 50 cm, 55 cm, and 60 cm.

The machine utilisation factor (also referred to as the time utilisation factor or the ratio of productive to total working time) depends on maintenance, repairs, and other downtime. In practice, its value ranges between K_{03} = 0.5 and 0.8.

Plot length affects area performance through the number of headland turns. In practice, plot lengths range between 100 and 400 m.

Due to the short inter-hole distances, field measurements indicated an average inter-hole travel speed of v = 1.1 km/h.

The turning time at plot ends, determined by the machine's design and operation, is constant and was measured as t_f = 30.15 s on average.

The time required to complete one pass of auger drilling (*Eq. 1*) is given by the sum of total travel time, drilling time, and turning time:

$$t_1 = \frac{L}{v} + x \cdot t_g + t_f \quad (1)$$

where:

x = L/a+1, number of drilling positions per pass;

t_g = 12.32 s, average drilling time per hole, based on field measurements.

The productive-time and shift-time area performance values of the hole-drilling robot, as functions of the influencing parameters, are summarised in *Table 1* and *Table 2* and can be calculated using the following equations (*Eq. 2* and *Eq. 3*):

$$W_{01} = \frac{n \cdot b \cdot L}{t_1} \quad (2)$$

where: n = 3, number of holes drilled simultaneously per operation;

$$W_{03} = W_{01} \cdot K_{03} \quad (3)$$

Table 1: Productive-time area performance: W01 [ha/h]

a [m] / ***b*** [m]	1.8	2.0	2.2	2.4	2.5
0.40	0.041	0.044	0.046	0.049	0.050
0.45	0.046	0.049	0.052	0.055	0.056
0.50	0.051	0.055	0.058	0.061	0.063
0.55	0.056	0.060	0.064	0.067	0.069
0.60	0.061	0.066	0.070	0.073	0.075

Table 2: Shift-time area performance: W_{03} [ha/h]

K_{03} / ***W_{01}*** [ha/ha]	0.5	0.6	0.7	0.8
0.041	0.020	0.025	0.029	0.033
0.050	0.025	0.030	0.035	0.040
0.060	0.030	0.036	0.042	0.048
0.070	0.035	0.042	0.049	0.056
0.075	0.038	0.045	0.053	0.060

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3.3 Cost Analysis

The purpose of the cost analysis was to determine, for the haRiBOT V3 self-propelled robot:
- the hourly operating cost (HUF/h), and
- the operational cost of auger drilling (HUF/ha).

The cost analysis was carried out using 2024 prices.
The initial input data for the machine are as follows:
- Machine price including the attachment: A = 2,470,000 HUF according to the manufacturer (excluding VAT, since it is refundable and does not affect the operating cost);
- Annual operating time (number of annual working hours): t_{year} = 150 h, based on our measurements and literature data;
- Depreciation rate: p = 17 %;
- Repair cost factor (percentage of the machine price allocated annually to repairs and maintenance): r = 15 %, based on the 2022 average for hole-drilling machines at the MATE-MI (Hungarian University of Agriculture and Life Sciences, Institute of Technology) reference farm (no long-term data are available for the tested machine);
- Other cost factor (percentage of the machine price allocated annually to other costs): e = 0.40 %, also based on the 2022 average for hole-drilling machines at the MATE-MI reference farms.

The hourly fixed operating cost (ownership costs only) of the hole-drilling robot (*Eq. 4*) is calculated as:

$$F_{03} = \frac{A(p+r+e)}{t_{year}} = \frac{2{,}470{,}000(0.115+0.004)}{150} = 5{,}335\ HUF/h \tag{4}$$

The operational cost of auger drilling (*Eq. 5*) depends on:
- the hourly operating cost (F_{03}), and
- the machine's area performance during working time (W_{03}),

and is given by:

$$M_{03} = \frac{F_{03}}{W_{03}} \tag{5}$$

The achievable area performance during working time ranges between W_{03} = 0.020 and 0.060 ha/h. Accordingly, the operational cost of auger drilling ranges between M_{03} = 88,920 and 266,760 HUF/ha. The numerical values of the operational cost (M_{03}) as a function of the shift-time area performance are presented in *Table 3*. The relationship between operational cost and area performance is illustrated in *Figure 7*.

Table 3: Operational cost of auger drilling

W₀₃ **[ha/h]**	**0.020**	**0.030**	**0.040**	**0.050**	**0.060**
M₀₃ [HUF/ha]	266,760	177,840	133,380	106,704	88,920

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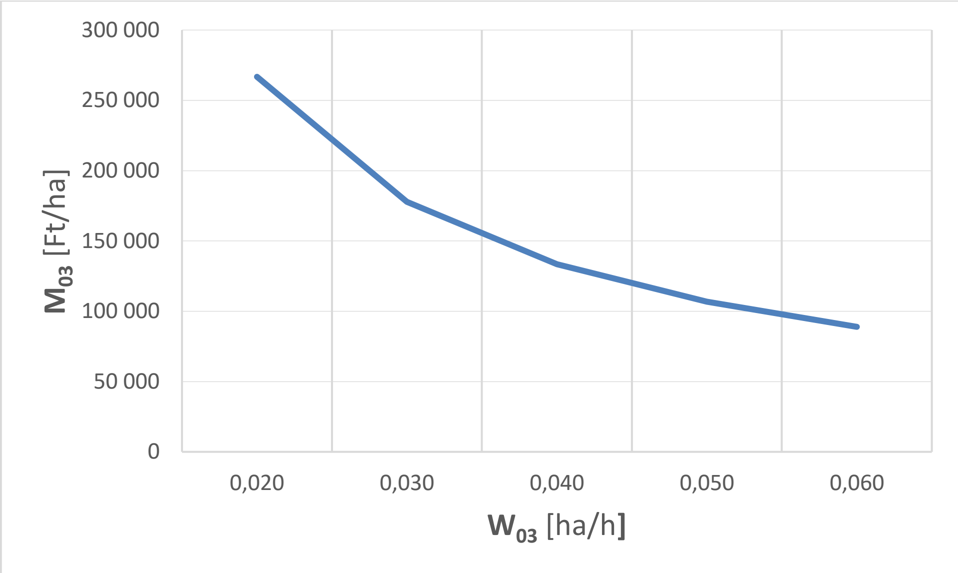

Figure 7: Operational cost of auger drilling as a function of area performance during working time

4. CONCLUSION

Our research suggests that self-propelled robots, when equipped with appropriate attachments, are already capable of performing forestry nursery tasks. With proper site preparation, they can also be applied in afforestation operations. However, further development is required to ensure reliable operation under diverse forest conditions.

The use of self-propelled robots is not yet legally regulated. In fenced areas where it is confirmed that no personnel are present, the machines can be left unattended. Otherwise, the operator must remain nearby. To this end, the remote control has an operational range of 200 m. At the same time, equipping self-propelled robots with additional safety devices – another method to reduce risk to anyone nearby – can increase the machine cost by 20-25 %.

The self-propelled robot can be fitted with multiple attachments, thereby increasing its utilisation and annual performance. Consequently, operating costs – including the hourly operating cost (F03) and the operational cost (M_{03}) - can be further reduced.

By employing additional attachments, the annual operating time can be increased to 500 hours. In this scenario, the operational cost of auger drilling is shown in *Table 4*, which presents significantly more favourable values.

Table 4: Operational cost of auger drilling at t_{year} = 500 h

W_{03} [ha/h]	0.020	0.030	0.040	0.050	0.060
M_{03} [HUF/ha]	80,028	53,352	40,014	32,011	26,676

The machine can be either purchased or rented. The manufacturer offers the robot for rent at a net rate of 18,000–22,000 HUF per operating hour, depending on the work volume. Using an average value of 20,000 HUF per operating hour and the shift-time area performance values (W_{03}) from *Table 1*, the operational cost of auger drilling (M_{03}) ranges between 333,333 HUF/ha and 1,000,000 HUF/ha. Based on these figures, it can be concluded that – even with a lower annual operating time (t_{year} = 150 h) – purchasing the machine is more cost-effective than renting.

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Önjáró gödörfúró robot vizsgálata erdősítési munkában

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ÖSSZEFOGLALÁS

Az elmúlt néhány évtizedben a mezőgazdasági gépesítés rohamosan fejlődött, a hazai növénytermesztésben többségében korszerű géppark áll a termelők rendelkezésére. Ugyanakkor az erdőgazdaságok és erdészeti vállalkozások gépparkjának jelentős részét néhány kivételtől eltekintve idős gépek alkotják. Az erdőgazdálkodásban használt gépek fejlettsége meg sem közelíti a mezőgazdaságban használtakét. Az erdészeti vállalkozások megerősödéséhez viszont elengedhetetlenek a korszerű gépek, technológiák. További problémát jelent az ágazatban is tapasztalható munkaerőhiány. Mindezek miatt elkerülhetetlen a digitális technológia, az automatizált gépek, robotok használatának bevezetése az erdészeti munkákban.
Az utóbbi években Magyarországon kifejlesztésre került egy kertészeti robot gépcsalád. A gépcsalád egyik tagját az őszi erdősítési időszakban a Zalaerdő Zrt. Nagykanizsai Erdészetének területén tölgy erdősítésben teszteltük. Jelen cikkünkben ennek üzemeltetési tapasztalatait mutattuk be, valamint ökonómiai értékelését végeztük el.
Kulcsszavak: autonóm magajáró robot, autonóm navigációs szoftver, precíziós erdészet, GPS-alapú pozicionálás, teljesítmény- és költségelemzés

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