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# DEVELOPING TREE PLANTING ROBOTS WITH HELP OF SIMULATION

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## ABSTRACT

Because labor costs for manual tree planting are steadily increasing, tree planting robots are of interest. We created a general simulation model to analyze the planting results of conceptual tree planting robots. The results show that robots can plant adequate number of seedlings $ha^{-1}$, but the environmental impact may become a problem if too large digging tools are used during the soil preparation phase.

## 1 INTRODUCTION

Because labor costs for manual tree planting are steadily increasing, there is a clear need within Nordic forestry to mechanize tree planting to prevent overly high regeneration costs in the near future. The development of fully autonomous planting machines, i.e. tree planting robots, is of special interest. Hence, we created a general simulation model to analyze planting results of the conceptual tree planting robots.

## 2 MODELLING SOIL-MACHINE INTERACTION

The soil, or more precisely obstacles, was modelled based on real-life datasets (Figure 1). During the simulation presented in Table 1, the soil's stoniness was either 20, 30, 40, 50 or 60%. However, for efficient analyses, we always assumed that stumps (incl. zone of rapid taper) covered 10.2% of the regeneration site whereas roots covered 3.4%.

Fully adjustable machine settings allow us to cost-efficiently test how alternative solutions will affect the planting results without having to build expensive prototypes during early phases of the development process. This time, we set stumps and boulders above the surface as detectable objects, whereas roots and stones below the ground were set as non-detectable objects. Detectability means that the planting robot is capable of avoiding an obstacle during mechanical soil preparation (MSP). If the robot's digging tool hits a non-detectable object, then the MSP attempt fails. Every planting attempt is preceded by an MSP because MSP increases regeneration success. However, MSP attempts often fail, which poses a very common problem for tree planting machines.

Moreover, we varied the size of the digging tool (S, M, or L; Table 1), and the minimum allowable distance between planted seedlings (1, 1.5, or 2.0 m; Table 1). The diameter of the digging tool for L was 44.8 cm, which corresponds approximately to today's standard tools used in humanly operated tree-planting machines. The diameters of S and M were 33.4 and 39.5 cm, respectively. The target number of planted seedlings $ha^{-1}$ depends on numerous factors such as geography, site fertility, the landowner's preferences, legislation, etc. To keep our analysis as concise and as general as possible, we let the target number of seedlings vary from 1000 to 3000 seedlings $ha^{-1}$. And even if MSP improves regeneration success, it unfortunately has negative environmental and esthetical impacts. To limit those negative impacts, the number of failed MSP attempts must not exceed 15000 $ha^{-1}$.

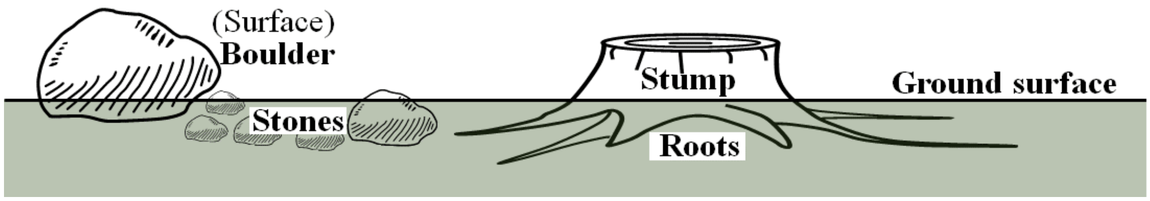


Figure 1: In our simulation model, an obstacle can be a stone, root or stump, and they all come in different sizes and in varying frequencies. Together these obstacles constitute the total obstacle quota.

## 3 RESULTS AND CONCLUSIONS

Reaching the minimum target number of seedlings (1000) did not pose any problem per se (Table 1), even when applying the longest minimum allowable distance between the seedlings. Indeed, the maximum number of planted seedlings (3000) was exceeded in many cases. However, failed MSP attempts was a problem especially when using larger digging tools on more stony soils. This was true despite us choosing relatively low soil stoniness because the forest industry will most certainly operate the first tree planting robots only in the easiest working conditions.

The results emphasize the importance of developing smaller digging tools than those used on today's tree planting machines (Ersson et al. 2014). A smaller digging tool reduces the negative environmental and esthetical impact in two ways. Firstly, the total number of failed MSP $ha^{-1}$ decreases with the decreasing size of the digging tool (Table 1). Secondly, when the MSP fails, a smaller digging tool will likely disturb less soil than larger ones do.

Table 1. The simulation results. The size of the digging tool was small (S), medium (M), or large (L). If the number of planted seedlings is crossed out, then the maximum number (15000) of failed mechanical soil preparation (MSP) attempts was exceeded. However, if the number of planted seedlings is bolded, then the planting met all requirements. Distance = Minimum allowable distance between planted seedlings.

| | | Number of failed MSP attempts $ha^{-1}$ | | | Number planted seedlings $ha^{-1}$ | | |
|---|---|---|---|---|---|---|---|
| Distance | Stoniness | S | M | L | S | M | L |
| 1.0 m | 20% | 9418 | 12122 | 14643 | >3000 | >3000 | >3000 |
| | 30% | 14105 | >15000 | >15000 | >3000 | ~~>3000~~ | ~~>3000~~ |
| | 40% | >15000 | >15000 | >15000 | ~~>3000~~ | ~~>3000~~ | ~~>3000~~ |
| | 50% | >15000 | >15000 | >15000 | ~~>3000~~ | ~~>3000~~ | ~~2670~~ |
| | 60% | >15000 | >15000 | >15000 | ~~>3000~~ | ~~2610~~ | ~~1862~~ |
| 1.5 m | 20% | 4640 | 6277 | 7498 | >3000 | >3000 | >3000 |
| | 30% | 7353 | 10570 | 13268 | >3000 | **2873** | **2662** |
| | 40% | 11240 | 14872 | >15000 | **2855** | **2540** | ~~2278~~ |
| | 50% | 14613 | >15000 | >15000 | **2600** | ~~2202~~ | ~~1900~~ |
| | 60% | >15000 | >15000 | >15000 | ~~2290~~ | ~~1825~~ | ~~1485~~ |
| 2.0 m | 20% | 2847 | 3752 | 4920 | **2132** | **2060** | **1952** |
| | 30% | 4742 | 6168 | 8138 | **1983** | **1890** | **1752** |
| | 40% | 6863 | 10235 | 12495 | **1853** | **1683** | **1543** |
| | 50% | 9803 | 14180 | >15000 | **1690** | **1498** | ~~1327~~ |
| | 60% | 13193 | >15000 | >15000 | **1562** | ~~1310~~ | ~~1082~~ |

## REFERENCES

Ersson, B. T., L. Jundén, E. M. Lindh, and U. Bergsten. 2014. "Simulated Productivity of Conceptual, Multi-Headed Tree Planting Devices". *International Journal of Forest Engineering* 25(3): 201–213.