THE EFFECT OF FIELD ROBOT PARAMETERS ON WEED CONTROL EFFICIENCY

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Abstract
Inter-row and intra-row weed control (WC) by self-propelled robots is a solution to reducing the need for tiring and time-consuming manual weeding. Field tests were performed with a solar-powered field robot in four treatments (RWC1, RWC2, RW3, and RWC4) by changing the performance parameters of the robot. The aim was to determine the efficiency of mechanical WC in sugar beet by controlling weeds at different speeds (740 and 400 m h^{-1}), distances (45 and 60 mm) between the weeding knife and the sugar beet in a row, and the percentage of the knife entering the crop row (85 or 100%). The results showed that the average WC efficiency was the highest (47%) with the robot operating speed of 740 m h^{-1} and a distance of 60 mm. To sum up, high-precision self-propelled field robots can replace manual weeding, but these systems need to be improved and more research is needed to achieve greater efficiency in WC.

Key words: *weeding, intra-row, solar-powered robot, operating speed, sugar beet, organic farming.*

INTRODUCTION

Weeds are considered to be a major problem in crop production and especially in organic farming. Weeds compete with staple crops for space, water, nutrients, and light (*Cioni and Maines, 2010*). In sugar beet, which is particularly susceptible to weed competition, yield losses due to poor weed control can be as high as 26–100% (*Cioni and Maines, 2010; Jalali and Salehi, 2013; Kunz et al., 2018; Bhadra et al., 2020*). Therefore, weed control is one of the most important factors in sugar beet production to ensure crop yield and quality (*Sabanci and Aydin, 2017*). Efficient weed control is particularly relevant in organic crop production, which already yields less compared to conventional farming that uses chemical weed control (*Abouziena and Haggag, 2016*).

Mechanical weed control methods such as harrowing and inter-row cultivation are commonly used in organic farming (*Šarauskis, 2019*). However, mechanical weed control methods require a high degree of precision, i.e. knowing the exact location of weeds and crop plants (*Åstrand and Baerveldt, 2002*). For this reason, precision technologies such as automatic machine control, video cameras, optical sensors, Real-Time Kinematic Global Positioning System (RTK-GPS), and others have been introduced. These advanced technologies not only increase the working speed of technological operations, and the mechanical efficiency of weed control, but also reduce crop damage (*Kunz et al., 2018; Gerhards et al., 2020*). Efficient weed control has become possible not only in the inter-row but also in the intra-row, which can significantly increase crop yield and quality (*Jalali and Salehi, 2013; Sabanci and Aydin, 2017*). Studies conducted by *Melander et al. (2015)* have shown that 50–90% weed control efficiency can be obtained by applying weed control within plant rows. According to other researchers, more than 90% weed control efficiency can be achieved by controlling weeds inter-row and intra-row (*Chandel et al., 2021; Gerhards et al., 2020*).

Robotic weed control systems with high precision enable site-specific weed management. The development and improvement of such systems has been a popular and relevant area of research over the last decade (*Åstrand and Baerveldt, 2002; Bawden et al., 2017; Sabanci and Aydin, 2017; Utstumo et al., 2018).* Autonomous weeding robots such as AVO (Ecorobotix), Dino and Oz (Naïo Technologies), Robotti (Agrointelli), FD20 (FarmDroid), Robot One (Pixelfarming Robotics), etc. are also available on the market. Robotic weed control systems that can improve weeding efficiency, save resources, improve crop yield and quality, replace manual weeding and reduce environmental pollution, have a great potential to replace traditional weeding methods.

Although there is a large body of research in the scientific literature on the development and improvement of robotic weed control systems, there are few research papers evaluating the efficiency of robotic weed control systems. The aim of this study was to experimentally investigate the efficiency of different robotic weed control methods in organic sugar beet production. It was aimed to determine the optimal robot operating parameters at which the robot performs the best weed control without damaging the sugar beet.

MATERIALS AND METHODS

The experimental trials were carried out in July 2021 in Panevėžys district, central Lithuania (55°49'19.4"N, 23°55'13.0"E), in an organic sugar beet field with sandy loam soil. The average air temperature during the study period was 22.2 °C and the average precipitation was 58 mm.
Sugar beet sowing and weed control were carried out by the same FD20 robot (FarmDroid, Denmark), powered by electricity, and equipped with solar modules and batteries. The sugar beet (variety Marley) was sown on 8 June 2021 with an inter-row spacing of 0.45 m and intra-row spacing of 0.18 m (sowing density 123 000 seeds ha^{-1}). The working width of the robot – 2.7 m. The FD20 uses GPS, so that after sowing, by knowing exactly where the seeds have been placed, the robot is able to carry out weed control inter-row and intra-row before the plants germinate, and later after germination without damaging the sugar beet plants.

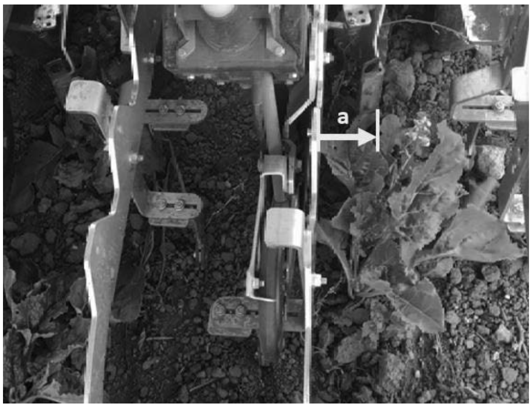

Fig. 1 Workflow of the robotic weeding knife in the crop row: a – entry of the weeding knife into the crop row

For the mechanical weed control of sugar beet, the robot's operating parameters were varied: the robot's working speed, the distance between the weeding knife and the sugar beet in the crop row, and the percentage of the knife entering the crop row (a) (Fig. 1). The different robotic weed control treatments RWC1, RWC2, RWC3, and RWC4 with different robot operational parameters are described in Table 1.

Tab. 1 Robot operational parameters

Treatment	Working speed m h^{-1}	Distance between weeding knife and sugar beet mm	Knife entered the crop row (a) %
RWC1	740	60	85
RWC2	740	60	100
RWC3	400	60	85
RWC4	400	45	85

To assess the efficiency of the robotic weed control methods, the number of weeds in an area of 0.25 m^2 using a 0.5 × 0.5 m frame was counted before the weed control operation (control) and after weeding. The trials were carried out in 8 different randomly selected field sites. The efficiency (E) of the different weed control methods was calculated according to the formula (*Chandel et al., 2021*):

$$E (\%) = (Wb - Wa)/ Wb \times 100 \quad (1)$$

where *Wb* is the number of weeds in the control before the weed control operation, and *Wa* is the number of weeds after the weed control operation.
Statistical analysis of the data was performed using Tukey's *HSD* test (*Tukey, 1979*) to detect significant differences between means. Different letters in the figures indicate significant differences between weed control methods ($p < 0.05$).

RESULTS AND DISCUSSION

The experimental results showed that the weed density before the robotic weed control ranged from 21 to 41 weeds m^{-2} and after the technological operation – from 15 to 30 weeds m^{-2}. The average weed control efficiency of the robotic weed control process in sugar beet rows and inter-rows was 47% in RWC1, 16, 23, and 32% in RWC2, RWC3, and RWC4, respectively (Fig. 2). The best result was achieved in RWC1 when the robot speed was 740 m h^{-1}, the distance between the weeding knife and the sugar beet was 60 mm and the knife entered the crop row at 85%. The worst result was obtained by RWC2 with only 16% weed control efficiency. The higher working speed of the robot and the longer path of the weeding knife resulted in one cut and one damaged sugar beet in this treatment. Thus, the selection and setting of the technological parameters of the robot is a very important element for the efficiency of weed control.

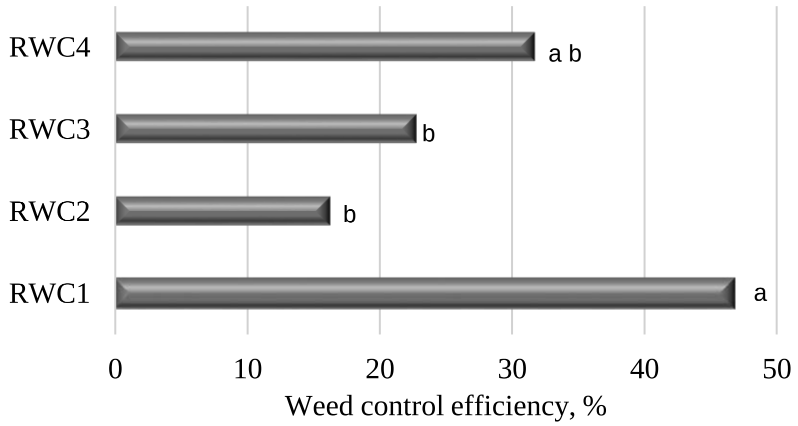

Fig. 2 The efficiency of different robotic weed control methods in sugar beet

It should be noted that the late sowing of sugar beet and the unfavorable weather conditions (rainy period) did not allow the robot to control weeds in time and at the right frequency, and led to weeds that were large and difficult to eradicate. Another possible reason for the low efficiency of weed control is that the weeds were not destroyed at the point of emergence and near the sugar beet, as the weeding knife was working at a distance of 45 to 60 mm around the plants. Abrasion of the weeding knife blades may also have contributed to poor weed control.
Pannacci et al. (2020) reported that 63–92% weed control efficiency could be achieved using combined inter-row and intra-row weed control. *Lati et al. (2016)* in a study with the Robovator found that the robotic intra-row cultivator removed 18–41% more weeds compared to a standard cultivator. *Bleeker et al. (2002)* obtained weed control efficiency of 30–88% in a sugar beet row. Meanwhile, studies with the robotic weed control platform BoniRob, which performs mechanical weed control with a tube-stamp, showed much better results than were obtained in our study. It has been found that the effectiveness of weed control can reach up to 94%. However, due to the special soil conditions required and the slow working process, robotic weed control platform has not been evaluated as a viable method for weed control (*Langsenkamp at al., 2014*).

CONCLUSIONS

In this study, experimental field trials were carried out in organic sugar beet crops comparing four different robotic mechanical weed control methods with each other. Robotic weed control in the plant row and in the inter-row was evaluated. The results showed that weed control efficiency in sugar beet crops ranged from 16 to 47%. The best result (47%) was achieved in the RWC1 variant, where the robot traveled at 740 m h^{-1}, the weeding knife was set at 60 mm from the sugar beet and the knife entered the crop row at 85%. This study only confirms that different operating parameters, field, and weather conditions need to be taken into account and evaluated when assessing the efficiency of robotic machines. Therefore, further extensive research is needed.

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