PhD THESIS

Weed control strategies under climate change conditions in sugar beet

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INTRODUCTION

The use of precision agriculture (PA) is an expedient way to steer the hoe close to the crop row and offers new research insights. Gerhards et al, (Gerhards et al., 2001) showed that it was possible to cultivate cereals with a 3 m chamber-guided hoe with a lateral displacement of only 19 mm relative to the crop row. In addition, the driving speed could be increased up to 8 km/h with a weed control efficiency of almost 80% and without crop loss (Plant, 2001). The use of AP in agriculture is gaining increasing importance due to the commercialization of new developments such as the Global Positioning System - GPS (Khan et al., 2021; Karunathilake et al., 2023; Radocaj et al., 2023) . AP operation can reduce labor costs and is capable of increasing the speed of applications (Gerhards et al., 2003). The use of global navigation satellite system (GNSS) technologies or digital image progression is necessary for accurate guidance (Tillett et al., 2002; Shen et al., 2019). In-field guidance systems identify the position of crop rows, and a hydraulic side-shift system steers the hoe (Fig. 4) close to the crop zone (5 cm on each side) and provides higher travel speeds by reducing farmer labor time (Slaughter et al., 2008; Fountas et al., 2022).

Fig.4. Precision hoeing with sensors and guidance intra-row and inter-row
(sursa/source : www.einbock.at)

Weed control in sugar beet crops is becoming increasingly difficult because the physiological stage of the crop is small and strict, and technical regulations are imposed with low and precisely fractionated doses (Hamed et al., 2023; Rašovský et al., 2022). Thus, it is of interest to analyze the differences between chemical and mechanical weed control in sugar beet (Zawada et al., 2023; Machleb et al., 2021). Mechanical weed control in agriculture has advanced in recent years in terms of precision and work rate (Restuccia et al., 2023). Real-time communication of implements with sensor systems has further enhanced the potential of mechanical control (Pannacci et al., 2018). There is a wide range of sensors available, including camera image analysis, GNSS, lasers, and ultrasonic systems, which can improve the effectiveness of weed control in combination with mechanical systems (Ghatrehsamani et al., 2023; Xie et al., 2022). Each type of sensor has its advantages and disadvantages (Triantafyllou et al., 2019).

Post-emergent inter-row weeding can be performed reliably over large areas in rows without excessive crop damage; however, removal of intra-row weeds (Fig. 4) is still a challenging task (Cloutier et al., 2007; Tillett et al., 2008). Therefore, a variety of different tools have been developed that physically deal with intra-row weeds. These include finger weeders, twist weeders, tactile weeders and weeding brushes (Rasmussen et al., 1995; Kouwenhoven, 1997).

Objectives of the research project

The research objectives are the following:

1.To inventory the weed species in sugar beet crop according to the specific climatic conditions of each agricultural year analysed.

2.To determine the degree of weediness in the technological variants tested in order to evaluate the efficiency of the different control methods applied.

3.To analyse the impact of the control methods on crop productivity by comparing the root production obtained in each experimental variant.

4.Evaluation of the influence of experimental factors on the economic profitability of agricultural production, with a view to formulating recommendations for the sustainable use of resources and technological inputs.

The main aim of this research, carried out in the sugar beet crop in the Mureș corridor (southern Transylvania, Vințana farm - Vințu de Jos commune), is to evaluate the effectiveness of integrated weed control methods, with a focus on the combined application of sensor-assisted mechanical control and chemical treatments. The study also aims to determine the feasibility of reducing the use of herbicides in the current context of climate change and increasing resistance of weed species to commonly used active substances in agriculture. In addition, the impact of these methods on root production and economic profitability of sugar beet crops is analysed in the light of current trends towards sustainable agriculture.

Experimental factors

This study investigated sugar beet technology in the years 2021-2023 in the Transylvanian hill depression. This depressional relief unit within the Carpathian arc has a predominantly hilly relief and the representative agricultural crops are cereals (maize, wheat, barley, triticale), oilseeds (sunflower, rapeseed, soybean) and technical crops, especially sugar beet. The experiments were conducted on the agricultural fields of the conventional farm "Vintana SA" in the village of Vintu de Jos (45,99 ∘ N, 23,48 ∘ E), jud. Alba.

The experimental variants were represented by the treatments (Table 6):

- V1: Untreated control;
- V2 : Mechanical weed control with Einbock Chopstar ;
- V3 : Chemical control with conventional herbicides;
- V4: Mix of 2× mechanical control with Einbock Chopstar (BBCH 19, 31) and 3× chemical weed control.

Herbicide application in the last two years was carried out with a mounted sprayer, model Amazone UF2002,from Amazone Hasbergen Dreyer GmbH&Cof Hasbergen, Germany, equipped with Lechler IDK120 nozzles from LecherGmbH, Metzingen, Germany, at a pressure of 8 bar and a speed of up to 8 to 10km/h.

The coulter system in the experiment had a camera to recognize 3 rows of sugar beet rows in the experimental field and a hydraulic side-shift system. Cultivation with the hoe was carried out parallel to the crop rows at a travel speed of 8 km/ h. The sugar beet rows were harrowed with two 20 cm brooms, two side knives and two protection disks.

Table 6.

Description table of the experimented methods

Nr. No.	Variantele Variants	Descriere Description
V_1	Control netratat	Fara control chimic sau mecanic
V_2	Control mecanic de precizie	Control mecanic cu Einbock Chopstar
V_3	Control chimic	3× Control chimic al buruienilor, 3 ori erbicidare cu mix 3 erbicide si 5 substante active diferite
V_4	Mix 2× control mecanic de precizie + 3× control chimic	2x Control mecanic al buruienilor cu Einbock Chopstar in stadiul 6 frunze (BBCH 19) si stadiul de 9 frunze (BBCH 31) al sfeclei + 3x control chimic al buruienilor, mix de 3 erbicide cu 5 substanțe active diferite

Variant 1 (UC) was left untreated throughout the growing season. However, it was ensured that the UC also received the same number of tractor wheel passes as the mechanical and chemical treatments.

Fertilization requirements by solid chemical fertilizers based on soil analysis and sugar beet consumption for root production at 80t/ha :

110-117 N + 82-129 P2O5 + 229-321 K2O expressed in kg/a.s./ha.

For mechanical weed control a parallelogram hoe (3 m working width) equipped with duck-foot blades (Einböck, Dorf an der Pram, Austria) was used for mechanical weed control. A Claas® OEM 3-D stereo camera with artificial lightning was used for automatic hoe steering in combination with an Einböck Row-Guard® hoe. The RGB stereo camera (Claas, Harsewinkel, Germany, Claas, Harsewinkel, Germany) identified crop plants based on plant size at a maximum speed of 14 km/h and minimum row spacing of 250 mm (Möller, 2010). The row detection accuracy was ± 50 mm, which is almost equal to commercial camera-based row guidance systems such as Garford-Robocrop®, K.U.L.T. Vision Control®, and Steketee IC® (Tillett et al., 2002; Melander, 2006; Griepentrog et al., 2007). The Einböck Row-Guard® uses hydraulic lateral displacement control. In this study, row-to-row pruning blades were automatically directed along crop rows at a distance of 60 mm (Fig. 28).

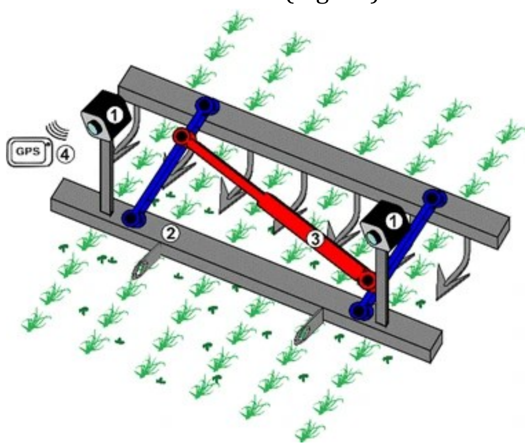

Fig. 28. Hoe (2) with hydraulic guidance (3), camera (1) and GPS (4)
(source : www.einbock.at)

The installation and set-up of the sensor harrow was carried out on the farm adapted to sugar beet cultivation, meaning that the width between the rows was aligned with the width of the tillage control wheels.

As each experimental field comprises six rows of sugar beet, seven implements were needed to mechanically control all inter-row areas in a 3 m wide experimental field. The safety distance from the sugar beet crop plants was set at 5cm width from the corresponding rows. For weed control in the weed gap between plants in the row, finger weeders were set above the ground and row guards were lowered to the ground to prevent the sugar beet crop from being destroyed.

On the two plots V2 and V4, chemical treatments were carried out twice after the chemical treatments, at two different growth stages of sugar beet, the six-leaf stage and the nine-leaf stage, meaning the two different BBCHs 19 and 31 (Table 7).

Table 7.

Aplication time (BBCH), active substances and the herbicide used in the experimental fields 2021-2023

BBCH 2021	**BBCH 2022-2023**	**Substanță activă Active substance**	**Nume produs comercial Comercial name**	**F M***	**Concentrație Concentration**	**Rata de aplicare Applicat -ion rate**	**Producător Manufactu-rer**
10,14, 19	10,14, 19	*ethofumesate*	Betanal tandem	SC	190 g a.i. L	285 g/ha	Bayer
10,14, 19	10,14, 19	*phenmedipham*	Betanal Tandem	SC	200 g a.i. L	300 g/ha	Bayer
03,10, 14	10,14,19	*metamitron*	Goltix	SC	700 g a.i. L	630 g/ha	Adama
03		*glifosat*	Clean up	SL	360 g a.i. L	1080 g/ha	Nufarm
	10,14, 19	*lenacil*	Venzar 500	SC	500 g a.i. L	125 g/ha	FMC
14,19		*clopiralid*	Lontrel 300	SL	300 g a.i. L	225 g/ha	Corteva
19	19	*quizalofop-p-tefluril*	Pantera 40	EC	40 g a.i. L	40 g/ha	Arysta

Weed density (weeds/m^2) and weed species were measured using a 0,5 m × 0,5 m frame. The frame was randomly placed three times per plot, three days after the application of mechanical treatments and 14 days after chemical as well as chemical treatments and three days on the uncontrolled plot. Sugar beet harvesting (to/ha) took place in mid-September or early October in the research years, depending on sugar content and weather conditions, which are particularly different in agriculture each year. Sugar beet harvesting was carried out with an Agrifac plot combine harvester, Kleine type K62, The Netherlands, and afterwards washing and weight measurement were carried out on the farm.

Results and discussions

The integrated weed control methods used in this study include post-emergent herbicides and sensor-based mechanical control that replace the use of pre-emergent herbicides as well as the possibility, why not, of post-emergent herbicides. The results show that by optimizing the integration of control methods, it is possible to reduce pre-emergent herbicides, but not completely replace post-emergent herbicides in the weed control scheme of sugar beet, because the crop is slow growing in the first two months after emergence. This is due to the high weed density and species abundance on most beet farms in the Transylvanian Depression area.

Weed control in sugar beet crops needs to be particularly monitored and carefully dosed in herbicides especially in the first 40 days after emergence, because sugar beet is small and the stress brought by herbicide active substances can greatly slow down the development of the crop in the early growth stages. How the results show that better yields can be obtained by incorporating integrated techniques and weed control strategies, especially those based on sensors and guidance. It should also be noted that the weed abundance is much higher in the research area (Transylvania) than in the Western European area where sugar beet is grown and state-of-the-art control practices are implemented. In particular, the percentage of weed species growing in agricultural fields in the researched area is up to 5-6 times higher than in Germany, for example, where these methods are often experimented and herbology departments are involved in research with advanced technologies.

The number of chemical herbicides approved for sugar beet is becoming smaller and active substances in herbicide compositions continue to be banned for use. Also, herbicide resistance of weeds is increasing, so the present study can contribute to herbicide reduction and research on the right time for precision weeding to have lower weed densities. Implicitly it can be determined which beet growth stage (BBCH) can be most suitable for mechanical control based on precision sensors and guidance.

The results of the study show that it is possible to achieve an increased production of beetroot with a significant reduction of applied chemicals on farms in the Transylvanian depression. Precision mechanical control methods could also achieve less plant stress and better soil aeration, and these facts can certainly increase the target yield. The growth stages experimented in this study were the 6-leaf and 9-leaf stages of sugar beet, i.e. BBCH 19 and 31, respectively, which are suitable for weed control and reduced crop losses. The results show that in a dry summer, as it was for sugar beet in 2022, mechanical and chemical weed control (V4) can provide a sustainable and accepted yield while controlling significant weed densities.

The integrated method (V3 - mechanical + chemical control) maximises profitability under real production conditions. In both years analysed (2022 and 2023), the V3 variant generated the highest net profit and the highest main production, demonstrating the efficiency of the combined use of modern mechanical sensor technologies and herbicides. Single chemical control (V2) is economically efficient but less efficient than the integrated method. V2 has achieved significant profits and low unit costs (especially in 2023), but its effectiveness is limited by the development of resistance of some weed species to herbicides, which jeopardises the long-term sustainability of this method. Mechanical-only control (V1) offers a decent return with positive environmental and soil impacts, but significantly lower yields. Although it has higher costs per unit of production and lower profit, the V1 method has important environmental advantages and can be a viable alternative in organic farming systems or in areas where herbicide resistance is high. The relationship between inputs and yields is non-linear. Increasing costs (especially in 2023) did not lead to decreasing returns, but on the contrary, methods with higher investments (V3) generated higher positive marginal positive returns due to the synergy between technologies. Modern machines (e.g. Einböck Chopstar) are economically feasible in the medium to long term. Even if they require a high initial investment, the operating costs and amortisation of the equipment justify the purchase economically, in particular by increasing productivity and reducing chemical application. The year 2023 showed increased crop sensitivity to technological and price factors. Although inputs were more expensive, yields increased significantly, emphasising the need for technological adaptation to the current economic context.

Similar recent studies from Germany have shown that sensor-based mechanical control between rows had less sugar beet crop losses and that uprooted plants were not significantly affected by the number of plants per hectare. Weeds close to the crop (intra-row), however, will remain a major constraint to mechanical control, making further research in this direction necessary for the Transylvanian lowland.

Originality

Weed control in sugar beet cultivation represents one of the greatest challenges of modern agriculture, especially in the context of climate change, reduction in pesticide use, the decreasing number of active substances approved in Romania for this sensitive crop in weed control and the transition towards sustainable practices. In this international framework of regulation and innovation, the PhD thesis makes a valuable and original contribution by exploring advanced technological solutions, adapted to Romanian soil and climatic conditions and correlated with European directives on sustainable agriculture. The originality and novelty of the thesis can be summarized in the following directions:

1. Integration of camera-based row detection technologies. This thesis is one of the first documented tests in Romania of an advanced camera-assisted mechanical row detection system, applied in sugar beet cultivation. The theme of the thesis is correlated with the current trends in the implementation of autonomous working systems in Europe.

2. Experimental comparison between mechanical and chemical methods with respect to the area of application (intra-row and inter-row). Separate, quantitative evaluation of the effectiveness of each method, with emphasis on reducing herbicide dependence. Essential approach in applying Farm to Fork and Green Deal strategies.

3. Application of combined and adaptive treatments according to crop and weed development stage. Proposing a differentiated and phased control model with proven effectiveness in reducing weediness. Aligned with the principles of Integrated Weed Management (IWM) in the literature.

4. Use precision technology to optimize field interventions. Integrate these systems into beet crop for precision guidance and overall infestation analysis. In line with the latest practices in agricultural digitization projects at European level.

5. Medium-term monitoring in a variable climate context. Analyzing the impact of climatic factors on the efficiency of technologies, an aspect little studied in Romania. Support for technology adaptation in climate-smart agriculture scenarios.

6. Formulation of a methodology applicable to commercial farms in Romania. Scalable solution, transferable in real conditions, easy to implement in the context of CAP and environmental protection requirements. Demonstration model with potential for replication in other European regions with similar challenges.

The work is distinguished by a rigorous and practical scientific approach oriented towards the future of sustainable agriculture. The integration of advanced technologies with immediate applicability in the field, in conjunction with environmental and economic efficiency requirements, makes this research a landmark in the field of plant protection and integrated weed management in sugar beet cultivation. The results obtained can contribute both to the scientific development of the field and to the foundation of modern agricultural policies based on innovation and sustainability.