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CONCEPT AND VIRTUAL PROTOTYPE OF A ROTARY HOE FOR INTRA-ROW WEED CONTROL IN ROW CROPS

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Abstract: In many scientific researches sustainable development in the agricultural sector cannot be based on use of high amount of agrochemicals. Requirements for non-chemical weed control techniques have steadily increased in the last decade as a consequence of pollution from pesticides. Concerning non-chemical weed control demands, research on new techniques for physical weed control and development of self-propelled weeding robots is particularly emphasized.

The main objective is development of a weeding tool which can be used in different plant spacing systems, different plant intra-row distances and growth stages. These tools require very precise steering for row-tracking.

In this paper a prototype of rotary hoe with duckfoots is presented. This tool can fulfill the requirements for inter-row tillage. It allows full adaptation to different crop species, different plant intra-row distances and plant growth stages.

Key words: *weed control, inter-row tillage, rotary hoe.*

INTRODUCTION

Sustainable development in the agricultural sector cannot be based on the use of high amounts of agrochemicals and therefore production techniques should shift toward systems with low or no input of pesticides. The need for non-chemical weed control techniques has steadily increased in the last decade of the last century, especially in the Western European countries, as a consequence of the pollution originated by pesticides. Constantly increasing interest by consumers for organically produced agricultural products and foodstuffs is another reason why non-chemical weeding is in the limelight nowadays. In EU-Regulation 2092/91 it is expressly stated that only non-chemical weed control can be used in organic production. However, mechanisation of intra-row area cultivation is a complex task and because of that, hand weeding is still the most frequently used method of intra-row weed control in Western European countries.

Concerning non-chemical weed control demands, research on new techniques for physical weed control and development of self-propelled weeding robots is particularly emphasised.

The main objective is development of a weeding tool which can be used in different plant spacing systems, different plant intra-row distances and growth stages. There are two streams of thought for solving the problem of intra-row weed control: with passive and active implements. Well-known passive implements for intra-row hoeing are finger weeder, tine weeder and torsion weeder (Cavalieri et al. 2001; Bond and Turner 2005). These implements require very precise steering for row-tracking which could be done automatically or manually, but on the other hand recognition of individual plants is not necessary. Timing is the most important factor when these implements are used. If the weeding is done late, weeds are stronger and they could survive tillage. The above mentioned methods are effective just with small weeds, so the weeding operation can have a limited impact. Another disadvantage of passive systems is that they are only suitable in situations where crops are robust enough to withstand damage caused by weeding equipment.

Advantages of the use of integrated mechanism design and simulation in development of a new tool for mechanical intra-row weed control

The path from idea to prototype can be significantly shortened by use of integrated mechanism design and simulations. CAD (computer aided design) and CAE (computer aided engineering) are tools which provide a possibility to build a virtual model without investment and at the same time with an opportunity to make various changes appear often during the design period. Different types of digital 3D analysis like FEA (finite element analysis) calculate stresses and deformations of designed parts. On the other hand, integrated mechanism design and simulation offer the possibility to obtain information about trajectories, kinematical and also dynamical behaviour of moving parts in assemblies.

Benefits of digital prototypes over the conventional physical prototypes could be achieved only when adequate software is used which can provide the robustness and accuracy of the physical world without lengthy design/build/change iterations.

The combination of powerful mechanical and mathematical tools built into software application helps to understand, evaluate, and optimize the complex motion behavior of developed assemblies against functional performance design targets. There is a possibility to rapidly evaluate multiple design alternatives early in the design process, as well as to test and refine the digital prototype until optimal system performance is achieved. Another benefit is the use of multiple simulation scenarios which can be evaluated simultaneously.

Virtual prototype of the rotary hoe for intra-row weeding

Taking into consideration all requirements a virtual prototype of the rotary hoe for intra-row weeding was designed in Pro/engineer® (Gobor et al. 2005; Gobor 2006). The basic idea was to simulate the manual hoeing motions. The hoeing tool consists of an arm holder and three or more integrated arms rotating around the horizontal axis above the crop row. It is attached to the motor shaft and the working height of the whole assembly is adjustable in accordance to the optimal hoeing depth, which should be between 20 and 30 mm. There is a possibility to change the arm lengths and their angular position in relation to the surface perpendicular to the rotation axis in which the arms holder is placed. Thus, small duckfoots placed on the arm ends have three degrees of freedom, which allow for the selection of the optimal trajectories dependent on the plant habit and necessary cultivation width.

The concept of the rotary hoe for intra-row weeding with various duckfoot adjustment possibilities is presented in figure 1.

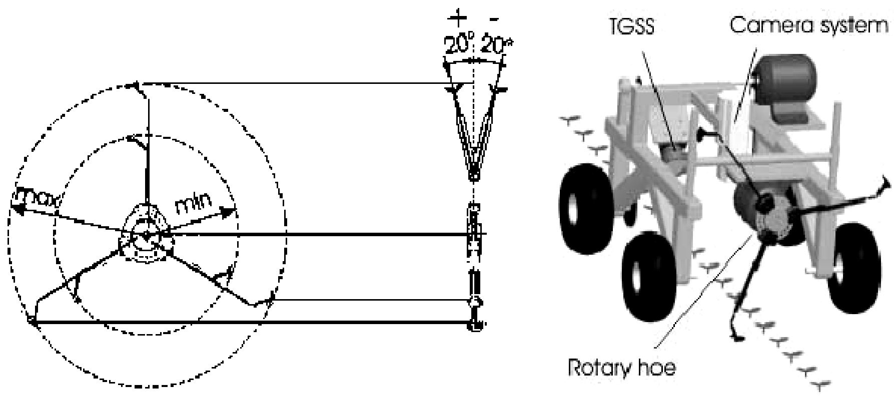

Figure 1: Concept of the rotary hoe

Depending on the duckfoots' shape and size the necessary number of cuts between two plants could be set, controlling the rotational speed of the hoe. Rotational speed is tuned according to the forward speed of the carrier vehicle, intra-row distance between plants and observed position of the arms. For testing a virtual sugar beet field has been used with a 400 mm distance between rows and a 200 mm intra-row distance between plants.

RESULTS

A number of kinematical simulations were conducted with the virtual prototype in which the carrier speed, plant growth stage, number of hoeing arms, arms length and angular position of the duckfoots were varied. Depending on the required hoeing depth, necessary confidence that duckfoots will achieve a cut under soil surface and a necessary hoeing width, maximal and minimal arm lengths were calculated, which are shown in Figure 2.

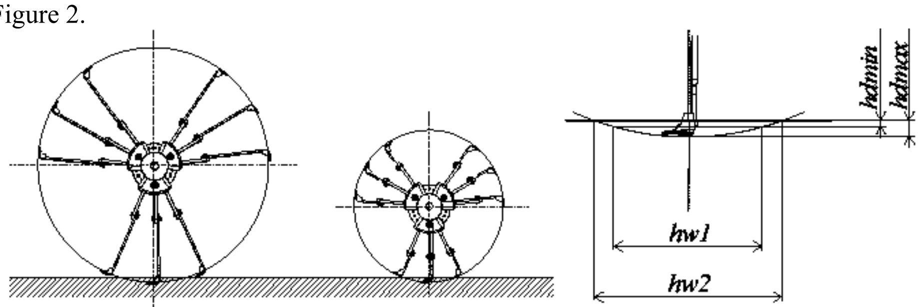

Figure 2. a) Hoeing tool with nine arms in active working position with maximal and minimal arm length; b) Hoeing trajectory of the duckfoot under the soil surface

It is estimated that an arm length in the range of 350-550 mm (from the axis to the cutting edge of the duckfoot), offers enough freedom for positioning the trajectory between plants as well as providing a hoeing width that is wide enough to cultivate the whole area which cannot be reached with inter-row equipment. Depending on the soil surface cultivation quality and flatness a minimal hoeing depth *hdmin* is to be defined, providing the optimal impact and necessary hoeing width on the weed's root system with a high level of confidence. An example of hoeing depth calculation *hw1* and *hw2* (Figure 2b) is given in Table 1.

Table 1. Calculation of hoeing width in dependence on the arm length and hoeing depth

For *hdmin*=15 mm	Arm length [mm]		
	350	450	550
hw2 (*hdmax*=20 mm)	233	265	294
hw1 (*hdmax-hdmin*=5 mm)	118	134	148
hw2 (*hdmax* =25 mm)	260	296	328
hw1 (*hdmax-hdmin* =10 mm)	166	189	209
hw2 (*hdmax* =30 mm)	284	323	358
hw1 (*hdmax-hdmin* =15 mm)	203	230	255

$$\left(\frac{hw1}{2}\right)^2 = R^2 - (R - (hd\max - hd\min))^2 \quad (1)$$

$$\left(\frac{hw2}{2}\right)^2 = R^2 - (R - (hd\max)^2 \quad (2)$$

For equal arm lengths the optimisation of the duckfoot trajectories under the soil surface in the intra-row area is possible with adjustment of the angular position of arms. The main advantage is that a small angular change provides the possibility of controlling the distance between consecutive cuts from equal to periodical where the protected area is much bigger than the cultivated area. An example of angular adjustment is given in Figure 3. The first graph presents the hoeing scenario of a rotary hoe with nine arms (arm length 450 mm) whose angular position has been adjusted to 0°. The second graph illustrates another scenario with the same arm length but with the angular position adjusted to 17°, 0°, -17°. The segments of the trajectories under the soil surface are highlighted on the both graphs with red color. The area around the expected crop position (*x=200 mm, 400 mm, 600 mm; y=0*) is much bigger in the second case, which demonstrates the applicability of the rotary hoe to different crop systems and growth stages.

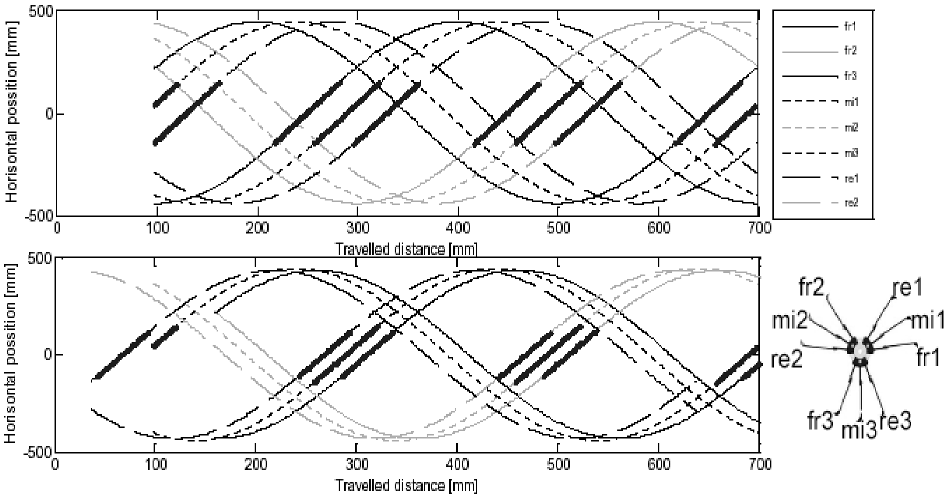

Figure 3. Duckfoots trajectories for different angular adjustment of arms

CONCLUSION

Neither a mechanical nor a physical system for effective intra-row weed control in row crops has been commercialised. The presented concept of an intra-row hoeing system can fulfils the requirements; it has sufficient degrees of freedom to allow full adaptation to different crop species, different plant intra-row distances and plant growth stages. In combination with a transversal hoe (Gobor et al. 2005) or installed on an autonomous vehicle, the rotary hoe could be a solution for accurate and rapid mechanical weed control.

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KONCEPT I VIRTUELNI MODEL ROTACIONE MAŠINE ZA UNUTARREDNU MEHANIČKU ZAŠTITU BILJA

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Sadržaj: Poslednjih godina se sve češće govori o održivoj poljoprivrednoj proizvodnji i, kao deo ovog koncepta, pominje se smanjenje upotrebe hemijskih zaštitinih sredstava. Jedna od alternativa hemijskoj zaštiti je mehnička zaštita bilja. Kada se govori u mehničkoj zaštiti širokorednih ratarskih kulutra, do sada su u širokoj upotrebi tehnička rešenja za međurednu kultivaciju. Cilj ovog rada je da prikaže koncept unutarredne obrade, u sistemu širokorednih useva, i prototp koji bi, obzirom na dobijene rezultate, mogao postati i realno, široko primenjivano tehničko rešenje. Uređaj predstavlja rotacionu mašinu sa radnim organima u vidu "pačije noge", postavljenim na podužnom vrailu. Uređaj je adaptibilan u smislu različitih biljnih vrsta, različitih unutarrednih rastojanja i različitih faza razvića useva.

Ključne reči: *kontrola korova, unutarredna zaštita, rotaciona mašina.*