Tube Stamp for mechanical intra-row individual Plant Weed Control

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ABSTRACT

Weeds are competitors against crop plants for resources such as water, light and nutrients. Consequently, weeds are responsible for a decrease in yield. In organic farming, only non-chemical weed reduction is possible. Many practicable techniques for mechanical inter-row weed treatment are available; however, options for intra-row treatment are more limited. In particular, there is no method for individual plant weed control for dense row crops such as carrots, due to the high risk of damaging the culture plant. Therefore, in organic farming of dense row crops this task is still conducted manually which leads to high labour costs. As part of the research project RemoteFarming.1 “web-based interactive crop farming at the example of robotic weed control in vegetables” a new tool for intra-row individual plant weed control was developed as component of an autonomous field robot. The field robot possesses all devices necessary for mechanical individual plant weed treatment - cameras, a manipulator arm and a weeding tool (tube stamp), as well as mobile network capabilities. The detection/identification of weeds is using a web-based approach assisted remotely by a human remote worker. In first studies, the tube stamp was tested regarding its efficiency in the field and its efficiency on various weed species under defined conditions. Weed plants treated with the novel tube stamp show none or very few remaining vegetation in BBCH-scales (**B**undessortenamt, **B**iological Federal Institute, **Ch**emical Industry) up to 12 allowing the crop plant to advance. Furthermore, this weed treatment technique does not introduce cuts in the soil nor causes broad soil loosening, which would stimulate the germination of new weed plants. Consequently, its very low impact zone of 11 mm of diameter allows reducing weeds in dense row crops and close to crop successfully.

Keywords: Intra-row, weed-control, carrots, field robot

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1. INTRODUCTION

In agricultural cultivation weeds are competitors against crop plants for resources such as water, light and nutrients. Consequently, weeds are responsible for low yield. Weeds grow between the lines (inter-row), within the lines (intra-row) and nearby the crop (close-to-crop). In conventional crop production, there are no differences between weed control techniques for different growing areas due to the allowance of chemical plant protection. One aim in organic crop production is to avoid the introduction of chemical plant protection products to the environment. Thus, in organic farming only non-chemical weed reduction is allowed. Beyond thermal and biological treatments, many practicable techniques for mechanical inter-row weed treatment are available, while options for intra-row treatment are extremely limited. Usually mechanical intra-row weed control is carried out by methods and mechanisms such as weeding harrows, torsion weeders, rotary hoes, finger weeders or vertical brush hoes (Mohler, 2001; Bond and Grundy, 2001; Upadhyaya and Blackshaw, 2007; van der Weide et al. 2008). In a very limited number of studies, selective mechanical methods were also developed. The systems differentiate between crop and weed and regulate the weed in the intra-row area without damaging the crop plant. For example the “Cycloid hoe”, tested in maize (Wißerodt et al., 1999, Kielhorn et al., 2000), the “Mobile robot” (Åstrand and Baerveldt, 2002) the “Rotating disc” (Tillett et al., 2008), a “Weeding machine” also tested in maize (Cordill and Grift, 2011) or a concept of a special “Rotary hoe” (Müter et al., 2013).

Furthermore, at the time being there is no practicable method for close-to-crop mechanical weed control, in particular in dense row crops like carrots (*Daucus carota*) and onions (*Allium cepa*), due to the high risk of damaging the culture plant. Thus far, this process is performed in dense row crops by hand-weeding. This method requires exhaustive and not ergonomic manual labor and is very time-consuming, which results in high cost and intensive labour management (van der Weide et al., 2008).

The new tool for intra-row individual plant weed control (tube stamp) was developed as part of the collaborative research project RemoteFarming.1 “web-based interactive crop farming at the example of robotic weed control in vegetables”. The project RemoteFarming.1 combines field robotics, sensors and actuators as well as web-based interactive communication technology, in one system (Sellmann et al., 2014). Within the project an autonomous, multipurpose field robot platform, called “BoniRob”, was built (Fig. 1, left). It can autonomously navigate along crop rows and ridges using a 3D laser scanner or freely using GPS data. The BoniRob is designed as a carrier, supplier and base for multiple BoniRob-Apps, which can be integrated into the platform using defined mechanical, electrical and logical interfaces (Bangert et al., 2013). One of these BoniRob-Apps is a mechanical weed control App, which was developed as part of RemoteFarming.1. It includes the tube stamp presented in this paper.

Figure 1: Autonomous field robot platform “BoniRob” with and without RemoteFarming.1 application for intra-row individual plant weed control (left). Manipulator and tube stamp actuator for single plant treatment (right)

The mechanical weed control App has a camera set up, supplemented by a wavelength adapted lighting system for recording high-resolution image data. The tube stamp is connected to a delta robot with a parallel kinematic structure (Veltru D8). It positions the tube stamp with visual servoing. Details on the vision based manipulation can be seen in Michaels et al. (2013).

In the first step of the project, called “RemoteFarming.1a”, the detection of weeds is performed solely by a remote worker using “human image processing”. The person marks the weeds in the image data acquired by the robot on the field. The positions of weeds are then transferred back to the BoniRob via mobile networks (Sellmann et al., 2014). The delta robot moves the actuator (Fig. 1, right) according to the previously selected position and eliminates the weed.

In the next step, called “RemoteFarming.1b”, the automatic detection of weeds based on an automatic plant classification system without segmentation (Haug et al., 2014) is included. Based on this automatic image processing the remote worker gets suggestions for weeds to be treated. Then the remote worker can confirm, modify or delete these target positions before the respective weed will be treated.

2. MATERIALS

The tube stamp essentially consists of a tube housing (Fig. 2, g), a high-helix lead screw (Fig. 2, a), a lead screw nut (Fig. 2, b), a special tube (Fig. 2, e), two springs with different spring constants (Fig. 2, d and f) and the stamp (Fig. 2, c) (diameter 11 mm) which is forced through the channel of the tube. It is powered by a 70 Watt BLCD motor (Fig. 2, h).

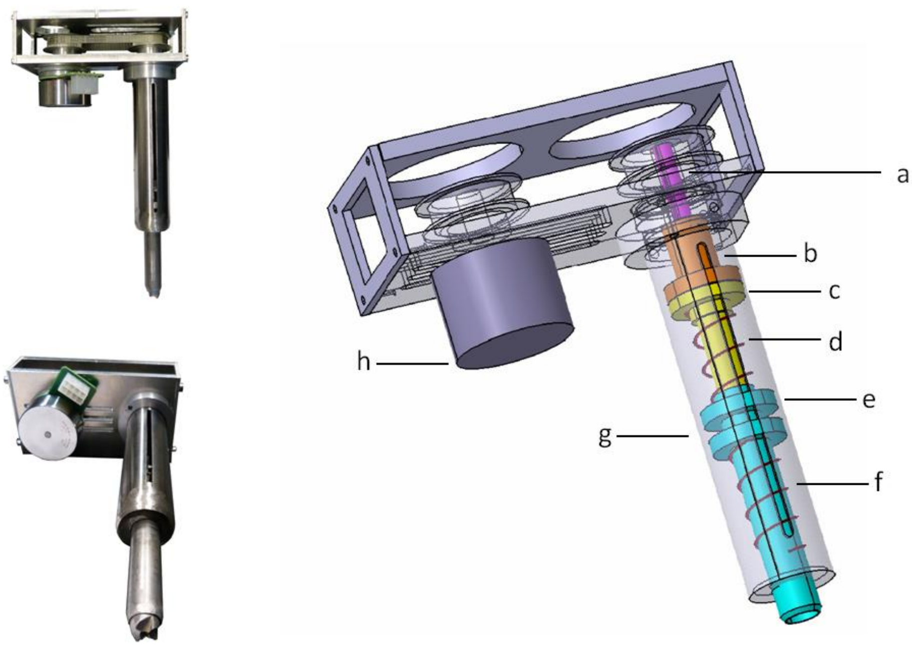

Figure 2: Tube stamp for single plant weed control in detail

Stamp and tube are connected using a combination of two springs. In phase 1, the system is at rest (Fig. 3) with all elements in starting position. The tube and the stamp are completely inside the tube housing. In the second step, phase 2 – the stamp is moved downward to penetrate the soil approximately 47 mm. The rotary motion of the motor is converted into a vertical movement using the high-helix lead screw/ lead screw nut combination. The spring constant (c_2) of the spring connecting the tube housing with the tube is lower than the constant (c_1) of the spring connecting the tube and stamp. Accordingly, the motion of the stamp is initially fixed along with the motion of the tube. The tube touches the ground first. It fixes the weed and holds it for the execution of weed termination. The tube and stamp are forced downward together until the spring (c_2) is completely compressed. In the last step of the stamp movement, phase 3 – stamping, the stamp advances downward through the tube until spring (c_1) is completely compressed. The stamp then makes contact with the weed and pushes it into the ground. It then proceeds to damage the weed with its sharpened head. The electric-motor then inverts the direction and removes the stamp from the soil. The tube is moved by the spring c_2 back to its initial position. The process duration is < 600 ms.

For tests, the tube stamp has been decoupled from the RemoteFarming.1 system and integrated into specially designed devices: a fixed device for greenhouse experiments and a mobile device for field trials.

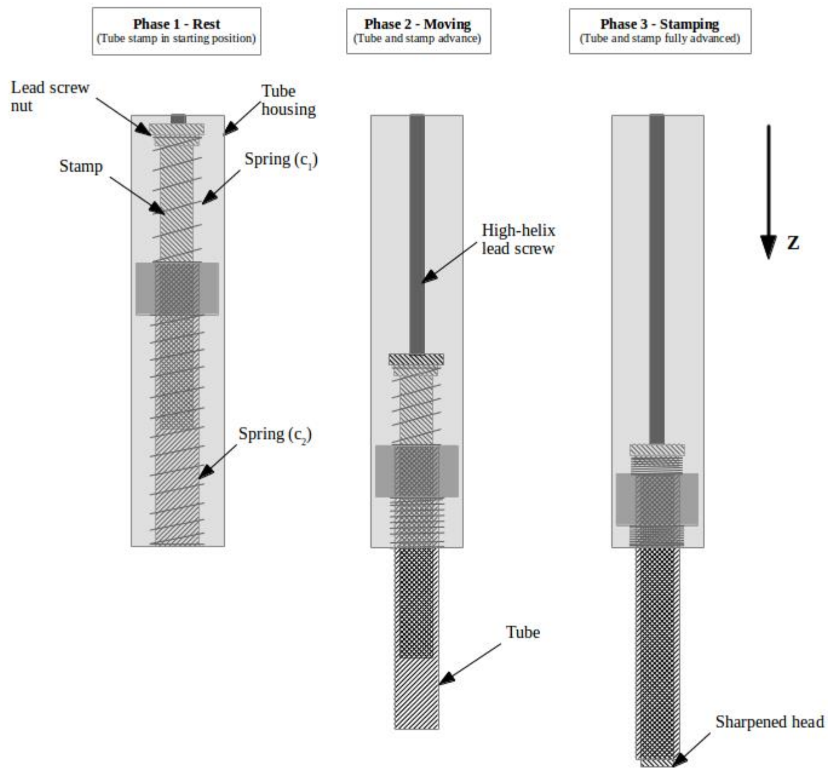

Figure 3: Basic structure of weeding process with the tube stamp

3. RESULTS

3.1 Experiment 1: Test under greenhouse conditions

Setup

In experiment 1, the effectiveness of the actuator in relation to different weed species was tested. The experiment took place under greenhouse conditions with controlled temperature, artificial lighting and species-appropriate irrigation. For this purpose, the species *Stellaria media*, *Capsella bursa pastoris*, *Daucus carota*, *Vivia cracca*, *Poa annua*, *Setaria viridis* were seeded in isolated flower pots. This was based on a substrate with the soil type lS (loamy sand). To eliminate the germination of species out of the substrate seed pool, the substrate was heated up to 80° C for four days. Ninety specimen of each species were seeded. The germination rate of each species differed. Consequently, there were different amounts of plant samples per type for the test. All plants were treated in BBCH-scale 10 to 11.

In order to perform the experiment in a greenhouse, the actuator was mounted on a stationary test bench, which also carried the system control and user interface. Thereby, the plants could be placed precisely below the actuator. The mechanism was activated manually. The actuator treatment took place and the flower pots were removed from the test bench. After regulation, the phenotyping of the regulated weed plants followed. This was done according to the following classification (in dependence on rules of agriculture value analysis of the German Federal Plant Variety Office (Bundessortenamt, 2000)):

Level 1 = no weed plant damage
Level 3 = low weed plant damage
Level 5 = moderate weed plant damage
Level 7 = high weed plant damage
Level 9 = weed plant dieback

Outcome

Figure 4 shows the result of experiment 1.The y-axis represents the percentage number of actuator treatments. The x-axis shows different plant species. Thus, the bar-chart demonstrates the percentage number of actuator treatments with the particular phenotyping level of each species. The absolute number of actuator treatments at the species *Stellaria media* is n = 28. One-hundred percent of this species are classified with the phenotyping level 9 (weed plant dieback). The results of *Capsella bursa pastoris* are similarly. One-hundred percent of this species are classified with phenotyping level 9 by an absolute number of actuator treatments n = 19. Any other species depend a lower influence of the actuator treatment (*Daucus carota* n = 51, 64.71% of them were classified with level 9, 1.96% with level 7 (high weed plant damage), 7.84% with level 5 (moderate weed plant damage), 7.84% with level 3 (low weed plant damage), 17.65 % with level 1 (no weed plant damage); *Vivia cracca*, n = 21, 57.14% with level 9, 4.76% with level 7, 0% with level 5, 4.76% with level 3, 33.33% with level 1; *Poa annua*, n = 86; 56.98% with level 9, 8.41% with level 7, 6.98% with level 5, 3.49% with level 3, 24.42% with level 1). With a result of 43.48% plant dieback (10.87% with level 7, 6.52% with level 5, 0% with level 3, 39.13% with level 1) by *Setaria viridis* (n = 46), the tube stamp had the lowest influence. The experiment shows that weeds tend to react differentially to the actuator treatment.

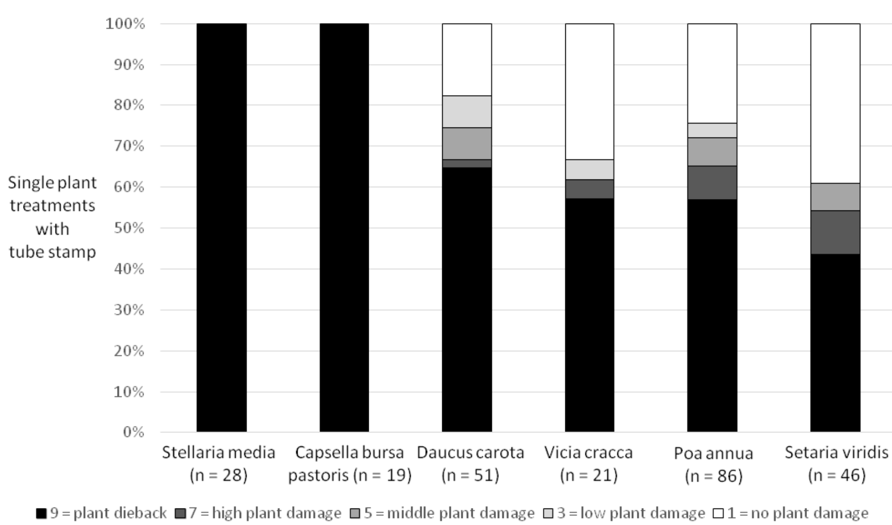

Figure 4: Effect of single plant treatments with tube stamp at different weed species under greenhouse conditions

3.2 Experiment 2: Field trial

Setup

To test the efficiency of the tube stamp, a field trial was performed. The Basis for the test section was a parcel with soil type sL (sandy loam). The field contained ridges with a peak-to-peak width of 750 mm and a height of 220 mm. Carrots of the variety *Nantaise* were seeded in the middle of the ridge. At the time of the field test, the weeds were in the BBCH-scale of less than 12. The diversity of the weed species was limited to *Stellaria media*, *Matricaria recutica*, *Viola arvensis*, *Convolvulus arvensis* and *Chenopodium album*. During the 7 day period from regulation to phenotyping there was an average temperature of 13° C with a maximum of 22° C and minimum of 8 °C. The accumulated precipitation was 14 mm. Plots were marked on the ridge crown with dimensions 30 cm long by 10 cm wide. In total there were 10 plots.
For this experiment, the actuator was installed on the mobile platform, which also carried the system control and user interface. The actuator can be moved along two axes using two linear bearings. Thus, it was possible position the actuator directly on top of the weed. The positioning and the activation of the tube stamp were done manually. Seven days after procedure the phenotyping of the individual plants took place. This was performed similarly with the procedure of experiment 1.

Outcome

Figure 5 shows the result of the experiment 2: field trial. The y-axis represents the percentage of actuator treatments. The x-axis shows the distribution of phenotyping classification. One-hundred and thirty plants have been treated. One-hundred and ten plants were rated as classification number 9 (weed plant dieback, 84.62%), 6 plants as classification number 7 (high weed plant damage, 4.62%), 6 plants as classification number 5 (moderate weed plant damage, 4.62%), 4 plants as classification number 3 (low weed plant damage, 3.08%) and 4 plants were rated as classification number 1 (no weed plant damage, 3.08%).

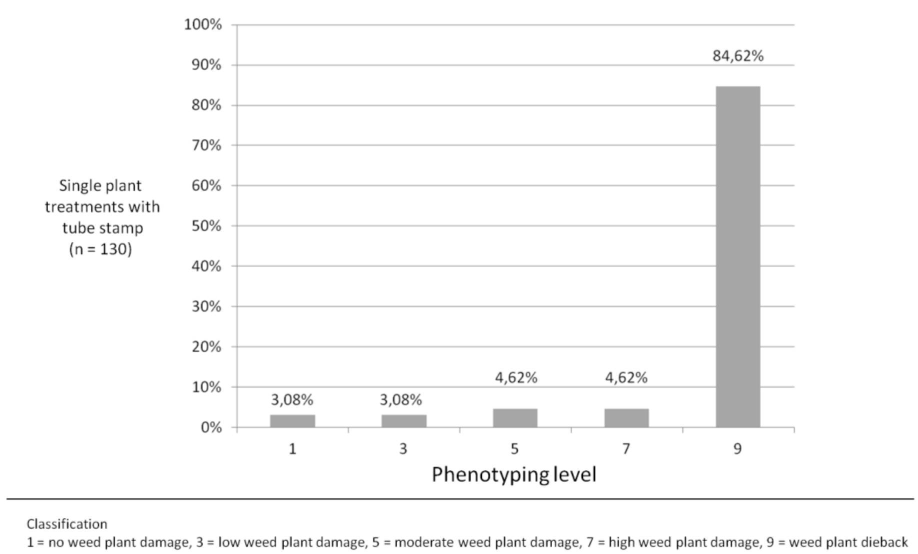

Figure 5: Results of single plant treatment in experiment 2: field trial Osnabrueck.

Figure 6 shows an example of actuator treatment (Fig. 6, top) compared with a control plot without tube stamp treatment (Fig. 6, bottom). The tube stamp treatment was realized on the ridge crown 13 days ago. The ridge sides were formed by a hoe. This two variants show significant differences.

Figure 6: Plot with tube stamp treatment compared to control plot without tube stamp treatment. The tube stamp treatment was realized 13 days ago.

4. DISCUSSION

The first experiments demonstrates the potential of the stamping mechanism. The results of experiment 2 show a significant effect of the tube stamp on weeds (Fig. 5 and Fig. 6). Eighty-four point sixty-two percent of weeds were fatally damaged. In each case, 4.62% were moderately to highly damaged. In addition these plants (plants with phenotyping note 5, 7 and 9) were damaged to a great extent. Therefore, there was none or very little remaining growth of the weed plant. Consequently, the culture plant could overtake the weed plant. Thus, a successful individual weed control rate of 93.86% was achieved. By comparison, own studies show a weed reduction of 63% to 82% per usual practice hand weeding in organic carrot production. This comparison demonstrates the high efficiency of the tube stamp process. Figure 6 which show a plot with tube stamp treatment compare to a control plot without tube stamp treatment, support this statement.

In experiment 1, the effectiveness of the tube stamp in relation to different weed species has been tested. All treaded plants were in BBCH-scale 10 to 11. All plant samples of species *Stellaria media* and ***C****apsella bursa pastoris* could be destroyed by the tube stamp. However, some samples of the species *Daucus carota*, *Vicia craca*, *Poa annua* and *Setaria viridis* persisted after the treatment by the actuator. In parts these species showed a remaining growth. The experiment shows that weeds tend to react differently to the tube stamp treatment. However, for all tested species the treatment at the mentioned growth stage significantly damaged the majority of

samples. Noticeable is the distribution of the tube stamp treatment results. Mainly, there is an irreversible mortally damage. High, moderate and low damage are very low. On the other hand, the level “no damage of the weed plant” increases. Consequently, in this study specific species have been damaged mortally or have shown no effect. Noticeable, too, is the high percentage of low or not damaged grasses *Poa annua* and *Setaria viridis*.
Further, this experiment was realized under well-defined conditions. Thus, there were ideal conditions for plant growth. Vice versa, there could be different and suboptimal conditions in the field. Especially suboptimal environmental conditions, like hotness, high/ low rainfall etc., could weaken the weed plant additionally. There was also no competition for resources between the culture plant and weed plant, which could further degrade the weed plant. Therefore, the results are different under field conditions. A negative aspect is the different germination rate of weeds. Therefore there is no significant statistic, only a tendency.
Consequently, in addition with the RemoteFarming.1 system it is possible to control weed growth in the close to crop area and less spaced culture plants. All previously known selective-mechanical operating systems were designed for row crops with wide row spacing (Åstrand and Baerveldt, 2002; Cordill and Grift, 2011; Müter et al., 2013; Wißerodt et al., 1999; Kielhorn et al., 2000) e.g., maize (*Zea mays*) and sugar beets (*Beta vulgaris*).These systems work on the whole intra-row area between the culture plants for example with rotating disc (Tillett et al., 2008) or special tines (Kielhorn et al., 2000; Gobor et al., 2013; Cordill and Grift, 2011). The novel tube stamp concept enables single plant treatment in crops with small in-row space; particularly weed treatment in the close to crop area.

5. CONCLUSION

Intra-row and close-to crop weeding in dense row crops is cost-intensive and time-consuming. As part of the project RemoteFamring.1 a new tool for intra-row individual plant weed control was developed, called tube stamp. In first studies the tube stamp was tested regarding its efficiency in the field and its efficiency on different weed species under defined conditions. The result of the field trial shows significant weed reduction. Thus, a successful individual weed control rate of 93.86% was achieved. Furthermore, the experiment shows that different weed species react not significant differently to the tube stamp treatment but show a clear tendency. Still there is a continued improvement of the tube stamp and the RemotFarming.1 system. Further studies are necessary to compare the RemoteFarming.1 system with other strategies. As well as research the potential influences of the tube stamp on culture plant yield. Consequently, the tube stamp works high effective under practical conditions in close-to-crop area. With the integration of the tube stamp in the RemoteFarming.1 module, the complete system could replace other existing, cost intensive systems for intra-row weed control.

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