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GPS-based weed control in field vegetable growing

In field vegetable production the aim is to produce, on the one hand, high quality products free of pesticide residues and undesirable weeds. On the other hand, there is an increase in minor use herbicide protection gaps or active ingredients that are approved cause undesirable residues. Mechanical methods are therefore increasingly applied. However, these are very time consuming and therefore costly. Whether modern GPS technology can support and optimise mechanical weed control is clarified in a master's thesis at the University of Geisenheim. The practical investigations led to the conclusion that weed control based on GPS guidance of machinery and implements can be carried out not only faster but also more cost-effectively and precisely.

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Abstract
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Control of weeds represents a great challenge, especially in vegetable growing. Even low populations of arable weeds are not tolerated by crops, particularly salad crops. Higher weed populations can bring yield penalties of up to 60 % [1]. Of course, the success of the farm business depends on more than weed control. But inefficient or unsuccessful control can lead to hand hoeing being the last answer, leading to immense labour costs. The range of required work hours per hectare can then run from 40 to sometimes over 500. And because every centimetre of mechanically untreated soil on each side of the crop plant represents around 10 extra work hours per ha for hand hoeing, the aim is therefore to work as close to the plants as possible in mechanical weeding actions.

To achieve such high precision, the current solution involves making the working width of the mechanical hoe the same as that of the seedbed. In practice, this then means that every growing bed has to be driven over by the mechanical hoeing implement. On top of this, the high precision required means that operational speed stays at just 3 km/h and thus often under the recommended working speed for the implement which can be 6–9 km/h [2]. Higher speeds would lead to disproportionately high demand on the concentration required by the operator and possibly increased damage to the growing crop. Thus the actual work rates realised can be very low at just approx. 0.5 ha/h [3]. Increasing the area performance means speeding up this operation. One solution is fitting the weeding implement with a rowcrop guidance system.

Most often applied in this respect are camera-based systems. Trial results show that such approaches can allow hoeing speeds of up to 12 km/h [4]. However, such systems react very sensitively to environment influences. For instance, too high a weed population, different foliage colouring such as with radicchio lettuce, or sunlight reflections can lead to functional errors in the implement steering [5]. Additionally, camera systems require a visible guideline for orientation.

Implement steering via GPS, on the other hand, can work without visible guidelines and direct the implement without being influenced by the above-mentioned environment features. Such systems can also be used for other operations on the farm, making payback time shorter. A practical trial was carried out in spring 2013 to assess whether efficiency increases in mechanical weed control through applying GPS are possible, and what approach in this respect might be best.

Trial design

The aim of this trial was to increase working speed during mechanical weed control step-by-step from 3 to 9 km/h. Field areas for the trial were made available by the Queckbrunnerhof Teaching and Research Farm for Horticulture (DLR Rhineland-Palatinate). These areas were drilled with onions and spinach, these crops being chosen because both represent especially high demands in weed population management. Mechanical weeding was carried out with two mounted hoes, these reflected the standard on such enterprises. Serving as reference in each case was the standard procedure with forward speed of 3 km/h and manual steering of the tractor. These were compared with

Fig. 1

Sowing with shifting frame (Photo: D. Hege)

two GPS supported variants. In variant 1 only the tractor followed the GPS signal. Hereby the McCormick C-Max 90 was fitted with Trimble Autopilot and a DCM (Digital Communication Modem) so that it could receive signals from an RTK (Real Time Kinematic) network. In variant 2, both tractor and mounted implement were GPS steered. To make the existing weeding implement suitable for GPS steering a hydraulically adjustable frame was attached between tractor and implement. This frame was from the manufacturer WiFO and developed originally for adjusting the operational positioning of mounted mowers. The firm geo-konzept modified the frame so that the implement could always be moved towards seedbed centre through a further GPS receiver and additional steering valve reacting to received correction data (**Figure 1**). In this way, implement positioning is active i. e. the hoe is self-steering. This configuration, called true tracker, is only possible in association with an autopilot and ensures highest precision.

An RTK correction signal was applied for rowcrop work, enabling precision of ± 2.5 cm. It was tested whether this precision capability would allow working speed to be increased to 9 km/h without weeding quality penalties. Quality factors considered were crop damage (plants completely pulled out) as well as successful elimination of weeds, this latter being assessed by comparing weed plant leaf surface areas before and after the weeding operation).

Determining leaf surface area involved taking photographs of the leaf surfaces with a digital camera before the weeding operation and two days afterwards. Areas photographed measured 0.25 m^2 with the camera attached to a special tripod to ensure accurate results. The resultant photographs were analysed on PC with the software WinDIAS which filtered out the leaf area of the non-crop plants. Crop damage was assessed by comparing the percentage of damaged plants to undamaged ones following the mechanical weeding operations. At the same time, the aim was to drive as close to the crop plants as possible in order to minimise labour input for required hand hoeing. In the onion crop the distance between edge of the mechanically weeded area and crop plants was 2.5 cm. This was 3.5 cm for spinach due to this plant's broader growth form.

The randomised trial areas were each rotavated and drilled. The trial started three weeks later than planned because of cold weather. In mid-April the im-plements were first of all adjusted and calibrated. In order to test mechanical functionality, a preliminary trial was carried out in an already-established crop of winter spinach. Work quality in this operation, at speeds of up to 12 km/h – four times the normal speed in normal mechanical hoeing operations – was assessed as extremely positive. Any further implement adjustments were deemed unnecessary.

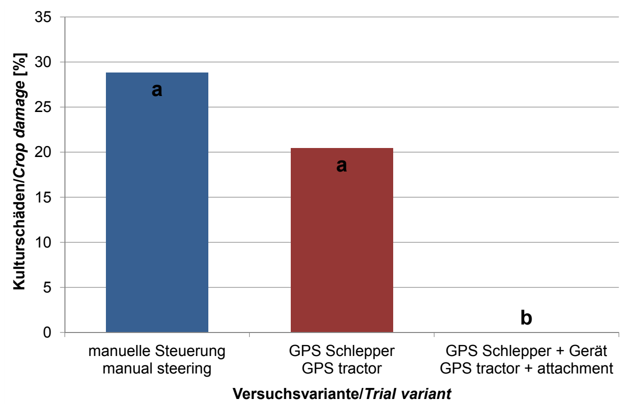
At the beginning of May the weeding work was begun. Weather conditions (with rain threatening) meant the time window for optimum weeding operations represented less than 12 hours. In total, 0.5 ha had to be weeded whereby an area of 282 m^2 was apportioned to each variant.

Evaluating the results:

Assessing the results confirmed the positive impression made by the preliminary trial work. In the trial variant with GPS steering of tractor and mounted implement this configuration resulted in the least damage in both crops with no plants showing damage (**Figure 2**).

On the other hand, the variant with manual steering caused average crop damage of 28 %, which is not economically acceptable. In both crops, increasing operative speed caused no reduction in the success of the respective weeding operations, although regrowth caused by subsequent rainfall just after the operation led to equally poor results for all variants, at approx. 50 % success. As a result, it can therefore be established that the operative speed in association with GPS controlled mechanical hoe steering can be increased to 9 km/h. This fact alone results in area performance increasing from 0.5 to 1.3 ha/h and thus to better exploitation of the most valuable farm business resource: labour input in terms of work hours, these being thus reduced from 1.88 to 0.76 work hours/ha.

Fig. 2



Crop damage in onions, depending on trial variant; different letters indicate differences between means; Wilcoxon test α = 5 %

Further calculations

The positioning technology, however, has still more potential. Thus, it is possible to use it in drilling or planting seedbeds with the machinery already available on the farm to give crop plant row precision of ± 2.5 cm and so permit precision mechanical weeding at working widths covering multiples of single seedbeds. For example three beds can be established to give a working width of 6 m which can then be mechanically weeded in a single pass, whereby area performance can be further increased to almost 4 ha/h. Using the KTBL database for organic agriculture [6] the diesel consumption was calculated as reduced from 4 to 3.5 l/ha, meaning CO_2 emissions per hectare are also able to be reduced. Another reduction features the number of wheel tracks. These can be reduced by a third whereby soil compaction is also reduced and soil organisms thus encouraged. The procedural costs are reduced from 60 € to approx. 25 €/ha (**Table 1**).

Because mechanical weeding with the hoe weeder only represents a part of the total weed control management system, an economic comparison between the normal farm operations and GPS supported ones represented the next step. Hereby, multiple weeding passes and other procedures for mechanical weed control were taken account of.

In spinach the normal system comprises 2 x mechanical weeding passes. Replacing this with the GPS supported approach and 6 m working width saved 70 €/ha in procedural costs. Diesel consumption was reduced by a total 1 l/ha. Working time required could be reduced by more than 3 work hours/ha.

The usual procedure in onion crops comprises 1 x burning, 3 x tine harrow passes and 2 passes with the mechanical hoe. The burning operation takes up around 50 % of costs because a great amount of gas is used. Up until now, however, it has not been possible to use the mechanical hoe for weed control before crop emergence, which is why the broad treatment of burning represented the most efficient technique. But using GPS positioning enables "blind" operation of the hoe in a pre-emergence crop. Possible also is reducing gas consumption in the burning operation through burning only between the rows, or desisting from using burning altogether. This could lead to a possible reduction in costs of up to 170 €/ha. Alongside the diesel saved can thus also be added savings in propane gas as CO_2 producer.

Conclusions

GPS supported mechanical hoeing can reduce procedural costs by up to 60 % compared with the procedures usually applied. Additionally, this technique allows existing implements and attachment systems to be used further and so helps costs to be minimized. There's also the possibility of saving diesel fuel and other input materials such as propane gas for burning operations. This improves the CO_2 balance. Through the possibilities of covering three beds in a single pass, wheeling on the field surface can be reduced thereby minimizing soil compaction and promoting soil organisms. Increasing working widths of implements can reduce required work time per hectare by up to 70 %. Thus the application of GPS supported mechanical weed control is practical, especially where treatment time windows

Table 1

Procedural costs 6 m working width, compared to the usual practice method

Kennzahl *Code*	**Einheit** *Unit*	**Praxisüblich 37-kW-Schlepper mit manueller Steuerung** *Practical usual method 37 kW tractor with manual steering*	**6 m Arbeitsbreite 54-kW-Schlepper mit GPS-Steuerung** *6 m working width 54 kw tractor with GPS-guidance system*
Abschreibung/*Capital allowance*	€/ha	11,46	3,04
Zinskosten/*Interest costs*	€/ha	2,76	1,83
Sonstiges/*Others*	€/ha	0,37	0,17
Reparaturkosten Schlepper/*Repair costs tractor*	€/ha	9,38	3,84
Reparaturkosten Hacke/*Repair costs hoe*	€/ha	3,00	3,30
Dieselkosten/*Diesel costs*[1)]	€/ha	4,87	4,21
Betriebsstoffe/*Supplies*	€/ha	0,07	0,07
Verschieberahmen/*Shifting frame*	€/ha	0,00	5,40
Lohnkosten/*Labour costs*[2)]	€/ha	28,13	3,82
Summe/*Sum*	€/ha	60,04	25,68
Änderung im Vergleich zum praxisüblichen Verfahren *Change compared to practice usual method*	%	-	-57

[1)] Dieselkosten 1,20 €/l/*Diesel costs 1,20 €/l.*
[2)] Lohnkosten für Festangestellte 15 €/h/*Labour costs for permanent workers 15 €/h.*

are limited. In this way good weather phases can be more efficiently exploited. Just how important this aspect can be was demonstrated by the wet and cold weather in spring 2013.

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