An analysis of the use of a computerised robotic weeder in horticultural operations at two locations in South Wales

Final Report

Date: 21 July 2022

Cronfa Amaethyddol Ewrop ar gyfer Datblygu Gwledig: Ewrop yn Buddsoddi mewn Ardaloedd Gwledig
European Agricultural Fund for Rural Development: Europe Investing in Rural Areas
Llywodraeth Cymru
Welsh Government

GENERAL NOTES

Title: An analysis of the use of a computerised robotic weeder in horticultural operations at two locations in South Wales

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About EIP-AGRI

The European Innovation Partnership for Agricultural productivity and Sustainability (EIP-AGRI) was launched by the European Commission in 2012. It aimed to foster a competitive and sustainable agriculture and forestry sector that "achieves more from less". It contributed to ensuring a steady supply of food, feed and biomaterials, and to the sustainable management of the essential natural resources on which farming and forestry depend, working in harmony with the environment.

EIP Wales

Menter a Busnes delivers the EIP Wales scheme on behalf of the Welsh Government and has received funding through the Welsh Government Rural Communities – Rural Development Programme 2014-2020, which is funded by the European Agricultural Fund for Rural Development and the Welsh Government.

For Welsh farm and forestry businesses to remain competitive, profitable and resilient, they will need to work on a continuous programme of improving both business and technical practices. The aim of EIP Wales is to solve common agricultural and forestry problems by bringing people from practical and scientific backgrounds together. It is an opportunity for farmers and foresters to put their ideas into practice by testing new technologies or techniques.

The project sought to analyse the impact of a computerised robotic weeder in horticultural systems. These weeders are commonplace in larger operations but their effectiveness (viability) in smaller scale situations has not been analysed. By trialling a computerised robotic weeder we sought to determine the savings in terms of labour (cost) and time that can be made when compared with the current methods of high labour requirement at specific times of the year.

EIP Operational group

The businesses represented in the operational group are:

Organisation	Name	Farm/Location
	Rob and Ryan Whittal	Square Farm, Mitchell Troy, Monmouth NP25 4JH
	Charlie Felstead	Puffin Produce Ltd Woodlands Site, Withybush Industrial Estate, Haverfordwest, Pembrokeshire SA62 4BS
	Pawel Wisniewski	Paul’s Organic Veg

Other members of the project

Organisation	Name	Location	Role
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EXECUTIVE SUMMARY

The project sought to analyse the impact of computerised robotic multi-row weeders in small scale horticultural systems. These weeders are commonplace in larger operations but their effectiveness (viability) in smaller scale situations has not been analysed.

There is a shortage of skilled labour available in the agricultural sector at present. Wage inflation and staff retention is another problem. This project sought to determine the savings in terms of labour (cost) and time that can be made from using the robotic weeder when compared with the current methods of high labour requirement such as hand weeding at specific times of the year.

One of the farms in the project is organic while the other was keen to look at alternatives to a conventional pesticide programme, so a system which is not reliant on the use of chemicals is essential to the long-term success of both operations. Hand weeding, where labour is available, is currently costing as much as £1-2,000 per Ha and may need doing twice or more per year. Herbicide options on conventional systems would cost approximately £100-200 per Ha, but there is increasing pressure within the industry to reduce chemical inputs.

The cost of hand weeding is a challenge to the Small and Medium Enterprises (SME) organic growers as popular vegetables including carrots, parsnips and the allium family are all slow germinators and poor competitors to weed pressure. However, without these basic crops it is difficult to offer a good range to market to customers.

The new range of weeders are fully adjustable and with precision technology can get much closer to the crop, reducing the need for repeat weeding. Labour in many areas in Wales is limited and can be costly so smaller growers must do a lot themselves. This however interferes with other essential tasks on the farm such as planning, harvesting and marketing of the crops.

This cultivation technique also offers other benefits as it can help alleviate surface compaction caused by traffic, but also capping by rain and irrigation, and many conventional growers will now cultivate on this basis. The machine can also be adapted to use in cereals and ridge up crops like leeks.

Unfortunately, the trialling within this project were limited due to several reasons including Covid-19 restrictions. However, results have shown that robotic weeding using vision-guided systems, normally used in broadacre crops, in different vegetable crops are extremely effective and if they are adaptable and at a reasonable purchase price, they will be a practical option for small scale growers going forward. There are also lots of exciting robotic system developments in Europe and the UK in vegetable crops that are increasing in popularity and availability soon.

CONTENTS

1 INTRODUCTION AND AIM

The aim of this project was to evaluate the practicality and efficiency of mechanical weeding technology developed for precision drilled broadacre crops in small-scale horticultural systems in Wales.

Weeding on a smaller scale can be challenging due to the need for high labour inputs for hand weeding or a lack of available machinery. Much of the precision technology has been focused on broadacre crops such as cereals that are more often precision drilled and the kit design is large. For smaller horticultural growers the need for adaptation of the large kit is ever increasing as labour costs continue to increase along with the requirement and trend for lower pesticide inputs and increased need for Integrated pest management (IPM) weed control options and tools. It was agreed following experimental Year 1 that the more advanced in-row weeder would not be used as the increased cost of using this equipment would be beyond the small-scale producer.

1.1 Introduction to the field sites

The farmers were keen to host the field trial sites and provided fields with a good weed population. Each farmer was actively involved in the project and contributed to meeting discussion and planning.

1.1.1 Square Farm

Square Farm is a mixed organic farm with shop, located just off the A40 near Mitchel Troy, Monmouth (see Figure 1). Annual rainfall for the area taken from Manner NPK is 861 mm per annum. The project location was 35 metres above sea level. Soil type from soil maps indicates that the field is on the Bromyard Association, a well-drained fine silty soil over sandstone. Hand texturing of the soils in the field would support a silty loam texture. The trial field has a gentle slope from south to north.

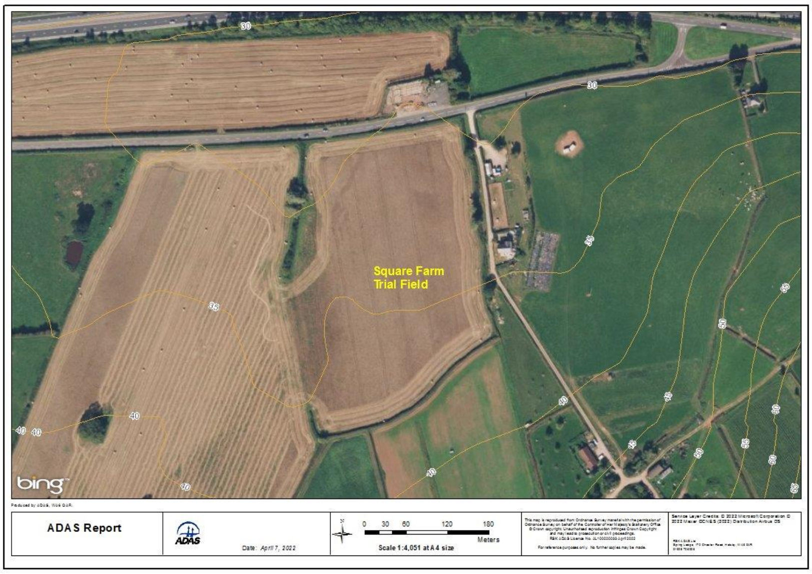

Figure 1. Aerial imagery of Square Farm showing topography

1.1.2 Haverfordwest Site

The Puffin Produce site is located near Haverfordwest, Pembrokeshire (**Figure 2**). Annual rainfall for the area taken from Manner NPK is 1,252 mm per annum. The project location is 60 to 80 metres above sea level. Soil type from maps indicates that the field is situated on the boundary of the Brickfield 2 and Neath Associations, a seasonally wet deep loam and a freely draining, fine loamy soil respectively. Aspect is north-westerly with a gentle to moderate slope. This site was used for the final year of the trial.

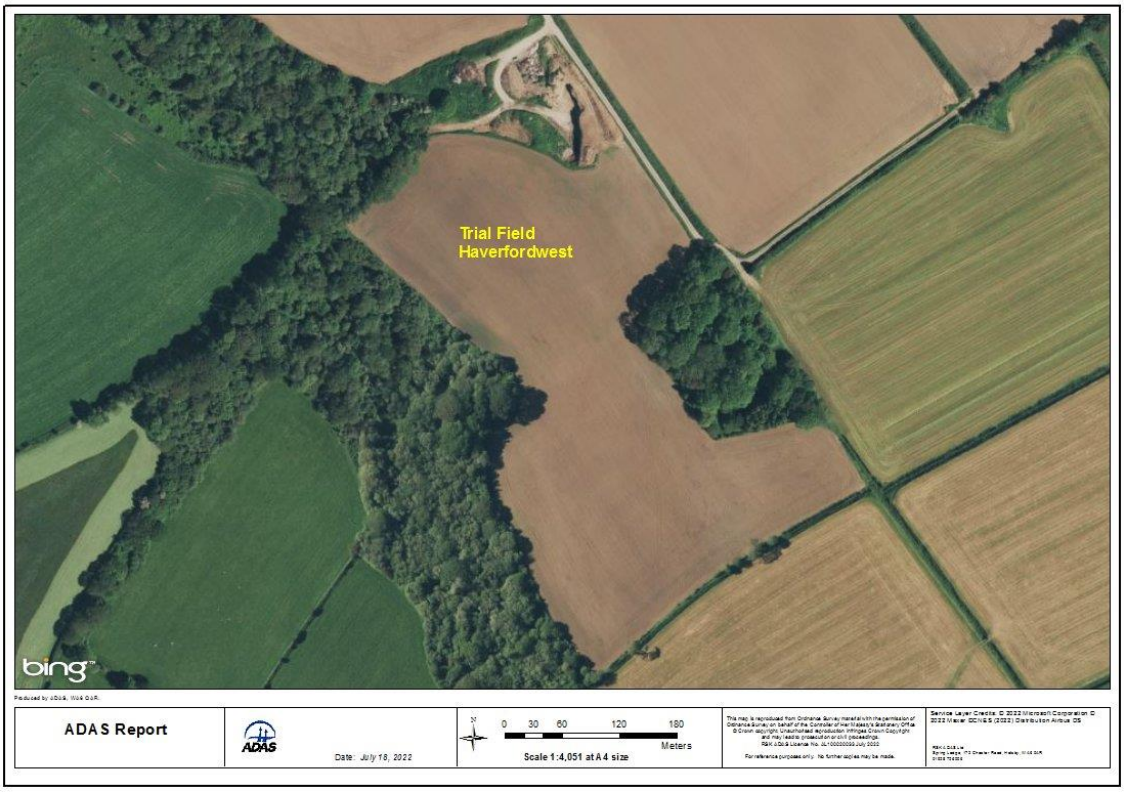

Figure 2. Aerial imagery of Haverfordwest Site

2 METHODOLOGY

2.1 Experimental design and implementation

The experimental design and implementation were led by the weed specialist/horticulturalist procured in line with WG protocols in conjunction with the various host farmers and the providers of the robotic weeding kit (Garfords, Lemken ARM Machinery Ltd, and Steketee). The design considered the constraints imposed by the sites, (such as slope; soil type, cropping and planting spacing), project budget and the methodological requirements of the management and monitoring operations.

The experimental design involved different treatments being carried out on different types of field vegetables (cabbage and curly kale in 2019, beetroot and turnip in 2021 and leeks in 2022). The plot size varied at each site but was generally a planting bed width x 10-30m length, with one area weeded using standard methods of hand hoeing, compared to using the vision guided inter-row weeder.

2.2 Experimental year one (2018-19) – Square farm, Monmouthshire

2.2.1 Field plots

Four different treatments were proposed to be compared by doing the two different cultivation techniques in two different crop types:

- Hand hoeing in a field vegetable crop (root crop) – Control 1
- Hand hoeing in an above ground crop e.g., brassica – Control 2
- Vision guided weeding in a field vegetable crop (root crop)
- Vision guided weeding in an above ground crop

These treatments were planned to be carried out after the crops had been drilled or planted, and after the first flush of weeds emerged. It was proposed that the hoe would then be repeated as necessary by the grower, i.e., approximately every 3-4 weeks, or as dictated by weed growth and pressure, through the season. Many factors can affect the growth of weeds such as temperature, day length and soil moisture. Implementation of the management options were flexible to take this into account.

During experimental year one (2018 season), the computerised in row weeder (Garford Robocrop) was brought to the OG farm and trials began in crops of cabbage and curly kale. However, difficulties were encountered due to the very dry weather conditions, uneven terrain, and plant spacing's (crops were module planted) resulting in an unsuccessful trial in terms of being able to weed properly. After consultation with the OG farmers, project group and funders it was agreed that the project was extended to allow another series of trials.

2.3 Experimental year two (2021) – Square farm, Monmouthshire

Covid restrictions in 2020 delayed any field trials within that period putting the project on hold.

During experimental year two a different field was selected for the weeding trials at Square Farm that was flatter, and a new planter had been purchased (based on the experience of year 1 of the trial) to allow more precise planting. The trial was set up on 16 August 2021, including two planting beds of two crops, either beetroot or turnip. For the mechanical weeding with the robotic weeder a 90m length was marked out (three replicates of 30m plots) and for the hand weeding a 30m length was marked out, as it was considered impractical to hand weed a 90m length for the purposes of the trial.

An untreated control area of 10m length was also marked out. Weeding was carried out both by hand, using a hoe and using the robotic weeder.

2.3.1 Weed assessments

Plots were assessed on the day of weeding and on two occasions post-weeding, 08 September and 29 October 2021 and a visual assessment of percentage weed cover in each crop was recorded.

2.3.2 Weeding time assessment

On the day of treatment (16 August 2021), the time taken to either mechanically weed or hand weed each plot was recorded for comparison.

2.4 Experimental year three (2022) – Haverfordwest, Pembrokeshire

Trial plots measuring 30m length by a crop bed width (approximately 2m) were marked out into a field crop of leeks in Pembrokeshire on 23 June 2022. The leeks had been planted with plant tape on 16 April 2022. There were two main weeding treatments (Table 1), the guided mechanical hoe (plots 101 and 201) or a hand hoe method, either a wheel hoe (plot 301) and hand hoe (plot 401). Each treatment was replicated three times. There was a 10m untreated control strip at the end of each treated strip for comparison.

Treatments were carried out on 23 June 2022, with the mechanical weeder ((Figure 3) Steketee EC-robotic weeder) being driven by the farm staff (at approximately 7-8 km/hr) and ADAS staff undertaking the hand hoeing.

Figure 3. Steketee EC-robotic weeder used at Haverfordwest in 2022. There are cameras attached to the middle section to detect the rows and the tines are on a second section that can be manually adjusted to fit the crop row spacing. Only a one-bed set of times was trialled.

The usual farm herbicide applications for this site would be one pre-emergence herbicide and 3-4 x post-emergence herbicides (starting approximately four weeks post planting).

Table 1 The weeding treatments for experimental year three (2022)

Treatment	Description	Timing of application
1	Untreated control	-
2	Hand weeding alone (A & B) *	Late-June
3	Weeder alone x1 pass	Late-June

** Hand weeding (A) was carried out using a **hand hoe** for plot 401 and a **wheel hoe** (B) for plot 301 weeder plots were 101 and 201 plots.*

2.4.1 Weed assessments

Weed populations were recorded pre-treatment on the day of treatment (23 June 2022) as plants numbers/m^2, using 10 x 0.1m^2 quadrats per plot. The top three weed species present were recorded in order of abundance. On one occasion post-weeding (13 July 2022) a visual assessment was carried out for the whole plot area recording plants per m^2 (method as above) and calculating percentage control of each treatment compared to the untreated area pre-treatment.

2.4.2 Crop assessments

On one occasion post-weeding (13 July 2022) a visual assessment was carried out for the whole plot area to record percentage damage (if any) of each treatment compared to the untreated area on the crop.

2.4.3 Weeding time assessment

On the day of treatment, the time taken to either mechanically weed (including turning headland) or hand weed each plot was recorded for comparison.

3 RESULTS

3.1 Experimental year one (2019) – Square farm

Limited data were collected for experimental year one as the weeder was not able to perform properly due to the terrain, planting scheme and extremely dry conditions. Data for fat hen (*Chenopodium album*) that dominated the weed population (Figure 4) showed that the mechanical weeded plots had on average 4.4 fat hen plants per m^2, compared to 11.5 plants per m^2 in the hand hoed plots. The module planting was not accurate enough for this weeder to function accurately and it resulted in crop damage as the modules were pulled out or disturbed (Figure 5).

Figure 4. Untreated plots with high level of fat hen in cabbage (Left), curly kale (Right)

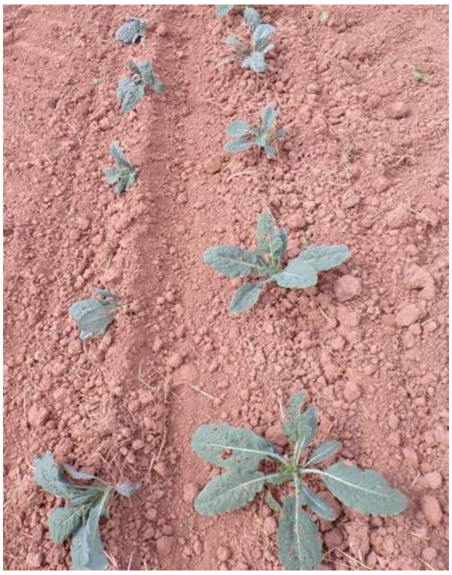

Figure 5. High level of weed control, but crop damage (row on left) due to crop rows being uneven and weeder blades hitting the crop.

3.2 Experimental year two (2021)- Square farm

3.2.1 Weed assessments

The weed species recorded were annual species such as chickweed (*Stellaria media*) and redshank (*Persicaria maculosa*), and perennial weeds such as broad-leaved dock (*Rumex obtusifolia*), dandelions (*Taraxacum officinale*) and couch grass (*Elytrigia repens*) (Figure 6).

Figure 6. General weed burden at Square Farm in August 2021 in beetroot crop area. A mix of annual and perennial weeds.

The mean percentage weed cover, assessed on two occasions post-weeding in both the beetroot and turnip crops are shown in Table 2.

Table 2 The mean % weed cover in beetroot and turnip compared to the untreated control in 2021

	Mean % weed cover in each crop treated				
	Untreated area	Beetroot		Turnip	
Date of assessment		Hand weeder	Robotic weeder	Hand weeder	Robotic weeder
16/08/21	60.0	10.0	11.7	10.0	13.3
08/09/21	100.0	10.0	11.7	10.0	6.7
29/10/21	100.0	85.0	81.7	80.0	86.7

On the day of weeding (16 August 2021) there was an overall weed ground cover of 60%. Both the weeding techniques significantly reduced the ground cover to 10% (hand weeding) and 11.7% (robotic weeder) in beetroot (Figure 7) and 10% (hand weeding) and 13.3% (robotic weeder) in turnips. Three weeks later the weeds in the untreated control area were

100% ground cover, however in both weeded areas the weed cover remained either the same as the first assessment or slightly less in the case of the robotic weeded turnip crop rows (6.7% cover), so giving over 90% control of the weeds. This may also have been due to the warm and dry summer weather conditions, so no new weeds were germinating in that time and any disturbed weeds had senesced. The final assessment was more than two months post weeding, and all plots had a significant amount of new autumn weed growth (all >80% weed cover).

Figure 7. Robotic weeded plots (L) against untreated plots (R) (left-hand side image) and a close-up of the robotic weeded plots in beetroot 16 August 2021 (right-hand side image).

The hand-held hoe that the farm owned was a Danish brand and it was more effective than the older ADAS hoe. However due to a national labour shortage the farm reported that it is extremely difficult to employ anyone to hand hoe at the current time.

3.2.2 Weeding time assessment

The time taken to hand weed the 30m plot length was 30 minutes compared to the robotic weeder taking 1.5 minutes to travel the same distance.

The National living wage is currently £9.50/hour, with £10.50/hour commonplace for skilled labour, so the economics of hand weeding or hoeing crops is becoming increasing difficult to justify and is a large input cost that is not easily transferable to the customer. If the beetroot crop had been hoed and hand weeded for the whole field it would have taken approximately 54 Hours/ha, therefore a cost to the grower of £513-£567/ha. It is likely that the crop would have required weeding on two or more occasions so the cost would have exceeded £1,000/ha.

3.3 Experimental year three (2022) – Haverfordwest

All treatments were carried out successfully and the soil conditions were very dry resulting in weeds lifting easily from both the mechanical weeding and hand-held tools (Figure 8 & Figure 9).

Figure 8. Robotic weeder in leek crop. Various examples of the blades lifting weeds.

The Steketee weeder was used with a Massey Ferguson 57715 (MF57715) was used. The farm would normally use a smaller tractor (100hp) with thinner wheel width but this was unavailable on the day. The MF57715 had wide wheels and if the leeks were any bigger would not have been possible to use.

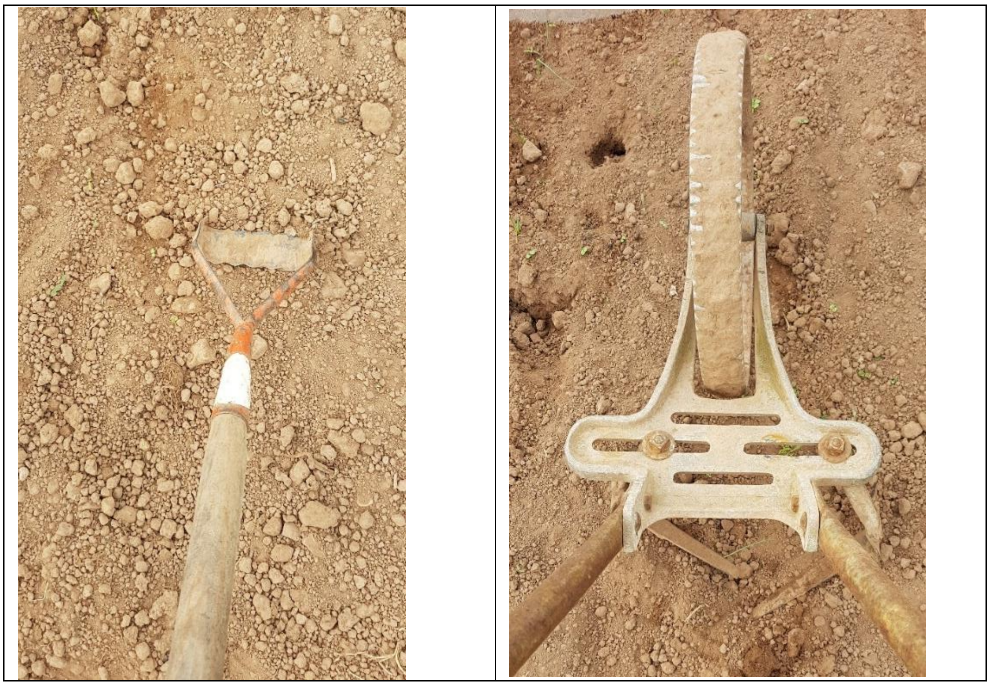

Figure 9. Hand hoeing (left), wheel hoeing (right)

3.3.1 Weed assessments

The weed species present at the Haverfordwest site included predominately annual meadow-grass (AMG) (*Poa annua*), white clover (*Trifolium repens*) and fat-hen (*Chenopodium album*). The annual meadow-grass was at a growth stage of late tillering (GS 28) to full flowering, so was not ideal for the start of the experiment as normally these grassweeds would have been removed at an earlier growth stage, such as GS12-13. Ideally weeding treatments would have been carried out at two different timings but only one timing could be carried out due to the hold up in delivery of the weeder from mainland Europe.

On the day of treatment (23 June 2022) the number of weeds per m^2 were assessed (Table 3) pre-treatment so the level of control could be compared post-treatment. There was more AMG in the plots that were to be robotically treated (63 plants/m^2), compared to the hand-held weeding plots (30 plants/m^2), just by chance.

3.3.1.1 Treatment timing one

Table 3 The mean weed number per m^2 on the day of treatment (Pre-treatment assessment)

Treatment	Description	Mean weed number per m^2	
		AMG	White clover
2A	Hand weeding A – wheel hoe	29.0	2.6
2B	Hand weeding B- hand hoe	30.0	4.3
3	Robotic weeder alone	63.3	6.0

Plots were then treated by the three different methods. The hand hoe was able to get very close to the leeks and weed very efficiently (Figure 10 & Figure 11). There was a lot of AMG within the crop row and this was difficult to access with all weeder methods, but the robotic weeder did not get close enough to the crop (Figure 12).

Figure 10. Example of the hand weeded treatment plots

Figure 11. Example of wheel hoe treatment plots – weed roots left exposed for desiccation

Figure 12. Robotic weeded plots. Untreated (Left), treated (middle and right) on the day of treatment.

Two-weeks post-treatment (13 July 2022) the level of weed control was assessed again for all treatments (Table 4).

Table 4 The mean number of weeds per m² two-weeks post-treatment

		Annual meadow-grass (AMG)		White clover	
Treatment	**Description**	**Mean weed number per m²**	**% reduction from UTC***	**Mean weed number per m²**	**% reduction from UTC***
1	Untreated control	36.0	-	1.0	-
2A	Hand weeding A - wheel hoe	22.0	24.0%	1.7	35.0%
2B	Hand weeding B - hand hoe	17.7	43.0%	2.7	37.2%
3	Robotic weeder alone	44.5	30.0%	5.0	17.0%

**this reduction was calculated from the pre-treatment plot count on 23/06/22*

The weather conditions had been extremely dry before the weeding treatments at the end of June and the follow-up assessment in mid-July. Therefore, no new weeds had emerged in that time. The results show that hand hoeing has been the most effective treatment in this trial achieving 43% reduction in AMG and 37% reduction in white clover compared to pre-treatment (Table 4). The robotic weeder achieved a 30% reduction in AMG between the crop rows, but the weeds were large and growing vigorously still close to the base of the leek plants (Figure 13). As previously mentioned, timing of the weeding was not ideal, due to the availability of the kit in spring 2022, so the weeds were at a much larger growth stage than ideal, and this has resulted in the lower levels of control recorded. The lowest level of control of white clover came from the robotic weeder in this trial.

Figure 13. Photos from assessment 13 July 2022, untreated control plot (Left) and robotic weeder treated plot (Right)

Although the levels of weed control were moderate there was no crop damage recorded on the post-treatment assessment indicating that the accuracy of the weeder between the crop rows was very good.

3.3.2 Weeding time assessment

The time taken for each treatment method to run through all plots is show in Table 5.

Table 5 Time taken for each weeding method in Haverfordwest

Trt. No.	Treatment	Time Taken for 3 x 10m plots
1	UTC	n/a
2 A	Hand hoe	16 minutes
2 B	Wheel hoe	10.5 minutes
3	Robotic weeder	21.60 secs*

**42 second turn around time at the end of the row (though if they were to use the weeder they would give themselves more space to turn at the row ends, therefore speeding up the process).*

It was obviously much faster to weed the plots using the robotic weeder than the hand weeding methods. Hand weeding took 16 minutes on average for a 30m length of one bed width of leeks, compared to only 21 seconds, for the same plot size with the robotic weeder. However in this trial the accuracy of the hand hoe resulted in a higher level of weed control as the weeder could go very close to the base of the leeks as was guided by eye and was much slower.

There were problems with stones lifting when the robotic weeder travelled at a higher speed, so the leeks were getting damaged (Figure 14). This was not in treatment plot areas, but in areas where the machine was being tested outside the trial. The damage was due to initial teething problems with the machinery and settings. The grower would like to combine the weeding with hilling up the leeks to provide a longer white stem in the future. This could be done by tine choice and speed as this equipment is very flexible and versatile.

Figure 14. Damage to leek crop when stones were lifted by the robotic weeder and the set-up was not adjusted properly. This was not in the trial area, but a test bed.

4 DISCUSSION AND CONCLUSIONS

Mechanically weeding vegetable crops with a robotic weeder, following set up, is obviously much faster than hand hoeing or weeding. Results from these trials conclude that the technology tested would be beneficial to small-scale horticultural growers to aid their weed control requirements, but the initial purchase cost and requirement to precision plant may deter some smaller growers. Appendix 1 outlines the annual cost of vision guided weeders at three different price points. The spreadsheet can be adapted for individual circumstances. The more expensive weeder would be difficult to justify on a small area. The ability to use the weeder in arable as well as horticultural crops, and using for tasks such as ridging up is beneficial in terms of increasing the area covered and reducing machinery cost/hectare. Multiple weed passes in a crop would also increase the machine area covered per crop, therefore reducing machinery cost/hectare.

There were problems encountered with uneven terrain and stony ground resulting in patchy weeding and some crop damage if stones were moved at speed. These could be over-come by reducing travelling speeds on such conditions or ensuring that the weeder tines were set correctly for that specific crop. The crop rows need to be extremely straight (precision planted) to ensure there is no crop damage as the tines get very close to the crop.

When comparing the time taken to mechanically weed compared to hand weeding within these trials it highlights the ever-increasing labour cost required for hand weeding, which can be as much as £16 per hour. However, labour is also more difficult to rely on and often in short supply as Brexit has affected peoples' choices to live and work in the UK from other parts of Europe and it is most often skilled seasonal staff of European background that have chosen these roles. Therefore, the continued development and uptake of such technology will benefit the horticultural industry going forward if labour continues to be limiting or more expensive.

For the purposes of the field trials in 2022 a Steketee EC-weeder was used with just the tine inter-row attachment. They can customise the hoeing machine to suit different crops and for different requirements to include inter-row and intra-row hoeing. They also have different tines for more stony ground and heavy soils, so there are many alternatives available beyond what were tested in these trials. This technology is therefore already available to growers and can be tailored to specific requirements. When intra-row hoeing is required the tractor speed is likely to be required to reduce to allow higher accuracy and reduce crop damage. As technology keeps improving and more autonomous systems are developed and used travelling speeds may increase.

The field operations analyst and tractor driver of Puffin produce/Blas Y Tir who trialled the Steketee machine in 2022 thought the mechanical weeder should reduce the need for one of the post-emergence herbicide applications and increase overall efficacy of weed control. They were very impressed with the Steketee kit and the control level achieved. It also has several different attachments and can be tailor-made for specific requirements on purchase. In the meantime, this grower has recently purchased an Edwards weeder, which was manufactured in the UK. The overall cost was cheaper, with the Edwards weeder approximately £20K, as opposed to approximately three times more for a Steketee machine (which is larger) and the size of this machine suits this grower. The design parts for the inter-row hoe are similar, and at the time of writing the lead in delivery time to purchase the Steketee machine was approximately 9 months, with the Edwards machine closer to 2 months. However, there are no data available to compare the efficacy of the Edwards machine in this project as it had not arrived on the farm. This grower may consider buying a second machine to have multiple units running at once in the future.

There are also other precise weeding machines commercially available in Europe fitted with vision guidance systems that can hoe within crop plants (intra-row) within a row for transplanted crops which were highlighted in the EIP-Agri Focus group report (2020). These include: Robovator (**www.visionweeding.com**), Robocrop (**www.garford.com**), Steketee IC (**www.steketee.com**) and Ferrari Remoweed (**www.ferraricostruzioni.com**). The Ferrari Remoweed uses infrared light sensors to detect crop plants, while the other three machines detect crop plants using cameras. It was concluded that all these machines are best suited for use in crop stands where a clear crop-weed distinction is present. It was discussed by Canon *et al*., (2019) that very few scientific-based evaluations of these weeding systems have been undertaken. The Robocrop system appears to have been trialled or reported the most, perhaps as it was one of the first systems developed with results in commercial cabbage crops showing low levels of crop damage and weed control ranging from 62-87% control (Tillet *et al*., 2008).

In Denmark there is a system called 'Optiweeder' developed by MSR Plant Technologies (https://www.msrplanttechnology.dk/opti-weeder/). It is used commercially in potato crops and has the advantages of being able to travel quite fast (10-25 km/hour) and claims it can get within 1cm of the crop without causing damage. It can inter-row weed between crop rows and on the side slopes and curves around the crop ridge. It is being trialled by Danish weed researchers currently for weed control efficacy. Also developed in Denmark are various machines produced by Agrointelli (Agro Intelligence) (https://agrointelli.com/) for precision planting and weeding including finger hoe and duck foot attachments. The machines are called 'Robotti' and are self-driving machines for use in vegetable crops including carrots, lettuce, onion, and potatoes. They are currently in distribution across 13 different countries and are continuing to be further developed and modified.

A slightly different Danish system is the FarmDroid ED20 (https://farmdroid.dk/en/product/) which is the world's first lightweight fully automatic field robot system for precision sowing and weeding in an ecological way as is CO2-neutral. There are no cameras for weeding so the seeding system has to be used first and then the crop is weeded based on the seeding plan. It can perform inter-row and intra-row weeding. The systems are small (3m width) but as they are very light weight, they reduce the risk of soil structure damage compared to heavy equipment and use solar panels for power. It can be left in the field continuously and re-charges automatically via the solar panels for the electrical charge required for power. They are recommended to be used as one robot per 20 hectares. It was initially developed for sugar beet but now used in onions, spinach, kale and herbs. By 2020 the FarmDroid was available in 7 countries.

In the UK the Small Robot Company have developed field robots (Tom, Dick and Harry) that are also fully autonomous (https://www.smallrobotcompany.com/). They combine robotics and artificial intelligence (AI) for state-of-the-art systems for mapping weeds, down to per plant accuracy that can then be controlled in a separate operation (such as precision spraying or electrical/thermal weeding).

The availability of herbicides may also be more limited in the future as many of the products used in vegetable crops require off label approval extension of authorisation for minor use (EAMUs) and regulation of such approvals are getting more challenging. The requirement to use less pesticide inputs from environmental, economic, and increasingly consumer choice will require growers who are currently not organic to choose more integrated weed management (IWM) options in the future. This type of technology is therefore an extremely valuable tool for IWM control strategies.

Unfortunately, the trialling within this project were limited due to several reasons including Covid-19 restrictions. However, results have shown that robotic weeding using vision-guided systems normally used in broadacre crops, in different vegetable crops are extremely effective and as long as they are adaptable and at a reasonable purchase price, they will be very valuable for small scale growers going forward. There are also lots of exciting robotic system developments in Europe and the UK in vegetable crops that are increasing in popularity and availability in the near future.

5 REFERENCES

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APPENDIX 1 - ANNUAL COST ASSOCIATED WITH MECHANICAL WEEDER

IMPLEMENT														
Purchase price			20,000		Purchase price			40,000			Purchase price			60,000
Selling pri	6	Years	8,000		Selling pri	6	Years	15,500			Selling pri	6	Years	23,000
Hectares worked annually			10		Hectares worked annually			10			Hectares worked annually			10
Fixed costs					**Fixed costs**						**Fixed costs**			
Average value per yr owned			14,000		Average value per yr owned			27,750			Average value per yr owned			41,500
Interest	4.5	% rate	630		Interest	4.5	% rate	1,249			Interest	4.5	% rate	1,868
Annual Depreciation			2,000		Annual Depreciation			4,083			Annual Depreciation			6,167
Insurance	0.15	% of purch	30		Insurance	0.15	% of purch	60			Insurance	0.15	% of purch	90
Annual re	6	% of purch	1,200		Annual re	6	% of purch	2,400			Annual re	6	% of purch	3,600
Total annual fixed cost			**3,860**		**Total annual fixed cost**			**7,792**			**Total annual fixed cost**			**11,724**
Fixed cost per Ha			**386.00**		**Fixed cost per Ha**			**779.21**			**Fixed cost per Ha**			**1,172.42**
Operating costs*					**Operating costs***						**Operating costs***			
Ha covered/ worked per hour	0.15				Ha covered/ worked per hour	0.21					Ha covered/ worked per hour	0.28		
Labour co	15	£/Hr			Labour co	15	£/Hr				Labour co	15	£/Hr	
Labour per ha			**£100.00**		**Labour per ha**			**£71.43**			**Labour per ha**			**£53.57**
Fuel price £/lt	0.9	£/Lt			Fuel price £/lt	0.9	£/Lt				Fuel price £/lt	0.9	£/Lt	
Fuel consumption lt/ha	8.00				ConsumptionL/ha	7.00					Fuel consumption lt/ha	6.00		
Cost of fuel per Ha			**£7.20**		**Cost of fuel per Ha**			**£6.30**			**Cost of fuel per Ha**			**£5.40**
Tractor hi	**15**	**£/hr**	**£100.00**		**Tractor hi**	**15**	**£/hr**	**£71.43**			**Tractor hi**	**15**	**£/hr**	**£53.57**
Total cost per Ha			**£593.20**		**Total cost per Ha**			**£928.37**			**Total cost per Ha**			**£1,284.96**
Hand labour cost	£/ha		**£1,100.00**		**Hand labour cost**	£/ha		**£1,100.00**			**Hand labour cost**	£/ha		**£1,100.00**
(based on 2 weedings)					(based on 2 weedings)						(based on 2 weedings)			

*Assume farm tractor cost on farm low Horsepower requirement and farmer labour at £15/hour