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Optimization of spray application on bed-grown vegetables. On-going developments within the OPTIMA project

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Summary

The development of a smart sprayer for carrot is one of the issues of the OPTIMA IPM project (www.optima-h2020.eu). The general design of this sprayer is combining several smart components with optimized application technologies adapted to crops grown in beds like carrot. A Decision Support System (DSS) uses local weather forecasts (resolution of about 1 km²) combined with an epidemiological model for Alternaria in order to predict potential infection periods. Alternaria disease is identified by using an Early Detection System (EDS) where disease spots are identified in images from a multispectral camera and dynamic detection is possible with deep learning. Besides the development and implementation of these smart components, the sprayer itself is also optimized. A first series of experiments was aimed at selecting the most appropriate nozzles and nozzle arrangements. Clusters of four nozzles are defined to spray on a single crop bed. Within a cluster, the distance between nozzles equals the boom height in order to focus sprays on crop beds in a way that distances/heights are adapted to crop development stage. Assuming the broadcast application is deemed to provide an acceptable biological efficacy, a potential dosage reduction of up to 60% can be reached when nozzle distance/height is 0.4 m corresponding to early development stage (Zwertvaegher *et al*., 2020).

Additional functionalities of the OPTIMA sprayer for carrots are studied in the project. A variable air support mounted on the boom sprayer is specifically designed using an electrical driven fan able to adapt the airflow in order to increase spray deposition and penetration inside the canopy, but also to reduce spray drift. Preliminary investigation with a 2 m wide prototype boom including four nozzles was tested showing contrasted results depending on the spray configuration at early and late development stages of carrots. Field tests will be conducted in 2021 to cross compare the reference situation using FF110 04 nozzles – 12 km h^{-1} – 158 L ha^{-1} without any smart devices with the smart sprayer including the optimized set of low drift nozzles and the air support. Deposition and spray drift will be tested according to ISO 25522 and ISO 22866 protocols respectively. PWM nozzle control is implemented on the sprayer in order to allow variable rate applications (VRA) according to a prescription map based on the EDS and DSS. This VRA functionality will be operated in the fields with either synthetic fungicides or BioPPP selected for their efficacy against Alternaria in laboratory conditions. Results of these field investigations will be presented.

Keywords: Bed-grown carrots, spray optimization, IPM

Introduction

Carrot production in Europe represents about 4.7 million tons and about 103 thousand hectares (Cook, 2020) mostly found in Poland, Germany, France and UK. Carrots represent a typical food component for humans and especially baby food. Several diseases are affecting carrot crop among them Alternaria Leaf Blight (*A. dauci*) a fungus that causes epidemic damages on leaves leading to a reduction of the crop yield and crop quality. Several fungicide applications can significantly reduce the risks (Callens *et al*., 2005) but raise the issue of Plant Protection Products (PPP) residues in carrots (Horska *et al*., 2021). Alternative solutions may also rely on less sensitive cultivars (Boedo *et al*., 2008) or the use of bio PPP (Koch *et al*., 2010). Conventional boom sprayers are generally used to spray on bed-grown vegetables through a broadcast application. However carrots are seeded considering three to four rows per bed of about 1.80 m, each row including three or two sub-rows respectively, the crop occupies a variable surface on beds according to the growth stage. Broadcast applications involve then substantial losses of product, especially during the early stages of the crop growth. Two ways are considered to mitigate the impact of PPP, the first one focuses on the improvement of the spray application, i.e. to maximize PPP deposits on the target crop and the other one aims at limiting losses to the environment through ground losses and spray drift. Giles & Slaughter (1997) developed a precision band spraying system for small plants using vision sensors and the automatic adjustment of the yaw angle of a flat fan nozzle. Modifying the spray footprint direction involved a better adjustment of the spray to the target width. In this case, a reduction in spray application rates of 66–80% was operated considering an increase in the target deposition efficiency of 2.5–3.7 times followed by a reduction of non-target deposition on the ground of 72–90% compared to conventional spraying. In addition, Giles & Slaughter (1997) also suggested a significant decrease in airborne spray drift with such precision spraying techniques. Other research by Holterman *et al*. (2018) was based on the adaptation of the spray pattern to different bed widths and the ability to apply different dose rates depending on the crop canopy height. However, they did not study the possibility of adjusting nozzle spacing and boom height to the canopy width depending on crop growth stage. The effect on canopy deposition, ground losses and spray drift potential, possibly further reducing PPP use and environmental contamination were the goal of this study

Specific cropping system and necessity to adapt the spray configuration

Another way to optimise spray applications on bed grown crops relies on the adaptation of the nozzle spacing and nozzle height to the bed width. This strategy theoretically involves target sprays on the bed and to minimise losses between the beds. Laboratory tests were conducted by Zwertvaegher *et al*. (2020) leading to the definition of optimal spray configurations. It is based on the improvement of spray deposit on crop with subsequent economic benefits and as well as biological efficacy.

These are among the goals of the H2020-project OPTIMA (OPTimised Integrated pest MAnagement for precise detection and control of plant diseases in perennial crops and open-field vegetables, www.optima-h2020.eu). Indeed, a smart sprayer is specifically developed for bed-grown carrots.

Materials and Methods

Necessity to develop a fully integrated IPM system from the risk evaluation to the application

The development of a smart sprayer for carrots is one of the issue of the OPTIMA IPM project (www.optima-h2020.eu). The general design of this sprayer is combining several smart components with optimized application technologies adapted to crops grown in beds like carrot. A Decision Support System (DSS) uses local weather forecasts (resolution of about 1 km^2) combined with an epidemiological model for Alternaria in order to predict potential infection periods. Alternaria disease is identified by using an Early Detection System (EDS) where disease spots are identified in images from a multispectral camera and dynamic detection is possible with deep learning.

These preliminary experiments aims at defining five spray configurations with different practical objectives:

- Broadcast application using FF spray at constant nozzle distance and nozzle height with an application rate of 160 L ha^{-1} (FF)
- Bed adapted configuration with wide angle FF sprays with reduced application rate (80 L ha^{-1}) (FFred)
- Bed adapted configuration with wide angle drift reducing air inclusion nozzles with an application rate of 160 L ha^{-1} (AIw)
- Bed adapted configuration with narrow angle drift reducing air inclusion nozzles with an application rate of 160 L ha^{-1} (AIn)
- Bed adapted configuration with drift reducing nozzles combining Off-Centre and wide angle air inclusion nozzles with an application rate of 160 L ha^{-1} (AIC)

In this case, a bed adapted configuration means that both nozzle distance and nozzle height are adjusted to focus the spraying on a variable target within the bed according to the crop stage. All configurations were tested under a pressure of 3 bar, a travel speed of 12 km h^{-1} and with three levels of air support (No – Low or High air speed) as possibly delivered by the fan.

Phase 2 : Characterization of spray efficacy

Each spray configuration was tested in semi-field conditions for validation at INRAE Montpellier using a prototype boom of 2 m width provided by Caffini Spa, Italy. The spray mix composed of dye tracer with water was distribute to nozzles using air pressurized container with a pressure controller. The air support was provided by a fan controlled with a two-phase inverter.

Fig 1. Deposition experiments on artificial collectors – source INRAE.

Carrots were grown in bins and experiments were achieved either at early development stage (BBCH 19) or at later stage closer to maturity (BBCH 49). Two different varieties (Soprano® and Maestro®, Vilmorin, France) were compared considering their differences in terms of leaves architecture (spread leaves or upright).

Deposition on carrot leaves and ground losses

Spray deposits on the crop leaves or ground losses were evaluated for the different spray configurations using a dye tracer (Brillant SulfloFlavine BSF 1g L^{-1}) in solution with water. Plastic collectors (of 7.5cm × 2.5 cm were distributed on carrot foliage and under the foliage for deposition and ground

Fig. 2. Carrots grown in bins and artificial collectors used for dye collection and quantification – Source INRAE.

losses evaluation respectively. Six collectors were placed on the foliage per bin (considering six bins in total) plus six collectors placed under the foliage. After each spray application, exposed collectors were let to dry and stored before analysis. The quantity of dye tracer on the collector was determined by spectrofluorometry after washing the collector with a known volume of water. For this purpose, a calibration curve was defined using successive dilutions of spray mix. Results were expressed as relative deposition in reference to the application rate.

Potential spray drift

Potential spray drift of the different spray configurations was evaluated using ISO 22401 (2017) methodology (Fig. 6). A test bench consisting of 20 dishes spaced 0.5 m were covered while the boom passed over the test bench. The spray mix consisted of BSF dye tracer at a concentration of 1 g L^{-1}. After the boom reached a distance of 2 m beyond the test bench, the dishes were automatically uncovered and droplet remaining in the atmosphere were collected. The advantages of this methodology were the absence of both a target vegetation and a natural wind. A global indicator of Potential Spray Drift was calculated with the addition of all deposits normalized by the application rate.

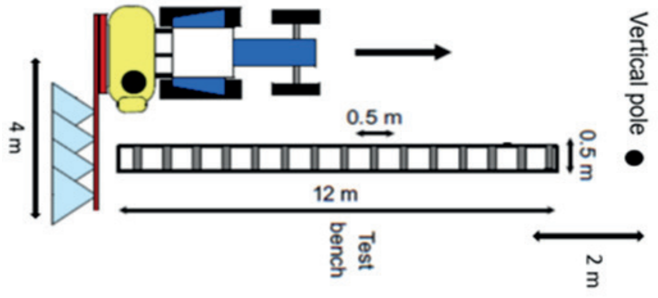

Fig. 3. Methodology for Potential Spray Drift measurement according to ISO 22401 (2017).

Field experiments

Field experiments were operated in Cestas, South West France, estate Planete Vegetal. Spray deposition and spray drift tests were conducted in a field with the comparison of the reference broadcast application (XR11004/XR11004/XR11004) with the Optima spray configuration (AIUB8504/AI11004/AIUB8504).

Results and Discussion

In an objective of simplicity, main results were expressed relatively to the reference spray configuration.

Compared to the reference, droplet size results followed some effects linked to nozzle angle, nozzle size or nozzle type (Table 1). For the same nozzle size (full application rate), a narrower angle

Table 1. *Median volume diameter and median volume velocity of a set of nozzles*

Spray configuration - 3 bar	Volume Median Diameter (µm)	Volume Median Velocity (m s^{-1})
Broadcast - FF Sprays wide angle - 160 L ha^{-1}	Ref	Ref
Bed adapted - Narrow angle - FF - 160 L ha^{-1}	+13%	+50%
Bed adapted - Narrow angle - FF - 80 L ha^{-1}	-13%	-12%
Bed adapted - Drift reducing Narrow/wide angle - 160 L ha^{-1}	+53%	-9%

induced an increase in the volume median diameter. Conversely, a reduction of the nozzle size (reduced application rate) induced a reduction of the volume median diameter (Nuyttens *et al*., 2009). Another effect was visible when comparing the reference FF nozzle with air inclusion nozzles. In this last case, the volume median diameter increased by 53% compared to the reference.

Droplet velocity was much higher for the reduced application rate nozzle compared to other nozzles and the reference nozzle. Sensitivity to the air support was also much visible in this case (results not shown).

Table 2. *Lateral Spray Distribution indicators considering a bed width of 1.60 m*

Spray configuration	CoV (%)	% Off target losses
Broadcast - FF Sprays wide angle - 160 L ha^{-1}	5.3%	33%
Bed adapted - Narrow angle - FF - 160 L ha^{-1}	8%	12%
Bed adapted - Narrow angle - FF - 80 L ha^{-1}	7%	12%
Bed adapted - Drift reducing Narrow/wide angle - 160 L ha^{-1}	5.9%	9%

The situation of a bed width of 1.60 m corresponded to an intermediate situation between the extreme values of 1.4 m and 2.2 m. As shown in Table 2, the CoV for all spray configurations was maintained in a range of 5% to 8% that was complying with the requirement of ISO 5682-2 with a maximum acceptable CoV under the boom of 9%. Beyond the acceptable evenness of the liquid distribution over the bed, the main benefit of bed adapted spray configurations was the significant reduction of the losses on both sides of the bed that can be up to three times less than the reference. When comparing the results on a wider range of bed widths, it was observed that the smaller the bed width, the higher the lag between the reference spray configuration and bed adapted ones. Conversely, increasing the bed width logically led to more homogeneous distribution performance (lower CoV) for the different spray configurations including the reference due to the increase in the boom height.

Table 3. *Relative deposition (late crop stage)*

Spray configuration	Relative deposition (%)	Ground Losses (%)
Broadcast - FF Sprays wide angle - 160 L ha^{-1}	Ref	Ref
Bed adapted - Narrow angle - FF - 160 L ha^{-1}	+25%	+50%
Bed adapted - Narrow angle - FF - 80 L ha^{-1}	+50%	+50%
Bed adapted - Drift reducing Narrow/wide angle - 160 L ha^{-1}	+62.5%	+50%

The deposition on the crop leaves shown in Table 3 increased for all bed adapted spray configurations compared to the reference. Surprisingly, the reduced application rate case gave higher relative deposition compared to the full application rate situation. Bed adapted spray configuration with air inclusion nozzles gave the highest relative deposition. Ground losses under the leaves were the lowest for the reference configuration. All spray configurations that were susceptible to the deposition on the crop also increased the ground losses probably due to the vertical porosity of the foliage.

Although some specific effect was observed, the global influence of the air support was not statistically significant for any of the bed adapted spray configurations. It is to consider the size of the prototype boom and the relatively high travel speed.

Table 4. *Potential spray drift*

Spray configuration	% drift reduction
Broadcast - FF Sprays wide angle - 160 L ha^{-1}	0
Bed adapted - Narrow angle - FF - 160 L ha^{-1}	24%
Bed adapted - Narrow angle - FF - 80 L ha^{-1}	-97%
Bed adapted - Drift reducing Narrow/wide angle - 160 L ha^{-1}	70%

As shown in Table 4, bed adapted spray configurations generally reduced spray drift compared to the reference except for the reduced application case involving a higher drift due to smaller droplets (*cf.* Table 1). The more visible effect on drift reduction was logically found for spray configurations using air inclusion nozzles. The influence of the air support was probably different depending on the spray configuration while no clear effect of the air support was demonstrated.

Elements for the definition of the specifications

The first objective of the project was to define optimal spray configurations in order to maximize the deposition of the spray liquid on the bed following the development of the crop during the season. The results showed that several spray configurations were found to cope with this objective assuming a proper adjustment of the nozzle distance and nozzle height. The second objective was to reduce the environmental impact in terms of spray drift. In this case, droplet size was probably the most important criteria leading to the exclusive choice of air inclusion nozzles.

However, these experiments did not demonstrate a clear and constant effect of the air support. A possible explanation lies on the small size of the prototype boom (1/10th of the boom width on the scale 1 sprayer) where with potentially high boundary effects of the air currents due to the travel speed compared to the air speed.

Additional specifications were considered in order to better adjust the application rate to a variable disease infestation. For this purpose, a PWM control of individual nozzles was implemented on the system and was tested with the different spray configurations inducing no significant change of the droplet size nor of the lateral spray distribution.

Conclusions

This project aims at developing a global solution against Alternaria combining IPM functionalities with a smart sprayer optimized for bed-grown carrots. The main proposals issued from a grower focus group were converted into technical specifications through laboratory measurements of nozzle flowrate, droplet size and velocity and lateral spray distribution and semi-field experiments for deposition and potential spray drift evaluation. The results demonstrated the benefit of bed adapted spray configurations where the nozzle spacing, and nozzle height are adjusted according to the crop development as expressed in terms of bed width. In this context, the use of air inclusion nozzles greatly helps in the potential reduction of spray drift. Field tests confirmed the benefit of an OPTIMA spray configuration based on the association of off-centre and air inclusion nozzles compared to a broadcast application.

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