Towards more target oriented crop protection

International advances in pesticide application

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Towards more target oriented crop protection

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Summary

Matching spray volume to crop canopy sizes and shapes can reduce chemical application, thus reducing operational costs and environmental pollution. Developments on crop adapted spraying are highlighted in orchard and arable crop spraying. A tree-specific variable volume precision orchard sprayer, guided by foliage shape and volume (canopy density sprayer; CDS) was developed. Spray deposition and biological efficacy and spray drift were evaluated in an orchard situation reducing spray drift by 25-90% and spray volume by 20-36% depending on growth situation. The transition of the potential of crop adapted spraying towards bed-grown arable crops is assessed. Sensor selection to quantify crop canopy is highlighted. Spray techniques to apply variable dose rates are evaluated. Potential volume rate savings are evaluated based on crop canopy structure evaluations during the growing season of bed-grown flower bulbs. It was shown that on average spray volume could be reduced by 25% and at early crop development stage even by more than 90%. Spray volume savings of a prototype plant-specific sprayer are shown to be more than 75% in early late blight spraying in potatoes.

Key words: precision farming, GPS, spray distribution, crop sensor, canopy density

Introduction

In crop spraying the goal is to achieve a uniform spray deposition all over the crop canopy structure or soil surface. Losses to the soil underneath the crop and outside the orchard or field, through spray drift are to be minimised. It is known that sprayer settings are important for spray distribution in tree and crop canopy. Matching spray volume and direction to orchard tree sizes and shapes can reduce chemical application, thus reducing operational costs and environmental pollution. Manual or sensor actuated orchard sprayers (Koch & Weisser, 2000; Molto *et al*., 2001; Solanelles *et al*., 2002) have shown potential reductions in agrochemical use of 30% and more. Sensors quantifying crop parameters such as quantity of biomass and photosynthesis activity are already commercially available. Sensors to evaluate the plant stress (MLHD 2004; Polder 2004) or spectral analysis of the crop canopy parameters (Bravo et al 2003; Vrindts et al 2003; Scotford & Miller, 2004) open the potential for more target oriented spraying in crop protection. Spray systems treating individual plants based on fluorescence (Rometron, Weed-It) as used on pavements (Kempenaar et al., 2007) or canopy reflection information (Ntech, GreenSeeker) used for fertilising are already developed. Precise application techniques recently developed able to vary dose rates are obtained by Pulse Width Modulation nozzles (Weed-It) and multi-nozzle holders (Lechler VarioSelect) with switchable number of nozzles varying in flow rate (Dammer & Ehlert, 2006); respectively in a continuous (50-300 l/ha) and a stepwise way (50-600 l/ha in 12 steps). Based on these possibilities we can achieve smaller units of treatment in the field. In spraying crop protection products this will lead from a full boom width treatment to section wise and even nozzle wise variable applications.

An example in which the different elements of precision farming are combined in fruit growing was the PreciSpray Project. An introduction is given to the next step in its development as part of ISAFRUIT project. The transition of the PreciSpray concept, from the orchard to arable crops, is in progress. A Canopy Density Sprayer (CDS) for bed-grown crops like flower bulbs and potatoes is under development. This paper presents an overview of recent developments and introductions in agricultural practice of crop adapted spraying for crop protection in orchard and arable crop spraying.

Materials and Methods

Fruit Growing

Developments on precision crop protection in orchard spraying started in The Netherlands with the PreciSpray project (Meron *et al*., 2003; Van de Zande *et al*., 2003; Achten *et al*., 2003). In the PreciSpray project a high-tech integral approach was developed to orchard spraying in which an advanced orchard management system is combined with a high-tech segmented cross-flow sprayer for orchard pest control. The control system consists of several interlinked components: an orchard management GIS, an aerial survey system, a pest/disease scouting system and a spraying system. The orchard management system is the integrator of all subsystems. Its basic functions are the data storage and processing, the processing of scouting information (infestation maps), semi-automatic generation of a spraying order, and the generation of a sprayer file with site-specific sprayer settings. The PreciSpray system controls an advanced prototype sprayer in a way that it adapts to local orchard conditions (tree volume, tree canopy location etc.). This prototype is a single sided cross-flow sprayer with five extendable segments (sections) of 0.50 m height above each other. The sections can move perpendicular to the driving direction by means of electrically actuated side-shifts. Each section has an air outlet and three nozzles that can be switched on/off individually. A summary description of the features of the prototype PreciSpray sprayer is given. Results from spray drift and spray deposition measurements and biological efficacy against apple scab are summarised.

Next steps in development of precision crop protection in fruit growing are generated in the IsaFruit project. IsaFruit aims at the reduction of chemical residue in fruit and minimizing the environmental impact of agrochemical application by precision dosing and crop oriented application of chemicals and thereby contributing to sustainable production of safe and healthy fruit and increased consumption of fruit and fruit products. The tools and methods of agrochemical application in sustainable fruit production have to be strictly oriented on the crop itself and the crop surrounding, taking into account the individual properties of the targets, the actual crop requirements, the environmental circumstances of treatments as well as pest/pathogen development. Due to spatial and transient variability within the crop-environment-pest/pathogen system the precision agriculture methods will be used for a site specific crop adapted application both in macro and micro scale. This crop adapted application consists in the integration of the following elements and using the extracted information for elaboration of application strategies and chemical dose adjustment according to the actual need and with respect to the environment:

- identification of crop characteristics and its variability across the vegetation season;
- identification of pest/pathogen development on the crop;
- identification of environmental circumstances during the treatment (climatic conditions, crop surrounding, sensitive areas, buffer zones);
- evaluation of effects of crop adapted spray applications.

Elements of IsaFruit are further described.

Arable Crops

A Canopy Density Sprayer (CDS) for bed-grown crops like flower bulbs and potatoes is under development. This CDS prototype spraying system combines detailed crop information (spectrum analysis) with very accurate application techniques. The system sprays only when there are crop plants under the spraying nozzle(s) (Figure 1). When leaves emerge from the soil only the leaves are sprayed: the sprayer operates as a patch sprayer. When the crop develops it forms rows and the CDS becomes a band sprayer. When the crop canopy covers the whole bed, only the bed will be sprayed but not the paths in between. When the crop develops to its maximum height (flowering) spray volume will be adapted to crop height or total leaf area to cover total leaf area uniformly. Expected reductions in agrochemical use vary from 25% in the full-developed canopy to more than 90% in the initial leaf stage based on crop growth development evaluations during the growing season of flower bulb crops grown on beds.

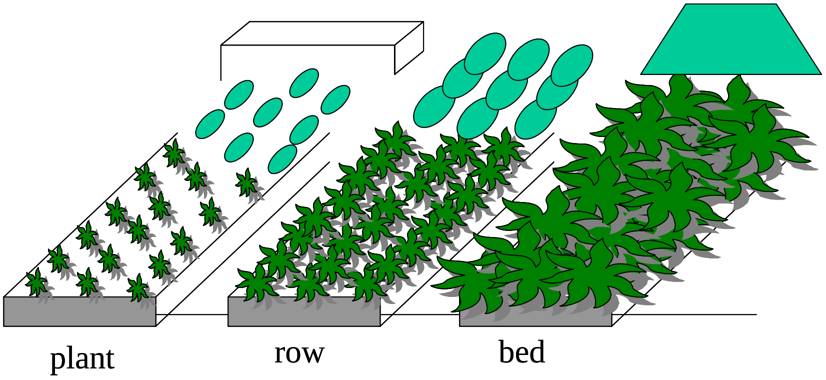

Figure 1 Schematic presentation of the development of a Canopy Density Sprayer for bed grown crops

With the GreenSeeker sensor reflection measurements have been performed in the spray technique laboratory to obtain information on variation in canopy reflectance with different growth stages. Based on these reflectance values in red and near-infrared wavelengths the Normalised Difference Vegetation Index (NDVI) is calculated. NDVI is assumed to be a good parameter to steer a sprayer for variable rate application for different growth stages. Pallets with lily plants in two densities (50 and 100 plants/m^2) and three growth stages (10cm, 30 cm, 60 cm) were placed under the spray track in the WUR-PRI laboratory. To the spray track a GreenSeeker sensor was attached which could move in 0.1, 0.5 and 1.0 m/s driving speed over the crop canopy to measure crop canopy reflectance. Canopy adapted spraying systems are momentarily tested in prototype versions in potato and flower bulb crops. Precise spraying and dose adaptation to the canopy volume are elements of research to optimise the spray deposition process. Variable dose rates are obtained by Pulse Width Modulation nozzles (Weed-It) and multi-nozzle holders with switchable number of nozzles varying in flow rate (Lechler VarioSelect); respectively in a continuous (50-300 l/ha) and a stepwise way (50-600 l/ha in 12 steps).

Results

Fruit Growing

How the PreciSpray sprayer operates in practice is schematically summarised in figure 2. To control the sprayer, the controller needs to know which trees are in front of the sections and how they are shaped (Figure 2, step 1). Therefore a tree shape and volume map is generated based on three-dimensional orchard maps supplied by an aerial photogrammetry system.

Based on the canopy distance from the trunk (Figure 2, step 2) the nozzle settings are defined to match spray volume to the canopy volume. For the different segment heights a sprayer application map is generated (Figure 2, step 3) defining how many nozzles are to be opened and what the position of the segments must be related to the canopy contour line. This application map is transferred to the sprayer controller (Figure 2, step 4).

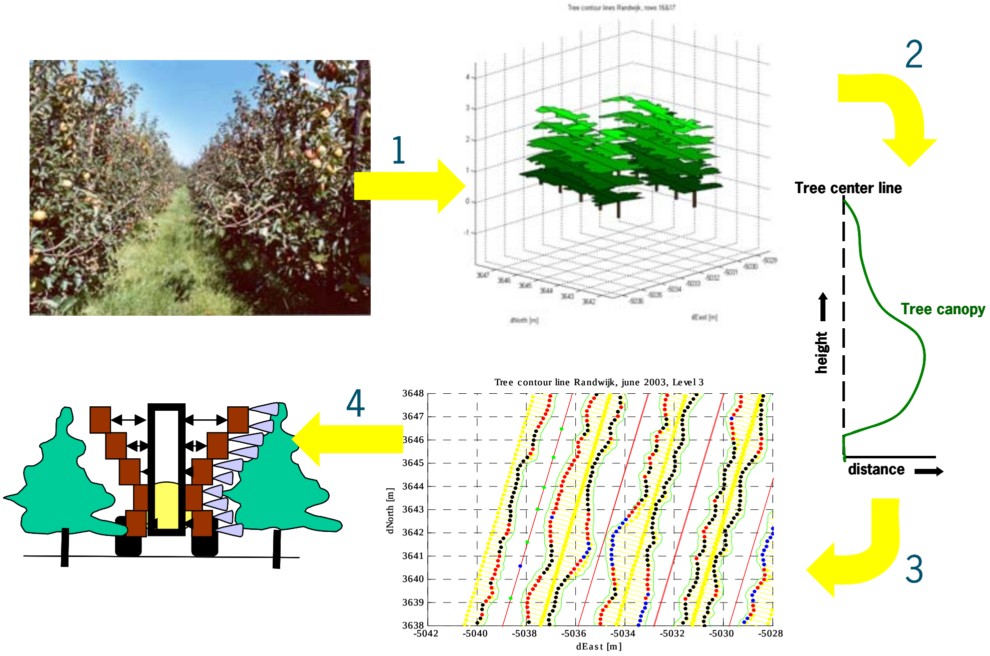

Figure 2 Schematic layout of the steps made from a target definition in the orchard to actual precise spraying: 1. a tree placement and volume map, 2 a nozzle setting definition by canopy contour distance, 3 a sprayer application map and 4 a working segmented cross-flow spraying with canopy adapted spray volume.

In order to control the orchard sprayer mechanics in a way that it adapts to local orchard conditions, electronics and software were designed and built. The electronic control system was split in a high- and a low-level control system. The low-level control (section control) system is responsible for the direct control of the sections. The high-level control (sprayer control) system is responsible for determining the position of the sprayer sections (by using RTK-DGPS) in the ‘digital’ orchard and controlling the low-level system according to the site-specific information in the application map. The electronics and software guided the sprayer smoothly through the orchard. The design, based on distributed computing (CAN-bus technology), is extensible and proved well suited for an accurate control of the sprayer.

The PreciSpray system shows that it is possible to guide an orchard sprayer that adapts to tree size and –shape through an orchard in order to reduce environmental pollution and operational costs. The sprayer performance was evaluated by using the on-line generated feedback file afterwards. With the aid of this feedback system it was also possible to trace spray liquid application at tree level. The PreciSpray project showed that a reduction of agrochemical input could be achieved (20-36%) by using ‘intelligent’ spraying while maintaining biological efficacy (Heijne et al. 2004). Especially the dynamic positioning of the spray elements showed that the spray deposit in the top of the trees increased (Zande et al. 2003) and thus improved efficacy.

The results of the PreciSpray project are an incentive for further development of the concept. Especially the real-time sensing of crop canopy density can be a useful option. This eliminates the need for an (often out of date) detailed sprayer application map because real-time orchard information is obtained on the go. Elements described are picked up in the ISAFRUIT project. Work Package 5.1 of this project 'Safe European fruit from a healthy environment, ECOFRUIT' aims at the reduction of chemical residue in fruit and minimizing the environmental impact of agrochemical application by precision dosing and crop oriented application of chemicals. An electronic crop identification system (CIS) will be developed that can drastically reduce the losses due to improper sprayer settings, and improve the efficacy of spray deposits. The CIS system will be fitted with ultrasonic sensors, forward speed sensor, software and series of actuators will be able to determine the presence of the target (tree or single branch), its geometry and phenological stage and to adapt the spray application (vertical pattern, number of active nozzles, spray and air volume), to those parameters. The target characteristics taken into account for the determination of the spraying parameters will be the canopy height (CH) and the growth stage, based on the BBCH classification. Thanks to this target-oriented spray approach and to the consequent reducing of the chemical dosages, an improvement of the uniformity of spray distribution on fruits is expected, as well as a minimisation of pesticide residues in the product.

Also novel technologies will be developed to quantify tree health conditions (Crop Health Sensor, CHS) in the orchard, based on the developments in crop sensing techniques for grassland and arable crop production (Schut, 2003), like vision and spectral analysis. By adapting the sensors for fruit production, dose and timing of chemicals will be determined based on crop health situation of the fruit tree. First results of the Crop Health Sensor under development show that apple scab can be detected on the apple leaves. Specific wavelength in the reflected light can be used to discriminate between healthy leaf and spots with apple scab infestation on the individual leaf. It is still under research what the earliest time after infestation is before apple scab can be detected. This is important to develop new crop protection strategies depending on the availability of specific agrochemicals. Health status maps of the orchard can be made based on the continuous measuring of plant health during spraying by means of the CHS and using the position of the sprayer (GPS) during the season. Spray volume will be adapted following the relationship between crop health and required protection level using a specific plant protection product; in this case an example is made for apple scab (*Venturia inequalis*) on apple leaves.

A novel spray application method will be developed for automatic on-line adjustment of sprayer working parameters in order to guarantee respecting the buffer zones and by that preventing the pollution of sensitive areas located within or outside the orchard; Environmentally Dependent Application System (EDAS). The application parameters such as nozzle type and air jet velocity will be adjusted based on the wind situation (velocity and direction), according to the local rules regarding buffer zones and depending on the position of the sprayer in relation to the neighbouring vegetation and sensitive areas (surface water, wells, buildings, sensitive crops, public areas, etc). The sprayer adjustments will be made to minimize the chemical deposition on the sensitive objects where it should be avoided and yet deliver a sufficient amount of spray on the target objects where it is needed to guarantee a satisfactory control of pests and diseases. The different elements will be integrated in a prototype sprayer and tested in the field.

Arable Crops

Potential use reduction

In order to quantify the potential of crop adapted spraying in arable crops an inventory of crop development in flower bulb growing was made. For a bed-grown crop like lilies it is obvious that easiest savings in spray volume can be made by not spraying the paths between the beds. As beds are created at 1.50m spacing and the planted area of the bed is 1.0m wide, about 30% of the area should not to be sprayed against fungal diseases. Canopy development and potential spray volume saving for the 2003 growing season of a lily crop (var. Stargazer) is shown for crop coverage on the bed and between beds on the paths and crop height on the bed (figure3). Potential spray volume savings in the early season are possible by only spraying the individual plants. More than 90% is not to be treated at first sprayings against fire blight (*Botrytis ssp.*) based on green area coverage. This reduction potential reduces as canopy develops to about 25% when the bed is fully covered with green canopy and only the paths in between the beds are not treated. Based on canopy height, savings can be generated up till the moment of maximum height of the crop which is moment of removing the flowers. As the crop is grown to produce flower bulbs the flowers are cut when starting to flower. Based on crop height the potential reduction in spray volume could be more than 90% for the early sprayings and on average around 45% for a whole crop growing season (fig 4).

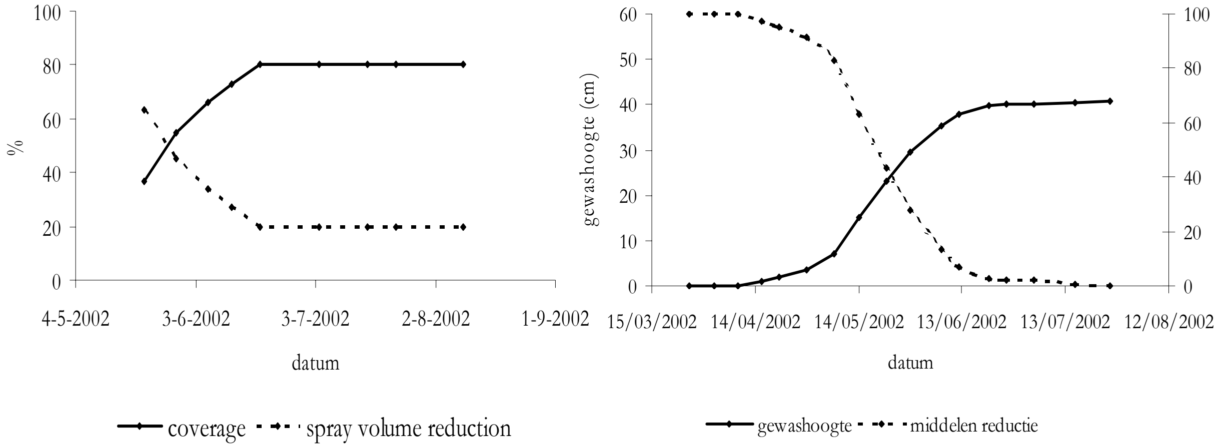

Fig. 3. Coverage with crop canopy (lily cv Stargazer) of the bed and the path between the beds during the growing season and potential spray volume reduction by only spraying green parts (left) and Crop height during the growing season and potential spray volume reduction (right) by adapting spray volume to crop height (full dose at maximum crop height).

To verify spray volume reduction in practice, a field experiment was performed applying the reduced spray volumes before full growth situation at reduced doses. Normally from the first spraying onwards a full dose is applied (1.6 l/ha Allure). First spraying was reduced to 0.1, 0.2, 0.4 or 0.8 l/ha and being doubled until full dose at each next group of applications. First results of this scheme on average lily bulb weight and relative yield shows (table1) that even starting first spraying in the season with only 1/16th of the advised dose did not affect average bulb yield significantly. Nor was average green area at harvest time significantly affected except with the lowest starting dose of 1/16th of advised. These first measurements show the potential of using lower doses at early sprayings. Automating the adaptation of dose to the crop canopy density would be a challenge. Sensors on the market, currently used for advising on fertilizer use could be an opportunity to use also for canopy density characterization.

Crop canopy sensor

In the laboratory different plant densities and heights of a lily crop were used to evaluate a GreenSeeker sensor for determining the reflection of different canopy densities. NDVI results are presented in table 2 for the three crop heights and two plant densities. There is no difference in NDVI for the middle and high crop irrespective of plant density. Only the low crop height shows a difference in reflection also between plant densities.

Table 1 Effect of crop adapted spraying against fire blight (*Botrytis ssp.*) on yield (average bulb weight g) of a lily crop and green area at harvest time (%) with reduced doses at early spraying and increasing dose to full dose (1.6 l/ha) at flower cutting (maximum crop height 60 cm)

spray Crop height (cm)	1st/2nd 10	3rd 20	4th/5th 30	6th/7th 40	8th 60	Average bulb weight (g)	Relative yield	Green area (%)
object								
1	-	-	-	-	-	57.5 c	100	0 d
2	0.1	0.2	0.4	0.8	1.6	70.0 ab	122	25 bc
3	0.2	0.4	0.8	1.6	1.6	70.0 ab	122	35 abc
4	0.4	0.8	1.6	1.6	1.6	68.9 ab	120	42 ab
5	0.8	1.6	1.6	1.6	1.6	69.3 ab	120	37 abc
6	1.6	1.6	1.6	1.6	1.6	72.7 a	126	50 a
7	-	-	-	-	1.6	66.6 b	116	20 c
8	-	0.2	0.4	0.8	1.6	71.8	125	35 abd
LSD(0.001)						4.4		19.2

same letter in column means no significant difference

Table 2 NDVI values for a lily crop with different plant densities and crop heights

	Crop height		
plants/m^2	low	middle	high
120	0.72	0.88	0.88
180	0.80	0.89	0.89

The laboratory results show that the Greenseeker is limited in use for adapting the dose depending on canopy density or crop height. The high values for the low crop height suggests an effect of soil surface on reflectance and will be further investigated.

First CDS sprayer test in potato leaf blight control
The Weed-||It sprayer, as used now on pavements for weed control is adapted to apply fungicides against late blight in an early potato crop. The system sprays only green areas as the sensor used detects chlorophyll reflection. First tests show a reduction of 60-80% in agrochemical use for the first 3 fungicide applications. Potato plants were still individual and crop coverage during these applications was around 30%.

Discussion

The developed Canopy Density Spraying system in orchards has shown that plant protection product use and spray drift can be reduced maintaining biological efficacy. Canopy Density Spraying on bed-grown crops, like potatoes and flower bulbs, have shown a potential reduction in PPP use, especially with first sprayings of the crop. Also when the crop covers soil surface completely but still develops in crop height and leaf mass, a reduction in PPP is possible maintaining biological efficacy. Further development of Canopy Density Spray systems and more target oriented sprayings can be realised when diseases are detected before visual appearance. Sensor evaluation shows potential in this direction. The evaluation of combinations of sensor and spray systems on the market show that some steps are still to be made before a good working Canopy Density Spray system is fully operational in practice. Further research in this field is continued.

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