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Precise spray application in fruit growing according to crop heath status, target characteristics and environmental circumstances

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Abstract

The objective of the project is to develop a model of sprayer that ensures precise, efficient and safe spray application in orchards according to actual needs and with respect to the environment. The Crop Adapted Spray Application (CASA) system consists of three sub-systems: (i) Crop Health Sensor – CHS, (ii) Crop Identification System – CIS, and (iii) Environmentally Dependent Application System – EDAS. The CHS determines a plant health status by performing a spectral analysis of apple leaves in the band-width 400-1600nm. A plant stress due to apple scab (Venturia inaequalis) infection is identified in real time in order to determine the timing of chemical treatments. The CIS identifies spray targets with a set of ultrasonic sensors delivering in real time data on tree canopy width and density at three levels. A spray application system was also developed to apply variable spray volume according to the target characteristics. The EDAS identifies environmental circumstances in order to protect sensitive areas neighbouring the treated orchards. The spray application parameters are adjusted according to the wind situation, measured on the sprayer with an ultrasonic anemometer, and sprayer position in relation to sensitive areas (e.g. surface water, public areas), determined by DGPS. Nozzles are altered to adjust droplet size and a novel fan construction allows the supporting airflow to the left and right hand sections of the sprayer to be adjusted independently.

Keywords: crop identification, crop adapted application, spectral analysis, ultrasonic sensor, GPS navigation, air-jet adjustment

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Introduction

In orchards, pesticides are usually applied regardless of the actual health status of protected crops, and with spray volume and airflow settings that ignore variable requirements of the target plants expressed in terms of their size and density. This is because conventional axial fan sprayers have no systems to identify plant health status and plant characteristics, and they are not equipped with devices to adjust critical spray application parameters such as spray volume, droplet size and airflow according to the actual need.

Plant protection, especially where pesticides are used very intensively as in fruit growing, should not have any negative impact on the environment; there may be sensitive areas neighbouring the orchards such as surface water, melioration wells, sensitive crops or public sites. These areas must not be contaminated by a spray drift (which is influenced by wind velocity, droplet size and airflow parameters). Conventional sprayers have no ability to alter the application parameters automatically according to the wind situation and proximity of sensitive areas.

The consumers' demand for healthy fruits, the growers' requirements for lower production costs and the environmental concerns of society stimulate research on low input plant protection techniques. Precision agricultural tools are needed to identify the problem and the target, as well as recognise the environmental circumstances in order to apply pesticides according to the actual requirements at a precise rate and with respect to the environment. This is one of the objectives of the EU project within the 6th Framework Programme: "Increasing fruit consumption through a trans disciplinary approach leading to high quality produce from environmentally safe, sustainable methods - ISAFRUIT" (ISAFRUIT, 2006). Within this 4-year project launched in 2006, a Crop Adapted Spray Application system (CASA) is being developed by three partners: Research Institute of Pomology and Floriculture in Skierniewice (Poland), University of Turin in Grugliasco (Italy) and Wageningen University in Wageningen (The Netherlands). The objective of the CASA system is to adjust spray application parameters automatically according to the crop health status and crop characteristics, as well as the wind situation and sprayer position in the orchard. This is in order to reduce pesticide input and hence improve the quality and safety of fruit and environment. The preliminary results of the on-going development of the CASA system are presented in this paper.

Materials and Methods

The CASA system will consist of three sub-systems being elaborated independently by the project partners which will ultimately be integrated on a CASA sprayer model: (i) Crop Health Sensor (CHS) – determining crop health status to support decision making on spray application, as reported by Van de Zande et al. (2007); (ii) Crop Identification System (CIS) - identifying target characteristics for precision spray application, as reported by Balsari et al. (2007); (iii) Environmentally Dependent Application System (EDAS) – recognising the wind situation and position of the sprayer to protect sensitive areas in the orchard environment, as reported by Doruchowski et al. (2007).

To develop the CHS a novel technology has been used to quantify tree health conditions in the orchard. This technology is based on developments in crop sensing techniques for grassland and arable crop production, such as vision and spectral analysis (Schut, 2003). A measuring tool developed for characterising grass-swards has been adapted to measure single apple leaves picked in an orchard and placed on the floor underneath the sensor in the laboratory. The device consisting of two spectral cameras, measures the reflection in the band-widths 400-900 nm and 900-1600 nm.
In the preliminary series of experiments with this device, spectral analysis measurements were performed on individual apple leaves from different apple cultivars: ‘Elstar’, ‘Jonagold’, ‘Rubens’, ‘Wellant’ and ‘Autento’. Both young and old leaves were measured on both the top and bottom sides. For the cultivars ‘Elstar’ and ‘Jonagold’, leaves infected with apple scab *(Venturia inaequalis)* and powdery mildew *(Podosphaera leucotricha)* were also measured.

In the second series of experiments, spectral analyses of individual leaves of two cultivars (‘Gala’, M9 rootstock) were taken to observe the change in spectrum in time. Samples will be compared for disparity between healthy and disease infected leaves (ascospores of apple scab) evaluated on 2 hours, 4 hours, 8 hours, 24 hours, 2 days, 14 days and 28 days after infection. The analyses of these spectral signatures are in progress.

The CIS is based on the ultrasonic sensors developed by DEIAFA and 3B6 company. With the CIS, the apple tree canopy width and density is determined based on the analysis of the echo of the ultrasonic signal emitted by the sensor. The frequency of the ultrasound used was 45 kHz, with the signal released by the sensor at a frequency of 10 Hz. The canopy width was calculated according to the formula: $W = R - 2 (x + d)$, where: W – canopy width; R – tree row spacing; x – constant distance from the sensor to sprayer axis; d – measured distance from the sensor to the canopy. The sensor-canopy distance was determined based on the time measured by the sensor, between signal transmission and receipt of the echo. The precision of distance measurement is less than 1% of the measured value; the detection range is up to 5 m. The tree canopy density was expressed as an index value, calculated based on the intensity and duration of the ultrasonic echo signal (Fig. 1). The density index value was mainly correlated with the number of leaf layers in the tree canopy.

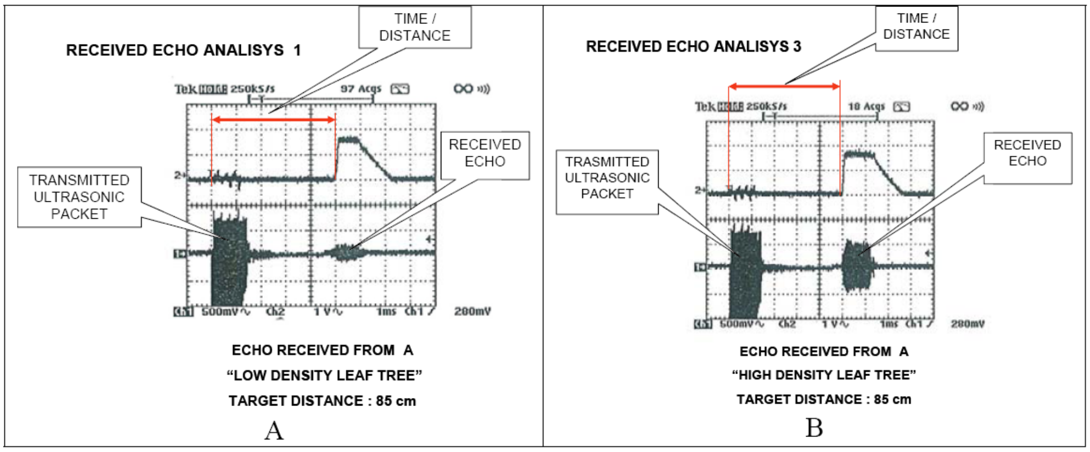

Fig. 1 Ultrasonic signals transmitted and echoes received from tree canopies of different densities: A – low density canopy; B – high density canopy

During the field experiments, the performance of ultrasonic sensors was tested in different aspects:

(a) assessment of repeatability of canopy width and density records acquired by one sensor, for different sprayer passes at travel velocity 6 km/h

(b) effect of travel velocity (2, 4, 6 and 8 km/h) on vegetation profile acquired by one sensor

(c) interference between 3 active sensors (travel velocity 6 km/h)

The experiments were carried out in an apple orchard of 'Golden Delicious', with 4 m trees, spaced 4,5 x 1,5 m. The sensors scanned a 70 m tree row. In tests (a) and (b), a single sensor passed the trees at a height of 2,0 m above ground level. In test (c), 3 sensors were mounted above each other at 1,0 m, 2,0 m and 3,0 m above ground level to record the canopy profile at three levels simultaneously (Fig. 2).

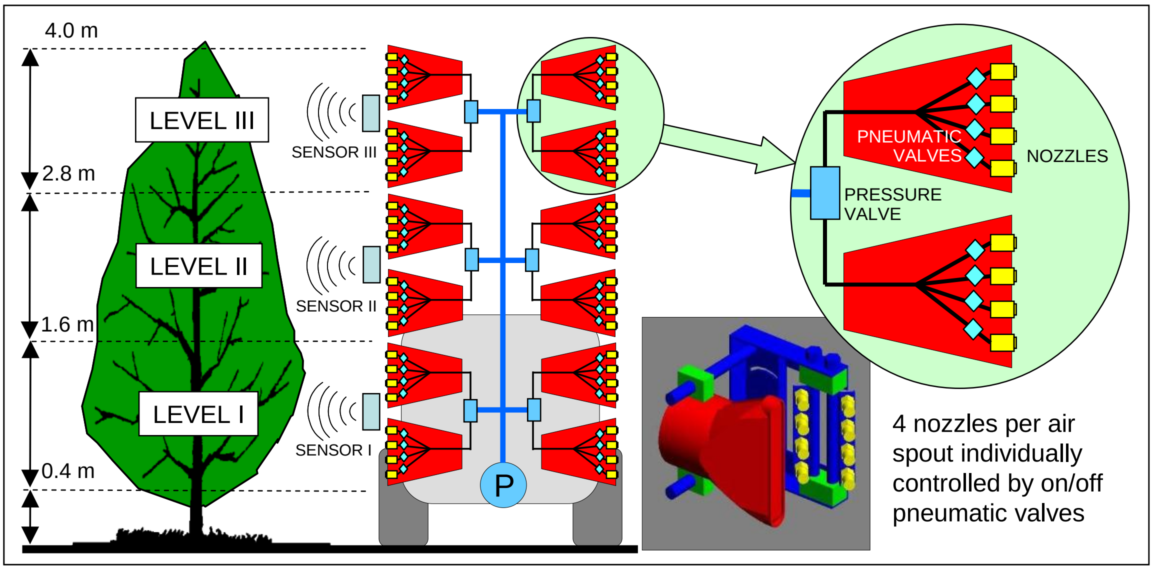

Fig. 2 Ultrasonic sensors and spray application system of CIS sprayer

Data acquired by the sensors will be processed by a control unit, the purpose of which is to control real time application of variable spray volumes related to the measured canopy width and density at 3 levels. For this purpose, a special spray application system was developed and mounted on a Hardi Arrow sprayer with a double rotor radial fan P540D (19 000 m^3/h). The airflow produced by the fan is ducted to 12 individually adjusted air spouts (6 at each side of sprayer) mounted on a vertical tower support. Each spout is equipped with a set of 4 nozzles, individually controlled by pneumatic on/off valves. The volume of spray to be applied towards a given level of the canopy (according to its width and density) can be adjusted by opening the appropriate number of nozzles. Thus, each of the 3 canopy levels being measured by the sensors is addressed by two air spots and 8 nozzles. Field trials with the CIS controlled spray application system will be carried out in spring 2008.

EDAS is a spray application system for orchards which identifies environmental circumstances and adjusts application parameters accordingly, so that spray distribution is optimised and spray loss is minimised. This protects sensitive areas neighbouring the orchards. The environmental circumstances to be identified are: wind velocity and direction measured with a ultrasonic anemometer (Vaisala WINDCAP® Ultrasonic Wins Sensor WMT50), and orchard boundary and sensitive areas such as surface water, melioration wells, buildings, sensitive crops, public sites, etc. from GIS. According to the wind situation and sprayer position relative to the orchard boundary/sensitive areas (GIS/GPS), the spray quality will be automatically adjusted by altering the nozzles (fine spray/coarse spray) in order to minimise the spray drift. In addition, appropriate nozzles will be closed to respect the local standards for buffer zones. Furthermore, in order to minimise the emission of spray towards sensitive areas, and yet ensure the best possible spray distribution in the orchard, the supporting air jet will be adjusted individually for left and right section of the sprayer by manipulation of airflow on the inlet and outlet of the fan.

The EDAS sprayer was designed and a novel air jet adjustment system was constructed and assembled on a Hardi Arrow sprayer with a double rotor radial fan P540D (19 000 m^3/h). Initially, an air collector for distribution of airflow to 16 individual air spouts (8 for each section of sprayer) was elaborated and fixed to the fan. Having obtained the uniform air distribution from the collector, an adjustable air vane was assembled inside it to adjust or close the airflow individually to the left and right sections of the sprayer (Fig. 3 A). The simultaneous measurements of air velocity from the 8 air spouts were made with a set of hot film anemometers and an 8-channel data logger in stationary, dynamic and orchard situations. In each scenario, closing the airflow on one section resulted in an increase in air velocity on the other section by 30-40%. In order to avoid this, a diaphragm leaf shutter was designed and fixed on the fan inlet (Fig. 3 B). Once the collector vane closes the airflow to one section, the leaf shutter will restrict the flow of air sucked in by the fan accordingly. Therefore, the air velocity will remain constant when one section is closed.

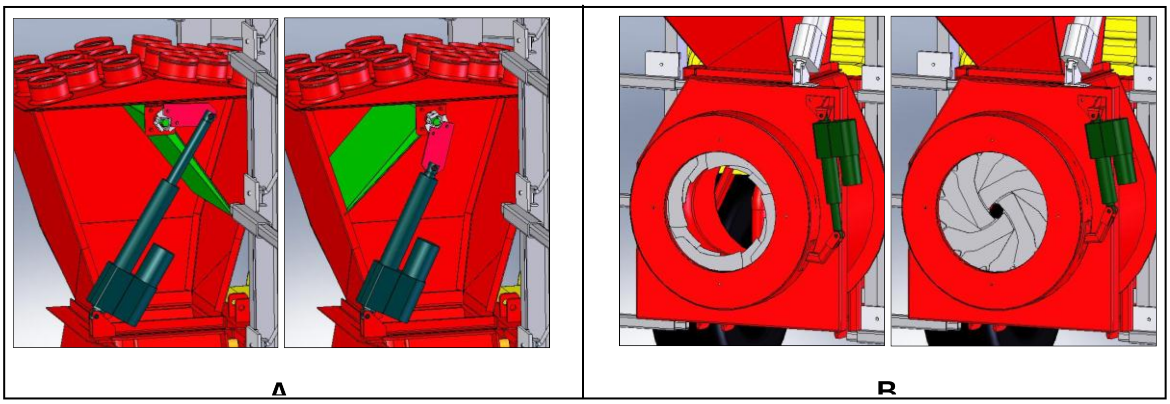

Fig. 3 Airflow adjustment system on EDAS sprayer: (A) air vane in the air collector (position V1 and V11); (B) diaphragm leaf shutter on the inlet of radial fan (position S4 and S0)

The measurements of air velocity, as described above, were repeated for all possible combinations of:

- 11 positions of air vane in the air collector (V1 ... V11)

  where: V1 = airflow closed to the right section and fully open to the left section

  V6 = central position – equal distribution of airflow to both sections

  V11 = airflow closed to the left section and fully open to the right section

- 6 positions of the leaf shutter (S0 ... S5)

  where: S0 = leaf shutter closed

  S5 = leaf shutter fully open

The measurements were made 30 cm from the outlet of the air spouts: in 5 replications for each combination, simultaneously for 8 spouts, separately for left and right section (in total: 5 280 measurements).

Double nozzle holders with fine spray and coarse spray nozzles controlled individually by on/off pneumatic valves, were assembled at the air spouts. The valves alter the nozzles (fine spray/coarse spray) depending on the wind situation and position of the sprayer in relation to the orchard boundary and the sensitive areas. A Control unit and software is being elaborated to control both air and spray emission systems in various situations and to integrate them with GPS. The field test of EDAS sprayer will be carried out in spring 2008.

Results and Discussion

CHS: First results show a difference in reflection between infected leaves and healthy leaves. The most evident differences in spectral signatures were observed for the wavelengths: 690, 820, 880, 1400 and 1550 nm (Fig. 4). These wavelengths may be used to discriminate between healthy and infected leaves to support decision on suspending or triggering the spray application.

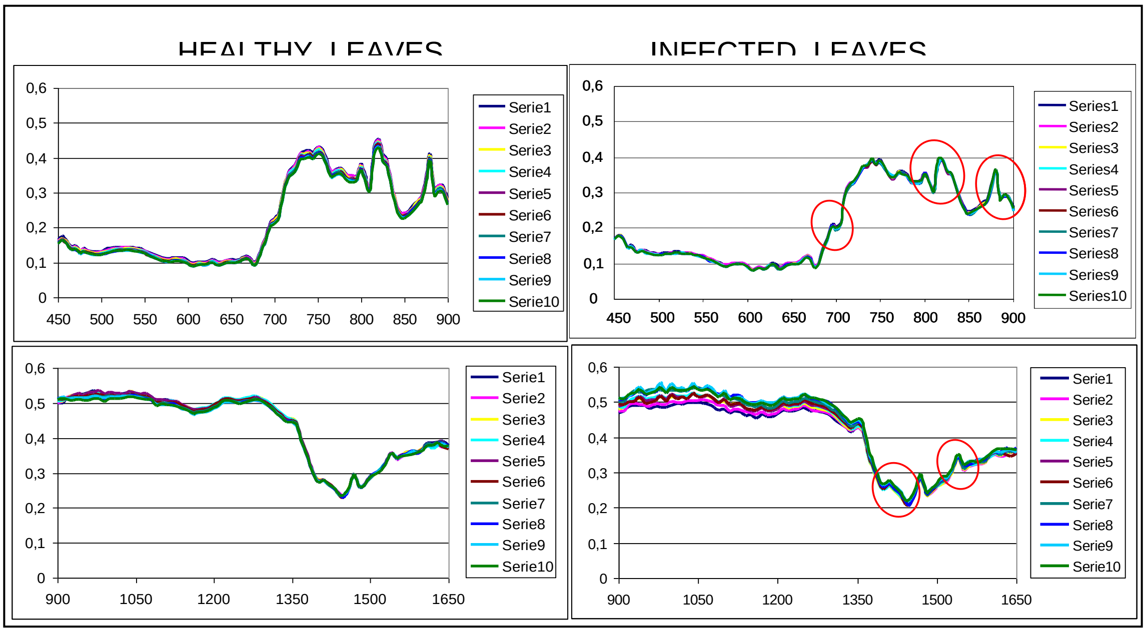

Fig. 4 Spectral signatures of healthy and apple scab infected apple leaves (‘Elstar’) with marked points of difference

Based on the data obtained, the development of the crop health sensor will start by identification of discriminate wavelengths for water stress, nutrient stress and cultivars. Having done this a CHS dedicated sensor will be developed. The CHS can then be integrated in CASA system, working together with the CIS and the EDAS sub-systems.

By adapting the sensors for fruit production, dose and timing of chemicals can be determined based on the crop health situation of the fruit tree. 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 can be adapted following the relationship between crop health and required protection level using a specific plant protection product.

CIS: The results of canopy width and density, measured by the ultrasonic sensor in three replications, gave fairly similar vegetation profile (Fig. 5). At the travel velocity 6 km/h and ultrasonic signal transmission frequency 10 Hz, the measurements were taken with a resolution of 10 cm of the driving distance. The observed differences in width and density measurements between the replications were mainly due to the difficulty of repeating exactly the same path in the field with this resolution. Analysis of the differences between the maximum and minimum values recorded for each sampling point in the three replications showed that for 80% of the points, the discrepancies in canopy width remained within 0,40 m and in canopy density index within 300 units. It has been assumed that for real time spray volume control during spray applications, sufficient accuracy will be obtained based on an average value of sensor measurements taken over 1 m of the tree row length.

Forward speed did not significantly affect the repeatability of the vegetation profile acquired by the sensor, either regarding canopy width (Fig. 6) or canopy density. For 80% of sampling points the canopy width discrepancies ranged within 0.25 m, and those for canopy density index remained within 250 units.

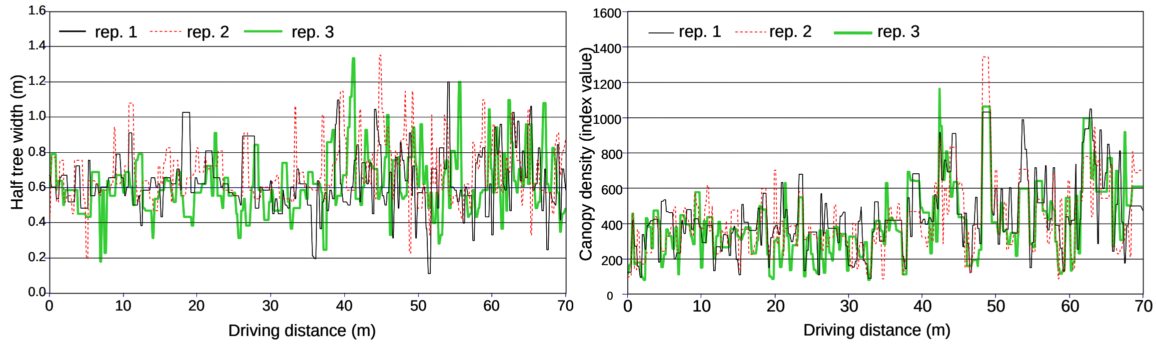

Fig. 5 Canopy width and density profile recorded by ultrasonic sensor at canopy level II, during three runs (6 km/h) over 70 m row of apple trees

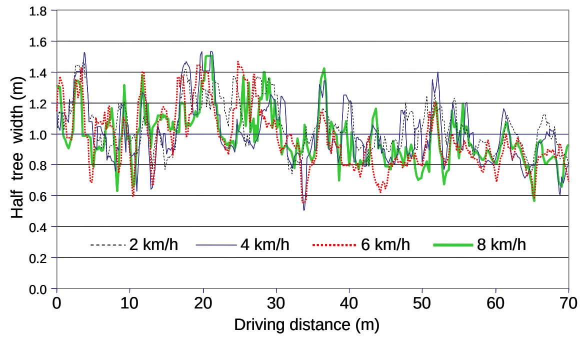

Fig. 6 Canopy width profile recorded by ultrasonic sensor at canopy level II, during runs over 70 m row of apple trees at different travel velocities

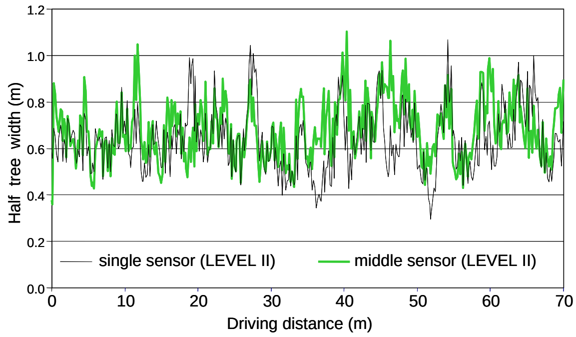

Fig. 7 Canopy width profile recorded at canopy level II by single ultrasonic sensor and by the middle sensor only with top and bottom sensors both active, during runs over 70 m row of apple trees at travel velocity 6 km/h

Comparing the vegetation profile obtained by the single sensor at the height 2,0 m above ground and the middle sensor (at the same height) out of three sensors scanning the three tree row levels, it has been observed that the top and the bottom sensors did not interfere with the middle one (Fig.7).

The obtained results showed that simple and relatively cheap ultrasonic sensors provide reliable data on tree canopy width and density, which may be used for real time control of spray volume adjustment according to the target characteristics. In this sense it is superior to more sophisticated and costly sensors, such as LIDAR (Walklate et al., 1997), which are used in post-processing applications.

EDAS: The results of air velocity measurements showed that by the manipulation of the diaphragm leaf shutter on the fan inlet and air vane in the air collector of EDAS sprayer, it was possible to adjust air velocity individually for each section. With the shutter/vane setting being S2/V6 as a reference (average airflow velocity LEFT/RIGHT section = 14,0/15,6 m/s) the combinations of shutter and vane positions were identified to obtain air velocities on LEFT/RIGHT air spout section fairly corresponding with the required ones in various typical situations (expressed in percentage deviation from reference air velocity values) (Fig. 8), e.g.:

- S0/V1 (+29%/-100%) or S0/V11 (-100%/+12%) – when spraying the boundary row,
- S0/V2 (+13%/-68%) or S0/V10 (-64%/+2%) – when spraying the last but one row,
- S1/V4 (-4%/-25%) or S1/V9 (-36%/+1%) – when spraying the last but two row,
- S3/V3 (+32%/-23%) or S3/V9 (-16%/+20%) – to counteract a cross wind ≥ 2 m/s.

The reference setting S2/V6 with a symmetrical airflow distribution is to be used inside the orchard (from the third row on), during longitudinal winds and cross winds < 2 m/s.

During spray application, the shutter/vane settings will be adjusted automatically according to the position of the sprayer in the orchard (GIS/GPS) and wind velocity/direction measured with the ultrasonic anemometer mounted on the sprayer. The airflow might also be adjusted based on the canopy width and foliage density measured by the ultrasonic sensors of CIS system to support the spray application concept proposed by Salyani (2007).

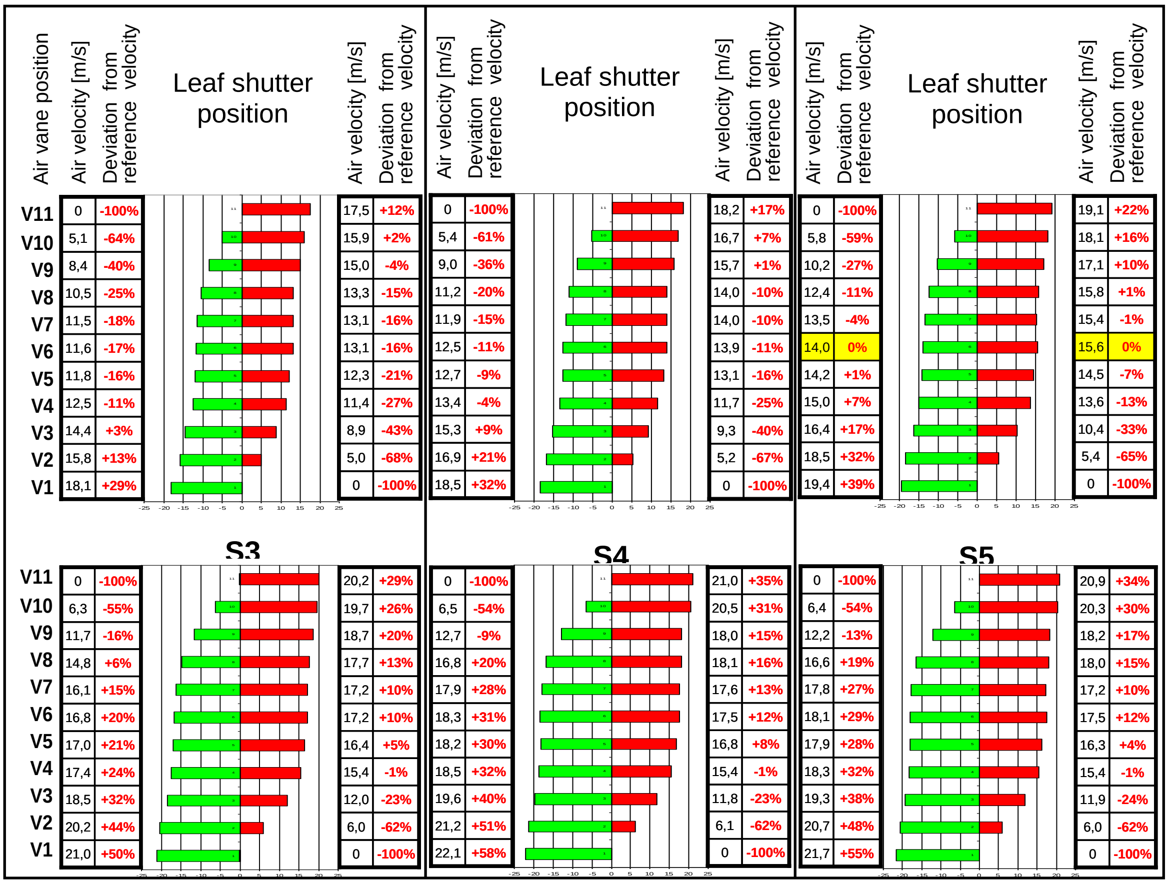

Fig. 8 Average airflow velocities (m/s) measured for LEFT and RIGHT air spout sections and air velocity deviations (%) from the reference setting (S2/V6) for different positions of diaphragm leaf shutter on the fan inlet and air vane in the air collector of EDAS sprayer model. Each average value was calculated from velocities measured at 8 air spouts in 5 replications.

Conclusions

The CASA system, consisting of CHS, CIS and EDAS sub-systems, at the described stage of development, shows the potential to recognise plant stress due to disease infection on apple leaves and identify the basic target characteristics such as tree canopy width and foliage density. The acquired information, when processed in real time can be used by the CIS sprayer model to perform on-the-go adjustment of the spray volume applied on the fruit trees and hence facilitate precise, crop adapted spray application in orchards.

The EDAS sprayer model equipped with wind sensor and GPS navigation system enables real time adjustment of application parameters such as airflow and spray quality to reduce the negative environmental impact of spray applications in orchards. It is going to be integrated with the CHS and CIS sub-systems to meet the objectives of the CASA system to the full extent.

Future work within the ISAFRUIT project will focus on finalising the development of software to control all the processes performed by the CASA system, and carrying out field experiments to evaluate the obtained effects in terms of application quality, biological efficacy and reduction of environmental pollution.

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