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Review

Development of alternative plant protection product application techniques in orchards, based on measurement sensing systems: A review

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ABSTRACT

The development of alternative plant protection product (hereinafter PPP) application techniques in recent decades has been based on various principles of sprayer operation. So far, several researchers have tried with partial success to find a compromise (a uniform standard) to ensure continuous PPP application to selected tree canopies in an orchard. Researchers have offered certain solutions for controlling dosage rates of PPP, based on special measurement systems and decision-making models to optimize the dosage rate of PPP. With sensing systems for electronic canopy characterization, which originally functioned on the basis of ultrasound waving and later on the principle of spectral reflection, characteristics of tree canopies in an orchard could be adequately estimated. However, attention must be paid to the fact that discrepancies in the original measurement systems were too large, owing to imprecise operation of various sensor components. Nevertheless it is necessary to underline that advanced spectral laser technology is a strong tool for developers of alternative PPP application techniques, and with it, tree canopy properties are sensed in real time. So it is no longer a major problem in the precise application to establish the tree canopy properties, but to control artificial intelligence actuation, which in the future will properly direct the air flow and the dosage rate of PPP per tree canopy in the orchard.

Contents

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1. Introduction

Plant protection against disease, insects and weeds is necessary to ensure good quantity and quality of harvest. It can be performed in many ways, but today chemical protection with PPP and a range of spraying techniques (sprayers, airblasters, foggers, etc.) represents the most common method. The purpose of plant protection by various chemicals is to exterminate harmful organisms and to prevent infection, but PPP residues remain in food and find their way into the environment. Pollution of the soil, groundwater, air, plants and animals are important problems for modern agriculture. It is impossible to solve these problems overnight by returning to the traditional way of farming or to the ecological method of cultivation without the use of PPP, because modern agriculture has already harmed biodiversity, biological cycles and soil biological activity. Sustainable agriculture must therefore strive to reduce harmful influences on the living environment. Sustainable agriculture will be the only future alternative, in relation to which issues of nature protection will have to be taken into consideration. The application of chemical substances in amounts as small as possible will need to be ensured; however, it must also to be ensured that plant protection quality will be retained. Among others methods, this can be achieved through selective and precise PPP application. On the contrary, fruit growers nowadays still make extensive use of traditional dose expression models. Owing to the use of traditional dose expression models, the dosage of PPP remains independent from the properties of each tree canopy in the orchard. The result is that potentially excessive dosages of PPP may be used in the orchard, because of the distinct properties (volume, leaf area, height, age, growth stage, etc.) of individual trees in the orchard. For example, researchers (Sutton and Unrath, 1984) have established that it is not appropriate to apply the same dosage of PPP on both small canopy and large canopy trees, without taking into account the common density of the total leaf area in the orchard.

Characterization of canopy trees in orchards is a very complex task where a Tree Row Volume (hereinafter TRV) model was first used to describe the geometric structure of canopy trees. TRV is based on manual measurements of the volume of tree canopies, (Byers et al., 1971). In practice, it was shown that a large TRV estimation uncertainty led to difficulties in determining the dosage of PPP. Later, the canopy height model was introduced, which today is the basic dose expression model for orchards in some European countries. This uses canopy height as the dominant crop parameter (Friessleben et al., 2007). In more advanced models for estimating properties of the tree canopy, some researchers (Ladd and Reichard, 1980; Giles et al., 1989; Balsari and Tamagnone, 1998; Doruchowski et al., 1998; Meron et al., 2000; Walklate et al., 2002; Escolà et al., 2007, 2011, 2013; Solanelles et al., 2006; Balsari et al., 2009; Wenneker et al., 2009; Doruchowski et al., 2011; Jejcic et al., 2011; Llorens et al., 2011; Sanz Cortiella et al., 2011; Stajnko et al., 2012; Chen et al., 2012; Osterman et al., 2013) have begun to use precision sensing systems including ultrasonic and spectral principles which assist in control of the PPP process. Instead of using canopy measurements obtained by sensors mounted on sprayers, some researchers (Meron et al., 2000; Shimborsky, 2003) found photogrammetric aerial scanning appropriate as an equivalent method of tree mapping. To link aerial scanning with sprayer position in the orchard, GIS and RTK-DGPS support is required (van de Zande et al., 2001; van de Zande et al., 2003). In recent years most commonly used measurement systems have operated on the principle of Light Detection and Ranging (hereinafter LIDAR) sensors for dose expression rate. The LIDAR measurement system is able to measure the distance between the sensor and objects in its surroundings quickly and precisely. Escolà et al. (2007) found that the spot diameter is clearly smaller for the LIDAR sensor than for the ultrasonic sensor; ultrasonic sensors measure only the foliage in front of them, while LIDAR sensors are able to estimate more precisely the tree foliage cross section. Moreover, LIDAR enables representation of an individual tree at the level of the leaves and branches. The capacity to estimate the three-dimensional spatial structure of canopy trees with LIDAR represents a significant advantage over competing sensing principles, such as ultrasonic, radar or aerial scanning.

Based on information provided by the sensors, the sprayer's processing system detects trees, and through input–output control units and actuators (electromagnetic valve EMV, hereinafter EMV) controls the dosage of PPP in ON/OFF, discrete or continuous mode. In recent years reports have emerged on the application of PPP, based on the principle of discrete decision and actuation (Moltó et al., 2001). The discrete system recommended by Moltó et al. (2001) operates on the principle of the ultrasonic sensor and can deliver three application dosages: full dosage, reduced dosage and the nil dosage, while in all other cases a fixed nozzle position and orientation were used. In the application of the PPP process, three modifying dosages through the EMV was defined as fixed, and precise dosage control could not therefore be provided. So in future, the possible alternative to precise control would be a continuous dosage control of PPP according to the individual tree canopy in an orchard.

At the current state of the art, the sprayers, positions and orientation of nozzles used for PPP application are fixed at a given height and are only partly adapted to the non-linear shape of the canopy tree over the entire height. A further development was reported by Osterman et al. (2013), who use an adapted prototype sprayer with adjustable hydraulic manipulator arms. They used three manipulator arms, with installed aerodynamic airflow support and PPP nozzles featuring 8 degrees of freedom in a plane perpendicular to the row, with the intention of spraying targets perpendicular to the canopy contour at a selected distance. However, in the process of PPP application, it is important to measure the geometrical characteristics of each tree canopy precisely by using an electronic measurement system, because this contributes significantly to delivery of an appropriate amount of PPP to the selected canopy segment. The majority of current state-of-the-art sprayers are not equipped with precision electronic measuring systems for defining the geometric properties of the tree canopy, and for this reason they are unable to deliver PPP precisely to selected targets; this means that a new generation of high precision sprayers is required. Sprayers that are currently available for orchards use axial, centrifugal and tangential fans for airflow support. They differ according to the