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Review Article

A review of applicable methodologies for variable-rate spraying of orchards based on canopy characteristics

Hossein Maghsoudi[1] and Saeid Minaei*

Biosystems Engineering Department, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran.

Abstract: Variable rate spray applications using proportional control systems can greatly reduce pesticide use and off-target contamination of environment in orchards. Variable rate spraying of the canopy allows growers to apply pesticides only to the target, only use the correct quantity according to canopy size, season and growth stage and to apply plant protection products in an economic and environmentally sound manner. A major challenge is the reduction of agrochemicals used as Plant Protection Products (PPP) while achieving suitable deposition on the canopy. Spraying efficiency can be improved by reducing the spray losses associated with deposition on the ground and off-target drift. Adjustment of application rate proportional to the size and shape of tree crops has shown high potential for reducing agrochemicals in automatically controlled sprayers. In recent years target detection methods have been developed by using advanced techniques such as vision and laser scanning systems or simpler ultrasound, infrared and spectral systems. These systems have made it possible to develop geometric maps of trees allowing site-specific management of orchards. Variable rate spraying can thus be utilized as a methodology for applying the required amount of PPPs to the canopy while preventing over dosage as well as drift. Utilization of sensors to monitor canopy, distances and location ensures better use of expensive inputs, resulting in a sustainable approach to an important practice. This paper discusses various methodologies available for determination of canopy structural parameters and introduces some applicable commercial systems while pointing out their similarities and differences.

Keywords: Variable-rate spraying, Target detection system, Ultrasonic sensors, Canopy structural characteristics

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Introduction

Environmental concerns for healthy fruits production lead to the study of sustainable spraying methods that could optimize pesticide application in orchards by more precise adjustment of liquid to canopy parameters. Variable rate spray applications using proportional control systems can greatly reduce pesticide use and off-target contamination of environment in orchard productions. Variable rate spraying of the canopy allows growers to apply pesticides only to the target, only use the correct quantity according to canopy size, season and growth stage and to apply plant protection products in an economic and environmentally sound manner. The use of

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* **Corresponding author**, e-mail: minaee@modares.ac.ir
[1] Present Address: Department of Agricultural Machinery Engineering, Shahid Bahonar University of Kerman, Kerman, Iran.

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sensors to monitor canopy, distances and location ensures better use of expensive inputs, resulting in a sustainable approach to an important horticultural practice.

Use of agricultural chemicals involves long and short-term negative impacts on the environment depending on the extent and intensity of application (Maghsoudi and Minaei, 2013). When pesticides are used in closed environments such as greenhouses, they pose immediate hazards for operator health. Various solutions have been proposed to deal with the issue. Although many methods have been introduced, little research has been conducted on computer vision-aided and robotic spraying systems (Mohammadzamani *et al.*, 2009b). Since pesticides are toxic and dangerous, reduction of direct contact with agrochemicals is important for human health. This is another reason for the need to develop automated sprayer systems besides the economical and ergonomic benefits. To this end, usable large-scale methods which can continuously determine accurate leaf position and tree structure details during spraying are required (Mohammadzamani *et al.*, 2009a).

Agrochemical application is ideal when the PPP is completely distributed over the canopy and, the pesticide application rate is suitably adjusted for reducing excess emission to the environment. It has been shown that there is an optimum application rate for any specific crop growth stage (Aguilar *et al.*, 2008). Since variable rate technology (VRT) has high potential for more efficient use of inputs, increasing crop yield, and preventing environmental pollution by extra agrochemical usage, growers' attitude for Site-specific management has increased (Aguilar *et al.*, 2008). One important element in the design of variable rate sprayers is dose adjustment ($l.ha^{-1}$). Optimum dosage for sprayings is related to canopy structure (Furness *et al.*, 1998) and Index of the canopy Leaf Area (Siegfried *et al.*, 2007; Zhu *et al.*, 2004) which is stated as a dimensionless variable showing the total leaf area per unit ground surface area (Aguilar *et al.*, 2008). The following text explains various methods and systems for characterization of canopy structure and compares their capabilities for usage in variable rate spraying.

Measurement of Tree volumetric characteristics

The use of electronic devices for canopy characterization and the need to clarify the dose expression concept have given rise to the concept of the variable application method (Jiaqiang *et al.*, 2005). In the past three decades, various procedures for detecting tree canopy volume have been suggested and developed in both forestry and agricultural sectors to assist the efficient application of agrochemicals (Maghsoudi, 2013). Dimensional characterization of plants can be performed by means of several remote sensing detection principles, including image analysis techniques, stereoscopy, photography, light spectrum analysis, infrared thermography, ultrasonic sensing and optical ranging (Rosell *et al.*, 2009).

Estimation of fruit tree volume using ultrasonic sensors

Spatial variability of tree canopy size is considerable in orchards, chiefly arising from planting of young trees in vacant spaces of old groves, hedging/topping practice, variable tree spacing, and soil restrictions (Schumann and Zaman, 2005). Ultrasonic sensors have typically been used for the digital control of application rates in sprayers and liquid fertilizer spreaders of tree crops for about two decades. Such systems were first developed before the arrival of commercial DGPS receivers and on the basis of real-time tree canopy sensing and adjusting of application rate based on canopy size detection (Balsari and Tamagnone, 1998; Giles *et al.*, 1989; Moltó *et al.*, 2000). Since 2000, use of the fast and accurate DGPS service and growing power of laptop computing, have created new opportunities for improved processing and topography mapping of orchard data acquired using ultrasonic sensors. Schumann and Zaman (2005), designed and evaluated a software application for ultrasonic orchard sensing by means of a 10-transducer array and DGPS for real-time sensing, monitoring, calculation, and map development for citrus tree canopy volume and height.

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A comparison was made between a conventional and an air-assisted sprayer for proportional chemical application to the canopy volume by Solanelles *et al.* (2002) in Spain. The arrangement which utilized two ultrasonic transducers and solenoid valves was able to save 30 and 65% of spray liquid in pear and olive orchards, respectively.

Accuracy and repeatability of the ultrasonic systems are sufficient for many site-specific or precision agriculture usages. Applications of the system could include the real-time calculation of tree canopy dimensions for yield estimation, variable rate fertilization or agrochemical spraying, as well as production of accurate orchard details and spatial maps to track every tree in the grove on a GIS. From the ultrasonically derived orchard map, individual trees with different ages or performance characteristics, as well as missing tree spaces, can be readily located (Schumann and Zaman, 2005). Various experiments with ultrasonic measurement systems for spraying control conducted by Schumann and Zaman (2005) presented 50 to 70% saving in spray volume. Savings in agrochemical materials were reported in relation with age, crop growth stage, foliage dimensions and vacant spaces between trees in the orchard.

Tree volume and section area estimation by Ground laser scanner

Usually, the structural and geometric parameters of trees, such as foliage volumes and areas, are derived from manual measurements of height and width as well as destructive sampling of leaves. However, since destructive sampling in fruit orchards is both slow and costly, other methods, such as ground-based LIDAR scanning systems, have been used over the last 20 years and found to be reliable. In recent years, much effort has been spent on determination of the geometry and other structural parameters of plants–such as Leaf Area Index (LAI)–using non-destructive methods based on the use of ultrasonic sensors and, more recently, ground-based scanning LIDAR (Sanz *et al.*, 2004).

Light Detection and Ranging (LIDAR) is a remote sensing technique based on the measurement of travel time from a laser transmitter to a target. LIDAR for vegetation studies generally involves applying near-infrared radiation, although, sometimes, visible light is also used. This laser radiation is reflected by leaves, branches and other elements and is received by the instrument. The distance between the scanner and surface of the reflecting object, is determined by measuring the elapsed time between the transmitted laser beam and its echo reception, which is called time-of-flight. In recent years, measurement of environmental parameters particularly for the characterization of forest and agricultural systems has been made possible by means of LIDAR sensors (Rosell *et al.*, 2009). The greater part of these measurements have been made using LIDAR sensors mounted on aircraft or satellites, but measurements can be based on terrestrial or ground-based LIDAR sensors as well (Tumbo *et al.*, 2002; Van de Zande *et al.*, 2006; Walklate *et al.*, 2002; Wei and Salyani, 2004). Ease of use and lower price are advantages of ground-based LIDAR. When used in combination with multispectral image data, LIDAR sensors can provide detailed three-dimensional information on land-cover. Furthermore, they can induce emission of electromagnetic radiation (especially as visible light) in plants which can be used to monitor plant health on large scale (Rosell *et al.*, 2009).

For agriculture implementations, Walklate *et al.*(2002) offered a procedure for managing and analyzing laser sensor data to find several dimensional parameters of apple trees (height and volume) as well as other properties that define the structural characteristics of trees (foliage density and foliage distribution). They comparatively evaluated the performance of various models for pesticide deposition by means of LIDAR field measurements of crop structure. They also measured deposition on apple trees foliage using different combinations of plantation density, rootstock, growth stage and age. Linear regression analysis of the measurements showed that the standard method of adjusting pesticide output, based on a linear scaling of the spray volume application rate per unit ground area, accounted for only 9% of the variation in the measurements. The uses of other models, based on different geometric scaling parameters of orchard structure were demonstrated to give improved correlation with measurements. Of these models, the best correlation was obtained by using a length-scale proportional to the ratio of the tree volume to total ground area and this accounted for 43% of the variation in the measurements. The use of orchard structure parameters, based on crop area estimates derived from a local Poisson distribution of light transmission, gave further improvements. Of these models, the best correlation was obtained with a length-scale proportional to the tree area density and this accounted for 78% of the variation in the measurements. The tree area density is thus the best single crop structure parameter to use as the basis for pesticide dose expression for the practices of apple orchard spraying represented by these measurements. The calculation of this parameter relies on the availability of LIDAR measurements. Alternatively, a simple method for estimating this parameter might easily be constructed as a pictograph showing the relative tree area density associated with orchard tree images that can be reconstructed from these measurements. This research further identifies the need for this type of crop structural information to improve standardization of the dose recommendations on pesticide labels.

Rosell *et al,* (2009) computed several parameters based on scanner data, and compared these with foliage areas in order to determine the suitability of laser sensors to characterize vineyards. Their extracted parameters describing the tree-row volume and the total crop surface area viewed by the LIDAR (expressed as a ratio of ground surface area) were derived by means of a suitable numerical algorithm. Derived results for apple and pear orchards and a wine producing vineyard were shown to be in reasonable agreement with the results derived from a destructive method of leaf sampling. In addition, good correlation was found between sensor-based and manual measurements of the foliage volume of tree-row plantations. Also, good correlation was obtained between destructive and non-destructive determinants of crop leaf area for the Tree Area Index parameter (TAI). It is proved that The LIDAR scanner system can be a powerful technique for prompt and non-destructive estimation of the volume and leaf-area characteristics of plants at a lower cost relative to aerial scanning (Rosell *et al.*, 2009).

Review of environmentally-friendly sprayers

Because of the hazards of agrochemical usage, there has been a trend for over three decades to reduce the amount of chemicals applied in fruit growing operations (Giles *et al.*, 1987). Various approaches such as breeding of cultivars resistant to pests and diseases or integrated fruit production have been used to reach this goal. Significant progress in this regard may also come from improvements in spray application technology. "Environmentally-friendly spraying techniques" have been developed to meet the requirements of modern plant protection as well as severe ecological safety standards.

For efficient and safe application of chemicals, a sprayer must ensure suitable chemical deposition on the target with minimal drift. Two methods which best meet these requirements are technically justified to be introduced in the practice are: shielded systems that recycle spray liquid and smart sprayers with the ability to recognize individual target trees and their characteristics. Various tests and research projects have shown that ecological and economic advantages are attainable with both of these techniques (Doruchowski and Holownicki, 2000).

Canopy detection has been improved either by using simple ultrasonic and spectral systems, or with more progressive techniques, such as laser scanning and vision systems. For many years, vision systems have been known for their ability to recognize the shape of the canopy and discriminate between crops and weeds (Mohammadzamani *et al.*, 2011). The laser tree-scanners using LIDAR could be used to measure the characteristics of the tree canopy and adjust the application dose rate accordingly (Walklate *et al.*, 2000). Nowadays, using these novel techniques are so costly which may limit their commercial production, while more suitable optic and ultrasonic sensors have already been utilized in orchards for proportional application of agrochemicals (Doruchowski and Holownicki, 2000).

At first, ultrasonic sensors could just discriminate between the presence and absence of the target. Balsari and Tamagnone (1998) described a high sensitivity sensor able to detect branches greater than 3-4 cm in diameter. However, due to the wide field of view of these sensors, it was not possible for them to identify small gaps in vegetation canopy. The minimum width detected for gap depending on the distance from sensor to target, was 35-120cm. Spectral systems based on optical reflectance not only can detect the targets but can also identify the type of vegetation (Hahn and Muir, 1993)and target characteristics as well as orchard architecture (Giles *et al.*, 1989).

Canopy-adapted dosing of agrochemicals has been widely discussed in many publications (Furness, 2003; Gil *et al.*, 2005; Godyn *et al.*, 2005; Pergher and Petris, 2008; Viret *et al.*, 2005; Walklate *et al.*, 2003). In fact, the main goal in all research efforts has been to adapt the total amount of agrochemicals to crop structures, but problems were encountered in selecting the most appropriate crop parameter for proportional application. Large variations in crop structural parameters has increased the complicacy of obtaining comprehensive solutions which are well adapted to all crops and conditions (Gil *et al.*, 2009).

Various methods for adjusting Plant Protection Product (PPP) application dosage to the canopy structure have been reported. Some are based on different parameters such as the Leaf Area Index-LAI-(Travis *et al.*, 1987) or the Tree Row Volume-TRV-(Byers *et al.*, 1971). However, there is shortage of simple and general methodology to connect the value of structural parameters to the finest sprayer configuration.

Recommendations on the pesticide label are usually given in the form of a constant application dose rate and minimum spray volume. Adjustments for different canopy structures, other than those characterized by the tree row width, are not easy to implement (Planas *et al.*, 2006). Consequently, due to the lack of clear guidance, performing optimum tuning of spraying systems is difficult for sprayer operators. Adjustment process can also be time consuming and limits routine sprayer optimization in commercial orchards.

Using more elaborate methods for monitoring canopy shape and density and characterizing the orchard structure can help simplify these difficulties and optimize the efficacy of precision orchard spraying. Although the first usage of sensors for controlling of precision orchard spraying systems belonged to 3 decades ago, this is still in progress with several research challenges (Stover, 2007).

Based on previous comments, currently two main types of commercial precision orchard sprayers are available: those based on ultrasonic sensors (Giles *et al.*, 1988) and those using laser scanners(Walklate *et al.*, 2000; Wangler *et al.*, 1992). Ultrasonic sensors measure the travel time of a transmitted sound wave and its reflection to compute the distance from the sensor to the canopy boundary. Spatial resolution has been limited because of the relatively wide divergence angle of ultrasonic waves leading to a large field of view when sensor-to-target distance increases. On the contrary, laser beams are highly collimated. Sensing with laser provides the chance of having a much more detailed representation of the canopy and allows the use of more elaborate analysis algorithms with precise density and structural parameters (Campoy *et al.*, 2010). Comparative analysis of ultrasonic and laser scanning sensors performance, to measure citrus canopy volume, has been carried out by Tumbo *et al.* (2002). Their results indicated that because of the higher resolution, Laser scanner had better prediction of canopy volume than the ultrasonic sensors, and that both laser scanner and ultrasonic sensors have capability for quantification of the canopy volume and automatic mapping of orchard trees.

Canopy detection in real-time control systems with ultrasonic distance sensors has been widely used by various researchers (Balsari and Tamagnone, 1998; Chueca *et al.*, 2008; Giles *et al.*, 1987; Koch *et al.*, 2000; Moltó *et al.*, 2000; Perry and Cordero, 1995; Schumann and Zaman, 2005; Solanelles *et al.*, 2006; Stajnko *et al.*, 2012). Ultrasonic sensors produce the raw analogue signal which is proportional to the distance from detected target. However, in field applications, various sources of error can often affect the raw data. For instance, attenuation of ultrasonic waves by the canopy may occur, and noises can be produced by electromagnetic sources, mechanical vibrations and moving leaves. Such factors have to be taken into consideration when an algorithm is being developed for automatic control. In the solution, the control algorithm should implement various appropriate filters such as median and mean filters on each reading before accepting the data (Chueca *et al.*, 2008; Moltó *et al.*, 2000).

Developments in precision sprayers for orchard trees started by interrupting the application flow rate when no foliage was detected using optical or ultrasonic sensors and electric valves (Gil *et al.*, 2007; Solanelles *et al.*, 2006). This could be implemented for all the nozzles or by different nozzle sections corresponding to independent canopy heights (Balsari and Tamagnone, 1998; Doruchowski and Holownicki, 2000; Giles *et al.*, 1989; Koch *et al.*, 2000). It was in 1983 when initial studies on electronic measurement of canopy structure began (McConnell *et al.*, 1983) and several technologies have been used since then. In the first stages, ultrasonic sensors were applied just for presence detection and quantification of the vegetation (Escolà *et al.*, 2002).

The following step was tailoring the PPP flow rate precisely to the canopy size. In the first approach, ON/OFF electric solenoid valves and various hydraulic circuits were used to spray three discrete spray dosages per side: full flow rate, half flow rate and no flow (Moltó *et al.*, 2001). The final step involved the development of a precise sprayer prototype for on-the-go continuous proportional adjustment of the dosage (Escolà *et al.*, 2007). After the utilization of laser scanner sensors for measuring the canopy parameters, several investigations were undertaken which confirmed the results obtained with ultrasonic sensors (Llorens Calveras *et al.*, 2011; Sanz *et al.*, 2004; Tumbo *et al.*, 2002; Walklate *et al.*, 2002).

An air-assisted sprayer equipped with a prototype of an electronic control system which worked on the basis of ultrasonic sensors and solenoid valves for proportional application of PPP to the tree canopy width was developed by Solanelles *et al.* (2006). The adjustment of sprayer flow rate in this prototype was done based on the relationship between the actual tree width and the maximum tree width of the orchard. Actual tree width was measured using ultrasonic sensors and sprayer forward speed in the orchard. The prototype was tested in apple, pear and olive orchards to evaluate the system performance in various crop structures. The spray deposit distribution was compared for selective prototype and conventional air-assisted applications. In order to reduce sampling variability, metal tracers were used for evaluation so that spray deposits for all treatments could be collected on the same samples. Liquid savings of 39%, 28% and 70% in comparison to a conventional application (constant flow rate), were obtained in apple, pear and olive orchards, respectively. Although results showed lower spray deposits on the leaves, a higher ratio between the total spray deposit and the liquid sprayer output was obtained which is explained as better application efficiency. For apple orchard in the control algorithm, a reduction of the maximum tree width parameter reduced spray savings but increased spray deposition on canopy. Spray savings compared to conventional air-assisted application mainly occurred in the mid-level of the outside canopy (Solanelles *et al.*, 2006).

The main advantages of ultrasonic sensors are their low cost and accessibility. Due to the constant speed of sound for the calculation of distance, it is not suitable for environments which experience dynamic changes. Air temperature affects sound speed, and as it travels, the sound pressure amplitude is reduced because of erosion losses in the transmission medium. With increasing frequency, attenuation of sound in air increases at any given frequency, and the signal attenuation is affected by the air relative humidity. Thus, it is difficult to reach high resolution within a short distance. Air turbulence between the sensor and the target, randomly changes average speed of sound, and results in different estimates of the same distance. Similar variations in the determination of range data will appear related to surface reflection. The moving of surface also plays a very crucial role in determining the arrival time of a target echo. Some objects, especially those with multiple surfaces, generate different echo patterns, and therefore range data may be inaccurate (Singh, 2004).

Ultrasonic sensors are very sensitive to background noise. Diminishing of the level of background ultrasonic noise is possible when frequency increases. At higher frequencies, less noise is produced in the air, and this noise is significantly attenuated when it travels through the environment. But due to unwanted side effects of higher energy dissipation, increasing the sound waves frequency has limitation. Specular reflection and crosstalk are major problems with ultrasonic sensors. The specular reflection is a phenomenon in which ultrasonic beam fails to return directly to the receiver because it was bounced off from the target object. When one sensor receives the emitted ultrasound waves from another sensor, crosstalk phenomenon is bound to occur. Error Eliminating Rapid Ultrasonic Firing System (EERUFS), which use time between transmission and receiving of pulse, is recommended in order to solve the problem caused by environmental noise and crosstalk (Singh, 2004).

Infrared Proximity sensor

Infrared proximity sensors form another type of active sensor used for distance determination. Most current infrared (IR) systems are ON/OFF type which transmit and receive a high intensity light pulse to detect the presence of objects within the range of the sensor. In general, range measurement by IR sensing requires more complex techniques, such as phase shift measurement or triangulation (Singh, 2004).

Although proportional sprayers equipped with ultrasonic sensors entail lower costs relative to LIDAR or imaging techniques, farmers cannot easily afford them. Thus, in recent years, new research in the field of low-cost infrared sensors has been undertaken to further reduce the cost of proportional sprayers.

In order to minimize pesticide use and drift in fruit crops, researchers at Cornell University have developed a number of automated precision canopy sprayers. The sprayer travels along the rows of vines, monitoring the presence or absence of canopy as well as canopy size and volume. Infra-red sensors allow them to monitor the dimensions of trees and thus alter both airflow output from the fan and liquid flow (application rate) in response to canopy variation. An automatic canopy sensor system was developed using 5 infrared sensors mounted on a mast. Their research describes the development and field testing of canopy sprayer retrofitted with infrared sensors and air restrictors that can adjust pesticide and airflow to match canopies and minimize drift in vineyards and apple orchards. Infrared sensors provided a reduction of up to 40% in pesticide use in the first sprays of the season. An adjustable louvre on the air outlet of an air blast sprayer reduced drift by as much as 71% in vineyards and about 63% in orchards (Landers *et al.*, 2010). They also reported that the application rate of pesticide varies significantly with growth stages and canopy volume.

Another tractor-mounted automatic target-detecting sprayer was designed and developed to meet the demands for chemical pest control in orchards of china. This light weight sprayer was reported to be highly efficient, reducing pesticide use and is friendly to the environment. The techniques of automatic target detection, electrostatics, and air-assisted spraying

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have been combined in this system. An infrared detector is utilized in the automatic target detection system. The sensors are aimed at the top, middle and bottom segments of the tree canopy in order to detect different shapes of fruit trees and provide signals to the control system. The reflected infrared signal from the targets was treated by a series of processing including magnification, selection of the proper frequency, and adjustment of pulses. Experimental results showed that the automatic target detecting orchard sprayer with infrared sensors can save 50% to 75% of agrochemicals, improve the utilization rate (over 55%), increase efficiency, and significantly decrease environmental pollution caused by pesticide application. The developers claim that sprayer can be commercialized easily due to the low price of infrared sensor detectors (Xiongkui *et al.*, 2011).

Use of infrared sensors for target detection is still in the early stages. Although, these sensors typically do not provide the actual distance to an object, they do detect whether or not something is present within the cone of detection. Infrared sensors are also very susceptible to external noise. The infrared ray present in visible light interferes with the desired reflected IR signal. The performance of infrared sensor is better indoors than outdoors and depends upon the type of the target it has to detect, for instance whether the object is light or dark colored (Singh, 2004).

Conclusions

Selective chemical application based on target detection is important in meeting environmental, economic and safety criteria for good agricultural practice. For about three decades various procedures and methods for tree canopy detection have been suggested and developed by both forestry and agricultural scientists. Results indicate that an ultrasonic sensor is an appropriate tool to determine the average canopy characteristics, while a LIDAR sensor provides more accuracy and detailed information about the canopy. Although using infrared sensors in variable rate sprayers is more affordable compared to the others, it is a novice methodology now. All these methods are able to characterize targets with reasonable accuracy, but widespread commercial production of these devices has not occurred. They assure satisfactory efficacy of pest and disease control with reduced use of agrochemicals and decreased drift to the environment compared with that resulting from conventional techniques. The proposed new technologies seem very appropriate as complementary tools to improve the efficiency of pesticide application, however further improvements are still needed. Although several groups have developed prototypes to adjust the application flow rate to variations in the canopy structural parameters using ultrasonic sensors, as it was shown, the solutions for variable rate spraying in orchards are still in the prototype phase. However, there are already commercially available sprayers for weed control as well as fertilization of agricultural fields.

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بررسی روش‌های سمپاشی "تیمار متغیر" درختان متناسب با ویژگی‌های تاج درخت

حسین مقصودی[1] و سعید مینایی*

گروه مهندسی مکانیک بیوسیستم، دانشکده کشاورزی، دانشگاه تربیت مدرس ، تهران، ایران.

* پست الکترونیکی نویسنده مسئول مکاتبه: minaee@modares.ac.ir

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چکیده: به‌کارگیری سمپاشی میزان متغیر با بهره‌گیری از سیستم‌های کنترل تناسبی می تواند مصرف آفت‌کش‌ها را به‌میزان قابل‌توجهی کاهش داده و از آلوده شدن مناطق غیر هدف در باغات میوه جلوگیری نماید. روش سمپاشی تاج درخت با تنظیم دبی خروجی موجب می‌شود که باغدار فقط محل هدف را سمپاشی نموده و تنها مقدار صحیح آفت‌کش را متناسب با اندازه تاج درخت، مرحله و فصل رشد مصرف نماید. این امر باعث می‌شود که مصرف سموم از نظر اقتصادی و زیست‌محیطی منطقی باشد. چالش اصلی در این راستا رسیدن به حداکثر نشست سم روی تاج درخت با حداقل مصرف سم است. کارایی سمپاشی می‌تواند از طریق کاهش هدر رفت سم روی زمین و بادبردگی ذرات سم به مناطق غیر هدف بهبود یابد. تنظیم میزان سمپاشی متناسب با اندازه و شکل درختان توسط سمپاش‌های کنترل خودکار در کاهش مصرف سم مؤثر است. در سال‌های اخیر روش‌های تشخیص محل هدف سمپاشی با استفاده از فنآوری‌های پیشرفته چون سامانه‌های تصویربرداری، اسکنرهای لیزری و یا سامانه‌های ساده‌تر چون حسگرهای فراصوتی، فروسرخ و طیفی بهبود یافته‌اند. این سامانه‌ها با تهیه نقشه‌های هندسی از درختان، مدیریت موضعی باغ‌ها را ممکن می‌سازند. به‌کارگیری حسگرها برای سنجش پوشش تاج، فاصله و محل درختان موجب تضمین بهره‌گیری بهتر از نهاده‌های گران‌قیمت، و در نتیجه رویکرد پایدار به این امر مهم می‌شود. روش‌های مختلفی برای تعیین پارامترهای ساختار پوشش تاج درخت در دسترس می‌باشد و این مقاله به معرفی برخی از سامانه‌های تجاری قابل اجرا و بررسی شباهت‌ها و تفاوت‌های آنها می‌پردازد.

واژگان کلیدی: سمپاشی تیمار متغیر، سامانه تشخیص هدف، حسگر فراصوتی، ویژگی‌های ساختاری توده درخت

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۱- آدرس فعلی: گروه ماشین‌های کشاورزی، دانشکده کشاورزی، دانشگاه شهید باهنر کرمان، کرمان، ایران.