Precision Agriculture and Drift Management

D. Ken Giles
Department of Biological & Agricultural Engineering
University of California, Davis, Davis, California, 95616 USA

Abstract

By definition, spray drift is composed of applied pesticide that has failed to reach the intended target. Most sprayers treat an entire area with little consideration for or ability to adapt to target or environmental conditions. Sensing and control systems for agricultural sprayers can reduce spray drift by adjusting the spray output to focus deposition exclusively on targets, compensate for variable environmental conditions or alter the application rate in accordance with a priori knowledge of the crop or other target. Technology and techniques for such applications is generally referred to as "precision agriculture". In this paper, the term "precision application" refers to technologies and strategies where broadcast application of agrochemicals is replaced by targeted application and / or control of the application based on sensing of environmental conditions. Specific examples include target detection systems for field and orchard crops, droplet size and rate control systems and selective application systems that allow reduction or elimination of chemicals with potential drift concerns. Sensing and control systems can significantly reduce the applied rate of pesticide while maintaining target deposition levels necessary for efficacious pest control. Order-of- magnitude reductions can be achieved under some conditions while 25 – 50% reductions in are present at the time of treatment. Examples include selective control of emerged weeds and foliar applications of insecticides and fungicides when crop plants are sparse or exhibit spatial non-uniformity. The systems require sensors, algorithms and spray system actuators with fast response times and high spatial resolution. "Spot spray" systems are examples of the sense-and-treat approach. Map-based control is often used for application of pre-emergent herbicides and crop nutrients on spatial scales limited by GPS accuracy or width of individually-controllable spray boom sections. In these systems, sensing and treatment chemical rate can be routinely achieved.

Introduction

There is increasing desire to reduce pesticide use rates and off-target movement that occurs from drift and runoff. If application efficiency is defined as the ratio of the spray deposited on the target to the total spray applied to the field, the common broadcast applications of pesticide, with no adjustment for target or environmental conditions, are very inefficient. Much of this inefficiency is caused by variability in both the size and location of the spray target. Conventional sprayers are usually designed, evaluated and approved with primary emphasis on uniformity of distribution across a spray boom or vertical crop outline; however the distribution of actual target pest may exhibit significant non-uniformity. Target sensing sprayers can adapt the output of the spray to match the sensed target.

There are two primary approaches to precision application systems: real-time sensing and control and map-based control. Real time sensing is used for improving application efficiency when pests or targets are temporally distinct, often separated by months.

Scenarios for Drift Reduction through Precision Application

There are a number of possible scenarios through which precision application can reduce spray drift; most commercial and prototype precision application systems fit one of the following scenarios:

1. Highly targeted delivery using conventional application methods. In this scenario, sensors are used to detect the target and focus the spray deposition exclusively onto the target. Application is done with conventional spray nozzles. Examples of this approach include weed-activated spot sprayers such as NIR-based weed sensing systems. This approach

reduces spray drift by reducing the amount of pesticide applied and by facilitating the use of lower risk chemicals.

2. Highly targeted delivery using improved application methods. In this scenario, similar to the previous scenario, sensors are used to guide application. However, the application technique is altered to exploit additional capabilities from the sensed information. Examples include machine-vision detection of weeds for targeted spray deposition using jets, large droplets and micro-dosing. This approach reduces spray drift by reducing the amount of pesticide applied, reducing the driftable fraction of released spray and by facilitating the efficacious use of lower risk chemicals.
3. Map-based, variable rate application using conventional application methods. This situation is the most commonly perceived "precision agriculture" method. In this scenario, DGPS positioning and preloaded, a priori prescription maps are used to make a variable rate application using traditional spray nozzles. The prescription maps may be based on remote sensed crop characteristics, historical data for the field, GIS-layered maps of environmentally sensitive areas or field scouting. This approach reduces spray drift by reducing the rate of chemical applied and offering the capability of changing the spatial distribution of the spray release in relation to pre-mapped drift sensitive areas. Examples of this technology include virtually all commercial spray rate controllers linked to GPS systems.
4. Map-based, constant or variable rate application using on-vehicle sensing and improved application methods. In this situation, similar to the previous scenario, DGPS positioning and a priori maps are used to guide the application; however, the addition of on-board sensors for parameters such as weather and target conditions provide real time adjustments to the spatially-based optimal dose rate. Additionally, improved application techniques such as injection mixing, controllable air carrier and droplet size control can optimize the spray characteristics for the immediate temporal and spatial conditions. This approach reduces spray drift by reducing the overall chemical rate, allowing variable tank mixes of different chemicals, spatially and temporally selective use of adjuvants, adapting the spray release to immediate weather conditions and control of chemical release rate and spray characteristics in relation to proximity to drift-sensitive areas. Examples of this technology include controllable air carrier sprayers and electronic droplet size control systems.

Development and Performance of Precision Application Systems

The scenarios discussed in the preceding section have been realized through commercially-available products or prototype systems in development. This paper is not intended as a comprehensive review of the technology but rather will discuss selected examples of technologies that have been reported in the literature (Giles *et al.*, 2002).

Target sensing, particularly of weeds and tree crops, has been an active development area for decades. Sensors for reflected radiation in the visible and near infrared (NIR) wavebands were used for detecting plants (Hooper *et al.*, 1976) and commercial products based on the NIR approach are now marketed (e.g., the Weedseeker system from NTech Industries). For insecticide and fungicide applications, Reichard and Ladd (1981) developed intermittent sprayers using mechanical and photoelectric sensors to trigger bursts of sprays onto vegetable plants; field tests of the system confirmed that pest control was maintained while pesticide use was reduced 24 to 51% (Ladd and Reichard, 1980). The field crop systems developed by Reichard and Ladd (1981) required that the target be capable of passing through an emitter-detector pair or physically contacting a sensor. The reflective sensors required a distinct plant – soil contrast. Giles *et al.* (1987, 1988) developed an ultrasonic measurement system for fruit and nut trees. When operated in a simple, intermittent mode where the spray output was activated only when a tree was present, spray use was reduced by 10 to 17% and 20 to 27% in peach and apple orchards, respectively. With more advanced control algorithms, spray savings were 28 to 34% and 36 to 52% in peach and apple orchards, respectively (Giles *et al.*, 1989). While not specifically documented, these target sensing systems can be expected to reduce drift by at least the proportionate amount of pesticide rate reduction. Moreover, it is reasonable to expect that actual drift reduction may be greater in that the spray is released only when a target is present and available to capture the emitted spray.

The development of video-based and RTK GPS guidance and steering systems allows further precision in targeting the spray deposition exclusively to targets. In row crops, these systems allow mechanical or thermal cultivation for weed removal to be conducted at high ground speeds and in close proximity to crop seed lines. This capability facilitates reduction in the application rates of pre- and post-emergent herbicides. Concurrently, the capability of spray treating only a narrow band of crop seedline can significantly reduce insecticide and fungicide application rates by eliminating overspray. A prototype system was developed to treat young row crops by limiting the spray band width to the width of lettuce plants within the row and to precisely position the spray nozzle over the center of the row (Giles and Slaughter, 1997). Tool position over the row center was maintained by a video imaging system that controlled a hydraulic actuation for centering an adjustable tool bar (Slaughter *et al.*, 1995). Since the camera was mounted on the adjustable tool bar with the nozzles, this effectively kept the nozzles centered over the rows. Spray band width was adjusted by yawing flat fan nozzles that were mounted on a rotating coupling on a spray boom. Since the spray nozzles covered only the crop rows and no overlap was required, the nozzles were lowered until the combination of yaw and height produced a nozzle band width equal to the crop row width. Nozzles were positioned approximately 6 cm above the crop and operated at 2 bar or less. The system was tested in a commercial lettuce field and compared to a conventional broadcast spray application. Spray deposition on the crop and on the soil surfaces between rows and beds were measured. Spray drift potential was measured by mounting collection strings around the spray boom during the applications. The precision spraying system allowed spray application rates to be reduced by 66 to 80% with a deposition efficiency (defined as deposited material / application rate) of 2.5 to 3.7 times greater than that of conventional spray. Deposition on the soil surfaces was reduced by 72 to 90% from that of conventional spraying. Potential spray drift was similarly reduced by 62 to 93%.

Perhaps the greatest engineering challenge in target sensing and precision spraying is the selective spraying of pest weeds within a crop row. This capability represents an additional dimension beyond narrow band spraying. Not only must the weed plant be discriminated from the crop plant but also the weed must then be treated or removed without damage to the adjacent crop plants. At reasonable ground speeds, this sequence of operations must occur quickly and with high spatial resolution. Lee (1998), Lee *et al.* (1999) and Lamm (2000), for example, have addressed the development of an image processing based system for control of weeds within the row of high-value crops during the early season.

An imaging camera is used to inspect the region of the crop row. Using shape-based algorithms, crop plants are distinguished from any weeds that may be in close proximity. A micro-map is generated with the locations of the weeds to be sprayed. A micro-boom of micro-nozzles is then used to spot spray the weeds. Since the spray material is selectively applied only to the weeds, herbicides which are not chemically selective can be used, provided that inadvertent herbicide deposition does not strike the crop plants. An additional benefit of this approach is that weeds are selectively controlled at stages of growth when they are highly competitive with the crop plants and have the greatest potential for economic damage through yield suppression.

With the high spatial resolution (<6 mm) of the spray treatment, specialised application components were needed. In addition to the small pattern, a fast actuation time (c. 10 ms) was required. To accomplish this, a micro-boom of micro-sections of micro-nozzles was developed. The width of the micro-boom was 10.16 cm and it was split into 8 micro-boom sections of 1.27 cm width. The geometry determined the working width of each spray cell across the direction of travel. Each micro-boom section consisted of 5 micro-nozzles. Each nozzle was a straight tube of 0.28 mm i.d. stainless steel tubing. Micro-nozzles were evenly spaced at 2.54 mm across each boom micro-section. Each micro-section was controlled by an individual high-speed, direct-acting electrical solenoid valve. The valve was capable of delivering a 10 ms pulse of liquid. The liquid did not atomise into small droplets; rather the emitted jet disintegrated into large droplets under Rayleigh break-up conditions.

Video detection systems can reduce application rates down to the minimum required to treat only the explicit target area, such as weeds. In this case, the drift will be reduced by not only the reduction in amount of active ingredient but also by the benefit of using large droplets released from very short orifice to target heights. These systems may also allow use of lower toxicity and reduced risk chemicals due to their much higher application efficiency. The potential drift for reduction is significant.

Aside from target sensing systems, the addition of positional and environmental condition awareness to a spray vehicle can allow spray drift to be directly mitigated by incorporating the proximity to environmentally sensitive areas and weather conditions into the spray control system. The layering of GIS data and the referencing to established databases of sensitive areas such as wildlife or aquatic habitats, occupied structures, established crops and other areas of interest allows the location of the spray vehicle to be determined relative to such areas. The incorporation of real-time, on-board measurement of wind and weather conditions (Lange, 2002) allows the calculation of potential drift transport. The information can be used to alert the operator to the potential for off-target spray movement. A further implementation of this capability is the automatic mitigation of the drift potential by altering the spray rate, droplet size spectra or both (Henderson *et al.,* 1998). Giles and Downey (2003) developed a field control and mapping system where proximity to an urban area and measurement of ambient wind was used to change the droplet size spectrum of a spray application and to record the position of the sprayer, ambient wind, spray application rate and droplet size spectrum used for the application.

Conclusions and Implications

Sensing and real time control of spray application can significantly reduce the amount of pesticide required to maintain acceptable efficacy; concurrently, non-target deposition and spray drift can be virtually eliminated through focusing pesticide deposition exclusively on the targets. Integration of GPS systems and on-board sensors can allow real-time mitigation of spray drift. In addition to drift mitigation, all these technologies can potentially improve efficacy, allow greater use of reduced-risk chemicals, increase applicator productivity and significantly improve accountability for agrochemical use.

References

Giles, D.K, Delwiche, M.J. and R.B. Dodd. 1987. Control of orchard spraying based on electronic sensing of target characteristics. Transactions of ASAE 30:1624-1630,1636.

Giles, D.K, Delwiche, M.J. and R.B. Dodd 1988. Electronic measurement of tree canopy volume. Transactions of ASAE 31:264-272.

Giles, D.K, Delwiche, M.J. and R.B. Dodd 1989. Sprayer control by sensing orchard crop characteristics: orchard architecture and spray liquid savings. Journal of Agricultural Engineering Research 43:271-289.

Giles, D.K. and D.C. Slaughter. 1997. Precision band spraying with machine-vision guidance and adjustable yaw nozzles. Transactions of ASAE 40:29-36.

Giles, D.K., Slaughter, D.C. and S.K. Upadhyaya. 2002. Biological target sensing and sprayer control. Aspects of Applied Biology 66: 129-138.

Giles, D.K. and D. Downey. 2003. Quality control verification and mapping system for chemical application. Precision Agriculture 4:103-124.

Henderson, G.W, D.K. Giles, K. Funk and T. Kolb. 1998. Positive responsive control system and method for sprayer. United States Patent 5,704,546.

Hooper, A.W., G.O. Harries and B. Ambler. 1976. A photoelectric sensor for distinguishing between plant material and soil. Journal of Agricultural Engineering Research 21:145-155.

Ladd, T.L and D.L. Reichard. 1980. Photoelectrically-operated intermittent sprayers for insecticidal control of horticultural pests. Journal of Economic Entomology 73:525-528.

Lamm, R.D. 2000. Robotic weed control for cotton. Ph.D. Dissertation, Biological and Agricultural Engineering Department, University of California, Davis, USA.

Lange, A.F. 2002. GPS weather data recording device for use with the application of chemicals to agricultural fields. United States Patent 6,686.878.

Lee, W.S. 1998. Robotic weed control system for tomatoes. Ph.D. Dissertation, Biological and Agricultural Engineering Department, University of California, Davis, USA.

Lee, W.S., D.C. Slaughter and D.K. Giles. 1999. Robotic weed control system for tomatoes. Precision Agriculture 1:95-113.

Reichard, D.L and T.L. Ladd. 1981. An automatic intermittent sprayer. Transactions of ASAE 24:893-896.

Slaughter, D.C., R.C. Curley, P. Chen and D.K. Giles. 1995. Robotic cultivator. United States Patent 5,442,552.