Spray deposition on plant surfaces: a modeling approach

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Introduction

Pesticides are widely used in agriculture for the management of pests (weeds, insects or pathogens). They are generally applied as a spray to cover the target (e.g. an insect, leaf surfaces or part of a plant) with pesticide-laden droplets. Spray may, however, be lost to non-target areas within a crop through deposition on to the soil or on non-target plant surfaces. The plant architecture of the crop and weed species can influence the distribution of the spray droplets. The action of wind may also result in spray moving away from the spray area. By selecting and using spray equipment and techniques that maximise deposition of pesticides onto the target it is possible to both maximise the effectiveness of the pesticide application and reduce the amount of off-target deposition and damage.

Droplet movement (spray) models and plant architecture models are being combined using three-dimensional computer modeling techniques based on L-systems (Prusinkiewiez *et al.*, 2000) to develop a probabilistic model of turbulence-related spray transport around various plant architectures (Fig. 1). Measurements of pesticide droplet interactions with the crop canopy from wind tunnel and field studies are being used to refine and validate the combined spray and plant architecture model.

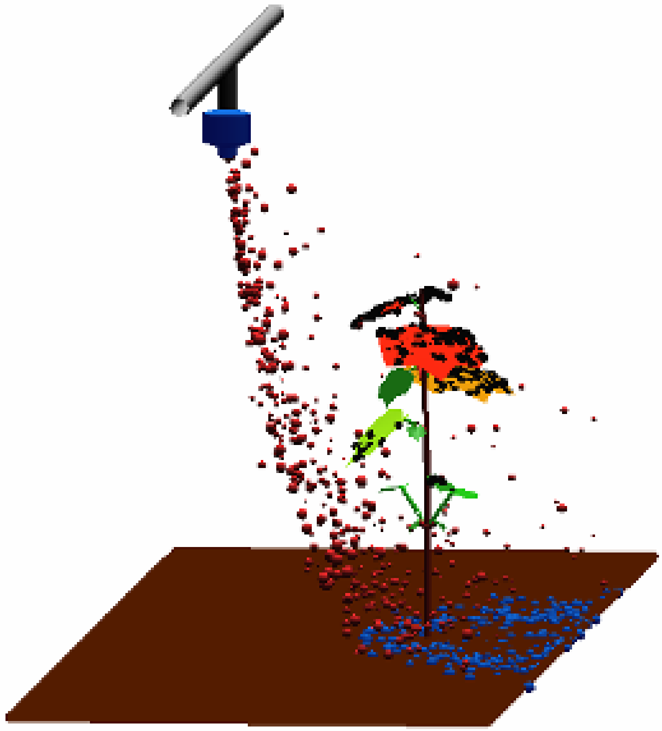

Fig. 1. Simulation of the movement of spray droplets and deposition on a cotton plant

Spray Model

Considerable research has been focused on understanding the movement of sprays from the release point and various computational models have been developed to simulate the spray application process. In general, spray application can be regarded as two-phase fluid flow where liquid droplets are released into an air (gas) flow. To adequately model this situation it is necessary to determine both the airflow in the system and spray movement in the prevailing airflow.

Models of droplet movement in the near nozzle region are often ballistic or particle trajectory models and are based around applying Newton's Second Law of Motion ($F=ma$). The two main forces acting on droplets during a typical spraying situation are gravity and drag. Velocity can be obtained by integrating the equations developed from Newton’s Second Law of Motion and the position can be obtained by a further integration (Marchant, 1977). Since only empirical equations are available to describe the drag coefficient a numerical solution is required. A fifth-order variable step Runge-Kutta numerical integration technique has been used.

The trajectory of each droplet is followed as it moves through the atmosphere by dividing it into a large number of small discrete time steps during which the velocity components (u,v,w) of the particle are kept constant. A meaningful estimate of dispersal statistics can be obtained by following a large number of trajectories (Hashem and Parkin, 1991). The spray program (Dorr *et al.*, 2006) includes algorithms to account for droplet evaporation, entrained air and movement of air around the spray, droplet splash (Saint Jean *et al.*, 2004; Vander Wal *et al.*, 2006) and retention.

Plant Architectural Models

Existing functional-structural models of plants developed using cpfg, for example cotton (Room and Hanan, 1995) and sowthistle (Cici, 2007) have been sourced where possible. These have been inserted into the spray model as sub L-systems. An environment call (?E(leaf_id,area)) was added to the existing plant models before the code that generates the plant objects to be tested for interception with the spray droplets. The object is also given a unique identifying code and an extra module is added to enable the color of the object to change depending on the amount of spray impacting the object. The surface area of the object can be specified if it is known, otherwise it is calculated within the environmental program.

Dynamic plant models that show the development of the plant over time have been incorporated into the spray model. Since the time frame for plant growth is much greater than the time steps required for the spray model, the plant is allowed to develop for a predefined number of steps and then stopped before the spraying commences.

Environmental Program

The spray program is linked to an environmental program to determine if spray droplets will impact on plant components. If any plant object intersects a straight line between the start and finish position of the droplet for each time step the identity of the object and impact co-ordinates are returned from the environmental program to the spray program. The finish position of the droplet can be specified by the spray program or calculated within the environmental program. The C programming language used by the environmental program allows greater flexibility and capability than cpfg through the use of modules such as Runge-Kutta routines for calculation of the final droplet position and velocity.

An *Octree Space Partitioning* (OSP) data structure that automatically groups objects hierarchically while avoiding the representation of empty portions of the space is used to locate objects in a three-dimensional space (Yamaguchi *et al.*, 1984). Initially, the octree has only one cell representing the entire space it is modeling and this cell is called the root cell. The tree grows when the number of objects in a cell becomes greater than a pre-set maximum value. When a cell contains too many objects, only that cell is expanded into 8 children (of equal size), and the objects in the original cell are distributed to its new children.

Using this type of data structure over a simpler one (e.g. a single array containing all objects) can give a dramatic improvement on performance, which becomes apparent when a large number of droplets are added to the system. If a single array was used to contain all objects, then each droplet would need to be checked against each object in the array for intersection in every step. When using an octree, the search can be narrowed down so that only objects in the cell containing the droplet are checked for intersection. Since the plant does not change in size or position during the spraying process a flag is used to keep the previous arrangement once the plant development ceases and prevent the octree being recreated each time step. This significantly reduces the running time of the program.

Comparison with Spray Deposition Measured in a Wind Tunnel

Sow thistle (*Sonchus oleraceus*) plants were grown in 150mm pots in a glasshouse until the advanced rosette stage (Fig. 2). Roundup CT (450g/L glyphosate) was applied to the sow thistle plants using an extended range nozzle (XR110015) and air induction nozzle (TDCFFC110015) at two application rates (57L/ha and 80 L/ha). A fluorescent tracer (pyranine) was added to the spray mix at a rate of 0.5g/L. An electronically controlled traversing mechanism was used within the tunnel to move the spray boom at a constant velocity along the length of the working section.

Fig 2. Example of sow thistle plants at the advanced rosette stage.

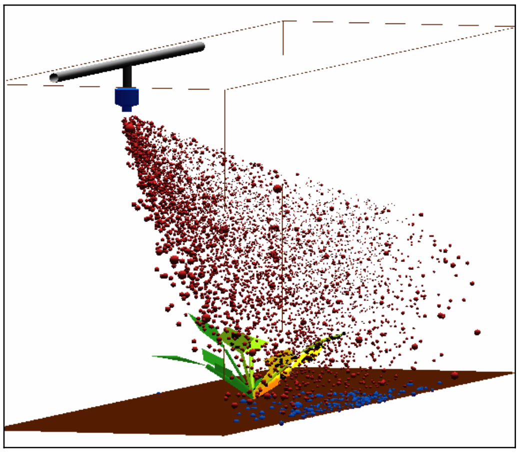

Fig 3. L-Studio simulation of sow thistle plant being sprayed in the wind tunnel.

After spraying all above ground parts of the sow thistle plant was placed in a plastic bag, 60mL of de-ionised water was added to the sample and the bag shaken. The concentration of dye was measured by a calibrated fluorometer (Turner-Sequia model 450). After the dye was removed from the sample the sow thistle leaves were removed, arranged flat on a stand, a photograph was taken and image analysis software (Image Pro v 5.0) was used to measure the surface area of the sample. The amount of dye per unit area was expressed as a percentage of the application rate to enable the two different rates to be compared. Fig. 3 shows an example of the simulation and Fig. 4 shows a comparison of measured spray deposition to modelled spray deposition. All treatments resulted in 100% control of the sow thistle plants.

Conclusion

By combining particle trajectory models with plant architectural models that enable the location of various plant components in 3-D space it is possible to effectively study the removal of spray droplets by various vegetative elements.

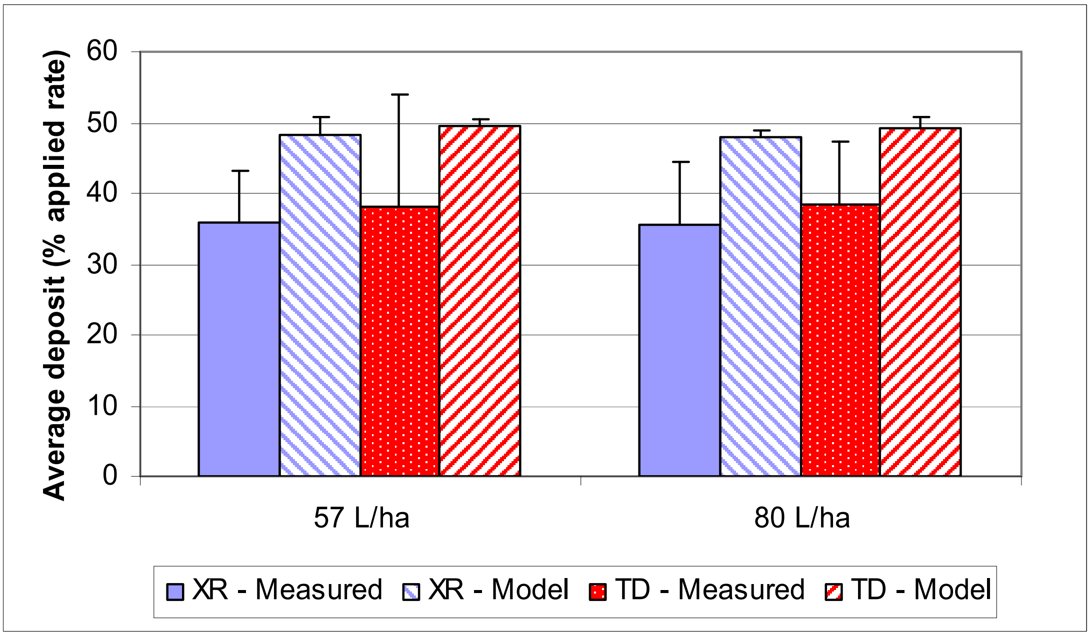

Fig 4. Comparison of measured and modeled spray deposition on sow thistle plants. Error bars show the standard deviation of the results.

Acknowledgments

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