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Transport of Individual Droplets in Crop Spraying

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Spray drift is the movement of any sprayed agrichemical away from the target area and into an area where it may harm human or animal health, or the environment. At present, methods for limiting drift include spraying only in appropriate weather conditions (for example, at low wind speeds), and also the use of shelterbelts and buffer zones.

The aim of this research is to create a mathematical model for spray droplet transport in the atmosphere which can predict the trajectories and deposition of individual droplets as well as clouds of them, and include the effect of varying parameters such as wind speed and direction, temperature, relative humidity, droplet size, and spray velocity and direction.

The work presented here focuses on the trajectories of individual droplets; at present the droplets are assumed to be pure water and the atmosphere is assumed to be uniform (i.e. constant wind speed and direction). Force balancing according to Newton's second law has been used to determine a second order differential equation for the trajectory of a single droplet in a spray, this equation has then been used to find an analytic formula for the density of deposition of droplets on the ground from certain source types, and finally the relative humidity effect on the evaporation and the trajectory of a single droplet has been investigated.

Individual Droplet Trajectories

An individual droplet moving in an air stream is under the influence of three forces: the air resistance, its own weight, and the buoyancy force due to the air displaced by the droplet (although this effect is negligible). Summing these forces according to Newton's second law gives a second order differential equation describing the trajectory of a droplet.

The formula for the air resistance involves a drag coefficient that is a function of the Reynolds number, which is itself a function of droplet diameter and the relative speed between the droplet and the surrounding air; therefore the differential equation above must be solved numerically. However, if the Reynolds number is less than 1 then Stokes drag applies for the air resistance which means it is a linear function of the relative velocity between the droplet and the surrounding air, and therefore the differential equation can be solved analytically. This analytic solution was used to investigate the density of deposition of droplets on the ground when released from certain sources.

Droplets in sprays very quickly assume their terminal velocity, which corresponds to the wind speed horizontally and a constant "settling speed" downwards (the magnitude of which depends on the droplet size).

Density of Deposition on the Ground

Considering a spray as a group of individual droplets which do not affect each other, using Stokes drag force for the air resistance allows an analytic solution to be determined for the density of deposition of droplets along the ground. In this case two sources were considered, a horizontal line source and a point source. For each source the density formula was found by considering a small amount of mass

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released from the source and determining the area on the ground in which this mass landed. For each source it was found that the density of droplets laid out along the ground was far from uniform – a region at the edge of the landing area had a density many times greater, and for certain wind conditions there were regions where the density suddenly doubled in value.

Droplet Evaporation

When a droplet suspended in still air evaporates, liquid water at the droplet's surface becomes water vapour, and the rate of evaporation is controlled by the diffusion of that water vapour out through the surrounding air. However, when there is relative velocity between the droplet and the air, the transfer of water vapour becomes convective rather than diffusive, which tends to increase the evaporation rate. The effect is usually described using a ventilation coefficient, the dimensionless ratio between the evaporation rate of a moving droplet and the evaporation rate of a non-moving droplet.

Also during the evaporation heat is lost from the droplet in order to evaporate some of the water. This heat loss causes a reduction in the droplet temperature, and as a result heat is conducted to the droplet from the air. A steady state is rapidly reached where there is zero net heat exchange, and the droplet temperature is constant but cooler than the surrounding air. When there is a non-zero relative velocity between the droplet and the surrounding air the heat transfer becomes convective rather than conductive; however it can be shown that this has very little effect.

The trajectory of an evaporating droplet can be found by solving a coupled system of first order differential equations; one for the droplet displacement, one for the droplet velocity, and another for the droplet mass. The effect of evaporation on the trajectory of a droplet is quite marked: as the droplet becomes smaller its falling speed decreases, therefore the droplet is blown further by the wind before it reaches the ground or in some cases evaporates completely. The graph below is an example of the trajectories of droplets with initial diameter 100 μm fired horizontally with initial speed 5 m/s from a height of 3 m above the ground into air of different relative humidity. There is a 1 m/s wind blowing in the same direction as the droplet release, and the ambient temperature is 20 °C.

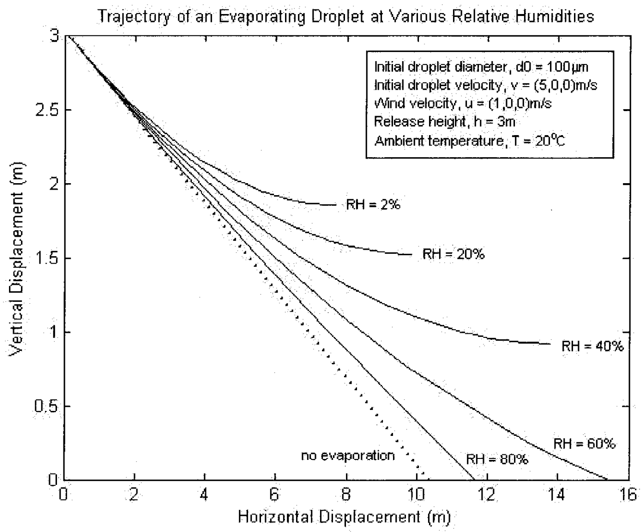

Figure 1 Trajectory of an evaporating droplet at various relative humidities

Termination of the lines above zero vertical displacement indicates that the droplet has completely evaporated before it reaches the ground. This graph shows the significance of the evaporation; at low relative humidity the droplet completely evaporates, and if it does reach the ground it travels further than a non-evaporating droplet.

There are several improvements to be made to this model for droplet trajectory – in particular the assumption of a uniform atmosphere is quite unrealistic. Building in some sort of variation in wind conditions and investigating the effect of both this and evaporation on droplet deposition is the subject of current work.