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**VARIABLE RATE APPLICATION TECHNOLOGY IN  
THE NEW ZEALAND AERIAL TOPDRESSING  
INDUSTRY**

A thesis presented in partial fulfilment of the requirements of the degree of Doctor of  
Philosophy in Agricultural Engineering  
at Massey University, New Zealand



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## ABSTRACT

Greater use of technology to assist aerial application of fertiliser will be of benefit to the topdressing industry and farmers. Benefits arise through automating the fertiliser flow control system; reducing off target fertiliser application, and managing fertiliser inputs based on the potential outputs of the farmland; thus increasing the profitability of hill country farming systems. A case for technology assisted application is developed by investigating the field performance of conventional and enhanced flow control systems and the effect of variable rate application on hill country pasture production.

A single particle model that predicts flight trajectory from the particle force balance based on the aircraft groundspeed, axial and tangential propeller wash, wind characteristics and particle properties including sphericity was developed. Model predictions were compared to predictions from AGDISP 8.15. Results and trends were similar.

The single particle ballistics model described above was extended to predict the lateral distribution of fertiliser after release from an aircraft. To achieve this, two parameters are important, the transverse flow profile of material leaving the hopper gatebox and the sphericity of the particles. Techniques for measuring these parameters are described and experimental results are presented for superphosphate. These data were used in the model to predict the lateral distribution pattern from a Gippsland Aeronautics 200C for a known discharge mass, which was compared to a measured pattern from the same aircraft for the same discharge mass. Good agreement between the shapes of the two distributions was found. The transverse distribution model provides a practical tool for optimising the design of spreaders, or optimum particle characteristics for a given spreader. It has the ability to predict the distribution profile of any particle size distribution from each, or all, of the spreader ducts.

Culmination of the single particle and transverse distribution models led to the development of a deposition footprint model that was capable of predicting field application within a 25 ha trial site. The deposition footprint model was embedded inside a geographical information system and comparisons were made between the actual and predicted deposition across a series of transect lines. Good agreement was found.

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Following this, a comparison of the predicted field performance between an automated and manual control system were made. Economic benefits for a single application of superphosphate were identified through using automated control, where 10% less fertiliser was applied outside of the application zone when compared to the manually operated system. This equated to a net benefit of NZD \$2800 for a 1500 ha hill country farming system. The value of improving the performance of a topdressing aircraft, on an industry level, was also examined. Cost/benefit analysis between a manual and automated system revealed a benefit of NZD \$111,700 yr<sup>-1</sup> for a single topdressing aircraft using the automated system.

The economic impact of Variable Rate Application Technology (VRAT) is examined, using Limestone Downs as an example. The spatially explicit decision tree modelling technique was used to predict the annual pasture production over the entire Limestone Downs property. The resulting decision tree classes tended to follow the farm's digital elevation model. A series of six different fertiliser application scenarios were developed for comparison to a base line scenario using conventional aerial application techniques. VRAT outperformed the fixed rate applications in terms of pasture production and fertiliser utilisation. Full variable rate application and a model optimised prescription map, produced the highest annual pasture yield. Variable rate techniques were predicted to increase annual production and the spatial variability of that production. An economic analysis of the six production scenarios was undertaken. Farm cash surplus was calculated for each scenario and clearly revealed the benefits of using variable rate application technology. VRAT was found to be the most efficient and highest returning application method per hectare. Additional costs and increased charge-out rates were likely to occur under VRAT; nevertheless, the analysis indicated that significant financial incentives were available to the farmer. A sensitivity analysis revealed that even with a 20% increase in charge-out rate associated with VRAT, the farm's annual cash position varied by only \$4500 (0.4%), suggesting the cost of implementing such a system is not prohibitive and would allow aircraft operators to add value to their services.

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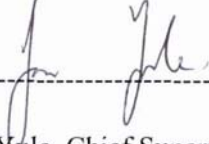
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## STATEMENT REGARDING RESEARCH CONTRIBUTION

The thesis is founded on six papers which have either been published or submitted for publication. The order of authorship reflects the contribution made to the individual pieces of work. In five of the six papers, Robert Murray is the main author. One paper, Chapter 2, has Dr Jim Jones as main author, this reflects his contribution in developing the mathematical model described. Robert Murray understands the model and worked closely with Dr Jones in verifying and testing the core mathematics used in the modelling process.

Signed  Date 18/03/2008

Associate Professor Ian Yule, Chief Supervisor.

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**NOMENCLATURE**

$A$  = area [ $\text{m}^2$ ]

$Arsh$  = inverse hyperbolic sine

$A_{sp}$  = specific area

$C_D$  = drag coefficient

$CV$  = coefficient of variation

$ch$  = hyperbolic cosine

$D_p$  = diameter of particle [m]

$du, dd$  = directly upstream, directly downstream of propeller

$g$  = gravitational acceleration [ $\text{m s}^{-2}$ ]

$H$  = height above ground [m]

$I_a$  = axial flow induction factor

$I_r$  = tangential flow induction factor

$m, n$  = wind constants

$R, r$  = radius of propeller [m]

$Re$  = Reynolds number

$S$  = aircraft planform area [ $\text{m}^2$ ]

$S_p$  = projected area of particle [ $\text{m}^2$ ]

$S_{x,y,z}$  = distance from release point in  $x, y, z$  axis [m]

$sh$  = hyperbolic sine

$SU$  = stock unit

$th$  = hyperbolic tangent

$t$  = time [s]

$U_{x,y,z}$  = velocity components [ $\text{m s}^{-1}$ ]

$|U|$  = slip velocity between particle and air [ $\text{m s}^{-1}$ ]

$V_p$  = volume of particle [ $\text{m}^3$ ]

$x, y, z$  = components along  $x, y$  and  $z$  axis respectively



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$y_{prop}$  = distance from centre of propeller in  $y$  direction

$z_{prop}$  = distance from centre of propeller in  $z$  direction

$\rho_p$  = density of particle [ $\text{kg m}^{-3}$ ]

$\rho_{air}$  = density of air [ $\text{kg m}^{-3}$ ]

$\mu_{air}$  = air viscosity [Pa s]

$\phi$  = particle sphericity [-]

$\Delta$  = incremental change [-]

$k$  = constant

$\alpha$  = integration constant

$\omega$  = angular velocity of the rotating wake at radius  $r$  [ $\text{rad s}^{-1}$ ]

$\Omega$  = the angular velocity of the propeller [ $\text{rad s}^{-1}$ ]