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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: PS2018
2. Project title: Improving dose expression and adjustment for row crops
3. Contractor organisation(s): East Malling Research, New Road, East Malling, Kent, ME19 6BJ
4. Total Defra project costs (agreed fixed price): £ 282,670
5. Project: start date .... 01 June 2008
   end date .... 31 May 2011

6. It is Defra's intention to publish this form.
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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Brief history of PACE research sponsored by CRD

Pesticide labels for orchard spraying in the UK express dose as amounts of the product to be applied per unit ground area, regardless of tree size or density, and for many pesticides, regardless of crop growth stage. Before this research had started, it had long been known that this practice probably resulted in wide variation in deposits above the minimum for biological efficacy and thus was wasteful for many applications. The potential wastefulness of this practice was also recognised by various fruit growers, adopting *ad hoc* methods of dose adjustment to reduce pesticide usage. In a series of CRD sponsored research projects, undertaken collaboratively by Dr Peter Walklate (formerly SRI) and Prof Jerry Cross (EMR), the PACE (Pesticide dose Adjustment to the Crop Environment) method was devised, developed, tested and transferred into practice.

PACE research, aimed at efficient use of orchard spraying products on a wide range of orchards of different canopy size and density, emerged from previous research (PA1710 (1/1/97 – 31/12/99) and PA1721 (17/1/00 – 30/12/01)). Developments were made during these projects to improve the number of spray trials that were possible with a small team of researchers and their assistants[1-11], notably: the use of spray tracers based on EDTA chelates of metals to enable multiple spray applications to target trees[1,3] and a tractor mounted scanning LIDAR system to make rapid non-invasive recordings of orchard tree-row structure[2,10]. Dose adjustment was identified as the most effective basis for: improving the efficiency of pesticide use and mitigation of off-target drift contamination from the synthesis of results obtained from these early measurements of spray deposit distribution on target trees, off-target contamination distribution and tree-row structure parameters for a range of orchards of different sized apple trees ("small" and "medium" trees on M9 rootstocks and "large" trees on MM106 rootstocks) and a range of different sprayer settings.

Subsequent research (PA1732 (1/11/01 – 31/1/04) and PS2002 (1/8/04 – 31/7/07) was aimed at supporting the practical development of the UK PACE scheme for dose adjustment including: efficacy testing[14], farm-scale integration with different planting systems[15] and different types of tree fruit[17-21]. The first PACE scheme for apples was presented to UK growers at four special workshops held within the main areas of pome fruit production in the UK during February and March 2006 together with publication of an attendant HDC Factsheet[16]. This scheme combined advice on sprayer calibration with structured assessment of the need to adjust the sprayer output based on knowledge of the pesticide type and grower assessments of: canopy density, height and row spacing. A pictographic key was constructed from LIDAR images of selected canopies to show the relative density of different apple orchards at the pre-blossom and full-leaf growth stages. This key was also made available on the CRD website to identify the scope of the scheme for UK pesticide registration. The Crop Adjustment Factors for canopy density, defined by this key, were given values according to the fraction of the label dose adjustment and these were published in the Efficacy Guideline 403, 2006. The scheme also introduced the concept of a standard orchard to help growers establish a reference structure for the purpose of sprayer calibration at full label dose rate.

Research project (PS 2018 (1/6/08 – 31/5/11)) was aimed at simplifying the original PACE scheme for the grower by reconstructing it as a webpage linked system to improve the flow of information and the quality control of input and output. This system used a generalised quantitative model for efficient dosage and crop structure standards that it can easily be adapted to support any European method of label dose rate expression[24]. The UK standards were used to enable regulators to translate the harmonised Leaf-Wall-Area dose rate into the equivalent worst-case dose per ha for comparison with the regulatory limit for environmental fate[25].

The crop structure information that has been accumulated through the now standard use of scanning LIDAR recordings of orchards has been a useful resource throughout the last decade for analysing key regulatory problems, including: harmonising label dose expression[13] and new aspirations for efficient dosage for the wide diversity of orchard spraying products and target structures with different methods of label dose expression[18,22,25].

Executive summary of this project

Objective 1. Deliver PACE information technology to UK pome and stone fruit growers by providing HDC Factsheets, PACE assistant software and workshops/training courses

A revised HDC factsheet has been produced and made available as part of the revised UK Best Practice Guides to Apple and Pear Growing to all UK growers on the HDC website (http://www.hdc.org.uk/apples/pesticide-dose-adjustment-for-tree-fruit-spraying.asp?) (See Annex on page 15 of this report). In addition to this, a webpage dose rate adjustment calculator (http://www.pace.pjwrc.co.uk/DoseAdjustment.htm) has been developed and tested throughout the course of this project[SC4, SC5] and has been used to establish important advances over the PACE leaflet[IJ1], including much needed quality control of: user inputs and processing of results based on a generalised dosage model [SJ2]. The webpage for controlling input & output of dose adjustment information (user interface) has been developed to simplify the use of the UK PACE system for the grower. Details about each step of the PACE process is automatically available via pop-up information pages. The presentation of summary results support a simplified strategy for practical implementation of dose adjustment based on the linking of individual sprayer controls to the separate adjustments for orchard canopy (i.e. tank concentration, pump pressure and the number of operational nozzles are linked, respectively to: growth-stage, branch-density and tree-height). However, this may be overridden by more experienced users to allow for the setting of the tank concentration independently of growth-stage.

Following the training courses in 2006 (in project PS2002) and subsequent presentations at industry conferences as part of this project [IOP1, IOP2], many UK growers are now aware of PACE, but few have the confidence to use it to its full potential. Also, grower confidence in PACE is undermined by the resistance from the agrochemical industry to endorse the concept of label dose rate adjustment. Furthermore, some agrochemical companies are currently promoting the use of the Leaf Wall Area (LWA) methods of dose expression for pome- and stone-fruit orchard spraying products in other EU countries, but this ignores conventional regulation of pesticide use based on a fixed limit for the dose per ha of ground area (i.e. the existing UK method of dose expression linked to the dose per ha limit for environmental fate). The LWA method of dose expression has been adopted by the Belgium regulatory authority. PACE avoids the need to change the method of dose expression; it regulates pesticide use based on human and environmental safety and provides a seamless transition to sustainable pesticide use based on the concept of an applied dose to achieve constant target deposit across a wide range of orchard structures.

Further work is needed to promote the use of the PACE dose adjustment calculator and demonstrate the practical benefits for: growers, independent advisors and agrochemical representatives.

The PACE web based system could be further developed to support commercial equipment (i.e. adjustment strategies involving different nozzle types and flow controllers), but this would need commercial funding to support suitable linkage with characteristic data for specific products.

Objective 2. Determine the relationship between the point of spray volume saturation and key crop structure parameters of fruit trees

Field measurements of spray saturation were made in tree fruit orchards of very widely varying canopy size and density at Broadwater farm, West Malling and EMR at different growth stages by spraying replicate plots with tracer at increasing volume application rates (100, 200, 400, 800, 1600, 3200 and 6400 l/ha) using a motorised air-assisted knapsack sprayer. Analysis of the LiDAR crop structure measurements and deposit measurements were made to identify key characteristics above and below the point of saturation.

The results show a strong linear relationship between volume application rate and deposit below the point of saturation[SC2]. In all the cases we examined (including small, young trees) the point of saturation occurred at water volume applications rates greater than 1000 l/ha (i.e. well above the range recommended on most pesticide labels). This work also supports the generalised dosage model that underpins the practical use of PACE dose adjustment [SJ2]. Run-off losses were observed at a wide range of volume application rates above and below the point of saturation. Therefore, it was judged that run-off observations are not a useful indicator of the point of saturation beyond which the generalised PACE dosage model begins to break down.

Objective 3. Attempt to establish European wide consensus on PACE principles

The "European Tree Fruits Dose Expression and Adjustment Discussion Group" was formed with assistance from David Richardson, CRD, and the Plant Protection Service, NL. The group consists of 30 members including regulators, agrochemical companies and researchers. The first one day meeting of the group took place in Wageningen, NL, on 29 September 2009. Over decades a number of different dose expression methods for foliar pesticide applications to 3 dimensional crops have been developed within different European countries, with some counties supporting more than one method. The lack of a harmonised expression is posing a problem for regulators in processing mutual recognition applications, for companies in developing data packages for registration applications and growers would not comprehend expressions used in other countries. The meeting reflected on the suitability of the current position, brought new information forward and discussed what may be possible in terms of harmonisation of dose expression and dose adjustment. Participants showed a willingness to change from the current situation but could not agree on a single system of expression of dose rate for fruit tree crops that could be accepted by all the regulators, chemical companies and scientists present. Substantive points agreed were 1) that maximum dose per ha should be on all labels 2) concentration method of expression alone was not acceptable 3) comprehensive information on tree structure was needed from efficacy trials 4) dose /ha ground area, dose per ha Leaf Wall Area (LWA) and dose per ha at a given Tree Row Volume (TRV) were acceptable methods of expression 5) the web based dose translation service [SC1] developed as part of this project is highly valuable. However, the need for and methods of dose adjustment were not discussed after our presentation on this subject [IOP3]. A report of the meeting[SC3] was prepared by us and has been fed back to EPPO with other actions as appropriate to the discussions held.

Scientific examination of the LWA dose expression[SJ1] established the relationship with the European method for regulating commercial orchard spraying products based on the environmental fate threshold (i.e. the maximum dose per ha of ground area). Also, a method for estimating the maximum dose per ha of ground area by multiplying the dose per ha of LWA by an empirical coefficient was established using a special statistical method based on published LiDAR measurements of English orchards. An estimate of this coefficient (0.85) was discussed and agreed at meetings with CRD[IOP5] and Syngenta[IOP6] for mutual recognition applications for pesticide registration in the UK using pesticide efficacy trials data based on LWA dose expression. Further work may be required to provide similar scientific support for converting the dose per ha of LWA into other European methods of dose expression, but may not be appropriate for exclusive CRD funding.

Objective 4. Establish PACE approaches for boom spraying of another row crop, e.g. potatoes

Deposit distribution and LiDAR measurements have been made after spray applications (200 l/ha with a standard boom sprayer) in potato crops of different varieties; representing a wide range of canopy sizes and densities in two years (2009: Desiree, King Edward, Melody and Maris Piper; 2010: Desiree, King Edward, Melody and Estima) and different growth stages spanning each growing season at St Nicolas Court Farm, Kent.

The results of the first year trials were presented to industry to establish further interest in subsequent trials in 2010 [IOP4]. The accumulated results for two years of deposit measurements show good agreement with the PACE dosage model developed for typical boom spraying scenarios [SC6]. The results show that canopy density accounts for around 87% of the variation of dose adjustment to achieve minimum variation of canopy deposit.

Efficacy demonstration trials are now needed to evaluate practice. These should include canopy structure measurements to establish a practical standard to represent label dose rate.

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Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;

- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

Objective 1. Deliver PACE information technology to UK pome and stone fruit growers by providing HDC Factsheets, PACE assistant software and workshops/training courses.

A revised HDC factsheet has been produced and made available as part of the revised UK Best Practice Guides to Apple and Pear Growing to all UK growers on the HDC website (http://www.hdc.org.uk/apples/pesticide-dose-adjustment-for-tree-fruit-spraying.asp?) (See Annex on page 15 of this report). In addition to this, a webpage dose rate adjustment calculator (http://www.pace.pjwrc.co.uk/DoseAdjustment.htm) has been developed and tested throughout the course of this project[SC4, SC5] and has been used to establish important advances over the PACE leaflet[IJ1], including much needed quality control of: user inputs and processing of results based on a generalised dosage model [SJ2]. The webpage for controlling input & output of dose adjustment information (user interface) has been developed to simplify the use of the UK PACE system for the grower. Details about each step of the PACE process is automatically available via pop-up information pages. The presentation of summary results support a simplified strategy for practical implementation of dose adjustment based on the linking of individual sprayer controls to the separate adjustments for orchard canopy (i.e. tank concentration, pump pressure and the number of operational nozzles are linked, respectively to: growth-stage, branch-density and tree-height). However, this may be overridden by more experienced users to allow for the setting of the tank concentration independently of growth-stage.

Following the training courses in 2006 (in project PS2002) and subsequent presentations at industry conferences as part of this project [IOP1, IOP2], many UK growers are now aware of PACE, but few have the confidence to use it to its full potential. Also, grower confidence in PACE is undermined by the resistance from the agrochemical industry to endorse the concept of label dose rate adjustment. Furthermore, some agrochemical companies are currently promoting the use of the LWA methods of dose expression for pome- and stone-fruit orchard spraying products in other EU countries, but this ignores conventional regulation of pesticide use based on a fixed limit for the dose per ha of ground area (i.e. the existing UK method of dose expression linked to the dose per ha limit for environmental fate). The LWA method of dose expression has been adopted by the Belgium regulatory authority. PACE avoids the need to change the method of dose expression; it regulates pesticide use based on human and environmental safety and provides a seamless transition to sustainable pesticide use based on the concept of an applied dose to achieve constant target deposit across a wide range of orchard structures.

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The PACE web based system could be further developed to support commercial equipment (i.e. adjustment strategies involving different nozzle types and flow controllers), but this would need commercial funding to support suitable linkage with characteristic data for specific products.

Objective 2. Determine the relationship between the point of spray volume saturation and key crop structure parameters of fruit trees

2.1. Introduction

The characteristic volume application rate (i.e. amount of water per ha of ground area) where leaf deposit of pesticide (i.e. amount recovered from the target per ha of leaf area) reaches the maximum or saturation value is a source of uncertainty that influences the efficacy evaluation of commercial orchard spraying products in particular when they are performed at high water volume application rates. The objective of this work was to determine the point of spray volume saturation and identify the dependency of key tree fruit structure parameters. To achieve this objective, the spray volume saturation characteristics of tree fruit orchards of widely varying structures comprising different foliage types (smooth vs hairy), tree sizes (large vs small) and different branching densities (low density vs high density) were determined in relation to the classical crop-row parameters (measured using LiDAR) for spraying at two different growth stages, early and late season. Appropriate methodology was determined in a preliminary experiment in 2008, not reported here. A simple data fitting model (Barabási & Stanley 1995) was used to extract key parameters that may be used to describe the characteristic variability [SC2]. In subsequent additional work, we also used a simple leaf dipping method to investigate the saturation point in relation to fruit tree species, variety and leaf surface characteristics.

2.2. Methods and materials

2.2.1. Spray saturation

Single tree plots within different orchards of pome and stone fruit (pear cv conference; apple cv Braeburn, Bramley, Ceeval; cherry mixed cvs) and widely varying structure (272 – 1905 trees/ha, 1 – 32 years in age) at Broadwater Farm, West Malling and EMR) were sprayed with a tracer tank mixture (water + sodium flourescein at a concentration of 0.5 g/l + the wetter Activator 90 at 0.01% concentration) using a Birchmeier B245s motorised air-assisted knapsack sprayer set-up to give a liquid flow rate of 11.33 ml/s and a very fine spray quality (Figure 2.1). The effects of inter-plot contamination were minimised by arranging the treatments in ascending order of spray volume along the row. Each plot consisted of one tree with a single guard tree separating it from the next plot. Different spray volumes in increasing 2 fold steps viz. 100, 200, 400, 800, 1600, 3200, 6400 per ha were applied by spraying trees for different durations. The actual volume rates varied somewhat between orchards due to the variations in plant density and the need for spray durations to be in multiples of whole seconds for timing purposes. For the largest trees (272 trees per ha), the spray duration ranged from 6 to 2048 s per tree, to achieve the range of volume rates required.

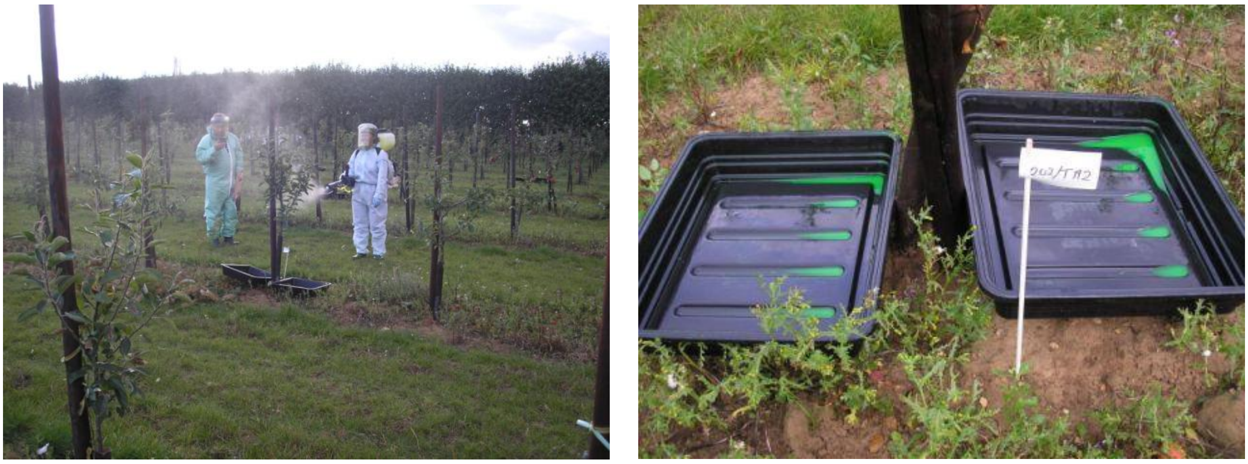


Figure 2.1. Left: Spray application with a motorised knapsack sprayer to a young (1 year old) orchard. Right: Trays used for collecting run-off.

Run-off was collected in a pair of trays positioned under the central sampled tree in each plot (Figure 2.1). To quantify spray deposits, two bulk sample of 25 leaves were taken from each tree with sampling at random. Each sample was picked from the tree into a new polythene bag, weighed to nearest 0.1 g, followed by wash off extraction of flourescein sodium deposits with 100 ml of 0.1M phosphate buffer (pH 7.1) + 0.01% Activator 90 wetter. As soon as the sample has been extracted and the aliquot sample taken into a tube, the sample was stored in the dark, to minimise UV degradation. Spiked and blank samples were used in the field to provide AQA data and to correct for any UV degradation. Quantification of amounts of spray deposit were done in the laboratory at EMR using a Jenway 6280 fluorimeter (excitation 490 nm; emission 515 nm). Leaf areas were quantified by area:weight ratio determination, the area weight ratio for each variety being determined on 3-5 samples of 25 leaves from each orchard. Leaf area measurements were made with a LiCor leaf area meter. Exposure and sampling of each plot was replicated. Further details of these experimental methods are given by Cross (2008). LiDAR recording of the tree plots were made using the methodology described by Walklate et al (2002) to sample each row of trees containing the single tree plots. Specialised software (LidarAssistant6, 2008) was used to extract sub-samples of tree structure parameters representing each single tree plot scanned from the avenues on either side of the tree-row.

Experimental work was done on10, 28 September 2008, 20 April 2009, 22 April and 25 Aug 2010.

2.2.2. Leaf dipping

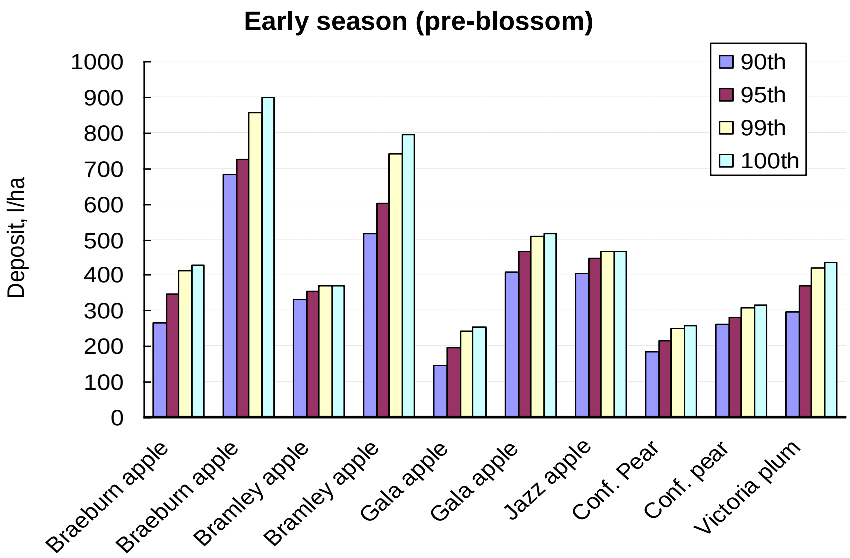
In 2010, six replicate samples of 25 leaves were collected into polythene bags from a range of orchards comprising different species, varieties and tree sizes of widely varying ages at Broadwater Farm, West Malling early in the season pre-blossom on 22 April and from the same orchards at full leaf in the middle of the season on 25 August. Photographs were taken against a graph paper background for scale, of the upper and lower surfaces of typical leaves from each orchard, as a record of their size and leaf surface characteristics. The samples were transferred to the laboratory where immediately 500 ml of a stock solution of tartrazine (1 g/l) + fluorescein sodium (0.5 g/l) + Activator 90 (0.1%) was added to each of three of the replicate samples from each orchard. These were then shaken vigorously to ensure the leaves were coated with the stock solution. Leaves were then removed from the bag and spread out on trays on blue paper towel to dry. Once completely dry, the samples were returned to fresh bags and extracted with 100 ml of 0.1M phosphate buffer in the same way as described for the main leaf deposit sampling above. Concentrations of fluorescein and tartrazine were determined using a

Jenway 6280 Fluorimeter and a Komptron Spectrophotometer, respectively. Note that the two different tracer dyes and methods of determination were used so that the results could be validated against each other, providing a valuable cross-check. The remaining 3 replicate samples from each orchard were used to estimate the leaf area:weight ratio for that orchard, so that the deposits on the leaves could be expressed in terms of amounts per unit area, using the same methodology as described above for the spray saturation experiments. The deposits retained on the leaves (l/ha of leaf surface) were plotted in histograms.

2.3. Results

2.3.1. Spray saturation

In general, the results (Figure 2.2) show that the upper percentile deposit levels, determined by these experiments, vary with: growth-stage, fruit species and variety. Furthermore, where the variations of percentile values are approximately constant this gives an indication of the saturation conditions (i.e. deposit is independent of the applied volume). Species/varieties with hairy leaves (e.g. Bramley and Braeburn apple shown on the left hand side) appear to retain higher deposits than hairless and smooth leaved species/varieties (e.g. Gala and Jazz apple, Conference pear or Victoria plum). Pre-blossom deposits gave more variability between the same species/varieties than post-blossom full-leaf deposits.



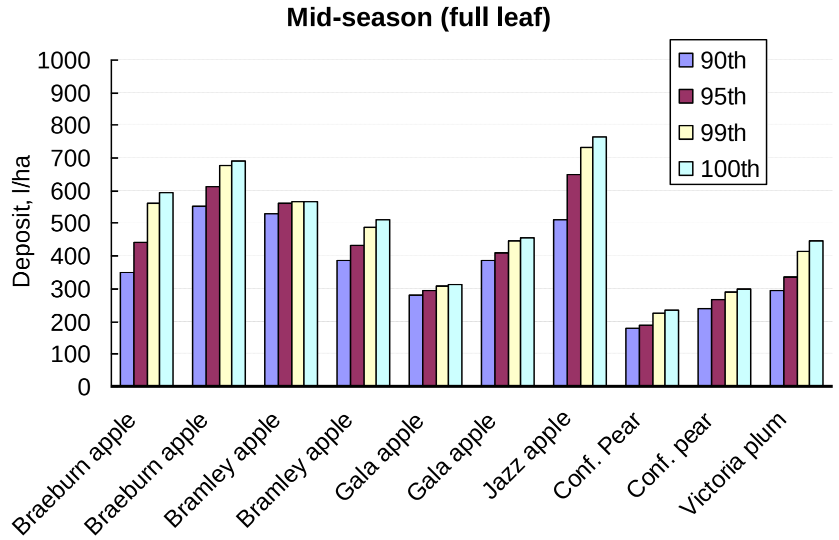
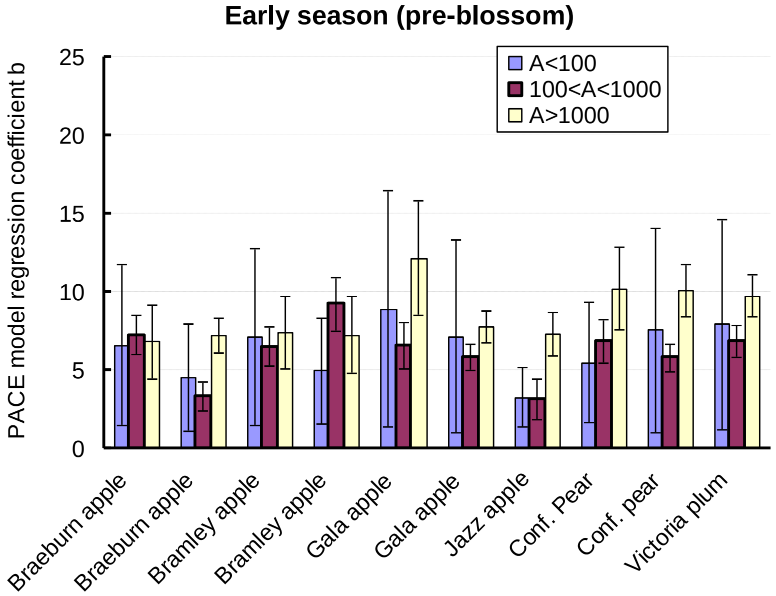


Figure 2.2. 90th, 95th, 99th and 100th percentile deposits retained on the leaves (l/ha of leaf surface) sampled from different orchards early season (pre-blossom) on 22 April and mid-season (at full leaf) on 25 August 2010

Figure 2.3 shows a different approach to the examination of saturation characteristics by removing the variability predicted by the PACE dosage model (i.e. based on canopy scaling effects of size and density). Hence the regression coefficient b (i.e. the ratio of applied volume to the product of deposit, tree-height and density) has been estimated for three different groups of application rate (i.e. below 100 l/ha, between 100 and 1000 l/ha and above 1000 L/ha) to establish where b increases significantly to indicate saturation. Examples of this saturation characteristic are clearly discernable for many of the smooth leaved species/varieties (Gala & Jazz apple, Conference pear and Victoria plum). By contrast with this, the hairy leaved species/varieties do not give such clearly discernable saturation characteristics and tend to produce more variability below 100 l/ha at full-leaf. The estimates of b are, in general, much larger than previous estimates made for trailed orchard sprayers (Walklate et al., 2011) and this is indicative of an inefficient spray application method. In this case the inefficiency is probably the result of the multiple pass spray applications leading to enhanced cumulative disturbance of leaves, resulting in premature run-off which was readily observable (Fig 2.1). However, the point of first run-off was rarely accompanied by the classical saturation characteristics.



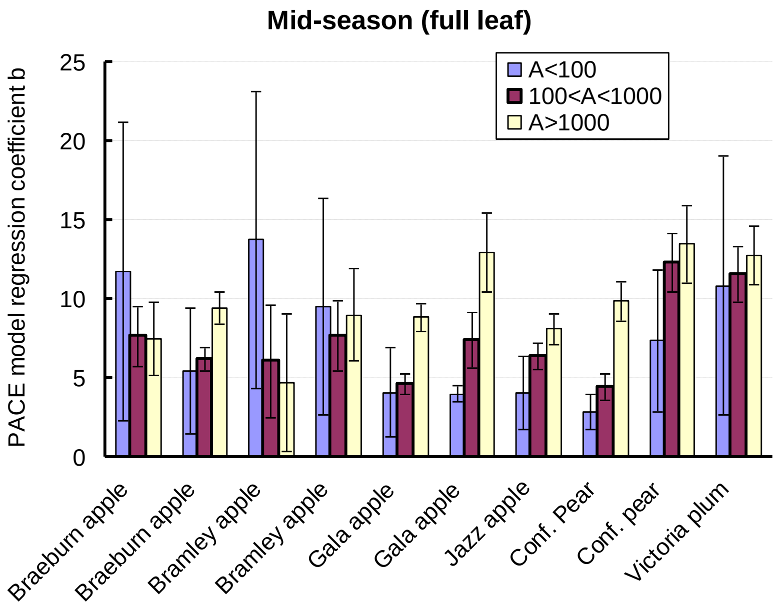


Figure 2.3. The PACE regression coefficient estimates b for different orchards early season (pre-blossom) on 22 April and mid-season (at full leaf) on 25 August 2010, The error bars indicate the upper and the low limits based on the 5% and 95% estimates of b assuming normal distribution.

2.3.2. Leaf dipping

Deposits (l/ha of leaf surface) obtained by dipping leaves from the different orchards early (pre-blossom on 22 April 2010) versus mid-season (full leaf on 25 August 2010) were substantially lower and more uniform than those obtained in the spraying experiments above (Figure 2.4). Early season, mean deposits ranged from 29.6 l/ha for Gala 1 orchard leaves to 87.7 l/ha for leaves from “cherry2” orchard. Mid-season, mean deposits ranged from 67.1 l/ha for leaves from “Gala1” orchard to 243 l/ha for leaves from “Gala3” orchard. The pattern of deposits among varieties and the values were quite different at the two sampling dates. There was no evidence that varieties with hairy leaves (Bramley, Jazz) retained greater deposits than those with smoother, hairless leaves (Gala, Conference).

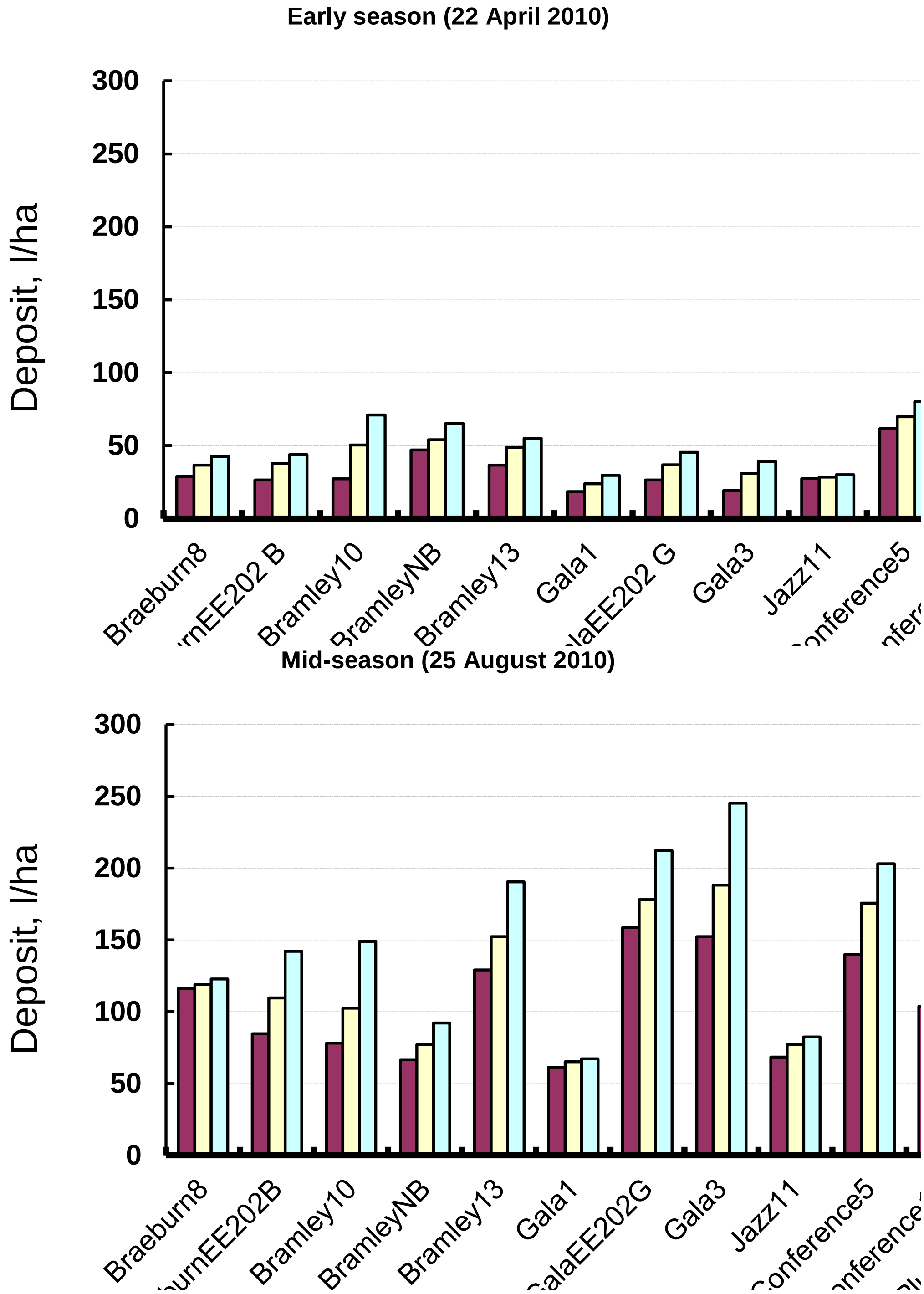


Figure 2.4. Mean deposits (l/ha of leaf area, both surfaces) on leaves from dipping in the laboratory early and mid-season 2010

2.4. Discussion

2.4.1. Spray saturation

The results show a strong linear relationship between volume application rate and deposit below the point of saturation[SC2]. In all the cases we examined (including small, young trees) the point of saturation occurred at water volume applications rates greater than 1000 l/ha (i.e. well above the range recommended on most pesticide labels). This work also supports the generalised dosage model that underpins the practical use of PACE dose adjustment [SJ2]. Run-off losses were observed at a wide range of volume application rates above and below the point of saturation. Therefore, it was judged that run-off observations are not a useful indicator of the point of saturation beyond which the generalised PACE dosage model begins to break down.

2.4.2. Leaf dipping

The results indicate that the leaf dipping method is not a good indicator of the results of spray saturation deposit experiments in the orchard. The values obtained by leaf dipping were considerably lower. There are a number of probable reasons for this difference: Firstly, instantaneous dipping does not reflect the spraying process, where the spray is deposited on the leaves and blown off by the air stream. Evaporation and possibly localised drying occurred in knapsack sprayer air-assisted spray applications. This effect was particularly pronounced on the large trees where the duration of spraying to reach saturation was long. Another contributory factor may be that the dye was not behaving like the water carrier. The dye may have accumulated on the target well beyond the point of carrier liquid saturation, hairs on leaves simply giving more surface for the dye to adhere to when the application was of longer duration. These are possible reasons why it was difficult to observe a saturation like characteristic on larger trees in the spray saturation experiments.

2.5. References

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Objective 3. Attempt to establish European wide consensus on PACE principles

The “European Tree Fruits Dose Expression and Adjustment Discussion Group” was formed with assistance from David Richardson, CRD, and the Plant Protection Service, NL. The group consists of 30 members including regulators, agrochemical companies and researchers. The first one day meeting of the group took place in Wageningen, NL, on 29 September 2009. Over decades a number of different dose expression methods for foliar pesticide applications to 3 dimensional crops have been developed within different European countries, with some counties supporting more than one method. The lack of a harmonised expression is posing a problem for regulators in processing mutual recognition applications, for companies in developing data packages for registration applications and growers would not comprehend expressions used in other countries. The meeting reflected on the suitability of the current position, brought new information forward and discussed what may be possible in terms of harmonisation of dose expression and dose adjustment. Participants showed a willingness to change from the current situation but could not agree on a single system of expression of dose rate for fruit tree crops that could be accepted by all the regulators, chemical companies and scientists present. Substantive points agreed were 1) that maximum dose per ha should be on all labels 2) concentration method of expression alone was not acceptable 3) comprehensive information on tree structure was needed from efficacy trials 4) dose /ha ground area, dose per ha Leaf Wall Area (LWA) and dose per ha at a given Tree Row Volume (TRV) were acceptable methods of expression 5) the web based dose translation service [SC1] developed as part of this project is highly valuable. However, the need for and methods of dose adjustment were not discussed after our presentation on this subject [IOP3]. A report of the meeting[SC3] was prepared by us and has been fed back to EPPO with other actions as appropriate to the discussions held.

Scientific examination of the LWA dose expression[SJ1] established the relationship with the European method for regulating commercial orchard spraying products based on the environmental fate threshold (i.e. the maximum dose per ha of ground area). Also, a method for estimating the maximum dose per ha of ground area by multiplying the dose per ha of LWA by an empirical coefficient was established using a special statistical method based on published LiDAR measurements of English orchards. An estimate of this coefficient (0.85) was discussed and agreed at meetings with CRD[IOP5] and Syngenta[IOP6] for mutual recognition applications for pesticide registration in the UK using pesticide efficacy trials data based on LWA dose expression. Further work may be required to provide similar scientific support for converting the dose per ha of LWA into other European methods of dose expression, but may not be appropriate for exclusive CRD funding.

Objective 4. Establish a PACE approach for boom spraying of another row crop, e.g. potatoes

4.1. Introduction

The efficiency of pesticide use might be improved for potato spraying applications by making dose adjustments. Currently available products do not provide appropriate support for dose adjustment and PACE informatics could be developed to bridge the gap between the basic dose rate information on product labels and the additional information required for efficient use of that product across a broad range of crop varieties at different growth stages with different soil types.

Field measurements of spray deposit and target canopy structure have been made to evaluate the scope for PACE dose adjustment of potato spraying products. The combined measurements for two growing seasons (2009 – 2010) are presented here for five different varieties of potato. These measurements are used to evaluate a data fitting model based on the PACE dimensionless paradigm for dose adjustment (Walklate et al., 2011).

The results of data fitting show that a single canopy density parameter (i.e. the ratio of the single-trial to cumulative interception probabilities) accounts for 87% of the applied dose variation for efficient use of product with a minimum crop-to-crop variation of deposit. The data fitting model has potential to support quantitative sensors for new crop adapted band spraying equipment (Zande et al., 2009) and the development of qualitative assessment methods for use with existing boom spraying equipment.

4.2. Methods and materials

4.2.1. Spray deposit experiments

The spray volume deposit characteristics of different potato crop structures were determined for different varieties grown in different fields with soil types (ranging from rich peaty soils on the marsh to brick earths in the less low lying areas) and growth stages during 2009 and 2010 at St Nicolas Court Farm, Kent. Single variety plots were sprayed with a tracer tank mixture (water + sodium flourescein at a concentration of 0.5 g/l + the wetter Activator 90 at 0.01% concentration) at 200 l/ha using a 24 m boom sprayer set-up to give "Medium" spray quality. Plots were large (>10 x 30 m) and where they were in the same field, they were generally side by side so they could be sprayed simultaneously.

Each sample was picked into a new polythene bag, weighed to nearest 0.1 g, followed by wash off extraction of flourescein sodium deposits with 100 ml of 0.1M phosphate buffer (pH 7.1) + 0.01% Activator 90 wetter. As soon as the sample has been extracted and the aliquot sample taken into a tube, the sample was stored in the dark, to minimise UV degradation. Spiked and blank samples were used in the field to provide AQA data and to correct for any UV degradation. Quantification of amounts of spray deposit were done in the laboratory at EMR using a Jenway 6280 fluorimeter (excitation 490 nm; emission 515 nm).

Leaf areas were quantified by area/weight ratio determination, the area weight ratio for each variety being determined on 3-5 samples of 25 leaves from each orchard. Leaf area measurements were made with a LiCor leaf area meter. Exposure and sampling of each plot was replicated.

Sprays were applied to different varieties of potato (i.e. Desiree, King Edward, Melody, Maris Piper in 2009 and Desiree, King Edward, Melody, Estima in 2010) using a standard 24 m boom sprayer (nominal application rate of 200 l/ha).

4.2.2. Data fitting model

<u>Generalised case - with adjustment for vegetative target width</u>

The PACE dose adjustment paradigm, originally aimed at improving the efficiency of pesticide use for broadcast air-assisted spraying of tree-row crops (Walklate et al 2011), has been further adapted to evaluate field measurements of spray deposit on potato crops for band spraying (i.e. the general case of a boom sprayer with variable target width). These adaptations resulted in the following model for data fitting and analysis of spray deposit data:

$$D/d = b\,\sigma\, w/s \qquad (1)$$

where D/d is the ratio of the ground area applied dose rate to the canopy averaged deposit, b is a data fitting coefficient, σ is a special canopy density parameter that expresses the ratio of the single trial interception probability to the cumulative interception probability, w is the vegetative target width and s is the spacing of the potato row.

For this case the special canopy density parameter is determined using an approximation based on Beer's law of light interception to obtain the following expression:

$$\sigma = a\,h / \left(1 - \exp\left(-a\,h\right)\right) \qquad (2)$$

where the average interception probability of the crop is given by the product of a the leaf area density and h the height.

<u>Simplified case - with no adjustment for vegetative target width</u>

For a conventional boom sprayer, where no adjustment is made to account for variable width of the target (i.e. $w = s$), Eq (1) become:

$$D/d = b\,\sigma \qquad (3)$$

and because the leaf area index, given by the identity $\alpha = a\,h\,w/s$, Eq (2) can be expressed in terms of this more familiar parameter, as follows:

$$\sigma = \alpha / \left(1 - \exp\left(-\alpha\right)\right). \qquad (4)$$

4.2.3. LiDAR recordings of crop structure

In addition to the destructive measurements of crops made as part of the deposit measurements, LiDAR recordings (Walklate et al., 2002) of crop structure were made using LMS200 scanning system (Sick AG Germany). This system was traversed along the potato row at a constant height above the top of the canopy. The height and orientation of the LiDAR was set so that the light beam would intercept the crop along a range of trajectories similar to the spray droplet trajectories of a conventional flat fan nozzle. The output from the LiDAR was recorded and processed using specialised software (LidarAssistant7, 2010). This software was developed to determine the crop structure parameters we have introduced in section 4.2.2 based on the 2-dimension probability interception distribution (Figure 4.1). This required further modification of the original LidarAssistant6 software developed for processing data from tree-fruit orchards.

The LiDAR was mounted on a separate small tractor boom to traverse the potato plots during the experiments of 2009. However, the need for a separate small tractor for this duty was obviated by the use of a hand-held boom to traverse the LiDAR in the spray deposit experiments of 2010.

4.3. Results

The results (Figure 4.2) show plot-to-plot variation of the ratio $D/d\,b$ (i.e. the normalised applied dose per unit ground area to deposit) plotted as a function of σ (i.e. the special canopy density parameter). The renormalized model (correlation function) accounts for 87% of the data variation. The values for regression coefficient b are significantly different for 2009 data compared with 2010 data. This may be due to the use of the Syngenta potato nozzle in 2009 (110 degree nozzle angled forward and back by 30 degrees) producing a more stratified deposit distribution (i.e. more deposit at the top of the canopy) than the deposit for the conventional flat fan nozzle in 2010.

4.4. Conclusions

The results of deposit experiments with potato crops have been used to establish suitable PACE informatics (i.e. dose adjustment model and crop standards) to support the efficient use of spray products across a wide range of common potato varieties at different growth stages. Efficacy demonstration trials are now needed to further evaluate practice based on PACE informatics.

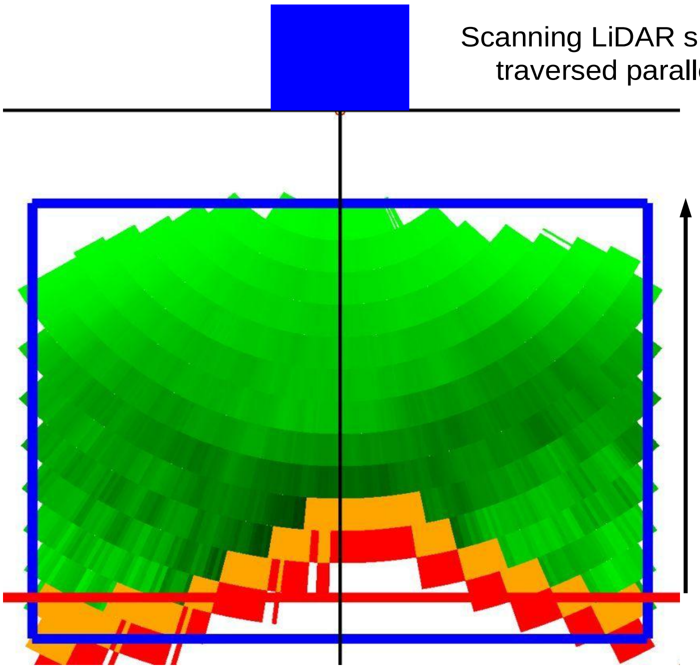

Figure 4.1 Cross-section the potato row, derived from LiDAR recordings, showing a coloured map of the 2-dimensional interception probability distribution (green > 0.01; black=0.95; Red =1). The orange & red elements are removed for the purpose of estimating integral crop canopy parameters (i.e. area density and leaf area index).

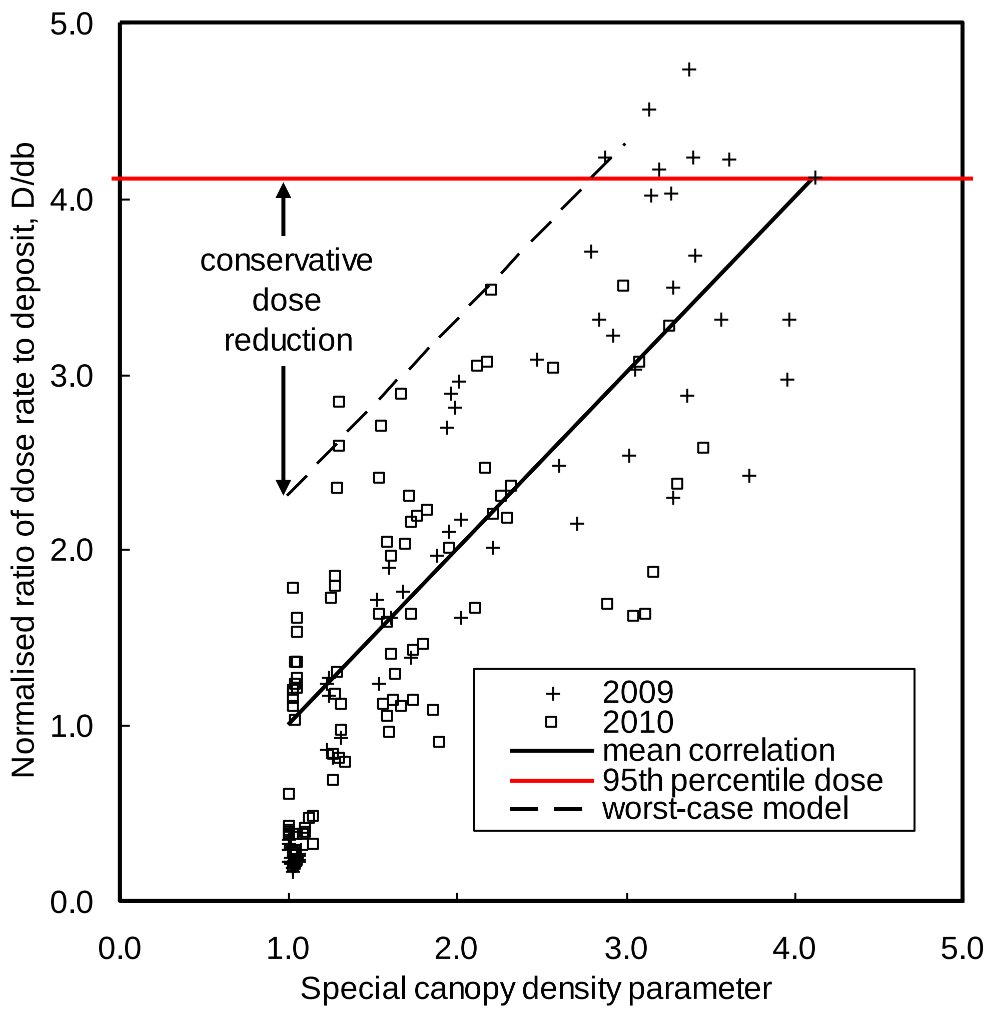

Figure 4.2. Variation of the normalised ratio dose per unit ground area to deposit plotted against the special canopy density parameter σ . Multiple linear regression analysis of data using Eq(1) gives r^2=0.87 with b(2009)=6.75±0.44 and b(2010)=4.12±0.48.

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LidarAssistant7 (2010) Software for recording and processing output from an industrial standard Sick LMS200 LiDAR system.

Annex

The revised UK Best Practice Guides to Apple and Pear Growing to all UK growers on the HDC website (http://www.hdc.org.uk/apples/pesticide-dose-adjustment-for-tree-fruit-spraying.asp?).

Pesticide dose adjustment for tree-fruit spraying

Background

In early 2006, East Malling Research held a series of HDC workshops to inform apple growers of an important new approach to dose adjustment for spray applications to dwarf dessert and culinary apple orchards.

- Extensive work had shown that when sprays are applied at a fixed recommended dose as recommended on pesticide labels, there is a greater than 5 fold variation in average pesticide deposits between different apple orchards at different growth stages due to variation in tree size and canopy density.
- Canopy density and tree height combined explained over 90% of deposit variation from one orchard to another.
- So there is opportunity for making significant dose reductions in orchards with less dense canopies and/or smaller trees than the standard.

The PACE (Pesticide Adjustment to the Crop Environment) system of adjusting the dose according to tree height and canopy density was developed to give approximately constant tree-average deposit across a wide range of different orchards throughout the season (HDC Factsheet 20/05 'Apple orchard spraying: Opportunities for dose reduction'). The original scheme, which covered only dwarf and semi-dwarf dessert and culinary apple orchards, has been simplified and extended to cover a wider range of pome and stone-fruit orchards.

The benefits of appropriate dose adjustment are:

- Reduced pesticides residues on fruit
- Reduced environmental and bystander contamination
- Reduced operational costs by more efficient use of pesticide
- Reduced aquatic buffer zones under a Local Environmental Risk Assessment for Pesticide (LERAP). Note that ¼ full-dose applications reduce the risk of non-target contamination from drift by 75% and can be used to reduce the aquatic buffer zones according to the Defra LERAP guide for broadcast air-assisted sprayers.

Many growers already make dose adjustments based on successful practice and on *ad hoc* trials with different orchard/product combinations. The new webpage provides a dose adjustment system based on soundly derived scientific measurements. There is the potential to apply pesticides from full-dose down to ¼ of the full-dose depending on canopy density and tree height.

Further information

Further information can be found on the PACE website **http://pjwrc.co.uk**. A specific webpage has been created to guide the users of tree-fruit spraying products through the process of dose adjustment (http://pjwrc.co.uk/DoseAdjustment.htm).

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Publications arising directly from the project

Scientific Journals

[SJ1] Walklate, P.J., Cross J. V., (2011). An examination of Leaf-Wall-Area dose expression. In press: Crop Protection http://www.sciencedirect.com/science/article/pii/S0261219411002742.

[SJ2] Walklate, P.J., Cross J. V., Pergher, G., (2011). Support system for efficient dosage of orchard and vineyard spraying products. Computers and Electronics in Agriculture (75), 355-362. http://www.pjwrc.co.uk/DocumentPDFs/2010_CompAndElecInAgric.pdf

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[SC1] Walklate, P. J., Cross, J. V., (2009). Regulatory support system for translation of dose expression and dose adjustment. Discussion paper presented at the Tree Fruits Dose Expression and Adjustment Discussion Group. 1st meeting, 29 September 2009, Wageningen, NL. http://www.pjwrc.co.uk/DocumentPDFs/Introduction-TheNeed.pdf

[SC2] Walklate, P. J., Cross, J. V., Harris, A. L., Richardson, G. M., (2009). The variation of leaf deposit with volume application rate and the onset of saturation during tree fruit spraying with an air-assisted knapsack. SuproFruit 2009 10th Workshop on Spray Application Techniques in Fruit Growing September 30 - October 2. Book of Abstracts. Wageningen UR. NL.

[SC3] Cross, J V. (2010). Tree Fruits Dose Expression and Adjustment Discussion Group: Outline report of 1st meeting, 29 September 2009, Wageningen, NL issued 15/01/2010.

[SC4] Walklate, P. J., Cross, J. V., (2010). A webpage calculator for dose rate adjustment of orchard spraying products. Aspects of Applied Biology (99), 359-366.

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[IOP1] Cross, J. V., Walklate, P. J., (2008). The PACE dose adjustment calculator (MS windows application software). Oral presentation to the National Fruit Show, Detling 16/10/2008.

[IOP2] Cross, J. V., Walklate, P. J., (2009). The PACE dose adjustment calculator (webpage form software). Oral presentation and new webpage demo for: The British Independent Top Fruit Growers 14/01/2009 and the Grower group meeting at Ware Farm (organised by Norman Collett Ltd) 19/02/2009.

[IOP3] Walklate, P. J., Cross, J. V., (2009). Regulatory support system for translation of dose expression and dose adjustment. Discussion paper for presentation at the Tree Fruits Dose Expression and Adjustment Discussion Group. Preliminary presentation/discussion with CRD 20/08/2009. .

[IOP4] Walklate, P.J., Cross, J.V., (2010). Field measurements of spray deposit on potato in 2009. Presentation and discussion at: SNCF 21/04/2010 and Cambridge Agronomy Centre of Cambridge University 25/05/2010.

[IOP5] Cross, J. V., Walklate, P. J., (2011). Progress report on PS 2018. Private meeting with D Richardson at Syngenta Fulborn 20/1/2011.

[IOP6] Walklate, P.J., Cross, J.V., (2011). Meeting with Syngenta Crop Protection to discuss the support needed to translate LWA dose rate (i.e. new industrial standard for mutual recognition applications to register orchard spraying pesticide) to UK dose expression. Syngenta, Fulborn 20/1/2011.