Optimising ground-based and aerial applications of concentrated, low-volume, agrochemical sprays on avocados

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Abstract
This paper summarises studies undertaken in New Zealand over six years in commercial Hass orchards of varying tree size and density. Sprays were applied with commercial ground-based airblast sprayers or by helicopter. Deposits, efficacy and residues from standard dilute spray applications (600-3000 L/ha) were compared with up to five-times concentrated, low-volume sprays with addition of varying rates of a superspreader adjuvant, Du-Wett®. Spray deposits on fruit and foliage were quantified; on inner and outer canopy zones within lower, mid and upper tree sections. Pest pressure was monitored in the orchard and through packout rates and reject analysis. Post-harvest fruit quality was assessed by scoring samples of fruit from each treatment. Pesticide residues were measured at harvest. Concentrate sprays, with adjuvant addition, gave higher and more evenly distributed spray deposits on fruit and foliage throughout the canopy than dilute sprays. Three-times concentrate sprays gave more consistent spray coverage and higher deposits than the lower volume, five-times concentrate due to the large canopy volume of the trees. Full-season, commercial orchard trials confirmed pest and disease control was at least as effective with the low volume, three-times concentrate sprays, residues were unaffected and efficiency gains for growers were substantial. Best Practice guidelines were developed; to set up sprayers for concentrate sprays, to accurately apply them to different sized avocado canopies, and to prescribe adjuvant rates to maximise the quantity and evenness of concentrate spray deposits on fruit and foliage.

Este es un resumen del estudio realizado durante seis años en Nueva Zelanda en huertos comerciales de palta Hass plantados a distintas densidades y diverso tamaño de árbol. Se aplicó con pulverizadores terrestres de turbina o con helicópteros comparándose aplicaciones convencionales (600-3000 L/Ha) con aplicaciones concentradas de hasta cinco veces la dosis normal a bajo volumen. Se evaluaron depósitos sobre la fruta, eficiencia y residuos. Adicionalmente se evaluaron dosis del adyuvante, Du-Wett ®. Se cuantificaron depósitos en fruta y follaje, dentro y fuera de la copa a alturas baja, media y alta. Se monitorearon plagas en campo y se evaluó el porcentaje de descarte. La calidad post-cosecha se evaluó muestreando fruta de cada tratamiento. Se evaluaron residuos post cosecha. Aplicaciones concentradas con adyuvante, produjeron mejor distribución de depósitos en fruta y follaje en la copa comparado con aplicaciones convencionales. Debido al gran tamaño de copa, aplicaciones concentradas donde se triplicó la dosis produjeron mejor cobertura y mostraron más depósitos comparados con aplicaciones cinco veces concentradas. Pruebas en huertos comerciales confirmaron que el control de plagas y enfermedades con aplicaciones a volumen bajo (dosis triplicada) fueron tan eficaces como las convencionales. La presencia de residuos no fue afectada y se observó mejora en la eficiencia del control. Se desarrollo una guía de buenas prácticas para calibrar los equipos de aplicación concentrada y mejorar su eficiencia incluyendo la utilización de adyuvante para maximizar la distribución de depósitos.

Keywords: avocado, pesticide sprays, air-blast, aerial, low volume sprays, superspreader adjuvant

Introduction
Typical NZ avocado orchards are planted on 7-14 m squares with tree heights of up to 14 m. Trees are removed as they mature and this results in large variations in tree size and canopy density between different orchard blocks. These variations affect both the actual canopy surface area on a per hectare basis and the canopy density in individual trees. While large trees can be highly productive, they present considerable difficulties for growers with regards to pesticide application. To further compound these difficulties, avocado plant surfaces vary widely in their wettability (Gaskin, Pathan 2006).

Industry pest and disease management has typically involved high volume (up to 6000 litres/ha on large trees) airblast applications of sprays to ensure good spray coverage, up to 10 times per season. The use of such high water rates in dilute spray applications increases the risk of off-target spray drift and contamination of orchard soils due to excessive runoff of sprays. The New Zealand Avocado Growers Association (AGA) and MAF Sustainable Farming Fund have sponsored a four year research project to develop Best Practice technology for improving spray application practices and outcomes in NZ avocados. This has been achieved with the use of a novel class of superspreader adjuvant; by concentrating pesticide sprays and applying in reduced application volumes, with the superspreader (Du-Wett® or Du-Wett® Rainmaster) substituting for water volume (Gaskin, Manktelow, Pak 2008). The resultant gains in spraying efficiency and efficacy have lead to improved profitability for growers.

Additional studies have extended the Best Practice recommendations. Aerial sprays are increasingly employed to target pests and diseases in tall, dense avocado canopies. These sprays are typically applied in 600-700 L/ha; reducing aerial spray volumes would substantially reduce application costs and may improve pest and disease control. A study to investigate the effect of the superspreader adjuvant on the distribution of concentrate sprays applied by air was undertaken in 2010 (Gaskin, Steele, Elliott 2011). Oil sprays are an important component of airblast spray programmes on New Zealand avocado orchards, but must be applied as dilute, high volume, sprays to avoid damaging the crop. Because of this they have been excluded from the concentrate programme, to the chagrin of growers and contractors. Studies to concentrate (i.e. reduce the spray volumes of) oil sprays and improve their spraying efficiencies are in progress, using the superspreader adjuvants with no adverse effects.

This paper is a summary of research studies undertaken in New Zealand since 2005 to develop Best Practice concentrate spraying recommendations for avocado growers, to improve the efficiency of their spray operations, and the sustainability and profitability of their orchards. Data from six separate studies are summarised; three have not been published previously.

1. Deposit audits of existing practices

The effectiveness of spray application techniques, with respect to the quantity and coverage of spray deposits on avocado canopies, was unknown when the project commenced in 2006. Growers measure spray efficacy in terms of pest and disease control, and this was often found to be wanting in avocado crops. There were no best practice guidelines for spray application to avocados and the industry had no coherent information on spray practices and equipment used by growers. This study was undertaken to provide quantitative and comparative baseline information on existing spray practices. Spray deposited on fruit and foliage of three size classes of tree, by four sprayers, was measured. Sprayers belonged to three separate contractors and one grower and were selected as representative of spray practices in the industry as determined by a comprehensive survey of grower spray practices (Pak 2005).

Three blocks of Hass avocado trees were sprayed by each sprayer: small (5-6 years old, ca 4 m height), medium (8 years, 5-6 m height) and large (>25 years, >10 m height). All of the sprayers used were fitted with rear entry axial fans set up for single sided spraying with a volute to direct air up into the tops of the trees. The volutes were fitted with three Massotti gun nozzles and these were used to deliver spray into the mid to top sections of medium and large canopies. The lower to mid canopy zones were sprayed using 5-7 nozzles around the main fan ring. In all of the small canopies treated, the gun nozzles on the volute were not used. In all cases, over 50% of the sprayer output was directed into the top half of the target trees. Air outputs ranged from around 25,000-35,000 m^3/hr, and travel speeds from 2.3-4.3 km/hr, with a tendency for higher travel speeds to be used in the smallest trees. Each of the sprayers in these tests were used as setup by the grower or contractor for “normal” operation, All sprayers applied identical treatments (Kocide 2000 at 150 g/100 litres) with the addition of tartrazine food dye as a tracer (250 g/100 litres). Samples of fruit and foliage were taken from six canopy zones on each size class of tree; lower, mid and upper tree zones, on both inner and outer canopies as described in Gaskin et al 2008. Leaf and fruit samples were processed and deposits were calculated as dose per area or weight (μg/cm^2 or μg/g), respectively as described in Gaskin et al. 2008.

The variation in volumes applied by the airblast sprayers was large (Table 1) and drivers were often applying more spray, particularly to large trees, than they thought. This was a function of driving patterns; i.e. whether trees were sprayed on two sides or four. There was no correlation between spray volume applied and deposits retained on fruit (Table 1) or leaves (Table 2). The common belief that more volume equalled better efficacy (i.e. greater spray deposits) was not supported by these results. If a sprayer was not well setup and calibrated for the target tree, then it did not deliver the required deposits, regardless of the spray volume applied. There were large variations between sprayers, with respect to deposits on different sized trees. Mean deposits on fruit varied by factors of 2.5 on small trees, 1.6 on medium trees, and 20 on large trees (Table 1). For leaves, mean deposits on small trees varied by factors of 1.8 on small trees, 1.7 on medium trees and 4.1 on large trees (Table 2).

Mean deposits on both fruit and leaves were greatest on small trees and least on large trees (Tables 1&2). As expected, inner canopy deposits were consistently less than those on the outer canopy. Mean deposits on inner canopy fruit were on average 35% less than on outer fruit (Table 1), and inner canopy leaf deposits were 45% less than on outer leaves (Table 2).

Table 1. Comparison of spray volumes applied (litres/ha) and mean deposits (μg/g) on fruit on three tree sizes, from different sprayers

Sprayer #	Tree size						Mean deposit (μg/g)	
	Large		Medium		Small			
	volume	deposit	volume	deposit	volume	deposit	inner	outer
1	3400	3.20 a	2200	2.20 b	1500	3.00 a	1.95 b	3.65 a
2	5350	1.40 c	3500	2.25 b	3000	4.40 a	2.60 b	3.15 a
3	3100	0.16 b	2500	1.40 a	2000	1.57 a	0.92 b	1.50 a
4	6200	1.87 a	2500	1.98 a	2000	1.72 a	1.46 b	2.31 a
Mean	4513	1.66	2675	1.96	2125	2.67	1.73	2.65

Tree size means for each sprayer sharing common postscripts (across rows) are not significantly different (NSD; LSD test, P0.05). Inner/outer deposits for each sprayer are significantly different.

Table 2. Comparison of spray volumes applied (litres/ha) and mean deposits (μg/cm^2) on leaves on three tree sizes, from different sprayers

Sprayer #	Tree size						Mean deposit (μg/cm^2)	
	Large		Medium		Small			
	volume	deposit	volume	deposit	volume	deposit	inner	outer
1	3400	5.00 a	2200	3.95 b	1500	5.10 a	3.00 b	6.40 a
2	5350	3.65 c	3500	4.95 b	3000	6.95 a	3.70 b	6.65 a
3	3100	1.21 c	2500	2.90 b	2000	3.95 a	1.91 b	3.47 a
4	6200	4.18 a	2500	3.46 b	2000	4.37 a	3.09 b	4.91 a
Mean	4513	3.51	2675	3.82	2125	5.09	2.93	5.36

Footnotes as for Table 1.

There were often large differences in mean spray deposits within the lower, mid and upper height canopy zones for all three tree sizes. For fruit (Table 3) in large and medium sized trees, the lower and mid height zones were targeted better than upper canopy. In small trees, mid height canopy fruit were generally targeted best and lower canopy worst. Medium sized trees were the densest and the most difficult to evenly deposit spray on the inner canopy (data not presented). Results demonstrated that a well set-up sprayer (see sprayer #1) could deliver consistently high deposits to most canopy positions on most tree sizes (Table 3).

For leaves (data not presented), the mean deposits across all canopy sizes were surprisingly similar, except that as for fruit, deposits on the tops of large trees were generally very poor, and deposits on the mid and upper canopy positions of small trees were excessively high. It was obvious that spray volume does not dictate the efficiency of dilute spraying, it is a function of sprayer setup. It was expected that optimising sprayer setup would provide significant gains in spraying efficiency on avocado canopies of all sizes.

Table 3. Comparison of mean deposits (μg/g) on fruit in lower, mid and upper height canopy positions on three tree sizes, from different sprayers

Sprayer #	Tree size: Large			Medium			Small		
	lower	mid	upper	lower	mid	upper	lower	mid	upper
1	n/a	3.45 a	2.88 b	2.33 c	2.55 bc	1.70 d	2.52 bc	3.63 a	3.05 ab
2	n/a	2.28 d	0.73 e	3.13 cd	2.33 d	1.25 e	4.28 ab	5.18 a	3.80 bc
3	n/a	0.27 b	0.06 b	1.94 a	1.54 a	0.71 b	1.51 a	1.78 a	1.48 a
4	n/a	2.78 ab	1.03 cd	3.20 a	1.92 b	0.82 d	1.70 bc	1.74 bc	2.02 b
Mean	-	2.20	1.18	2.65	2.09	1.12	2.50	3.08	2.59

n/a = fruit not available; Means across rows sharing common postscripts are NSD (LSD, P0.05)

2. Variation in the wettability of plant surfaces and spray coverage by superspreader adjuvant

Avocado trees are not an easy target to spray. This is obvious from their complex architecture, density and size, but the wettability of avocado plant surfaces also influences the retention and distribution of agrichemical sprays. Wettability is a function of surface micro-roughness and is modified by surface contours, trichomes and waxes (Gaskin, Steele, Forster 2005). Adjuvants are known to be beneficial to increase spray retention on difficult-to-wet surfaces, but can be detrimental to chemical deposits and potential efficacy on easy-to-wet surfaces if they cause spray to be lost through run-off to the ground.

In a study by Gaskin & Pathan (2006) avocado fruit, foliage and flowers were sampled throughout the 2005/06 season. A laboratory technique (Forster, Zabkiewicz 2001) was used to differentiate their surface roughness and to rank their wettabilities. This indicated whether adjuvant addition was likely to be beneficial for agrichemical sprays targeted at these surfaces (Gaskin et al, 2005). Contact angles (CAs) of droplets of around 60° indicate easy-to-wet surfaces, 70-90° are moderate, ≥90° denotes a difficult-to-wet surface and ≥120° is very difficult (Gaskin et al, 2005).

Avocado flowers and the underside of leaves were generally very difficult-to-wet (Table 4) and will repel spray droplets strongly. These targets will benefit most from the addition of adjuvants that can improve spray droplet adhesion and surface coverage. Fruit were generally a difficult target for sprays and will benefit from addition of a spreader adjuvant. Mature Hass fruit were more difficult-to-wet than immature. Leaf top-surfaces were comparatively easy-to-wet and adjuvants would provide lesser advantages on this surface. Seasonal trends were apparent, with autumn foliage more water repellent than spring foliage.

Table 4. Surface roughness (CA) of avocado foliage, fruit and flowers (Gaskin et al, 2006)

Date	mature leaves topside	mature leaves under	young leaves topside	young leaves under	fruit mature	fruit young	flowers Peduncle 1°	flowers Peduncle 2°	flowers petal
Sept 2005	64	113	-	-	92	-	-	-	-
Nov 2005	64	120	79	126	-	-	107	150	129
Jan 2006	73	129	75	152	97	85	-	-	-
March 2006	78	135	88	180	101	81	-	-	-
July 2006	74	133	-	-	100		-	-	-

Colour code for surface wettability	**easy**	**moderate**	**difficult**	**very difficult**

The large variation between avocado plant surfaces presents a dilemma for the grower. Dilute, high volume agrichemical sprays will not be retained on or cover the lower leaf surfaces well. If optimised with adjuvants to target the under-surface of leaves, fruit or flowers, spray is likely to be lost to runoff from the upper leaf surfaces. Concentrating sprays, to reduce volumes available to run-off target surfaces, and adding a very good spreader adjuvant, to increase surface coverage of sprays, would likely provide large benefits for retention and distribution of sprays on avocados.

The major objectives in this project were to improve spray deposition and coverage, and thus spray efficacy, on avocados and also to improve spraying efficiency. Low volume, concentrate spray applications with superspreader adjuvants was seen as the best option to meet all of these goals. Spreader adjuvants are essential to make the water go further in concentrate sprays. They can assist sprays to cover targets better and so increase control of pests and diseases (Gaskin, Steele, Elliott 2004).

Organosilicone superspreader adjuvants were evaluated for their ability to increase the spread and coverage of pesticide sprays on avocado foliage (Gaskin et al, 2006). Nineteen of the most often-used commercial pesticides in the New Zealand avocado spray programme were screened, at five times concentrate rates, with two superspreader adjuvants, Du-Wett (Figure 1) and Bond® Xtra. Their superspreading properties were influenced greatly by individual pesticide formulations; eight insecticides antagonised their superspreading. Provisional adjuvant prescriptions were made for superspreader use with avocado sprays and to overcome the pesticide antagonisms. The prescriptions were tested in field trials and refined as necessary to maximise deposits for concentrate spray volumes on different tree sizes.

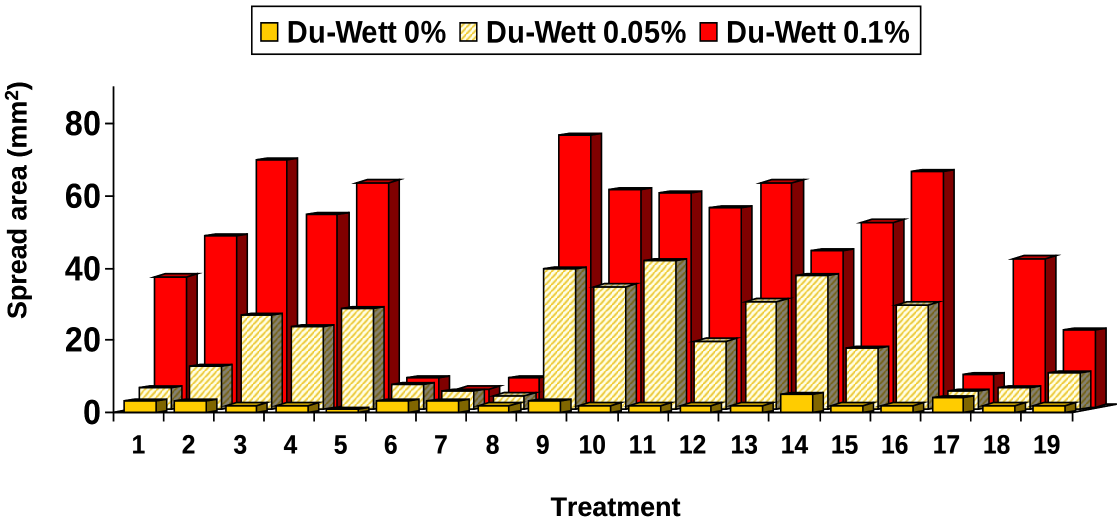


Figure 1. Effect of 19 commercial pesticide formulations on Du-Wett spreading (0.5 µl droplets) on avocado leaf adaxial surface. LSD ($P_{0.05}$) = 7 (Gaskin et al, 2006)

3. Concentrate airblast spray prescriptions

Current industry pest and disease management typically involves high volume (up to 6000 litres/ha on large trees) airblast spray applications to ensure good spray coverage, with up to 10 applications per season. The superspreader adjuvant Du-Wett has been used in a variety of crops to improve spray deposition on-target. This has been achieved by concentrating sprays and applying in reduced application volumes, with the superspreading adjuvant substituting for water volume. Du-Wett was shown to be non-phytotoxic and improve spray deposits on four year old avocado trees using 3-5 times less volume than standard practice (Gaskin, Manktelow, Skinner, Elliott 2004; Gaskin, Hofstee, Elliott 2003). Reduced volume concentrate sprays have the potential to improve the net efficiency of agrichemical use by delivering higher average doses on leaves and fruit than would be achieved from dilute sprays. Most importantly, superspreader surfactants are expected to provide effective deposits on avocado lower leaf surfaces, which are very poorly wetted with most dilute spray mixtures. Concentrate spraying also offers improved work rate efficiencies over dilute spraying.

Studies were undertaken in 2006 to determine optimum spray volumes and adjuvant prescriptions to improve airblast application of concentrated sprays to large and dense avocado canopies. The series of studies (Gaskin et al, 2008) were carried out on two different commercial orchards, on medium-sized, dense trees (5-6 m tall) planted on 7 m row spacings and on large, less dense trees (7-8 m tall) on 14 m row spacings. They compared on-target spray deposits from “standard” industry dilute spray applications (up to 3000 L/ha) versus three and five times concentrate sprays (600-1000 L/ha) with the addition of different rates of Du-Wett. Spray deposits were measured on fruit and foliage on six canopy zones; the inner and outer sections of the lower, mid and upper tree.

Low volume concentrated sprays with the superspreader adjuvant added were found to give higher spray deposits on foliage than dilute sprays in dense, medium-sized trees (Figure 2). In less dense large trees, the concentrate sprays delivered higher mean deposits than the dilute, but adjuvant addition did not appear to have any effect (Figure 2). However, the low volume concentrated sprays were more evenly distributed throughout both canopies than dilute sprays and Du-Wett markedly improved deposits on the difficult-to-target inner and upper canopy zones (Figures 3 A&B). The higher adjuvant rate maximised quantity and evenness of spray deposits in three times concentrate sprays, which were more effective than five times concentrate sprays due to the large canopy volume of the trees (Gaskin et al, 2008). Specific adjuvant prescriptions have been developed for the use of Du-Wett superspreader to concentrate pesticide sprays on New Zealand avocado crops (Etec 2010). These prescriptions cover all chemical use and combination sprays, and use of an alternative sticker-superspreader adjuvant (Du-Wett Rainmaster) if rain is anticipated within five days of spraying.

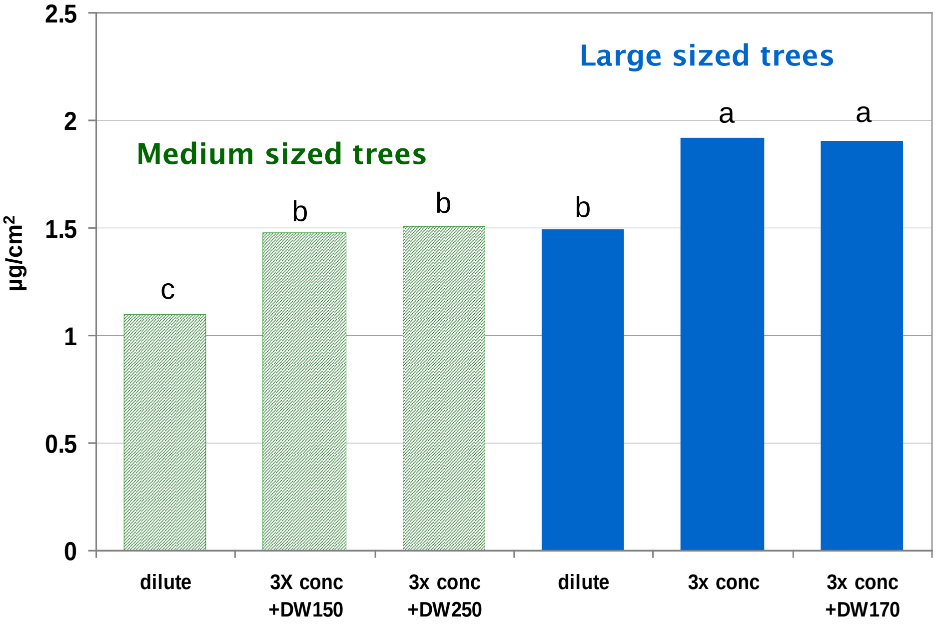
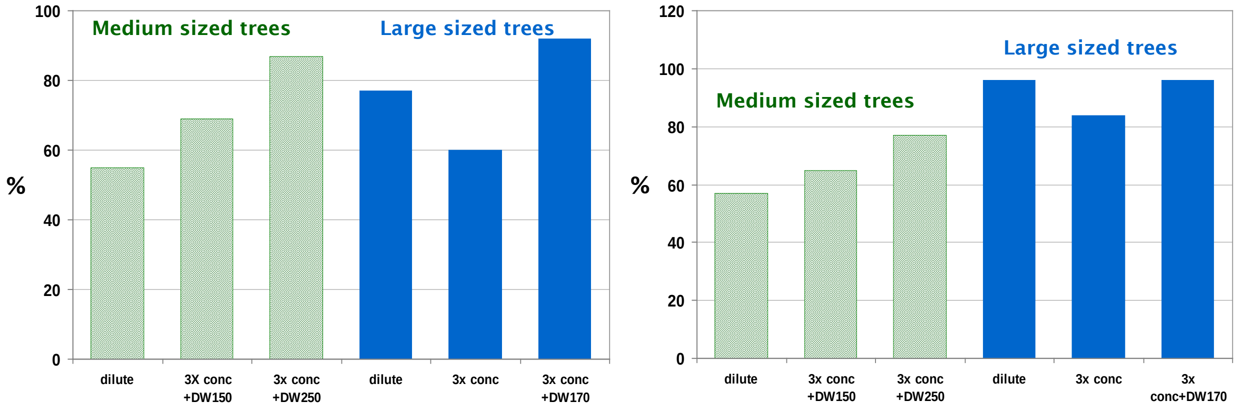


Figure 2. Mean leaf deposits (µg/cm^2) on avocado foliage with varying spray volumes ± Du-Wett adjuvant (ml/ha), on medium and large trees (data from Gaskin et al, 2008).
(Treatments sharing common postscripts are NSD (LSD, P0.05))

In addition to any improvements in pesticide efficacy afforded by low volume concentrate sprays, the cost benefits to growers of improving sprayer work rate efficiencies can be considerable. As an example (Table 5), work rates can be increased by >30% with >20% reduction in spraying costs. Higher work rates permit more area to be treated more quickly and allow better spray timing at disease and pest peaks, increasing operational flexibility for growers. The use of the superspreader adjuvant technology was expected to also result in improved efficacy from concentrate spray applications in avocado crops.

On the basis of the results from these extensive spray deposit studies, an Australian system for distance based calibration has been adapted for use with New Zealand avocado canopies (Manktelow, May 2009). Tables giving recommended spray delivery volumes per 100 m of sprayed row have been prepared for different sized canopies, along with a table specifying the required L/min sprayer output volumes to deliver these target application volumes at different travel speeds. The recommendations cover both dilute and concentrate spray operations.



A B

Figure 3. Mean leaf deposits (μg/cm^2) on avocado foliage with varying spray volumes ± Du-Wett adjuvant, on medium and large trees as (A) inner canopy as a proportion of outer canopy zone, and (B) upper canopy as a proportion of mid canopy zone (data from Gaskin et al, 2008).

Table 5 . Spraying work-rates comparison for an avocado orchard (3 ha, 100 m rows, 2000 L spray tank, single sided sprayer, $120/h spraying costs tractor+sprayer+labour)

	Scenario	
	#1	#2
Spray application volume (L/ha)	3000	1000
Work rate (ha per hour)	0.94	1.44
Cost per ha (NZD$)	128	88
Time to spray block (h)	3.2	2.2
Cost to spray block	385	265
Time saving (%)	-	31
Cost saving (%) (inc. adjuvant at $10/ha)	-	23

4. Commercial orchard trials

Large scale grower trials were conducted from June 2007-July 2008, to test sprayer setups and prescriptions developed for concentrate spray programmes. The trials were conducted on two commercial orchards, located in Northland (Cliff Orchard) and the Bay of Plenty (BOP, Crozier Trust Orchard), on large (>15 year old) and small (5 year old) trees. The three-times concentrate sprays (i.e. applied in one-third of dilute volume with Du-Wett adjuvant addition) were superimposed on the individual growers' spray programme and compared against the same programme applied in dilute sprays (i.e. standard grower practice), in paired blocks of >1 ha size. Thus all blocks on an orchard received identical pesticide treatments (the same products at equivalent chemical application rates) throughout the year, but they were applied in different spray volumes. All sprayers were re-nozzled for concentrate sprays and professionally calibrated prior to the trial, and adjuvant prescriptions for all concentrate agrichemical sprays were provided to growers. No aerial sprays were applied to trial blocks for the duration of the trial and if any oil sprays were required, they were applied in dilute volume to all blocks. AvoGreen™ monitoring for pests and diseases was undertaken throughout the trial by Fruitfed Supplies. Fruit was picked separately from all treatment blocks at harvest and packhouse (Apata Ltd) reports included commercial packout analysis and reject analysis, and library tray assessment. Fruit were sampled at three commercial harvest dates, in September, October and January, for multi-residue analysis.

Monitoring indicated no marked differences in pest infestation between the dilute and concentrate spray programmes in any orchard; the 3x concentrate most often had equivalent or slightly lower pest presence than in the dilute control programme (Table 6). Six-spotted mite and leafroller caterpillar pressure was high in Northland and both programmes controlled these pests similarly. There was no disease detected in any orchard.

Export packout of fruit from the Northland orchard was reduced by 6% in the concentrate programme (Table 7). Some of this was due to leafroller damage, but also to wind damage; the concentrate spray block was more elevated and exposed (M West, pers. comm.). In the BOP orchard, export packout from the concentrate programme was greatly increased at all harvests, by an average of 29% in the older trees and by 19% in the younger (Table 7). In the BOP study, total blemish due to insect pests was consistently reduced by the concentrate spray programme.

Table 6. Monitoring results from orchard studies comparing dilute (control) and 3x concentrate (plus adjuvant) spray programmes (data is mean of all monitoring periods).

Orchard location	Tree age (yrs)	Spray program	Insects present on % of samples						
			LR[1] larvae on fruit	LR[1] larvae on leaves	mite eggs on leaves	mealy bugs	scale	SSM[2] on leaves	thrips on fruit
Northld	>18	dilute	0	5	23	0.3	0	21	0
		conc.	0	4	19	0.3	0	19	0
BOP	>15	dilute	0.5	1.5	0.4	0	0.3	1.3	0.3
		conc.	0.1	0.3	0	0	0	0.6	0.3
BOP	5	dilute	0.4	0.9	0.4	0	0	1.3	0
		conc.	0.2	1.5	1.0	0	0	2.1	0.8

[1]leafroller, [2]Six-spotted mite

Table 7. Commercial packhouse packout reports comparing dilute (control) and 3x concentrate (plus adjuvant) spray programmes.

Orchard location/ harvest date	Tree age (yrs)	Spray program	Sample size (kg)	% In grade analysis			Reject analysis (%)	
				export	local	reject/oil	thrip blemish	leafroller blemish
Northld/ Sept.	>18	dilute	2412	81	17	2	0	32
		conc.	2130	75	23	2	0	38
BOP/ Oct.	>15	dilute	3080	70	27	3	36	32
		conc.	2290	87	12	1	36	21
BOP/ Jan.	>15	dilute	2853	38	38	24	44	19
		conc.	2181	79	0	21	23	16
BOP/ Oct.	5	dilute	833	72	27	1	9	45
		conc.	830	91	8	1	8	19

Table 8. Residue analysis of fruit at harvest comparing dilute (control) and 3x concentrate (plus adjuvant) spray programmes.

Orchard location	Harvest date	Tree age (yrs)	Spray program	Residues (mg/kg)	
				chlorpyrifos-ethyl	pirimiphos-methyl
Northland	September	>18	dilute	-[1]	0.026
			conc.	0.016	0.042
BOP	October	>15	dilute	0.24	0.014
			conc.	0.30	0.040
BOP	January	>15	dilute	-	-
			conc.	0.19	0.014
BOP	January	5	dilute	0	0
			conc.	0.03	0

[1]not tested

Chlorpyrifos-ethyl and pirimiphos-methyl were the only residues detected in the multi-residue testing. Residues were generally slightly elevated in the concentrate spray programme (Table 8). Neither programme exceeded the New Zealand MRL for either chemical (chlorpyrifos=0.2 ppm, pirimiphos=0.1 ppm), except fruit from the large BOP trees in the October harvest, and then both programmes would have exceeded MRLs for chlorpyrifos.

The concentrate spray programme utilising Du-Wett adjuvant has proven to be an attractive option to improve the efficiency of orchard spray operations. The BOP grower can now spray his entire orchard in one day instead of three using the concentrate programme (J Crozier, pers. com). With better control of pests and diseases come gains in crop quality and increased profitability for growers. The concentrate programme has increased export packouts and orchard returns for both growers since they adopted it orchard-wide in 2008. Du-Wett adjuvant and its partner adjuvant in the programme, Du-Wett Rainmaster, have given New Zealand growers the tools to move to three-times concentrate spray programmes with confidence. The Avocado Industry Council (AIC) has endorsed the concentrate programme and produced Best Practice Guidelines for ground-based sprayers (Manktelow, May 2009). The critical points identified for growers to successfully adopt the technology are: (1) have sprayers accurately set up and calibrated for concentrate applications, (2) follow all prescriptions to identify correct output volumes for tree size, canopy density, row spacings and travel speed, and correct adjuvant addition, (3) keep accurate spray diary records and record all adjuvant use, and (4) use only Du-Wett and Du-Wett Rainmaster adjuvants in concentrate programmes. These two adjuvants have been extensively studied in developing concentrate spray programmes for avocados and are the only adjuvants currently recommended by the AIC.

5. Developing concentrate aerial prescriptions

The avocado industry had comprehensive Best Practice guidelines for dilute and concentrate ground-based spray application to avocado orchards (Gaskin et al, 2008; Manktelow, May 2009), but there were no guidelines for aerial spray applications. Aerial sprays, applied in 600-700 L/ha, are used to target pests and diseases in tall, dense tree canopies and are increasingly being used to spray large-scale new plantings. There is potential to substantially reduce application costs and improve pest and disease control by concentrating sprays with the use of a superspreader adjuvant, as has been done for airblast applications. A study in 2010 (Gaskin et al, 2011) investigated the effect of Du-Wett on the distribution of concentrate sprays applied by air to avocados.

The study was undertaken on a commercial Hass orchard containing 12 m tall, dense trees in the BOP. Sprays were applied with a Squirrel AS350 BA helicopter through TeeJet XR8010SS nozzles mounted on an 8 m boom. Flying speed varied from 14-19 knots. Deposits from a copper spray application (Kocide® Opti, 2.6 kg in 600 L/ha) were compared with the same quantity of chemical per hectare in two-times (300 L/ha) and three-times (200 L/ha) lower application volumes with addition of varying rates of the superspreader adjuvant, Du-Wett® (DW). Spray deposits on fruit and foliage were quantified (Gaskin et al, 2011).

Reduced volume sprays with Du-Wett adjuvant consistently gave higher spray deposits on difficult-to-wet fruit than the 600 L/ha control (Table 9). Deposits on fruit in all canopy zones were increased with the lowest volume sprays, but particularly in the upper, lower and outer canopy zones. The lowest volume sprays increased deposits on both inner and outer canopy fruit relative to the more dilute control spray. Because fruit is moderately difficult-to-wet, and much more so than the upper surface of avocado leaves (Gaskin et al, 2006), it is likely to benefit more than leaves from Du-Wett addition to increase deposits from aerial sprays. On foliage, concentrate sprays with adjuvant addition gave similar spray deposits to the dilute spray (Gaskin et al, 2011). Leaves in mid and inner canopy zones tended to be slightly less well targeted by the lower volume sprays. This should be considered when targeting very dense trees with aerial sprays.

Table 9. Retention of aerial sprays (µg/g, normalised for 1 kg a.i./ha) on avocado fruit in different canopy zones with varying spray volumes and adjuvant rates (Gaskin et al, 2011)

Treatment	Canopy zone					Mean
	lower	mid	Upper	inner	outer	
600 L/ha Control*	0.36	0.46	0.57	0.40	0.52	0.46
300 L/ha+DW 200 ml/ha	0.96	0.41	0.79	0.60	0.83	0.72
200 L/ha+DW 200 ml/ha	1.12	0.78	1.41	0.97	1.24	1.10
200 L/ha+DW 300 ml/ha	1.32	0.89	1.10	0.96	1.25	1.10
LSD (P=0.05)	--------------0.40--------------			--------0.32--------		0.23

*contained 250 ml/ha Latron® B-1956 adjuvant (Dow Agrosciences)

Overall, deposits were highest in the lowest volume sprays, particularly on fruit. This is likely to be a function of increasing the Du-Wett concentration as water volume is reduced. There was no marked effect of Du-Wett rate evident, but the higher rate of 300 ml/ha tended to give a slightly more even distribution of deposits over all canopy zones. An increase in deposits on fruit raises the question of increased residues with lower volume, more concentrated sprays. An examination of results over five years of deposit studies (Gaskin, unpublished) indicates that the deposits from these concentrate aerial sprays are still well within the limits of deposits achieved by applying dilute or concentrate sprays from ground-based sprayers. Residues from concentrate aerial sprays are unlikely to exceed those resulting from airblast spray programmes (cf deposits from Tables 1-3).

Aerial spray applications to large open trees targeted upper and outer canopy zones well. However, mid and lower inner/outer canopies were not targeted as well and will benefit from airblast spray applications applied in parallel. In particular, ground-based sprays may be necessary to support aerial sprays on very dense young trees.

6. Concentrate oil sprays for avocados

In 2010, a preliminary study was undertaken to determine if the use of superspreader adjuvants would allow oil sprays to be concentrated on avocados without causing damage to the crop. Three treatments were each sprayed six times at monthly intervals (August-January) on five year old Hass trees in a commercial orchard in the Bay of Plenty. The treatments were: (1) 15 L (0.5%) Excel oil in 3000 L/ha (control), (2) 15 L (1.5%) Excel oil plus Du-Wett (400 ml) in 1000 L/ha, and (3) 15 L (1.5%) Excel oil plus Du-Wett Rainmaster (800 ml/ha) in 1000 L/ha and (4) unsprayed controls. Phytotoxicity assessments were made every month until harvest in late January. Fruit were assessed by a commercial packhouse after four weeks storage at 5°C and ripening at 20°C.

There was no sign of leaf drop or any discolouration indicating phytotoxicity on any foliage on any trees throughout the trial. There was no evidence of damage on fruit due to any treatment. The packhouse assessment indicated no differences between treatments in any assessment (e.g. firmness, colour, external rots, vascular browning or flesh adhesion). Concentrating the oil three times by reducing spray volumes caused no damage to avocados when the superspreader adjuvants were included in concentrate sprays. On the basis of these results, the safety and efficacy of concentrate oil spray programmes will be tested by growers in commercial orchard trials in Northland and the Bay of Plenty in the 2011/12 season.

Conclusions

Concentrated low-volume sprays, with Du-Wett adjuvant addition, provide higher and more evenly distributed spray deposits on fruit and foliage throughout the canopy than dilute sprays. Pest and disease control is maintained or improved with low volume, three-times concentrate sprays, and gains for growers, in spray efficiency and orchard returns, are substantial. Best Practice guidelines have been developed for New Zealand avocado growers; to set up sprayers for concentrate sprays, to accurately apply them to different sized avocado canopies and to prescribe the adjuvant to maximise the quantity and evenness of concentrate spray deposits on fruit and foliage. Reduced volume, concentrate prescriptions for aerial sprays have also been confirmed and prescriptions for applying insecticidal oils in concentrate sprays are currently being developed.

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