CHARACTERISING PLANT SURFACES AND ADJUVANT INTERACTIONS TO IMPROVE PESTICIDE SPRAY RETENTION AND COVERAGE ON AVOCADOS

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ABSTRACT

A laboratory technique was used to establish the wettability of avocado leaves, fruit and flowers, throughout a season, and to determine whether adjuvant addition was likely to be beneficial for agrichemical sprays targeted at these surfaces. Flowers and the underside of leaves are very difficult-to-wet and repel spray droplets strongly. These will benefit most from the addition of adjuvants that can improve spray droplet adhesion and surface coverage. Fruit is generally a difficult-to-wet target and will also benefit from adjuvant addition. Upper leaf surfaces are easier to wet and adjuvants may not be beneficial, particularly in high volume spray applications. The large variation between avocado plant surfaces presents a dilemma for the grower. Sprays optimised for the upper leaf will not be retained on or cover the lower leaf surface. If optimised with adjuvants to target the under-surface of leaves, or flowers, the spray is likely to be lost to runoff from the upper leaf surface. Thus, it was concluded that concentrating sprays by reducing spray volumes and improving their retention on target surfaces with the use of a suitable superspreader adjuvant was likely to benefit spray applications to this crop. Two organosilicone superspreader adjuvants were evaluated for their ability to increase the spread and coverage of pesticide sprays on avocado foliage. The 19 most often-used commercial pesticides in the avocado spray programme were screened, at a concentrate rate, with the superspreaders. The ability of Du-Wett® and Bond® Xtra to superspread was influenced greatly by individual pesticide formulations. Provisional adjuvant prescriptions for field trials have been made taking this into account.

Keywords: *spreading, adhesion, wettability, superspreader, concentrate sprays*

INTRODUCTION

The adhesion, retention and distribution of agrichemical sprays on plant surfaces are influenced by the target wettability (*i.e.* microscopic roughness). A simple technique for describing surface roughness has been developed to compare plant surfaces (Forster and Zabkiewicz, 2001), which differentiates between easy, difficult and very difficult-to-wet species. This tool is used to predict spray droplet adhesion and rank plant surfaces for retention properties (Gaskin *et al.*, 2005). Target surfaces on a species may vary widely in their wettability, and spray retention on these surfaces can also vary significantly through a growing season (Hall *et al.*, 1997).

High volume applications are commonly used by growers to increase the retention and coverage of pesticide sprays on their crops. The economic and environmental advantages of lowering spray volumes are well recognised but not easy to achieve. When plant surfaces are classified as difficult-to-wet, appropriate adjuvant addition can be beneficial to improve retention of agrichemical sprays and to increase the spread of spray droplets on those surfaces (Gaskin *et al.*, 2005). Superspreader adjuvants are often used to increase spray retention and coverage on difficult-to-wet surfaces, and also to reduce spray application volumes without adversely affecting agrichemical performance (Gaskin *et al.*, 2000; 2001; 2002). However, the properties of superspreaders can be adversely affected by many commercial pesticide formulations and this must be taken into account when prescribing their use.

In this study, avocado fruit, foliage and flowers were sampled throughout a growing season. The roughness of abaxial and adaxial leaf surfaces, of flowers and of developing fruit, was measured to provide a quantitative comparison of seasonal changes and to estimate how these might affect spray droplet adhesion on plant surfaces. The pesticide formulations most often-used by avocado growers were screened to determine their compatibility with two superspreaders, with the aim of providing adjuvant prescriptions which are likely to improve pesticide efficacy on avocados, specifically in concentrate spray applications.

MATERIALS AND METHODS

Determination of surface roughness/wettability
Foliage, fruit and flowers were sampled at regular intervals throughout the season, from Hass avocado trees growing in the Bay of Plenty. Trees 5-8 years old were in good health and had not had any agrichemical sprays applied for at least a week prior to each sampling. Droplets (1 µl) of 20% acetone in water were applied with a microsyringe to the surfaces of leaves and fruit (30 reps/sample from 5-10 separate trees) and the contact angle of the droplet with the plant surface was measured as described by Forster and Zabkiewicz (2001). Contact angles of approximately 60^0 indicate easy-to-wet surfaces, 70-80^0 is moderate, >90^0 denotes a difficult-to-wet surface and >120^0 is very difficult (Gaskin et al., 2005).

Determination of droplet spreading
Nineteen of the most often-used pesticide formulations were identified for testing via an analysis of spray diaries from the 2004 season (H Pak, pers. comm.). These included insecticides and fungicides which generally comprised about 1% or more of the spray diary applications in that year (Table 1). More than one commercial formulation of the most common actives was frequently used (*e.g.* copper), hence only fifteen active ingredients were included in the study. Each pesticide was screened at the recommended label rate per hectare, applied in a spray volume of 500 litres/ha (rather than at dilute 2000-3000 litres/ha), which equated to a use rate of 4-6 times concentrate. This was considered to cover the likely concentrate rate on avocados, for reduced volume applications with superspreader adjuvants.

Mature foliage from Hass avocado trees was sampled in early January from a Te Puke orchard and stored at 4^0C until used, within two days of sampling. Samples were equilibrated to room temperature before use. Spreading measurements were undertaken only on upper and lower surfaces of mature leaves, as fruit wettability was intermediate between the two. Droplets 0.5 µl size as 12 replicates of aqueous spray formulations were applied 15 minutes after mixing, to three randomly-selected upper and lower leaf surfaces per treatment. All treatments incorporated a water-soluble fluorescent dye (0.5% Blankophore P, Bayer), which was added to solutions immediately prior to droplet dispensing, to enable visualisation under UV light. When droplets were visibly dry (*i.e.* spreading complete), their images were captured by video camera and spread areas quantified by image analysis (V++ Software). Analysis of variance and least significant difference (LSD) tests at P<0.05 were used to compare treatment means.

The study focussed on testing two organosilicone superspreader adjuvants because of their success in improving pesticide efficacy of concentrate sprays in other crops (Gaskin *et al.*, 2000; 2002) and their potential for doing likewise in avocados (Gaskin *et al.*, 2004), and their proven safety on avocados (Gaskin *et al.*, 2003). Du-Wett® (Elliott Technologies Ltd) is a novel blend of organosilicone and conventional adjuvants developed specifically for low volume spray programmes on horticultural crops. Bond® Xtra (Elliott Technologies Ltd) is a novel sticker-superspreader adjuvant, which is formulated to substitute (at higher use rates) for Du-Wett® in a low volume spray programme when rain is expected within five days of spray application. Both superspreader adjuvants were screened at two concentrations, with each pesticide (Du-Wett® at

0.05 and 0.1%; Bond® Xtra at 0.2 and 0.4%). They were screened only in concentrate sprays because the rationale for their use is that their low surface tensions allow a given volume of water to cover a far greater surface area than normal. ***They should not be used in high volume, dilute sprays because they will promote excessive run-off.*** Droplet spreading of all concentrate pesticide sprays, without adjuvant addition, was also determined.

RESULTS AND DISCUSSION

Surface wettability

The upper surfaces of leaves were relatively easy-to-wet compared to other avocado plant surfaces, with contact angles of 64-88^0 (Table 2), which is not dissimilar to e.g. apple and pear leaves. The lower leaf surfaces were generally very difficult-to-wet (113-180^0 contact angle), on a par with grape berries and brassica foliage (*e.g.* cabbage, broccoli). Such surfaces will repel spray formulations which do not have very good wetting properties. The seasonal trend was for leaves to become more water repellent as the season progressed, spring (September) through to autumn (March). Young, flushing foliage was consistently more difficult-to-wet than mature leaves, particularly its lower surface (Table 2), which was consistently the least wettable of all leaf surfaces (126-180^0).

Very young, expanding fruit were moderately difficult-to-wet (average 83^0 contact angle, Table 2). Large, more mature fruit were difficult-to-wet at all times (92-102). Flowers were as difficult-to-wet, or even more so than the underside of leaves (Table 2). This has important implications for spray deposition and retention when trees are carrying large flower loads; *e.g.* in early November, an avocado tree canopy carrying flowers and flushing foliage represents a highly water-repellent target. At this time, the use of adjuvants is likely to be very beneficial for improving deposition and coverage of pesticide sprays.

Table 1. Pesticides screened for compatibility with superspreader adjuvants

TREATMENT	Pesticide	active ingredient (a.i.)	a.i. as % of spray diaries	Rate/ha
1	Chlorpyrifos 48 EC	chlorpyrifos	18	1.7 L
2	Lorsban® 50 EC	chlorpyrifos	18	1.3 kg
3	Blue Shield® DF	copper hydroxide	37	2.5 kg
4	Kocide® 2000 DS	copper hydroxide	37	3.4 kg
5	Kocide® 2000 LF	copper hydroxide	37	3.4 L
6	Attack®	permethrin/pirimiphos methyl	12 / 7	2.0 L
7	Averte® EC	permethrin/diazinon	12 / <5	2.0 L
8	Basudin® 600 EW	diazinon	<5	2.0 L
9	Dew™ 500	diazinon	<5	2.0 L
10	Carbaryl 50F	carbaryl	≤1	3.2 L
11	Sevin® Flo	carbaryl	≤1	3.2 L
12	Success™ Naturalyte	spinosad	7	0.8 L
13	Mimic® 700 WP	tebufenozide	<3	172 g
14	Malathion 50 EC	maldison	<5	6.0 L
15	Delfin® WG	Bt	<5	1.0 L
16	Mavrik® Flo	taufluvalinate	3	0.4 L
17	Mit-E-Mec®	milbemectin	≤1	1.5 L

Table 2. Surface roughness (contact angle) and wettability of avocado leaves, fruit and flowers

Date	mature leaves		young leaves		fruit			flowers	
	upper	lower	upper	lower	large	young	peduncle	peduncle	petal
Sep 05	64	113	-	-	92	-	-	-	-
Nov 05	64	120	79	126	-	-	107	150	129
Jan 05	73	129	75	152	97	85	-	-	-
Mar 06	78	135	88	180	101	81	-	-	-
July 06	74	133	-	-	102	-	-	-	-

Colour code for surface wettability	easy	moderate	difficult	very difficult

Droplet spreading with adjuvants
Adjuvants had no effects on the solution stability, at 0 hours and 6 hours after mixing, of any pesticide spray solution screened in the study (Table 1). Droplet spreading of all commercial formulations, without adjuvant addition, was similar and poor on both the upper and lower surfaces of leaves. The mean values were 2.1 and 1.3 mm^2 for upper and lower surfaces, respectively (Table 3). Droplets of some formulations were unable to be deposited on the very-difficult-to-wet underside of avocado leaves.

The superspreader adjuvants increased droplet spread by up to 20-fold (Table 3). With addition of superspreader, spray formulations spread on average 2.3-2.7 times more on the easy-to-wet upper surface of leaves than on the lower surface. Droplet spreading on fruit is predicted to be intermediate between the two leaf surfaces.

Adjuvant treatment means indicated a typical linear spreading response for superspreaders on avocado leaves (*i.e.* spreading increased proportionally as adjuvant concentration increased), and Du-Wett® spread much more than the sticker adjuvant, Bond® Xtra (Table 3). The linear response between concentration and spreading of organosilicones can be affected by commercial pesticide formulations. When the increase in spread is not proportional to the increase in superspreader concentration, then the pesticide formulation is considered to have an effect, either synergistic or antagonistic, on the adjuvant performance. This is most commonly due to co-formulant emulsifiers and adjuvants present in the commercial pesticide formulations (Policello and Murphy, 1993).

The 19 pesticide formulations screened (Table 1) had wide-ranging effects on the superspreading

Table 3. Comparison of spreading means (mm^2) for all formulations (Table 1) in concentrate sprays on upper and lower surfaces of leaves

Leaf surface	adjuvantadjuvant concentration (% w/v)					
	0	0.05	0.1	0.2	0.4	
upper	+ Du-Wett®	2.1	19.9	43.6	-	-
	+ Bond® Xtra	2.1	-	-	11.7	30.5
lower	+ Du-Wett®	1.3	7.7	16.1	-	-
	+ Bond® Xtra	1.3	-	-	5.2	12.6

properties of the two adjuvants. These effects were generally more obvious on the easier-to-wet upper surface of leaves, than on the lower surface (data not presented), and with the better spreader, Du-Wett® (Figure 1), than with Bond® Xtra (Figure 2).

There was little difference between commercial formulations in their ability to spread on avocado leaf surfaces (Figures 1 and 2) and several treatments without adjuvant addition were totally repulsed by the waxy lower surface (data not presented). Kocide® 2000LF was used as a standard to compare formulation effects on spreading. Formulations antagonistic to Du-Wett® spreading (Figure 1) at the lower concentration of 0.05%, were Chlorpyrifos 48 EC, Lorsban®, Attack®, Averte®, Basudin®, Mit-E-Mec®, Avid® and Orthene®. Success™ and Delfin® were mildly antagonistic. The three copper fungicides Blue Shield®, Kocide® DS and Kocide® LF, Dew™,

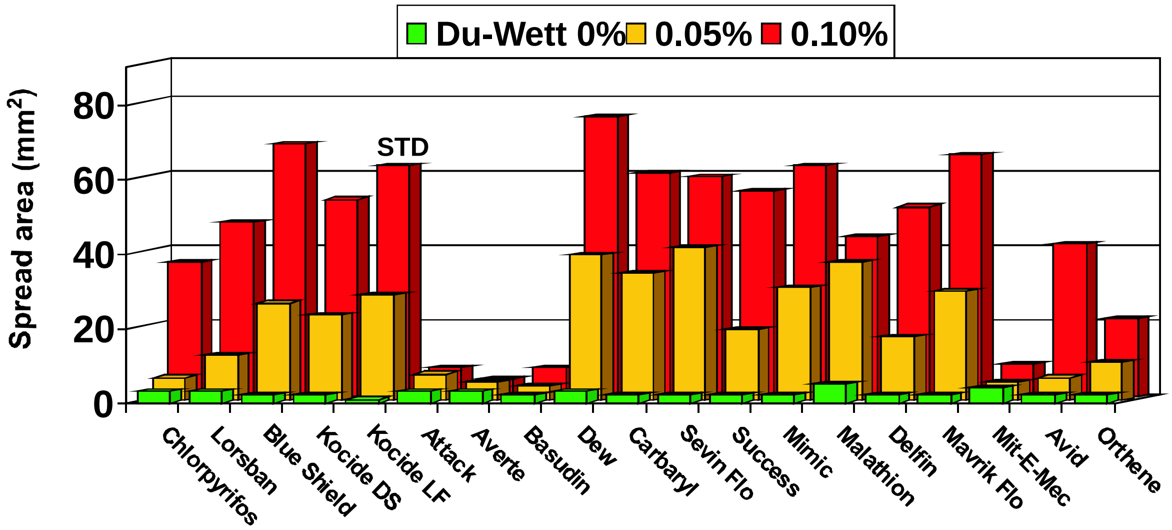

Figure 1. Effect of pesticide formulations on Du-Wett® spreading (0.5 µl spray droplets) on avocado upper leaf surface. Treatments described in Table 1. STD = Kocide® 2000LF as standard treatment. LSD ($P_{0.05}$) = 7mm^2

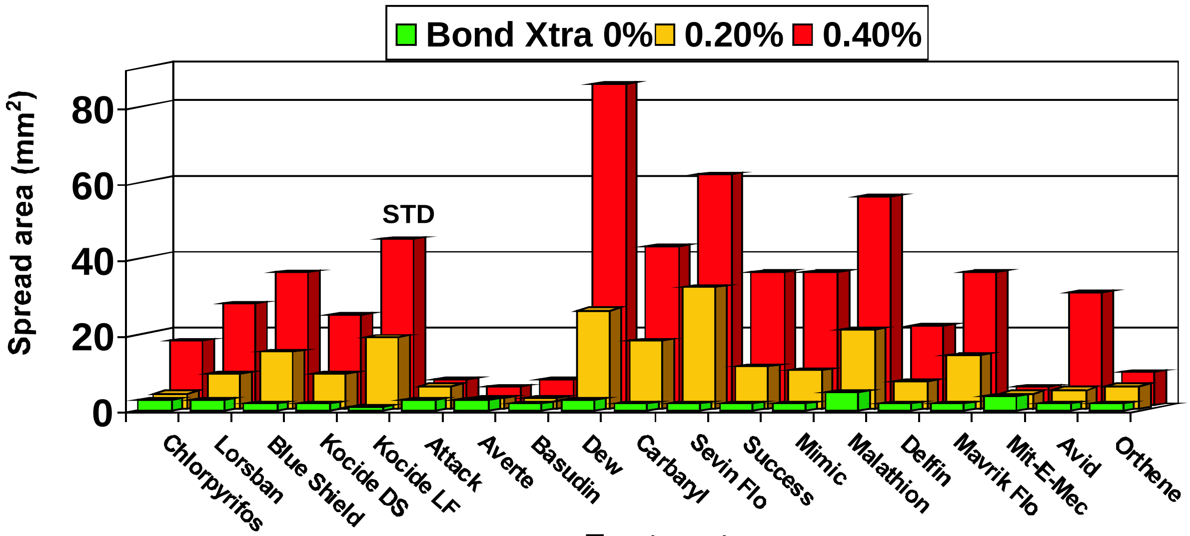

Figure 2. Effect of pesticide formulations on Bond® Xtra spreading (0.5 µl spray droplets) on avocado upper leaf surface. Treatments described in Table 1. STD = Kocide® 2000LF as standard treatment LSD ($P_{0.05}$) = 9mm^2

Carbaryl, Sevin® Flo, Mimic®, Malathion and Mavrik® had no adverse effects on Du-Wett® performance. Similar trends were evident with Bond® Xtra at 0.2% (Figure 2).

At the higher adjuvant concentration (0.1%), Attack®, Averte®, Basudin®, Mit-E-Mec® and Orthene® severely antagonised Du-Wett® spreading properties (Figure 1), and the performance of Bond® Xtra at 0.4% (Figure 2). While these five pesticides do not constitute a large proportion of growers' spray programmes (Table 1), they are the products used to control important insect pests at critical periods. The most commonly used insecticides, Chlorpyrifos 48 EC and Lorsban® 50 EC, can be classified as moderately antagonistic. The pesticides used most often on avocados are the copper fungicides, which do not antagonise the superspreading properties of Du-Wett® and Bond® Xtra (Figures 1 and 2).

The marked effect that commercial formulation constituents can have on the physical properties of the superspreaders was demonstrated with the two diazinon pesticides, Basudin® 600 EW and Dew™ 500. The former severely antagonised droplet spread, while the latter enhanced spreading compared to the Kocide® standard (Figures 1 and 2).

The superspreading property of organosilicones can be advantageous or undesirable, depending on the plant surfaces or canopy architecture. While maximising coverage of plant surfaces is desirable, excessive spreading can lead to spray runoff and a reduction in pesticide efficacy when inappropriately high spray volumes are used. Previous studies have indicated that too high a Du-Wett® concentration (ca. 0.1%), even in spray volumes as low as 500 litres/ha, may reduce spray deposits on avocado canopies if sprayers are not optimised or canopy size not taken into account (Gaskin *et al.*, 2004).

An accepted rule must be that superspreader adjuvants should not be used for dilute spray applications, applied to runoff, on avocados. Eight years of research in pipfruit, wine grapes and citrus have provided good data to conclude that superspreaders work best to improve spray deposits on tree crops when sprays are concentrated by a factor of 3-5; spray volume is reduced to 20-33% of the volume required to wet the canopy to the point of runoff. Superspreaders make water go further and increasing their concentration compensates for reducing water volumes.

CONCLUSIONS

Avocado tree surfaces vary greatly in wettability, affecting the adhesion, retention and distribution of agrichemical sprays. Flowers and the underside of leaves are very difficult-to-wet and fruit is generally difficult-to-wet, therefore spray retention and coverage on these targets will benefit from adjuvant addition. Upper leaf surfaces are easiest to wet and adjuvants may not be beneficial, particularly in high volume spray applications. Sprays optimised for the upper leaf will not be retained on or cover the lower leaf surface. If optimised with adjuvants to target the under-surface of leaves, or flowers, spray is likely to be lost to runoff from the upper leaf surface. Reducing spray volumes and using a suitable superspreader adjuvant is likely to reduce spray runoff and increase spray retention and coverage. The ability of two organosilicone adjuvants to superspread was influenced greatly by individual pesticide formulations. Provisional adjuvant prescriptions have been made taking this into account. These prescriptions are to be tested in field trials, to confirm the best concentrate spray application volumes to maximise deposits on foliage and fruit and on trees of all sizes.

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