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Plant pathology

Effects of adjuvants on herbicidal action. III. Effects of petroleum and rapeseed oils on diclofop-methyl action on ryegrass

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Summary — Petroleum oil, rapeseed oil and its methyl ester derivative enhance efficacy of an Illoxan CE emulsion of diclofop-methyl on ryegrass (*Lolium multiflorum* Lam) by 65, 29 and 57% respectively. These adjuvants only marginally improve spray retention by plants. The abaxial leaf surface retains more spray than the adaxial surface: 3.4, 4.0, 7.3 and 6.9 times at 0, 30, 60 and 80° leaf inclination respectively. Droplet drying was 110 to 150% accelerated by both the oils and the emulsifier. This was accompanied by an increase in the spread of droplets : 3.7 times with the methyl ester derivative on a surface basis. Diclofop-methyl penetration into ryegrass (adaxial surface) was not affected by the emulsifier; was 210% increased by rapeseed oil, 310% by its methyl ester and 500% by petroleum oil. Diclofop-methyl penetration after 24 h was 20% of the applied herbicide on the adaxial surface (poorly wettable), but only 4% on the abaxial surface (highly wettable). Addition of rapeseed oil methyl ester derivative increased it to 81 and 9% respectively.

diclofop-methyl / petroleum oil / rapeseed oil / droplet spread / penetration

Résumé — Effet d'adjuvants sur l'action herbicide. III. Effets d'huiles minérale et végétale sur l'action du diclofop-méthyl sur le ray-grass. *Une huile minérale, une huile végétale (colza), ainsi que son ester méthylique, augmentent l'efficacité du diclofop-méthyl sur ray-grass (*Lolium multiflorum *Lam) respectivement de 65, 29 et 57% (fig 1). Ces adjuvants n'améliorent que peu ou pas la rétention de pulvérisation par les plantes (tableaux I, II et IV). La face abaxiale retient davantage de pulvérisation que la face adaxiale : 3,4, 4,0, 7,3 et 6,9 fois plus à, respectivement, 0, 30, 60 et 80° d'inclinaison (tableau III). Le séchage des gouttelettes déposées sur le feuillage est accéléré par les huiles ou l'émulgateur seul (de 110 à 150%) (fig 2), et leur étalement augmenté (3,7 fois en surface par l'ester méthylique) (fig 3). La pénétration du diclofop-méthyl par la face adaxiale n'est pas affectée par l'émulgateur mais est augmentée de 210% par l'huile de colza, 310% par son ester méthylique et 500% par l'huile minérale (fig 4). En 24 h, 20% du diclofop-méthyl appliqué pénètre par la face adaxiale (peu mouillable) et seulement 4% par la face abaxiale (très mouillable). L'addition d'ester d'huile de colza accroît ces valeurs à, respectivement, 81 à 9% (tableau V).*

diclofop-méthyl / huile minérale / huile végétale / étalement de goutte / pénétration

INTRODUCTION

In recent years, several reports have shown that crop or petroleum oil as an adjuvant in aqueous formulations can increase the efficacy of post-emergence herbicides, *eg* fluazifop-butyl, haloxyfop-methyl and sethoxydim (Buhler and Burnside, 1984), acifluorfen and sethoxydim (Chen and Penner, 1985), atrazine, cyanazine, bentazon, sethoxydim and diclofop-methyl (Nalewaja, 1986), diclofop-methyl (Ayres, 1987; Bouchet and Beaufreton, 1988), phenmedipham (Parmentier, 1987), sethoxydim, fluazifop-p, quizalofop, haloxyfop and cloproxydim (Barrentine and McWhorter, 1988), fluazifop (Smeda and Putnam, 1989).

The higher efficacy in the presence of oil was attributed to effects on several parameters of herbicidal action: spray retention (Nalewaja, 1986; De Ruiter *et al,* 1987), droplet spread on leaf sur-

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face (McWhorter and Barrentine, 1988; Wanamarta *et al,* 1989; Schott *et al,* 1990), penetration (Gillepsie *et al,* 1988; Grafstrom and Nalewaja, 1988; McCall, 1988; Wanamarta *et al,* 1989; Gauvrit and Dufour, 1990; Schott *et al,* 1990) as well as translocation (Gillepsie *et al,* 1988).

Moreover, it is currently under debate as to whether crop oils are comparable with petroleum oils. In particular, among the aforementioned studies, those of Nalewaja (1986), Parmentier (1987), De Ruiter *et al* (1987), McWhorter and Barrentine (1988), Gillepsie *et al* (1988) and Schott *et al* (1990) dealt with seed oils of various origins. Basically, they have the same action as petroleum oils, being equally or more effective with some herbicides, less effective with others. Methylated esters obtained from seed oils usually perform better than the parent oil (Nalewaja, 1986; Schott *et al,* 1990).

We feel that further investigations are required to obtain a clearer picture on the mode of action of oils. To begin with, we studied the consequences of the addition of petroleum, oil, rapeseed oil and its methyl ester derivative (hereafter referred to as oil ester) on the efficacy of diclofop-methyl on ryegrass (*Lolium multiflorum* Lam). We then examined the effect of these oils on retention, droplet spread and penetration of diclofop-methyl in ryegrass. Since the two surfaces of ryegrass leaf have different wettability properties (Field and Bishop, 1988), we paid particular attention to this factor.

MATERIALS AND METHODS

Plant culture

Ryegrass (*Lolium multiflorum* Lam cv Adret) seeds were germinated for 4 d at 25°C then sown in a clay loam soil: sand mixture (1:1). Plants were then placed in a growth cabinet at 14/9 °C (d/night), 14 h photoperiod and 65/95% relative humidity. All experiments were performed when the third leaf was 1 to 3 cm long.

Oils

Petroleum oil was "Base Insecticide d'Eté" from the Esso company (sulfonation index > 92%; viscosity at 40°C: 13 $mm^2 \cdot s^{-1}$). Refined rapeseed oil (saponification index: 188-192; iodine index: 112-116; viscosity at 50 °C: 54 $mm^2 \cdot s^{-1}$) and its methyl ester derivative (saponification index: 180-190; iodine index: 100-120; viscosity at 50°C: 3.9 $mm^2 \cdot s^{-1}$) were obtained from the Robbe company. All 3 oils were prepared with 15% common emulsifier (25% calcium alkylarylsulfonate, 75% polyethoxylated nonylphenol BC 6 (6 mol ethylene oxide). As petroleum oil, rapeseed oil and oil ester are not miscible in Illoxan CE emulsions, it is implicit that the emulsifier is present whenever they are used. It must be stressed that our oil preparations differed from the corresponding commercial preparations since the common emulsifier we used was different from the emulsifier systems present in the marketed products.

Diclofop-methyl efficacy on ryegrass

Diclofop-methyl was applied as an Illoxan CE emulsion by means of an indoor sprayer consisting of a movable boom with 2 blue "Albuz" 110° nozzles positioned 50 cm apart. Plants were placed 48 cm under the nozzles and were sprayed at 150 $g \cdot ha^{-1}$ diclofop-methyl, 150 $l \cdot ha^{-1}$. Oils and emulsifer additions were 0.33 and 0.05% (v/v) respectively. Nine replications with 8 plants each were carried out for each treatment and after 20 d the shoots were cut off at ground level and placed at 80°C for 24 h for dry weight determination. Treatments with Illoxan CE emulsion without any adjuvant will be referred to as Illoxan spray.

Retention measurements

The sprays contained 0.01% fluorescein as in Richardson's experiments (1984). After the spray had dried on the foliage, the plants were cut off at ground level and shaken for 30 s in 50 ml 5 $mmol \cdot l^{-1}$ NaOH. Readings were made in a Jobin and Yvon 3-D spectrofluorimeter at 490/510 nm. Plants were then placed at 80°C for 24 h and dry matter weighed. Six replications with 8 plants each were carried out for each treatment.

To study the influence of leaf inclination on retention, 3 x 10 fragments (11 cm long) of the second leaf were placed 1.5 cm apart on a filter paper which was placed at the desired inclination (0, 30, 60 and 80°) under the sprayer.

To determine whether oil modifies spray distribution on the plant, a retention experiment was conducted in which, following treatment, plants were cut into the following parts: tiller, leaf sheathes, third leaf, and the first and second leaves portions were distinguished according to their abaxial or adaxial exposure towards the spray (at this stage ryegrass leaves are often twisted and present their abaxial and adaxial surfaces alternatively).

Contact angle

Two-µl droplets were deposited by means of a Hamilton microsyringe on the leaf surface. Angles were measured 30 s after deposition with a Wild binocular microscope equipped with a goniometric device. Five measurements were performed for each condition. Temperature was 22°C and relative humidity 41–46%.

Drop evaporation and spread

Three 2-µl droplets were deposited on the adaxial surface of a detached second leaf and weight evolution was monitored with 0.03 mg accuracy. To determine droplet spread, photographs were taken through a binocular microscope and image analysis used to measure droplet area. The experiments were conducted at 22°C and 48-52% relative humidity.

Diclofop-methyl penetration

Ring ^{14}C labelled diclofop-methyl (257 MBq•mmol^{-1}, 98.5% radiochemical purity) was dissolved in ethanol. An aliquot containing the desired radioactivity was deposited at the bottom of a conical tube and the ethanol was evaporated to dryness. An aqueous emulsion of Illoxan CE was added, at a concentration corresponding to a 150 g•ha^{-1} diclofop-methyl, 150 l•ha^{-1} treatment. Gentle shaking for 2 h interspersed with two 10-s sonication spells redissolved radiolabelled diclofop-methyl. Radioactivity of the preparation was 16.7 Bq•µl^{-1} and cold herbicide was 99.6% of total herbicide. When oils were added, their concentration was 0.33% (v/v).

Four 0.5-µl droplets of the above emulsion were deposited on the upper third of the second leaf. Penetration was determined 1 and 3 d after treatment. Each measurement was carried out on 5 plants from the same pot and the experiment was conducted with 3 replicates. Absorption was evaluated by washing the treated area of each leaf with 1 ml acetone then 1 ml chloroform. Washes were combined and evaporated to dryness. Ethanol was added to dissolve diclofop-methyl which was counted in Dynagel (JT Baker Chemicals, The Netherlands) by scintillation counting. Leaves were dried (24 h, 80 °C) and combusted in an oxidizer for radioactivity assessment.

Statistics

Data were submitted to analysis of variance and means were compared using the Newman and Keuls test at the 5% level (Cochran and Cox, 1968). In the tables and figures data marked with the same letters do not differ significantly.

RESULTS

Diclofop-methyl efficacy on ryegrass

The effect of petrolenum oil, rapeseed oil and the oil ester on diclofop-methyl efficacy on ryegrass is shown in figure 1. Under our experimental conditions 150 g•ha^{-1} diclofop-methyl reduced growth by 49% on a dry matter basis. All adjuvants significantly enhanced diclofop-methyl action, the most active being petroleum oil and the oil ester which brought growth inhibition up to 81 and 77% respectively. The emulsifier added alone increased diclofop-methyl efficacy to the same extent as rapeseed oil.

Retention

At the stage studied, ryegrass retained 222 µl Illoxan spray per g dry matter. Addition of oils increased retention but only with petroleum oil was it significant: + 20% (table I).

The presence of the oil ester in the sprayed emulsion did not modify its distribution on the plant (table II). As expected, the wettable abaxial leaf surface retained more spray than the adaxial surface (about 4 times) and it accounted for almost two thirds of total retention.

Retention greatly varied with leaf inclination (table III): from 0 to 80° it decreased by 82% on the adaxial leaf surface and by 63% on the abaxial surface.

Contact angle

On the abaxial leaf surface Illoxan emulsion droplets spread in a few seconds and no contact angle could be measured. On the adaxial leaf surface contact angle measured 30 s after deposition were greatly decreased by all 3 oils and even more by the emulsifer alone (table IV).

Table I. Effect of oil adjuvants on spray retention by ryegrass. Abbreviations: ILL, Illoxan CE emulsion; EM, PO, RO and OE, Illoxan CE emulsion combined with the emulsifier, petroleum oil, rapeseed oil and the rapeseed oil methyl ester derivative, respectively.

	Retention *(µl•g^{-1})*
ILL	222^{b}
EM	544^{ab}
PO	266^{a}
RO	250^{ab}
OE	238^{ab}

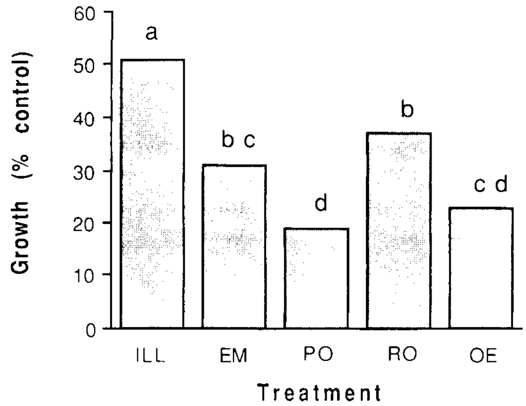

Fig 1. Effect of oil adjuvants on diclofop-methyl efficacy on ryegrass. Data are expressed as % control growth (1.77 g dry matter). Abbreviations: ILL, Illoxan CE emulsion; EM, PO, RO and OE, Illoxan CE emulsion combined with the emulsifier, petroleum oil, rapeseed oil and the rapeseed oil methyl ester derivative, respectively.

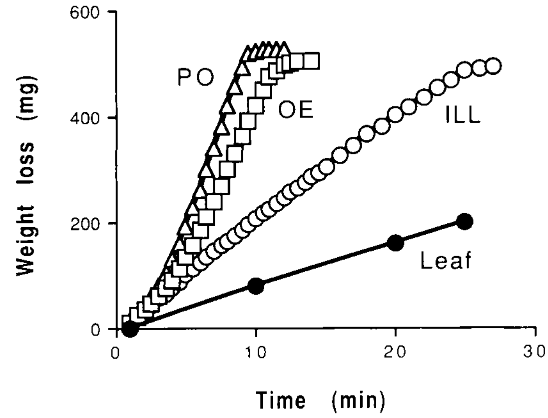

Fig 2. Effect of oil adjuvants on the evaporation kinetics of diclofop-methyl droplets. Data are expressed in weight loss (mg) of the leaf on which droplets were deposited. Leaf: leaf without deposit. Other abbreviations are defined in figure 1. This is a typical experiment taken from 5 with similar results.

Droplet evaporation and spread

Droplet evaporation could be accurately monitored by weighing the detached leaf on which 3 2-μl droplets had been deposited (fig 2). Weight loss from the leaf was linear throughout the experiment. Illoxan emulsion deposits dried in 25-30 min whereas in the presence of rapeseed oil or the oil ester it took less than 15 min and around 10 min with petroleum oil. The emulsifier accelerated desiccation to the same extent as rapeseed oil and the oil ester.

Figure 3 shows that Illoxan emulsion droplets evaporated without spreading on the adaxial surface. Hence, contact angle evolution was solely due to evaporation. By contrast, when the oil ester was present in the emulsion, spread occurred and once desiccation was completed, the deposit surface had been multiplied by 3.7. In this case, contact angle decrease was faster.

On the abaxial leaf surface spread occurred even in the absence of the oil ester but was so rapid that it had taken place before measurements could be made. Its extent was the same with or without the oil ester (data not shown).

Penetration

Diclofop-methyl penetration into ryegrass second leaf differed according to which surface radiolabelled herbicide was deposited on. Penetration through the abaxial surface was low whereas it was 5 times more important through the adaxial surface (table V). Addition of the oil ester dramatically increased penetration which was about quadrupled on the adaxial surface and more than doubled on the abaxial surface.

Table II. Effect of the methylated derivative of rapeseed oil on spray repartition on ryegrass plants. Partition of the plants is detailed in the text. "Abaxial" and "Adaxial" refer to spray exposure on the first and second leaves. Figures in brackets are retention in % of total plant. ILL, OE: see table I.

	Retention (μl•g⁻¹, %)			
	ILL		*OE*	
Tiller	356^a	(3.8)	350^a	(3.9)
Leaf sheathes	$97b^b$	(10.6)	103^b	(11.2)
Third leaf	184^c	(12.2)	195^c	(13.4)
Adaxial	108^d	(8.0)	128^d	(8.7)
Abaxial	406^e	(65.4)	402^e	(62.8)
Plant (total)	237^f	(100.0)	242^f	(100.0)

Table III. Spray retention by detached leaves as a function of inclination.

	Retention (μl•g⁻¹)		
	Abaxial surface	*Adaxial surface*	*Ratio*
Leaf inclination (°)			
0	693	204	3.4
30	586	147	4.0
60	411	56	7.3
80	255	37	6.9

Table IV. Effect of oil adjuvants on the contact angle of diclofop-methyl droplets deposited on the adaxial surface of ryegrass second leaf. Abbrevations: see table I.

	Contact angle (°)
ILL	88[a]
EM	40[c]
PO	55[b]
RO	58[b]
OE	60[b]

Table V. Effect of leaf surface and methylated rapeseed oil derivative on diclofop-methyl penetration into ryegrass second leaf. Penetration is expressed in % applied radioactivity. ILL, OE: see table I.

	Penetration (%)	
	ILL	*OE*
Abaxial surface	4[a]	9[b]
Adaxial surface	20[c]	81[d]

All 3 oils promoted diclofop-methyl penetration into ryegrass. This is shown in figure 4: on the abaxial surface, diclofop-methyl penetration from Illoxan emulsion was only 3% after 3 d; the emulsifier had no significant effect, whereas rapeseed oil increased it to 9%, the oil ester to 12% and petroleum oil to 17%.

DISCUSSION

Diclofop-methyl efficacy on ryegrass

Our results confirm the well-known fact that oil can increase the efficacy of postemergence herbicides. Petroleum oil was significantly more active than rapeseed oil in promoting diclofop-methyl action. Nalewaja (1986) found a similar result using sunflower or linseed oil (the lower performance of soybean oil was not significant).

From the few studies published, it emerges that whether petroleum or seed oils give better results depends on the herbicide considered. It seems that petroleum oils are better with diclofop-methyl (Nalewaja, 1986, and the present study), bentazon (Nalewaja, 1986; Wanamarta *et al*, 1989) and fenoxaprop, fluazifop and haloxyfop (Nalewaja, 1986). Seed oils perform better with glyphosate (De Ruiter *et al*, 1987) and cyanazine (Nalewaja, 1986), whereas they are equally effective as petroleum oils with phenmedipham (Parmentier, 1987), sethoxydim (Nalewaja, 1986; Wanarmata *et al*, 1989), atrazine, acifluorfen and clopropoxydim (Nalewaja, 1986).

In our experiments the action of the oil ester was similar to that of petroleum oil. Nalewaja (1986) found the same with soybean or sunflower methylated oils and herbicides such as diclofop-methyl, sethoxydim, clopropoxydim, fluazifop, fenoxaprop and haloxyfop. Hence, these derivatives appear to be promising adjuvants.

A last point worth noting is that under our conditions, rapeseed oil and the emulsifier brought about the same increase in diclofop-methyl effi-

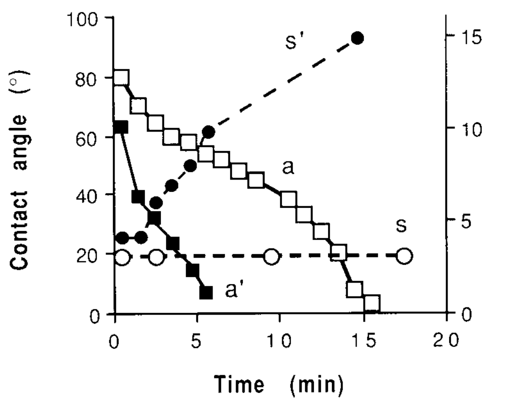

Fig 3. Effect of methylated derivative of rapeseed oil on contact angle and deposit surface evolutions. a, s: angle and surface for an Illoxan CE emulsion; a', s': angle and surface for an Illoxan CE emulsion combined with the oil ester. This is a typical experiment taken from 3 with similar results.

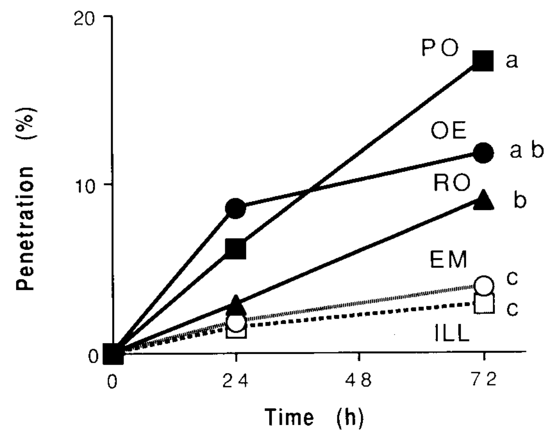

Fig 4. Effect of oil adjuvants on diclofop-methyl penetration through the adaxial surface of ryegrass second leaf. Results are expressed in % penetration of applied radioactivity. Abbreviations: see figure 1.

cacy. As rapeseed oil contained the emulsifier, one can question the action of rapeseed oil *per se.*

Retention

Field and Bishop (1988) have shown that the 2 leaf surfaces of ryegrass (*Lolium perenne* L) differ greatly in their properties. They found contact angles of 118 and 36° for formulated glyphosate droplets on the adaxial and abaxial surfaces respectively, which shows that the abaxial surface is by far the most wettable. Moreover, at 3rd leaf appearance, the 2nd leaf begins to twist and exposes its abaxial face to the spray. Hence, ryegrass morphology can be expected to influence retention and we felt that it was important to see whether we could observe the same wettability difference on *Lolium multiflorum* before assessing the effect of oil on retention by this species.

Table II shows that almost two thirds of the spray was retained by the abaxial surfaces exposed to it. Hence, they largely determine retention by the whole plant. Adaxial surfaces accounted for only 8% of total retention and the sheathes – the nearest parts to the meristem – for 11%. Retention per dry weight unit was 3.8 times greater on abaxial surfaces.

As it is difficult on a twisted ryegrass leaf to separate unambiguously abaxial from adaxial exposures to the spray, we also studied retention on detached leaves. At low inclination (0–30°), the retention ratio between the two surfaces lay between 3.4 and 4.0 and went up to 7.3 and 6.9 as angle increased to 60 and 80°. These results also show the dramatic influence of inclination on retention: at 0° the abaxial surface retained 693 μl spray per g dry matter and 255 μl at 80°, the decrease being proportionally greater for the adaxial surface: 204 and 37 $\mu l \cdot g^{-1}$, respectively.

These results illustrate the importance of morphology for spray retention by ryegrass. At the 2-leaf stage foliar parts are upright, adaxial surfaces are exposed to the spray and retention is expected to be low. As the third leaf develops, the second leaf bends and twists. As a consequence, it exposes a significant portion of the abaxial (wettable) surface in an almost horizontal position to the spray. It follows that at this stage retention is high, as exemplified by our results, and can be compared to that of dicotyledonous plants such as *Chamomilla reticuta* and *Solanum nigrum* (De Ruiter and Uffing, 1988).

Spray retention was not greatly affected by oils: only with petroleum oil could we observe a significant – although limited (20%) – increase (table I). Two explanations for this lack of effect can be put forward. Firstly, ryegrass is a wettable plant: at 500 l spray per ha it retained more than 500 μl per g dry matter (Gauvrit and Dufour, 1990). It is known that adjuvants can increase spray retention markedly on poorly wettable plants but only marginally on wettable ones (Blackman *et al,* 1958; De Ruiter and Uffing, 1988). Secondly, the surface tension of Illoxan emulsions is close to 30 $mN \cdot m^{-1}$ and is not modified by any of the oils we used (data not shown). Since surface tension plays a predominant role in spray retention (Anderson *et al,* 1987) this explains why oil – actually oil plus emulsifier – addition does not affect the retention of Illoxan emulsions.

Since diclofop-methyl is all the more phytotoxic as it is applied nearer to the leaf basis (Walter *et al,* 1990), it was important to see whether oils could affect emulsion distribution on the plant. Table II shows that the oil ester had no effect, in particular, retention was not significantly increased on the non-wettable portions of the leaf.

It can be concluded from the above experiments that the reason for the increased diclofop-methyl phytotoxicity in the presence of oils does not lie in retention phenomena.

Contact angle, drop evaporation and spread

After deposition, the contact angle of the droplets began to decrease, and we had thus to measure them after a well defined time; for practical reasons we chose 30 s.

Contact angle on the adaxial surface was greatly affected by the oils studied (table IV). Emulsifier alone was even more active, showing that it is responsible, at least partly, for the decrease in contact angle. Its action can be viewed as a lowering of surface tension between the liquid phase of the drop and the cuticule, allowing spread. A reason for the greater efficiency of the emulsifier applied alone might be that, as it is not involved in interactions with oil, more of it is available to interact with cuticle.

There seems to be a discrepancy between the observed effects of oils on contact angles and their lack of effect on retention. However, it might be only apparent for 3 reasons. Firstly, in our case, the addition of oils did not decrease surface tension in Illoxan emulsions – which is already low. Secondly, the angles were measured

30 s after deposition, in the course of a relatively fast decrease and with our method we had no access to the value of the contact angle immediately following deposition. Figure 3 shows that the contact angle difference between Illoxan emulsion droplets with and without oil increased with time. We can therefore suppose that the difference following deposition is not so important as 30 s after (visual qualitative estimations confirm this view). Finally, spray retention results from phenomena taking place in a few ms, whereas we measured contact angles on a time scale several orders of magnitude higher. In this line, Anderson *et al* (1987) noted that retention and spread relate to different parameters, namely, dynamic and equilibrium surface tension respectively, and one can alter them independently.

As our experiments were conducted in a relatively dry atmosphere (41 to 52% relative humidity), droplets evaporated rapidly. This process was accelerated by oils (fig 2). At the same time, and only in the presence of oil, did the droplets spread (fig 3). As spreading increases drop-leaf and drop-air contact surfaces, it enhances thermic and matter transfers and, as a consequence, droplet evaporation.

Penetration

As almost two thirds of the spray is retained on the abaxial leaf surfaces, we decided in a first step to study penetration through this. Figure 4 shows that diclofop-methyl penetration is quite low through this surface since after 3 d it amounted to only 3% of the applied ^{14}C diclofop-methyl. The emulsifier had no significant effect, whereas all 3 oils promoted penetration. Petroleum oil performed the best and increased penetration to 17%, followed by the oil ester (12%) and rapeseed oil (9%). Increased penetration in the presence of oil had already been observed for herbicides such as fluazifop (Grafstrom and Nalewaja, 1988), haloxyfop (McCall, 1988), sethoxydim and bentazon (Wanamarta *et al,* 1988) and diclofop-methyl (Gillepsie and Nalewaja, 1989; Gauvrit and Dufour, 1990; Schott *et al,* 1990). This action has not yet been clearly explained, all the more as the interactions between oil and the cuticule components are poorly understood.

Since the abaxial and adaxial leaf surfaces differ greatly, it was of interest to observe the consequence on diclofop-methy l penetration. Table V shows that it was better (5 times in this experiment) through the poorly wettable adaxial surface than through the wettable abaxial surface. According to Field and Bishop (1988) on *Lolium perenne,* the first one presents dense deposits of crystalline wax whereas the latter is covered with amorphous wax sheet. This well explains the difference in wetting and is in agreement with results obtained by Holloway and Silcox (1985) who studied non-ionic surfactant penetration into plants. They found that it was faster into waxy leaves such as rape (*Brassica napus* L) and pea (*Pisum sativum* L) leaves which possess microcrystalline wax deposits on their surface.

The oil ester promoted diclofop-methyl penetration to different extents according to the leaf surface: about twice on the abaxial and about 4 times on the adaxial surface (table V). Spread increases contact surface and hence can be thought to also increase penetration. However, it cannot explain the improved penetration through the abaxial surface since the Illoxan emulsion droplets spread to the same extent with or without the oil ester. Hence, in this case, the oil ester seems to have a direct effect on diclofop-methyl penetration. By contrast, the spread which occurred on the adaxial surface may play a role in the increase in penetration since here, absorption was increased 4 (instead of 2) times by the oil ester. The relationship between spread and penetration is not clear. For example, Wanamarta *et al* (1989) found no relationship between sethoxydim droplet spread and absorption, whereas some, however slight, could be detected with bentazon.

Hence, the higher diclofop-methyl efficacy on ryegrass in the presence of oils could be attributed to better penetration into the plant and perhaps also to droplet spread on the leaf surface.

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