THE EFFECT OF SURFACTANTS ON THE UPTAKE AND TRANSLOCATION OF GLYPHOSATE IN YORKSHIRE FOG.

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SUMMARY

The uptake and translocation of glyphosate applied to Yorkshire fog (*Holcus lanatus*) leaves was enhanced most by the addition of Triton X-45 surfactant. No improvement over the glyphosate formulation alone was obtained by the addition of Silwet L-77 or a mixture of Silwets L-77 and L-7607. In all cases, uptake was greater from treatment of the adaxial leaf surface. The wetting and spreading of the formulations on leaves was examined, as well as the rate of droplet drying and phytotoxicity of the solutions. Differences in uptake could not be attributed to any of the physical properties of the formulations measured.

INTRODUCTION

The grass Yorkshire fog (*Holcus lanatus*) is a persistent problem weed on many forest sites and frequently is not eradicted completely by aerial application of herbicide. There is a need for a cost-effective ground-applied treatment to control any remaining infestations. Glyphosate is a potentially suitable herbicide for this purpose. Tests were undertaken to identify the best adjuvant to use with glyphosate for the control of Yorkshire fog. The physical properties of the spray solutions were also examined in an effort to explain the differential uptake.

METHODS AND MATERIALS

Yorkshire fog was grown from seed, in pots containing a peat-pumice mix, for 2 months in a glasshouse. Plants were reduced to a single plant per pot prior to conditioning them in a controlled environment (20°/15°C, day/night temperature; 70% relative humidity; 12 h photoperiod with 0.5 h dawn and dusk ramp; 450-550 $\mu mol/s/m^2$ photosynthetic irradiance) for 2 weeks before treatment. Water was supplied as required and fertiliser (Response Black Label @ 0.2% v/v) was applied weekly. The third-youngest, fully-expanded leaf on each plant was used for treatment.

Glyphosate (as Roundup at 20 ml/litre water) was formulated alone or with the addition (0.2% v/v) of Triton X-45 (Rohm and Haas), Silwet L-77 (Union Carbide), or a Silwet L-77 + L-7607 mixture (1:1). Triton X-45 is a conventional nonionic surfactant (octylphenoxypolyethoxy ethanol); both the Silwets are nonionic organosilicone adjuvants (silicone polyalkyleneoxide copolymers). [^{14}C]glyphosate (Amersham, 98.3% pure) was formulated as the isopropylamine salt and incorporated in the formulations. Six 0.5 μl droplets were applied to the mid-section of the adaxial or abaxial surface of a leaf on individual plants (four replicates). Equivalent droplets of treatment solution were dispensed into scintillation vials to determine the dose of [^{14}C]glyphosate applied to the plants.

Uptake was determined 24 h after treatment by excising the treated leaves, washing (2 x 4 ml) with 50% aqueous ethanol (10 s) and quantifying the [^{14}C] in the wash by liquid scintillation counting. The radioactivity within the treated leaf was determined using a biological oxidiser (Harvey OX300) and scintillation counting. Uptake was expressed as a percentage of the total radioactivity applied. Translocation was calculated as the radioactivity which was not recovered in the washes or by oxidation of the treated tissue and expressed as a percentage of both the [^{14}C]glyphosate absorbed and applied.

Contact angles were determined by projecting and measuring the image of 1 μl droplets applied to either upper or lower surfaces (minimum 20 replicates) of fully expanded leaves (Zabkiewicz *et al* 1985). Where total wetting (TW) of the leaf surface by a formulation was observed, this occurred within 5 s, slow TW within 20 s, and very slow TW within 60 s.

An image analyser (Optomax) was used to measure the spread area of 0.5 μl droplets on upper and lower leaf surfaces (Zabkiewicz *et al* 1987). A minimum of ten replicates was used for each treatment.

Drying rates were determined from the time taken for ten droplets of a formulation (each 1 μl) to dry after application to an artifical wax surface (three replicates; Zabkiewicz *et al* 1985). Drying was determined from the change in droplet weight over time and was considered complete when weight loss ceased. All wetting, spreading and drying measurements were made at 20 °C and 70% RH.

Phytotoxicity was quantified as electrolyte leakage from Yorkshire fog leaves after immersion in the treatment formulations for 6 h (Gaskin and Kirkwood 1989). The conductivity was measured, the treatment solutions boiled, cooled and remeasured. Electrolyte leakage was expressed as a percentage of total ion leakage after boiling. Each treatment was replicated six times on five 7 cm leaf portions.

RESULTS

The uptake and translocation data and the physical properties of the treatment formulations are presented in Tables 1 and 2 respectively. In all cases uptake was greater from treatment of the adaxial leaf surface (Table 1). Addition of Triton X-45 significantly improved uptake of [^{14}C]glyphosate into Yorkshire fog foliage. This was not the case with the Silwet surfactants which reduced uptake compared with the glyphosate (Roundup) formulation alone.

TABLE 1: Uptake and translocation of glyphosate in Yorkshire fog

	Uptake (%)			Translocation (%)	
Treatment	from adaxial	from abaxial	mean	of [^{14}C] absorbed	of [^{14}C] applied
glyphosate	59a	23b	41.1b	30.5b	13.2b
glyphosate + 0.2% Triton X-45	76a	47a	62.0a	40.9ab	27.2a
glyphosate + 0.2% Silwet L-77	31b	17b	24.2c	53.8a	13.4b
glyphosate + 0.1% Silwet L-77 + 0.1% Silwet L-7607	36b	23b	29.8c	56.4a	19.6ab

Within columns, means sharing common postscripts are not significantly different at P = 0.05 (LSD test).

The translocation of the glyphosate absorbed with Triton X-45 was not significantly different from the other treatments but because of the greater uptake, the proportion of applied glyphosate which was translocated was increased.

The physical properties (Table 2) were largely as expected, namely:

- all combinations with surfactants caused improved leaf wetting
- spread area of droplets was increased by all surfactants and was largest with added Silwet L-77 (50-56 mm^2 per droplet)
- drying rate of droplets was increased by all surfactants and was fastest with added Silwet L-77 (5.5% wt/min)
- all surfactants increased the phytotoxicity of the formulation, conductivity being greatest with added Silwet L-77 (43.1%).

TABLE 2: Physical properties of glyphosate formulations

Treatment	Leaf surface	Contact angle (°)	Spread area (mm^2)	Drying rate (% wt/min)	Conductivity (%)
glyphosate	adaxial	137	0.5	3.3	9.2
	abaxial	134	0.7		
glyphosate	adaxial	STW	36	4.6	12.2
+ 0.2% Triton X-45	abaxial	STW	32		
glyphosate	adaxial	TW	50	5.5	43.1
+ 0.2% Silwet L-77	abaxial	TW	56		
glyphosate	adaxial	VSTW	24	4.6	19.7
+ 0.1% Silwet L-77	abaxial	VSTW	28		
+ 0.1% Silwet L-7607					

TW = Total Wetting; STW = Slow Total Wetting; VSTW = Very Slow Total Wetting

DISCUSSION

Studies in the laboratory and in the field with several plant species have shown that Silwets L-77 and L-7607 can enhance the uptake and translocation of glyphosate as compared to the herbicide formulation alone or with the addition of other non-ionic surfactants (Stevens *et al* 1988; Zabkiewicz *et al* 1985). This was not the case with Yorkshire fog as the most effective combination was glyphosate plus Triton X-45, where twice as much of the applied [^{14}C]glyphosate was translocated compared to the nil additive treatment (Table 1). This was primarily the result of increased uptake. Triton X-45 has been shown to increase the uptake of herbicides into plants (Stevens and Bukovac 1987b; Stevens *et al* 1988). However, the mechanism by which Triton X-45 enchances absorption of chemicals into leaves is unknown. The surface tension of aqueous Triton X-45 solutions is not sufficiently low to allow stomatal infiltration (Stevens and Bukovac 1987a).

Silwet L-77 solutions are known to be capable of rapid infiltration of leaf stomata (Field and Bishop 1987; Zabkiewicz *et al* 1987) and can give good uptake of herbicides into plants such as gorse and bracken (Stevens *et al* 1988). However this is not always the case with grass species. Studies with perennial ryegrass have produced results where, after 21 h, the amount of glyphosate uptake was the same from spray solutions with or without Silwet L-77 (Field and Bishop 1987). In contrast, initial uptake (i.e. <3 h) in these circumstances was considerably greater from solutions containing Silwet L-77. Comparison of Silwet L-77 with several other surfactants and three herbicides on brome grass (*Bromus sterilis*) again showed that the other surfactants could equal or better the Silwet additive in enhancing spray efficacy (West *et al* 1988). In the case of pampas grass, glyphosate absorption was dependent on surfactant and leaf age; in young leaves infiltration was excessive and caused phytotoxicity which led to reduced translocation (Gaskin and Murray 1988). Uptake into older foliage occurred without phytotoxicity and translocation was enhanced (Gaskin and Zabkiewicz 1987).

In the present studies with Yorkshire fog, observations showed no evidence of stomatal infiltration at the surfactant concentrations tested, despite the presence of open stomata on both leaf surfaces. Uptake was consistently greater from adaxial leaf surfaces, indicating differential cuticular diffusion as the probable mechanism.

The physical properties of the spray solutions used in this work (Table 2) do not provide an answer for the relative performance of the formulations. As expected, there was increased wetting with all formulations containing surfactants; the spread area of the solution with Silwet L-77 was approx. 100 times greater than that of the glyphosate solution alone while the other surfactant solutions also substantially enhanced droplet spread but to a lesser extent. The droplet drying rates did not differ as much as was expected from the spread areas. This may be attributed to measurements being made on artifical, smooth, wax surfaces. In practice, there will be considerably larger differences on leaf surfaces and this may be a significant factor in reducing uptake from formulations that dry fast and are not capable of stomatal infiltration.

Although conductivity values were highest for Silwet-containing solutions, this did not reduce the proportion of herbicide translocated within the plant. A degree of increased electrolyte leakage suggests the formulation is entering the leaf symplast and may improve transport of the herbicide by increasing membrane permeability. Excessive ion leakage probably indicates severe leaf cell damage and formulation phytotoxicity which can inhibit phloem translocation. This does not appear to be a problem with Yorkshire fog at the herbicide and surfactant rates tested.

CONCLUSION

Uptake of glyphosate into Yorkshire fog foliage was enhanced most with Triton X-45 surfactant. This is expected to result in greater field efficacy because translocation was not inhibited by this formulation. In the absence of stomatal infiltration, greater spread and faster drying of spray droplets may be the factors reducing uptake of glyphosate from formulations containing Silwet surfactants in this grass species.

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