UPTAKE AND TRANSLOCATION OF GLYPHOSATE IN OATS AFTER DROUGHTING

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SUMMARY

Rehydration of droughted 10 day old oat (*Avena sativa*) plants, 48 h or less, before ^{14}C -glyphosate application increased foliar uptake compared to well droughted plants. Translocation and pattern of distribution of glyphosate in the plant were not significantly different for varying rehydration times. The significance of these findings to the performance of glyphosate in dry soil conditions is discussed.

INTRODUCTION

It is widely recognised that environmental conditions such as light, temperature, humidity, rain and wind, before and after spraying, are major causes of inconsistency and reduced herbicide efficacy. Glyphosate is a non-selective, post emergence herbicide used for the control of annual and perennial weeds. In common with other post emergence herbicides, environmental conditions, especially water stress, influence performance (Caseley and Coupland 1985).

Water stress before, during and after spray applications may affect glyphosate activity by influencing biochemical and physiological processes that are necessary for glyphosate performance (Moosavi-Nia and Dore 1979). The pre-spraying conditions largely determine the size, shape and physiological status of the plant, and in this way influence herbicide retention and penetration (Price 1983). The water potential of leaves during and after spraying is important because an increasing soil moisture deficit results in gradual stomatal closure causing a rapid fall in photosynthesis, a general decline in respiration and eventual wilting (Caseley and Coupland 1985). Some or all of these factors may reduce herbicide penetration and translocation (Moosavi-Nia and Dore 1979). Soil moisture stress during the post spraying period can alter the distribution and movement of glyphosate and photo-assimilates (Klevorn and Wyse 1984).

The present research investigates the effects of water stress on glyphosate uptake, translocation and the associated distribution of photo-assimilates.

MATERIALS AND METHODS

Polystyrene cups were filled 170 g of oven dried Rapaki silt loam soil. All cups were weighed and water was added to bring the soil moisture content to field capacity (FC) (36.9% w/w). Oat seedlings (cv. Amuri) were planted individually into each cup and raised in a controlled environment chamber (14 h photoperiod, 23 °C/15 °C day/night temperatures, 55-60% relative humidity, photosynthetic photon flux density 350-400 $\mu\text{mol}/\text{m}^2/\text{s}$). Water stress treatments were imposed by withholding water from three of the treatments at the full expansion of the second leaf. Once wilting point was reached (soil water = 16.2% w/w), the plants were stressed for a further 5 days, with water being added daily to bring the pots up to the weight corresponding to wilting point. In some treatments soil was returned to field capacity 24 or 48 h prior to applying ^{14}C glyphosate or $^{14}\text{CO}_2$. In all there were four soil water treatments replicated 10 times; field capacity (FC), wilting point (WP) and two re-watering to field capacity treatments, at 24 (-24) and 48 (-48) hours. At the time of radioactive labelling the degree of moisture stress suffered by plants in their respective treatments was quantified by measuring leaf water potential with a Wescor C-51 psychrometer (Savage and Cass 1984). The Haun scale of growth units was used to assess the status of plant physiological development. This involved counting the number of fully expanded leaves plus the ratio of the lamina length of the last visible growing leaf to that of the preceding leaf (Haun 1973).

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Radioactive glyphosate (^{14}C) was formulated as the isopropylamine salt and applied in formulated glyphosate (as Roundup) at 1.08 kg ai/ha in 250 litres water. The ^{14}C -glyphosate uptake and translocation measurements were determined from applications to the second leaf of $6 \times 0.5 \mu\text{l}$ droplets along the middle of the distal third of the lamina. Total radioactivity applied was $0.018 \mu\text{Ci}$ per plant. Subsequent determination of uptake was derived by recovering the ^{14}C -glyphosate from the lamina surface by washing with distilled water after 24 h and subtracting this value from the total ^{14}C -glyphosate applied. Plant tissue samples (sheath, leaf 1, leaf 3 plus apical meristem and roots) were freeze dried before grinding in liquid nitrogen and solubilizing in solulene/toluene (50% v/v). Benzoyl peroxide was then added to decolourise the samples before scintillation counting using a Triton-x-100 cocktail (Bishop and Field 1983). Total translocation and the partitioning of ^{14}C -glyphosate was determined from radioactivity recovered, which was greater than 80% of total applied.

A similar procedure was used for ^{14}C -assimilate labelling, except the treated lamina was fed $^{14}\text{CO}_2$ by enclosing it in a mylar cuvette bag and injecting $4.0 \mu\text{Ci Na}_2^{14}\text{CO}_3$ (specific activity 510 Ci/mg) and HCl into an association reaction vial, with the release of $^{14}\text{CO}_2$. The lamina was exposed to $^{14}\text{CO}_2$ for 20 minutes.

Statistical analysis was carried out using the Genstat package.

RESULTS

At the time of radioactive labelling the leaf tissue of re-watered and WP treatments was -0.22 MPa and approximately -2.01 MPa less than the FC treatment (-0.29).

The Haun scale showed that the FC and WP plants had a value of 2.5 and the rehydrated treatments were slightly more developed with a value of 2.8.

The uptake of ^{14}C -glyphosate was reduced by over 20% by soil water stress (Table 1) although uptake was not significantly reduced when plants had been rehydrated, and kept at field capacity, prior to radio-labelling.

TABLE 1: The uptake, translocation and partitioning pattern of ^{14}C -glyphosate in watered and droughted plants. (S = sheath, L1 = leaf 1, L3 = leaf 3 plus apical meristem, R = roots).

Treatment	Uptake (%)	Percentage of ^{14}C -glyphosate in treated lamina	Percentage distribution of translocated ^{14}C -glyphosate			
			S	L1	L3	R
FC	27.6	39.0	5.9	12.3	23.7	58.1
-24	30.2	55.9	7.4	9.9	18.5	64.2
-48	35.1	48.0	7.9	12.7	19.9	59.5
WP	7.9	53.7	9.6	17.7	26.4	46.3
SEM	4.91	3.13	0.54	1.42	1.90	1.93

Although more ^{14}C -glyphosate was absorbed when plants were rehydrated, in comparison with the WP treatment, the amount translocated to other plant parts did not increase. In all treatments the partitioning of ^{14}C -glyphosate was primarily to the roots, with leaf 3 plus apical meristem, leaf 1 and sheath fractions receiving lesser amounts, in that order. The root fraction was 14.3% less in the WP treatment compared with the mean of the other treatments.

Total translocation of ^{14}C -assimilate from the treated lamina showed similar trends to ^{14}C -glyphosate (Table 2), although partitioning of radioactivity to the various sinks was different.

The FC treatment translocated at least 20% more ^{14}C -assimilate than the other treatments ($P < 0.001$). The partitioning of ^{14}C -assimilate was preferentially to the roots, sheath, leaf 3 plus apical meristem and leaf 1 and was similar for all treatments, except the WP treatment. In this case, the sheath accumulated at least 30% more of the translocated radioactivity, than other treatments and there was a corresponding decline in accumulation by the roots.

TABLE 2: The amount of translocation and partitioning pattern of ^{14}C -assimilate in watered and droughted plants. (For abbreviations see Table 1).

Treatment	Percentage of ^{14}C -assimilate in treated lamina	S	Percentage distribution of translocated ^{14}C -assimilate		
			L1	L3	R
FC	42.7	32.0	3.76	6.84	57.4
-24	63.9	36.8	2.20	10.20	50.8
-48	62.9	39.5	2.60	9.10	48.8
WP	64.1	71.9	1.80	6.60	19.7
SEM	4.99	5.36	0.41	1.68	5.22

DISCUSSION

When oat plants were water stressed prior to glyphosate application, uptake was reduced compared to plants that were watered (FC) or rehydrated (-24, -48) (Table 1). The higher uptake in the FC treatment was probably associated with active translocation of ^{14}C -glyphosate away from the inner surface of the cuticle, or diffusion into the apoplast, which maintained a high chemical potential between the outside and inside of the leaf surface (Price 1983). However, this would not have been the case in the rehydration treatments as the translocation of ^{14}C -glyphosate was not significantly different from the WP treatment. It is therefore suggested that the differences in uptake were largely associated with leaf morphological and micro-environmental changes.

The micro-environment (e.g. boundary layer) around the well watered and rehydrated plants may have had a higher relative humidity, which reduced the rate of droplet drying and maintained the ^{14}C -glyphosate in solution for a longer period, so increasing uptake (Price 1983). Uptake may also have been increased because of changes within the cuticle, which became more hydrated, stretched and permeable, facilitating glyphosate uptake in the aqueous phase (Caseley and Coupland 1985). This may have been the overriding factor in increasing uptake in the -24 and -48 treatments.

The percentage of ^{14}C -glyphosate and ^{14}C -assimilate translocated was also reduced by water stress (Tables 1 and 2). This supports Ahmadi *et al* (1980) who found that plants under water stress translocated less herbicide. Reasons for the reduced translocation are uncertain, and it is not known if desiccation affects the source (leaf photosynthesis and phloem loading), the sink (phloem unloading) or the translocation mechanism. Clearly one of the main reasons for reduced translocation of ^{14}C -assimilate, and probably ^{14}C -glyphosate, was reduced leaf photosynthesis as the water potential of the leaves reached -2.3 MPa (Hsiao 1973).

Caseley and Coupland (1985) stated that most published reports have made no attempt to study glyphosate translocation in isolation from uptake. Droughting and rehydrating plants may be a useful method to study herbicide uptake by leaves without the effects of translocation interacting. The translocation results showed that if ample water was supplied to the roots of previously droughted plants for 1 or 2 days before glyphosate application, physiological transport processes do not immediately restart and this may have major implications for herbicide efficacy. The present data supports that of Moosavi-Nia and Dore (1979) who showed that 3 and 5 days of rehydration were not sufficient for glyphosate to kill *Imperata* and *Cyperus*, but this could be achieved with a 7 day rehydration period. Translocation of assimilate by the rehydrated plants was found to be not significantly different from the WP treatment.

Reduced sink demand for photo-assimilates may have been a reason for reduced translocation of both ^{14}C -glyphosate and ^{14}C -assimilate (Tables 1 and 2) in the WP and rehydration treatments. Price (1983) stated that temperature and water stress can both cause reduced meristematic activity, and limit sink demand. Alternatively, reduced phloem loading and unloading and phloem translocation may explain some of the reduced translocation. Relatively little is known about how herbicides and photo-assimilates are loaded into the sieve tubes (Price 1983), although environmental

conditions are known to influence cellular uptake of compounds through cell membranes (Whitwell *et al* 1980). If cell membranes lose their integrity under drought conditions the loading of ^{14}C -glyphosate and ^{14}C -assimilate via the symplast may be inhibited.

Translocated ^{14}C -glyphosate and ^{14}C -assimilate were partitioned to the primary sinks (roots, new leaves, sheaths) with minimal accumulation in mature leaves (Tables 1 and 2). However, more ^{14}C -glyphosate accumulated in leaf 3 plus apical meristem than did ^{14}C -assimilate which accumulated largely in the sheath and roots. The greater percentage of ^{14}C -assimilate partitioned to the sheath, especially in the WP treatment agrees with Dewey and Appleby (1983) who found that more ^{14}C -assimilate than ^{14}C -glyphosate was partitioned to the stem of tall morning glory (*Ipomoea purpurea*). The increased partitioning of ^{14}C -glyphosate to leaf 3 plus apical meristem in the current experiment may have been due to apoplastic movement of glyphosate after it transferred from the phloem to xylem. The reasons for the higher percentage of ^{14}C -assimilate partitioned to the sheath is unknown, but may be associated with deposition of high and low molecular weight compounds preferentially in the sheath bases for later remobilisation, particularly in water stressed plants (Danckwerts and Gordon 1987). Also the reduced deposition of ^{14}C -glyphosate in the sheath may have been associated with differences in effective mass transfer in the sheath phloem caused by differential lateral movement of the solutes out of the sieve tubes into storage cells.

These experiments were carried out under controlled environmental conditions, and care should be taken in extrapolating the results to the field situation. Further research is necessary to determine the requirements for rainfall or irrigation if glyphosate performance is to be effective on previously droughted plants.

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