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Factors Affecting Preemergence Bioactivity of Diclofop: Rainfall, Straw Retention, and Plant Growth Stage

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ABSTRACT

Diclofop {(±)-2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid} controls downy brome (*Bromus tectorum* L.) when mechanically incorporated after application, but preemergence surface applications result in erratic control of downy brome. To determine the physical factors that enhance diclofop bioactivity, laboratory and greenhouse studies were conducted with two soils: sand (Ustic Torripsamment) and sandy clay loam (Aridic Paleustoll). An oat (*Avena sativa*) root bioassay was used to measure bioactivity of diclofop. Movement of diclofop downward by simulated rainfall was affected by soil type and time of rainfall event. Oat root growth of seed planted 25 mm deep was reduced by >80% in the sand when 25 mm of rain was applied, but less than 30% in the sandy clay loam. Diclofop movement was reduced if the rainfall event was delayed by 4 d after application to the sand soil, indicating the need for precipitation within a few days after diclofop application. Surface straw interception and retention reduced diclofop activity by 20 to 30%, but simulated rainfall reduced this retention. Diclofop bioactivity was greatest when applied before oat seed germination. Diclofop applied to the soil surface after oat seedlings had emerged reduced plant growth 20 to 30%, while diclofop applied before oat germination reduced plant growth 75 to 85%. Preemergence surface applications of diclofop to the sand soil would be suitable for irrigated wheat (*Triticum aestivum* L.) production on the sand, provided that diclofop was applied before weed germination and an irrigation of 25 mm occurred within 2 to 4 d after application.

Downy brome continues to be a troublesome weed in the Central Great Plains, and selective herbicide control of this weed in winter wheat is limited. Diclofop in soil controls downy brome by inhibiting root growth (9). Diclofop movement to the weed seed in the soil is achieved by two methods: mechanical or rainfall incorporation. Diclofop bioactivity has been inconsistent, however, when its distribution in the soil is dependent on rainfall incorporation (1,6,10,11). Several environmental factors may influence diclofop bioactivity when applied preemergence. Unsuitable rainfall timing and amount after application were suggested as causing the erratic performance of diclofop on downy brome in Kansas (11). Surface soil conditions at time of application also influence herbicide bioactivity. Ethofumesate [(±)-2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate] degraded more rapidly when applied to a dry soil surface as adsorption to the soil matrix was enhanced and abiotic chemical degradation increased (5). Chlorsulfuron (2-chloro-*N*-{[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)-amino]-carbonyl}benzenesulfonamide) applied to air-dried soil was less available to plants because of its adsorption to hydrophilic exchange sites on soil colloids (3).

Herbicides may also be absorbed and retained by surface plant residue, thus reducing their bioactivity. Immediately after application, 60% of atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] was intercepted by wheat stubble. The atrazine was washed off the stubble by 50 mm of rain, however (2).

No-till cultural practices in dryland winter wheat areas are increasing, resulting in a need for an effective herbicide that does not require mechanical incorporation to control downy brome. Also, with the present economic situation, producers with center-pivot irrigation systems in the Central Great Plains are growing continuous no-till wheat, a production scheme that increases the level of downy brome infestations (7,13). The objectives of this study were to examine the physical factors influencing the preemergence activity of diclofop, thus identifying the causes of diclofop inconsistent bioactivity when applied preemergence, and with this understanding, identify the winter wheat production systems in the Central Great Plains where preemergence use of diclofop can be effective for weed control.

MATERIALS AND METHODS

General Procedures

Two soils, a Platner sandy clay loam (fine, montmorillonitic, mesic Aridic Paleustolls) composed of 58% sand, 20% silt, 22% clay, and 1.5% organic matter, and a Valent sand (mixed, mesic Ustic Torripsamments) composed of 91% sand, 6% silt, 3% clay and 0.7% organic matter, were used for this study. The Platner soil is used for dryland production systems in the Central Great Plains, while the Valent soil is the predominant soil used for center-pivot irrigation production systems.

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An oat root growth bioassay was used to determine diclofop activity in soil (4). The sensitivities of oat and downy brome to diclofop in soil are similar, as the concentration of diclofop in the sand that reduced root growth 50% (LD_{50}) was 98 ng/g for oat and 148 ng/g for downy brome. Rates of diclofop examined in this study were 20 to 100 times this concentration range. The reason for using oat as the bioassay plant was that oat germination and seedling growth are uniform, characteristics not found with downy brome. Four oat seeds were planted at selected depths, with the desired soil water level maintained by covering the pots with aluminum foil to reduce evaporation. After incubation for 7 d at 18°C, oat seedlings were removed from the soil and the longest root of each oat seedling was measured to the nearest millimeter. Each treatment conducted in all studies had five replications, with a control treatment of herbicide-free soil used as a basis for determining percent growth inhibition. A randomized complete-block design was used for all studies, unless noted otherwise. Analyses of variance of the data were performed according to techniques described by Steel and Torrie (12).

Rainfall Effect on Diclofop Bioactivity Studies

The first study was conducted to measure the effect of rainfall levels on diclofop movement in both soils. Plastic pots (with drainage holes) 150 mm in diameter and 150 mm in depth were filled with 1200 g of soil. Three oat seeds were planted at three depths: 6, 13, and 25 mm. Diclofop at 1.1 and 1.6 kg/ha was applied to the surface in 60 g of treated soil (approximately 1-mm layer of treated soil) to simulate a preemergence application. Rainfall levels of 3, 6, 13, and 25 mm were then applied to the soil surface. The pots were covered with aluminum foil and incubated at 18°C to conduct the bioassay as described above.

A second study evaluated the effect of rainfall timing on diclofop movement. Utilizing the same technique as described above, with oat seed planted 6 and 13 mm deep, 13 mm of water was applied to each soil 0, 2, 4, and 6 d after herbicide application. The pots were covered with aluminum foil after each watering treatment and incubated at 18°C. The longest root of each oat seedling was measured 7 d after watering.

A third study evaluated the effect of an extended dry period immediately after application on diclofop bioavailability. One treatment consisted of establishing the soil water content for the sand at 0.18 kg/kg by applying water immediately after the diclofop application. The other treatments consisted of allowing the diclofop-treated surface soil to air dry at 18°C, then establishing the soil water content at 0.18 kg/kg for each soil 56 and 84 d after diclofop application. The oat root growth bioassay was initiated 21 d after the establishment of the soil water content, with the oat seed planted 13 mm deep. Seven days later, the oat seedlings were removed for root measurement without mixing the soil, which was replanted in future bioassays. Bioassays were repeated every 3 wk until the growth of oat roots in diclofop-treated soil did not differ from that in nontreated soil. All three studies were conducted twice for each soil.

Straw Interception Study

Diclofop at 2.3 mg/kg in 6 mL of water was applied with a pipette to wheat straw (1680 kg/ha) on the surface of the sand to determine if wheat straw adsorbed diclofop and reduced its bioactivity in the soil. In one series of pots, a simulated rainfall of 6 mm was applied one, two, or three times at weekly intervals to the treated straw. For comparison, diclofop was also applied to the soil surface. Nontreated straw was then added, and three rainfall events were applied. The straw was removed after the third rainfall application for all treatments. Oat seed was planted 13 mm deep for the bioassay, with the bioassay repeated every 3 wk until the growth of oat roots in diclofop-treated soil did not differ from that in nontreated soil. The soil water content was maintained at 0.08 kg/kg for the duration of the study after the initial bioassay.

A second series of pots received 6 mm of simulated rainfall three times over a 3-wk period. In one treatment, the diclofop-treated straw was removed before each watering, then returned to the pot. A second treatment received 3 mm of water applied to the treated straw, and 3 mm of water applied to the bare soil. A third treatment consisted of the 6 mm of water applied to the treated straw. Diclofop was also applied to the soil surface without a straw cover, but after the herbicide treatment, straw was placed on the surface and 6 mm of water was applied to the nontreated straw. After these rainfall treatments, the straw was removed and the pots were capped with aluminum foil to maintain the soil water content at 0.08 kg/kg for the duration of the study. Oat seed was planted 13 mm deep for the bioassay, which was conducted every 3 wk until growth inhibition by the treated soil was not observed. Both studies were repeated.

Oat Growth Stage Study

Diclofop was applied at 1.1 kg/ha to the sandy clay loam 0, 3, 4, 5, and 6 d after six oat seeds had been planted 13 mm deep. To simulate a surface application, diclofop was mixed with 60 g of soil, then applied to 1000 g of soil in 150-mm-diam. by 150-mm deep pots. Water was applied to germinate the oat seed in all treatments on the day of planting. After diclofop application, the pots were watered daily. Eleven days after planting, shoot height, shoot wet weight, and length of the longest root were measured for each seedling. The experiment was conducted twice in a greenhouse with an average daily temperature of 22 ± 3°C.

RESULTS AND DISCUSSION

Rainfall Effect on Diclofop Bioactivity Studies

Movement of diclofop bioactivity was influenced by seed depth, soil type, and level of rainfall. With the sand, diclofop bioactivity was not affected by rate; thus, Fig. 1 is an average of the two rates applied. Diclofop inhibited root growth of oat planted 6 mm deep by more than 90% at all rainfall levels, but diclofop bioactivity decreased when oat was planted deeper. At the 13-mm depth, at least 13 mm of rain was required before $>$80% inhibition occurred, while only 25 mm of rain moved sufficient concentrations of diclofop to reduce root growth 80% when oat was planted 25 mm deep.

A diclofop rate × seed depth × rainfall level interaction occurred with the sandy clay loam. Diclofop bioactivity at 1.1 kg/ha was minimal on oat planted at the 25-mm depth, regardless of the rainfall level applied (Fig. 2). When oat was planted 13 mm deep, diclofop inhibited root growth >80% only when 25 mm of rainfall was applied. When oat was 6 mm below the soil surface, at least 13 mm of rain was required for diclofop to inhibit root growth by more than 80%.

Increasing the rate of diclofop from 1.1 to 1.6 kg/ha increased diclofop bioactivity on oat root growth at all seed depths (Fig. 3). When oat was 6 mm deep, root growth reduction of >80% occurred when 3 mm of rain was applied, while four times that rainfall level was required for diclofop at 1.1 kg/ha to inhibit root growth >80% (Fig. 2). This trend of higher diclofop bioactivity at the 1.6 kg/ha rate with lower rainfall also occurred with oat planted at the 13- and 25-mm depths (Fig. 2 and 3). However, diclofop mobility was less in the sandy clay loam than in the sand, shown by comparing growth inhibition levels when oat was planted 25 mm deep. Thus, in the drier areas of the Central Great Plains, where the average monthly precipitation during September or October is normally less than 25 mm, preemergence bioactivity of diclofop would probably fail to adequately control deeper seeded weeds. The downward movement of diclofop by rain was related to soil type; therefore, successful preemergence applications may be restricted to coarse-textured soils. Since the sand is used predominantly for irrigated production systems, diclofop could easily be incorporated with a 25-mm irrigation event. However, the timing of the rainfall after diclofop application also influenced diclofop mobility. Delaying the rainfall for 6 d reduced diclofop bioactivity on oat root growth at depths of 13 mm in the sand from 79 to 32% (Fig. 4). This reduction in diclofop movement with delay of rainfall also occurred with the sandy clay loam. This timing of rainfall effect on leaching has also been found with picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) (8). With the sand, the irrigation event should occur within 2 to 4 d of application of diclofop to ensure adequate movement downward into the soil zone where weed seed germinates.

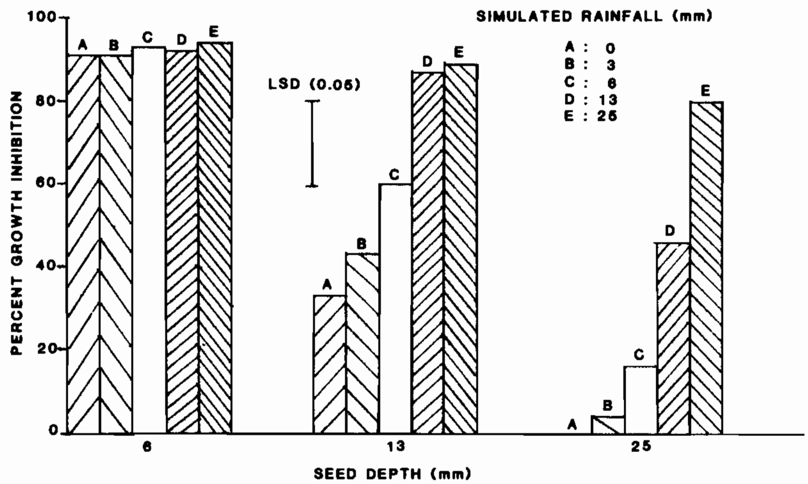

Fig. 1. Effect of simulated rainfall on the mobility of diclofop in the sand. Data are the average of both rates of diclofop, 1.1 and 1.6 kg/ha, and are expressed as percent root growth inhibition compared to the nontreated control.

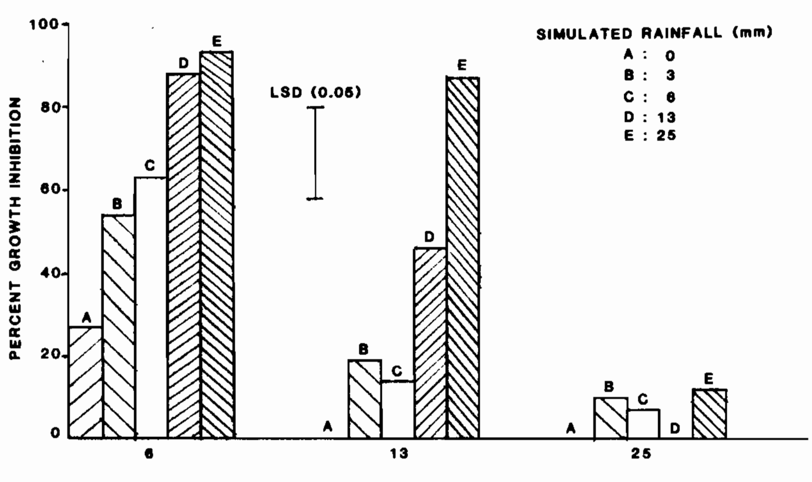

Fig. 2. Effect of simulated rainfall on the mobility of diclofop at 1.1 kg/ha in the sandy clay loam. Data are expressed as percent root growth inhibition compared to the nontreated control.

On the Central Great Plains, extended dry periods occur in the fall, conditions that may reduce a herbicide's duration of bioactivity (5). With diclofop, however, the occurrence of an extended dry period after application increased its duration of bioactivity (Table 1). A dry period of 56 d increased diclofop duration of bioactivity in the sandy clay loam to 190 d, or 127 d longer than in the same soil where water content was maintained at 0.18 kg/kg from the day of application. The same results occurred with the sand. Thus, extended dry periods after diclofop applications lengthened diclofop's persistence rather than enhanced its breakdown, as occurred with ethofumesate (5).

Straw Interception Study

Wheat residue partially retained diclofop. Applying diclofop to the residue without any simulated rainfall passing through the residue (treatment C in Fig. 5) reduced the duration of diclofop bioactivity by 30 d (26%) compared to the soil surface application (treatment D), and by 21 d (20%) compared to treatment A where three simulated rainfalls of 6 mm each were applied to the diclofop-treated residue (Fig. 5). This reduction in duration of diclofop bioactivity probably resulted from diclofop being retained on the residue and not being available in the soil for oat seedling uptake. With increased rainfall, however, the residue retained less diclofop (Fig. 6). Increasing the number of rainfall events from one to three increased the duration of diclofop bioactivity by 2 d (19%). These results indicate that wheat residue retains a limited amount of diclofop, but with succeeding rainfall events diclofop is released by the wheat residue. Similar results occurred with atrazine-treated stubble where atrazine was washed off the stubble and deposited on the soil surface by rainfall following application (2).

Oat Growth Stage Study

Delaying diclofop application after oat germination significantly reduced diclofop's effect on oat seedling growth. Applying diclofop 3 d after water imbibition by the oat seed resulted in a 19-fold increase in root

Table 1. Influence of length of dry period after diclofop application on its duration of bioactivity in two soils. Data expressed as number of days (d) required before inhibition of oat root growth was less than 20%.

Duration of dry period	Soil: Sandy clay loam	Soil: Sand
	d	
0	63	136
56	190	237
84	197	232
LSD (0.05)	10	18
CV, %	5	6

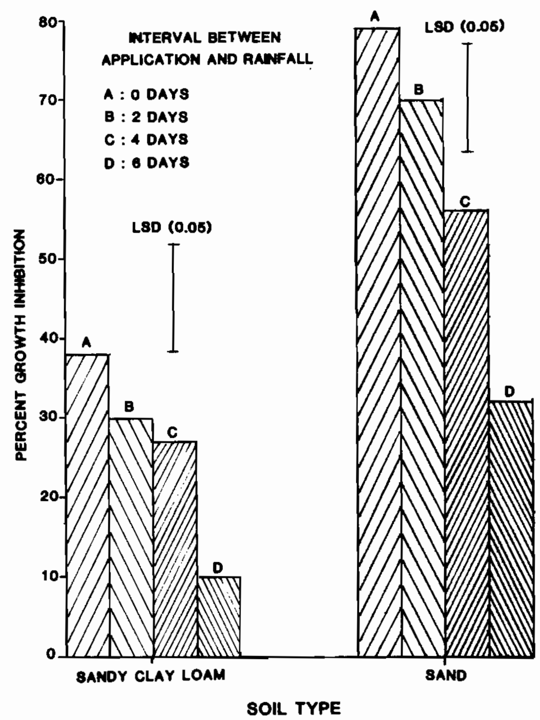

Fig. 4. Effect of time interval between application of diclofop at 1.1 kg/ha and 13 mm of rainfall on bioactivity of diclofop on oat seed planted 13 mm deep. Data are expressed as percent root growth inhibition compared to the nontreated control.

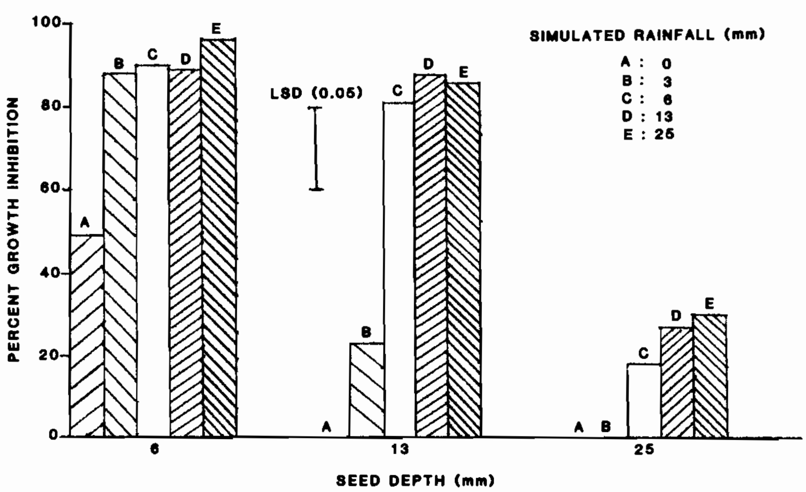

Fig. 3. Effect of simulated rainfall on the mobility of diclofop at 1.6 kg/ha in the sandy clay loam. Data are expressed as percent root growth inhibition compared to the nontreated control.

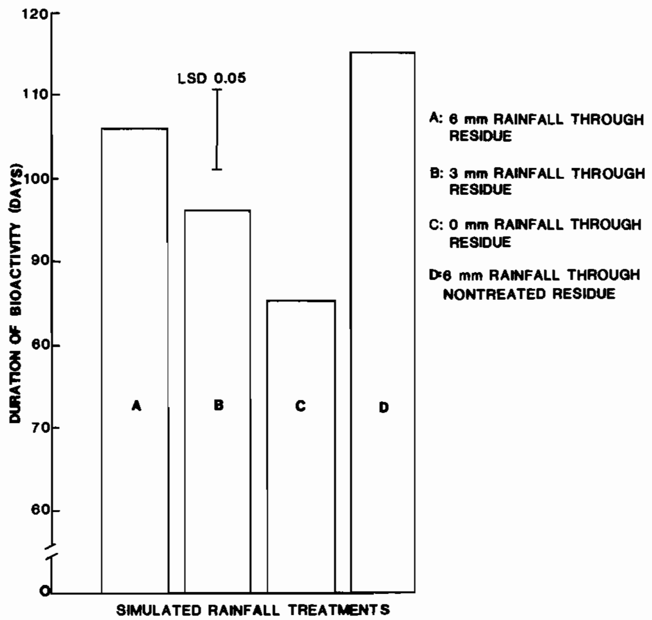

Fig. 5. Diclofop interception and retention by wheat residue. Data are expressed as number of days required before inhibition of oat root growth was less than 20%.

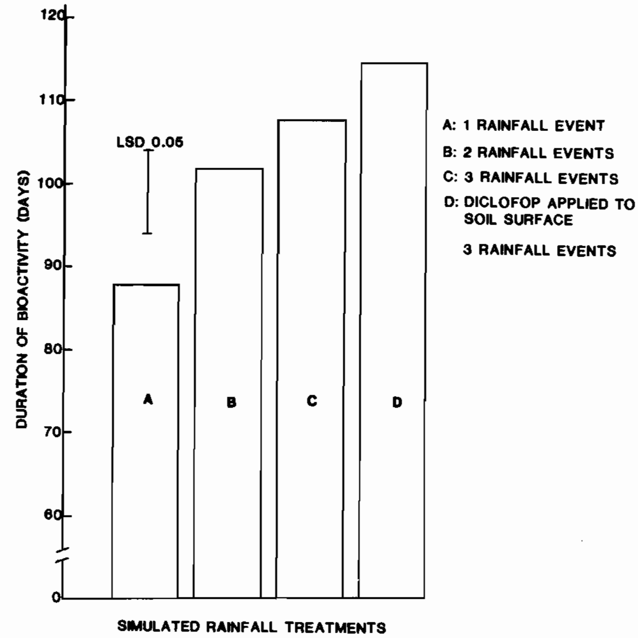

Fig. 6. Effect of rainfall events on diclofop retention by wheat residue. Data are expressed as number of days required before inhibition of oat root growth was less than 20%.

growth, a twofold increase in shoot height, and a fourfold increase in shoot weight, compared to seedling growth when diclofop was applied on the day of planting (Table 2). After the oat seedlings had emerged above the soil surface (3 d after planting), root growth inhibition by diclofop was only 9 to 20%, while shoot wet weight reductions ranged from 23 to 41%. Thus, applying diclofop before oat seed germinated was the most effective method to reduce plant growth.

Summary

Within the production systems prevalent in the Central Great Plains, opportunities for the preemergence use of diclofop appear limited to center-pivot irrigated winter wheat grown on the sand series. With this soil and with the producer's potential to irrigate following application, diclofop can be adequately distributed in the soil to enhance activity on germinating weed seed. The irrigation operation should occur within 2 d after herbicide application. The interception and retention of diclofop by wheat straw will not adversely affect diclofop bioactivity in a no-till production system. Diclofop should be applied before weed seed germinates for optimal control. Due to diclofop's immobility, usage on a sandy clay loam will be limited to production systems where mechanical incorporation will enable adequate mixing of diclofop within the upper 30 mm of soil, precluding its use in no-till production systems.

Table 2. Effect of oat growth stage on diclofop activity. Study was conducted with the sandy clay loam soil in a greenhouse with an average daily temperature of 22 ± 3°C.

		11 d after planting		
Herbicide application	Plant height at application	Root growth	Shoot height	Shoot weight
Days after planting		mm		g
Control	--	143.4	134.9	0.47
0	--	6.3	34.3	0.07
3	Emerging	114.2	80.0	0.27
4	25–35	124.6	88.5	0.31
5	64–68	129.9	108.3	0.33
6	80–85	123.2	110.6	0.36
LSD (0.05)		13.7	10.5	0.06
CV, %		14	13	20

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