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Response of Rotational Crops to BAY MKH 6561[1]

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Abstract: BAY MKH 6561, a sulfonylaminocarbonyl-triazolinone herbicide for postemergence control of annual grasses and selected broadleaf weeds in wheat, was evaluated for weed control and rotational crop (barley, pea, lentil, and mustard) injury in the Pacific Northwest. BAY MKH 6561 was applied postemergence in winter wheat at 22, 45, and 90 g ai/ha during fall 1997 and spring 1998 near Moscow, ID, Pendleton, OR, and Wilcox, WA, to determine its effect on barley, pea, lentil, and mustard planted during spring 1999. At Pendleton, BAY MKH 6561 reduced barley height 6% and grain yield 11%, when applied in the spring at 90 g/ha, and visibly injured mustard 4 to 19% when applied at 45 or 90 g/ha. All BAY MKH 6561 treatments reduced mustard seed yield 47 to 54% at Moscow and 38 to 48% at Wilcox. Pea and lentil seed yields were not affected by herbicide treatments at all locations, whereas barley was not affected at Moscow and Wilcox. In growth chamber soil bioassay experiments, fall-applied BAY MKH 6561 dissipated 10 to 48% faster at Moscow compared to Pendleton, and the predicted half-life ranged from about 68 (Moscow) to 79 d (Pendleton). Dissipation of spring-applied BAY MKH 6561 at 45 and 90 g/ha was 17 to 21% slower at Moscow than Wilcox, and the predicted half-life ranged from 60 (Wilcox) to 69 d (Moscow).
Nomenclature: BAY MKH 6561, methyl 2-({[(4-methyl-5-oxo-3-propoxy-4,5-dihydro-1*H*-1,2,4-triazol-1- l)carbonyl]amino}sulfonyl)benzoate sodium salt; barley, *Hordeum vulgare* L. 'Baronesse'; lentil, *Lens culinaris* Medic. 'Pardina'; mustard, *Sinapsis alba* L. 'Tilney'; pea, *Pisum sativum* L. 'Columbia'; winter wheat, *Triticum aestivum* L. 'Cashup', 'Madsen', 'Stephens'.
Additional index words: Corn root bioassay, dissipation, MON 37500, pH, precipitation, soil temperature, soil residues, yield.
Abbreviations: DAT, days after treatment; OM, organic matter; PNW, Pacific Northwest; POST, postemergence; PPI, preplant incorporated.

INTRODUCTION

In the Pacific Northwest (PNW), winter wheat (*Triticum aestivum*) often is grown in rotation with barley (*Hordeum vulgare*), pea (*Pisum sativum*), lentil (*Lens culinaris*), mustard (*Sinapsis alba*), and other crops planted in spring. Crop rotations can increase wheat grain yield by reducing weed, insect, disease, and nutrient problems associated with monoculture wheat cropping systems (Barberi et al. 1997; Cook and Veseth 1991). In 1998, Idaho produced 1.7, Oregon 1.5, and Washington 3.7 million metric tons of winter wheat, accounting for approximately 13% of the total United States winter wheat production (National Agricultural Statistical Services 1998).

Producing a profitable winter wheat crop depends, in part, on effectively controlling weeds that can reduce wheat yield and quality by competing for water, light, and nutrients. The predominant annual grass weeds infesting many winter wheat fields in the PNW are downy brome (*Bromus tectorum* L. #[3] BROTE), wild oat (*Avena fatua* L. # AVEFA), feral rye (*Secale cereale* L.), and jointed goatgrass (*Aegilops cylindrica* L.) (Rydrych and Muzik 1968). When possible, wheat growers usually rely on selective postemergence (POST) herbicides to control weed infestations (Appleby and Morrow 1990). However, some herbicides used to control weeds in wheat can persist in the soil for longer than one growing season, injuring subsequently planted rotational crops (Shinn et al. 1998; Wiese et al. 1988). The amount of bioavailable herbicide and degree of crop injury can vary considerably between locations and/or years (Vencill and Banks 1994). Factors such as precipitation, soil

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds,* Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

Table 1. Soil used in BAY MKH 6561 field and bioassay studies.

Location	Series	Texture	Classification	pH	OM[a]	Sand	Silt	Clay
Moscow, ID	Palouse-Latahco	Silt loam	Argiaquic Xeric Argialbolls	5.4	3.2	26	58	16
Pendleton, OR	Walla Walla	Silt loam	Typic Haploxerolls	5.7	2.3	28	60	12
Wilcox, WA	Snow	Silt loam	Cumulic Haploxerolls	5.6	4.7	32	60	8

[a] OM, organic matter content.

pH, soil organic matter (OM) content, microbial activity, and herbicide chemistry can affect herbicide dissipation (Brown et al. 1987, McDowell et al. 1997). In addition, sensitivity to herbicide residues often varies among rotational crops and can affect the level of injury in the field (Moyer 1995). Chlorsulfuron applied to an acidic soil (pH 5.8) in the Willamette Valley of western Oregon persisted about 26 mo (Brewster and Appleby 1983) but persisted more than 4 yr in the alkaline soils (pH 7.0 to 8.5) of southern Alberta, Canada (Moyer et al. 1990). MON 37500 [1-(2-ethylsulfonylimidazol[1,2-a]pyridin-3-ylsulfonyl)-3-(4,6-dimethoxypyrimidin-2-yl)urea] applied in wheat to a Walla Walla silt loam (pH 6.1, organic matter 2.1 %) near Pendleton, OR, reduced seed yield of subsequently planted barley, canola (*Brassica ripa* L.), and pea 13 to 73% but did not injure lentil. The same herbicide applications to a Westlake-Latahco silt loam (pH 5.4, organic matter 2.6%) near Moscow, ID, did not affect growth and seed yield of the same four crops (Shinn et al. 1998).

BAY MKH 6561 (proposed, procarbazone-sodium) is a new sulfonylaminocarbonyl-triazolinone herbicide for POST control of annual grasses and selected broadleaf weeds in wheat. This herbicide inhibits acetolactate synthase (also known as acetohydroxy acid synthase, EC 4.1.3.18) (Feucht et al. 1999). Anticipated use rates of 30 to 45 g/ha applied in fall or spring effectively controlled most annual *Bromus* species and several Brassicaceae weed species (Scoggan et al. 1999). BAY MKH 6561 injured sweet corn (*Zea mays* L.) seedlings 16 mo after application under irrigated conditions in western Oregon (soil pH 6.1) and reduced biomass and seed yield of oat (*Avena sativa* L.) planted 13 mo after application under dryland conditions in eastern Oregon (soil pH 5.7) (Al-Sayagh 1998).

Structurally, sulfonylaminocarbonyl-triazolinone herbicides are similar to the sulfonylurea herbicides in that both classes of herbicides consist of a sulfonamide bridge, an aryl group, and a nitrogen-containing heterocycle. However, the sulfonamide bridge of BAY MKH 6561 is not fully saturated, causing the central nitrogen in the bridge to have a negative charge (pKa = 2.1). Consequently, the half-life of BAY MKH 6561 via chemical hydrolysis is consistent between pH 4 and 9. Laboratory tests estimated the half-life of BAY MKH 6561 to be $>$ 111 d via chemical hydrolysis (unpublished data).[4] However, in field tests in northern Europe the half-life of BAY MKH 6561 averaged 9 d (Feucht et al. 1999), indicating that microbial degradation may play a large role in its dissipation. Sulfonylurea herbicides persist less under conditions of low soil pH, high soil OM content, moderate to high precipitation, and warm temperatures, which promote both chemical and microbial degradation (Frederickson and Shea 1986; Joshi et al. 1985).

Little is known about the dissipation of BAY MKH 6561 in the soil, which could influence when and how often the herbicide is used to control weeds in wheat. The purpose of this study was to determine the effect of BAY MKH 6561 rate and application timing on weed control and rotational crop injury at three locations in the PNW. Additionally, a growth chamber soil bioassay was performed to quantify the dissipation rate of BAY MKH 6561 at each location.

MATERIALS AND METHODS

Rotational Crop Studies. Field studies were established in November 1997 at the University of Idaho Parker Research Farm near Moscow, ID, the Oregon State University Columbia Basin Agricultural Research Center near Pendleton, OR, and in a producer's field 26 km west of Pullman, WA, near Wilcox, WA. Soils are described in Table 1. Madsen soft white winter wheat was seeded at 112 kg/ha on October 1, 1997, at Moscow, and Cashup soft white winter wheat was seeded at 101 kg/ha on September 27, 1997, at Wilcox using a double-disk grain drill with 18-cm row spacing. A 1:1 mixture of Madsen and Stephens soft white winter wheat was seeded at 95 kg/ha using a no-till double-disk grain drill with 25-cm row spacing on October 14, 1997, at Pendleton.

The experimental design at each site was a randomized complete block with a split plot treatment arrangement and four replications. Main plot treatments (her-

[4] BAY MKH 6561 Technical Data Bulletin. pp. 1–5. Revised October 5, 1999.

Table 2. Mustard (*Sinapsis alba*) injury and yield at Moscow, ID, and Wilcox, WA, and mustard injury and barley injury and yield at Pendleton, OR.[a]

Treatment	Rate	Timing	Mustard injury			Barley stunting	Yield		
			Moscow 7/8/1999	Wilcox 7/8/1999	Pendleton 6/24/1999	Pendleton 6/24/1999	Moscow mustard	Pendleton barley	Wilcox mustard
	g/ha		%				kg/ha		
BAY MKH 6561	22	Fall 1997	0	0	0	0	921	3,740	898
BAY MKH 6561	45	Fall 1997	4	4	3	0	849	3,932	949
BAY MKH 6561	90	Fall 1997	14	11	15	0	552	3,735	631
MON 37500	35	Fall 1997	8	9	11	0	711	3,569	725
BAY MKH 6561	22	Spring 1998	1	0	0	0	1,030	4,066	807
BAY MKH 6561	45	Spring 1998	5	8	6	3	824	3,794	874
BAY MKH 6561	90	Spring 1998	19	14	19	6	485	3,500	532
MON 37500	35	Spring 1998	0	0	0	0	889	3,749	960
Untreated control	—	—	0	0	0	0	1,037	3,930	1,014
LSD (0.05)			4	3	5	2	293	322	308
Orthogonal contrasts of fall-applied vs. spring-applied BAY MKH 6561 effect								P value	
Mustard injury at Moscow, ID								0.0289	
Mustard injury at Pendleton, OR								0.0939	
Barley injury at Pendleton, OR								< 0.0001	
Mustard injury at Wilcox, WA								0.0114	
Mustard yield at Moscow, ID								0.1855	
Barley yield at Pendleton, OR								0.9748	
Mustard yield at Wilcox, WA								0.4213	

[a] Evaluation dates correspond to 611, 617, and 595 d after treatment for fall applications and 456, 491, and 462 d after treatment for spring applications at Moscow, ID, Wilcox, WA, and Pendleton, OR, respectively.

bicide treatments) are shown in Table 2, and split plots were rotational crops. Main plots at Moscow and Wilcox were 6.1 by 19.5 m and at Pendleton were 4.6 by 12.2 m. BAY MKH 6561 plus a nonionic surfactant[5] at 0.25% (v/v) was applied to main plots at 22, 45 (proposed use rate), and 90 g/ha on November 4, 1997, or March 31, 1998, at Moscow; October 28, 1997, or February 24, 1998, at Wilcox; and November 6, 1997, or March 11, 1998, at Pendleton. MON 37500, a sulfonylurea herbicide used to control annual *Bromus* species in wheat, was applied at 35 g ai/ha with a nonionic surfactant[5] at 0.25% (v/v) at Moscow and Wilcox and 0.5% at Pendleton in both fall and spring. All fall applications were made when the wheat had one to two leaves, and spring applications were made when the wheat had five to six leaves and two to three tillers. An untreated control was included in each experiment. At Moscow and Wilcox, treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 94 L/ha at 275 kPa, and at Pendleton, treatments were applied with a small-plot tractor sprayer delivering 109 L/ha at 206 kPa.

Crop injury was evaluated visually in all treatments 11 and 22 d after spring treatments were applied on a scale of 0 (no injury) to 100% (dead). Weed control was evaluated visually at Moscow on June 6, 1998, and at Wilcox on July 13, 1998, on a scale of 0 (no control) to 100% (complete control). Few weeds infested the Pendleton site, and weed control was not evaluated. Aboveground crop biomass samples were collected from two 0.25-m^2 areas randomly located within each plot on June 3 at Pendleton, June 10 at Wilcox, and June 17, 1998, at Moscow when the winter wheat was fully headed. Wheat plants were counted, cut at the soil surface, placed in paper bags, dried at 60 C for 72 h, and weighed. Wheat was harvested from an area 1.2 by 18.6 m in each plot at Wilcox and Moscow on August 6 and 14, and from an area 1.5 by 12.2 m at Pendleton on July 21, 1998, using a small-plot combine. Wheat grain was cleaned using a small commercial seed cleaner then weighed, and test weights (grain weight per unit volume) were determined.

During fall 1998, plots at Pendleton were chisel plowed 15 cm deep, plots at Wilcox were burned to remove the wheat residue and plowed with an offset disk 12 cm deep, and plots at Moscow were moldboard plowed 20 cm deep. Primary tillage practices used in the study were common to the growing area and were influenced by the amount of wheat stubble remaining after harvest. Fertilizer was applied during the spring at Moscow and Wilcox and incorporated with a field cultivator prior to seeding. Plots at Pendleton were shallow tilled with a field cultivator prior to seeding, and fertilizer was applied at seeding using a no-till drill. Fertilizer rates were based on soil tests, specific crop, and local recommendations. Trifluralin was applied preplant incorporated (PPI) at 560 g ai/ha and incorporated 5 cm deep

[5] R-11 (alkylarylpolyethoxylate and compound silicones), Wilfarm, L.L.C., 1952 West Market Street, Nappanee, IN 46550.

with two passes with a field cultivator on April 26 at Wilcox and May 12, 1999, at Moscow to control weeds in mustard. A mixture of imazethapyr at 53 g ai/ha plus triallate at 1.4 kg ai/ha was applied PPI and incorporated 5 cm deep to control weeds in pea and lentil at Wilcox and Moscow. All PPI treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 95 L/ha at 220 kPa. Baronesse barley at 112 kg/ha, Tilney mustard at 11.2 kg/ha, Pardina lentil at 50 kg/ha, and Columbia pea at 112 kg/ha (224 kg/ha at Pendleton) were seeded at Pendleton on March 23, at Wilcox on April 27, and at Moscow on May 13, 1999. Crucifer flea beetles [*Phyllotreta cruciferae* (Goeze)] destroyed the mustard stand at Pendleton and plots were reseeded on May 4, 1999. Crops were seeded at Pendleton using a no-till double-disk drill with rows spaced 25 cm and at Wilcox and Moscow using a conventional double-disk drill with rows spaced 18 cm. Split plots were 6.1 by 4.9 m at Moscow and Wilcox and 41.4 by 3.0 m at Pendleton.

At Moscow, broadleaf weeds in barley were controlled with bromoxynil at 280 g ai/ha plus MCPA amine at 280 g ai/ha applied POST on June 7, 1999. Weeds in mustard were controlled with 210 g ai/ha clopyralid applied POST on June 17, 1999. At Wilcox, all POST weed control treatments were applied on June 11, 1999. Mustard was treated with quizalofop-P at 70 g ai/ha plus clopyralid at 210 g/ha. Barley was treated with bromoxynil at 280 g/ha plus MCPA amine at 280 g/ha. Pea and lentil were treated with quizalofop-P at 61 g/ha.

Plants were counted for each crop from two 0.25-m^2 areas randomly located within each subplot on June 8 at Pendleton and Wilcox and on June 20, 1999, at Moscow. Injury to rotational crops was evaluated visually on a scale of 0 (no injury) to 100% (dead) at Pendleton on June 24 and July 28, at Wilcox on July 8 and July 28, and at Moscow on July 8 and August 9, 1999. Aboveground crop biomass was collected at Pendleton on June 24, at Wilcox on July 2, and at Moscow on July 6, 1999, when the barley was fully headed and the pea, lentil, and mustard were beginning seed pod set. Pea, lentil, and barley were collected from one 0.25-m^2 area, and mustard was collected from one 0.5-m^2 area randomly located within each subplot, counted, placed in paper bags, dried at 60 C for 72 h, and weighed.

Barley, pea, lentil, and mustard were harvested August 16, 1999, at Wilcox from an area 1.3 by 5.5 m using a small-plot combine. At Pendleton, pea was harvested July 13, barley July 22, lentil July 26, and mustard August 16, 1999, from an area 1.5 by 4.0 m. At Moscow, barley and lentil were harvested on August 19, pea on August 25, and mustard on September 7, 1999, from an area 1.3 by 5.5 m. Harvested seeds were weighed and barley test weight was determined.

Data were analyzed by ANOVA. Weed control; winter wheat plant density, biomass, and yield; visible injury; and wheat and barley test weights were separated using Fisher's protected LSD test, and orthogonal contrasts were conducted to make comparisons between fall and spring application timings. Rotational crop plant density, crop biomass, and seed yields were analyzed using a square root transformation of percentage of untreated control and were separated using Fisher's protected LSD test. In data sets with a significant herbicide treatment by crop interaction, observed data were analyzed for individual crops and separated using Fisher's protected LSD test, and orthogonal contrasts were conducted to compare fall- and spring-applied BAY MKH 6561 treatments. All computations were carried out using SAS v.6.12 (SAS 1991).

Corn Root Bioassay. The dissipation of BAY MKH 6561 at the three field sites was estimated using a corn root bioassay (Sunderland et al. 1991). Standard dose–response curves relating corn root growth to concentration of BAY MKH 6561 in soil from each field test site were developed with the following methods. About 20 kg of soil were collected from an untreated area at each field location prior to fall 1997 herbicide applications. The soil was sifted through a 5-mm sieve, air dried for 72 h, sifted through a 2-mm sieve, placed in plastic bags, and frozen. Stock herbicide suspensions were prepared by mixing 0.0565 g (product) of BAY MKH 6561 into 1,000 ml of distilled water. The appropriate volume of the stock solution was pipetted into 10 ml of distilled water and applied with an atomizer to 500 g of air-dried soil in a 33- by 40-cm plastic bag to achieve final herbicide concentrations of 0, 0.5, 1, 2, 4, 8, 16, and 32 ng ai/g. The estimated concentration of BAY MKH 6561 in the top 20 cm of soil (approximated to weigh 2.86 million kg/ha) immediately after herbicide application was 8, 16, and 32 ng/g for the 22, 45, and 90 g/ha rates, respectively. Treated soil was mixed by shaking the soil in the bag for 2 min and was air-dried for 12 h.

A 2.5-cm-wide by 14-cm-long double-layer strip of paper towel wick was placed along the bottom of a plastic 10-cm-diam by 15-mm-deep petri dish, so that 4 cm of wick protruded over the edge. Four petri dishes were filled with 100 g each of treated air-dried soil and tamped gently to ensure uniform wetting. A petri dish lid was placed next to a soil-filled dish and filled with 60 ml distilled water. The paper towel wick was placed in the water to begin wetting. The paper towel wick was removed from the water and cut near the edge of the petri dish after the wetting front had moved approximately 9 cm across the soil surface. The soil was allowed to equilibrate for 1 h. A thin line was drawn across the soil surface 2.5 cm from the edge on the wetting front side of the petri dish. Four uniformly germinated 'Jubilee' sweet corn seeds (germinated in the dark for 36 h at 28 C) were placed on the soil surface near the edge of the petri dish so that the tip of the radical touched the line on the soil. The lid was placed on the dish and secured with a strip of clear tape, precisely marking the location of the line on the soil surface. The dishes were placed in a growth chamber for 24 h at 30 C at a 45° angle so that the roots would grow downward along the soil–lid interface. After 24 h, the length of the three longest roots was measured beginning at the line on the soil surface. Standard curve experiments for each soil type were repeated a minimum of three times. The response of root length to BAY MKH 6561 concentration was calculated as a fraction of the untreated control treatment and fitted to the standard curve model

$$Y = B_0 - B_1(\ln(\text{Dose} + 1)), \qquad [1]$$

where Y is root length as a fraction of the untreated control, B_0 is the response at Dose = 0 (mean of 24 observations), B_1 is the rate of response as Dose increases, and Dose is the herbicide concentration (ng/g). The equation is an exponentially decreasing curve, where percent root length decreases as dose increases.

Immediately prior to fall and spring herbicide applications at all locations, soil was collected from the untreated check plots and from each plot receiving a BAY MKH 6561 application at that timing. Soil samples were collected from fall-treated plots at 0+ (2 h after application), 30, 90, 150, 210, 330, and 480 d after treatment (DAT). For spring herbicide applications, soil samples were collected at 0+, 11, 22, 45, 90, 135, 180, and 360 DAT. At each sampling time, three 8.3-cm-diam by 20-cm-deep soil cores were collected from each plot using an aluminum soil auger. Soil cores from each plot were placed into a plastic bag 33 by 40 cm and frozen at −24 C until processing. Samples were later thawed at room temperature for 1 h, sifted through a 5-mm sieve, air dried for 72 h, and sifted through a 2-mm sieve, and a 1,000-g subsample was placed into a plastic bag 18 by 20 cm and frozen. After the final sampling date, all samples from one location were removed from the freezer and tested once using the bioassay procedure previously discussed. Standard curve and field sample experiments were run simultaneously to minimize variability. The standard curves were used to estimate BAY MKH 6561 concentration in the field soil. Following standard curve conversion, the estimated dose data were fitted to the regression model

$$\ln(Y + 0.01) = B_0 - B_1 \times \text{DAT}, \qquad [2]$$

where DAT is days after treatment, Y is herbicide concentration level as a fraction of the initial estimated level at 0 + DAT, B_0 is the fraction of initial predicted dose at 0 + DAT, and B_1 is the rate of decrease in dose over time. This is a first-order degradation model (Hamaker 1972; Zimdahl et al. 1994).

Models were developed using linear regression, and comparisons between model slopes (B_1) were made using dummy variable regression techniques. All models were subjected to residual analysis to assess fits and did not reveal any gross violations of the assumptions underlying normal linear regression. Computations were carried out using SAS v.6.12 (SAS 1991). BAY MKH 6561 half-lives for all rates and locations were estimated using the appropriate dissipation model.

RESULTS AND DISCUSSION

Field Studies. *Wheat response and weed control.* At all locations, no herbicide treatment visibly injured wheat (data not shown). Also, winter wheat plant density, biomass, and grain yield were not different among treatments at the three locations, except at Moscow, where grain yield was 11% less when BAY MKH 6561 was applied in the spring at 90 g/ha compared to both MON 37500 treatments (data not shown). Average wheat yield was 6,710, 6,980, and 5,030 kg/ha at Moscow, Pendleton, and Wilcox, respectively. On average, BAY MKH 6561 applied fall or spring controlled mayweed chamomile (*Anthemis cotula* L.) 55 and 68% at Moscow and Wilcox (data not shown).

Rotational crop response. Pea and lentil were not visibly injured by herbicide residues in any study. At Pendleton on June 24, spring-applied BAY MKH 6561 at 90 g/ha reduced barley height approximately 6% (Table 2). Injury was not visible on July 28, 1999. Barley was not visibly injured at Moscow and Wilcox. Mustard was visibly injured (stunting, terminal bud necrosis, and excessive branching) 4 to 19% by BAY MKH 6561 applied at 45 and 90 g/ha in fall or spring and 8 to 11% by fall-applied MON 37500 when initially evaluated at all locations. Injury was usually most severe with spring-applied BAY MKH 6561 compared to fall-applied BAY MKH6561 (Table 2). A later evaluation showed similar injury, along with delayed flowering (data not shown).

Rotational crop density and crop biomass were not affected by herbicide treatment or crop (P = 0.73 and P = 0.81, respectively) at all three locations (data not shown). Analysis of rotational crop relative seed yield data (percentage of untreated control) showed a significant herbicide treatment by crop interaction at all three locations (data not shown). Therefore, actual yield data for each crop were analyzed separately. Rotational barley, pea, and lentil seed yields were not affected ($P \geq 0.43$) by herbicide treatments at Moscow and Wilcox (data not shown).

At Moscow, mustard seed yield was reduced 47% by fall-applied BAY MKH 6561 at 90 g/ha, 54% by spring BAY MKH 6561 at 90 g/ha, and 32% by fall-applied MON 37500 (Table 2). Fall- and spring-applied BAY MKH 6561 at 90 g/ha reduced mustard seed yield at Wilcox 38 and 48%.

At Pendleton, pea, lentil, and mustard seed yields in herbicide-treated plots were not different from the untreated control (data not shown). However, mustard seed yield was poor (flea beetle damage and reseeding) and did not accurately reflect observed injury (Table 2). Barley seed yield was reduced 10% by fall-applied MON 37500 at 35 g/ha and 11% by spring-applied BAY MKH 6561 at 90 g/ha. Overall, fall- and spring-applied BAY MKH 6561 affected mustard or barley yields similarly (Table 2).

Mustard was the crop most sensitive to BAY MKH 6561 and injury was similar at Moscow and Wilcox. Mustard biomass and yield data at Pendleton were highly variable because of the poor, uneven stand. However, visual injury to mustard was similar to the injury observed at the other sites. Mustard visual injury usually was greatest with BAY MKH 6561 applied at 90 g/ha (twice the proposed use rate), with spring applications causing slightly more injury than fall applications. The shorter time period between the planting date of the rotational crops and the spring 1998 vs. fall 1997 applications likely caused this difference. MON 37500 injury often was greater when applied in the fall compared to spring, which is similar to findings in another study that postulated that differences in MON 37500 dissipation rate between fall and spring applications were due to a higher percentage of wheat ground cover at the time of herbicide application in the spring (Shinn et al. 1998). More herbicide likely was intercepted by wheat leaves and metabolized with spring compared to fall application. Injury from MON 37500 generally was greater at Pendleton than at Moscow and Wilcox. Shinn et al. (1998) reported similar findings. Differences were attributed to less precipitation, lower soil OM content, and possibly higher soil pH at Pendleton compared to Moscow. These differences also existed in the current study (Table 1; Figure 1). Sulfonylurea herbicides dissipate fastest under warm, moist, acid soil conditions and slowest in cold, dry, alkaline soils (Beckie and McKercher 1990; Hurle and Walker 1980; Nord-Christerson and Bergstrom 1989).

Injury of rotational crops by BAY MKH 6561 was similar at all three locations, but was different between locations for MON 37500. This indicates that dissipation of BAY MKH 6561, a sulfonylaminocarbonyl-triazolinone, and MON 37500, a sulfonylurea herbicide, may be affected differently by soil characteristics and/or environmental conditions. Because BAY MKH 6561 has a negative charge on the central nitrogen and a pKa of 2.1, it exists primarily in the negatively charged form, which limits its degradation by chemical hydrolysis under the pH range of most agricultural soils. In laboratory tests, the BAY MKH 6561 half-life via chemical hydrolysis was > 111 days and was consistent between pH 4 and 9 (unpublished data),[4] unlike the sulfonylurea herbicides, where hydrolysis is faster at lower pH (Brown et al.1987; McDowell et al. 1997).

Corn Root Bioassay. Corn root growth in the standard curve experiments for fall and spring herbicide applications at each location was not different (Figure 2). Therefore, the data were combined and a single standard curve was developed for each location. The model in Equation 1 provided a good fit for corn root length data vs. herbicide dose for each soil, and R^2 values were 0.97, 0.99, and 0.99 at Moscow, Pendleton, and Wilcox, respectively. The rate of change with increasing BAY MKH 6561 dose, B_1, was 13% slower for the Wilcox soil compared to the Pendleton soil (Figure 2), and the Moscow soil was intermediate and not significantly different from the other two locations.

BAY MKH 6561 dose was estimated for each field sample using the corn root length standard curve. Equation 1 was used to convert corn root length data from field samples to an estimated dose. These data were regressed against DAT using Equation 2. Model comparisons, parameter estimates, parameter standard errors, and model R^2 values are given in Table 3. All model fits were good, and residual analysis showed no trends or exceptional points.

Dissipation of fall-applied BAY MKH 6561 at all

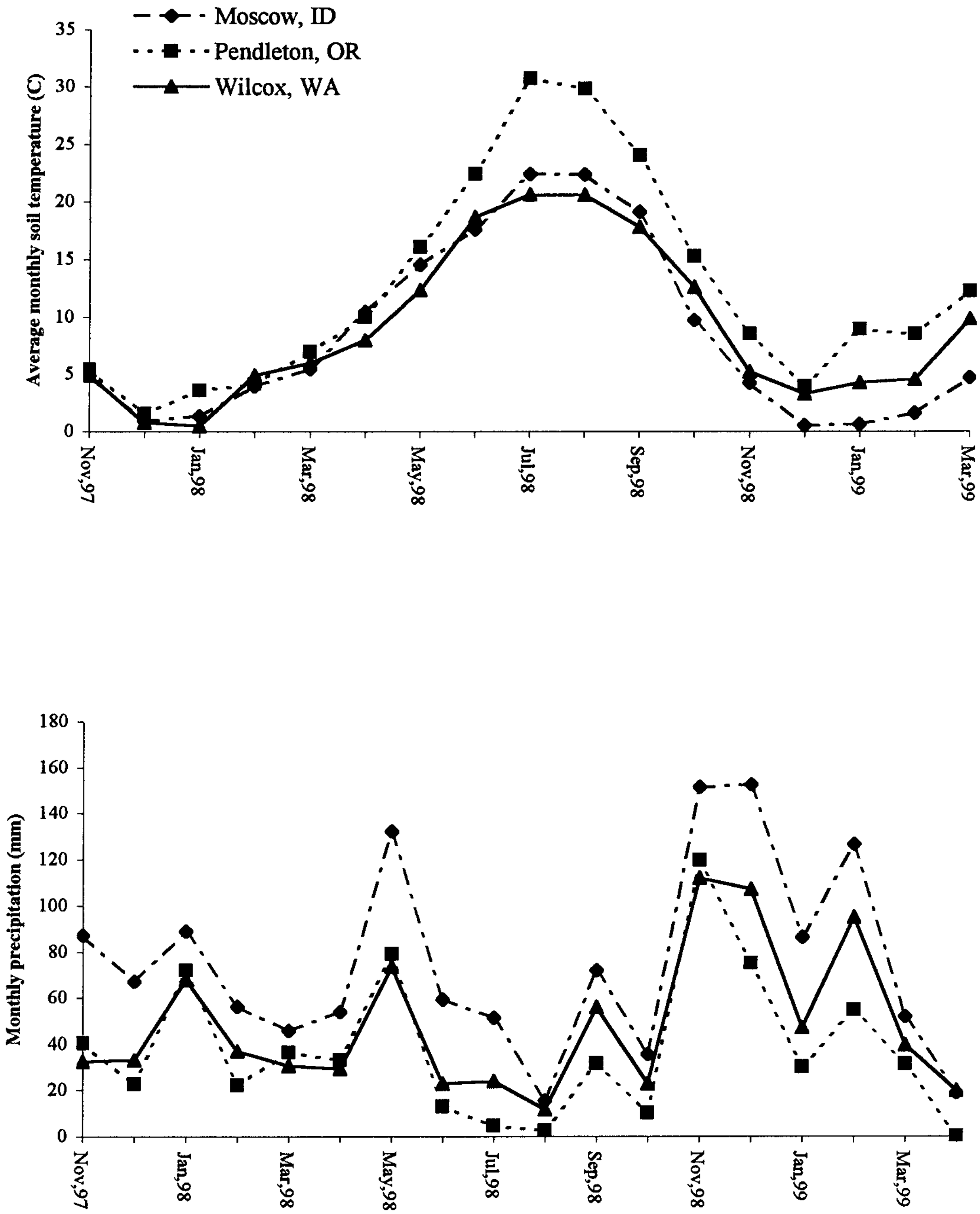

Figure 1. Average monthly soil temperature (20 cm deep) and monthly precipitation totals for November 1997 through March 1999 at Moscow, ID, Pendleton, OR, and Wilcox, WA.

three rates always was faster (10 to 48%) at Moscow than at Pendleton (Table 3; Figure 3). Dissipation at the Wilcox site was intermediate to the Moscow and Pendleton sites. Averaged over all rates, the predicted half-life ranged from about 68 (Moscow) to 79 d (Pendleton) (Figure 3). Based on model calculations, about 8 to 12% of the herbicide applied remained in the soil 240 DAT and less than 1% remained 480 DAT. Slightly faster dissipation at Moscow than Pendleton likely was due to more precipitation throughout the study period (Figure 1); higher soil OM content (Table 1), which may have facilitated faster microbial degradation (Feucht et al. 1999; Shea 1985; Voos and Groffman 1997); and perhaps more aggressive primary tillage (moldboard vs. chisel plow) (Curran et al. 1992; Shea 1985). However, soil temperatures generally were warmer at Pendleton (Figure 1), especially during the summer months when the top few centimeters of soil were dry.

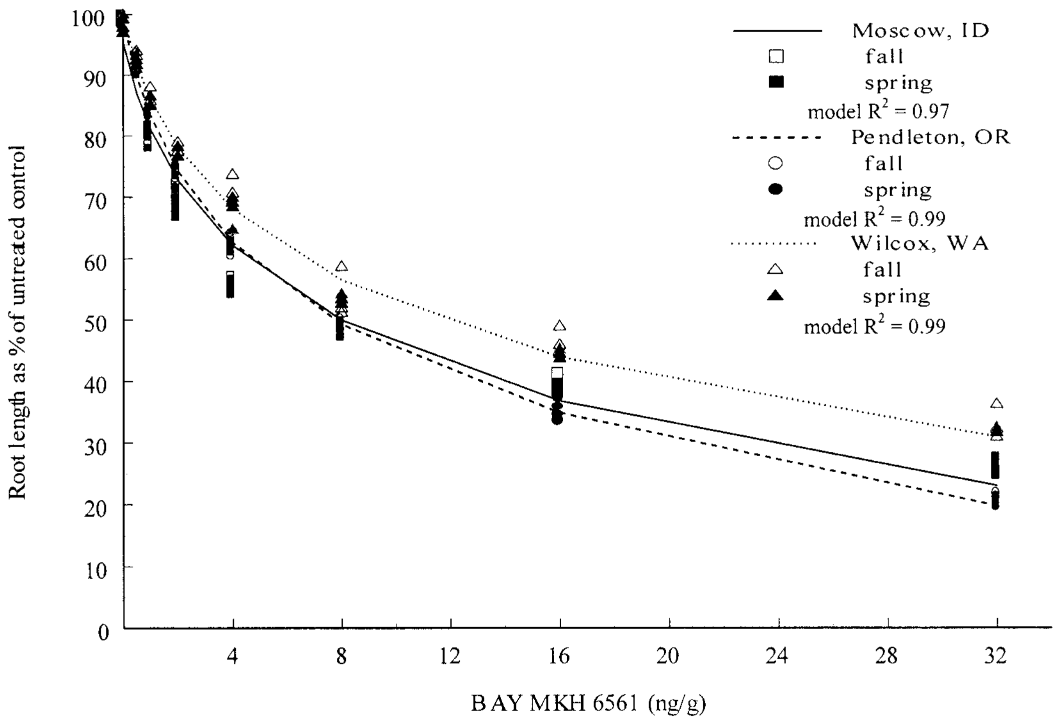

Figure 2. Corn root bioassay standard curve. The effect of MKH 6561 on corn root length in soils from Moscow, ID, Pendleton, OR, and Wilcox, WA.

Dissipation of spring-applied BAY MKH 6561 at 22 g/ha was not different among locations (Table 3; Figure 4). However, dissipation of spring-applied BAY MKH at 45 and 90 g/ha was 17 to 21% slower at Moscow than at Wilcox. The dissipation rate of BAY MKH 6561 was intermediate at Pendleton. Averaged over all rates, predicted half-life ranged from 60 (Wilcox) to 69 d (Moscow). By 180 DAT, 10 to 16% of the initial estimated herbicide concentration was present at all locations, and by 360 DAT, < 1 to 2% of the initial estimated concentration was present. The trend for slower dissipation at Moscow, compared to Pendleton and Wilcox, may be partially related to very wet to completely saturated soils at Moscow during the spring immediately following application. Precipitation levels were 12 cm above the 30-yr average at Moscow for the first 120 DAT.

Based on the predicted half-life and BAY MKH 6561 fall and spring application dates, the predicted concentration of BAY MKH 6561 was slightly higher on the rotational crop planting dates at each location for spring applications compared to fall applications. In field studies, injury also was usually greatest in plots treated with

Table 3. Parameter estimates, parameter standard errors, and model R^2 values for the exponential dose–response model fit to estimated concentration and days after treatment for each 1997 fall-applied and spring-applied BAY MKH 6561 rate at Moscow, ID, Pendleton, OR, and Wilcox, WA.[a,b]

		Fall applications			Spring applications		
		Parameter estimates			Parameter estimates		
Location	Rate	B_0	B_1	Model R^2	B_0	B_1	Model R^2
	g/ha						
Moscow	22	0.3514	−0.01465 a	0.96	−0.0211	−0.01364 a	0.93
Pendleton	22	0.0877	−0.00991 b	0.98	0.08438	−0.01253 a	0.99
Wilcox	22	−0.0272	−0.01295 a	0.99	−0.1537	−0.01267 a	0.96
Moscow	45	0.3439	−0.01014 a	0.97	−0.0249	−0.00971 a	0.98
Pendleton	45	0.1291	−0.00889 b	0.97	0.0123	−0.01004 a	0.99
Wilcox	45	0.1278	−0.00989 b	0.98	−0.0326	−0.01174 b	0.99
Moscow	90	0.134	−0.00823 a	0.97	0.0557	−0.00817 a	0.99
Pendleton	90	−0.0696	−0.00749 b	0.98	−0.0879	−0.00978 b	0.97
Wilcox	90	0.0059	−0.00802 b	0.99	0.02	−0.00958 b	0.99

[a] B_0, predicted starting dose (natural log of fraction of initially predicted concentration ± 0.01); B_1, rate of decrease in dose.
[b] The same letter within a column for each rate denotes no significant difference at $P < 0.05$.

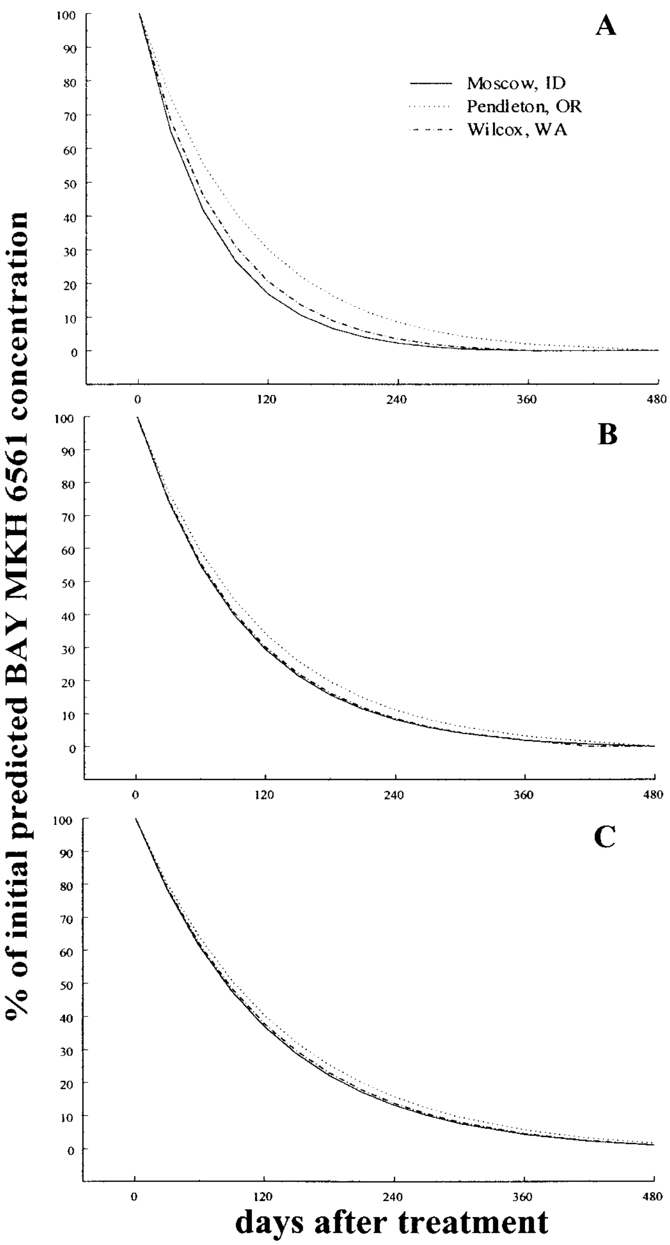

Figure 3. Estimated concentration of 1997 fall-applied BAY MKH 6561 in soil at Moscow, ID, Pendleton, OR, and Wilcox, WA, applied at 22 (A), 45 (B), and 90 g/ha (C).

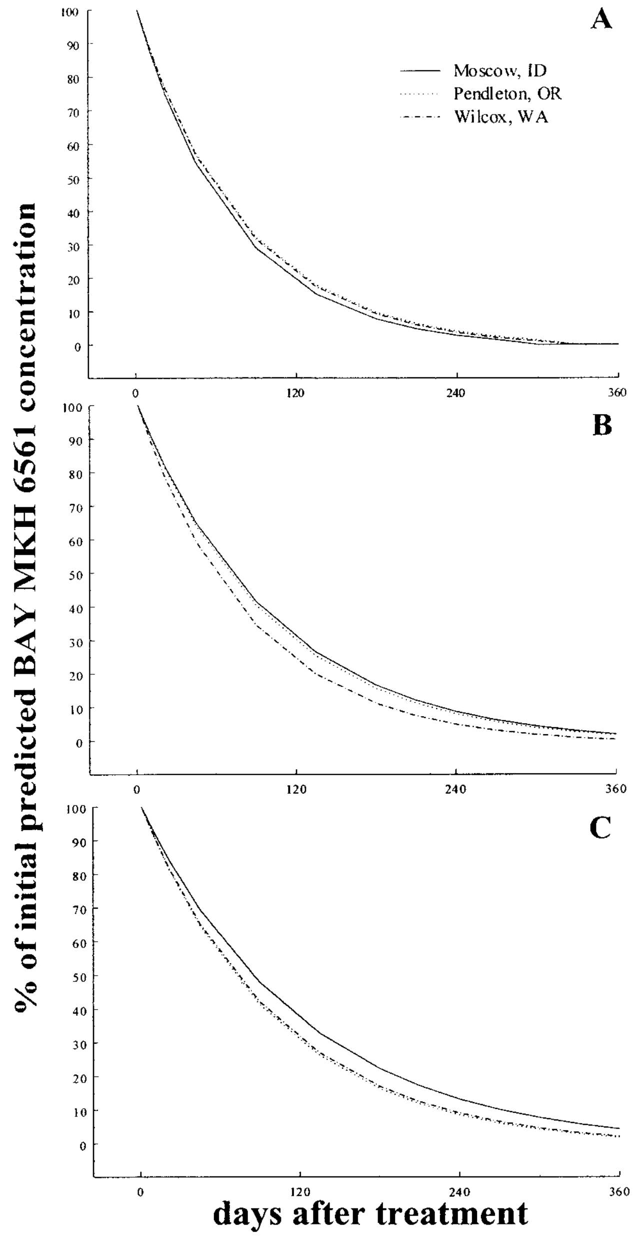

Figure 4. Estimated concentration of 1998 spring-applied BAY MKH 6561 in soil at Moscow, ID, Pendleton, OR, and Wilcox, WA, applied at 22 (A), 45 (B), and 90 g/ha (C).

BAY MKH 6561 in the spring. Microbial degradation is reported to play a large role in the dissipation of BAY MKH 6561 (H. Santel, personal communication). BAY MKH 6561 had an average half-life of 9 d in field studies in northern Europe, and herbicide persistence and injury to rotational crops was not of concern (Feucht et al. 1999). BAY MKH 6561 half-life was estimated to be approximately 100 d in preliminary soil dissipation studies in the United States (H. Santel, personal communication). Oat and sweet corn planted 13 and 16 mo, respectively, after BAY MKH 6561 applications were injured in the semiarid PNW (Al-Sayagh 1998). In the seasonally dry soils of the PNW, dissipation of BAY MKH 6561 may be slower than in European soils, consequently leading to longer half-lives and herbicide carryover into the next growing season.

Where and how often BAY MKH 6561 is used likely will depend on soil characteristics, climate, and crop rotation system. A cautious approach for the PNW would be to avoid planting mustard, barley, and other sensitive crops for at least one growing season following BAY MKH 6561 applications. Spring wheat, and possibly pea and lentil, may be planted after winter wheat treated with BAY MKH 6561.

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