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Effect of imazamox, fomesafen, and acifluorfen soil residue on rotational crops

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Field studies were conducted at Goiânia, GO, Brazil, on an Oxisol (clayey, kaolinitic, isothermic, Typic Haplustox) and at Jussara, GO, Brazil, on an Oxisol (loamy sand, kaolinitic, isothermic, Typic Haplustox) during 1995 and 1996 to determine the carryover effect of fomesafen, imazamox, and acifluorfen, applied to edible bean, on rotational crops (maize, sorghum, rice, and millet) and to estimate the level of soil residues under Brazilian Savanna conditions. Averaged across locale, year, and rate, fomesafen dissipation time (DT_{50}) (37.5 d) was longer than acifluorfen (27.5 d) and imazamox (25.9 d). For both locations, soil herbicide persistence (average of herbicides) was longer in 1995 than in 1996. This was due to higher soil moisture content in 1996. The sensitivity of rotational crops to fomesafen and imazamox residues was, in decreasing order: sorghum, corn, millet, and rice, and for acifluorfen: sorghum, corn, rice, and millet. The period between herbicide application and rotational crop planting (PAP) varied in agreement with the sensitivity of rotational crops to herbicide residues in soil and the persistence of the herbicide. Considering both location and year, the PAP for fomesafen (250 g ai ha^{-1}) ranged from 69 to 132 d for corn, 114 to 179 d for sorghum, 29 to 95 d for rice, and 52 to 111 d for millet; the PAP for imazamox (40 g ai ha^{-1}) ranged from 68 to 111 d for corn, 78 to 139 d for sorghum, 25 to 75 d for rice, and 40 to 102 d for millet; and the PAP for acifluorfen (170 g ai ha^{-1}) ranged from 56 to 89 d for corn, 96 to 139 d for sorghum, 61 to 95 d for rice, and 43 to 82 d for millet.

Nomenclature: Fomesafen; imazamox; acifluorfen; edible bean, *Phaseolus vulgaris*; corn, *Zea mays*; rice, *Oryza sativa*; millet, *Pennisetum americanus*; sorghum, *Sorghum bicolor*.

Key words: Diphenylether, imidazolinone, planting interval, herbicide carryover, herbicide persistence, half-life, soil bioassay.

The Brazilian Savanna, locally known as Cerrado, with distinct dry and wet seasons, is the region where grain production has been recently improved. It is possible to have two crops per year with irrigation. Edible bean is planted on an estimated 600,000 ha from March to July, and rice, millet, sorghum, and principally corn are planted in November (crop rotation). The herbicides fomesafen, acifluorfen, and imazamox are used to control broadleaf weeds in edible bean, but the response of rotational crops to residues of these herbicides in the soil following use in edible bean is unknown.

Fomesafen and acifluorfen are diphenylether herbicides registered for weed control in edible bean in Brazil. Fomesafen degradation under anaerobic conditions occurs in less than 3 wk, and in aerobic soil conditions, herbicide half-life ranges from 6 to 12 mo (Johnson and Talbert 1993). Oyamada and Kuwatsuka (1988), studying the degradation of the diphenylether herbicides (chlornitrofen, nitrofen, and chlonetoxynil), reported that the half-lives varied largely with soil conditions: 9 to 173 d for chlornitrofen, 3 to 87 d for nitrofen, and 8 to 64 d for chlometoxynil. The herbicides degraded rapidly under anaerobic conditions.

Weber (1993) reported that fomesafen exhibited weakly acidic properties, pK_a = 3.0. Mobility, bioavailability, and

Table 1. Selected chemical and physical characteristics of soil in Goiânia and Jussara, GO.

Location	pH	O.M.[a]	CEC[b]	Clay	Silt	Sand
		%	$Cmol_c kg^{-1}$		%	
Goiânia	5.4	2.1	7.98	43.0	21.5	35.5
Jussara	6.2	0.7	4.70	10.5	3.0	86.5

[a] Organic matter by Walkley Black method.
[b] Ca and Mg extracts in KCL 1N. Al extract in NaOH. K. P extracts in Mehlich (HCL 0.5 N + H_2SO_4 0.025 N).

Table 2. Precipitation (millimeters) during the 1995 and 1996 crop seasons in Goiânia and Jussara, GO.

Time (DAA)[a]	Goiânia 1995	Goiânia 1996	Jussara 1995	Jussara 1996
0–15	47.5	115.0	53.2	81.2
16–30	63.8	98.0	68.3	92.0
31–45	74.8	90.2	64.9	88.0
46–60	84.5	80.5	100.2	93.2
61–75	18.9	81.2	90.3	80.3
Average day^{-1}	3.86	6.19	5.02	5.79
76–90	129.4	46.4	51.2	33.0
91–105	40.1	34.8	85.0	100.2
106–120	36.0	141.5	92.1	87.0
121–135	106.8	29.2	82.3	75.2
136–150	32.5	72.9	90.7	102.0
Average day^{-1}	4.99	4.32	5.35	5.29

[a] DAA, days after herbicide application.

Table 3. Standard equations to determine concentration of herbicides in Goiânia and Jussara, GO, soils.

Herbicide	Location	Crop	Standard equations	
Imazamox	Goiânia	Sorghum	$y^{a} = 97.5 - 5.99X^{1/2\,b}$	$R^2 = 0.91$
Imazamox	Jussara	Sorghum	$y = 90.2 - 6.01X^{1/2}$	$R^2 = 0.86$
Acifluorfen	Goiânia	Sorghum	$y = 108.28 - 7.569X^{1/2}$	$R^2 = 0.84$
Acifluorfen	Jussara	Sorghum	$y = 99.5 - 6.418X^{1/2}$	$R^2 = 0.90$
Fomesafen	Goiânia	Sorghum	$y = 108.16 - 2.2X + 0.01301X^2$	$R^2 = 0.92$
Fomesafen	Jussara	Sorghum	$y = 108.6 - 2.65X + 0.017X^2$	$R^2 = 0.93$

[a] y = growth percentage of sorghum plants.
[b] X = soil herbicide concentration (ppb).

degradability of the herbicide fomesafen in soil are expected to be lower at low pH than at high or neutral pH, due to high sorption to soil colloids.

Johnson and Talbert (1993) determined carryover potential of fomesafen (0.28 kg ha^{-1}) to snap bean (*Phaseolus vulgaris* L.), watermelon (*Citrullis lunatus* L.), cucumber (*Cucumis sativus* L.), black mustard [*Brassica nigra* (L.) W.J.D. Koch], and common sunflower (*Helianthus annuus* L.). The herbicide injured all crops initially, but did not injure snap bean, sunflower, watermelon, and cucumber planted 16 wk after application.

Santos (1991) applied fomesafen to edible bean and detected potential injury of sorghum from herbicide residue for 100 d after application (DAA) of 250 g ha^{-1} and for 180 DAA of 375 g ha^{-1}. Cobucci (1996), studying the effect of fomesafen application to edible bean on rotational maize, detected fomesafen residues in soil up to 20 cm deep, but residue concentration was higher 0 to 10 cm deep. Fomesafen residues reduced leaf chlorophyll content and root volume of 10-d-old maize when planted 65 DAA, but these were not affected when maize was planted 212 DAA. The decrease in leaf chlorophyll and root volume 65 DAA did not affect maize yield.

Weissler and Poole (1982) leached fomesafen (0.3 kg ha^{-1}) in columns with 660 mm of water over 9 wk in a loam (4.2% organic matter, [O.M.]), loamy sand (2.1%

Table 4. Soil degradation equations and dissipation time (DT_{50}) for imazamox, acifluorfen, and fomesafen in Goiânia and Jussara, GO, soils during 1995 and 1996.

Herbicide	Location	Year	Rate (g ai ha^{-1})	Soil degradation equations		DT_{50} (days)	DT_{50} average[a]
Imazamox	Goiânia	95	40	$y^{b} = 64.5 - 5.47X^{1/2\,c}$	$R^2 = 0.83$	34.7	25.9
Imazamox	Goiânia	96	40	$y = 77.3 - 8.40X^{1/2}$	$R^2 = 0.96$	21.1	
Imazamox	Goiânia	96	80	$y = 125.0 - 13.5X^{1/2}$	$R^2 = 0.96$	21.4	
Imazamox	Jussara	95	40	$y = 64.5 - 6.14X^{1/2}$	$R^2 = 0.89$	27.5	
Imazamox	Jussara	96	40	$y = 66.6 - 6.87X^{1/2}$	$R^2 = 0.88$	23.4	
Imazamox	Jussara	96	80	$y = 108.7 - 10.4X^{1/2}$	$R^2 = 0.93$	27.3	
Acifluorfen	Goiânia	95	170	$y = 86.4 - 6.876X^{1/2}$	$R^2 = 0.93$	39.4	27.5
Acifluorfen	Goiânia	96	170	$y = 82.4 - 7.931X^{1/2}$	$R^2 = 0.89$	26.9	
Acifluorfen	Goiânia	96	340	$y = 110.3 - 10.56X^{1/2}$	$R^2 = 0.89$	27.2	
Acifluorfen	Jussara	95	170	$y = 117.1 - 11.22X^{1/2}$	$R^2 = 0.87$	27.2	
Acifluorfen	Jussara	96	170	$y = 100.3 - 10.64X^{1/2}$	$R^2 = 0.90$	22.2	
Acifluorfen	Jussara	96	340	$y = 135.1 - 14.2X^{1/2}$	$R^2 = 0.91$	22.6	
Fomesafen	Goiânia	95	250	$y = 74.2 - 5.16X^{1/2}$	$R^2 = 0.89$	51.6	37.8
Fomesafen	Goiânia	96	250	$y = 70.0 - 6.09X^{1/2}$	$R^2 = 0.96$	33.0	
Fomesafen	Goiânia	96	500	$y = 167.6 - 14.9X^{1/2}$	$R^2 = 0.96$	31.6	
Fomesafen	Jussara	95	250	$y = 93.3 - 0.97X + 0.0022X^2$	$R^2 = 0.99$	55.0	
Fomesafen	Jussara	96	250	$y = 90.5 - 1.87X + 0.0098X^2$	$R^2 = 0.99$	28.5	
Fomesafen	Jussara	96	500	$y = 156.1 - 3.36X + 0.0180X^2$	$R^2 = 0.99$	27.2	

	Location	Year	DT_{50} average[d]
	Goiânia	95	41.9
	Goiânia	96	26.8
	Jussara	95	36.5
	Jussara	96	25.2

[a] Averaged across locale, year, and rate.
[b] y = soil herbicide concentration (ppb).
[c] X = days after herbicide application.
[d] Averaged across herbicide and rate.

TABLE 5. Lowest concentration of herbicide in soil that does not affect growth of rotation crops (LCSH) and rotational crop planting intervals (PAP) after fomesafen application in edible bean in Goiânia and Jussara, GO, soils during 1995 and 1996.

Rotational crop	Location	Year	Rate g ai ha^{-1}	Growth equations		LCSH[a] (ppb)	PAP[b]
Corn	Goiânia	95	250	$y^c = 60.4 + 0.30X^d$	$R^2 = 0.97$	14.9	132
	Goiânia	96	250	$y = 63.8 + 0.779X - 0.00385X^2$	$R^2 = 0.95$	19.4	69
	Goiânia	96	500	$y = 40.8 + 1.13X - 0.00508X^2$	$R^2 = 0.95$	15.6	104
	Jussara	95	250	$y = 41.1 + 5.31X^{½}$	$R^2 = 0.98$	7.2	123
	Jussara	96	250	$y = 45.9 + 5.69X^{½}$	$R^2 = 0.98$	6.4	90
	Jussara	96	500	$y = 14.5 + 8.74X^{½}$	$R^2 = 0.99$	6.5	95
					Average	11.6	
Sorghum	Goiânia	95	250	$y = 10.2 + 0.53X$	$R^2 = 0.90$	< 5	179
	Goiânia	96	250	$y = 19.1 + 1.139X - 0.00391X^2$	$R^2 = 0.99$	< 5	123
	Goiânia	96	500	$y = -0.99 + 8.55X^{½}$	$R^2 = 0.87$	< 5	139
	Jussara	95	250	$y = 26.2 - 0.261X + 0.0061X^2$	$R^2 = 0.99$	< 5	179
	Jussara	96	250	$y = 26.9 + 6.56X^{½}$	$R^2 = 0.98$	< 5	114
	Jussara	96	500	$y = 10.6 + 7.49X^{½}$	$R^2 = 0.93$	< 5	142
					Average	<5.0	
Rice	Goiânia	95	250	$y = -63.2 + 3.02X - 0.012X^2$	$R^2 = 0.81$	28.3	74
	Goiânia	96	250	$y = 69.7 + 1.23X - 0.0069X^2$	$R^2 = 0.98$	37.0	29
	Goiânia	96	500	$y = 35.7 + 1.14X - 0.00409X^2$	$R^2 = 0.99$	32.6	82
	Jussara	95	250	$y = 28.1 + 0.75X$	$R^2 = 0.87$	24.3	95
	Jussara	96	250	$y = 53.7 + 1.27X - 0.0076X^2$	$R^2 = 0.99$	18.0	54
	Jussara	96	500	$y = 38.2 + 1.28X - 0.00607X^2$	$R^2 = 0.95$	6.5	76
					Average	24.4	
Millet	Goiânia	95	250	$y = 36.2 + 0.57X$	$R^2 = 0.85$	19.8	111
	Goiânia	96	250	$y = 55.7 + 1.22X - 0.00607X^2$	$R^2 = 0.89$	26.0	52
	Goiânia	96	500	$y = 16.6 + 1.01X$	$R^2 = 0.95$	32.6	82
	Jussara	95	250	$y = 49.9 + 0.40X$	$R^2 = 0.81$	14.5	108
	Jussara	96	250	$y = 54.0 + 0.622X$	$R^2 = 0.95$	5.7	74
	Jussara	96	500	$y = 29.3 + 0.58X$	$R^2 = 0.95$	13.0	121
					Average	18.6	

[a] Soil fomesafen concentration to rotational crop does not present carryover injury.
[b] Rotational crop planting intervals (days to get LCSH).
[c] y = growth percentage of rotational crop.
[d] X = days after fomesafen application.

O.M.), silty clay loam (6.0% O.M.), and a coarse sand (1.1% O.M.). In the loam, loamy sand, and silty clay, fomesafen had moderate mobility, with between 47 and 67% remaining in the top 10 cm. In the coarse sand, however, mobility was greater and only 18% remained in the top 10 cm.

Imazamox is an imidazolinone herbicide recently registered to control broadleaf weeds in edible bean in Brazil. Some imidazolinone herbicides can persist in soil and cause carryover problems to rotational crops (Barnes et al. 1989; Johnson and Talbert 1993; Krausz et al. 1994; Loux et al. 1989a; Monks and Banks 1991; Peterson and Arnold 1985; Ritter et al. 1988; Wixson and Shaw 1992). However, Silva et al. (1995) found that carryover injury to corn and sorghum from imazamox (50 and 100 g ai ha^{-1}) applied to soybean [*Glycine max* (L.) Merr.] did not occur 90 d after application. Factors such as temperature, soil texture, soil moisture, microbial activity, and pH can affect soil degradation of ALS-inhibiting herbicides (Goetz et al. 1986, 1990; Thirunarayanan et al. 1995; Wiese et al. 1988).

Little information on imazamox, fomesafen, and acifluorfen dissipation rate and carryover problems is available in Brazilian Cerrado soils. Therefore, the objective of this study was to determine the effect of fomesafen, imazamox, and acifluorfen carryover residue on rotational crops and to estimate the level of these residues under Brazilian Cerrado conditions.

Materials and Methods

Field studies were conducted at Goiânia, GO, Brazil, on an Oxisol (clayey, kaolinitic, isothermic, Typic Haplustox) and at Jussara, GO, Brazil, on an Oxisol (loamy sand, kaolinitic, isothermic, Typic Haplustox) during 1995 and 1996. The characteristics of each soil are presented in Table 1. The experimental design was a randomized block with four replicates. The treatments consisted of imazamox (40 g ha^{-1} in 1995; 40 and 80 g ha^{-1} in 1996), fomesafen (250 g ha^{-1} in 1995; 250 and 500 g ha^{-1} in 1996), and acifluorfen (170 g ha^{-1} in 1995; 170 and 340 g ha^{-1} in 1996) application to edible bean and one untreated check. Plot size for the experiment was four 50-cm rows, each 8 m long.

Soils at both locations were prepared by plowing followed by two harrowings. Cultivar 'Aporé' (200,000 plants ha^{-1}) was planted June 17, 1995, and May 31, 1996, in Goiânia and July 12, 1995, and July 15, 1996, in Jussara.

The treatments were applied July 13, 1995, and July 5, 1996, in Goiânia and August 10, 1995, and August 20, 1996, in Jussara, with a CO_2 backpack sprayer, with 200 L ha^{-1} total volume, at 275 kPa. All plots were maintained

TABLE 6. Lowest concentration of herbicide in soil that does not affect growth of rotational crops (LCSH) and rotational crop planting intervals (PAP) after imazamox application in edible bean in Goiânia and Jussara, GO, soils during 1995 and 1996.

Rotational crop	Location	Year	Rate g ai ha^{-1}	Growth equations		LCSH[a] (ppb)	PAP[b]
Corn	Goiânia	95	40	$y^{c} = 45.6 + 5.45X^{1/2}$[d]	$R^2 = 0.96$	10	99
	Goiânia	96	40	$y = 46.8 + 1.159X - 0.0055X^2$	$R^2 = 0.96$	19.3	68
	Goiânia	96	80	$y = 40.1 + 1.363X - 0.00679X^2$	$R^2 = 0.87$	16.1	65
	Jussara	95	40	$y = 27.8 + 6.8X^{1/2}$	$R^2 = 0.96$	< 5	111
	Jussara	96	40	$y = 27.2 + 7.7X^{1/2}$	$R^2 = 0.97$	< 5	88
	Jussara	96	80	$y = 25.4 + 7.29X^{1/2}$	$R^2 = 0.98$	< 5	105
					Average	—	
Sorghum	Goiânia	95	40	$y = 39.7 + 5.11X^{1/2}$	$R^2 = 0.76$	< 5	139
	Goiânia	96	40	$y = 43.4 + 6.38X^{1/2}$	$R^2 = 0.94$	< 5	78
	Goiânia	96	80	$y = 30.0 + 7.72X^{1/2}$	$R^2 = 0.87$	< 5	82
	Jussara	95	40	$y = 28.0 + 7.12X^{1/2}$	$R^2 = 0.90$	< 5	102
	Jussara	96	40	$y = 32.7 + 6.62X^{1/2}$	$R^2 = 0.90$	< 5	101
	Jussara	96	80	$y = 18.3 + 7.8X^{1/2}$	$R^2 = 0.90$	< 5	109
					Average	—	
Rice	Goiânia	95	40	$y = 27.4 + 9.63X^{1/2}$	$R^2 = 0.97$	23.5	56
	Goiânia	96	40	$y = 37.8 + 2.91X^{1/2}$	$R^2 = 0.97$	35.3	25
	Goiânia	96	80	$y = 20.7 + 1.97X - 0.00811X^2$	$R^2 = 0.99$	28.5	51
	Jussara	95	40	$y = 36.3 + 7.33X^{1/2}$	$R^2 = 0.88$	11.3	75
	Jussara	96	40	$y = 39.6 + 7.13X^{1/2}$	$R^2 = 0.81$	8.3	72
	Jussara	96	80	$y = 28.4 + 7.8X^{1/2}$	$R^2 = 0.73$	13.3	84
					Average	39.9	
Millet	Goiânia	95	250	$y = 18.0 + 8.95X^{1/2}$	$R^2 = 0.85$	11.7	93
	Goiânia	96	250	$y = 4.08 + 15.14X^{1/2}$	$R^2 = 0.92$	24.1	40
	Goiânia	96	500	$y = -6.0 + 13.4X^{1/2}$	$R^2 = 0.91$	18.7	62
	Jussara	95	250	$y = 22.4 + 7.68X^{1/2}$	$R^2 = 0.98$	< 5	102
	Jussara	96	250	$y = 26.1 + 7.33X^{1/2}$	$R^2 = 0.99$	< 5	101
	Jussara	96	500	$y = 15.1 + 8.2X^{1/2}$	$R^2 = 0.85$	< 5	107
					Average	—	

[a] Soil fomesafen concentration to rotational crop does not present carryover injury.
[b] Rotational crop planting intervals (days to get LCSH).
[c] y = growth percentage of rotational crop.
[d] X = days after fomesafen application.

weed free. Amount of water received during the experimentation (rainfall plus supplementary irrigation) is listed in Table 2.

Ten 8-cm-diam soil samples per plot were collected to a depth of 10 cm at both locations 0, 50, 75, 100, 125, and 150 d after treatment for bioassays. Samples were air dried and ground to pass through a 10-mm sieve, and 750 g soil from each sample was placed in a 1-kg pot. Five pregerminated rotational crop seeds (corn [AG 603], rice [Maravilha], millet [BN1], and sorghum [Cargill C-42]) with a radicle length of 3 mm were planted to a depth of 2 cm in each pot. Soil was saturated with water and maintained near field capacity. Greenhouse temperature was maintained at approximately 20 C at night and 30 C during the day. Dry weights of the plants were measured 13 d after planting (DAP) for each crop, year, and treatment, and growth was expressed as a percentage of control. The growth percentages of rotational crops over time were subjected to regression analysis for each crop, year, locale, and treatment.

Untreated soil samples from both locations were treated separately with imazamox, fomesafen, and acifluorfen to obtain soil concentrations of 0, 5, 10, 20, 30, 50, 100, 150, 200, and 300 ppb (w/w) to establish a standard curve. Five pregerminated sorghum seeds (Cargill C-42) were planted as the indicator species, and dry weights of plants were measured 13 DAP. The effect of each treated soil was expressed as a percentage of the untreated controls. The standard equations to determine herbicide concentration are represented in Table 3.

The percentages of sorghum growth from field samples taken 13 DAP were entered into their respective standard equation to determine the herbicide concentration that was bioavailable. The lower detection limit for the bioassay was 5.0 ppb herbicide (w/w). Herbicide concentrations over time were subjected to regression analysis for each year, locale, and treatment to obtain herbicide degradation equations.

The period between herbicide application and rotational crop planting (PAP) (time required before plant growth in treated soil to equal untreated check plant growth) of each rotational crop, year, and locale was determined from the equation that describes the growth of rotational crops over time. The PAP of each herbicide, rotational crop, year, and locale was entered into its respective herbicide degradation equation to determine the lowest concentration of herbicide in soil that does not affect the growth of rotational crops (LCSH). Herbicide dissipation time (DT_{50}) for each locale and year was calculated from the initial concentrations (Y-intercept) using the degradation equation.

Regression analyses were subjected to polynomial models

TABLE 7. Lowest concentration of herbicide in soil that does not affect growth of rotational crops (LCSH) and rotational crop planting intervals (PAP) after acifluorfen application in edible bean in Goiânia and Jussara, GO, soils during 1995 and 1996.

Rotational crop	Location	Year	Rate g ai ha^{-1}	Growth equations		LCSH[a] (ppb)	PAP[b]
Corn	Goiânia	95	170	$y^c = 77.7 + 2.51X^{1/2\,d}$	$R^2 = 0.67$	25.6	78
	Goiânia	96	170	$y = 84.8 + 2.02X^{1/2}$	$R^2 = 0.89$	23.0	56
	Goiânia	96	340	$y = 75.9 + 2.65X^{1/2}$	$R^2 = 0.97$	14.6	82
	Jussara	95	170	$y = 86.7 + 6.7X^{1/2}$	$R^2 = 0.97$	11.2	89
	Jussara	96	170	$y = 47.3 + 5.93X^{1/2}$	$R^2 = 0.99$	7.0	78
	Jussara	96	340	$y = 35.2 + 7.2X^{1/2}$	$R^2 = 0.98$	7.3	81
					Average	14.7	
Sorghum	Goiânia	95	170	$y = 17.9 + 6.95X^{1/2}$	$R^2 = 0.87$	< 5	139
	Goiânia	96	170	$y = 40.2 + 5.59X^{1/2}$	$R^2 = 0.92$	< 5	114
	Goiânia	96	340	$y = 29.5 + 6.46X^{1/2}$	$R^2 = 0.91$	< 5	118
	Jussara	95	170	$y = 26.8 + 6.96X^{1/2}$	$R^2 = 0.92$	< 5	110
	Jussara	96	170	$y = 34.8 + 6.63X^{1/2}$	$R^2 = 0.98$	< 5	96
	Jussara	96	340	$y = 25.9 + 6.82X^{1/2}$	$R^2 = 0.95$	< 5	117
					Average	< 5	
Rice	Goiânia	95	170	$y = 42.4 + 6.28X^{1/2}$	$R^2 = 0.64$	23.3	84
	Goiânia	96	170	$y = 55.6 + 5.66X^{1/2}$	$R^2 = 0.79$	20.4	61
	Goiânia	96	340	$y = 31.7 + 1.46X - 0.0068X^2$	$R^2 = 0.88$	21.9	70
	Jussara	95	170	$y = 50.0 + 0.52X$	$R^2 = 0.96$	7.1	95
	Jussara	96	170	$y = 72.2 + 3.2X^{1/2}$	$R^2 = 0.79$	9.3	73
	Jussara	96	340	$y = 50.2 + 5.6X^{1/2}$	$R^2 = 0.92$	9.6	78
					Average	15.2	
Millet	Goiânia	95	170	$y = 70.3 + 0.489X - 0.00152X^2$	$R^2 = 0.89$	24.1	82
	Goiânia	96	170	$y = 80.1 + 3.02X^{1/2}$	$R^2 = 0.72$	30.3	43
	Goiânia	96	340	$y = 83.2 + 2.43X^{1/2}$	$R^2 = 0.78$	37.9	47
	Jussara	95	170	$y = 60.5 + 4.43X^{1/2}$	$R^2 = 0.79$	17.3	79
	Jussara	96	170	$y = 84.2 + 2.23X^{1/2}$	$R^2 = 0.70$	25.0	50
	Jussara	96	340	$y = 42.7 + 6.40X^{1/2}$	$R^2 = 0.92$	8.1	80
					Average	23.7	

[a] Soil fomesafen concentration to rotational crop does not present carryover injury.
[b] Rotational crop planting intervals (days to get LCSH).
[c] y = growth percentage of rotational crop.
[d] X = days after fomesafen application.

(first and second order with or without square root transformation) whose coefficients were tested using the t test ($P \leq 0.05$). The model chosen was the one that obtained significance for all coefficients or, at least, the highest order and the highest R^2.

Results and Discussion

Herbicide Persistence in Soil

Herbicide degradation equations and herbicide dissipation time (DT_{50}) for each year and locale are listed in Table 4. Averaged across locale, year, and rate, fomesafen persistence (DT_{50}, 37.5 d) was longer than acifluorfen (27.5 d) and imazamox (25.9 d). Persistence of herbicides (average of fomesafen, acifluorfen, and imazamox) was compared between the 2 yr within each location, although in 1996, there were two rates for each herbicide and only one in 1995. At both locations, herbicide persistence was longer in 1995 than in 1996, which was attributed to more precipitation (rainfall plus supplementary irrigation) during the 75 d after herbicide application in 1996, compared to 1995 (Table 2). Soil moisture increases microbial degradation of imidazolinones (Basham and Lavy 1987) and diphenylethers (Harvey et al. 1980). There are many microorganisms in soil that reduce the nitro group of diphenylethers under anaerobic condition (Oyamada and Kuwatsuka 1988). In addition, herbicide adsorption is lower in wet than in dry soil; therefore, herbicide molecules tend to remain in soil solution longer and are subjected to greater leaching, plant absorption, and microbial degradation. Persistence of the imidazolinones imazaquin and imazethapyr is longer in wet than in dry soil (Basham and Lavy 1987; Goetz et al. 1986, 1990). Weissler and Poole (1982) leached fomesafen (0.3 kg ha^{-1}) in columns with 660 mm of water. In soils with 6.0% (low leaching) and 2.1% organic matter, herbicide concentrations were 185 and 100 ppb, respectively, in the top 10 cm, 63 DAA.

Persistence patterns of herbicides (average of imazamox, fomesafen, and acifluorfen) were compared between the two locations within each year. In 1995, dissipation time was 5.4 d longer in Goiânia than in Jussara (Table 4). This difference could be attributed to lower precipitation (rainfall plus supplementary irrigation) (Table 2) and higher organic matter and clay contents (Table 1) in soils from Goiânia than in those from Jussara. Soil persistence of fomesafen (Weissler and Poole 1982) and imazaquin and imazethapyr (Basham and Lavy 1987; Cantwell et al. 1989; Goetz et al. 1986, 1990; Loux et al. 1989b) is greater in soil with higher organic matter and clay contents due to greater herbicide adsorption. In 1996, dissipation time was only 1.6 d longer in the Goiânia than in the Jussara soil. Despite the higher organic matter and clay contents in the Goiânia soil, the higher precipitation in 1996 may have had the most influence on herbicide degradation.

Effect of Herbicide Residue on Rotational Crops

The equations that describe the growth of the rotational crops over time, the PAP, and the LCSH for each year, locale, and herbicide are presented in Tables 5–7.

Averaged across locale, year, and rate, sorghum following fomesafen application had lower LCSH (< 5 ppb) (more sensitive to soil fomesafen residue) than corn (11.6 ppb), millet (18.6 ppb), and rice (24.4 ppb) (Table 5). Sensitivity to imazamox herbicide residue was, in decreasing order: sorghum, corn, millet, and rice (Table 6). Sorghum was more sensitive to soil acifluorfen residue (LCSH, < 5 ppb) than corn (14.7 ppb), rice (15.2 ppb), and millet (23.7 ppb) (Table 7).

The LCSH for all rotational crops (except sorghum) was lower in Jussara than Goiânia soils (Tables 5–7) and may be due to the lower organic matter and clay contents in the former soil (Table 1). Lower herbicide adsorption may have occurred at Jussara, increasing the concentration of herbicide in soil solution, thus requiring a lower concentration of herbicide in soil not to affect plant growth.

The period between herbicide application and rotational crop planting varied in agreement with the estimated susceptibility of the rotational crop to soil herbicide residue and soil herbicide persistence. In 1995, for all herbicides, locales, and rotational crops, PAP was longer than in 1996, within the same herbicide rate, due to lower herbicide degradation (Tables 5–7). Precipitation (rainfall plus supplementary irrigation) had a greater effect on herbicide degradation, and therefore a greater influence on the PAP. Averaged across location (Goiânia and Jussara) and year, the PAP for fomesafen (250 g ai ha^{-1}) ranged from 69 to 132 d for corn, 114 to 179 d for sorghum, 29 to 95 d for rice, and 52 to 111 d for millet (Table 5); the PAP for imazamox (40 g ai ha^{-1}) ranged from 68 to 111 d for corn, 78 to 139 d for sorghum, 25 to 75 d for rice, and 40 to 102 d for millet (Table 6); and the PAP for acifluorfen (170 g ai ha^{-1}) ranged from 56 to 89 d for corn, 96 to 139 d for sorghum, 61 to 95 d for rice, and 43 to 82 d for millet (Table 7).

Considering that the planting of rotational crops after the harvest of edible beans occurs about 75 d after chemical application, the likelihood for sorghum injury from fomesafen (250 g ai ha^{-1}), acifluorfen (170 g ai ha^{-1}), or imazamox (40 g ai ha^{-1}) is high. For corn, rice, and millet, injury is possible under certain environmental conditions (i.e., low soil moisture content and high clay and organic matter soil) but appears to be low with high precipitation conditions (in Goiânia, 6.19 mm day^{-1}).

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