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Evaluation of Weed Efficacy and Crop Safety of Fluorochloridone in China

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Dinitroaniline and amide herbicides have been continually applied in garlic in China, leading to the change of weed community and dominant weed species. Catchweed bedstraw, shepherd's-purse, and flixweed have become major troublesome weeds. Crop safety of fluorochloridone to 18 crops (at rates of 500 and 1,000 g ai ha^{-1}) and weed efficacy against 35 weeds (at rates of 125 and 250 g ha^{-1}) were determined in greenhouse studies. Visual estimate indicated that fluorochloridone was not safe to many crops, especially cruciferous crops. Among all of the trial crops, garlic was the only crop which was not injured in both PRE and POST application at rate of 500 g ha^{-1}, even when treated with 1,000 g ha^{-1}. Fluorochloridone showed high efficacy against most weeds tested in this experiment when applied PRE, but could not offer a satisfactory control when applied POST. Further rate-response study of fluorochloridone to garlic and six weeds was also investigated. PRE application of fluorochloridone to garlic was safer than POST, and the rates for 10% growth reductions (GR_{10}s) were 1,959 g ha^{-1} for PRE and 537 g ha^{-1} for POST. When applied PRE, GR_{90}s of shepherd's-purse and flixweed were 19.2 and 70.3 g ha^{-1}, respectively. Though GR_{90} of catchweed bedstraw was 541 g ha^{-1}, it could be totally controlled without injuring garlic. On the basis of these results, fluorochloridone has an excellent prospect for weed control in garlic fields.

Nomenclature: Fluorochloridone; catchweed bedstraw, *Galium aparine* L.; flixweed, *Descurainia sophia* (L.) Webb. Ex Prantl; shepherd's-purse, *Capsella bursa-pastoris* (L.) Medik; garlic, *Allium sativum* L.

Key words: Greenhouse, rate-response, PRE application, POST application.

Los herbicidas dinitrioaniline y amide han sido aplicados continuamente en ajo en China, lo que ha llevado a cambios en la comunidad de malezas y las especies de malezas dominantes. *Galium aparine*, *Capsella bursa-pastoris* y *Descurainia sophia* se han convertido en las mayores malezas problemáticas. En estudios de invernadero, se determinó la seguridad para 18 cultivos de fluorochloridone (a dosis de 500 y 1,000 g ai ha^{-1}) y su eficacia para el control de 35 especies de malezas (a dosis de 125 y 250 g ha^{-1}). Estimados visuales indicaron que fluorochloridone no fue seguro en muchos cultivos, especialmente especies crucíferas. Entre todos los cultivos del estudio, el ajo fue el único cultivo que no fue dañado en aplicaciones PRE y POST con la dosis de 500 g ha^{-1}, e inclusive cuando se trató con 1,000 g ha^{-1}. Fluorochloridone mostró alta eficacia de control en la mayoría de las malezas evaluadas en este experimento cuando se aplicó PRE, pero no pudo ofrecer un control satisfactorio cuando se aplicó POST. También se investigó la respuesta a dosis de fluorochloridone de ajo y seis malezas. La aplicación PRE de fluorochloridone a ajo fue más segura que la POST, y las dosis que causaron reducciones del crecimiento de 10% (GR_{10}s) fueron 1,959 g ha^{-1} para PRE y 537 g ha^{-1} para POST. Cuando se aplicó PRE, GR_{90}s de *C. bursa-pastoris* y *D. sophia* fueron 19.2 y 70.3 g ha^{-1}, respectivamente. Aunque GR_{90} para *G. aparine* fue 541 g ha^{-1}, esta maleza se puedo controlar totalmente sin dañar al ajo. Con base en estos resultados, fluorochloridone tiene un excelente potencial para el control de malezas en campos de ajo.

Fluorochloridone is a selective herbicide, absorbed by roots and stems of sensitive weeds, bleaching the leaves by inhibiting biosynthesis of carotenoids, chlorophyll, and abscisic acid (Klicova et al. 2002; Lay and Niland 1983) and eventually causing necrosis. It is applied to control dicot and some grass weeds in sunflower (*Helianthus annuus* L.), potato (*Solanum tuberosum* L.), and carrot (*Daucus carota* L.) (Anonymous 2008). Research at Kiel in 1986 showed that catchweed bedstraw (*Galium aparine* L.), commom lambsquarters (*Chenopodium album* L.), black nightshade (*Solanum nigrum* L.) and common chickweed [*Stellaria media* (L.) Vill.] could be controlled effectively by fluorochloridone in potato (Nohl-Weiler and Hindersmann 1986). In sunflower, fluorochloridone tank mixed with acetochlor offered a high

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efficacy against wild mustard (*Sinapis arvensis* L.) and field pennycress (*Thlaspi arvense* L.) (Friesen 1987; Jursík et al. 2011).

Although fluorochloridone can control large numbers of weeds, few crops showed high tolerance to this herbicide. Loss of chlorophyll was observed in wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.) seedlings when treated with 320 μmol L^{-1} fluorochloridone (Devlin et al. 1979). PRE application of fluorochloridone in potato fields caused chlorosis and 11% yield loss (Murray et al. 1994) while applied in buckwheat (*Fagopyrum esculentum* Moench) fields fluorochloridone resulted in severe injury with a 50% loss of yield (Friesen 1988).

Because the area of tillage per capita was quite limited in China, continuous cropping became a widespread agriculture measure for farmers to improve their revenue in some specific crops such as garlic. However, continuous cropping led to soil quality degradation, crop yield reduction, and crop pest aggravation, which was known as a succession cropping obstacle (Liu 2011). Reports suggested it may be related with rhizosphere microbe and soil enzymes (Liu et al. 2010). Rational rotation and intercropping were the common measures used to solve continuous cropping obstacles in agriculture (Betencourt et al. 2012; Keeling et al. 2013; Martin-Rueda et al. 2007). Garlic rotated with corn, hot pepper (*Capsicum annuum* L.), eggplant (*Solanum melongena* L.), radish (*Raphanus sativus* L.), or cotton (*Gossypium hirsutum* L.), and intercropped with Indian mustard [*Brassica juncea* (L.) Czern.] or cucumber (*Cucumis sativus* L.) could improve the land productivity and reduce the occurrence of plant disease (Hao et al. 2011; Li et al. 2010; Ran et al. 2012; Sarker et al. 2007; Zhou et al. 2011). However, fluorochloridone has a 40 to 90 d half-life at 20 C, allowing it to persist long enough to cause damage to subsequent crops such as soybean [*Glycine max* (L.) Merr.] (Buhler 1988; Walker 1987).

So far, fluorochloridone has not been registered for use in China (Institute for the Control of Agrochemicals 2013). Considering the diversity of crops and weeds in China, the objectives of this study were (1) to determinate the crop safety of fluorochloridone to 18 crops and efficacy against 35 weeds and (2) to evaluate selectivity of fluorochloridone between a safe crop and some common weeds.

Materials and Methods

Weeds and Crops. Weeds and crops used in this study are presented in Tables 1 and 2.

Herbicide Formulation. Fluorochloridone (Suzhongjiahui chemical company, Jiangsu, China) with 95% purity was dissolved in a proper volume of acetone before adding alkylphenol formaldehyde resin ethoxylates tank-mixed with calcium dodecylbenzenesulfonate. The mixture was diluted with deionized water to the needed rates.

Crop Safety. Seeds of crops were germinated in a growth chamber (Model RXZ, Ningbojiangnan Instrument Factory, Ningbo, China). According to the size of crop seeds and seedlings, a proper number of germinated seeds were sown per plastic pot (200 mm diam), containing air dried, sieved (2 mm mesh) soil in a greenhouse in Shandong Agricultural University (natural lighting, daytime temperature ∼23 to 29 C, night temperature ∼ 15 to 19 C). The soil has a pH of 6.8, with an organic matter content of 1.7%. PRE applications were at 24 h after planting at the rates of 500 and 1,000 g ha^{-1} while POST applications were at the three- to five-leaf stage using an auto-spraying tower (Model ASS-4, National Agricultural Information Engineering and Technology Center of China) with a Teejet 9503EVS flat-fan nozzle calibrated to deliver 450 L ha^{-1} at 280 kPa. A nontreated check was included for each crop. All treatments were replicated three times, and the experiment was conducted twice. Visual estimates of herbicide damage of seedlings were recorded by an independent assessor 28 d after treatment (DAT) using a scale of 0 to 100% (0 = no damage, 100 = total death). Observation of plant whitening was also recorded to describe treatment performance.

Weed Spectrum. Weed seed germination, culture, and spraying conditions are consistent with the crop safety experiment. Both PRE (24 h after sown) and POST (when weeds reached the three- to five-leaf stage) applications were sprayed at 125 and 250 g ha^{-1}. All treatments were replicated three times, and the experiment was conducted twice. At 28 DAT, weed plants were cut at soil surface and dried for at least 48 h at 80 C, and dry weights were recorded.

Selectivity Index (SI). Seed germination, culture, and spraying conditions are consistent with the crop safety experiment. Garlic, flixweed, shepherd's-

Table 1. Visual injury ratings of trial crops treated with fluorochloridone relative to the nontreated control in a greenhouse study 28 d after treatment (DAT) [a].

	Crop injury rating (SE)			
	PRE[b]		POST	
Trial crops	500[c]	1,000	500	1,000
	——%——			
Garlic (*Allium sativum* L. 'Jiaxiang garlic')	0	0 NS[d]	0	0 NS
Sunflower (*Helianthus annuus* L. 'Jinkui 10′)	0	0 NS	48 (6.1)	68 (5.2) *
Potato (*Solanum tuberosum* L. 'Luyin 10′)	0	7 (2.7) *	10 (0)	18 (5.2) *
Coriander (*Coriandrum sativum* L. 'Dayouye')	0	25 (5.5) *	41 (4.9)	49 (5.8) NS
Carrot (*Daucus carota* L. 'Zhengshenfengshouhong')	0	23 (5.2) *	8 (5.2)	9 (3.8) NS
Cotton (*Gossypium hirsutum* L. 'Lumianyan37′)	11 (2.0)	28 (4.2) *	41 (3.8)	51 (4.9) *
Peanut (*Arachis hypogaea* L. 'Fenghua 5′)	18 (2.6)	38 (2.6) *	10 (4.5)	40 (6.3) *
Soybean [*Glycine max* (L.) Merr. 'Zaoshu 1′]	17 (6.8)	40 (3.2) *	39 (4.9)	52 (5.2) *
Corn (*Zea mays* L. 'Zhengdan 958′)	19 (4.9)	50 (5.5) *	0	0 NS
Wheat (*Triticum aestivum* L. 'Shannong 14′)	68 (6.1)	91 (5.9) *	30 (7.1)	68 (7.5) *
Cucumber (*Cucumis sativus* L. 'Jinyan 4′)	78 (4.1)	100 *	59 (4.9)	81 (3.8) *
Rice (*Oryza sativa* L. 'Lindao 11′)	100	100 NS	72 (2.6)	92 (5.2) *
Grain sorghum [*Sorghum bicolor* (L.) Moench 'Jinyu red']	100	100 NS	71 (4.9)	88 (6.1) *
Mung bean [*Vigna radiate* (L.) Wilczek 'Weilv 7′]	100	100 NS	71 (2.0)	90 (3.2) *
Scallion (*Allium fistulosum* L. 'Zhangqiu scallion')	100	100 NS	9 (4.9)	28 (2.7) *
Pakchoi cabbage (*Brassica chinensis* L. 'Huangyang')	100	100 NS	100	100 NS
Rape (*Brassica campestris* L. 'Siyueman')	100	100 NS	100	100 NS
Radish (*Raphanus sativus* L. 'Big radish 3′)	100	100 NS	100	100 NS

[a] Injury rating scale: 0 = consist with contrast treatment, 0∼30% = cotyledon and minority of functional leaves showed whitening except newborn leaves, 30∼60% = cotyledon, minority of functional leaves and newborn leaves showed whitening, 60∼100% = majority of the plants showed serious whitening symptoms, some plant even necrosis, 100% = all plants showed whitening symptoms and necrosis.

[b] Abbreviation: PRE, pre-emergence; POST, post-emergence.

[c] Unit is omitted: 500 g ha^{-1}, 1000 g ha^{-1}.

[d] Significant differences between the two PRE rates or the two POST rates according to Fisher's protected LSD test. *, significant; NS, not significant.

purse, corn gromwell (*Lithospermum arvense* L.), catchweed bedstraw, Japanese foxtail (*Alopecurus japonicus* Steud.), and wild oat (*Avena fatua* L.) were treated with both PRE and POST applications. PRE or POST applications to garlic and six weeds were done simultaneously. All treatments were replicated four times, and the experiment was conducted twice. At 28 DAT, plants were cut at soil surface and dried for at least 48 h at 80 C, and dry weights were recorded.

Data Analysis. Data from repeated experiments of crop safety and weed spectrum were analyzed by ANOVA. Since variance between repeated experiments was not significant, data were pooled and means were separated using Fisher's protected LSD test at $\alpha = 0.05$.

Rate–response curves were obtained through non-linear regression to fit the log-logistic function using equation 1 (Seefeldt et al. 1995):

$$Y = C + (D - C)/\left\{1 + \exp\left[b\left(\log(x) - \log(GR_{50})\right)\right]\right\}$$

where C is the lower limit of response, D is the upper limit of response, x is the herbicide rate, GR_{50} is the rate causing 50% of the maximum response and b is the slope of the curve around the GR_{50}.

The rate-response curve regression analysis was performed using data from all the replicates using the regression utility of the drc package of R software (Knezevic et al. 2007). On the basis of the regression parameters, the GR_{10}, GR_{50} and GR_{90} values for the herbicide selectivity were calculated (Ritz and Streibig 2005). Graphs were created by SigmaPlot version10.0 (Systat Software Inc., Rich-

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Table 2. Dry weight inhibitions of trial weeds treated with fluorochloridone relative to the nontreated control in a greenhouse study 28 d after treatment (DAT).

Trial weeds	Dry weight inhibition (SE)			
	PRE [a]		POST	
	125[b]	250	125	250
	%			
Green foxtail [*Setaria viridis* (L.) Beauv]	99 (0.2)	98 (0.8) NS[c]	20 (1.9)	32 (1.6) *
Shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik.]	99 (0.6)	99 (1.1) NS	92 (1.3)	92 (0.1) NS
Thymeleaf sandwort (*Arenaria serpyllifolia* L.)	98 (1.2)	99 (0.6) NS	83 (2.1)	94 (0.6) *
Flixweed [*Descurainia sophia* (L.) Webb. ex Prantl]	98 (1.3)	98 (1.1) NS	81 (2.3)	89 (0.7) *
Indian mustard [*Brassica juncea* (L.) Czern.]	98 (1.9)	98 (1.0) NS	45 (1.7)	51 (2.4) *
American slough grass [*Beckmannia syzigachne* (Steud.) Fern.]	97 (0.9)	98 (0.5) NS	8 (1.1)	45 (2.6) *
Large crabgrass [*Digitaria sanguinalis* (L.) Scop.]	97 (0.8)	98 (1.3) NS	20 (1.5)	39 (1.6) *
Commom lambsquarters (*Chenopodium album* L.)	96 (1.6)	97 (0.7) NS	61 (3.2)	82 (2.8) *
Purple nutsedge (*Cyperus rotundus* L.)	96 (1.4)	98 (0.6) NS	53 (1.5)	84 (2.1) *
Lyrate hemistepta (*Hemistepta lyrata* Bunge)	95 (1.2)	99 (0.4) *	74 (2.5)	88 (1.6) *
Goosegrass [*Eleusine indica* (L.) Gaertn.]	95 (0.6)	95 (1.2) NS	57 (0.3)	61 (2.1) *
Water foxtail (*Alopecurus aequalis* Sobol.)	95 (0.6)	97 (0.3) *	58 (1.8)	82 (2.0) *
Hardgrass [*Sclerochloa dura* (L.) Beauv.]	95 (1.0)	96 (0.7) NS	21 (2.8)	50 (1.4) *
Late juncellus (*Juncellus serotinus* Rottb.)	95 (2.6)	96 (2.0) NS	50 (2.5)	64 (3.3) *
Chinese sprangletop [*Leptochloa chinensis* (L.) Nees]	94 (2.3)	98 (1.1) *	59 (2.0)	84 (0.7) *
Common purslane (*Portulaca oleracea* L.)	94 (2.3)	95 (0.9) NS	96 (0.7)	97 (0.7) NS
Figleaved goosefoot (*Chenopodium ficifolium* Sm.)	93 (1.1)	95 (1.8) NS	75 (3.0)	90 (0.6) *
Water starwort [*Myosoton aquaticum* (L.) Moench]	93 (2.2)	93 (2.5) NS	90 (1.4)	94 (0.4) *
Japanese brome (*Bromus japonicus* Thunb. ex Murr.)	92 (1.6)	96 (2.6) NS	7 (1.5)	9 (2.2) NS
Japanese foxtail (*Alopecurus japonicus* Steud.)	92 (1.1)	96 (1.3) *	14 (1.6)	19 (2.5) *
Black nightshade (*Solanum nigrum* L.)	88 (2.5)	98 (1.6) *	31 (3.1)	53 (2.8) *
Corn gromwell (*Lithospermum arvense* L.)	88 (1.0)	95 (1.5) *	51 (0.7)	76 (2.2) *
Eclipta [*Eclipta prostrate* (L.) L.]	86 (1.7)	94 (2.5) *	16 (2.1)	28 (2.1) *
Redroot pigweed (*Amaranthus retroflexus* L.)	84 (1.3)	93 (1.5) *	17 (1.4)	31 (3.2) *
Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.]	70 (2.7)	97 (1.2) *	9 (2.2)	23 (1.0) *
Catchweed bedstraw (*Galium aparine* L.)	69 (0.7)	80 (3.2) *	30 (0.8)	56 (2.5) *
Sun spurge (*Euphorbia helioscopia* L.)	60 (1.1)	74 (2.5) *	27 (2.4)	44 (1.9) *
Cone catchfly (*Silene conoidea* L.)	54 (1.3)	75 (1.9) *	8 (1.7)	22 (2.1) *
Wild oat (*Avena fatua* L.)	44 (2.8)	74 (0.7) *	13 (1.0)	21 (1.0) *
Velvetleaf (*Abutilon theophrasti* Medik.)	31 (2.8)	55 (1.6) *	45 (2.3)	60 (1.8) *
Italian ryegrass [*Lolium perenne* L. ssp. multiflorum (Lam.) Husnot]	27 (2.6)	37 (2.3) *	10 (1.2)	21 (2.0) *
Hairy beggarticks (*Bidens pilosa* L.)	22 (0.8)	51 (2.5) *	8 (1.7)	24 (2.0) *
Barb goatgrass (*Aegilops triuncialis* L.)	19 (0.5)	30 (1.4) *	12 (2.4)	32 (2.4) *
Sickle senna (*Cassia tora* L.)	17 (1.6)	25 (1.7) *	12 (1.9)	21 (2.8) *
Japanese morningglory [*Ipomoea nil* (L.) Roth]	10 (0.8)	34 (2.1) *	17 (2.4)	29 (2.1) *

[a] Abbreviation: PRE, pre-emergence; POST, post-emergence.

[b] Unit is omitted: 125 g ha^{-1}, 250 g ha^{-1}.

[c] Significant differences between the two PRE rates or the two POST rates according to Fisher's protected LSD test. *, significant; NS, not significant.

mond, CA) with means of dry weight (% of residual) and standard deviations.

The SIs of fluorochloridone were calculated as equation 2:

$$SI_{(10,90)} = GR_{10(crop)}/GR_{90(weed)}$$

Where GR_{10} equals a 10% effect on garlic and GR_{90} equals a 90% effect on the trial weeds. The more SI increases above 1, the more selective fluorochloridone between *Allium sativum* and weeds (Tind et al. 2009).

Results and Discussion

Crop Safety. Among all of the trial crops, garlic is the only crop which was not injured from both PRE and POST applications, even when treated with

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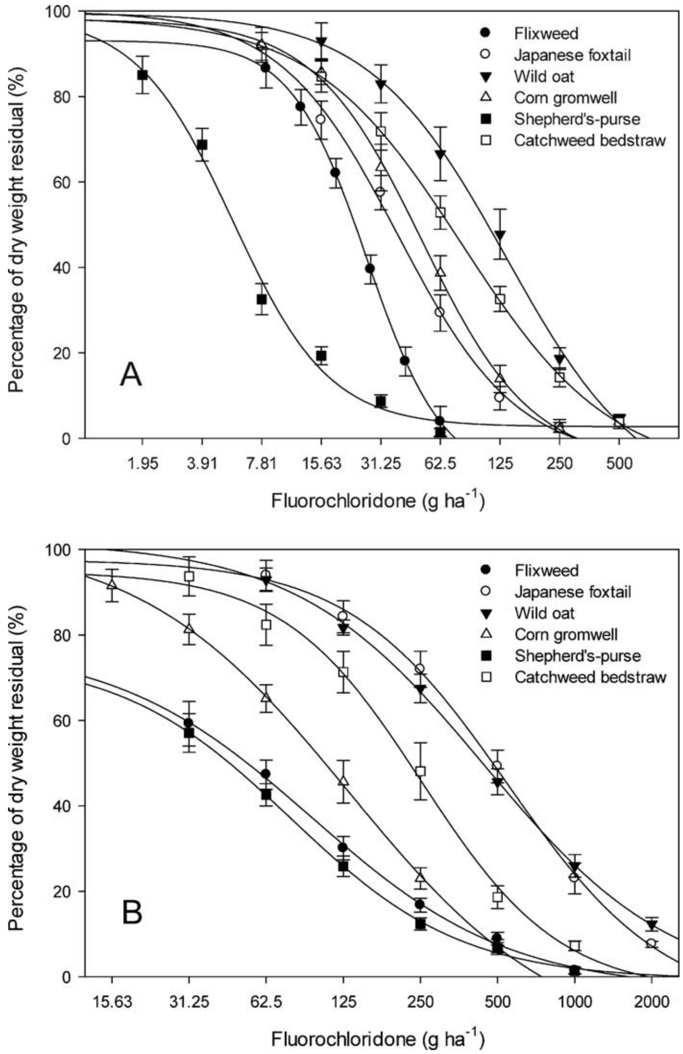

Figure 1. Percentage of dry weight residual of flixweed, Japanese foxtail, wild oat, corn gromwell, shepherd's-purse and catchweed bedstraw response to increasing fluorochloridone rates in greenhouse study 28 d after treatment (DAT) based on nonlinear regression fit to a log–logistic curve model; $Y = C + (D - C) / \{1 + \exp [b(\log(x) - \log(GR_{50}))]\}$. (A) PRE-applied (B); POST-applied.

1,000 g ha^{-1} (Table 1). Tolerance of potato and umbelliferae crops to fluorochloridone PRE at 500 g ha^{-1} was observed. Significant injury to these crops was observed when treated with 1000 g ha^{-1}. Field studies in sunflower showed that only temporary phytotoxicity were observed without significant influence on yield when fluorochloridone was applied PRE at 600 g ha^{-1} (Friesen 1987). However, in our study, whitening was not observed in sunflower when applied PRE at 500 and 1,000 g ha^{-1} (Table 1). Corn showed high tolerance to fluorochloridone applied POST (Table 1), which was consistent with the report that atrazine tank-mixed with fluorochloridone could be used for early POST application in corn (Vrbnicanin et al. 2006). However, fluorochloridone was not safe to many crops tested in this experiment, especially to cruciferous crops such as pakchoi cabbage (*Brassica chinensis* L.) which were injured at 500 g ha^{-1} when treated with PRE or POST applications (Table 1). Beyond that, when applied PRE at the rate of 500 g ha^{-1}, rice (*Oryza sativa* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], mung bean [*Vigna radiate* (L.) Wilczek], and scallion (*Allium fistulosum* L.) were injured (Table 1).

Weed Spectrum. At the rate of 125g ha^{-1}, PRE application of fluorochloridone offered a very high efficacy (>90%) against 20 weeds tested in this experiment. When treated at 250 g ha^{-1}, the number increased to 25 (Table 2). However, fluorochloridone had no efficiency on some dicot and grass weeds such as Japanese morningglory [*Ipomoea nil* (L.) Roth] and Barb goatgrass (*Aegilops triuncialis* L.) (Table 2). This was probably caused by the size of weed seeds. PRE herbicides like *S*-metolachlor and alachlor provide high efficacy against a large number of small-seeded weeds, but offer only limited control of large-seeded weeds (Keeling et al. 2013). When the rate increased from 125 to 250 g ha^{-1}, the efficacy against dicot weeds and grass weeds like black nightshade (*Solanum nigrum* L.) and Japanese foxtail increased (Table 2).

Fluorochloridone also has some POST herbicidal activity (Friesen 1988); however, inhibition of phytoene desaturase is less when applied POST than PRE (Arai et al. 2006). Our study similarly proved that POST application of fluorochloridone showed lower efficacy than PRE application (Table 2). At the rate of 125 g ha^{-1}, only common purslane (*Portulaca oleracea* L.) and shepherd's-purse could be controlled well with POST application. Efficacy above 80% was only offered against water starwort [*Myosoton aquaticum* (L.) Moench], thymeleaf sandwort (*Arenaria serpyllifolia* L.), and flixweed. In contrast, for other weeds, fluorochloridone performed poorly when applied POST. When applied at 250 g ha^{-1}, efficacy against other weeds was improved but was still unsatisfactory (Table 2).

Selectivity Index. Based on the results mentioned in crop safety experiment, a rate-response study was

Table 3. Rates of fluorochloridone causing 10% and 50% growth reduction of garlic and 50% and 90% growth reduction of 6 weeds, and selectivity index (SI)[a] between garlic and 6 weeds in a greenhouse study 28 d after treatment (DAT).

Trial plants	Timing	GR^{b}_{10} (SE)	GR_{50} (SE)	GR_{90} (SE)	SI
		g ha^{-1}			
Garlic	PRE	1,959 (693)	10,743 (2,502)	—	—
Shepherd's-purse	PRE	—	5.6 (1.3)	19.2 (7.6)	102
Flixweed	PRE	—	26.6 (0.2)	70.3 (2.1)	27.9
Japanese foxtail	PRE	—	38.3 (5.1)	175 (60.4)	11.2
Corn gromwell	PRE	—	50.6 (3.5)	204 (40.8)	9.6
Catchweed bedstraw	PRE	—	80.7 (2.7)	541 (58.5)	3.6
Wild oat	PRE	—	135 (24.3)	779 (456)	2.5
Garlic	POST	537 (330)	2,219 (423)	—	—
Shepherd's-purse	POST	—	77.9 (11.5)	424 (61.6)	1.3
Flixweed	POST	—	94.2 (19.6)	665 (209)	0.8
Japanese foxtail	POST	—	547 (51.6)	2,604 (766)	0.2
Corn gromwell	POST	—	132 (9.6)	1,047 (264)	0.5
Catchweed bedstraw	POST	—	253 (35.5)	991 (432)	0.5
Wild oat	POST	—	446 (29.0)	2,859 (667)	0.2

[a] Selectivity index was calculated by $SI_{(10,90)} = GR_{10(crop)} \ / \ GR_{90(weed)}$.

[b] Abbreviation: GR, growth reduction; PRE, pre-emergence; POST, postemergence; SI, selectivity index.

conducted to determine whether PRE or POST application was safer to garlic. Selectivity between garlic and six common weeds was also confirmed. In general, PRE and POST application of fluorochloridone had higher efficacy against dicot weeds than grass weeds. Compared with the other four tested weeds, shepherd's-purse and flixweed were more sensitive to fluorochloridone in both PRE and POST application (Figure 1). Similar results have been reported that fluorochloridone provided high efficacy against cruciferous weeds (Friesen 1987; Friesen and Clayton 1986). Wild oat was more tolerant than any other weed in our experiment (Table 3).

A comparison of GR_{50} control levels between PRE and POST application clearly shows that PRE application has greater efficacy than POST (Table 3). Compared with PRE application, garlic was more sensitive when applied POST with fluorochloridone (Table 3). Moreover, except shepherd's-purse, SIs of other five weeds were all below one in POST treatments. Therefore, PRE application of fluorochloridone was safer to garlic and more effective against treated weeds.

Dinitroanilines and amides, which control grass weeds better than dicot weeds, are the herbicides most widely used for PRE application in garlic in China. They have been continuously applied for more than 10 yr, influencing the weed community and dominant weed species (Zhao 2004.). Catchweed bedstraw, shepherd's-purse, and flixweed have become the major trouble weeds in garlic field. In our study, PRE application of fluorochloridone was safe to garlic, and could control large numbers of weeds. It was noted previously that a compound could safely be used in a crop when the SI is above two (Bartley 1993). It is worth mentioning that fluorochloridone has good efficacy against shepherd's-purse and flixweed, SIs of which reach up to 102 and 27.9. Though efficacy of fluorochloridone against catchweed bedstraw was not outstanding when contrasted with shepherd's-purse and flixweed, the SI data indicated that it could also be controlled effectively (Table 3). Furthermore, fluorochloridone could tank mixed with dinitroanilines and amides for a more widely weed control in garlic field.

In our study, cruciferous crops, mung bean, scallion, and rice were very sensitive to fluorochloridone. Considering the herbicide residues, fluorochloridone application was not recommended when garlic in rotation or intercropping with them. It is beneficial to deeply plough and cultivate the soil before follow-up crop is planted. Recent reports demonstrate that fluorochloridone was safe to potato and cotton (Gao et al. 2012). Therefore, fluorochloridone could be a candidate for crop intercropping of garlic - potato or garlic - cotton.

Though our study was totally based on the idealized environment in greenhouse, it could provide related application guidance in the field.

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