Establishing targeted control of creeping perennial weeds with soil-active chemical injections: assessment of subterranean bud responses in contact.

Key Words: Soil injection, Soil-active herbicide, Urban vegetation management, Creeping perennial weed, Flurprimidol

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Abstract

Increased infestation of aggressive creeping perennial weeds is a significant problem in urban vegetation management programs. These weeds produce vigorous biomass and extensive underground networks of either rhizomes or creeping roots that easily regrow from numerous buds. Foliar application of proper systemic herbicides has been a most effective way to suppress regrowth from underground creeping organs; however, killing the mature plants has disadvantages from aesthetic, economic, and ecological viewpoints. Therefore, we intended to test the possibility of soil-injection of soil-active herbicides for effective control of the perennial weeds which develop underground network systems. A pot experiment using combinations of seven species (seven rhizomatous and two having creeping roots) and five chemicals (four herbicides and a plant growth regulator) was conducted to assess whether and how chemicals diffused in soil affect the sprout and growth of buds on creeping organs. All the tested herbicides completely inhibited bud sprouting in one and more species when applied at median or high rates, while most of the flurprimidol applied segments sprouted but shoot elongation was significantly reduced. Characteristics of each herbicide were also reflected in the selectivity and features of new outgrowth. The results indicated that chemicals existing in soil were undoubtedly absorbed and affected bud activities. It is concluded that soil injection that delivers the probable soil-active chemicals to subterranean creeping systems could be a promising technology for controlling noxious creeping perennials.

Introduction

It is generally recognized that vegetation is an essential element of our natural environment. However, vegetative quality has largely deteriorated during the last decades in Japan because of an increased infestation of creeping perennial weeds. Creeping perennials are distinguished by having creeping roots, rhizomes, or stolons that elongate and produce new plants from reproductive buds on these organs (Anderson, 1999). The most serious and uncontrollable species are those that develop extensive underground network systems of either rhizomes with determinate buds at the nodes or creeping roots that produce adventitious buds (Ito et al, 1966; Yukinaga et al., 1975; Tominaga, 2007; Miyazaki, 2008; Ito et al., 2005a; Ito, 2020). Typical weed species include *Solidago altissima, Artemisia indica* spp. *Boehmeria nivea, Imperata cylindrica, Sorghum halepense, Cayratia japonica,* and *Solanum carolinense.* They invaded nationwide recently across urban and semi-urban areas; on roadsides, railroad right of ways, and river banks; in abandoned fields, waste areas, and ornamental shrubberies; and even in unplanted agricultural areas (Ito, 2020).

Most weed vegetation has been managed with mechanical mowing (usually twice a year) , which is more publicly accepted compared to chemical use, and this has apparently resulted in an enhanced domination of vigorous creeping perennials in the vegetation. Physiologically, it is obvious that the removal of growing areal shoots reduces the apical dominance of these weeds and results in the stimulation of underground bud sprouting and regrowth (Ito, 2020). Therefore, the only promising way to precisely suppress underground bud sprouting is the application of the proper chemicals at the proper timings. Considerable evidences support the efficacy of foliar application of several systemic herbicides that translocate to the subterranean system of plants, accumulate in buds and destroy their meristematic activities (Ito, 2018). For example, some aryloxyphenoxys (Candrasena & Sagar, 1987; Tardif & Lerous, 1990) and glyphosate have been successfully used to control rhizomatous grasses; triclopyr for broadleaves; and asulam for bracken fern (Yukinaga et al., 1973) and field horsetail (Veerasekaran & Kirkwood, 1977; Ito & Asai, 1995). However, spraying chemicals on large plants can have adverse effects on off-target plants and environment, cause economic loss through excess chemical waste, and produce unsightly appearances of dead weed plants.

On the other hand, several soil-active herbicides are also known to inhibit and/or disturb cell division or meristematic activities (Ito, 2000; Ito et al., 2005b; Weed Science Society of America 2017). Accordingly, we came up with an idea of applications of these chemicals by means of soil injection that is popular for soil sterilization in agriculture to kill fungi, nematodes and some weed propagules. The important point for success is to deliver and distribute the chemicals precisely to the zones of underground creeping systems, otherwise remain shallow in soil surface applications. For this capability, we already had an evidence that soil injected clorpropham suppressed the regrowth of *Fallopia japonica* (Ito, unpublished) from deeply penetrated rhizomes, so well as found in *Solanum carolinense* from creeping roots with its soil incorporation (Ito et al, 2005b).

A series of trails were intended to determine the reliability of our idea. In this paper, we demonstrate, as the first step, that candidate chemicals in soil be absorbed surely by subterranean creeping organs and subsequently affect their bud activities,

Materials and Methods

Materials: Five rhizomatous and two creeping-roots species that are most noxious in urban vegetation and uncontrollable by mowing were tested (Table 1). Chlorpropham, trifluralin, and dichlobenil were selected as candidate herbicides because of their characteristic ability to inhibit cell division and/or disturb meristematic activities and their high volatility, which creates thick herbicide layers in the soil (Table 2). They used to be widely used for weed control in crops with soil incorporation (Ito, 2019). The other herbicide, triclopyr, is a synthetic auxin that is commonly used as a foliar-active herbicide but has been reported to be moderately persistent in soil with an average half-life of 30 days (Weed Science Society of America, 1994). In addition, we tested the efficacy of flurprimidol, which is a soil-active plant growth regulator used to retard growth in a wide range of mono- and di-cotyledonous weed species (Anonymous, 1983).

Table 1. Subterranean characteristics of seven tested perennial species

Species	Family	Subterranean system	Depth of system distribution †	Depth from shoot emergence‡
Artemisia indica	Asteraceae	Rhizome	20 cm	<15 cm
Solidago altissima	Asteraceae	Rhizome	20 cm	<15 cm
Calystegia japonica	Convolvulaceae	Rhizome	20 cm (40 cm)	<20 cm
Fallopia japonica	Polygonaceae	Rhizome	60 cm (90 cm)	<20 cm
Imperata cylindrica	Poaceae	Rhizome	40 cm (60 cm)	<20 cm
Cayratia japonica	Vitaceae	Creeping-root	60 cm (90 cm)	<40 cm
Solanum carolinense	Solanaceae	Creeping-root	60 cm (90 cm)	<30 cm

† and ‡ refer to Ito & Morita (1997). Data in parentheses indicate maximum depth.

Table 2. Characteristics and application rates of the five chemicals tested in the experiment.

Chemical	Category †	Characteristic‡	Application rate (g ai/L)		
			Low	Median	High
Trifluralin	Herbicide, soil-active	inhibits cell division (mitosis), volatile	0.09	0.18	0.36
Dichlobenil	Herbicide, soil-active	inhibits actively dividing meristems, volatile	0.13	0.27	0.55
Chlorpropham	Herbicide, soil-active	inhibits cell division (mitosis), volatile	0.13	0.27	0.55
Triclopyr	Herbicide, foliar-active	disturbs and inhibits cell division and growtl	0.11	0.22	0.44
Flurprimidol	Plant growth regulator, soil active	reduces internodes and leaf elongation	0.20	0.40	0.80

† and ‡ reference: the Weed Science Society of America (1994) and (2017), respectively.

Experimental procedures: Rhizomes and creeping root species were collected from *in situ* populations growing in non-crop areas of Fukui Prefecture, Japan, and cut into 5 – 7 cm segments. Samples of rhizome species had one or more nodes each.

Soil used for the experiment was a mixture of two commercial soils; that for turf topdressing and seedbed, which mainly consisted of perlite and peat moss (pH: 5.3-7.0, soil moisture: 30-45%). Two-liter pots that were 12-cm tall and 14.5-cm in diameter were filled with soil to 1.5-cm below the pot top. Segments of the rhizome or creeping root were placed laterally 4 cm below the soil surface.

Chemical application rates were fixed at three levels based on the doses recommended for common soil application as a median dose and at one-half, one, and two times that of the median rate. Adequate water volume for dilution of the chemicals was calculated to be 1000 mL/m^2 based on the volume that could saturate the soil without leaching from the bottom of the pot. Thus, the concentrations were considerably lower than standard soil application. Ten pots were provided for a unit consisting of a species, a chemical and one application rate. Each solution was sprayed evenly over a 1 m x 1 m area where ten pots of each species were placed, using an automatic garden-sprayer. After spraying, the surfaces were covered with an additional 1 cm untreated soil. Pots sprayed with tap water were used as a control. Treated pots were then placed in a greenhouse and buds of the collected segments were allowed to sprout and grow for approximately seven weeks. Thereafter, plants were harvested, washed, and new growth was determined by measuring total fresh weight and the lengths of the longest, newly emerged shoots per segment. As the greenhouse was not air-conditioned, we conducted the experiments in late March to early July, depending on the most suitable sprouting time for each species.

Data analysis: Efficacy levels of the five chemicals on controlling bud outgrowth in the seven perennial weed species were evaluated by recording the new growth from rhizome or creeping root segments. Both total fresh weight and the length of the longest, new shoots were measured for each segment, with the latter used for statistical analysis because some segments produced more than one shoot, which contributed the fresh weight. As a reference, high correlations between the longest length and flesh weight were calculated; the Pearson's coefficients varied between 0.744 and 0.984 depending on the species. Differences in the mean of the longest shoot length within one unit (e.g., 10 replicates of a species-chemical-rate combination) were assessed with one-way ANOVA followed by Tukey's t-test for each chemical treatment. The data are presented as a percent of the untreated control.

Results and Discussion

The mean length of the shoots that developed from treated segments significantly decreased when compared with that of untreated control in most combinations of a species and a treatment (Fig. 1). At the median and high rates, all four herbicides almost completely inhibited sprouting in one or more species. In contrast, most of the segments treated with flurprimidol sprouted but exhibited significant reductions of shoot elongation in all seven species, even at the low application rate.

We also found that there were differential characteristics reflected in the plant responses for each herbicide. Triclopyr and dichlobenil were highly effective on six broad-leaved species, particularly on two climbing species, *Calystegia japonica* and *Cayratia. japonica* when compared with the grass species, *I. cylindrica*. Trifluralin was equally effective on both grass and broad-leaved species, while chlorpropham was less effective than the other four chemicals tested. The result might account for the high volatility of chlorpropham accompanied by a relatively high soil temperature during the experimental period, as this chemical is known to be extremely lowered its effect under temperatures higher than 25℃ (Motegi, 1993). It was noticeable, despite under such conditions, that chlorpropham completely suppressed rhizome bud activities of *F. japonica* (Japanese knotweed), a most aggressive species which is difficult to control and listed as one of the world's worst alien invasive species (Invasive Species Specialist Group, 2004).

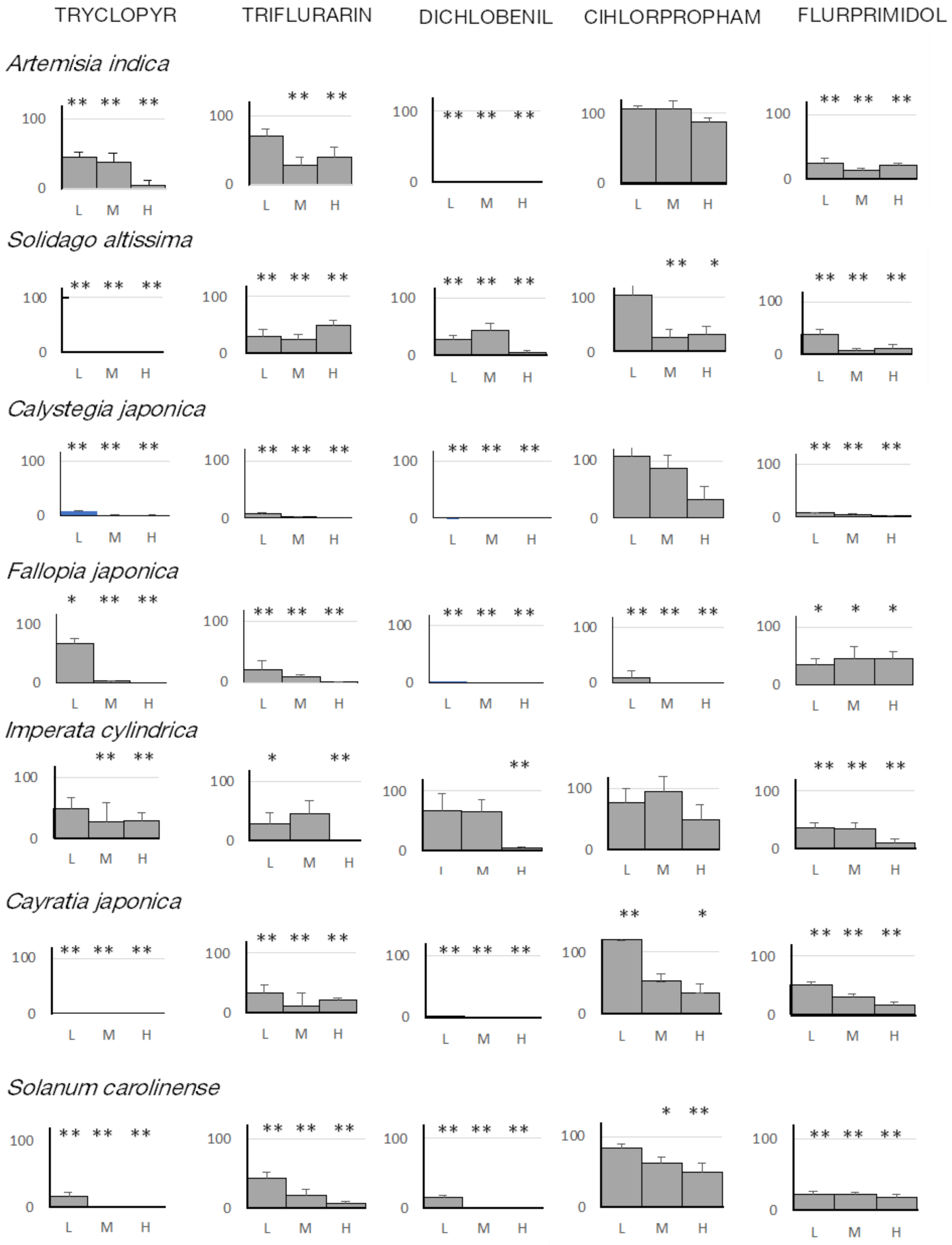
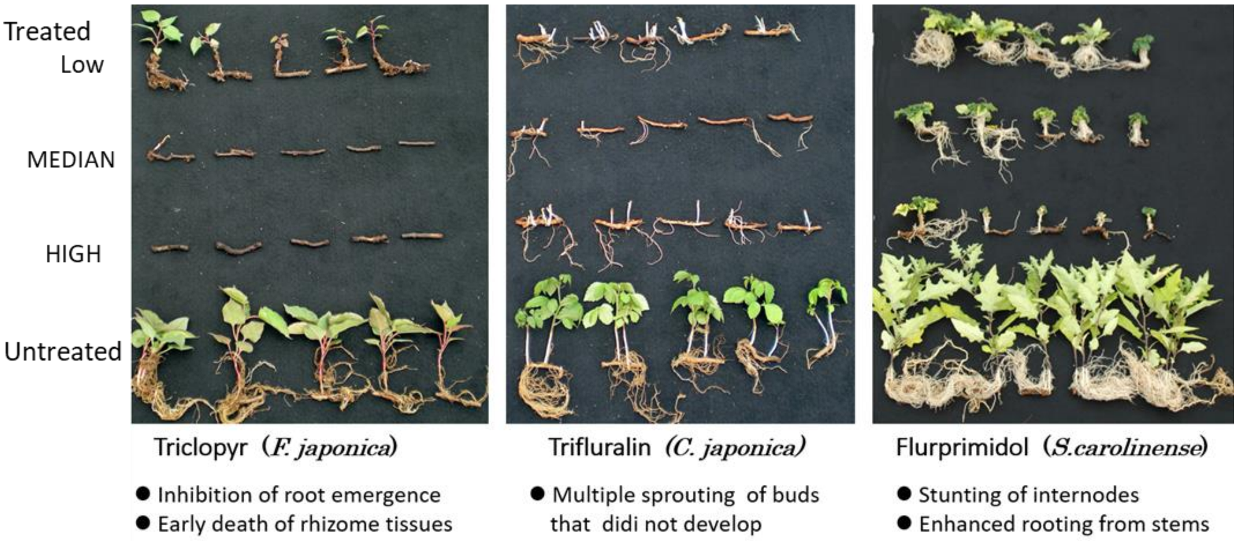


Fig.1 Length of new shoots that grew from the rhizome or creeping root segments placed in soil treated with different chemicals. The results are expressed as % of the untreated control. L, M and H represent low, median and high concentrations, respectively. Vertical bars indicate the standard error. Asterisks * and ** indicate significant differences from the untreated control at P<0.05 and P<0.01, respectively.

In addition, one or more chemicals were proved to be available for effective control of species provided in this experiment, although which chemical is the best for each species did not identified because the application rates used were rather tentative. It was also apparent that physiological differences among the chemicals were reflected in the features of new growth (Fig. 2). As a whole, the experiment revealed that the chemicals dispersed in soil would surely be absorbed by plant parts and affect the sprout and development of buds. Thus, the reliability of our idea aiming to control the subterranean creeping systems with soil injection is supported.



Triclopyr (*F. japonica*)

- Inhibition of root emergence
- Early death of rhizome tissues

Trifluralin (*C. japonica*)

- Multiple sprouting of buds that didi not develop

Flurprimidol (*S.carolinense*)

- Stunting of internodes
- Enhanced rooting from stems

Fig. 2 Examples of differential responses to chemicals observed in the feature of new growth from the segments 7 weeks after application.

Several trials are now underway with typical perennial species to confirm their responses in field conditions in relation to the application technologies such as injection depth, spacing, etc., and soil types. We focus on winter application when target plants are dormant because this satisfies the aesthetic, economic and ecological conditions which are essential for the best vegetation management in urban or non-crop areas. Another advantage is that soil-active chemicals retain their activities in cold climates and provide the precise suppress of spring flushes from subterranean creeping systems.

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Disclosure Statement

The authors declare no conflict of interest.

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