Crop Efficacy and Weed Control Evaluation of a New Herbicide for Sensitive Herbaceous Ornamental Crops

by

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Abstract

Preemergence herbicides are needed in the container nursery industry due to the high cost of hand weeding, but few preemergence herbicides are labeled for use on sensitive herbaceous ornamental crops. Currently, Snapshot® (isoxaben + trifluralin) is the only granular formulated preemergence herbicide labeled for many sensitive herbaceous ornamental crops. Fortress® (isoxaben + dithiopyr) is a new granular preemergence herbicide made by OHP, Inc. for use on sensitive herbaceous ornamental plants. In one experiment, four species of ornamental herbaceous crops in #1 containers were treated with Fortress at 150, 300, and 600 lbs/A, a spray combination of Gallery® (isoxaben) plus Dimension® (dithiopyr) at 0.75+0.38 lbs ai/A, and Snapshot (isoxaben + trifluralin) at 150 lbs/A. Also, #1 containers filled with amended 6 pine bark : 1 sand substrate were treated with Fortress at 100, 150, and 200 lbs/A, Gallery (isoxaben) plus Dimension (dithiopyr) at 0.75+0.38 lbs ai/A, and Snapshot (isoxaben + trifluralin) at 150 lbs/A and then overseeded with 25 seeds of either oxalis, bittercress, eclipta, phyllanthus, spurge, or crabgrass. Fortress had no effect on size index and caused no significant phytotoxicity of crops tested. Fortress had 100% control of bittercress and oxalis 30 and 60 days after treatment (DAT) and significantly better control than other treatments 90 DAT. Fortress controlled eclipta well 30 and 60 DAT. It provided 97.5% to 99.4% control of spurge 30 DAT but almost none 90 DAT. Fortress provided 75% to 76.9% phyllanthus control 60 DAT while Snapshot provided 91.4% control. All herbicide treatments provided at least 90.5% crabgrass control 90 DAT. Fortress had no effect on size index and caused no significant phytotoxicity of the crops tested. In another experiment, #1 containers filled with amended 6 pine bark : 1 sand substrate were

treated with Fortress (isoxaben + dithiopyr) at 100, 150, and 200 lbs/A, Freehand® (dimethenamid-P + pendimethalin), Gemini® (prodiamine + isoxaben), and Snapshot (isoxaben + trifluralin) and then overseeded with 25 seeds of either oxalis, bittercress, eclipta, phyllanthus, spurge, or crabgrass. All herbicide treatments provided at least 95.5% control on oxalis 30, 60, and 90 DAT. Fortress at all rates provided better control than Freehand and Snapshot 120 DAT. Overall, Fortress provided similar bittercress control compared to Snapshot and Gemini, and better control than Freehand. While Fortress at 200 lbs/A provided similar spurge control compared to Snapshot up to 90 DAT, all Fortress provided better spurge control than Snapshot 120 DAT. Fortress at 150 lbs/A provided similar eclipta control compared to Snapshot, while Fortress at 200 lbs/A provided better eclipta control than most treatments. Overall, Fortress at 150 lbs/A provided similar phyllanthus control compared to Snapshot, while Fortress at 200 lbs/A provided better phyllanthus control than all other herbicide treatments.

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WSSA Weed Science Society of America

Lbs Pounds

Oz Ounces

Yd Yard

a.i. Active Ingredient

A Acre

DAT Days After Treatment

g Gram

Chapter 1

Introduction and Literature Review

Weeds are typically the most common problem in container nursery production. They hinder a plant's ability to grow, compete for nutrients, and have an adverse influence on the quality of nursery stock (Robbins and Boyd, 2011). Weeds can drastically affect the growth of a plant. Up to a 43% reduction in crop shoot weight was documented as a result of weed competition (Berchielli-Robertson et al., 1990). A single weed in a #1 container can adversely affect the growth of a nursery crop (Case et al., 2005). Weeds can also be hosts for harmful insects, diseases and pathogens (Altland, 2003).

A major challenge container nurseries face is the high cost of labor for hand weeding (Gilliam et al., 1990). Nurseries can spend up to an estimated $4,000 (equivalent to $5,550 in 2018) per acre each year on weed control (Mathers, 2003). Although hand weeding is still necessary, weed control costs can be reduced when preemergence herbicides are applied (Gilliam et al., 1990). Preemergence herbicides are either liquid or granular chemicals designed to suppress and kill weeds before their shoots emerge from the substrate or soil.

In addition to cost of weed control, there are limited management strategies for specific ornamental plants (Fausey, 2003). Weed management in herbaceous ornamental crops is difficult because there are very few herbicides tolerated by the sensitive nature of these plants (Case et al., 2005). Because of the sensitive foliage of herbaceous crops, it has been difficult to provide good weed control without damaging them. Injuries from preemergence herbicides to herbaceous ornamental crops included leaf burning and stunted growth (Derr, 1994). Spray formulations of herbicides are typically less expensive than granular formulations, but not all herbaceous plant material can be treated with a spray formulation (Senesac, 2004). Although some spray formulations are available, mostly granular preemergence herbicides are used to control weeds in sensitive herbaceous perennial crops (Case et al., 2005).

In a study involving several herbaceous crops, problem weeds, and preemergence herbicides, dithiopyr, pendimethalin, and prodiamine provided excellent weed control with little to no crop injury (Derr, 1994). Another study indicated that along with prodiamine, isoxaben + trifluralin also controlled weeds well, with little injury to herbaceous plants (Mervosh and Ahrens, 1998). Within the last few decades, an increasing number of herbaceous species were added to the labels of pendimethalin, isoxaben, and isoxaben + oryzalin (Case et al., 2005). Dithiopyr, pendimethalin, prodiamine, trifluralin, and oryzalin are used to control grasses and belong to Weed Science Society of America (WSSA) herbicide group 3, which are mitosis inhibitors. Isoxaben is used to control broadleaf weeds and belongs to group 21, which are cellulose synthesis inhibitors (Armstrong, 2017). These herbicides are used primarily on herbaceous crops. Because only a few herbicide groups are represented, herbicide resistance tends to be a big concern when it comes to controlling weeds in herbaceous crops.

The preemergence herbicide options for sensitive herbaceous crops are limited, posing a problem in managing herbicide resistance. Weeds can become resistant to herbicides and survive if the herbicide is used continuously (Case et al., 2005). This resistance occurs because a very small percentage of the target weed population can be genetically different, allowing these plants to survive even if the rest of the population is successfully killed. The one plant, or small group of plants, continues to reproduce while the herbicide being used is ineffectual (Campbell et al., 2011). This is why rotating herbicides with different modes of action to prevent weed populations from developing resistance to a particular mode of action is an important practice. There is a need for more herbicides with different modes of action that are safe for herbaceous crops and that provide effective weed control.

Currently some of the most common herbicides used on herbaceous crops include: isoxaben (Gallery®, DOW Chemical, Midland, MI) and dithiopyr (Dimension®, DOW Chemical, Midland, MI) which are applied as spray formulations, as well as granular formulations such as isoxaben + trifluralin (Snapshot® 2.5TG, DOW Chemical, Midland, MI), dimethenamid-P + pendimethalin (Freehand® 1.75 G, BASF Corporation, Research Park Triangle, NC), and prodiamine + isoxaben (Gemini® G, Everris NA, Inc., Dublin, OH). Combinations in product formulations are common to include both grass and broadleaf weed control.

Regardless of the substrate used in container production, weeds can emerge and reproduce. Some of the most common weeds that affect nurseries are oxalis (*Oxalis stricta* L.), hairy bittercress (*Cardamine hirsuta* L.), common groundsel (*Senecio vulgaris* L.), spotted spurge (*Euphorbia maculata* L.), and mouseear chickweed (*Cerastium vulgatum* L.) (Cross and Skroch, 1992). Other weeds that occur in container production include, but are not limited to, crabgrass (*Digitaria sanguinalis* L.), eclipta (*Eclipta prostrata* L.), henbit (*Lamium amplexicaule* L.), yellow nutsedge (*Cyperus esculentus* L.), and annual bluegrass (*Poa annua* L.) (Case et al., 2005). Not all weeds can be controlled by a single application of herbicide. Several applications throughout the year are typically required. Some weed species require larger rates of herbicide application to successfully suppress weeds. Herbicide companies try to formulate herbicides that control a wide range of weeds while avoiding damage to non-target nursery crops.

OHP, Inc. has developed a new granular preemergence herbicide, isoxaben + dithiopyr (Fortress®, OHP, Inc., Bluffton, SC), for sensitive herbaceous ornamental crops in the nursery industry. Preemergence tank mixtures or combination products are often marketed to combat both broadleaf weeds and grasses. These are common because they reduce the number of preemergence applications that have to be made to control weeds (Marble et al., 2015). Although spray formulations such as Gallery and Dimension contain the same active ingredients (isoxaben and dithiopyr), Fortress is the first herbicide to use dithiopyr in a granular combination. In container production, granular herbicides are the most utilized formulations (Case et al., 2005). There are advantages and disadvantages to both spray and granular formulations, but generally, granular herbicides can be applied more uniformly and more safely while minimizing drift (Altland, 2003). Fortress uses a granular formulation called Verge® (Oil-Dri Corp. of America, Chicago, IL). This type of formulation reduces the amount of dust emitted when applying and allows for better uniformity. Fortress and Snapshot 2.5TG both contain the active ingredient isoxaben for control of broadleaf weeds, but their active ingredients used for controlling grasses differ. Dithiopyr is used in Fortress while trifluralin is used in Snapshot 2.5TG. Isoxaben is used in many herbicide formulations to provide excellent preemergence control of broadleaf weeds (Colbert and Ford, 1987; Saha, et al., 2017). Dithiopyr provided excellent control of grass-like weeds such as crabgrass and was often used in combination with an active ingredient for broadleaf weed control (McCullough et al., 2014). Trifluralin also showed to have excellent control of grass weeds such as crabgrass (Watschke et al., 1989). This poses the question of which formulation and active ingredient will provide the most effective control on grasses as well as broadleaf weeds. Since the herbicides are in the same WSSA herbicide groups, rotation between these herbicides is not a good option to prevent resistance. However, it is important to determine if these chemicals differ in control according to grass weed species so that growers can target problem weeds with the most effective herbicide.

Like all new herbicides, Fortress needs to be tested at several rates on herbaceous crops to determine plant tolerance. It also needs to be tested on common container nursery weeds to determine the rates at which it should be applied to control them. It is important to compare results of the new herbicide to commonly used herbicides in the nursery industry so growers can know the benefits of using one product versus another. The objective of this research was to evaluate a new preemergence herbicide, Fortress, for crop safety and efficacy on herbaceous ornamental crops for over-the-top application and effectiveness of controlling common weeds.

Chapter 2

Fortress Weed Efficacy and Phytotoxicity Compared to Snapshot and Gallery plus Dimension Spray

Introduction

Weed control is one of the biggest problems container nurseries face. Weeds reduce crop quality by taking in nutrients the crops need and overcrowding their containers (Robbins and Boyd, 2011). Weeds can also be hosts for harmful insects, diseases and pathogens (Altland, 2003). Not only do weeds reduce plant growth and harbor pests, they also are costly to control without the use of preemergence herbicides. Hand weeding may still be necessary, but preemergence herbicides drastically reduce the amount of labor needed to control weeds (Gilliam et al., 1990). Preemergence herbicides are designed to kill weeds before they emerge from the soil or substrate by inhibiting the seedling growth (Case et al., 2005).

Two common formulations of herbicides used on herbaceous crops are the tank mixed spray formulation of isoxaben (Gallery®, DOW Chemical, Midland, MI) and dithiopyr (Dimension®, DOW Chemical, Midland, MI) and the granular formulation of isoxaben + trifluralin (Snapshot® 2.5TG, DOW Chemical, Midland, MI). A new product developed by OHP, Fortress®, was formulated to provide weed control in sensitive herbaceous ornamental crops.

The purpose of the first experiment was to determine the efficacy of Fortress at three different rates on six common weeds in southern container nursery production and to compare these treatments to commonly used granular and spray formulations of herbicides designed to control weeds in herbaceous crop production.

In the past, it was difficult to find a large number of herbicides that can be tolerated by sensitive herbaceous ornamental species (Case et al., 2005). However, several studies showed dithiopyr, pendimethalin, prodiamine, isoxaben + trifluralin, and isoxaben + oryzalin to be effective at controlling weeds without damaging herbaceous crops (Case et al., 2005; Derr, 1994; Mervosh and Ahrens, 1998). Both granular and spray formulations were used to control weeds in herbaceous crops, but not all plants can tolerate spray formulations (Senesac, 2004).

Two common formulations of herbicides that are used on herbaceous crops are the tank mixed spray formulation of isoxaben (Gallery) and dithiopyr (Dimension) and the granular formulation of isoxaben + trifluralin (Snapshot 2.5TG).

The purpose of the second experiment was to determine the effects of Fortress at three different rates on the phytotoxicity of four commonly grown herbaceous crops and to compare the effects of these treatments to commonly used granular and spray formulations of herbicides designed to control weeds in herbaceous crop production.

Materials and Methods

On 30 March 2017, #1 containers were filled with a 6 pine bark : 1 sand (by volume) substrate amended with 1.93 kg dolomitic lime/yd^3, 6.55 kg/yd^3 15N-3.9P-10K 12- to 14-month controlled release fertilizer (Osmocote® 15-9-12, ICL Specialty Fertilizers, Dublin, OH), and 0.60 kg/yd^3 MicroMax® (ICL Specialty Fertilizers, Dublin, OH) micro-nutrient package. On 12 April 2017, pots were treated with Fortress at 100, 150, or 200 lbs/A, Gallery + Dimension spray at 0.75 + 0.38 lbs a.i./A, Snapshot 2.5TG at 150 lbs/A, or untreated. On 13 April 2017, ten pots of each treatment were seeded with 25 oxalis (*Oxalis stricta*) seed, and ten pots of each treatment were seeded with bittercress (*Cardamine hirsuta*) seed. Each treatment consisted of 10 containers per weed species and 60 pots per species. Containers were placed by weed species in a randomized complete block design with ten blocks under a retractable roof greenhouse with open sides and closed roof, and under overhead irrigation. Subjective percent coverage ratings were recorded 30, 60, and 90 days after treatment. Fresh weights were recorded 90 DAT.

On 13 June 2017, #1 containers were filled with a 6 pine bark : 1 sand (by volume) substrate amended with 1.93 kg dolomitic lime/yd^3, 6.55 kg/yd^3 15N-3.9P-10K 12- to 14-month controlled release fertilizer (Osmocote 15-9-12), and 0.60 kg/yd^3 MicroMax micro-nutrient package. On 14 June 2017, pots were treated with Fortress at 100, 150, or 200 lbs/A, Gallery + Dimension spray at 0.75 + 0.38 lbs a.i./A, Snapshot 2.5TG at 150 lbs/A, or untreated. On 15 June 2017, pots were seeded with 25 seeds of eclipta (*Eclipta prostrata*), longstalk phyllanthus (*Phyllanthus tenellus*), spurge (*Euphorbia maculata*), or crabgrass (*Digitaria ciliaris*) seed per pot. Each treatment consisted of 10 containers per weed species and 60 pots per species. Containers were placed by weed species in a randomized complete block design with ten blocks in full sun under overhead irrigation. Subjective percent coverage ratings were recorded 30, 60, and 90 days after treatment. Fresh weights were recorded 90 DAT.

On 11 April 2017, #1 containers were filled with a 6 pine bark : 1 sand (by volume) substrate amended with 1.93 kg dolomitic lime/yd^3, 6.55 kg/yd^3 15N-3.93P-9.96K 12- to 14-month controlled release fertilizer (Osmocote 15-9-12), and 0.60 kg/yd^3 MicroMax micro-nutrient package. On 11 April 2017, liners of tickseed (*Coreopsis grandiflora* 'Baby Sun'), purple coneflower (*Echinacea purpurea*), switchgrass (*Panicum virgatum*), and black-eyed Susan (*Rudbeckia fulgida* var. *sullivantii* 'Goldsturm') were transplanted one per container into 48 containers per species. On 12 April 2017, plants were treated with with Fortress at 150, 300, or 600 lbs/A, Gallery + Dimension spray at 0.75 + 0.38 lbs a.i./A, Snapshot 2.5TG at 150 lbs/A, or untreated. Plants were placed in a completely randomized block design by species with ten blocks under overhead irrigation. Plants were placed in full sun. Size indices and flower counts were recorded 90 DAT.

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). Percent coverage efficiency for oxalis, bittercress, eclipta, spurge, phyllanthus, and crabgrass were in a randomized complete block design. The treatment design was a 2-way factorial of herbicide treatment and data recording date. Where residual plots and a significant COVTEST statement with the HOMOGENEITY option indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity. Least squares means comparisons among herbicide treatments were determined using the simulated method. Linear and quadratic trends over data recording date were tested using qualitative/quantitative regression models. Size index and flower count for tickseed were analyzed as a randomized complete block design with treatments in a 1-way design. Least squares means comparisons among herbicide treatments were determined using the simulated method, and the control was compared to other treatments using simulated method. The probabilities of linear or quadratic trends over Fortress rates were determined using orthogonal contrasts. All significances were at α =0.05.

Results

Throughout the experiment, percent weed coverage in untreated containers was typically many times greater than in treated containers. For instance, treated containers had no oxalis or bittercress 30 DAT, while untreated containers had 62% oxalis coverage and 30.5% bittercress coverage. By 60 DAT, untreated containers had 3.4 to 54.4 times greater weed coverage than treated containers. As a result, differences between herbicide treatments were typically masked due to the large differences in weed growth between treated and untreated containers. Untreated containers contained significantly higher percent weed coverage than treated containers 60 DAT among all weed species. Since the main objective of this research was to compare Fortress to industry-accepted herbicides commonly used for herbaceous crops, untreated data was excluded.

All herbicide treatments provided at least 99.5% oxalis control 30 and 60 DAT with no differences between treatments (Table 2.1). Fortress at 100, 150 and 200 lbs/A resulted in less oxalis percent coverage than Gallery + Dimension, and Fortress at 100 and 200 lbs/A resulted in less percent coverage than Snapshot 90 DAT. Oxalis fresh weight 90 DAT was similar across herbicide treatments (data not shown).

All herbicide treatments provided at least 99.5% bittercress control 30 and 60 DAT with no differences between treatments (Table 2.2). Fortress at 100, 150 and 200 lbs/A resulted in less bittercress percent coverage than Gallery + Dimension, and Fortress at 150 and 200 lbs/A resulted in less bittercress percent coverage than Snapshot 90 DAT. Bittercress percent coverage decreased linearly with increasing Fortress rate 90 DAT, but no trend was found for 30 and 60 DAT.

Bittercress fresh weight in containers treated with Fortress at 200 lbs/A was less than those treated with Gallery + Dimension. Bittercress fresh weight in containers treated with Fortress at 100 and 150 lbs/A was similar to those treated with Gallery + Dimension and Snapshot. Bittercress fresh weight decreased linearly with increasing Fortress rate.

Day after treatment was not significant in eclipta percent coverage (Table 2.3). Fortress at 200 lbs/A had less average percent coverage than Snapshot. All Fortress treatments had similar percent coverage as Gallery + Dimension. Eclipta percent coverage decreased linearly with increasing Fortress rate. Eclipta fresh weight 90 DAT was similar across herbicide treatments (data not shown).

Spurge percent coverage was similar and resulted in a quadratic trend with increasing DAT across all herbicide treatments. Spurge fresh weight 90 DAT was similar across herbicide treatments (data not shown).

Phyllanthus percent coverage was similar and resulted in a quadratic trend with increasing DAT across all herbicide treatments. Phyllanthus fresh weight 90 DAT was similar across herbicide treatments (data not shown).

Crabgrass percent coverage and fresh weight were similar across all herbicide treatments with excellent control throughout the study (data not shown).

There were no differences in size indices of tickseed for the Fortress 600 lbs/A, Gallery + Dimension, Snapshot, and control treatments (Table 2.4). Fortress 150 lbs/A and Fortress 300 lbs/A had larger size indices than the untreated. There were no height differences among the treatments. Plants in containers treated with herbicides were different in plant width compared to the control, however plants treated with Snapshot were 43.3 cm in plant width, which was less than Fortress 150 lbs/A and Fortress 300 lbs/A at 56 cm and 61.1 cm, respectively. Plants treated with Gallery + Dimension had a higher flower number than any other treatments, almost 11 flowers per plant. All other treatments' flower counts were not different than the untreated.

There were no differences in size indices, height, or number of flowers between treatments on the other plants in the study.

Discussion

All Fortress treatments provided at least 99.5% control of oxalis 30 and 60 DAT. Fortress at 100 and 200 lbs/A provided better control than Gallery + Dimension and Snapshot 90 DAT. All Fortress treatments provided at least 99.5% control of bittercress 30 and 60 DAT. Fortress at 150 and 200 lbs/A provided better control than Gallery + Dimension and Snapshot 90 DAT. All herbicide treatments provided similar control of eclipta, spurge, phyllanthus, and crabgrass throughout the study.

Gallery + Dimension, Snapshot, and all Fortress treatments showed no suppressive effect on purple coneflower, black-eyed Susan, and switchgrass. There were no differences in size indices, height, or number of flowers within these species.

Tickseed plants treated with Fortress 150 and 300 lbs/A had larger size indices than the untreated but were similar size to other plants treated with herbicides. Tickseed treated with the Gallery + Dimension spray had higher flower numbers than the other treatments.

With these results, it can be concluded that Fortress at all treatment rates, Gallery + Dimension, and Snapshot are safe to use on purple coneflower, black-eyed Susan, and switchgrass. No herbicides affected growth of tickseed, but the plants treated with the two lowest Fortress rates had the highest size indices and plants treated with Snapshot had the lowest size indices.

Table 2.1. Herbicide efficacy on oxalis (*Oxalis stricta*) based on percent coverage.[z]

Treatment	Rate	% Coverage			
		30 DAT	60 DAT	90 DAT	Sign.[y]
Fortress	100 lbs/A	0.0ns[x]	0.0ns	8.2c	NS
Fortress	150 lbs/A	0.0	0.0	13.7bc	L*
Fortress	200 lbs/A	0.0	0.0	3.6c	NS
Gallery + Dimension	0.75+0.38 lbs ai/A	0.0	0.0	36.0a	Q***
Snapshot	150 lbs/A	0.0	0.5	26.6ab	Q**
		Pr > F[v]			
	Fortress linear	1.0000	1.0000	0.4020	
	Fortress quadratic	1.0000	1.0000	0.1021	

[z]The treatment by days after treatment interaction was significant at $P < 0.05$.

[y]Not significant (NS) or significant linear (L) or quadratic (Q) trends using qualitative-quantitative model regression at $P < 0.05$ (*), 0.01 (**) or 0.001 (***).

[x]Least squares means comparisons among treatments (lower case in columns) using the simulated method at $P < 0.05$. ns = not significant.

[v]Probability of linear or quadratic trends over OHP concentrations using orthogonal contrasts.

Table 2.2. Herbicide efficacy on bittercress (*Cardamine hirsuta*) based on percent coverage and fresh weight.[z]

		% Coverage				Fresh weight (g)
Treatment	Rate	30 DAT	60 DAT	90 DAT	Sign.[y]	90 DAT
Fortress	100 lbs/A	0ns[x]	0ns	46.5bc	Q***	1.9ab
Fortress	150 lbs/A	0	0	35.1c	Q**	1.2ab
Fortress	200 lbs/A	0	0	12.4d	NS	0.1b
Gallery + Dimension	0.75+0.38 lbs ai/A	0	0.5	69.5a	Q***	2.6a
Snapshot	150 lbs/A	0	0	60.5ab	Q***	2.3ab
		Pr > F[v]				Pr > F
	Fortress linear	1.0000	1.0000	<0.0001		0.0452
	Fortress quadratic	1.0000	1.0000	0.3453		0.7937

[z]The treatment by days after treatment (DAT) interaction was significant at $P < 0.05$.

[y]Not significant (NS) or significant linear (L) or quadratic (Q) trends using qualitative-quantitative model regression at $P < 0.05$ (*), 0.01 (**) or 0.001 (***).

[x]Least squares means comparisons among treatments (lower case in columns) using the simulated method at $P < 0.05$. ns = not significant.

[v]Probability of linear or quadratic trends over OHP concentrations using orthogonal contrasts.

Table 2.3. Herbicide efficacy on eclipta (*Eclipta prostrata*) based on percent coverage.[z]

Treatment	Rate	% Coverage
Fortress	100 lbs/A	38.8a[y]
Fortress	150 lbs/A	36.6ab
Fortress	200 lbs/A	15.9b
Gallery + Dimension	0.75+0.38 lbs ai/A	27.5ab
Snapshot	150 lbs/A	38.9a
		Pr > F[x]
	OHP linear	0.0064
	OHP quadratic	0.1887

[z]The herbicide treatment main effect was significant at $P < 0.05$.

[y]Least squares means comparisons among treatments (lower case in column) using the simulated method at $P < 0.05$.

[x]Probability of linear or quadratic trends over OHP concentrations using orthogonal contrasts.

Table 2.4. Evaluation of size index and flower count on tickseed (*Coreopsis grandiflora* 'Baby Sun') 90 DAT.[z]

Treatment	Rate	Size index	Flower count
Fortress	150 lbs/A	58.2a[y]	5.9b
Fortress	300 lbs/A	61.4a*	5.4bc
Fortress	600 lbs/A	53.3ab	5.0bc
Gallery + Dimension	0.75+0.38 lbs ai/A	56.1ab	10.9a*
Snapshot	150 lbs/A	46.6ab	2.8c
Control		51.2b	3.4bc
		Pr > F[w]	Pr > F[v]
	Fortress linear	0.0782	0.4310
	Fortress quadratic	0.1057	0.8924

[z]The size index and flower count were significant at $P < 0.05$.

[y]Least squares means comparisons among treatments (lower case in column) using the simulated method at $P < 0.05$.

[x]Least square means comparisons of treatments to the control using the simulate method at $P < 0.05$ (*).

[w]Probability of linear or quadratic trends over OHP concentrations using orthogonal contrasts.

Chapter 3

Fortress Weed Efficacy Compared to Other Commonly Used Granular Herbicides

Introduction

Preemergence herbicides are usually produced in either granular or spray formulations. Both are used in herbaceous ornamental production, but granular preemergence herbicides are most common (Case et al., 2005). Spray formulations of herbicides are typically less expensive than granular formulations, but some plant material is more susceptible to damage from spray formulations (Senesac, 2004). There are advantages and disadvantages to both spray and granular formulations, but generally, granular herbicides can be applied more uniformly and more safely while minimizing drift (Altland, 2003).

Three common granular formulations of herbicides used on herbaceous crops are dimethenamid-P + pendimethalin (Freehand® 1.75G, BASF Corp., Research Triangle Park, NC) at 150 lbs /A, prodiamine + isoxaben (Gemini® G, Everris NA Inc., Dublin, OH), and isoxaben + trifluralin (Snapshot® 2.5TG, DOW Chemical, Midland, MI). A new granular preemergence herbicide developed by OHP, Inc. (Bluffton, SC), Fortress®, was formulated to provide weed control in sensitive herbaceous ornamental crop production.

The purpose of this experiment was to determine the efficacy of Fortress on six common weeds in southern container nursery production and to compare these treatments to commonly used granular formulations of herbicides designed to control weeds in herbaceous crop production.

Materials and Methods

On 19 April 2018, #1 containers were filled with a 6 pine bark : 1 sand (by volume) substrate amended with 7.48 kg/yd^3 15N-3.9P-10K 12- to 14-month controlled release fertilizer with micronutrients (Osmocote® Plus 15-9-12, ICL Specialty Fertilizers, Dublin, OH) and 2.27 kg dolomitic lime/yd^3 . On 2 May 2018, pots were treated with Fortress at 100, 150, or 200 lbs/A, Freehand 1.75G (dimethenamid-P + pendimethalin, BASF Corp., Research Triangle Park, NC) at 150 lbs/A, Gemini G (prodiamine + isoxaben, Everris NA Inc., Dublin, OH), Snapshot 2.5TG (isoxaben + trifluralin, DOW Chemical, Midland, MI), or untreated. On 3 May 2018, 6 pots per treatment were seeded with 25 seeds of oxalis (*Oxalis stricta*), and 6 pots per treatment were seeded with 25 seeds of bittercress (*Cardamine hirsuta*). Containers were placed by weed species in a completely randomized design under a 47% shade structure. Subjective percent coverage ratings were recorded 30 and 60 days after treatment (DAT). On 1 July 2018, weeds were cut down to the substrate and fresh weights were recorded. Glyphosate (Ranger Pro®, Monsanto Company, St. Louis, MO) was then applied to the surface of the substrate at a rate of 2 oz/1 gal. On 2 July 2018, containers were again treated with the same granular herbicide treatments. On 3 July 2018, 25 oxalis or 25 bittercress seed were applied per container. Subjective percent coverage ratings were recorded at 30 and 60 DAT. On 31 August 2018, weeds were cut down to the substrate and fresh weights were recorded.

On 11 June 2018, #1 containers were filled with a 6 pine bark : 1 sand (by volume) substrate amended with 7.48 kg/yd^3 15N-3.9P-10K 12- to 14-month controlled release fertilizer with micronutrients (Osmocote Plus 15-9-12) and 2.27 kg dolomitic lime/yd^3 . On 12 June 2018, pots were treated with Fortress at 100, 150, or 200 lbs/A, Freehand 1.75G at 150 lbs/A, Gemini G at 150 lbs/A, Snapshot 2.5TG 150 lbs/A, or untreated. On 13 June 2018, six pots per treatment were seeded with 25 seeds of eclipta (*Eclipta prostrata*), longstalk phyllanthus (*Phyllanthus tenellus*), spurge (*Euphorbia maculata*), or crabgrass (*Digitaria ciliaris*). Containers were placed by species in a completely randomized design in full sun under overhead irrigation. Subjective percent coverage ratings were recorded 30 and 60 DAT. On 11 August 2018, weeds were clipped at substrate level and fresh weights were recorded. Glyphosate was then applied to the surface of the substrate at a rate of 2 oz/1 gal. On 12 August 2018, containers were again treated with the same granular herbicide treatments. On 13 August 2018, 25 seeds of eclipta, longstalk phyllanthus, spurge, or crabgrass were applied per container. Subjective percent coverage ratings were recorded 30 and 60 DAT. On 11 October 2018, weeds were cut down to the substrate and fresh weights were recorded.

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). The experimental design was completely randomized, and the treatment design was a 2-way factorial of herbicide treatment and days after treatment. The Poisson probability distribution was used for percent coverage and the Gaussian probability distribution was used for fresh weight. Where residual plots and a significant covariance test for homogeneity indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity when using the Gaussian or Poisson distributions. Least squares means comparisons among herbicide treatments were determined using the simulated method. Linear and quadratic trends over days after treatment for percent coverage were examined using qualitative/quantitative model regressions in cases of significant interactions, and simple model regressions were used in cases of significant main effects. Differences between fresh weight days after treatment were determined using F-tests. Linear and quadratic trends over Fortress rates were examined using orthogonal polynomials. Differences among the herbicide treatments were estimated when using the multinomial distribution. All significances were at $\alpha=0.05$.

Results

Throughout the experiment, percent weed coverage in untreated containers was typically many times greater than in treated containers. For instance, untreated containers had on average 1.3 times greater weed coverage than treated containers in the case of eclipta and phyllanthus 60DAT, while untreated containers had on average 47 times greater oxalis coverage than treated containers. As a result, differences between herbicide treatments were typically masked due to the large differences in weed growth between treated and untreated containers. Since the main objective of this research was to compare Fortress to industry-accepted granular herbicides commonly used for herbaceous crops, untreated data was excluded.

All herbicide treatments provided at least 97.7% oxalis control 30 DAT and 90 DAT (30 days after clipping and reseeding) with no differences among treatments (Table 3.1). Fortress at 100 lbs/A had greater percent coverage than Freehand or Gemini 60 DAT, while percent coverage in containers treated with Fortress at 150 and 200 lbs/A were similar to those treated with Freehand, Gemini, and Snapshot. Percent coverage decreased linearly with increasing Fortress rate. Fortress at 150 and 200 lbs/A and Gemini provided at least 99.7% oxalis control 120 DAT, while Fortress at 100 lbs/A had less oxalis percent coverage than Freehand or Snapshot. Oxalis fresh weight 60 and 120 DAT were similar across herbicide treatments (data not shown).

All herbicide treatments provided at least 99.7% bittercress control 30 DAT with no differences among treatments (Table 3.2). Fortress at 100 lbs/A and Freehand had more percent coverage than Fortress at 150 and 200 lbs/A, Gemini, or Snapshot 60 DAT, while Snapshot had less percent coverage than Gemini. Percent coverage changed quadratically with increasing Fortress rate with the lowest coverage at 150 lbs/A. Freehand and Snapshot had more bittercress percent coverage 90 DAT than Fortress at 150 lbs/A or 200 lbs/A, while having similar coverage as Fortress at 100 lbs/A and Gemini. Percent coverage decreased linearly with increasing Fortress rate. Freehand had greater bittercress percent coverage than all other herbicide treatments 120 DAT. Fortress rate had no effect on bittercress control 120 DAT. Bittercress fresh weight 60 and 120 DAT were similar across herbicide treatments (data not shown).

Fortress at 100 lbs/A had greater spurge percent coverage than Fortress at 200 lbs/A, Freehand, or Snapshot 30 DAT, while Fortress at 200 lbs/A had less percent coverage than Gemini (Table 3.3). Percent coverage decreased linearly with increasing Fortress rate. By 60 DAT, spurge percent coverage was at least 44% in all treatments. Freehand and Snapshot had less percent coverage than Fortress at 100 and 150 lbs/A or Gemini. Fortress at 200 lbs/A had similar percent coverage compared to Freehand and Snapshot. Percent coverage decreased linearly with increasing Fortress rate. Fortress at 100 lbs/A had greater percent coverage than all other herbicide treatments 90 DAT. Fortress at 150 lbs/A had less percent coverage than Snapshot, although percent coverage with Fortress at 200 lbs/A was similar to those treated with Snapshot. Percent coverage changed quadratically with increasing Fortress rate with the lowest coverage at 150 lbs/A. Fortress at 100 and 200 lbs/A had less percent coverage than Freehand or Snapshot 120 DAT, while Fortress at 200 lbs/A had a similar percent coverage as Gemini. Percent coverage changed quadratically with increasing Fortress rate with the lowest coverage at 150 lbs/A. Spurge percent coverage decreased with increasing Fortress rate 30 and 60 DAT. Regression analysis of Fortress rate resulted in a quadratic trend 90 DAT with higher percent coverage at 100 lbs/A and similar lower percent coverage at the two higher rates. Spurge fresh weight 60 and 120 DAT were similar across herbicide treatments (data not shown).

All Fortress treatments resulted in less eclipta percent coverage than Freehand or Gemini 30 DAT and a similar percent coverage to Snapshot (Table 3.4). By 60 DAT, all treatments provided poor eclipta control with percent coverage ranging from 45.8% to 99.2%. Fortress at 200 lbs/A had less percent coverage than all other herbicide treatments with 45.8% coverage, while Fortress at 150 lbs/A and Snapshot resulted in less percent coverage than Fortress at 100 lbs/A, Freehand, or Gemini. Fortress at 200 lbs/A resulted in less percent coverage than all other herbicide treatments 90 DAT, while Fortress at 150 lbs/A and Gemini resulted in less percent coverage than Fortress at 100 lbs/A and similar control as Snapshot. Gemini resulted in less percent coverage than all herbicide treatments 120 DAT, while Fortress at 200 lbs/A had less percent coverage than Fortress at 100 lbs/A, Freehand, or Snapshot and similar percent coverage as Fortress at 150 lbs/A. Eclipta percent coverage decreased linearly with increasing Fortress rate 60, 90, and 120 DAT.

Eclipta fresh weight in containers treated with all rates of Fortress was similar to those treated with Snapshot 60 DAT, but lower than those treated with Freehand. Fortress at 150 and 200 lbs/A provided better eclipta control than Gemini. Eclipta fresh weight in containers treated with Fortress at 200 lbs/A was less than eclipta treated with Fortress at 100 lbs/A 120 DAT and similar to those treated with Fortress at 150 lbs/A, Freehand, Gemini, or Snapshot. Eclipta fresh weight decreased with increasing Fortress rate 120 DAT.

Fortress at 100 lbs/A had greater percent coverage of phyllanthus than all herbicide treatments 30 DAT (Table 3.5). Fortress at 150 lbs/A had similar percent coverage compared to Gemini and Snapshot, and less percent coverage than Freehand. Fortress at 200 lbs/A had less phyllanthus percent coverage than all herbicide treatments except Gemini 30 DAT. Percent coverage decreased linearly with increasing Fortress rate. By 60 DAT, phyllanthus percent coverage in containers treated with Fortress at 100 lbs/A and 150 lbs/A was 93.3% and 80.8%, respectively, and higher than percent coverage in containers treated with Gemini, Snapshot, and Fortress at 200 lbs/A. Fortress at 200 lbs/A resulted in less phyllanthus percent coverage than all other herbicide treatments 60 DAT with 21.8% coverage. Fortress at 200 lbs/A and Gemini resulted in less percent coverage than all other herbicide treatments 90 DAT with only 5.3% and 3.7% coverage, respectively. Fortress at 150 lbs/A resulted in similar percent coverage compared to Snapshot and less percent coverage compared to Freehand and Gemini. Percent phyllanthus coverage was higher in containers treated with Fortress at 100 lbs/A compared to all other treatments. By 120 DAT, Fortress at 200 lbs/A and Gemini resulted in less percent coverage than all other herbicide treatments, while Fortress at 100 and 150 lbs/A resulted in greater percent coverage than Freehand and similar percent coverage as Snapshot. Increasing Fortress rate resulted in decreasing quadratic trends 60, 90, and 120 DAT with the lowest percent coverage at 200 lbs/A.

Only herbicide treatment as a main effect was significant for phyllanthus fresh weight. Fortress at 100 lbs/A had higher fresh weight than all other treatments. Fresh weight decreased linearly with increasing Fortress rate.

Crabgrass percent coverage and fresh weight were similar across all herbicide treatments with excellent control throughout the study.

Discussion

All herbicide treatments provided at least 95.5% control on oxalis 30, 60, and 90 DAT. Fortress at all rates provided better control than Freehand or Snapshot 120 DAT. Overall, Fortress provided similar bittercress control compared to Snapshot and Gemini, and better control than Freehand. While Fortress at 200 lbs/A provided similar spurge control compared to Snapshot up to 90 DAT, all Fortress rates provided better spurge control than Snapshot 120 DAT. Fortress at 150 lbs/A provided similar eclipta control compared to Snapshot, while Fortress at 200 lbs/A provided better eclipta control than most treatments. Overall, Fortress at 150 lbs/A provided similar phyllanthus control compared to Snapshot, while Fortress at 200 lbs/A provided better phyllanthus control than all other herbicide treatments.

Table 3.1. Herbicide efficacy on oxalis (*Oxalis stricta*) based on percent coverage.[z]

Treatment	Rate	% Coverage 30 DAT	60 DAT	90 DAT	120 DAT	Sign.[y]
Fortress	100 lbs/A	0ns[x]	4.5a	1.0ns	13.5c	L***
Fortress	150 lbs/A	0	2.2ab	0	0.3d	Q*
Fortress	200 lbs/A	0	1.5ab	0	0d	NS
Freehand	150 lbs/A	0	0.7b	2.3	43.3a	L***
Gemini	150 lbs/A	0.2	0.7b	0	0d	NS
Snapshot	150 lbs/A	0.2	1.3ab	1.7	27.5b	Q**
		Pr > F[v]				
	Fortress linear	1.0000	0.0093	0.9880	0.9860	
	Fortress quadratic	1.0000	0.5918	0.9946	0.9917	

[z]The herbicide treatment by days after treatment (DAT) interaction was significant at P < 0.05.

[y]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using qualitative/quantitative regression models at P < 0.05 (*), 0.01 (**) or 0.001 (***).

[x]Least squares means comparisons among herbicide treatments (lower case in columns) using the simulated method at P < 0.05. ns = not significant.

[w]Linear and quadratic trends were estimated using orthogonal polynomials.

Table 3.2. Herbicide efficacy on bittercress (*Cardamine hirsuta*) based on percent coverage.[z]

		% Coverage				
Treatment	Rate	30 DAT	60 DAT	90 DAT	120 DAT	Sign.[y]
Fortress	100 lbs/A	0.3ns[x]	12.5a	2.3ab	1.3b	Q***
Fortress	150 lbs/A	0.2	3.7bc	0.8b	2.3b	Q*
Fortress	200 lbs/A	0	4.5bc	0.7b	0.7b	Q***
Freehand	150 lbs/A	0.3	15.3a	4.7a	7.7a	Q***
Gemini	150 lbs/A	0	7.0b	1.8ab	1.7b	Q***
Snapshot	150 lbs/A	0	1.7c	4.3a	2.8b	Q***
		Pr > F[v]				
	Fortress linear	0.9829	<0.0001	0.0290	0.2599	
	Fortress quadratic	0.9846	0.0036	0.4478	0.0276	

[z]The herbicide treatment by days after treatment (DAT) interaction was significant at P < 0.05.

[y]Significant (Sign.) quadratic (Q) trends using qualitative/quantitative regression models at P < 0.05 (*) or 0.001 (***).

[x]Least squares means comparisons among herbicide treatments (lower case in columns) using the simulated method at P < 0.05. ns = not significant.

[w]Linear and quadratic trends were estimated using orthogonal polynomials.

Table 3.3. Herbicide efficacy on spurge (*Euphorbia maculata*) based on percent coverage.[z]

Treatment	Rate	% Coverage				
		30 DAT	60 DAT	90 DAT	120 DAT	Sign.[y]
Fortress	100 lbs/A	7.8a[x]	75.0a	15.2a	51.2cd	Q***
Fortress	150 lbs/A	4.3ab	60.8b	3.8cd	62.5bc	L***
Fortress	200 lbs/A	3.3bc	53.3bc	7.2bc	46.2de	Q***
Freehand	150 lbs/A	3.0bc	44.2c	5.7bcd	64.2b	L***
Gemini	150 lbs/A	6.0ab	65.8ab	3.2d	37.8e	Q***
Snapshot	150 lbs/A	1.3c	44.2c	8.3b	96.7a	Q*
		Pr > F[v]				
	Fortress linear	0.0018	<0.0001	<0.0001	0.2171	
	Fortress quadratic	0.4885	0.5436	<0.0001	0.0002	

[z]The herbicide treatment by days after treatment (DAT) interaction was significant at $P < 0.05$.

[y]Significant (Sign.) linear (L) or quadratic (Q) trends using qualitative/quantitative regression models at $P < 0.05$ (*) or 0.001 (***).

[x]Least squares means comparisons among herbicide treatments (lower case in columns) using the simulated method at $P < 0.05$. ns = not significant.

[w]Linear and quadratic trends were estimated using orthogonal polynomials.

Table 3.4. Herbicide efficacy on eclipta (*Eclipta prostrata*) based on percent coverage and fresh weight.[z]

		% Coverage					Fresh weight (g)	
Treatment	Rate	30 DAT	60 DAT	90 DAT	120 DAT	Sign.[y]	60 DAT	120 DAT
Fortress	100 lbs/A	2.3c[x]	93.3a	70.8ab	99.2a	Q***	22.8bc	80.2a
Fortress	150 lbs/A	1.0c	61.7b	48.3c	87.5ab	Q***	5.9c	50.1ab
Fortress	200 lbs/A	2.3c	45.8c	29.2d	82.5b	Q***	5.8c	29.6b
Freehand	150 lbs/A	15.0a	99.2a	78.3a	100.0a	Q***	64.1a	75.6ab
Gemini	150 lbs/A	9.2b	96.7a	56.0c	63.3c	Q***	44.6ab	54.4ab
Snapshot	150 lbs/A	2.3c	65.0b	57.5bc	100.0a	Q***	10.2c	69.1ab
		Pr > F[w]					Pr > F[w]	
	Fortress linear	1.0000	<0.0001	<0.0001	0.0030		0.0974	0.0054
	Fortress quadratic	0.0621	0.3574	0.4075	0.5342		0.3387	0.7452

[z]The herbicide treatment by days after treatment (DAT) interaction was significant at $P < 0.05$.

[y]Significant (Sign.) quadratic (Q) trends using qualitative/quantitative regression models at $P < 0.001$ (***).

[x]Least squares means comparisons among herbicide treatments (lower case in columns) using the simulated method at $P < 0.05$.

[w]Linear and quadratic trends were estimated using orthogonal polynomials.

Table 3.5. Herbicide efficacy on phyllanthus (*Phyllanthus tenellus*) based on percent coverage and fresh weight.[z]

		% Coverage					Fresh weight (g)
Treatment	Rate	30 DAT	60 DAT	90 DAT	120 DAT	Sign.[y]	Treatment
Fortress	100 lbs/A	39.3a[x]	93.3a	65.0a	93.3a	Q***	60.7a
Fortress	150 lbs/A	6.2c	80.8ab	35.0b	92.5a	Q***	19.0b
Fortress	200 lbs/A	0.7d	21.8e	5.3d	49.2c	L***	4.2b
Freehand	150 lbs/A	11.0b	70.0bc	13.0c	68.3b	L***	16.8b
Gemini	150 lbs/A	2.8cd	46.0d	3.7d	50.2c	L***	10.7b
Snapshot	150 lbs/A	5.3c	61.7c	27.7b	81.8ab	Q***	21.8b
		Pr > F[w]					Pr > F
	Fortress linear	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001
	Fortress quadratic	0.5381	<0.0001	<0.0001	<0.0001		0.0364

[z]The herbicide treatment by days after treatment (DAT) interaction was significant for percent coverage, and the herbicide treatment main effect was significant for fresh weight at $P < 0.05$.

[y]Significant (Sign.) linear (L) or quadratic (Q) trends using qualitative/quantitative regression models at $P < 0.001$ (***).

[x]Least squares means comparisons among herbicide treatments (lower case in columns) using the simulated method at $P < 0.05$.

[w]Linear and quadratic trends were estimated using orthogonal polynomials.

Chapter 4

Conclusion

In the phytotoxicity study from Chapter 2, none of the three Fortress treatments, Gallery + Dimension, or Snapshot caused leaf burn or damage to the four herbaceous species studied.

In the weed efficacy portion of Chapter 2, all Fortress treatments provided 100% control of oxalis and bittercress 30 and 60 DAT. Fortress at 100 and 200 lbs/A provided better oxalis control than Gallery + Dimension and Snapshot 90 DAT. Fortress at 150 and 200 lbs/A provided better bittercress control than Gallery + Dimension and Snapshot 90 DAT. Fortress and Gallery + Dimension have the same active ingredients (isoxaben and dithiopyr) but differ in that Fortress is granular and Gallery + Dimension is a spray formulation. Throughout the study Fortress provided better control of oxalis and bittercress than Gallery + Dimension and similar control of eclipta, spurge, phyllanthus, and crabgrass as Gallery + Dimension. All herbicide treatments provided similar control of eclipta, spurge, phyllanthus, and crabgrass throughout the study.

In Chapter 3, all herbicide treatments provided at least 95.5% control on oxalis 30, 60, and 90 DAT. Fortress at all rates provided better control than Freehand and Snapshot. Overall, Fortress provided similar bittercress control compared to Snapshot and Gemini, and better control than Freehand. While Fortress at 200 lbs/A provided similar spurge control compared to Snapshot up to 90 DAT, all Fortress provided better spurge control than Snapshot 120 DAT. Fortress at 150 lbs/A provided similar eclipta control compared to Snapshot, while Fortress at 200 lbs/A provided better eclipta control than most treatments. Overall, Fortress at 150 lbs/A provided similar phyllanthus control compared to Snapshot, while Fortress at 200 lbs/A provided better phyllanthus control than all other herbicide treatments.

These studies have shown that Fortress can provide as good or better weed control as some of the industry standard preemergence herbicides. Furthermore, the studies showed that Fortress can be used for its intended purpose of controlling weeds without damaging herbaceous crops. Because it is the first granular combination of isoxaben and dithiopyr, interest in Fortress may be significant for those wanting to apply granular formulations of preemergence herbicides as opposed to spray formulations. Although Fortress did not suppress herbaceous crops and provided good control of weeds, the active ingredients do not provide new modes of action that would assist in preventing weed resistance by herbicide rotation. However, Fortress does use Verge granules that reduce the amount of dust and odor during application.

Further research on preemergence herbicides should be done to continue to determine which chemicals help growers create most optimal growing environments for container grown plant material. Further studies should also be done with Fortress such as determining safety on other herbaceous crops, efficacy on other weed species, and effectiveness in other temperature zones.

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