Imazapyr, A New Tool for Forest Site Preparation in California: A Two-Year Program Report for a Multilocation Study of Imazapyr Rate, Application Timing and Conifer Planting Timing Across Varying Precipitation Regimes

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Introduction

Imazapyr is a newly registered herbicide in California used primarily for forest vegetation management, control of noxious weeds on forestry sites and wildland areas, and certain right-of-way, industrial and non-crop uses. For forestry sites, imazapyr is available in a water soluble liquid formulation containing four pounds acid equivalent (ae) per gallon (Arsenal® Applicators Concentrate) or as an emulsifiable concentrate containing two pounds ae per gallon (Chopper®). Stalker®, also an emulsifiable concentrate formulation, is registered for industrial, right-of-way, and non-crop uses in California. Imazapyr is in the imidazolinone herbicide family, structurally similar to herbicides used in food crop production. Imazapyr is absorbed through foliage, root and stem tissues and translocates quickly in the apoplasm (xylem) and symplasm (phloem) with accumulation in meristematic regions (Shaner 1988). Imazapyr is an uncompetitive inhibitor of acetohydroxyacid synthase (AHAS), also known as acetolactate synthase (ALS) (EC 4.1.3.18), an enzyme mediating the first and rate limiting reaction leading to the synthesis of branched chain amino acids valine, leucine and isoleucine (Shaner et al. 1984, Anderson and Hibberd 1985). This enzyme is not found in humans, birds, fish, insects and other animals, accounting in part for imazapyr's low toxicity (Ahrens 1994).

Imazapyr is in animal toxicity category IV, the lowest toxicity category. Oral and dermal LD_{50} values are greater than 5,000 mg/kg. Imazapyr does not cause skin irritation, skin sensitization, or eye irritation. Imazapyr is classed in carcenogenicity group E, with no evidence of carcenogenic effects, the safest rating. Imazapyr is not teratogenic or mutagenic. Imazapyr has limited vertical movement in soil due to sorbption by clay and organic colloids and moderate water solubility (11,272 mg/l), with residues detected only within 15 cm of the soil surface (Mangels 1991). The field half-life of imazapyr ranges from 25-142 days in published studies, depending on soil type and environmental conditions. Microbial degradation is the principal means of imazapyr dissipation in soil. In water, rapid photodegradation occurs, with a 2-3 day half-life in shallow ponds. Imazapyr is a non-volatile herbicide.

Although field testing for forest vegetation management was just initiated in 1996 (Fredrickson and DiTomaso 1997), Arsenal and Chopper are the most widely used forestry herbicides in the Southern United States, particularly for loblolly pine (*Pinus taeda*) management. Applications may be made pre- or post-emergence for herbaceous weed control, but weed control is most effective with early post-emergence timing. Pre-plant herbaceous weed control applications provide the best conifer selectivity but require higher use rates to ensure adequate duration of weed control. For woody plant control, including hardwood brush and trees, optimum application timing is generally late in the growing season (mid-July through September) (Minogue, 1985). Conifer tolerance is also best late in the growing season, so over-the-top conifer release applications are normally planned for this period. Non-selective applications such as directed spray and site preparation may be accomplished prior to the late season by use of higher herbicide rate, tank mixtures, and applications with the emulsifiable concentrate formulation Chopper® in oil emulsion carrier which appears to improve foliar absorption (Minogue, et al. 1996, Minogue, et al. 1997). The optimum timing for cut stem, cut stump, and basal stem treatment is also during the late-season period but applications throughout the year are effective, except for a brief period in the early spring during strong sapflow.

Forests in California offer a great diversity in environmental conditions; elevation, rainfall, soils, crop tree species and associated plant communities. Rainfall and soil organic matter are expected to strongly influence microbial degradation rates and thus imazapyr persistence and herbicide rate response. This research was initiated on sites with contrasting environments to explore imazapyr rate and application timing effects for shrub, tree-forming hardwood, and herbaceous weed control in site preparation applications. Conifer tolerance was determined for early and late planting dates for Douglas-fir (*Pseudotsuga menziesii*), Ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), Redwood (*Sequoia sempervirens*), red fir (*Abies magnifica*), and white fir (*Abies concolor*). This report presents second-year results from this five-year study. First-year findings were published by DiTomaso and others, 1999.

Methods

A similar study design was established at three locations in Northern California (Table 1) to examine imazapyr rate and timing as main plots (Table 2). Treatments were assigned in a completely randomized design or randomized complete block design (Dana location, blocked on slope position) with 3 or, in the case of the McCloud location, 6 replications of main treatments. Main plots were split into four quadrant subplots to test conifer crop species and planting date effects.

Table 1. Environmental parameters and crop tree species for three study locations in Northern California.

Study Location	Cooperator	Rainfall (inches/yr)	Elevation (feet)	Crop Tree Species
Smith River	Simpson	120	300	Douglas- fir, Redwood
McCloud	Sierra Pacific	45	6000	Douglas-fir, Ponderosa pine, Red fir, White fir
Dana	Sierra Pacific	25	4000	Douglas-fir, Ponderosa pine, Sugar Pine

Herbicides were applied to 36x50 ft main plots using a CO_2 pressurized backpack research sprayer with a 12 ft, hand-held boom fitted with eight 8002 nozzles delivering 16 gallons per acre total spray volume at 25 psi. Imazapyr was tested using the Chopper formulation in 25% (vol:vol) Hasten® esterified seed oil carrier at 0.125, 0.25, 0.5, and 1.0 lb ae/acre (8, 16, 32, and 64 oz Chopper product per acre). At the Dana location, Arsenal AC was also applied at the late application timing using water carrier with 1% R-11 surfactant at 0.125, 0.25, and 0.5 lb ae/A (4, 8, and 16 oz Arsenal AC product per acre). At the Smith River and Dana locations, two application timings, targeted for May and August, were also tested in main plots. Herbicide treatments were compared to an untreated control, one for each application timing. Early versus late planting timing and crop tree species were tested in quadrant subplots within each of the rate and timing main plots, with random assignment of split plot treatments.

Arborescent hardwood rootstocks were assessed for species and live height in a 28x42 ft hardwood measurement subplot prior to treatment and at 1 and 2 years after treatment (YAT). Percent cover for groups; grass, sedge, forb, *Rubus*, vine, legume, fern, shrub, tree, weed free and debris was assessed in two 14x21ft quadrant subplots in each main plot prior to treatment and at 1 and 2 YAY. Dominant vegetation, having 5% or more of total cover, was assessed for percentage cover by individual species in the two quadrants at these same times.

Fifteen individuals of each crop tree species were planted into 14x21 quadrants. Seedlings were measured for total height in inches and groundline diameter in mm following planting and during the first and second dormant season following treatment. During the first and second growing season, following elongation of the spring flush, seedlings were assessed for phytotoxic symptoms using the condition following codes: 0=no damage, 1=chlorosis of foliage, 2=necrosis of foliage, 3=abnormal apical leader, 4=fasciculation in elongating shoots, 5=leader dieback, 6=mortality. Seedlings are assigned the code indicating the worst damage, ie the highest number.

Table 2. Herbicide treatments tested.

Main Plots

Product	Imazapyr Rate (lb ae/A)	Product Vol. (fluid ounces)	Carrier	Application Timing
Chopper	0.125	8	25% Hasten	May
Chopper	0.25	16	25% Hasten	May
Chopper	0.50	32	25% Hasten	May
Chopper	1.0	64	25% Hasten	May
Untreated Check	0	0		May
Chopper	.125	8	25% Hasten	3rd week August
Chopper	0.25	16	25% Hasten	3rd week August
Chopper	0.50	32	25% Hasten	3rd week August
Chopper	1.0	64	25% Hasten	3rd week August
Untreated Check	0	0		3rd week August
Arsenal AC	0.125	4	1% R-11	3rd week August
Arsenal AC	0.25	8	1% R-11	3rd week August
Arsenal AC	0.50	16	1% R-11	3rd week August

Application Date	Smith River	McCloud	Dana
May target	May 26, 1997	August 1, 1997	May 20, 1997
August target	July 30, 1997		July 31, 1997

Split Plots - For the planted crop tree species given for each location in Table 1

Planting Date	Smith River	McCloud	Dana
Early	December 8, 1997	October 29, 1997	October 25, 1997
Late	February 12, 1998	June 16, 1998	March 20, 1998

Results And Discussion

Vegetation

The Smith River study was installed in a two-year-old redwood and Douglas-fir plantation and had established vegetation when herbicides were applied (Table 3). The McCloud location was intensively prepared with machinery and was essentially bare ground when treatments were applied. The Dana study was also established in an existing one-year-old Ponderosa pine and Douglas-fir plantation, and thus had herbaceous vegetation, shrubs, and some tree species at the time of treatment.

Table 3. Associated woody and herbaceous vegetation at the three study locations.

Location	Woody Species	Herbaceous Species
Smith River, CA Del Norte Co.	Blue blossom (*Ceanothus thyrsiflorus*) Huckleberry (*Vaccinium spp*.) Coyotebush (*Baccharis pilularis*) Red alder (*Alnus rubra*) Blackberries and raspberries (*Rubus spp*.)	Fireweed (*Erechtites sp*.) Silver hairgrass (*Aira caryophyllea*) Blue wildrye (*Elymus glauca*) Japanese cudweed (*Gnaphalium japonicum*) Jubatagrass (*Cortaderia jubata*)
McCloud, CA Siskiyou Co.	Greenleaf manzanita (*Arctostaphylos patula*) Whiteleaf manzanita (*Arctostaphylos viscada*) Chinquapin (*Chrysolepis* sp.) Snowberry (*Symphoricarpos albus*) Bittercherry (*Prunus emarginata*)	Sedge (*Carex* spp.)
Dana, CA Shasta Co.	Squaw carpet (*Ceanothus prostratus*) Black oak (*Quercus kelloggii*) Greenleaf manzanita (*Arctostaphylos patula*) White fir (*Abies concolor*) Snowberry (*Symphoricapos albus*)	Sedge (*Carex* spp.) *Apocynum cannabinum* *Amelanchier alnifolia* *Cirsium vulgare* *Gayophytum sp*.

Effect of application date

In considering application date effects, one must recognize that differences between the two dates are due in part to treatment effects but are also influenced temporal differences; simply, different plants are present at May verses August assessment dates. Analysis of variance components showed significant application date effects only at the Smith River location (Table 4). At two years following treatment, sedge, forb, legume, and tree cover were greater for the May than August application. Tree cover would be least influenced by temporal differences, since these are perennial. Studies of application timing in other regions have demonstrated optimum tree forming hardwood control for applications late in the growing season. Cover for the weed free component was greater in August than May, but differences were not large.

Table 4. Percent cover 2 YAT for groups having a significant application date effect at the Smith River location.[1]

Date	Grass	Sedge	Forb	Legume	Tree	Weed Free
	(%)					
May	16 B	2.6 A	50 A	2.1 A	5.0 A	8 B
August	25 A	1.1 B	41 B	0.2 B	0.9 B	12 A
P>F [2]	.0065	.0012	.0122	.0001	.0074	.0012

[1]Within a column, means following by the same letter are not significantly different using Duncan's New Multiple Range Comparison at alpha=0.05. (n=15 plots)
[2]The probability of a greater F statistic for application date source effects from analysis of variance components.

Effect of imazapyr rate

At the Smith River location application rate had a significant effect on percent cover of shrub, tree, and weed free components. Cover of woody plants decreased with increasing imazapyr rate and weed free cover increased with increasing rate as would be expected. Orthogonal contrasts were done to examine linear, quadratic, and cubic effects for rate response. Cover of these components showed significant linear effects for the response to rate (shrub P>F .0007, tree P>F .0382, weed free P>F .0011) with significant quadratic (P>F .0036) and cubic (P>F .0217) effects shown for shrub cover.

Table 5. Percent cover for groups having a significant application rate effect 2 YAT at the Smith River location.[1]

Imazapyr Rate (lb ae/A)	Shrub	Tree	Weed Free
	(%)		
0	5.7 A	7.4 A	6.3 B
0.125	2.3 B	3.0 AB	7.5 B
0.25	1.0 B	0.8 B	10.4 AB
0.5	1.2 B	3.3 AB	12.5 A
1.0	0.8 B	0.5 B	12.9 A
P>F[2]	.0004	.0789	.0081

[1]Within a column, means followed by the same letter are not significantly different using Duncan's New Multiple Range Comparison at alpha=0.05. (n=6 plots)
[2]The probability of a greater F statistic for imazapyr rate source effects from analysis of variance components.

At the McCloud location significant rate effects were observed at 2 YAT for sedge, shrub, and weed free components (Table 6). Only small amounts of plant cover were present and differences in cover between application rates were not large, but cover for sedge and shrub components decreased with increasing rate whereas weed free cover increased with rate. Orthogonal contrasts showed highly significant linear rate effects for all three cover variables (P>F .0001).

Table 6. Percent cover for groups having a significant application rate effect 2 YAT at the McCloud location.[1]

Imazapyr Rate (lb ae/A)	Sedge	Shrub	Weed Free
	- - - - - - - - (%) - - - - - - - -		
0	1.3 A	2.2 A	96.6 C
0.125	1.0 AB	1.2 B	98.8 B
0.25	0.7 BC	0.9 BC	99.0 AB
0.5	0.4 C	0.8 BC	99.1 AB
1.0	0.4 C	0.6 C	99.3 A
P>F[2]	.0005	.0001	.0001

[1]Within a column, means followed by the same letter are not significantly different using Duncan's New Multiple Range Comparison at alpha=0.05. (n=12 plots)
[2]The probability of a greater F statistic for imazapyr rate source effects from analysis of variance components.

Imazapyr rate had a significant effect only on shrub and weed free cover for the 2 YAT assessment at the Dana location (Table 7). Shrub cover decreased and weed free cover increased with increasing imazapyr rate in a linear fashion, as determined by orthogonal contrasts (shrub P>F .0003, weed free P>F .0094). For weed free cover only the 1.0 lb ae/A imazapyr rate was significantly greater than the check at this assessment.

Table 7. Percent cover for groups having a significant application rate effect 2 YAT at the Dana location.[1]

Imazapyr Rate (lb ae/A)	Shrub	Weed Free
	- - - - - - (%) - - - - - -	
0	10 A	69 B
0.125	5.6 AB	73 B
0.25	5.8 AB	74 B
0.5	1.8 B	72 B
1.0	1.0 B	82 A
P>F[2]	.0018	.0432

[1]Within a column, means followed by the same letter are not significantly different using Duncan's New Multiple Range Comparison at alpha=0.05. (n=6 plots)
[2]The probability of a greater F statistic for imazapyr rate source effects from analysis of variance components.

Conifer tolerance and seedling growth

At the Smith river study location there were no significant effects of imazapyr rate or application timing on redwood and Douglas-fir crop tree height at 1 YAT, groundline diameter at 1 YAT, survival at 2 YAT, and all various seedling condition codes 2 YAT. Second dormant season height and diameter data have been only recently collected and data entry is in progress. To further examine possible injury effects on planted crop trees orthogonal contrasts for Chopper treatment versus the untreated check showed no effect on survival 2 YAT (Douglas-fir P>F .7823, redwood P>F .4839) or percentage of seedlings showing no symptoms at the 2 YAT assessment (Douglas-fir P>F .7977, redwood P>F .7192). At this study location 885 seedlings were assessed for each crop tree species. A few of the Douglas-fir seedlings treated with 1.0 lb ae/A, 25% more than the maximum labeled rate, showed evidence of imazapyr symptoms. Interestingly, two-year-old redwood seedlings oversprayed during study establishment showed severe injury, but most had resumed normal growth in the second growing season.

At the McCloud location there were significant imazapyr rate effects 2 YAT only for ponderosa pine (Table 8). Imazapyr treatment did not have a significant effect on seedling survival, but seedling height was less than the untreated check with 1.0 lb ae (twice the maximum labeled rate) and groundline diameter was less than the check for the 0.5 and 1.0 lb rates. This location has little weed cover and thus the effect herbicide absorption by associated plants has little impact on rate response in conifer tolerance.

At the Dana study location no significant Chopper or Arsenal rate effects were observed for Ponderosa pine, Douglas-fir, or sugar pine height, groundline diameter, or seedling survival at the assessments two years after treatment. Seedling phytotoxic symptom codes collected during the second growing season following treatment indicated no significant Chopper or Arsenal rate effects, except for Ponderosa pine (Table 9). A comparison of the mean percentage of trees showing no symptoms (or mortality) for

Table 8. Ponderosa pine seedling height, groundline diameter, and survival as effected by imazapyr rate at the McCloud study location in the second dormant season following planting.[1]

Imazapyr Rate (lb ae/A)	Total Height (inches)	Groundline Diameter (mm)	Survival (%)
0	12.5 AB	11.4 A	93
0.125	13.1 A	11.9 A	94
0.25	12.2 AB	11.2 A	93
0.5	11.6 BC	9.6 B	94
1.0	10.7 C	8.5 B	88
P>F [2]	.0107	.0005	.9831

[1]Within a column, means followed by the same letter are not significantly different using Duncan's New Multiple Range Comparison at alpha=0.05. (n=6 plots)
[2]The probability of a greater F statistic for imazapyr rate source effects from analysis of variance components.

Chopper and Arsenal application dates and rates indicate no differences from the check except for the 0.5 lb Arsenal treatment in August and the 1.0 lb Chopper rate applied in May and August. These results indicate that Chopper rates should not exceed 0.5 lb ae/A to ensure tolerance to planted Ponderosa pine on dry sites.

Table 9. Percentage of Ponderosa pine seedlings showing no symptoms 2 YAT at the Dana location.[1]

Imazapyr Rate (lb ae/A)	Chopper May	Chopper August	Arsenal AC August
	(%)		
0	84 A	89 A	
0.125	84 A	87 A	88 A
0.25	98 A	93 A	85 A
0.5	83 A	74 AB	61 BC
1.0	54 BC	49 C	

[1]For all means in this comparison, those followed by the same letter are not significantly different using Duncan's New Multiple Range Comparison at alpha=0.05. (n=3 plots of 15 seedlings)
[2]The probability of a greater F statistic for imazapyr rate source effects from analysis of variance components.

Effect of planting date

Significant planting date effects were evident for all crop tree species planted at the McCloud study location; Douglas-fir. Ponderosa pine, red fir, and white fir. Seedling survival and growth was better for the October planting than June for all species except white fir. Large difference in seedling survival were noted for Douglas-fir, red fir, and white fir between the two planting dates.

Table 10. Comparison of October, 1997 and June, 1999 planting dates on crop tree seedling height, groundline diameter (GLD), and survival during the second dormant season following treatment at the McCloud study location.[1]

Planting	Ponderosa Pine			Douglas-fir			Red fir			White fir		
	Height (in)	GLD (mm)	Surv. (%)	Height (in)	GLD (mm)	Surv. (%)	Height (in)	GLD (mm)	Surv (%)	Height (in)	GLD (mm)	Surv. (%)
October	13 A	12 A	99 A	n.s.	8 A	73 A	9 A	n.s.	76 A	8 B	6 B	67 B
June	11 B	9 B	86 B	n.s.	7 B	46 B	7 B	n.s.	43 B	9 A	7 A	80 A
P>F[2]	.0008	.0001	.0011		.0183	.0001	.0001		.0001	.0118	.0250	.0056

[1]Within a column, means followed by the same letter are not significantly different using Duncan's New Multiple Range Comparison at alpha=0.05. (n=6 plots)
[2]The probability of a greater F statistic for imazapyr rate source effects from analysis of variance components.

Conclusions

Imazapyr persistence is largely determined by rates of microbial degradation. The study locations contrast sites with varying rainfall, soil organic matter, elevation, and associated vegetation. At the Smith River location the persistence of herbaceous weed control was short, a few months, in contrast to the McCloud and Dana locations where lower rainfall and a shorter growing season provided slower microbial degradation and herbaceous weed control for two or more years. Imazapyr is known for broad spectrum control of woody shrubs and trees, including some species difficult to control with other herbicides such as tanoak, blueblossom, black oak, and bigleaf maple. Site preparation applications to control established brush, following harvest or in forest site rehabilitation, will provide long-term control of competing brush.

Conifer tolerance for planted Douglas-fir, redwood, red fir, white fir, and sugar pine was very good with Chopper and Arsenal site preparation applications, even with rates in excess of label recommendations (1 lb ae/A). This study demonstrated concerns for the use of imazapyr rates greater than 0.5 lb ae/A for site preparation in advance of planting Ponderosa pine in dry sites or at high altitude.

This work adds to a growing body of research information which will enable site-specific recommendations to best meet the needs of vegetation managers. Additional measurements and analyses are planned to garnish species control information and crop growth response in the coming years.

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