AN ABSTRACT OF THE THESIS OF

Amir Attarian for the degree of Master of Science in Crop Science presented on March 6, 2013.

Title: Weed Management for Giant Reed (*Arundo donax L.*) Biomass Production in Oregon

Abstract approved:

Carol A. Mallory-Smith

Giant reed (*Arundo donax L.*) is a candidate to provide feedstock for the Portland General Electric power plant in Boardman, Oregon. Giant reed is a fast perennial grass, producing 23-27 metric tons ha^{-1} of biomass and has the ability to adapt to diverse environments making it a good candidate for biomass production. This study tested postemergence and preemergence herbicides for controlling weeds in giant reed during the establishment year in which giant reed plants are more sensitive to weed competition. The greenhouse study demonstrated that among the tested herbicides, bromoxynil plus MCPA at 0.841 kg ai ha^{-1}, nicosulforun at 0.035 kg ha^{-1}, and dimethenamid-p at 0.735 kg ha^{-1} did not injure giant reed. In a field study, preemergence application of dimethenamid-p at 0.735 kg ha^{-1} followed

by a postemergence application of 2,4-D amine at 0.560 kg ha^{-1} and a postemergence application of bromoxynil plus MCPA at 0.841 kg ha^{-1} did not injure giant reed. The presence of weeds in a field does not always mean that crop yield will be reduced and there are some periods during the growing season when weeds will not cause considerable yield loss. Therefore, predicting a critical period of weed control (CPWC) that includes the best time for weed control in giant reed could improve weed management in the field. The length of the CPWC could be different depending on the level of acceptable yield loss (AYL). Our results are reported for AYL of 5 and 10%. The CPWC started at 290 accumulated growing degree days (GDD) and ended at 820 for a 5% AYL, while for a 10% AYL, it started at 333 GDD and ended at 727 GDD. Based on the results, there are some herbicides which could be selected for further study for weed control in the giant reed and the estimated CPWC which could be used to inform weed management practices in giant reed production.

Weed Management for Giant Reed (*Arundo donax*) Biomass Production in Oregon

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Amir Attarian, Author

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Dedication

To my father, **Hassan Attarian**, who gave so much to others and asked nothing for himself.

Weed Management for Giant Reed (*Arundo donax*) Biomass Production in Oregon

General Introduction

Energy crops are cultivated with the purpose of using their biomass to produce energy. As such, they have attracted increasing interest because they may satisfy a part of the energy demand and at the same time reduce carbon dioxide emission (Ragauskas et al. 2006). These plants can potentially be grown in large fields and reduce carbon emissions from fossil fuels. Perennial, rhizomatous grasses display several positive attributes as energy crops because of their high productivity, low demand for nutrient inputs due to the recycling of nutrients by their rhizomes, and their tolerance to biotic and abiotic stresses (Renz et al. 2009). Among these grasses, giant reed (*Arundo donax* L.) is of special interest as an energy crop because it ranked first in some comparative studies for yield (Lewandowski *et al*. 2003). Recently, giant reed has been considered as a biomass crop for replacing coal at the Portland General Electric (PGE) power plant at Boardman, Oregon, because PGE need to find alternative fuel source to reduce carbon emissions due to coal use. Giant reed is a strong candidate to be used as a renewable biofuel source because of its fast growth rate, ability to grow in different soil types and adaptability to different climatic conditions (Angelini et al. 2005). Giant reed is tolerant to different soils and environmental conditions (Bell 1997). Giant reed is capable of producing 23-27 metric tons ha^{-1} of dry biomass (Angelini et al. 2005).

Rieger et al. (1989) reported that giant reed growth rates from established rhizomes in California, averaged 6 cm per day in the first 40 growing days and 2.5 cm per day in the first 150 growing days. Perdue (1958) reported giant reed can grow more than 5 cm per day under optimal conditions. Dormant giant reed is able to survive temperatures as low as 0 C, but it can suffer severe damage by frost at the seedling stage or during spring re-growth (Perdue 1958). Although giant reed produces flowers in some areas, no seed production has been reported in North America and giant reed population expansion occurs through vegetative reproduction (Bell 1997).

Sufficient moisture is needed after planting in the first year in order to assure a good stand that may last an average of 10 years (Gilbert et al. 2008). Giant reed growth can be reduced by lack of moisture during its first year but drought does not cause usually damage to stands which are two- to three years old. Giant reed can overcome dry growing conditions and still produce yields of up to 20 tons ha^{-1} dry biomass (Christou et al. 2000), although with moderate irrigation it may produce larger yields. Because of low precipitation, growing giant reed as biofuel in eastern Oregon will require irrigation in order to reach to the maximum biomass yield. Due to its high growth rate and superior resource capture of light, water and nutrients, giant reed was not affected by weed competition in the second year in central Italy (Christou et al. 2000) but its ability to compete with weeds in the United States needs further study.

In many cropping systems, selective herbicides are used to control certain weed species without damaging the crop. Generally, this selectivity is based on the ability of the crop to metabolize the herbicide into non-toxic secondary compunds. There are only a few registered herbicides for weed control in giant reed in Oregon, including: glyphosate, acetachlor, acetachlor plus atrazine and 2,4-D.

Because giant reed is known as an invasive weed in the riparian areas, most of the management efforts in the United States have been focused on its control and prohibiting its infestation of new regions. On the other hand, this invasiveness, high growth rate, tolerance to low nutrient soils, salinity and drought make this plant good for biomass production (Christou et al. 2000). In this case, giant reed would not be considered a noxious weed but a valuable biomass crop which will need its own weed management practices. When considering a species such as giant reed as a crop, there may be lack of information for its adaptation and requirements in a domesticated environment and basic research and establishment studies are needed in order to obtain its highest growth potential and biomass yield.

During the establishment year the biomass production and growth rate of giant reed plants can be affected by weed species and different levels of weed infestation (Christou et al. 2001). Giant reed is not vigorous during the first months after planting and competitive weeds including redroot pigweed (*Amaranthus retroflexus*) and barnyardgrass (*Echinochloa crus-galli*) may reduce the growth rate and biomass production. Therefore, management efforts should focus on reducing weed populations through the first months after planting. Minimizing the crop-weed competition in the field using the most effective selective herbicides at the correct time could increase the biomass production.

Many researchers have studied the effect of weed density and populations on crop yield in order to estimate negative affects caused by weeds on yield. Massinga et al. (2001) stated that corn leaf area index decreased with an increase in Palmer amaranth (*Amaranthus palmeri*) density in the field. Sheibany et al. (2009) reported that increasing redroot pigweed (*Amaranthus retroflexus*) density in the field to more than 65 plants m^{-1} of row reduced the corn grain and biomass yield. Bosnic and Swanton (1997) reported that barnyardgrass at the density of 200 plants m^{-1} of row decreased the corn yield by 26 to 35%. Weeds have the ability to become more or less competitive throughout the growing season and studying the crop-weed interactions throughout the growing season can be an effective tool for better management and prediction of weed competition.

There are periods of time during the growing season in which the presence of weeds can cause crop yield reduction and some periods that weed presence does not cause yield reduction. The critical period of weed control (CPWC) determines these points and can help growers control weeds within the crop to minimize yield loss to an acceptable yield loss (AYL). CPWC studies consist of two series of treatments which are applied at different time periods. CPWC studies include weed free and weed infested treatments. In weed infested treatments, weeds are allowed to remain in the field for increasing periods of time and after which plots are kept weed free for the rest of growing season. For weed free treatments, plots are kept weed free for increasing periods of time and after which weeds are allowed to grow to the end of growing season. A season long weed free treatment is included in order to compare the yields in different treatments and to express yield as the percentage of the weed free yield. In a typical approach for estimating the CPWC, a logistic nonlinear model will fit weed infested data while a nonlinear Gompertz model fits weed free data. Having a CPWC estimation for giant reed may help growers prevent yield loss by controlling the weeds at the proper time in order to minimize their competition with giant reed throughout the growing season.

Considering the potential importance of giant reed as a biomass crop and the importance of weed management and control in the newly established fields in Oregon, it is necessary to determine the tolerance of giant reed to herbicides. In this study, we tested several preemergence and postemergence herbicides in the greenhouse and field in order to evaluate giant reed sensitivity and tolerance. Herbicides that cause no or little injury could be pursued for weed control in giant reed production and herbicides which cause injury to giant reed might be registered and used for giant reed control in the field borders or adjacent areas.

Response of Giant Reed (*Arundo donax*) to Herbicides

Abstract

Studies were conducted under greenhouse and field conditions to determine the tolerance of giant reed to preemergence and postemergence herbicides. Plants were evaluated for visible injury, dry above- and belowground biomass production for the greenhouse study and injury and aboveground biomass production for the field study. The experimental design was a randomized complete block with four replications for both studies. In the greenhouse study, bromoxynil plus MCPA at 0.84 kg ha^{-1}, nicosulfuron at 0.035 kg ha^{-1}, and dimethenamid-p at 0.73 kg ha^{-1} did not cause injury and did not reduce giant reed biomas. Bromoxynil plus pyrasulfotole applied at 0.27 kg ha^{-1} and mesotrione applied at 0.21 kg ha^{-1} caused the greatest injury and reduction of both above- and belowground biomass. In the field study, a preemergence application of 0.735 kg ha^{-1} dimethenamid-p plus a postemergence application of 0.56 kg ha^{-1} 2,4-D amine and a postemergence application of 0.84 kg ha^{-1} bromoxynil plus MCPA resulted in the least injury to giant reed and the best weed control. A preemergence application of acetochlor at 1.67 kg ha^{-1} followed by a postemergence application of 2.4-D amine at 0.56 kg ha^{-1} caused 25% injury to giant reed. In the field study, a preemergence application of premixed acetochlor plus atrazine at 2.53 kg ha^{-1} alone and when followed by a postemergence application of 2,4-D amine at 0.56 kg ha^{-1} caused 38 and 39% crop injury, respectively.

Introduction

Giant reed (*Arundo donax L.*) has a high growth rate and can produce up to 27 metric tons ha^{-1} biomass during a growing season (Angelini et al. 2005). In order to reduce carbon dioxide emissions by using fossil fuels, giant reed has been suggested as a biomass crop for providing feedstock for the coal fired Portland General Electric (PGE) power plant in Boardman, Oregon.

Because giant reed generally is known as an invasive species, most management techniques including chemical management methods, which rely on postemergence applications of glyphosate, fluazifop-butyl and sethoxydim, are for its control and eradication (Bell, 1997). Because there are only a few available herbicides labeled for use in biomass crops, determination of alternative weed control methods is needed and testing of herbicides available in the market to adapt those herbicides for use in this biomass crop is also needed. Miscanthus (*Miscanthus sinensis L.*) and swithchgrass (*Panicum virgatum*) are biomass crops which are grown in the Midwestern United States. Several corn and sorghum herbicides have been tested for use in miscanthus (Burner et al. 2009). A preplant application of acetochlor and acetochlor plus atrazine for biomass production of giant miscanthus (*Miscanthus × giganteus*) has been recommended by United States Department of Agriculture (USDA, 2011). Eken and Lym (2009) reported a postemergence treatment of propoxycarbazone at 0.06 kg ha^{-1} and sulfometuron at 0.21 kg ha^{-1} and 0.035 kg ha^{-1} increased switchgrass yield and reduced quackgrass (*Elymus repens*) by more than 98% compared to the control.

Postemergence herbicides are an essential tool in biomass crop production and their use should be determined through herbicide assessment studies that measure biomass crop tolerance to available herbicides. Anderson et al. (2010) found that preemergence and postemergence broadleaf herbicides (bromoxynil, 2,4-D and dicamba) did not cause injury or biomass reduction in miscanthus, while use of herbicides with grass activity (clethodim and sethoxydim), resulted in injury ranging from 22 to 25% and biomass loss of 69 to 78%. In another study, Golebiowska and Domaradzki (2012) stated that application of tritosulfuron plus dicamba at 0.2 kg ha^{-1} provided the best control of broadleaf weeds and resulted in no injury and the greatest biomass in sorghum (*Sorghum vulgare*) production. Odero and Gilbert (2012) tested labeled post-emergence herbicides used in sugarcane, including asulam and trifloxysulfuron, for controlling and managing giant reed plants in sugarcane fields and concluded that even high application rates of these herbicides did not control giant reed in sugarcane fields. Therefore, these herbicides may have the potential for weed control in giant reed biomass production.

Different plant species and biotypes have different susceptibility or tolerance to herbicides. Bryson and Wills (1985) examined the herbicide susceptibility of bermudagrass (*Cynodon dactylon*) biotypes to seven postemergence herbicides and concluded that none of the biotypes was more susceptible or tolerant to one herbicide than another. Ashley (1998) found that postemergence treatments of clethodim applied at various rates in sethoxydim-tolerant corn caused significant crop injury and yield loss.

There are a limited labeled herbicides for controlling weeds in biofuel grasses (Renz et al. 2009). If giant reed is planted on a large scale in eastern Oregon to provide enough biomass for the PGE power plant, it will be necessary to identify herbicides for use in giant reed. The first months following field establishment have been shown to be the most sensitive period for giant reed growth and development in response to weed competition (Bell 1997). Christou et al. (2000) reported that giant reed plants were not affected by weed competition in the second year, due to the high growth rate and superior resource capture capacity of giant reed for light, water and nutrients.

This study was conducted to determine the tolerance of giant reed to preemergence and postemergence herbicides applied at different rates.

Materials and Methods

Greenhouse Study

A study was conducted to evaluate the tolerance of giant reed to 10 herbicides each applied at three different rates (Table 1.1). The experiment was conducted as a complete randomized block design with four replications and was repeated (Studies 1 and 2). Both experiments were conducted under the same greenhouse conditions. The greenhouse temperature was 27 C with 16/8 hours lighting day/night and plants were watered daily throughout the study.

Tissue culture giant reed seedlings, 13 cm tall, were received on November 18, 2011, and May 10, 2012, for the first and second studies, respectively, from Booshoot Gardens Company (Mount Vernon, Washington, USA). Plants were transplanted to 12 cm diameter by 16 cm depth pots (1 plant per pot) using Sunshine Mix Soil (Sun Grow

Horticulture Inc., 15831 N.E. 8th Street, WA 98008). Plant heights were recorded prior to herbicide treatments. Herbicide treatments were applied 7 days after planting (DAP) using an experimental overhead compressed air sprayer calibrated to deliver 187 L ha^{-1} at 275 KPa.

Plants were rated for herbicide injury based on a scale of 0 (no injury) to 100% (dead). Each study consisted of two harvests. At 28 days after treatment (DAT), plant heights were recorded and plants were cut at the soil surface, dried at 65 C for 48 hrs and weighed. Plant height for the first harvest was reported as the difference between plant height at the time of herbicide treatment and plant height at the time of harvest, and for the second harvest plant height was measured as the regrowth from the soil surface. The second harvest was 84 DAT. Plant heights were measured and plant injury was determined in the same way as for the first harvest. Plant roots in each pot were washed, dried at 65 C for 72 hrs and weighed.

Field Study

A field experiment was conducted in 2012 at Schmidt Research Farm, Oregon State University, Corvallis, Oregon (44° 37’ North latitude, 123° 12’ West longitude). On May 14, 2012, giant reed plants that averaged 40 cm were transplanted into the field using a mechanical transplanter and irrigated the same day. Prior to the transplanting, the field was plowed, harrowed, leveled and fertilized with N and S, at 140 and 7.7 kg ha^{-1}, respectively. Irrigation pipes were installed after planting and maintained for the rest of the season. The field received 2.5 cm of water once a week throughout the growing season.

Eleven preemergence and postemergence herbicides were tested at the recommended field rates to determine the effect on giant reed injury and aboveground biomass and weed control (Table 2.1). These herbicides are used for weed control in corn and may have the potential to be labeled for weed control in giant reed. Preemergence applications were made 10 DAP and postemergence treatments 45 DAP via a bicycle wheel compressed air sprayer (210 KPa), with a 2.3 m boom length equipped with Green Leaf AM 11002 nozzles. Giant reed injury percent was recorded on 60 DAP by rating the plants on a scale of 0 (no injury) to 100% (dead). Weed control was recorded based on the most prevalent weeds at the site including: shepherd's purse (*Capsella bursa-pastoris*), henbit (*Lamium amplexicaule*), common groundsel (*Senecio vulgaris*) and sow thistle (*Sonchus oleraceus*). Giant reed plants were harvested 154 DAP (22 WAP) from four interior rows of each plot, two plants per row for a total 8 plants per plot. Plants were dried for 72 hrs at 80 C and weighed.

Statistical Analysis

Field and greenhouse studies were arranged as a complete randomized block design with 11 and 12 treatments, respectively, and four replications. Data were tested for the normality of the residuals using the UNIVARIATE procedure and subjected to ANOVA using PROC GLM procedure in SAS (SAS Institute 2010). When data were not normally distributed or data did not meet the assumption of normality, appropriate transformation was applied before performing analysis to test the effects of herbicides on height, injury and above- and belowground biomass. Injury data were transformed to arcsin in order to reduce the high variation between them (0 to 100). Because there was a significant difference between greenhouse experiments, the data could not be pooled. Therefore, the results are reported separately for each experiment. All herbicide treatments were compared to the untreated control using linear contrasts at $\alpha = 0.05$. Significantly different means were separated at the 0.05 probability level by the least significant difference (LSD) test (Gomez and Gomez, 1984).

Results and Discussion

Greenhouse Study

Study 1

Harvest 1. Dimethenamid-p and nicosulfuron did not cause injury or biomass reduction at 0.735 and 0.035 kg ha^{-1}, respectively. Dicamba at 0.560 kg ha^{-1} and dicamba plus 2,4-D at 1.177 kg ha^{-1} reduced the aboveground biomass (Table 1.3). Bromoxynil plus pyrasulfotole at 0.135 kg ha^{-1}, fluroxypyr at 0.137 kg ha^{-1} and mesotrione at 0.105 kg ha^{-1} caused injury and reduced height and above- and belowground biomass (Table 1.4)

Harvest 2. Bromoxynil plus pyrasulfotole at 0.270 kg ha^{-1} and fluoxypyr at 0.275 kg ha^{-1} reduced plant height and caused injury and reduced belowground biomass. At the highest treatment rate (0.420 kg ha^{-1}), mesotrione reduced the height, aboveground biomass, and caused injury and reduced belowground biomass. Bromoxynil plus pyrasulfotole at 0.135 kg ha^{-1}, fluroxypyr at 0.137 kg ha^{-1} and mesotrione at 0.105 kg ha^{-1} caused injury and reduced plant height, above- and belowground biomass (Table 1.5). Bromoxynil plus pyrasulfotole at 0.270 kg ha^{-1}, fluroxypyr at 0.275 kg ha^{-1} and mesotrione at 0.210 kg ha^{-1} reduced the above- and belowground biomass (Table 1.3). Bromoxynil plus pyrasulfotole, fluroxypyr and mesotrione caused injury and reduced biomass at 0.135, 0.137 and 0.105 kg ha^{-1} and higher rates, respectively. Mesotrione, bromoxynil plus pyrasulfotole, dicamba and dimethenamid-p reduced the aboveground biomass at 0.420, 0.540, 1.120 and 1.470 kg ha^{-1}, respectively. Other herbicides caused less or no injury.

For the both harvests, bromoxynil plus pyrasulfotole at 0.270 kg ha^{-1} and fluoxypyr at 0.275 kg ha^{-1} reduced height and caused injury. At the highest rate, mesotrione at 0.420 kg ha^{-1} reduced the height, aboveground biomass, and caused injury. Bromoxynil plus pyrasulfotole at 0.135 kg ha^{-1}, fluroxypyr at 0.137 kg ha^{-1} and mesotrione at 0.105 kg ha^{-1} caused injury and reduced plant height. Dicamba plus 2,4-D at 1.177 kg ha^{-1} decreased the height and caused injury.

Study 2

Harvest 1. Nicosulfuron applied at 0.035 and 0.0175 kg ha^{-1} was the only herbicide that did not cause biomass reduction. All other herbicide treatments reduced height and biomass. Bromoxynil plus pyrasulfotole at 0.135 kg ha^{-1} and mesotrione at 0.105 kg ha^{-1} reduced the aboveground biomass. Mesotrione at 0.105 kg ha^{-1} injured giant reed by 21%. At the lowest rate, the only herbicide that reduced belowground biomass was bromoxynil plus pyrasulfotole at 0.135 kg ha^{-1} (Table 1.7). Bromoxynil plus pyrasulfotole at 0.270 kg ha^{-1} and mesotrione at 0.210 kg ha^{-1} injured giant reed 74 and 85%, respectively, and decreased height, above- and belowground biomass. Bromoxynil plus pyrasulfotole at 0.540 kg ha^{-1} and mesotrione at 0.420 kg ha^{-1} reduced aboveground biomass and injured giant reed (Table 1.7).

Harvest 2. The only herbicide that did not cause injury and above- and belowground biomass reduction was dicamba plus 2,4-D at 1.177 and 0.588 kg ha^{-1}. At the lowest rate, the only herbicide that reduced belowground biomass was bromoxynil plus pyrasulfotole at 0.135 kg ha^{-1} (Table 1.8). Bromoxynil plus pyrasulfotole at 0.540 kg ha^{-1} and mesotrione at 0.420 kg ha^{-1} reduced below- and aboveground biomass and injured giant reed (Table 1.8).

In conclusion, bromoxynil plus MCPA, nicosulfuron, dimethenamid-p and dicamba plus 2,4-D caused no or little injury and biomass reduction. Therefore, these herbicides could be candidates for weed control in giant reed production. Giant reed was more susceptible to bromoxynil plus pyrasulfotole, mesotrione and fluroxypyr, especially at the recommended and higher rates. These herbicides are not an option for use in giant reed production but could be labeled for controlling escaped giant reed. Other treatments caused intermediate injury and biomass reduction. Bromoxynil plus MCPA at 0.841 kg ha^{-1} and nicosulfuron at 0.035 kg ha^{-1} were the herbicides which caused no injury nor biomass reduction (Tables 1.7 and 1.8).

Field Study

Field study results demonstrated that among the tested herbicides, the preemergence application of 0.735 kg ha^{-1} dimethenamid-p plus a postemergence application of 0.560 kg ha^{-1} 2,4-D amine and a postemergence application of 0.841 kg ha^{-1} bromoxynil plus MCPA resulted in the least injury to giant reed plants. A preemergence application of acetochlor at 1.669 kg ha^{-1} followed by a postemergence application of 2.4-D amine at 0.560 kg ha^{-1}, a preemergence application of the premix of acetochlor plus atrazine at 2.532 kg ha^{-1} alone or when followed by a postemergence application of 2,4-D amine at 0.560 kg ha^{-1} caused injury. Other tested herbicides provided less weed control and caused crop injury and biomass loss (Table 1.9).

In summary, among the herbicides evaluated in the greenhouse and field study, bromoxynil plus MCPA at 0.841 kg ha^{-1} did not injure giant reed and did not reduce biomass. Further studies are required to confirm these results, and more herbicides should be tested, including herbicides such as asulam and trifloxysulfuron, which may control weeds in giant reed biomass production with no injury and biomass reduction.

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Table 1.1. Herbicide treatments and rates for the greenhouse study.

Common name	Trade name	Formulation	Herbicide Rate ($kg ai/ae ha^{-1}$)			Manufacturer	Location
			0.5 X	X[a]	2X		
Bromoxynil+ MCPA	Bronate Advanced	EC	0.420	0.841	1.682	Bayer CropScience	Research Triangle Park NC
Bromoxynil + Pyrasulfotole	Huskie	EC	0.135	0.270	0.540	Bayer CropScience	Research Triangle Park NC
Carfentrazone	Aim	EC	0.0175	0.035	0.070	FMC Corp.	Philadelphia PA
Dicamba	Clarity	SC	0.280	0.560	1.120	BASF Corp.	Research Triangle Park NC
Dicamba + 2,4-D amine	Latigo	EC	0.588	1.177	2.354	Helena Chemical Company	Collieville TN
Dimethenamid-p	Outlook	EC	0.367	0.735	1.470	BASF Corp.	Research Triangle Park NC
Fluroxypyr	Starane	EC	0.137	0.275	0.550	Dow AgroScience	Indianapolis IN
Mesotrione	Callisto	SC	0.105	0.210	0.420	Syngenta	Wilmington DE
Nicosulfuron	Accent	WDG	0.0175	0.035	0.070	DuPont	Wilmington DE
Thifensulfuron+ Tribenuron	Affinity Broadspec	WDG	0.0155	0.031	0.062	DuPont	Wilmington DE

All treatments included a non-ionic surfactant (NIS) at 0.25% v/v

[a]: Recommended rates

Table 1.2. Herbicide treatments, rates and application time for the field study.

Common name	Trade name	Formulation	Herbicide Rate (kg ai/ae ha^{-1})	Application (DAP)[c]	Manufacturer	Location
2,4-D [a]	2,4-D	Amine	0.560	45	Nufarm	St.Joseph MO
Acetochlor[a] + 2,4-D [a]	Harness 2,4-D	EC Amine	1.669 0.560	45 45	Monsanto Nufarm	St.Louis MO St.Joseph MO
Acetochlor-Atrazine	Harness Xtra	EC	2.352[d]	10	Monsanto	St.Louis MO
Acetochlor-Atrazine + 2,4-D [a]	Harness Xtra 2,4-D	EC Amine	2.352 0.560	10 45	Monsanto Nufarm	St.Louis MO St.Joseph MO
Bromoxynil + MCPA[a]	Bronate Advanced	EC	0.841	45	Bayer CropScience	Research Triangle Park, NC
Carfentrazone [a]	Aim	EC	0.035	45	FMC Corp.	PhiladelphiaPA
Clethodim [b]	Select Max	EC	0.140	45	Valent Corp.	Walnut Creek, CA
Dicamba[a]	Clarity	SC	0.560	45	BASF Corp.	Research Triangle Park, NC
Dicamba + 2,4-D [a]	Latigo	EC	1.177	45	Helena Chemical Company	Collieville TN
Dimethenamid-p + 2,4-D [a]	Outlook 2,4-D	EC Amine	0.735 0.560	10 45	BASF Corp. Nufarm	Research Triangle Park, NC St.Joseph, MO
Metsulfuron methyl[a]	Ally XP	WDG	0.0042	45	DuPont	Wilmington DE

a: Non-ionic surfactant (NIS) at 0.25% v/v

b: COC at 1% v/v

c: Days after planting in the field

d: Premix of 2.35 kg ai ha^{-1}acetochlor and 3.14 kg ai ha^{-1} atrazine

Table 1.3. Study 1. Giant reed response to herbicide treatments applied at the recommended label rate (x) in the greenhouse.

Treatment	Height (cm)		Injury %		Aboveground biomass (g)		Belowground biomass (g)
	1st Harvest	2nd Harvest	1st Harvest	2nd Harvest	1st Harvest	2nd Harvest	2nd Harvest
Control	7.55	22.75	0.00	0.00	2.86	3.12	2.04
Bromoxynil+ MCPA	6.00	25.00	20.00*	3.75	2.95	4.47	3.01
Bromoxynil+ Pyrasulfotole	0.75*	0.00*	65.00*	100.00*	1.84	0.00*	0.26*
Carfentrazone	1.75*	18.25	47.50*	31.25*	2.30	2.42	1.40
Dicamba	0.50*	23.75	37.50*	1.25	1.42*	2.55	1.77
Dicamba+2,4-D	0.25*	13.75*	48.75*	33.75*	1.56*	1.35	1.43
Dimethenamid-p	6.00	25.25	3.75	0.00	3.39	2.69	2.45
Fluroxypyr	1.00*	0.00*	48.75*	100.00*	1.61*	0.00*	0.34*
Mesotrione	4.25	1.00*	22.50*	92.50*	2.22	0.02*	0.43*
Nicosulfuron	7.00	25.00	0.00	0.00	3.15	3.09	2.98
Thifensulfuron+ Tribenuron	1.25*	19.75	20.00*	6.25	2.50	2.17	1.57

* Significant difference between the treatment and untreated control at α=0.05

1.4. Study 1. Harvest 1. Least significant differences (LSD) for giant reed injury and aboveground biomass at different herbicide rates.

Injury

	Herbicide rate			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	27.50 AB	20.00 B	31.25 A	0.00 C
Bromoxynil+Pyrasulfotole	41.25 B	65.00 A	3.75 C	0.00 C
Carfentrazone	23.75 B	47.50 A	0.00 C	0.00 C
Dicamba	33.75 B	37.50 B	57.50 A	0.00 C
Dicamba+2,4-D	40.00 A	48.75 A	42.50 A	0.00 B
Dimethenamid-p	23.75 A	3.75 B	26.25 A	0.00 B
Fluroxypyr	27.50 B	48.75 A	25.00 B	0.00 C
Mesotrione	18.75 A	22.50 A	31.25 A	0.00 B
Nicosulfuron	22.50 A	0.00 B	3.75 B	0.00 B
Thifensulfuron+Tribenuron	0.00 B	20.00 A	26.25 A	0.00 B

*Means with the same letters with a row are not different

[a]: Recommended rate

Aboveground biomass

	Herbicide rate			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	2.83 A	2.95 A	2.65 A	2.86 A
Bromoxynil+Pyrasulfotole	1.95 A	1.84 A	2.53 A	2.86 A
Carfentrazone	3.21 A	2.30 A	3.59 A	2.86 A
Dicamba	2.04 B	1.42 C	1.59 BC	2.86 A
Dicamba+2,4-D	1.59 B	1.56 B	2.02 AB	2.86 A
Dimethenamid-p	2.64 A	3.39 A	2.30 A	2.86 A
Fluroxypyr	2.39 A	1.61 A	2.58 A	2.86 A
Mesotrione	2.08 AB	2.22 AB	1.54 B	2.86 A
Nicosulfuron	1.87 B	3.15 A	2.37 AB	2.86 A
Thifensulfuron+Tribenuron	4.41 A	2.50 B	2.75 B	2.86 B

*Means with the same letters with a row are not different

[a]: Recommended rate

1.5. Study 1. Harvest 2. Least significant differences (LSD) injury, above and belowground biomass at different herbicide rates.

Injury

	Herbicide rate			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	5.00 A	3.75 A	0.31 A	0.00 A
Bromoxynil+Pyrasulfotole	91.25 B	100.00 A	1.18 C	0.00 C
Carfentrazone	6.25 AB	31.25 A	0.00 B	0.00 B
Dicamba	1.25 B	1.25 B	77.50A	0.00 B
Dicamba+2,4-D	5.00 B	33.75 A	0.22 B	0.00 B
Dimethenamid-p	25.00 A	0.00 B	0.84 B	0.00 B
Fluroxypyr	100.00A	100.00 A	1.57 B	0.00 C
Mesotrione	77.50 A	92.50 A	1.52 B	0.00 B
Nicosulfuron	25.00 A	0.00 B	0.00 B	0.00 B
Thifensulfuron+Tribenuron	0.00 B	28.75 A	0.50 B	0.00 B

*Means with the same letters with a row are not different

[a]: Recommended rate

Aboveground biomass

	Herbicide rate			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	3.81 A	4.47 A	2.92 A	3.12 A
Bromoxynil+Pyrasulfotole	0.08 B	0.00 B	0.32 B	3.12 A
Carfentrazone	4.15 A	2.42 A	4.35 A	3.12 A
Dicamba	4.12 A	2.55 A	0.32 A	3.12 A
Dicamba+2,4-D	3.56 A	1.35 A	3.24 A	3.12 A
Dimethenamid-p	2.52 A	2.69 A	0.63 B	3.12 A
Fluroxypyr	0.00 B	0.00 B	2.06 A	3.12 A
Mesotrione	0.11 B	0.02 B	0.00 B	3.12 A
Nicosulfuron	0.92 A	3.09 A	2.86 A	3.12 A
Thifensulfuron+Tribenuron	4.36 A	2.17 BC	1.48 C	3.12 AB

*Means with the same letters with a row are not different

[a]: Recommended rate

Belowground biomass

	Herbicide rate			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	2.72 A	3.01 A	2.66 A	2.04 A
Bromoxynil+Pyrasulfotole	0.45 B	0.26 B	0.68 B	2.04 A
Carfentrazone	2.66 AB	1.40 B	3.21 A	2.04 AB
Dicamba	2.20 A	1.77 A	0.85 B	2.04 A
Dicamba+2,4-D	1.90 A	1.43 A	2.66 A	2.04 A
Dimethenamid-p	1.56 A	2.45 A	0.75 B	2.04 A
Fluroxypyr	0.77 BC	0.34 C	1.57 AB	2.04 A
Mesotrione	0.38 B	0.43 B	0.46 B	2.04 A
Nicosulfuron	0.98 B	2.98 A	2.11 A	2.04 A
Thifensulfuron+Tribenuron	3.04 A	1.57 B	1.36 B	2.04 AB

*Means with the same letters with a row are not different

[a]: Recommended rate

Table 1.6. Study 2. Giant reed response to herbicide treatments applied at the recommended label rate in the greenhouse.

Treatment	Height (cm)		Injury %		Aboveground biomass (g)		Belowground biomass (g)
	1st Harvest	2nd Harvest	1st Harvest	2nd Harvest	1st Harvest	2nd Harvest	2nd Harvest
Control	1.62	16.25	_[a]	0.00	3.05	1.27	3.38
Bromoxynil + MCPA	0.25*	15.50	_	1.25	2.26	1.11	3.28
Bromoxynil + Pyrasulfotole	0.75	5.00*	_	73.75*	1.72	0.08*	0.88*
Carfentrazone	0.25*	15.75	_	1.25	2.26	0.87	2.15
Dicamba	0.25*	18.50	_	1.25	2.37	1.09	2.90
Dicamba + 2,4-D	0.50	16.50	_	0.00	2.45	1.20	3.41
Dimethenamid-p	0.25*	14.50	_	2.50	2.71	0.85	2.85
Fluroxypyr	0.50	16.00	_	6.25	1.96	0.70	1.96*
Mesotrione	1.50	4.75*	_	85.00*	2.66	0.10*	1.53*
Nicosulfuron	0.25*	17.00	_	8.75	3.59	1.02	2.30
Thifensulfuron + Tribenuron	0.75	17.25	_	1.25	2.76	1.00	2.64

*Significant difference between the treatment and untreated control at α=0.05

[a]: data not available

1.7. Study 2. Harvest 1. Least significant differences (LSD) for aboveground biomass at different herbicide rates.

Aboveground biomass

	Herbicide rates			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	3.47 A	2.26 A	3.05 A	3.05 A
Bromoxynil+Pyrasulfotole	1.83 AB	1.72 B	2.19 AB	3.05 A
Carfentrazone	2.74 AB	2.26 AB	1.89 B	3.05 A
Dicamba	2.51 A	2.37 A	2.35 A	3.05 A
Dicamba+2,4-D	2.35 A	2.45 A	1.96 A	3.05 A
Dimethenamid-p	2.79 A	2.71 A	1.97 A	3.05 A
Fluroxypyr	2.65 A	1.96 A	2.04 A	3.05 A
Mesotrione	2.86 A	2.66 A	2.45 A	3.05 A
Nicosulfuron	2.78 A	3.59 A	2.61 A	3.05 A
Thifensulfuron+Tribenuron	2.16 B	2.76 AB	3.79 A	3.05 AB

*Means with the same letters with a row are not different

[a]: Recommended rate

1.8. Study 2. Harvest 2. Least significant differences (LSD) for injury, above and belowground biomass at different herbicide rates.

Injury

	Herbicide rate			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	1.25 A	1.25 A	3.75 A	0.00 A
Bromoxynil+Pyrasulfotole	17.50 B	73.75 A	95.00 A	0.00 B
Carfentrazone	6.25 A	1.25 A	0.00 A	0.00 A
Dicamba	0.00 A	1.25 A	8.75 A	0.00 A
Dicamba+2,4-D	3.75 A	0.00 A	11.25 A	0.00 A
Dimethenamid-p	3.75 A	2.50 A	1.55 A	0.00 A
Fluroxypyr	0.00 A	6.25 A	0.00 A	0.00 A
Mesotrione	21.25 BC	85.00 A	61.25 AB	0.00 C
Nicosulfuron	10.50 A	8.75 A	12.50 A	0.00 A
Thifensulfuron+Tribenuron	1.25 A	1.25 A	1.25 A	0.00 A

*Means with the same letters with a row are not different

[a]: Recommended rate

Aboveground biomass

	Herbicide rate			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	1.54 A	1.11 A	1.34 A	1.27 A
Bromoxynil+Pyrasulfotole	0.67 A	0.08 C	0.00 C	1.27 A
Carfentrazone	0.98 AB	0.87 AB	0.71 B	1.27 A
Dicamba	1.08 A	1.08 A	1.15 A	1.27 A
Dicamba+2,4-D	0.88 A	1.20 A	0.70 A	1.27 A
Dimethenamid-p	0.94 A	0.85 A	1.22 A	1.27 A
Fluroxypyr	1.10 A	0.70 A	0.73 A	1.27 A
Mesotrione	0.52 B	0.10 B	0.13 B	1.27 A
Nicosulfuron	1.11 A	1.02 A	1.78 A	1.27 A
Thifensulfuron+Tribenuron	0.79 B	1.00 AB	1.56 A	1.27 AB

*Means with the same letters with a row are not different

[a]: Recommended rate

Belowground biomass

	Herbicide rate			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	3.86 A	3.28 A	3.13 A	3.38 A
Bromoxynil+Pyrasulfotole	1.47 B	0.88 B	0.85 B	3.38 A
Carfentrazone	2.29 AB	2.15 AB	1.89 B	3.38 A
Dicamba	2.71 A	2.90 A	2.87 A	3.38 A
Dicamba+2,4-D	2.47 A	3.41 A	2.86 A	3.38 A
Dimethenamid-p	2.85 AB	2.85 AB	1.92 B	3.38 A
Fluroxypyr	2.73 AB	1.96 BC	1.33 C	3.38 A
Mesotrione	2.86 AB	1.53 B	1.74 B	3.38 A
Nicosulfuron	2.41 A	2.30 A	2.44 A	3.38 A
Thifensulfuron+Tribenuron	2.64 B	2.64 B	4.48 A	3.38 AB

*Means with the same letters with a row are not different

[a]: Recommended rate

Table 1.9. Giant reed response to herbicide treatments applied at the recommended field rate in the field.

Treatment	Herbicide rate kg ai/ae ha^{-1}	Giant reed dry weight kg/$2m^2$	Injury %				
			Giant reed	Shepherd's purse	Henbit	Common groundsel	Sowthistle
Control	0.00	0.994	0.00	0.00	0.00	0.00	0.00
Acetochlor [a] + 2,4-D amine[b]	1.669 0.560	2.985	24.75*	100.00*	100.00*	96.00*	100.00*
Dimethenamid-P[a] + 2,4-D amine[b]	0.735 0.560	3.421*	0.00	100.00*	100.00*	99.25*	100.00*
Acetochlor-Atrazine	2.352	1.888	37.50*	100.00*	100.00*	10.00*	100.00*
Acetochlor-Atrazine[a] + 2,4-D amine[b]	2.352 0.560	2.229	38.75*	100.00*	100.00*	100.00*	100.00*
Clethodim	0.140	0.312	47.50*	10.00*	25.00	0.00	0.00
Metsulfuron methyl	0.0042	0.998	0.00	3.75	0.00	0.00	0.00
2,4-D amine	0.560	1.155	2.50	70.00*	13.75	85.00*	81.25*
Dicamba	0.560	0.604	30.00*	42.50*	25.00	61.25*	56.25*
Dicamba + 2,4-D amine	1.177	0.580	32.50*	67.50*	27.50	92.50*	97.50*
Bromoxynil + MCPA	0.841	3.992*	3.75	61.25*	62.50*	97.50*	95.00*
Carfentrazone	0.035	1.527	30.00	94.25*	67.50*	56.00*	87.50*

* Significant difference between the treatment and untreated control at $\alpha = 0.05$

[a]: preemergence application

[b]: postemergence application

Estimating the Critical Period of Weed Control for Giant Reed (*Arundo donax L.*) Biomass Production

Abstract

The critical period of weed control (CPWC) was determined in giant reed in order to estimate a period of time in which growers would be able to manage weeds in the field more efficiently. The CPWC can be defined as the days after planting or accumulated growing degree days (GDD) in which weeds within a field should be controlled to avoid a crop yield reduction. A grower can decide on a level of acceptable yield loss (AYL) and based on this AYL value in the model, the CPWC can be determined. In this study, seven different intervals for weed free and weed infested treatments plus season long weed infested and weed free treatments were used to determine the CPWC. AYL levels of 5 and 10% were used to estimate the CPWC for giant reed. A base temperature of 7 C was used to calculate the GDD for giant reed. Results indicated that at an AYL level of 5%, the CPWC started at 290 GDD and ended at 820 GDD. This time period was shorter compared to an AYL level of 10% was used. At AYL= 10%, the CPWC started at 333 GDD and ended at 727 GDD. Total weed dry matter increased as the length of weed infested treatments increased, and decreased with the increasing time of weed free treatments.

Introduction

Energy Crops

Energy crops are cultivated with the purpose of using their biomass to produce energy. In recent years, these crops have attracted increasing interest because they may satisfy a part of the energy demand, especially in developed countries and at the same time reduce carbon dioxide emission, because when these crops are grown on a large scale they may be able to absorb high amounts of carbon dioxide from the air and decrease the carbon dioxide emissions (Ragauskas et al. 2006). Perennial rhizomatous grasses display several positive attributes as energy crops compared to annual biomass crops, because of their high productivity, low demand for nutrient inputs and tolerance to biotic and abiotic stresses (Lewandowski et al, 2003). Among these grasses, giant reed (*Arundo donax* L.) is of special interest as an energy crop (Lewandowski et al, 2003; Angelini et al. 2005). Giant reed is capable of producing 23-27 metric tons ha^{-1} dry biomass after its establishment in the field (Angelini et al. 2005). Giant reed is also a strong candidate to be used as a renewable biofuel source because it has desirable qualities including a fast growth rate and the ability to grow in different soil types and in variable climatic conditions (Bell 1997). Due to its high growth rate and superior resource capture of light, water and nutrients, giant reed is not often affected seriously by weed competition after the establishment year (Christou et al. 2000). However, weed management during the establishment year may be critical. This study was conducted to determine the period when weed control in giant reed is needed to prevent yield loss. This period is called the critical period of weed control (CPWC).

Critical Period of Weed Control

Weed interference in the field can cause crop yield reduction. However, this interference is not uniformly injurious to the yield over the duration of the growing season. There are periods during the growing season in which presence of weeds does not substantially reduce the crop yield, and also other periods of time when weed control is essential to prevent yield loss. CPWC is designed to estimate the required period of the growing season in which weed control can be most beneficial (Knezevic et al. 2002). According to Hall et al. (1992), the CPWC is an estimate of the duration that weed control must be effective to prevent weed interference from reducing yields. Swanton and Weise (1991) defined CPWC as the time interval when it is essential to maintain a weed free environment to prevent crop yield losses.

During the first few weeks after crop emergence, resources present in the environment are generally sufficient to support both weed and crop growth. With continued and increasing demand on limited resources, interference between weeds and crops intensifies such that the weeds begin to have a negative effect on the crop. This point marks the beginning of the CPWC. The maximum time period in which crop must be kept free of weeds to prevent yield loss is the critical weed-free period. An understanding of the CPWC helps to design management strategies that minimize weed interference during the critical periods of crop development (Hall et al. 1992). Factors such as climate, land preparation and cultural practices, crop genetics, topography, planting date and cropping systems, may affect the CPWC by influencing the weed composition and density, time of weed and crop emergence, or their development (Hall et al. 1992).

Evans et al. (2003) found that the end of the CPWC is not stable and is highly related to density, competitiveness, and emergence periodicity of weed populations present in the field. For estimating the CPWC, researchers usually apply two types of treatments, or different intervals of weed control and weed presence, in field experiments. In weed infested treatments, weeds are allowed to remain in the field for certain periods of increasing time, and then these plots are kept weed free for the rest of the growing season. The second treatment includes weed free periods, in which plots are kept weed free for certain length of time and then weeds are allowed to grow to the end of the season in those plots. A season long weed free treatment required so that response data can be stated as the percentage of the yield of the weed free plots (Oliver 1988). The CPWC could be determined using either the biomass or grain yield data, depending on the crop and production goal.

In order to estimate the CPWC, nonlinear regression models are fit to the data (Knezevic et al. 2002). A logistic model is usually used to fit the weed infested data while the weed free data are subjected to a Gompertz model. The CPWC is estimated by fitting these two models and depending on the acceptable yield loss (AYL) levels, this period could be short or long. The grower must determine the crop yield loss that is acceptable. Typical levels of AYL for estimating the CPWC for a crop are 5 and 10% (Knezevic et al. 2002). However, Hall et al. (1992), recommended that a 2 to 5% AYL is the best range for estimating the CPWC in corn production. The AYL level is adjustable based on the weed control expenses, crop production system and predicted crop revenue. In this study, AYL levels of 5 and 10% were used to estimate the CPWC. A range of 2.5 to 10% AYL is the most commonly reported in other CPWC studies for grain crops (Mahmoodi et al. 2009; Martin and Williams, 2006; Uremis et al. 2009).

Weed-Crop Competition

Sheibany et al. (2009) reported that increasing redroot pigweed (*Amaranthus retroflexus*) density in the field to more than 65 plants m^{-1} of row reduced corn grain and biomass significantly. Bosnic and Swanton (1997) reported that barnyardgrass (*Echinochloa crus galli*) at a density of 200 plants m^{-1} of row decreased corn yield by 26-35%. Through the establishment year, the biomass production of giant reed may be affected by weed species present in the field compared to following years. Giant reed plants that are transplanted may be more vulnerable to competition. There is little information about giant reed response to weed competition especially during the establishment year and further studies on giant reed-weed competition are needed.

Growing Degree Days

Predictions of plant growth have been successfully based on the accumulation of heat units or degree-days. Degree day based equations have been helpful in forecasting the initiation of giant reed growth from vegetative propagules (Spencer and Ksander, 2006). The use of growing degree days (GDD) can be useful for determining the CPWC on the basis of the respective crop and weed growth stages because the rate of plant development is well correlated with the thermal time (Knezevic et al. 2002).

Knowing the CPWC will help growers manage weeds effectively and help them make decisions on the timing of weed control. By applying the CPWC to management decisions, it may be possible to reduce the use of herbicides by using them only when the weed control is needed, and this may help to reduce the selection pressure for herbicide-resistant weeds via spraying less herbicide in the field (Hall et al. 1992). This study was conducted to estimate the CPWC for giant reed.

Materials and Methods

Field Preparation and Experimental Design

A field experiment was conducted in 2012 at Schmidt Research Farm, Oregon State University, Corvallis, Oregon (44° 37’ North latitude, 123° 12’ West longitude). On May 14, 2012, giant reed plants that averaged 40 cm in height were transplanted into a tilled field using a mechanical transplanter and were irrigated the same day. Prior to the transplanting, the field was plowed, harrowed, leveled and fertilized with N and S, 140 and 7.7 kg ha^{-1}, respectively. Irrigation pipes were installed after planting and maintained for the rest of the season. The field was irrigated once a week with 2.5 cm of water.

In addition to naturally occurring weed populations in the field, 5700 redroot pigweed (*Amaranthus retroflexus*) seeds (70% viability) and 8000 Japanese millet (*Echinochloa frumentacea*) seeds (50% viability) were planted to establish a population of 4000 plants for each species per plot (15 m^2). These species were chosen in order to ensure we would have a competitive weed population in the field and to simulate a weed population similar to that observed in field near Boardman, Oregon.

Treatments and Sampling

In this study, the experimental design was a randomized complete block (RCBD) with four replications. Two sets of treatments were imposed to represent both increasing duration of weed interference and weed-free period after planting. The first set of treatments were seven levels of increasing duration of weed interference completed by delaying weed control from the time of giant reed planting in the field to weekly intervals of 5, 6, 7, 8, 9, 10 and 11 WAP at which time, weed control was initiated and maintained for the remainder of the growing season (Table 2.1). The second set of treatments established seven levels of increasing length of weed free periods by keeping the plots weed free from the time of giant reed planting for 5, 6, 7, 8, 9, 10 and 11 WAP and then subsequently leaving emerged weeds until harvest. In addition, season long weedy and weed-free controls were included. Weeds were removed by hand and hoeing. For the weed infested plots, before each weeding, a 1 m^2 sample was taken from the 2 middle rows of each plot (15 m^2). The samples were sorted to the following groups: Japanese millet, redroot pigweed, annual bluegrass (*Poa annua*), and other broadleaf species (Table 2.2), dried at 70 C for 48 hrs and weighed. After the last weeding at (11 WAP), weed infested plots were maintained without further manipulation until giant reed harvest. One day before harvest, average height and tiller number of five giant reed plants per plot were measured.

At 21 WAP, eight giant reed plants from each plot were cut at the ground level, and dried at 70 C for 72 hrs and weighed. Weeds were cut at ground level, sorted and dried at 70 C for 48 hrs. Biomass yield data of individual plots were calculated as the percentage of weed free yield.

Statistical Analysis

Relative biomass yield data were subjected to analysis of variance with the use of the PROC MIXED function of Statistical Analysis System (SAS 2010) to evaluate the effect of the length of the weed free period and increasing duration of weed interference on relative giant reed biomass (Norsworthy and Oliveira, 2009). Nonlinear regression analysis with the PROC NLMIXED function of SAS was applied to estimate the relative biomass yield of giant reed as a function of increasing duration of weed interference or as a function of the length of the weed free period (Knezevic et al. 2002). A logistic equation was used to describe the effect of increasing duration of weed interference on giant reed relative biomass yield. The following logistic equation was used:

$$Y = \left[\left(\frac{1}{(\exp[c \times (T - d)]) + f}\right) + \left(\frac{f-1}{f}\right)\right] \times 100 \tag{Eq.1}$$

where Y is the relative biomass yield (percent of season-long weed free yield), *T* is the duration of weed interference measured from the time of giant reed planting in growing degree days (GDD), *d* is the point of inflection in GDD, and *c* and *f* are constants.

A four parametric Gompertz equation (Ratkowsky, 1990) was used to predict the relationship between relative biomass yields as influenced by the length of the weed free period. The following Gompertz equation was used:

$$Y = \delta + a \exp[- \times \exp(b - kX)]$$

(Eq.2)

where Y is the relative yield (percent of season-long weed free biomass yield), δ is the yield asymptote or maximum yield in the absence of weed interference, α, *b* and k are constants, and *X* is the length of the weed free period after giant reed planted in GDD.

Goodness of fit was evaluated in terms of minimum mean square error (MSE) and maximum R^2. The logistic equation (1) was used to determine the beginning of the CPWC, and the Gompertz equation (2) was used to determine the end of the CPWC for acceptable yield loss levels of 5% and 10% (Knezevic et al. 2002).

GDD were accumulated from giant reed planting to quantify the duration of weed presence and length of the weed free period for the CPWC (Knezevic et al. 2002). GDD were determined using minimum and maximum air temperatures recorded at Hyslop Farm, near Corvallis, OR. GDD were determined by using the formula:

$$\mathrm{GDD} = (T_{max} + T_{min}) / 2 - T_{base}$$

where T_{max} is the maximum daily temperature, T_{min} is the minimum daily temperature, and T_{base} is the minimum base temperature. A base temperature of 7 C was used as the minimum temperature for giant reed growth and 30 C was used as the air temperature associated with optimal giant reed growth (Spencer and Ksander, 2006).

Results and Discussion

Weed Population and Critical Period of Weed Control

The most common weeds in the trial were redroot pigweed, shepherd's purse (*Capsella bursa pastoris*), Japanese millet and black nightshade (*Solanum nigrum*) (Table 2.2). Broadleaf weeds were the most dominant weeds in the weed infested plots ranging from 50 to 82% of the total weed biomass, while Japanese millet was the dominant weed in the weed free plots ranging from 29 to 75% of total weed dry weight throughout the sampling periods (Table 2.3).

The average giant reed biomass in the whole-season weed free plot was 15.6 tons ha^{-1} and 4.5 tons ha^{-1} for the whole-season weed infested plots. Giant reed biomass yield showed a significant relationship with the presence or absence of weed populations in the field. This relationship is presented by the regression models with R^2 values of 99 and 98%, for logistic and gompertz models, respectively (Table 2.4).

When weeds were allowed to compete with the giant reed for the whole growing season, they reduced the giant reed biomass by 71% (Table 2.5) compared to the whole season weed free treatment. Weed dry weight was affected by the duration of weed infested treatments. The greatest weed biomass was quantified in the season long weed infested treatment and 6 WAP weed free treatment while the least weed biomass occurred in the 5 WAP weed infested treatments (Figures 2.1 and 2.2). In weed infested treatments, dominant weed species which caused biomass reduction by weed competition were broadleaves while in weed free treatments, grasses caused the most giant reed biomass reduction compared to the other species growing in the plots, especially in the shorter weed free treatments. This difference between dominant weed species in weed infested and weed free treatments could be explained by the variable germination of these species. Broadleaves germinated in earlier treatments and grasses germinated in the middle to latest periods of sampling. The biomass reduction in longer weed infested treatments (9-11 WAP) and shorter periods of weed free treatments (5-6 WAP) could be due to lower amounts of available nutrients, light, and water for the giant reed which were limited by the competition from the weeds. Martin et al. (2001) and Mahmoodi et al. (2009) reported that corn grain yield increased with longer weed free periods and decreased with longer weed infested periods.

Changes in giant reed height in response to weed competition were similar to impacts on giant reed biomass. As the duration of the weed infested period increased from 7 WAP to 9 WAP, giant reed height decreased from 190 to 140 cm which was a 28% reduction in height. Increasing the weed free period did not result in as a large difference in height as was observed for weed infested treatments (Figure 2.3). There was a negative relationship between giant reed tiller number per plant and duration of weed interference in the field from 7 WAP to the end of the growing season. Tiller number decreased 57% over this time period. There was no affect of duration of weed free period after 8 WAP on tiller number per giant reed plant (Figure 2.4).

The length of the CPWC differed with respect to AYL values. The AYL levels of 5 and 10% were used to calculate the CPCW for giant reed. The CPWC for giant reed at AYL= 5% started at 290 and ended at 820 GDD (Figure 2.5) and at AYL= 10%, the onset was at 333 and ended at 727 GDD (Figure 2.6). Therefore, weeds should be controlled between 5 to 6 WAP and treatments could end at about 10 to 11 WAP to avoid a yield loss of more than 10% (Table 2.1). If the management goal is to maximize the giant reed biomass then a less conservative AYL value such as 5% should be used. In this case, weed control should start approximately 4 WAP and continue to about 12 WAP (Table 2.1). The grower should determine what level of AYL is the most applicable based on the economic aspects of management and expected biomass yield.

In this study, the data from weed free and weed infested treatments were analyzed using statistical nonlinear models in order to determine a period of time through the giant reed growing season which leads us to an understanding of an effective weed control period in this biomass crop. The CPWC could be used as a tool by growers for optimizing their weed management and targeting weeds by applying postemergence herbicides or other weed control methods in the field while providing them with knowledge to approximate crop yield loss due to not controlling weeds throughout the CPWC.

We estimated the CPWC for giant reed at AYL= 5 and 10% (Figures 2.4 and 2.5). This period can help growers to control weeds in a field with postemergence herbicides during the growing season. CPWC could be used as a tool in order to save time and production costs for giant reed growers. The start or end of CPWC may vary based on geographical area and weed populations (Hall et al. 1992), and the results from the same experiments may not demonstrate similar periods of CPWC for a certain crop depending on a variety of factors.

Further studies need to be conducted in the giant reed production area in Oregon over different years to confirm the CPWC from this study. Other levels of AYL can be tested to determine different CPWC periods for weed management in the field to allow the growers to choose the best CPWC for their weed management. In the future studies, the intervals (WAP) for calculating weed free and weed infested treatments should be adjusted, because in our study the gap between the last data interval (11 WAP) and harvest (21 WAP) was too long to reach 100% yield.

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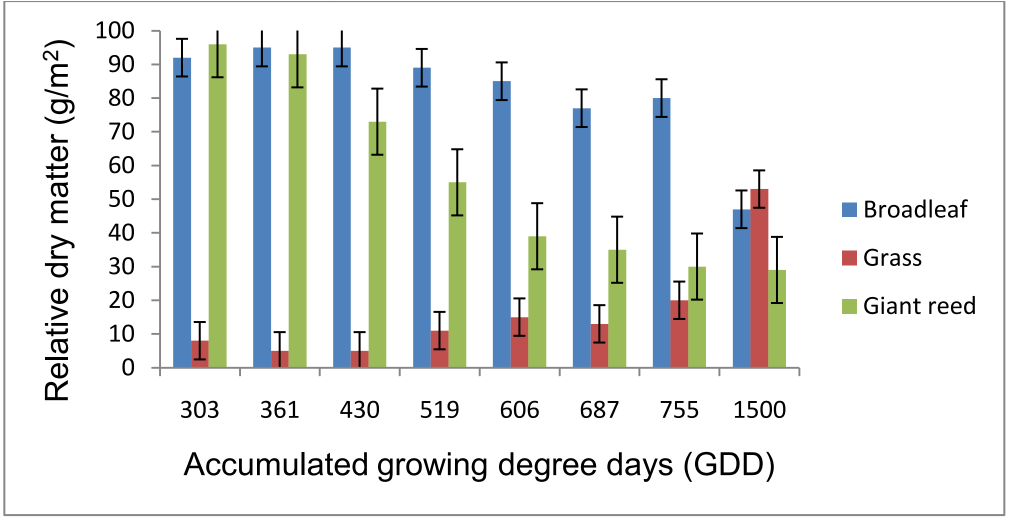
Figure 2.1. Effect of weed infested duration on weed relative biomass[a] and giant reed relative yield[b].

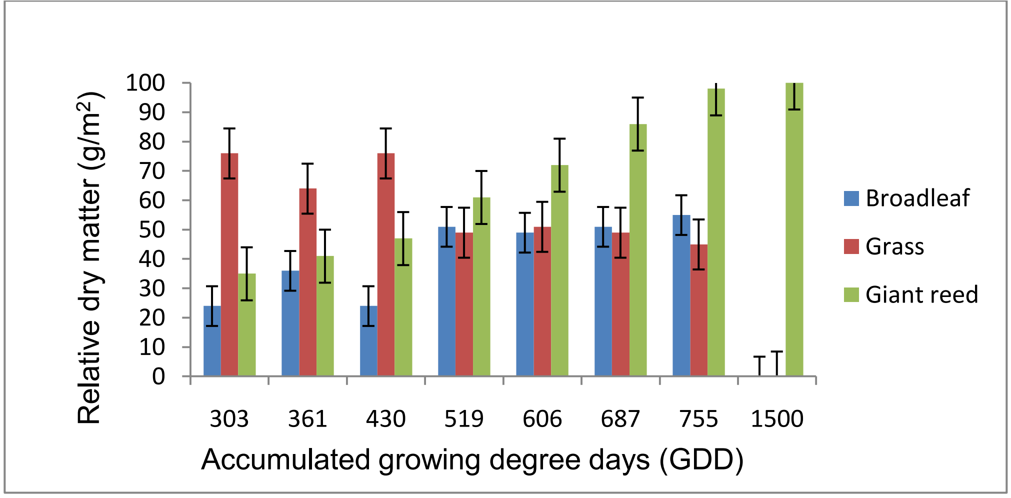


Giant reed biomass reduced with the longest weed infested periods because of weed competition mostly caused by the broadleaf weeds.

[a]: Relative biomass compare to the total weed biomass

[b]: Relative yield compare to the season long weed free treatment

Figure 2.2. Effect of weed free duration on weed relative biomass[a] and giant reed relative yield[b].



Giant reed biomass increased with the longest weed free periods while its biomass reduced at the shorter weed free period because of weed competition mostly caused by grasses.

[a]: Relative biomass compare to the total weed biomass

[b]: Relative yield compare to the season long weed free treatment

Figure 2.3. Effect of critical period of weed control on giant reed height.

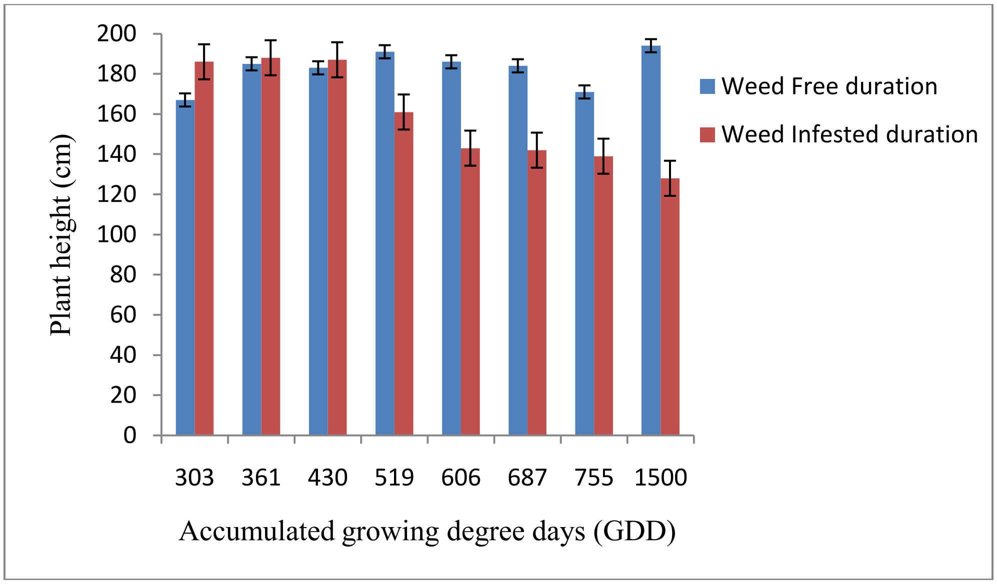


Figure 2.4. Effect of critical period of weed control on giant reed tiller number per plant.

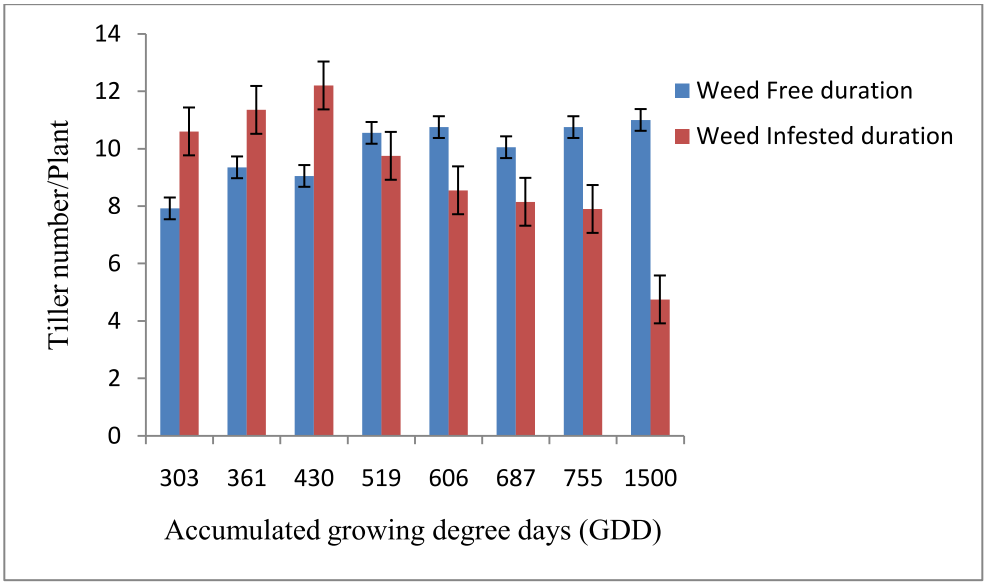


Figure 2.5. Gompertz and logistic fitted curves for critical period of weed control in giant reed at AYL = 5%.

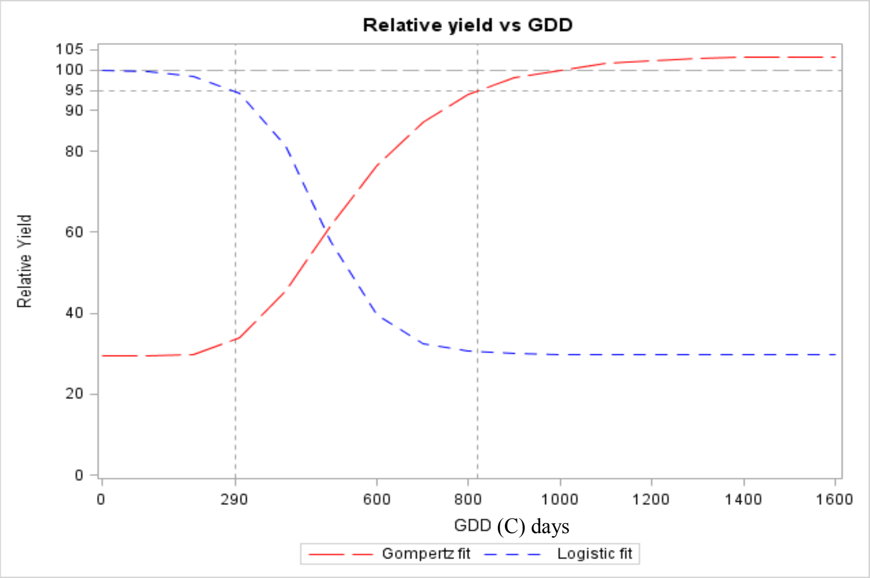


Figure 2.6. Gompertz and logistic fitted curves for critical period of weed control in giant reed at AYL = 10%.

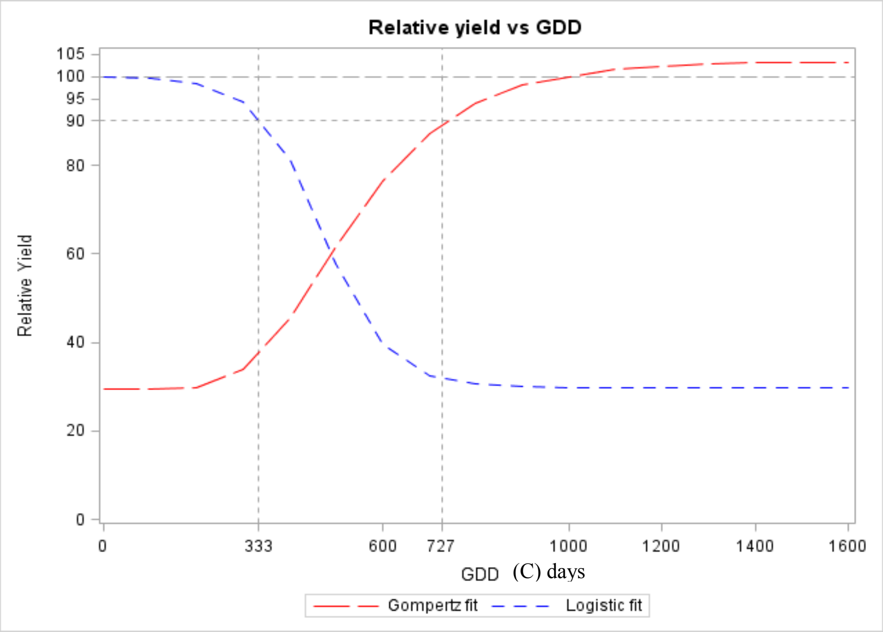


Table 2.1. Accumulated growing degree days (GDD), weeks after planting (WAP) and acceptable yield lose (AYL) for the critical period of weed control (CPWC) in giant reed.

GDD	WAP	10% AYL	5% AYL
303	5		290[a]
361	6	333[a]	
430	7		
519	8	394	530
606	9		
687	10	727[b]	
755	11		820[b]
1500	21		

[a]: Minimum duration of weed infestation

[b]: Maximum duration of weed free

Table 2.2. Predominant species present in the field.

Broadleaf		Grass	
Common name	**Scientific name**	**Common name**	**Scientific name**
Redroot pigweed	*Amaranthus retroflexus*	Japanese millet	*Echinochloa formentacia*
Shepherd's purse	*Capsella bursa pastoris*	Annual blue grass	*Poa annua*
Black nightshade	*Solanum nigrum*		
Common lambsquarters	*Chenopodium album*		
Spiny sowthistle	*Sonchus asper*		
Wild buckwheat	*Plygonum convolvulus*		
Desert rockpurslane	*Calandrinia ciliata*		
Corn spury	*Spergula arvensis*		
Henbit	*Lamium amplexicaule*		

Table 2.3. Weed species percentages of the total weed dry weight in the field at different GDD intervals.

	Pigweed		Broadleaves		Japanese Millet		Annual bluegrass	
GDD[a]	WI[b]	WF[c]	WI	WF	WI	WF	WI	WF
303	11.5	6.5	80.1	17.5	4.6	75.7	3.6	0.2
361	13.3	15.6	81.5	20.4	3.0	62.8	2.2	1.2
430	10.9	14.3	84.3	9.6	3.7	74.8	1.1	1.3
519	16.7	32.0	71.6	19.1	7.1	48.5	4.7	0.3
606	11.9	26.1	72.5	23.2	11.2	49.7	4.3	1.0
687	30.5	24.7	46.2	26.3	21.7	37.8	1.5	11.2
755	30.7	27.0	49.3	28.1	18.7	18.4	0.9	3.0
1500	18.8	0.0	27.6	0.0	48.3	0.0	5.4	0.0

[a]: Accumulated growing degree days
[b]: Weed infested
[c]: Weed free

Table 2.4. Parameter estimates for the Gompertz and logistic models.

Gompertz parameters						**Logistic parameters**						
c[a]	d[b]	f[a]	s2b[c]	s2e[d]	R^2	δ[b]	a[a]	b[a]	k[a]	s2b	s2e	R^2
0.01	250	1.5	16.402	25.366	98	15	85	5	1.1	20	50	99

[a]: Constant
[b]: Point of inflection
[c]: Block random error
[d]: Residual random error

Table 2.5. Least square means for giant reed relative dry weight in weed infested and weed free treatments.

Treatment	GDD[1]	Estimate	
		Weed Infested	Weed Free
5 WAP	303	96.50	36.00
6 WAP	361	89.50	41.25
7 WAP	430	73.50	52.00
8 WAP	519	55.50	62.25
9 WAP	606	38.75	72.25
10 WAP	687	35.50	87.25
11 WAP	755	30.00	98.50
21 AWP	1500	29.00	100.00

1: Accumulated growing degree days

General Conclusions

This study demonstrated that there are some herbicides that could be used in giant reed fields that do not cause crop injury and yield loss. A critical period of weed control (CPWC) for giant reed would enable the growers to manage weeds during this period which may result in a better weed control within the giant reed fields and also benefit the environment by using less herbicide. A CPWC might help to reduce weed control costs and consequently decrease the production expenses for the grower while maintaining a level of giant reed biomass yield based on the chosen acceptable yield loss (AYL).

There are some herbicides in the market which are registered for biomass crops but need to be evaluated for use in giant reed, and would enable the growers to control the weeds throughout the growing season. There are other herbicides that may also be of value so studies were conducted to evaluate them. Results from the greenhouse and field studies determined that bromoxynil plus MCPA at 0.841 kg ha^{-1} and nicosulfuron at 0.035 kg ha^{-1} caused no injury or giant reed biomass reduction compared to the untreated control. Giant reed was succeptible to some of the tested herbicides including bromoxynil plus pyrasulfotole at 0.135 kg ha^{-1} and mesotione at 0.105 kg ha^{-1} and higher rates, so these herbicides would not be appropriate for weed control within the giant reed field but might have utility for management of escaped giant reed plants around field margins or adjacent farms.

The CPWC for giant reed was determined by using two separate nonlinear regression models including the logistic model for the duration of weed infested period and a four parametric Gompertz model for the duration of weed free period. AYL of 5 and 10% were applied to determine the CPWC based on accumulated growing degree days (GDD). Results from the CPWC study, showed that a 5% level of AYL, the CPWC for giant reed started at 290 GDD and ended at 820 GDD (approximately 4 to 12 WAP) and with an AYL= 10%, the CPWC started at 333 GDD and ended at 727 GDD (approximately 5.5 to 10.5 WAP).

In summary, results from our studies provide a period of time in which the growers would be able to control weeds in the field using postemergence herbicides like bromoxynil plus MCPA and nicosulfuron. An available CPWC for the area of giant reed production in Oregon would save time and money for the growers to control weeds within the field at the proper time and with the best available herbicides. This would benefit both the growers and the environment while still producing biomass yield. Further studies are needed on alternative herbicides for use in giant reed. Furthermore, it is necessary to conduct the CPWC estimation studies in Hermiston, Oregon, the main area suggested for giant reed prouction to confirm our results from this study or test this period for other AYL levels.

There are some concerns about giant reed biomass production in Oregon, including the risk of its escape to the nearby fields or riparian areas. Giant reed has the ability to adapt to the new areas and its population can increase quickly via vegetative reproduction. Preliminary studies conducted at Oregon State University, showed that giant reed plants are able to survive cold temperatures during the winter in western Oregon. Giant reed stems with nodes might disperse through the transportation from the fields to the PGE power plant and establish in new areas. As these stem parts may be able to survive and reproduce, risk assessment studies should be conducted to avoid giant reed from becoming a new invasive weed in Oregon riparian and agricultural areas and fields.

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Appendix

A1. Study 1. Harvest 1. Least significant differences (LSD) for giant reed height at different herbicide rates.

Height

	Herbicide rate			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	4.00 A	6.00 A	3.50 A	7.54 A
Bromoxynil+Pyrasulfotole	1.75 B	0.75 B	7.25 A	7.54 A
Carfentrazone	3.50 AB	1.75 B	6.00 AB	7.54 A
Dicamba	0.00 B	0.50 B	0.50 B	7.54 A
Dicamba+2,4-D	0.50 B	0.25 B	1.25 B	7.54 A
Dimethenamid-p	6.00 A	6.00 A	5.25 A	7.54 A
Fluroxypyr	2.75 BC	1.00 C	5.25 AB	7.54 A
Mesotrione	3.50 B	4.25 AB	2.00 B	7.54 A
Nicosulfuron	2.25 B	7.00 A	4.50 B	7.54 A
Thifensulfuron+Tribenuron	10.50 A	1.25 C	0.75 C	7.54 B

*Means with the same letters within in a row are not different

[a]: Recommended rate

A2. Study 1. Harvest 2. Least significant differences (LSD) for height at different herbicide rates.

Height

	Herbicide rate			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	26.00 A	25.00 A	20.50 A	22.75 A
Bromoxynil+Pyrasulfotole	4.50 B	0.00 B	5.25 B	22.75 A
Carfentrazone	27.75 A	18.25 A	25.00 A	22.75 A
Dicamba	26.25 A	23.75 A	4.75 B	22.75 A
Dicamba+2,4-D	22.75AB	13.75 B	24.25 A	22.75 AB
Dimethenamid-p	22.00 A	25.25 A	15.25 A	22.75 A
Fluroxypyr	0.00 B	0.00 B	17.50 A	22.75 A
Mesotrione	3.75 B	1.00 B	0.25 B	22.75 A
Nicosulfuron	14.00 B	25.00 A	25.50 A	22.75 A
Thifensulfuron+Tribenuron	32.00 A	19.75 B	15.25 B	22.75 AB

*Means with the same letters within in a row are not different

[a]: Recommended rate

A3. Study 2. Harvest 1. Least significant differences (LSD) for height at different herbicide rates.

Height

	Herbicide rate			
	Low rate (X/2)	Medium rate (X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	1.50 A	0.25 AB	0.00 B	1.62 A
Bromoxynil+Pyrasulfotole	2.50 A	0.75 A	0.75 A	1.62 A
Carfentrazone	1.25 A	0.25 A	0.00 A	1.62 A
Dicamba	2.00 A	0.25 B	0.75 AB	1.62 AB
Dicamba+2,4-D	0.75 AB	0.50 AB	0.25 B	1.62 A
Dimethenamid-p	0.50 A	0.25 A	1.50 A	1.62 A
Fluroxypyr	1.00 A	0.50 A	0.75 A	1.62 A
Mesotrione	0.50 A	1.50 A	0.50 A	1.62 A
Nicosulfuron	0.25 B	0.25 B	0.25 B	1.62 A
Thifensulfuron+Tribenuron	0.75 A	0.75 A	1.50 A	1.62 A

*Means with the same letters within in a row are not different

[a]: Recommended rate

A4. Study 2. Harvest 2. Least significant differences (LSD) for height at different herbicide rates.

Height

	Herbicide rate			
	Low rate (X/2)	Medium rate(X)[a]	High rate (2X)	Control
Bromoxynil+MCPA	16.75 A	15.50 A	16.00 A	16.25 A
Bromoxynil+Pyrasulfotole	15.75 A	5.00 B	0.75 B	16.25 A
Carfentrazone	15.50 A	15.75 A	15.25 A	16.25 A
Dicamba	16.38 A	18.50 A	18.75 A	16.25 A
Dicamba+2,4-D	15.50 A	16.50 A	13.50 A	16.25 A
Dimethenamid-p	15.00 A	14.50 A	18.75 A	16.25 A
Fluroxypyr	16.50 A	16.00 A	17.25 A	16.25 A
Mesotrione	11.50 AB	4.75 B	8.50 AB	16.25 A
Nicosulfuron	14.25 A	17.00 A	17.50 A	16.25 A
Thifensulfuron+Tribenuron	15.50 A	17.25 A	19.00 A	16.25 A

*Means with the same letters within in a row are not different

[a]: Recommended rate

A5. Study 1. Harvest 1. ANOVA and LSD tables for height, aboveground biomass and injury at the low rate of each herbicide.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	23.5590	7.8530	1.22	0.3189
Treatment	10	387.8130	38.7813 **	6.03	<.0001
Error	30	192.8501	6.4283		
Corrected total	43	604.2222			
CV(%)	65.9484				
R-Squared	0.6808				

Level of significance: P<0.01; **, P<0.05; *.

Aboveground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	6.5119	2.1706 *	3.36	0.0317
Treatment	10	25.4169	2.5416 **	3.93	0.0017
Error	30	19.3842	0.6461		
Corrected total	43	51.3130			
CV(%)	31.6813				
R-Squared	0.6222				

Level of significance: P<0.01; **, P<0.05; *.

Injury

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.1870	0.0623	1.14	0.3483
Treatment	10	2.3032	0.2303 **	4.22	0.0010
Error	30	1.6389	0.0546		
Corrected total	43	4.1292			
CV(%)	53.4419				
R-Squared	0.6030				

Level of significance: P<0.01; **, P<0.05; *.

A5. Study 1. Harvest 1. ANOVA and LSD tables for height, aboveground biomass and injury at the low rate of each herbicide. (Continued)

Treatment	Height	Injury	Aboveground biomass
Control	7.540 AB	0.00 C	2.8563 BC
Bromoxynil+MCPA	4.000 BCD	27.50 AB	2.8303 BC
Bromoxynil+Pyrasulfotole	1.750 DE	41.25 A	1.9510 CD
Carfentrazone	3.500 CDE	23.75 AB	3.2185 B
Dicamba	0.000 E	33.75 AB	2.0433 CD
Dicamba+2,4-D	0.500 DE	40.00 A	1.5893 D
Dimethenamid-p	6.000 BC	23.75 BC	2.6490 BCD
Fluroxypyr	2.750 CDE	27.50 AB	2.3955 BCD
Mesotrione	3.500 CDE	18.75 AB	2.0855 BCD
Nicosulfuron	2.250 DE	22.50 AB	1.8725 CD
Thifensulfuron+Tribenuron	10.500 A	0.00 C	4.4180 A

*Means with the same letters within in a row are not different

A6. Study 1. Harvest 1. ANOVA and LSD tables for height, aboveground biomass and injury at the recommended rate of each herbicide.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	34.7254	11.5751	1.24	0.3130
Treatment	10	331.1000	33.1100 **	3.54	0.0035
Error	30	280.3545	9.3451		
Corrected total	43	646.1800			
CV(%)	92.6358				
R-Squared	0.5661				

Level of significance: P<0.01; **, P<0.05; *.

Aboveground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	3.3339	1.1113	1.75	0.1789
Treatment	10	18.6580	1.8658	2.93	0.0110
Error	30	19.0985	0.6366		
Corrected total	43	41.0905			
CV(%)	34.0265				
R-Squared	0.5352				

Level of significance: P<0.01; **, P<0.05; *.

Injury

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.0066	0.0022	0.19	0.9029
Treatment	10	4.3852	0.4385 **	37.71	<.0001
Error	30	0.3488	0.0116		
Corrected total	43	4.7407			
CV(%)	21.9386				
R-Squared	0.9264				

Level of significance: P<0.01; **, P<0.05; *.

A6. Study 1. Harvest 1. ANOVA and LSD tables for height, aboveground biomass and injury at the recommended rate of each herbicide. (Continued)

Treatment	Height	Injury	Aboveground biomass
Control	7.550 A	0.000 D	2.8568 ABC
Bromoxynil+MCPA	6.000 AB	20.000 C	2.9465 ABC
Bromoxynil+Pyrasulfotole	0.750 C	65.000 A	1.8388 CD
Carfentrazone	1.750 BC	47.500 B	2.3013 ABCD
Dicamba	0.500 C	37.500 B	1.4223 D
Dicamba+2,4-D	0.250 C	48.750 B	1.5598 D
Dimethenamid-p	6.000 AB	3.750 D	3.3863 A
Fluroxypyr	1.000 C	48.750 B	1.6128 D
Mesotrione	4.250 ABC	22.500 C	2.2175 BCD
Nicosulfuron	7.000 A	0.000 D	3.1540 AB
Thifensulfuron+Tribenuron	1.250 C	20.000 C	2.4980 ABCD

*Means with the same letters within in a row are not different

A7. Study 1. Harvest 1. ANOVA and LSD tables for height, aboveground biomass and injury at the high rate of each herbicide.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	33.8244	11.2748	0.94	0.4327
Treatment	10	260.3603	26.0360 *	2.18	0.0489
Error	30	359.0847	11.9694		
Corrected total	43	653.2695			
CV(%)	86.9071				
R-Squared	0.4503				

Level of significance: P<0.01; **, P<0.05; *.

Aboveground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.6618	0.2206	0.28	0.8372
Treatment	10	13.5264	1.3526	1.74	0.1183
Error	30	23.3843	0.7794		
Corrected total	43	37.5725			
CV(%)	36.2443				
R-Squared	0.3776				

Level of significance: P<0.01; **, P<0.05; *.

Injury

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.0824	0.0274	1.72	0.1836
Treatment	10	3.7188	0.3718 **	23.29	<.0001
Error	30	0.4791	0.0159		
Corrected total	43	4.2804			
CV(%)	30.6432				
R-Squared	0.8880				

Level of significance: P<0.01; **, P<0.05; *.

A7. Study 1. Harvest 1. ANOVA and LSD tables for height, aboveground biomass and injury at the high rate of each herbicide. (Continued)

Treatment	Height	Injury	Aboveground biomass
Control	7.540 A	0.000 D	2.8568 AB
Bromoxynil+MCPA	3.500 ABC	31.250 BC	2.6498 ABC
Bromoxynil+Pyrasulfotole	7.250 A	3.750 D	2.5373 ABC
Carfentrazone	6.000 AB	0.000 D	2.8568 AB
Dicamba	0.500 C	57.500 A	1.5933 BC
Dicamba+2,4-D	1.250 BC	42.500 AB	2.0245 BC
Dimethenamid-p	5.250 ABC	26.250 BC	2.3030 BC
Fluroxypyr	5.250 ABC	25.000 C	2.5808 ABC
Mesotrione	2.000 BC	31.250 BC	1.5390 C
Nicosulfuron	4.500 ABC	3.750 D	2.3763 ABC
Thifensulfuron+Tribenuron	0.750 C	26.250 BC	2.7473 ABC

*Means with the same letters within in a row are not different

A8. Study 1. Harvest 2. ANOVA and LSD tables for height, injury, above and belowground biomass at the low rate of each herbicide.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	84.7661	28.2553	0.67	0.5749
Treatment	10	4796.4090	479.6409 **	11.44	<.0001
Error	30	1258.2216	41.9407		
Corrected total	43	6139.3968			
CV(%)	35.3976				
R-Squared	0.7950				

Level of significance: P<0.01; **, P<0.05; *.

Injury

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.0411	0.0137	0.11	0.9515
Treatment	10	13.5720	1.3572 **	11.24	<.0001
Error	30	3.6210	0.1207		
Corrected total	43	17.2341			
CV(%)	66.1750				
R-Squared	0.7898				

Level of significance: P<0.01; **, P<0.05; *.

Aboveground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	11.4482	3.8160	1.90	0.1517
Treatment	10	134.9676	13.4967 **	6.70	<.0001
Error	30	60.4126	2.0137		
Corrected total	43	206.8285			
CV(%)	57.5315				
R-Squared	0.7079				

Level of significance: P<0.01; **, P<0.05; *.

A8. Study 1. Harvest 2. ANOVA and LSD tables for height, injury, above and belowground biomass at the low rate of each herbicide. (Continued)

Belowground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	4.4598	1.4866	2.40	0.0878
Treatment	10	35.5435	3.5543 **	5.73	<.0001
Error	30	18.6119	0.6203		
Corrected total	43	58.6152			
CV(%)	46.2644				
R-Squared	0.6824				

Level of significance: P<0.01; **, P<0.05; *.

Treatment	Height	Injury	Aboveground biomass	Belowground biomass
Control	22.750 ABC	0.00 C	3.118 A	2.0425 ABCD
Bromoxynil+ MCPA	26.000 AB	5.00 BC	3.815 A	2.7250 AB
Bromoxynil+ Pyrasulfotole	4.500 D	91.25 A	0.083 C	0.4500 FG
Carfentrazone	27.250 AB	6.25 BC	4.518 A	2.6650 ABC
Dicamba	26.250 AB	5.00 BC	4.123 A	2.2025 ABC
Dicamba+2,4-D	22.750 ABC	5.00 BC	3.568 A	1.9025 BCDE
Dimethenamid-p	22.000 BC	25.00 B	2.520 AB	1.5625 CDEF
Fluroxypyr	0.000 D	100.00 A	0.000 C	0.7700 EFG
Mesotrione	3.750 D	77.50 A	0.108 C	0.3875 G
Nicosulfuron	14.000 C	25.00 B	0.918 BC	0.9775 DEFG
Thifensulfuron+ Tribenuron	32.000 A	0.00 C	4.365 A	3.0425 A

*Means with the same letters within in a row are not different

A9. Study 1. Harvest 2. ANOVA and LSD tables for height, injury, above and belowground biomass at the recommended rate of each herbicide.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	149.1798	49.7266	1.34	0.2786
Treatment	10	4456.6818	445.6681 **	12.05	<.0001
Error	30	1109.5580	36.9852		
Corrected total	43	5715.4196			
CV(%)	38.3364				
R-Squared	0.8058				

Level of significance: P<0.01; **, P<0.05; *.

Injury

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.2079	0.0693	0.80	0.5051
Treatment	10	16.9213	1.6921 **	19.46	<.0001
Error	30	2.6079	0.0869		
Corrected total	43	19.7373			
CV(%)	52.7793				
R-Squared	0.8678				

Level of significance: P<0.01; **, P<0.05; *.

Dry matter

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	1.4109	0.4703	0.26	0.8539
Treatment	10	87.5436	8.7543 **	4.83	0.0004
Error	30	54.3477	1.8115		
Corrected total	43	143.3024			
CV(%)	67.6745				
R-Squared	0.6207				

Level of significance: P<0.01; **, P<0.05; *.

A9. Study 1. Harvest 2. ANOVA and LSD tables for height, injury, above and belowground biomass at the recommended rate of each herbicide. (Continued)

Belowground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	1.2378	0.4126	0.66	0.5831
Treatment	10	38.6996	3.8699 **	6.19	<.0001
Error	30	18.7526	0.6250		
Corrected total	43	58.6901			
CV(%)	49.1487				
R-Squared	0.6804				

Level of significance: P<0.01; **, P<0.05; *.

Treatment	Height	Injury	Aboveground biomass	Belowground biomass
Control	22.750 A	0.00 C	3.1175 AB	2.0425 AB
Bromoxynil+MCPA	25.000 A	3.75 C	4.4700 A	3.0150 A
Bromoxynil+Pyrasulfotole	0.000 C	100.00 A	0.0000 C	0.2575 E
Carfentrazone	18.250 AB	31.25 B	2.4175 B	1.4050 BCD
Dicamba	23.750 A	1.25 C	2.5550 AB	1.7675 B
Dicamba+2,4-D	13.750 B	33.75 B	1.3475 BC	1.4300 BCD
Dimethenamid-p	25.250 A	0.00 C	2.6950 AB	2.4550 AB
Fluroxypyr	0.000 C	100.00 A	0.0000 C	0.3375 DE
Mesotrione	1.000 C	92.50 A	0.0175 C	0.4350 CDE
Nicosulfuron	25.000 A	0.00 C	3.0900 AB	2.9775 A
Thifensulfuron+Tribenuron	19.750 AB	6.25 C	2.1675 B	1.5725 BC

*Means with the same letter are not significant in a row

A10. Study 1. Harvest 2. ANOVA and LSD tables for height, injury, above and belowground biomass at the high rate of each herbicide.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	25.5898	8.5299	0.14	0.9335
Treatment	10	3194.7272	319.4727 **	5.35	0.0002
Error	30	1792.8980	59.7632		
Corrected total	43	5013.2150			
CV(%)	48.2481				
R-Squared	0.6423				

Level of significance: P<0.01; **, P<0.05; *.

Injury

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.0808	0.0269	0.15	0.9321
Treatment	10	11.9266	1.1926 **	6.42	<.0001
Error	30	5.5732	0.1857		
Corrected total	43	17.5807			
CV(%)	74.5758				
R-Squared	0.6829				

Level of significance: P<0.01; **, P<0.05; *.

Aboveground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	3.3340	1.1113	0.43	0.7303
Treatment	10	86.6138	8.6613 **	3.38	0.0047
Error	30	76.8361	2.5612		
Corrected total	43	166.7840			
CV(%)	82.6000				
R-Squared	0.5393				

Level of significance: P<0.01; **, P<0.05; *.

A10. Study 1. Harvest 2. ANOVA and LSD tables for height, injury, above and belowground biomass at the high rate of each herbicide. (Continued)

Belowground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	4.4524	1.4841	1.90	0.1512
Treatment	10	34.8552	3.4855 **	4.46	0.0007
Error	30	23.4570	0.7819		
Corrected total	43	62.7646			
CV(%)	52.9708				
R-Squared	0.6262				

Level of significance: P<0.01; **, P<0.05; *.

Treatment	Height	Injury	Aboveground biomass	Belowground biomass
Control	22.750 A	0.00 D	3.118 AB	2.0425 ABC
Bromoxynil+MCPA	20.500 A	10.00 CD	2.925 ABC	2.6575 AB
Bromoxynil+Pyrasulfotole	5.250 BC	75.00 AB	0.323 D	0.6775 D
Carfentrazone	25.000 A	0.00 D	4.350 A	3.2125 A
Dicamba	4.750 BC	77.50 AB	0.318 D	0.8550 CD
Dicamba+2,4-D	24.250 A	8.75 D	3.243 AB	2.6575 AB
Dimethenamid-p	15.250 AB	55.00 BC	0.633 CD	0.7550 D
Fluroxypyr	17.500 A	30.00 CD	2.063 ABCD	1.5675 BCD
Mesotrione	0.250 C	98.75 A	0.003 D	0.4625 D
Nicosulfuron	25.500 A	0.00 D	2.863 ABC	2.1125 ABC
Thifensulfuron+Tribenuron	15.250 AB	28.75 CD	1.478 BCD	1.3625 CD

*Means with the same letters within in a row are not different

A11. Study 2. Harvest 1. ANOVA and LSD tables for height and aboveground biomass at the low rate of each herbicide.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	4.8806	1.6268	0.86	0.4729
Treatment	10	19.6022	1.9602	1.04	0.4392
Error	30	56.8068	1.8935		
Corrected total	43	81.2897			
CV(%)	119.8950				
R-Squared	0.3011				

Level of significance: P<0.01; **, P<0.05; *.

Aboveground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	3.1651	1.0550	1.36	0.2732
Treatment	10	7.7951	0.7795	1.01	0.4606
Error	30	23.2357	0.7745		
Corrected total	43	34.1959			
CV(%)	33.1136				
R-Squared	0.3205				

Level of significance: P<0.01; **, P<0.05; *.

Treatment	Height	Aboveground biomass
Control	1.6250 AB	3.0525 AB
Bromoxynil+MCPA	1.5000 AB	3.4750 A
Bromoxynil+Pyrasulfotole	2.5000 A	1.8325 B
Carfentrazone	1.2500 AB	2.7425 AB
Dicamba	2.0000 AB	2.5100 AB
Dicamba+2,4-D	0.7500 AB	2.3525 AB
Dimethenamid-p	0.5000 B	2.7950 AB
Fluroxypyr	1.0000 AB	2.6575 AB
Mesotrione	0.5000 B	2.8675 AB
Nicosulfuron	0.2500 B	2.7850 AB
Thifensulfuron+Tribenuron	0.7500 AB	2.1650 B

*Means with the same letters within in a row are not different

A12. Study 1. Harvest 2. ANOVA and LSD tables for height and aboveground biomass at the recommended rate of each herbicide.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.7443	0.2481	0.34	0.7998
Treatment	10	10.1250	1.0125	1.37	0.2417
Error	30	22.1931	0.7397		
Corrected total	43	33.0625			
CV(%)	137.6161				
R-Squared	0.3287				

Level of significance: P<0.01; **, P<0.05; *.

Aboveground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	12.1161	4.0387 *	3.49	0.0276
Treatment	10	10.6274	1.0627	0.92	0.5292
Error	30	34.6909	1.1563		
Corrected total	43	57.4345			
CV(%)	42.5304				
R-Squared	0.3959				

Level of significance: P<0.01; **, P<0.05; *.

Treatment	Height	Aboveground biomass
Control	1.6250 A	3.0525 AB
Bromoxynil+MCPA	0.2500 B	2.2600 AB
Bromoxynil+Pyrasulfotole	0.7500 AB	1.7200 B
Carfentrazone	0.2500 B	2.2625 AB
Dicamba	0.2500 B	2.3750 AB
Dicamba+2,4-D	0.5000 AB	2.4550 AB
Dimethenamid-p	0.2500 B	2.7100 AB
Fluroxypyr	0.5000 AB	1.9600 B
Mesotrione	1.5000 A	2.6625 AB
Nicosulfuron	0.2500 B	3.5900 A
Thifensulfuron+Tribenuron	0.7500 AB	2.7650 AB

*Means with the same letters within in a row are not different

A13. Study 1. Harvest 2. ANOVA and LSD tables for height and aboveground biomass at the high rate of each herbicide.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	5.7443	1.9147	1.70	0.1871
Treatment	10	14.2613	1.4261	1.27	0.2906
Error	30	33.6931	1.1231		
Corrected total	43	53.6988			
CV(%)	148.0309				
R-Squared	0.3725				

Level of significance: P<0.01; **, P<0.05; *.

Aboveground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.7240	0.2413	0.30	0.8266
Treatment	10	14.3519	1.4351	1.77	0.1101
Error	30	24.3088	0.8102		
Corrected total	43	39.3848			
CV(%)	36.1676				
R-Squared	0.3827				

Level of significance: P<0.01; **, P<0.05; *.

Treatment	Height	Aboveground biomass
Control	1.6250 A	3.0525 AB
Bromoxynil+MCPA	0.0000 B	3.0600 AB
Bromoxynil+Pyrasulfotole	0.7500 AB	2.1875 B
Carfentrazone	0.0000 B	1.8925 B
Dicamba	0.7500 AB	2.3550 B
Dicamba+2,4-D	0.2500 AB	1.9600 B
Dimethenamid-p	1.5000 AB	1.9700 B
Fluroxypyr	0.7500 AB	2.0400 B
Mesotrione	0.5000 AB	2.4500 B
Nicosulfuron	0.2500 AB	2.6125 AB
Thifensulfuron+Tribenuron	1.5000 AB	3.7975 A

*Means with the same letters within in a row are not different

A14. Study 2. Harvest 2. ANOVA and LSD tables for height, injury, tiller number per plant, above and belowground at the low rate of each herbicide.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	11.6377	3.8792	0.23	0.8769
Treatment	10	86.1022	8.6102	0.50	0.8739
Error	30	512.9475	17.0682		
Corrected total	43	610.6875			
CV(%)	26.9341				
R-Squared	0.1600				

Level of significance: P<0.01; **, P<0.05; *.

Injury

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.1447	0.0482	0.97	0.4185
Treatment	10	0.7075	0.0707	1.43	0.2166
Error	30	1.4880	0.0496		
Corrected total	43	2.3403			
CV(%)	168.3766				
R-Squared	0.3641				

Level of significance: P<0.01; **, P<0.05; *.

Tiller number per plant

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.7965	0.2655	0.40	0.7546
Treatment	10	16.2327	1.6232 *	2.44	0.0288
Error	30	19.9551	0.6651		
Corrected total	43	36.9844			
CV(%)	41.2430				
R-Squared	0.4604				

Level of significance: P<0.01; **, P<0.05; *.

A14. Study 2. Harvest 2. ANOVA and LSD tables for height, injury, tiller number per plant, above and belowground at the low rate of each herbicide. (Continued)

Aboveground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.4310	0.1436	0.88	0.4710
Treatment	10	3.1899	0.3189	1.92	0.082
Error	30	4.9950	0.1665		
Corrected total	43	8.6160			
CV(%)	41.1128				
R-Squared	0.4202				

Level of significance: P<0.01; **, P<0.05; *.

Belowground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	1.2483	0.4161	0.47	0.7045
Treatment	10	14.7053	1.4705	1.67	0.1357
Error	30	26.4797	0.8826		
Corrected total	43	42.4334			
CV(%)	34.7962				
R-Squared	0.3759				

Level of significance: P<0.01; **, P<0.05; *.

A14. Study 2. Harvest 2. ANOVA and LSD tables for height, injury, tiller number per plant, above and belowground at the low rate of each herbicide. (Continued)

Treatment	Height	Injury	Tiller number per plant	Aboveground biomass	Belowground biomass
Control	16.250 A	0.000 B	2.2525 ABCD	1.2750 AB	3.3825 AB
Bromoxynil+ MCPA	16.750 A	1.250 AB	2.7500 AB	1.5475 A	3.8625 A
Bromoxynil+ Pyrasulfotole	15.750 A	17.500AB	2.5000 ABC	0.6750 C	1.4750 C
Carfentrazone	15.500 A	6.250 AB	1.7500 BCD	0.9825 ABC	2.2900 BC
Dicamba	16.375 A	0.000 B	1.2500 D	1.0850 ABC	2.7100 ABC
Dicamba+2,4-D	15.500 A	3.750 AB	1.7500 BCD	0.8800 BC	2.4750 BC
Dimethenamid-p	15.000 A	3.750 AB	1.7500 BCD	0.9450 BC	2.8600 AB
Fluroxypyr	16.500 A	0.000 B	1.5000 CD	1.1000 ABC	2.7325 ABC
Mesotrione	11.500 A	21.250 A	1.7500 BCD	0.5225 C	2.8600 AB
Nicosulfuron	14.250 A	10.500 AB	3.2500 A	1.1100 ABC	2.4100 BC
Thifensulfuron+ Tribenuron	15.500 A	1.250 AB	1.2500 D	0.7950 BC	2.4625 ABC

*Means with the same letters within in a row are not different

A15. Study 2. harvest 2. ANOVA and LSD tables for height, injury, tiller number per plant, above and belowground biomass at the recommended herbicide rate.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	60.6434	20.2144	0.98	0.4142
Treatment	10	905.7272	90.5727 **	4.40	0.0008
Error	30	617.2543	20.5751		
Corrected total	43	1583.6250			
CV(%)	31.7807				
R-Squared	0.6102				

Level of significance: P<0.01; **, P<0.05; *.

Injury

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.1431	0.0477	0.85	0.4755
Treatment	10	8.7122	0.8712 **	15.59	<.0001
Error	30	1.6761	0.0558		
Corrected total	43	10.5314			
CV(%)	80.7470				
R-Squared	0.8408				

Level of significance: P<0.01; **, P<0.05; *.

Tiller number per plant

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	4.4560	1.4853	1.93	0.1454
Treatment	10	17.1495	1.7149 *	2.23	0.0436
Error	30	23.0456	0.7681		
Corrected total	43	44.6512			
CV(%)	55.0840				
R-Squared	0.4838				

Level of significance: P<0.01; **, P<0.05; *.

A15. Study 2. Harvest 2. ANOVA and LSD tables for height, injury, tiller number per plant, above and belowground biomass at the recommended herbicide rate. (Continued)

Aboveground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	2.2024	0.7341 *	4.41	0.0110
Treatment	10	6.5891	0.6589 **	3.96	0.0016
Error	30	4.9920	0.1664		
Corrected total	43	13.7836			
CV(%)	48.2103				
R-Squared	0.6378				

Level of significance: P<0.01; **, P<0.05; *.

Belowground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	10.2497	3.4165 **	4.69	0.0084
Treatment	10	26.0186	2.6018 **	3.57	0.0033
Error	30	21.8737	0.7291		
Corrected total	43	58.1420			
CV(%)	34.3962				
R-Squared	0.6237				

Level of significance: P<0.01; **, P<0.05; *.

A15. Study 2. Harvest 2. ANOVA and LSD tables for height, injury, tiller number per plant, above and belowground biomass at the recommended herbicide rate. (Continued)

Treatment	Height	Injury	Tiller number per plant	Aboveground biomass	Belowground biomass
Control	16.250 A	0.00 B	2.2525 AB	1.2750 A	3.3825 AB
Bromoxynil+ MCPA	15.500 A	1.25 B	1.7500 ABC	1.1075 A	3.2800 AB
Bromoxynil+ Pyrasulfotole	5.000 B	73.75 A	0.5000 C	0.0825 B	0.8850 E
Carfentrazone	15.750 A	1.25 B	1.2500 BC	0.8725 A	2.1500 BCD
Dicamba	18.500 A	1.25 B	1.5000 ABC	1.0875 A	2.9025 ABC
Dicamba+2,4-D	16.500 A	0.00 B	1.7500 ABC	1.2000 A	3.4100 A
Dimethenamid-p	14.500 A	2.50 B	2.7500 A	0.8525 A	2.8500 ABC
Fluroxypyr	16.000 A	6.25 B	1.0000 BC	0.7050 A	1.9650 CDE
Mesotrione	4.750 B	85.00 A	1.0000 BC	0.1025 B	1.5350 DE
Nicosulfuron	17.000 A	8.75 B	2.2500 AB	1.0225 A	2.3025 ABCD
Thifensulfuron+ Tribenuron	17.250 A	1.25 B	1.5000 ABC	1.0000 A	2.6450 ABCD

*Means with the same letters within in a row are not different

A16. Study 2. Harvest 2. ANOVA and LSD tables for height, injury, tiller number per plant, above and belowground biomass at the high herbicide rate.

Height

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	53.8761	17.9587	0.71	0.5556
Treatment	10	1218.0454	121.8045 **	4.79	0.0004
Error	30	762.5216	25.4173		
Corrected total	43	2034.4432			
CV(%)	34.3388				
R-Squared	0.6251				

Level of significance: P<0.01; **, P<0.05; *.

Injury

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.1256	0.0418	0.51	0.6761
Treatment	10	8.5477	0.8547 **	10.48	<.0001
Error	30	2.4462	0.0815		
Corrected total	43	11.1196			
CV(%)	96.4268				
R-Squared	0.7800				

Level of significance: P<0.01; **, P<0.05; *.

Tiller number per plant

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.9996	0.3332	0.80	0.5039
Treatment	10	21.5150	2.1515 **	5.16	0.0002
Error	30	12.5019	0.4167		
Corrected total	43	35.0166			
CV(%)	43.0300				
R-Squared	0.6429				

Level of significance: P<0.01; **, P<0.05; *.

A16. Study 2. Harvest 2. ANOVA and LSD tables for height, injury, tiller number per plant, above and belowground biomass at the high herbicide rate. (Continued)

Aboveground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	0.4040	0.1346	0.27	0.8500
Treatment	10	12.6845	1.2684 *	2.50	0.0257
Error	30	15.2423	0.5080		
Corrected total	43	28.3308			
CV(%)	73.8127				
R-Squared	0.4619				

Level of significance: P<0.01; **, P<0.05; *.

Belowground biomass

Source	DF	Sum of Squares (SS)	Mean Square (MS)	F value	Pr > F
Replication	3	1.2737	0.4245	0.31	0.8207
Treatment	10	42.8790	4.2879 **	3.09	0.0080
Error	30	41.6012	1.3867		
Corrected total	43	85.7540			
CV(%)	48.1004				
R-Squared	0.5148				

Level of significance: P<0.01; **, P<0.05; *.

A16. Study 2. Harvest 2. ANOVA and LSD tables for height, injury, tiller number per plant, above and belowground biomass at the high herbicide rate. (Continued)

Treatment	Height	Injury	Tiller Number per plant	Aboveground biomass	Belowground biomass
Control	16.250 A	0.00 C	2.2525 AB	1.2750 AB	3.3825 AB
Bromoxynil+ MCPA	16.000 A	3.75 C	1.7500 BC	1.3475 AB	3.1375 AB
Bromoxynil+ Pyrasulfotole	0.750 C	95.00 A	0.2500 E	0.0050 D	0.8550 D
Carfentrazone	15.250 AB	0.00 C	1.2500 CD	0.7150 BCD	1.8900 BCD
Dicamba	18.750 A	8.75 C	1.5000 BCD	1.1525 ABC	2.8675 ABC
Dicamba+2,4-D	13.500 AB	11.25 C	1.5000 BCD	0.7025 BCD	2.8625 ABC
Dimethenamid-p	18.750 A	1.25 C	1.5000 BCD	1.2200 AB	1.9225 BCD
Fluroxypyr	17.250 A	0.00 C	1.0000 CDE	0.7350 BCD	1.3325 CD
Mesotrione	8.500 B	61.25 B	0.7500 DE	0.1275 CD	1.7450 BCD
Nicosulfuron	17.500 A	12.50 C	3.0000 A	1.7800 A	2.4475 BCD
Thifensulfuron+ Tribenuron	19.000 A	1.25 C	1.7500 BC	1.5625 AB	4.4875 A

*Means with the same letters within in a row are not different

A 17.1. ANOVA table for giant reed dry weight in the CPWC study.

Source	DF	Sum of Squares(SS)	Mean Square (MS)	F value	Pr > F
Treatment	15	39697291.06	2646486**	41.22	<.0001
Error	48	3082084.98	64210.10		
Corrected total	63	42779376			
CV(%)	13.07				
R-Squared	0.92				

Level of significance: P<0.01; **, P<0.05; *

A 17.2. Least Significant Differences (LSD) Test for giant reed dry weight in the CPWC study.

Treatment	GDD	Dry Weight (kg ha^{-1})	
		Weed Infested	Weed Free
5 WAP	303	1515 AB*	5522 GH
6 WAP	361	1805 AB	6433 FG
7 WAP	430	2150 C	8137 EF
8 WAP	519	2595 E	9502 DE
9 WAP	606	3030 GH	11205 CD
10 WAP	687	3435 GH	13500 B
11 WAP	755	3776 GH	15317 A
21 WAP	1500	4480 H	15630 A

* Means with the same letter at row are different

A18. Growing degree days (GDD) data for May through October 2012. Hyslop Farm, Corvallis. Oregon.

	May	June	July	August	September	October
1	3.4	11.6	10.8	11.3	9.0	9.9
2	2.9	11.3	9.4	11.1	9.0	13.3
3	3.4	6.9	10.2	13.6	11.1	8.8
4	5.2	6.1	7.2	14.7	11.3	9.9
5	3.2	5.1	8.3	15.2	12.7	8.4
6	3.4	4.8	10.8	14.4	11.6	9.3
7	5.9	7.7	12.2	12.7	12.4	9.3
8	8.4	5.8	13.8	12.7	11.6	9.6
9	8.2	3.7	13.6	11.9	8.8	7.6
10	4.6	5.4	12.4	12.4	8.8	6.8
11	4.6	7.3	12.4	11.9	7.3	7.9
12	7.3	12.2	13.6	14.4	8.8	6.8
13	9.6	9.4	11.1	13.3	11.6	4.9
14	12.7	6.9	13.0	13.6	12.2	8.3
15	9.0	7.4	14.1	15.8	11.5	8.6
16	9.4	11.9	11.3	15.2	11.6	8.3
17	8.4	14.9	11.6	14.1	10.4	5.4
18	6.8	9.4	14.4	14.1	11.5	4.8
19	5.9	6.9	11.9	11.3	10.7	6.2
20	8.0	5.2	15.2	10.2	9.0	4.0
21	8.0	9.7	10.5	11.6	8.8	3.7
22	5.5	12.7	11.3	12.2	7.2	2.3
23	4.1	6.9	9.6	10.2	8.6	1.8
24	5.8	7.2	9.9	9.7	8.4	1.8
25	3.8	8.8	11.9	9.3	9.1	2.1
26	8.3	7.4	12.7	11.3	8.4	3.4
27	7.2	6.1	13.0	10.2	8.4	4.3
28	6.9	9.4	9.9	11.3	7.7	5.8
29	5.7	11.6	11.6	9.9	11.6	8.8
30	6.8	10.8	10.5	10.5	12.2	9.7
31	11.1		10.5	10.8		8.6

Total	203.6	250.5	358.7	380.9	301.6	210.3
Average	6.6	8.4	11.6	12.3	10.1	6.8

* All growing degree days reported as centigrade (C)