

Response of Teff, Barnyardgrass, and Broadleaf Weeds to Postemergence Herbicides

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Teff is a warm-season C4 annual grass crop grown for forage and food grain that has recently increased in production in parts of the United States. Hay from teff is well suited for livestock, especially horses. The objective of this study was to evaluate teff and weed response to selected herbicides in field studies conducted at the Malheur Experiment Station, Ontario, OR in 2009 and 2010. Herbicides were applied POST when teff was at the four-leaf stage. Broadleaf weed control at 21 d after treatment was greater than 91 % across herbicide treatments. Only the premix of 2.5 g ai ha⁻¹ florasulam + 99 g ae ha⁻¹ fluroxypyr + 15 g ai ha⁻¹ pyroxsulam provided acceptable control of barnyardgrass. Due primarily to barnyardgrass competition, teff treated with a premix of 2.5 g ha⁻¹ florasulam + 99 g ha⁻¹ fluroxypyr + 15 g ha⁻¹ pyroxsulam produced 7,200 kg ha⁻¹ of teff hay compared with 4,800 kg ha⁻¹ of teff hay for 2,4-D and dicamba and 4,200 kg ha⁻¹ teff hay when no herbicides were used. Teff grain production was greater with 2.5 g ha⁻¹ florasulam + 99 g ha⁻¹ fluroxypyr + 15 g ha⁻¹ pyroxsulam compared with any of the other treatments. The use of a premix of florasulam + fluroxypyr + pyroxsulam would improve broadleaf and grass weed control in ‘Tiffany’ and ‘Dessie’ teff varieties, improve hay and grain yield, and reduce production costs.

Nomenclature: Carfentrazone; dicamba; florasulam; fluroxypyr; pyroxsulam; 2,4-D amine; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv.; common lambsquarters, *Chenopodium album* L.; common purslane, *Portulaca oleracea* L.; hairy nightshade, *Solanum physalifolium* Rusby; redroot pigweed, *Amaranthus retroflexus* L.; Palmer amaranth, *Amaranthus palmeri* (S.) Wats.; teff, *Eragrostis tef* [Zucc.] ‘Dessie’, *Eragrostis tef* [Zucc.] ‘Tiffany’

Key words: Crop tolerance, herbicide injury, teff injury, weed control, weed management.

Teff es un pasto anual C4 de clima cálido que se produce para forraje y grano cuya producción se ha incrementado recientemente en diversas partes de Estados Unidos. El heno de teff es apropiado para ganado, y especialmente para caballos. El objetivo de este estudio fue evaluar la respuesta del teff y las malezas a varios herbicidas, en estudios de campo realizados en la Estación Experimental Malheur, Ontario, Oregon, en 2009 y 2010. Los herbicidas fueron aplicados POST cuando el teff tenía cuatro hojas. El control de malezas de hoja ancha a 21 d después del tratamiento fue superior a 91% en todos los tratamientos. Solamente la pre-mezcla de 2.5 g ai ha⁻¹ de florasulam + 99 g ae ha⁻¹ de fluroxypyr + 15 g ai ha⁻¹ de pyroxsulam brindó control aceptable de *Echinochloa crus-galli*. Debido principalmente a la competencia de *E. crus-galli*, teff tratado con una pre-mezcla de 2.5 g ai ha⁻¹ de florasulam + 99 g ae ha⁻¹ de fluroxypyr + 15 g ai ha⁻¹ de pyroxsulam produjo 7,200 kg ha⁻¹ de heno de teff comparado con 4,800 kg ha⁻¹ de heno de teff con 2,4-D y dicamba, y 4,200 kg ha⁻¹ de heno de teff cuando no se usaron herbicidas. La producción de grano de teff fue mayor con 2.5 g ai ha⁻¹ de florasulam + 99 g ae ha⁻¹ de fluroxypyr + 15 g ai ha⁻¹ de pyroxsulam al compararse con cualquiera de los otros tratamientos. El uso de una pre-mezcla de florasulam + fluroxypyr + pyroxsulam mejoraría el control de malezas de hoja ancha y gramíneas en las variedades de teff ‘Tiffany’ y ‘Dessie’, mejorando el rendimiento de heno y grano, y reduciendo los costos de producción.

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Teff is a warm-season annual cereal that has increased in popularity among hay producers in the western United States (Hunter et al. 2007; Norberg et al. 2009; Zenk 2005). Teff has long been grown for hay and grain in Ethiopia where it is a major food crop (Ketema 1997; Stallknecht 1997). Teff is commonly seeded at rates ranging from 6 to 12 kg ha⁻¹ to provide a dense population, which is expected to compete with annual weeds (Ketema 1997; Yu et al. 2007). Teff seed germination rates

of greater than 90% within 24 h of planting are expected when daytime temperatures are 25 C or greater (Debelo 1992). However, warm temperatures in June and ample water in irrigated fields allow weeds to grow faster and outcompete teff; hence the need for chemical weed control in certain environments and locations.

Studies of quantitative traits have demonstrated significant genetic variation among teff germplasm accessions and potential for improvement as a grain crop (Adnew et al. 2005). Some teff grain production occurs in the United States, primarily for ethnic markets using a small number of varieties available in different regions. However, there has been limited research on teff management, yield, and quality as a forage or grain crop (Twidwell et al. 2002). It has been suggested that rapid establishment, drought tolerance, and lack of significant disease make teff a viable candidate as a spring smother crop for weed control in corn (*Zea mays* L.) in organic production fields (DeHaan et al. 1994; Ketema 1997). Recently, teff varieties have been evaluated as a smother crop and as mixes with other crops (Wedryk and Cardina 2012a, 2012b). Nitrogen and irrigation needs of teff have also recently been published (Girma et al. 2012; Hunter et al. 2009; Roseberg et al. 2006).

Weed control has been identified as the most limiting factor in attaining better teff grain yield. Engstrom (1974) highlighted the poor competitive ability of teff against weeds and reported 130 kg ha⁻¹ grain yield in the nonweeded plots compared with 2,460 kg ha⁻¹ in the weeded plots. Also, Slotvisov et al. (1979) reported 18% yield loss due to weeds, whereas Ketema (1997) reported 52% yield loss without weed control. Very little herbicide testing has been done for weed control in teff since the work by Wondimagegnehu and Parker (1983). Preliminary research done in Kansas showed that POST applications of 2,4-D, dicamba, bromoxynil, carfentrazone, halosulfuron, and prosulfuron resulted in less than 5% injury on teff at 8 wk after treatment (Feldt et al. 2006). Research conducted in Ethiopia by Debelo (1992) found that plowing before planting increased teff grain yield from 216 kg ha⁻¹ to 951 kg ha⁻¹, primarily through increased number of panicles per unit area. Debelo found that application of 2,4-D amine at 0.5 kg ae ha⁻¹ at the tillering stage increased yield from 951 to 1,561 kg ha⁻¹.

At the inception of this study, there were no herbicides labeled for broadleaf weed control in teff in the United States, which we suspect limited the adoption of this crop. Now there is a supplemental label for the use of a premix of 2,4-D + dicamba to control broadleaf weeds in teff (Anonymous 2012). Therefore, the objectives of this research were to determine the tolerance of teff to selected POST herbicides and evaluate weed control to support labeling for broadleaf and grass weed control in teff.

Materials and Methods

Field studies were conducted in 2009 and 2010 at the Malheur Experiment Station near Ontario, OR (44.0°N, 117.0°W). The predominant soil was an Owyhee silt loam (coarse-silty, mixed, mesic Xerollic Camborthids) with a pH of 7.8 and 1.9% organic matter in both years. The field was moldboard plowed during the previous fall of each season and disked twice during spring to create a seedbed suitable for teff. Urea was applied at planting to supply 56 kg ha⁻¹ nitrogen. A cultipacker roller was used to create a firm seedbed that is required for teff production (Norberg et al. 2009). A hand spreader was used to distribute teff seed at a rate of 5.6 kg ha⁻¹ mixed with sand uniformly in each plot. In 2009 and 2010, 'Tiffany', a teff variety primarily grown for hay production, was used in the experiment. In 2010, along with Tiffany, 'Dessie', a teff variety primarily grown for grain, was planted in a separate area and treated with the same herbicide treatments. The field was furrow-irrigated to provide 10 cm of water (including runoff) on a weekly schedule to keep the moisture in the upper 30 cm of the soil profile.

Treatments were arranged in randomized complete blocks with three replications. Individual plots were 3 m wide (four beds) by 3.7 m in length. In 2009, teff was seeded on July 14, herbicides applied on August 3, with weed control and teff injury evaluations on August 10 (7 d after treatment [DAT]), and August 24 (21 DAT), and harvested on September 9. In 2010, planting was on June 14, with herbicide application on July 7. Evaluations for weed control and teff injury were on July 14 (7 DAT) and July 28 (21 DAT) and teff was harvested on August 11.

In 2009, the selected POST herbicide treatments included dimethylamine salt of 2,4-D at 540 or

Table 1. Teff injury and barnyardgrass control following POST-applied herbicides in 2009 and 2010 at the Malheur Experiment Station, Ontario, OR.

Treatment	Rate	Teff injury				Barnyardgrass control			
		7 DAT ^a		21 DAT		7 DAT		21 DAT	
		2009	2010	2009	2010	2009	2010	2009	2010
	g ae or ai ha ⁻¹	%							
Nontreated		0	0	0	0	0	0	0	0
2,4-D amine	540	0	0	0	0	0	15	0	12
2,4-D amine	1,100	0	0	0	0	5	33	5	12
Dicamba	280	0	13	0	0	2	20	8	12
2,4-D amine + dicamba	400 + 140	0	0	2	0	5	18	7	10
Carfentrazone	35	2	17	5	0	38	37	38	8
Florasulma + fluroxypyr + pyroxsulam	2.5 + 99 + 15	5	5	0	0	100	97	100	96
LSD (0.05)		NS	3.8	3.3	NS	10.5	4.3	10.9	3.8

^a Abbreviation: DAT, days after treatment.

1,100 g ha⁻¹, dimethylamine salt of dicamba at 280 g ae ha⁻¹, a premix of dimethylamine salt of 2,4-D amine at 400 g ha⁻¹ plus dimethylamine salt of dicamba at 140 g ha⁻¹, carfentrazone-ethyl at 35 g ai ha⁻¹, and a premix of 2.5 g ai ha⁻¹ florasulam + 99 g ae ha⁻¹ fluroxypyr + 15 g ai ha⁻¹ pyroxsulam. All herbicides were applied at the four-leaf teff stage when the plants were approximately 15 cm tall with two to three tillers.

Herbicides were applied using a CO₂-pressurized backpack sprayer fitted with four Teejet 8002 EVS nozzles calibrated to deliver 187 L ha⁻¹. The predominant weeds at the sites were a mixture of redroot pigweed and Powell amaranth (hereafter referred to as pigweed spp.), common lambsquarters, barnyardgrass, common purslane, and hairy nightshade. Evaluations for teff injury and weed control were based on a scale of 0% = no crop injury/no weed control and 100% = complete crop damage/total weed control. Aboveground biomass was harvested from 0.84 m⁻² in each plot and separated into broadleaf weeds, barnyardgrass, and teff. Each component was air dried in the greenhouse to determine biomass and grain yield. In 2010, we expanded the experiment to determine herbicide influence on teff variety Dessie grain yield. The harvested and dried teff plants were hand threshed to recover grain, and samples were cleaned and weighed. Data were tested and met the normality and homogeneity of variance before being subjected to ANOVA using SAS (2008) PROC GLM procedure and means compared using Fisher's Protected LSD test at P = 0.05. Means for

variables with year-by-treatment interactions were separated using a protected LSD at the 0.05 level. Data with no year-by-treatment interactions were combined over years and analyzed.

Results and Discussion

Teff Injury. Dessie and Tiffany teff varieties emerged 6 d after planting. Teff injury from the selected herbicides and rates was low and transient, ranging from 0 to 17% across treatments (Table 1). Teff injury from dicamba and carfentrazone was 0 and 2% in 2009 compared with 13 and 17% in 2010, respectively. These results are similar to those reported by Davison et al. (2010) and Hindes-Cook et al. (2011) when dicamba and carfentrazone were applied POST to teff at the two to five tillers growth stage. Variation in results could be attributed to weather difference and teff variety used in respective studies. Teff growth stage at herbicide application is important because significant herbicide injury and reduced grain yield had been reported when a combination of 2,4-D at 1.1 kg ha⁻¹ + dicamba at 0.035 kg ha⁻¹ was sprayed to teff at the boot stage (Davison et al. 2010).

Weed Control. Barnyardgrass control at 7 DAT and 21 DAT was > 96% with the premix of florasulam + fluroxypyr + pyroxsulam, but below 40% with any of the other treatments (Table 1). Control of barnyardgrass at 21 DAT with a premix of florasulam + fluroxypyr + pyroxsulam represented season-long control. The almost complete control for barnyardgrass allowed teff to grow

Table 2. Pigweed, common lambsquarters, and hairy nightshade control in teff with POST herbicides at the Malheur Experiment Station, Ontario, OR in 2009 and 2010.

Treatment	Rate	Pigweed spp.		Common lambsquarters		Hairy nightshade	
		7 DAT ^a	21 DAT	7 DAT	21 DAT	7 DAT	21 DAT
	—g ha ⁻¹ —						
Nontreated		0	0	0	0	0	0
2,4-D amine	540	89	96	87	91	90	97
2,4-D amine	1,100	94	98	93	93	94	98
Dicamba	280	87	98	89	95	91	99
2,4-D amine + dicamba	400 + 140	93	96	91	91	93	96
Carfentrazone	35	99	99	99	95	100	100
Florasulam + fluroxypyr + pyroxsulam	2.5 + 99 + 15	100	100	100	100	100	100
LSD (0.05)		11.1	2.2	9.5	2.7	9.4	2.0

^a Abbreviation: DAT, days after treatment.

quickly and form a dense canopy that covered the ground and minimized emergence of secondary weed cohorts.

Because ANOVA indicated no interaction between treatments and year for pigweed spp., common lambsquarters, and hairy nightshade, the data were combined over the years and analyzed. Pigweed spp. control with 2,4-D, dicamba and a premixture of 2,4-D plus dicamba ranged between 87 and 98% at 7 and 21 DAT (Table 2). Carfentrazone provided 99% control and the premixture of florasulam + fluroxypyr + pyroxsulam provided complete control for pigweed spp.

Common lambsquarters control with 2,4-D, dicamba, a premixture of 2,4-D + dicamba, and carfentrazone at 7 and 21 DAT ranged from 87 to 99% and 91 to 95%, respectively. Control with a premix of florasulam + fluroxypyr + pyroxsulam was 100%. A few common lambsquarters plants survived in the plots treated with carfentrazone but were generally reduced in size compared with plants in the nontreated control. Evaluations at 7 and 21 DAT indicated complete control of hairy nightshade in plots treated with carfentrazone and a premix of florasulam + fluroxypyr + pyroxsulam, whereas the other treatments provided 90 to 99% control (Table 2). Hairy nightshade plants that were injured by 2,4-D, dicamba, and a premixture of 2,4-D + dicamba were outcompeted by teff, resulting in higher ratings at 21 DAT.

Teff and Weed Biomass Production. Weed and teff biomass reflected the level of weed control in each treatment. Plants treated with the premix of florasulam + fluroxypyr + pyroxsulam produced the

highest teff forage yield of 7,230 kg ha⁻¹, which was 41% greater than the nontreated control (Table 3). The average teff forage yield for the 2,4-D amine, dicamba, and a premixture of 2,4-D plus dicamba was 4,590 kg ha⁻¹, which was not significantly different from the nontreated control and only 63% of the highest yield provided by the premix of florasulam + fluroxypyr + pyroxsulam. The 42% reduction in teff biomass yield corroborates findings by Ketema (1997), who reported 52% reduction in yield due to weed competition, but higher than the 18% reported by Slotvisov et al. (1979). The variation in yield reduction among different studies could be attributed to differences in varieties, weed seed bank densities, weed species, and other production practices. Adnew et al. (2005) reported significant genetic variation among teff germplasm accessions, which suggests potential for improvements in grain yield. Weed impact on grain yield (particularly barnyardgrass) was greater than forage yield, with virtually no seed or 100% yield loss in the 2,4-D, dicamba and carfentrazone treatments. Barnyardgrass was by far the most competitive weed in the nontreated control treatment and no herbicides are currently registered for grassy weed management in teff. Percent barnyardgrass control at 21 DAT was positively correlated ($r = 0.58$) with teff biomass produced; whereas barnyardgrass biomass was negatively correlated with teff biomass yield ($r = -0.73$). Currently, teff seed producers must avoid fields with high barnyardgrass seedbank or risk total crop failure (Norberg and Felix, personal observation). All the herbicides in this experiment significantly reduced broadleaf weed biomass (Tables 2 and 3). The average barnyard-

Table 3. Teff, broadleaf weed, and barnyardgrass weed biomass at Malheur Experiment Station, Ontario, OR averaged over 2009 and 2010.

Treatment	Rate	Weed and teff biomass ²			2010 teff grain yield	
		Tiffany teff	Broadleaf weeds	Barnyardgrass	Tiffany	Dessie
	g ai or ae ha ⁻¹	kg ha ⁻¹				
Nontreated		4,230	1,630	4,170	0	0
2,4-D amine	540	4,190	10	4,260	0	0
2,4-D amine	1,100	4,680	0	2,910	0	0
Dicamba	280	4,730	20	4,690	0	0
2,4-D amine + dicamba	400 + 140	4,760	0	3,830	0	0
Carfentrazone	35	5,590	370	2,530	0	0
Florasulam + fluroxypyr + pyroxsulam	2.5 + 99 + 15	7,230	0	260	1,160	760
LSD (0.05)		1,270	700	1,670	440	460

grass biomass was reduced 93% with the premix of florasulam + fluroxypyr + pyroxsulam compared with all other treatments. The premix of florasulam + fluroxypyr + pyroxsulam, which was the only herbicide with both high broadleaf and barnyardgrass control, resulted in 1,500 kg ha⁻¹ more teff forage compared with the next highest treatment, which was carfentrazone. Harvestable grain yield only occurred where barnyardgrass was controlled, which was with the premix of florasulam + fluroxypyr + pyroxsulam treatment. Teff has a very small and light seed, with the 1,000-seed weight of only 265 mg (Ketema 1997). The small seed size makes the harvesting of teff contaminated with weeds even more difficult and requires specialized equipment to clean the grain (personal observation). Presence of broadleaf weeds also results in poor hay storage because of mold growth in the middle of the bale.

In summary, the efficacy evaluations indicated that application of 2,4-D amine plus dicamba resulted in greater than 90% control of broadleaf weeds including pigweed spp., common lambsquarters, and hairy nightshade. Acceptable levels of crop safety were observed in response to applications of 2,4-D amine plus dicamba, and this combination was recently registered for weed control in teff (Anonymous 2012). Carfentrazone applied at 35 g ha⁻¹ was also safe to the crop and provided greater than 95% control of all broadleaf weeds and produced 5,590 kg ha⁻¹ of teff forage yield. The premix of florasulam plus fluroxypyr plus pyroxsulam significantly increased teff forage yield above all other treatments by controlling > 95% barnyardgrass and virtually 100% of all broadleaf weeds.

The premix of florasulam plus fluroxypyr plus pyroxsulam is not currently registered for weed control in teff, but would be a useful tool for weed control in teff hay and seed production. The limited number of herbicidal options for weed management in teff magnifies the importance of an integrated weed management approach especially when barnyardgrass is present.

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