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SMALL BURNET (*SANGUISORBA MINOR* SCOP.) RESPONSE TO HERBICIDES APPLIED POSTEMERGENCE

by

Ryan L. Nelson

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Plant Science

Approved:

Corey V. Ransom Major Professor	Grant E. Cardon Committee Member
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UTAH STATE UNIVERSITY
Logan, Utah

2013

ABSTRACT

Small Burnet (*Sanguisorba minor* Scop.) Response to Herbicides

Applied Postemergence

by

Ryan L. Nelson, Master of Science

Utah State University, 2013

Major Professor: Dr. Corey V. Ransom
Department: Plants, Soils, and Climate

Small burnet (*Sanguisorba minor* scop.) Is a hardy, relatively long lived evergreen forb native to Eurasia that has potential to improve grazinglands and extend grazing into late fall and winter. Trials evaluating small burnet tolerance to spring and fall postemergence herbicide applications were conducted at the Utah State University Evans farm in Millville, UT. Two small burnet genotypes were grown in a randomized complete block design with a split-plot arrangement. Twelve treatments, clethodim, clopyralid, imazamox, 2,4DB, metribuzin, aminopyralid, pendimethalin, dimethenamid-P, bromoxynil, dicamba, quinclorac, and an untreated were applied at moderate field use rates either spring or fall of the establishment year. Plots were rated for visual injury on a 0 to 100 scale where 0 = no injury and 100 = complete mortality. Ratings were done 7, 14, 60 days after treatment (DAT) and the spring following treatment. Seed yield, seed viability, and dry matter yield (DMY) were determined. Fall treatments of aminopyralid reduced seed yield 65%, seed germination 43%, and DMY 67%. Fall applied imazamox treatments reduced DMY by 36%, and seed yield by 33%, but did not impact germination. Visual injury was greatest from spring and fall applied aminopyralid treatments with ratings of 24% and 79%. Spring applied treatments did not impact seed yield or seed germination. Results suggest that clethodim, metribuzin, quinclorac, clopyralid, dimethenamid-P, bromoxynil, and pendimethalin cause little or no injury to small burnet.

(44 pages)

PUBLIC ABSTRACT

Small Burnet (*Sanguisorba minor* Scop.) Response to Herbicides Applied Postemergence

Ryan L. Nelson

Small burnet is a relatively unknown plant that is commonly used in North America. It is a hardy, relatively long lived forb native to Eurasia that grows well in most of North America. It is considered to be excellent forage for livestock and wildlife and because of its evergreen nature there is interest in its use to extend grazing of pastures and rangelands into late fall and winter.

Popular sources reference its use in salads, ice drinks, with cream cheese, as a desirable garnish due to its distinct cucumber aroma and flavor. It is also reported to be a superb wildlife attractant for game hunters.

There is limited literature available on seed production and general care of small burnet. This study was conducted to assist the small burnet seed producer and possibly the range/landowner who has small burnet in their pastures or range. Results from this study show that there are a number of herbicides that small burnet can tolerate. These herbicides include clethodim, metribuzin, quinclorac, clopyralid, dimethenamid-P, bromoxynil, and pendimethalin, which may cause some initial injury to small burnet but the small burnet recovers from the injury. Data suggests that aminopyralid and imazamox should not be used for weed control in small burnet.

Dedicated to my remarkable wife and partner, Laura, whom I love dearly and my fabulous children who helped motivate and encourage me to continue working hard and finish this degree.

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Ryan L. Nelson

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Small burnet (*Sanguisorba Minor* scop.) also known as sheep's burnet, salad burnet, and lesser burnet is an herbaceous, perennial, evergreen forb in the rose family. It is native to Europe, Western Asia, Siberia, and Northern Africa (Fryer 2008; Ogle 2002a). Small burnet is described as a hardy, relatively long lived forb that grows well in most parts of North America (Ogle 2002a; Peel et al. 2009).

Limited information suggests small burnet is an excellent forage with good quality and palatability for livestock and wildlife (Arzani et al. 2005; Fryer 2008; Viano et al. 1999). It can also be grazed year round or until it is covered by snow (Wills 2008). It averages height is 71 to 76 cm with adequate moisture and will establish in areas with as little as 25 to 31 cm of annual precipitation but does not usually persist with less than 36 cm (Buckland et al. 1997; Peel et al. 2009; Ogle 2002a). Small burnet grows best in well-drained soils and does well in infertile and disturbed soils. It has excellent cold tolerance and is considered fire resistant due to the fact that leaves and stems stay green with relatively high moisture content during the fire season (Fryer 2008; Ogle 2002a).

Small burnet is a prolific seed producer but generally is considered to be non-invasive. It will re-seed itself into open areas and has not been shown to invade established plant communities (Ogle 2002a). It maintains viable seed in the soil, enabling it to re-grow after fire or prolonged drought. Small burnet seed remains viable for up to 25 years (Fryer 2008; Stevens and Jorgenson 1994) and seeds provide a good food source for upland game birds and other small foraging animals (Everett et al. 1978; Karmiris and Nastis 2010; Pellant and Lysne 2005).

There is interest in the use of small burnet in grazinglands, particularly for extending grazing seasons. When most forage species are dormant, small burnet remains green. It has been observed that mule deer (*Odocoileus hemionus*) will dig through 20 to 25 cm of snow to graze on small burnet during winter months (Peel 2012 personal communication). Welch (2004) includes small burnet as a plant that can be used as an additional plant species to provide needed protein and energy for range animals. He states that there is no perfect forage species to meet nutritional requirements of range animals and that the best approach to meet those requirements is by diversifying the vegetation. Goodwin et al. (2004) suggest using small burnet as one of the plants in a seed mixture to assist in the revegatation of degraded landscapes in Montana.

With the increased use of small burnet in grazinglands it is important to understand small burnet response to herbicides used in agronomic settings and restoration efforts. More importantly, information on small burnet tolerance to herbicides that could be used for small burnet seed production as well as assisting land managers in establishing small burnet into sites with known weed problems. Available literature identifies four herbicides that should or should not be used on small burnet. Ogle (2002b) suggests that because small burnet is a broadleaf plant 2,4-D should be avoided, and that small burnet can be controlled with Roundup combined with 2,4-D or Escort, or Banvel and 2,4-D. Carrithers (1997) lists small burnet as being tolerant to aminopyralid.

There is minimal information available on basic management practices particularly weed control during seed production and stand establishment of small burnet. As typical with most species in the year of establishment, weed invasion is problematic and even though seed is not produced that year it can impact the health of the stand and subsequent production. If not controlled during establishment, weeds will continue to be a determent to seed production and contamination.

This study was conducted to determine the tolerance of small burnet to spring and fall postemergence applied herbicides. The impact on seed production and germination were the primary focus with a secondary focus on plant injury and forage yield. This research will identify herbicides that can potentially be used safely in small burnet seed production and with potential for use on grazinglands.

CHAPTER 2

LITERATURE REVIEW

Origin, Morphology, and Description

Small burnet (*Sanguisorba minor* scop.) also known as sheep's burnet, salad burnet, and lesser burnet is an herbaceous, perennial, evergreen forb in the rose family. It is native to Europe, Western Asia, Siberia, and Northern Africa (Fryer 2008; Ogle 2002a). Small burnet is described as a hardy, relatively long lived forb that grows well in most parts of North America (Ogle 2002a; Peel et al. 2009). It has a branched caudex with a prominent taproot which measures up to 100 cm long. Leaves are alternate pinnately compound and are oblong egg shaped, sharply toothed, and 4 to 20 cm long. The flowers are imperfect with lower flowers on the seed head staminate and upper flowers pistillate with no petals and 12 stamens. The seed is an achene paired in a hypanthium 3 to 5 mm long with prominent ridges. Plant height averages 71 to 76 cm with adequate moisture and 25 to 30 cm at the minimal moisture level under which small burnet will establish (25 to 36 cm). Generally small burnet plants do not persist with less than 36 cm of moisture (Fryer 2008; Ogle 2002a; Monsen 2004; Stevens and Wasser 1982). Small burnet grows best in well-drained soils, does well in infertile and disturbed soils, and will grow in acidic or alkaline soils (Buckland et al. 1997; Fryer 2008; Stevens and Monsen 2004; Toth et al. 1964; Wasser 1982). In a field trial (Valassis et al. 1957) conducted in Oregon, small burnet did well on the marginal soils. It has excellent winter tolerance and is considered fire resistant due to the fact that leaves and stems stay green with relatively high moisture content during the fire season (Fryer 2008; Ogle 2002a).

Small burnet is considered by many to be drought tolerant and persist under dryland conditions. Buckland et al. (1997) reported that during an extreme drought in Northern England the relative water content (RWC) was low in most of the vegetation of the shallow Daleside soils while the turgor of small burnet at these sites remained conspicuously high. While the average RWCs of vegetation in these sites decreased the RWC for small burnet remained constant. This suggests that the long taproot of small burnet was able to access subsoil moisture. In descriptions given by Fryer (2008), Ogle (2002a), Stevens and Monsen (2004), and Wills et al. (1987) small burnet is described as drought tolerant and/or a plant to be used in dryland plantings. Fryer (2008) similar to Buckland et al. (1997) suggests that the long tap root of small burnet possibly attributes to the drought tolerance because of the high water storage capacity of the taproots. Fryer (2008) also states that small burnet has the ability to adjust its water use efficiency as environmental conditions change. Stevens and Monsen (2004) discussed that there are 30 ecotypes of small burnet and that some of these ecotypes are more drought tolerant than others. The National Plant Germplasm System (NPGS) has 98 ascensions of small burnet available from 16 different countries. Peel et al. (2009) conducted a study to characterize all available small burnet germplasm for ploidy and agronomic characteristics. This study included 104 ascensions of small burnet. Ninety eight of these ascensions were from the Western Regional Plant Introduction Station at Pullman WA, 5 from the Great Basin Research Station in Ephraim, UT, and certified Delar seed which is the only commercial cultivar available in the US.

Nutritional Value

Good, nutritious, desirable forage is necessary to maintain healthy livestock and wildlife. Welch (2004) outlines basic range animal nutritional needs. He alludes to the fact that protein is a key component in an animal's ability to maintain its body weight and/or grow. He states that there is no "perfect forage species" on the range to supply animals with the correct amount of protein and nutrients. A diverse range of palatable shrubs, forbs, and grasses would be the best approach for range management. He provides a list of forages with their nutrient qualities throughout the growing season and classifies them into spring, summer, and fall/winter. Small burnet protein content is 17.4, 9.8, and 6.8% in the spring, summer, and fall respectively (Welch 2004). These values provide sufficient protein to livestock and wildlife. Spring and summer protein content is sufficient for cattle and some range animals. Fall/winter protein content is sufficient to maintain a cow or mule deer (*Odocoileus hemionus*). Arzani et al. (2006), Valassis et al. (1957), and Viano et al. (1999) list protein amounts of small burnet to be 8.5, 6.2, and 5.9%, respectively. The growth stage of the plants at the time of collection, location, and maturity of the plants varies thus giving a range of protein amounts when compared to the results of Welch (2004).

Others state that small burnet is very desirable, good quality forage (Ogle 2002b; Stevens and Monsen 2004; Valassis et al. 1957; Wasser 1982), and is eaten by birds, rodents, and insects (Stevens and Monsen 2004; Wills 2008). Toth et al. (1964) demonstrated that small burnet is utilized by white-tailed deer (*Odocoileus virginianus*), rabbits (*Sylvilagus floridanus*), penned quail (*Colinus virginianus*), and doves (*Zenaidura macroura*). In seed quality analysis done by Toth et al. (1964), small burnet seed contained 12 to17% protein. Additional evidence of the desirability of small burnet to game birds is illustrated in a study done by Pellant and Lynse (2005). They discuss strategies of how to diversify crested wheatgrass (*Agropyron cristatum* (L.) Gaerth) seedings. They state that small burnet is a forb preferred by sage grouse (*Centrocercus urophasianus*) and can be utilized to improve crested wheatgrass monocultures.

To further support animal preference for small burnet, Plummer (1968) states that small burnet seed is exceptionally attractive to rodents. He elaborates that any increase in numbers of small burnet plants from seed is negligible because rodents will eat all the seed shed from plants. He also writes that small burnet is a preferred forage plant of game animals particularly in the late winter and spring. A study conducted by Wills et al. (1987) of alternative dryland pasture plants observed that small burnet and pubescent wheatgrass (*Agropyron trichophorum* Link) were most preferred by merino sheep of all plants tested in their trial. Michael Peel (Personal communication 2012) observed that in January and February mule deer (*Odocoileus hemionus*) will dig through 25 cm of snow to graze small burnet plants.

Seed Production

Studies have shown that the use of herbicides to control weeds in seed fields increases seed production. McCarty et al. (1967) observed that by controlling weeds in side-oats grama (*Bouteloua curtipendula* (Michx.) Torr.) there was a substantial increase in seed produced compared to the untreated. In some treatments there was a 10 fold increase in seed production when herbicides were used for controlling weeds. Use of herbicides for weed control in the side oats grama also increased grass quality. Lee (1965) conducted a study of using herbicides to prepare seedbeds before planting and after planting. Several treatments such as paraquat, diuron, and amitrole proved to be very effective in controlling weeds. All treatments yielded at least 20% more seed when compared to the untreated. Warren and Lee (1965) state that herbicides are helpful in establishing grass stands for seed production in western Oregon.

Small burnet averages between 42,000 to 55,000 seeds per pound (Stevens and Monsen 2004; Wasser 1982). Fryer (2004) reported that an after ripening period improves seed germination, with seed germination increasing during the first 3 years of storage. Small burnet seed also maintains viability when stored for long periods of time. Stevens et al. (1981) reporteded that the viability of small burnet seed after 15 years of storage in a warehouse was 88%. A follow-up study done by Stevens and Jorgenson (1994) testing germination of rangeland species reported that 83% of small burnet seeds germinated after 25 years of storage.

Fisher et al. (1987) evaluated the effect of agronomic practices on small burnet seed production. Two row spacings and 11 different plant species were planted to evaluate establishment and seed production. It was found that the row width was not significant and that small burnet established very well compared to Rocky Mountain penstemon *(Penstemon strictus* Benth.), Lewis flax *(Linum lewisii* Pursh.), Indian ricegrass (*Oryzopsis hymenoides* (Roem. and Schult.) Barkworth), Fourwing saltbush (*Atriplex canescens* (Pursh.) Nutt.), tall fescue *(Festuca arundinacea* Schreb.), orchardgrass (*Dactylis glomerata* L.), western wheatgrass (*Elymus smithii* (Rydb.)), basin wildrye (*Leymus cinereus* (Scribn and Merr.) A. Love), Pine lupine *(Lupinus albicalis* Dougl.), and winter fat (*Ceratoides lanata* (Pursh) Moq). Small burnet was the highest seed yielder of the 11 species tested with yields ranging from 423 to1307 kg ha^{-1} compared to the next two highest yielders of tall fescue at 320 to 697 kg ha^{-1} and orchardgrass at 88 to 194 kg ha^{-1}.

Douglas et al. (1993) conducted a study examining the effect of genotype and seed size on early vegetative growth of small burnet. Seed lots of small burnet seed varying in size from less than 2.0 mm to more than 2.8 mm were evaluated. Seed size did not affect germination but 45 days after emergence, leaf area, shoot height, root length, and dry weight of seedlings was substantially greater from large seeds than from small and medium sized seeds. They suggested that more research/breeding be done to develop plants producing larger sized seeds.

Limited information is available on small burnet seed production practices and harvesting. The most extensive information is given by Stevens et al. (1996) and Ogle (2002b). Stevens et al. (1996) suggests planting rows 71 to 91 cm wide and planting 10 pure live seeds (PLS) per 30 linear centimeters of row either in fall (suggested) or spring, or late summer when irrigation is available. They also recommend weeding with mechanical and chemical fallowing prior to planting. Hand weeding may be required during seedling establishment. Irrigation should be 36 to 46 cm and a minimum of 3 irrigations are usually required, early summer, pre-flower, and late flower. With commercial seed harvesting and air cleaning, seed yields of 560 to 784 kg ha^{-1} are reported (Stevens et al. 1996).

Ogle (2002b) suggests planting 76 cm rows at 13.4 kg PLS per hectare up to 107 cm rows at 11.2 kilograms PLS per hectare or approximately 80 to100 seeds per linear meter. The wide spacings allow for mechanical weed control. Early spring planting is suggested with hand weeding during seedling establishment and fertilizer applied in the fall and spring to enhance production. Careful irrigation is needed to avoid plant stress during the late bud stage, pollination, and during regrowth. Seed yields of 784 to 1120 kg ha^{-1} under irrigation and 280 to 392 kg ha^{-1} under dry land are reported (Ogle 2002b).

Chemical Weed Control

Weeds in pastures and rangelands cost ranchers a substantial amount of money annually by reducing forage yields, quality of the forage, reduced animal use, and causing animal injury through toxicity, thorns or spines (Seller and Ferrell 2012). Herbicides are commonly used for improving rangelands and pastures by controlling weeds and giving desirable vegetation a competitive advantage. Petersen et al. (1983) in a study using herbicides to manipulate rangeland vegetation saw an increase in production of over 71% of desirable warm season grasses after treatments of glyphosate, atrazine, 2,4-D plus picloram, and 2,4-D.

Evans et al. (1963) stated that herbicides can prevent seed set of medusahead (*Elymus caput-medusae* (L.) Necski) when applied in the boot or at the soft dough stage. Caryopsis were reduced 60 to 100% and seed production decreased by 75 to 100% the following year. A properly timed herbicide application can help control an undesirable unwanted weedy species.

Masters and Sheley (2001) estimate that the economic impacts of leafy spurge and spotted knapweed in Montana, North Dakota, South Dakota, and Wyoming is $140 million dollars each year and costs will increase if these weeds are allowed to spread. They also elaborate that many rangelands have deteriorated to the point that desirable species no longer exist or exist in very low numbers. An integrated weed management approach using multiple weed control practices need to be implemented to return desirable species to the rangelands. They state chemical control is an important tool to assist in revegatating rangelands and reducing costs of rangeland maintenance.

Herbicide treatments are often done to remove unwanted species and allow planting of a desirable species. Weber (1986) determined that applying herbicides and allowing desirable vegetation to compete with weeds and postponing grazing was beneficial in restoring rangelands.

Very little literature can be found on herbicide usage for small burnet. Limited information is available on the use of herbicides to kill small burnet. Ogle (2002b) suggests that a combination of glyphosate and 2,4-D can effectively remove small burnet when combined with ploughing. Tank mixtures of dicamba, metsulfuron, and 2,4-D also should kill small burnet (Ogle 2002b). Carrithers (1997) reported findings on clopyralid (Transline®). Transline® has some selectivity and it does not control certain plants. Small burnet is listed as not sensitive to Transline® treatments. Douglas and Foote (1994) applied clopyralid and paraquat on small burnet to control weeds in a study of useful perennial species for soil conservation.

Chemical Classification

Growth-regulator herbicides contain some of the oldest herbicides commonly used. They are a diverse group that includes several chemical families. They mimic natural growth hormones in plants and upset the balance of the hormones in the plants. They are most commonly known for their activity on broadleaf species (Gunsolus and Curran 2002; Peterson et al. 2010; Shumway and Scott 2002). These herbicides are used for weed management in both crops and rangelands and included aminopyralid, clopyralid, 2,4-DB, quinclorac, and others.

One of the more recently developed growth regulator herbicides is aminopyralid (Milestone®). The Milestone® fact sheet (Anonymous 2009) states that it provides long lasting control of noxious weeds and invasive broadleaf species. Aminopyralid is most commonly known for its low use rates to control most thistles and knapweeds in pastures and rangelands. In a study conducted by Enloe et al. (2007) the use of aminopyralid provided very good control of Canada thistle (*Cirsium arvense* (L).Scop.) even at lower rates. In another study the control of Russian Knapweed (*Rhaponticum repens* (L.) Hidalgo) was excellent (> 90 %) with aminopyralid (Enloe et al. 2008).

Clopyralid (Transline®) is commonly used to control a wide variety of weeds in various settings and controls many tough western noxious weeds including knapweeds and thistles (Anonymous 2011b). Clopyralid can effectively control yellow starthistle (*Centaurea solstitialis* L.) in the application year as well as the following year (Morghan et al. 2003).

Dicamba, 2,4-DB, and quinclorac are other growth regulators commonly used in crop, noncrop, turf, grass seed, pasture, and hay fields. Labels also permit some range applications (Anonymous 2007, 2008a). Dicamba is a growth-regulator that controls many broadleaf weeds and is used for many different applications from specialty crops to rangeland. In a study using dicamba, Rinella et al. (2010) applied dicamba as well as 2,4-D on Japanese brome (*Bromus japonicus* Thunb) at various growth stages to limit or control seed set. Results were that 2,4-D was very effective and dicamba slightly less effective in inhibiting seed set of Japanese brome at the application timings of internode elongation, boot, and heading stages of growth. 2,4-DB is an herbicide that it is safe to use on alfalfa and other legumes such as soybeans and peanuts (Anonymous 2007). Its range of weeds controlled is less than 2,4-D yet it can be applied over the listed species without harming them like 2,4-D would. 2,4-DB is most effective when applied to weed seedlings (Fischer 1991). Quinclorac is labeled for use in fallow systems, grass seed fields, preplant wheat, and noncrop areas. Grossmann (1998) listed quinclorac as a growth regulator herbicide that is highly selective. It can be used to control or suppress a variety of broadleaf weeds such as dandelion (*Taraxacum officinale* Weber.), common ragweed (*Ambrosia artemisiifolia* L.), and prickly lettuce (*Lactuca serriola* L.), and will selectively control several grass weed species such as barnyardgrass (*Echinochloa crus-galli* L.) and green foxtail (*Setaria viridis* L.). Quinclorac also provides excellent control of field bindweed (*Convolvulus arvensis*, L.) (Anonymous 2008c, Ron Reed personal communication 2011). Mallory-Smith and Brewster (2001) stated that quinclorac treatments did not effect seed yield of perennial ryegrass (*Lolium perenne* L.), creeping red fescue (*Festuca rubra* L.), tall fescue (*Festuca arundinacea* Schreb.), or orchardgrass (*Dactylis glomerata* L.) yet provided better and longer lasting field bindweed control than 8.4 L ha^{-1} of 2,4-D ester.

Dimethenamid-P and pendimethalin are seedling growth inhibitor herbicides. Seedling growth inhibitors are generally applied preemergence or preplant and incorporated into the soil (Shumway and Scott 2002). Dimethenamid-P is classified as an acetamide herbicide that is used to control annual grasses and some small seeded broadleaf weeds and the primary site of absorption for broadleaf weeds is the roots and for grasses the shoot (Peterson et al. 2010). The Outlook® label (Anonymous 2008b) (active ingredient dimethenamid-P) lists several application areas that include beets, onions, and perennial grasses grown for seed. Similar to Dimethenamid-P, pendimethalin controls some broadleaf and annual grass weeds and is absorbed by both roots and shoots (Peterson et al. 2010). Pendimethalin is classified as a dinitroanaline herbicide and inhibits root and shoot growth. Prowl H_20® (Anonymous 2011a) (active ingredient pendimethalin) labeling lists application on crops from alfalfa and carrots to perennial grasses grown for seed.

Photosynthetic (PS) inhibitor herbicides work by disrupting photosynthesis and control many broadleaf and some grass weeds. PS inhibitors include propanil, bromoxynil, atrazine, and metribuzin. Weed death occurs rapidly because of secondary toxic substances that build up and destroy cell membranes (Gunsolus and Curran 2002; Peterson et al. 2010; Shumway and Scott 2002).

Metribuzin is a triazinone in the PS inhibitor family. It is soil applied early postemergence, when the desired species is dormant. It is translocated from the roots and shoots through the xylem. Sencor® (Anonymous 2003) (active ingredient metribuzin) controls certain grasses such as barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.), large crabgrass (*Digitaria sanguinalis* (L.) Scop.), and green and yellow foxtail (*Setaria viridis* (L.) P. Beauv., *Setaria pumila* (Poir.) Roem. & Schult. ssp. *pumila* L.). Some broadleaf weeds controlled are common lambsquarter (*Chenopodium album* L.), field pennycrest (*Thlaspi arvense* L.), and redroot pigweed (*Amaranthus retroflexus* L.). Crops and areas where metribuzin may be applied range from tomatoes, potatoes, soybeans, alfalfa, and alfalfa/ grass pastures. Dastgheib et al. (2003) found that metribuzin when applied preemergence had good control of annual brome grasses in cereals.

Bromoxynil is classified as a nitrile herbicide in the PS inhibitor family. It is an early postemergence contact herbicide that is not translocated through the plant and thorough spray coverage is essential for good weed control (Petersen et al. 2010). Crops and areas labeled for the application of bromoxynil include and are not limited to corn, sorghum, alfalfa, garlic, mint, grasses grown for seed, sod production, and conservation reserve program areas (Anonymous 2005).

Imazamox is classified as an imidazolinone in the amino acid synthesis inhibitor herbicides also known as the ALS inhibitors and has activity on both annual and perennial broadleaf and grass weeds. Uptake is through leaves and roots (Gunsolus and Curran 2002; Peterson et al. 2010; Shumway and Scott 2006). The Raptor® label (Anonymous 2010a) (active ingredient imazamox) lists application crops from alfalfa and chicory to soybeans. Canevari et al. (2003) lists the benefits of using Raptor® in seedling and established alfalfa. These benefits are that it can be applied to seedling alfalfa which has reached the two trifoliate stage and can be applied at any time to established alfalfa. It may also be applied to alfalfa used for seed production. Other benefits are that Raptor® (Anonymous 2010a) has very good control of many broadleaf and grass weeds such as burning nettle (*Urtica uerns* L.), filaree (*Erodium* spp.), black mustard (*Brassica nigra* L.), canarygrass (*Phalaris arundinacea* L.), ripgut brome (*Bromus diandrus* Roth), and downy brome (*Bromus tectorum* L.) (Anonymous 2010a).

Clethodim is a cyclohexanedione herbicide in the lipid synthesis or ACCase inhibitor class of herbicides and is primarily used in broadleaf crops to control grass weeds. Clethodim is highly selective and has very little or no activity in dicotyledenous plants. Clethodim is used postemergence and is absorbed through foliage and translocated in the phloem to meristematic regions of the plant (Gunsolus and Curran 2002; Peterson et al. 2010; Shumway and Scott 2002). The label for Select Max® (Anonymous 2010b) (active ingredient clethodim) lists its use in nearly every broadleaf crop from alfalfa to fruits and vegetables. Clethodim has good control on many grass species (Brewster and Spinney 1989)

Research Objectives

The objectives of this research were to study the tolerance of small burnet to 11 treatments, 2,4-DB, aminopyralid, bromoxynil, clethodim, clopyralid, dicamba, dimethenamid-P, imazamox, metribuzin, pendimethalin, quinclorac, and an untreated applied postemergence, on two genotypes of small burnet in the spring and fall. Information gathered from this study may lead to recommendations that can be made on which treatments can be safely used on small burnet for seed production and identify herbicides for potential use on grazinglands which contain small burnet.

CHAPTER 3

MATERIALS AND METHODS

The study was conducted at the Utah State University Evans Research Farm in Millville, UT. Two genetically and morphologically distinct genotypes of small burnet were used. 'Delar', which is the only commercially available cultivar, and C-05, an experimental line from the USDA, Forage and Range Research Laboratory (FRRL) Logan, UT. Delar is a tetraploid (2n=28) and C-05 octaploid (2n=56) (Peel et al. 2009). Delar is a leafy herbaceous plant with a majority of it growth around the caudex in shorter stems and leaves. C-05 is taller with longer stems and with less leaf mass than Delar. Delar seed weighs approximately 8 g/1000 seeds and the C-05 approximately 3 g/1000.

Plants were started in the greenhouse in cone-tainers (Stuewe and Sons Inc., Corvallis, OR 97333-9425) filled with a locally purchased soil medium (Miller Companies LLC Hyrum, UT 84319). The mixture consisted of three parts sand, one part peat moss, and one part vermiculite. Cones were hand watered with tap water until seedlings emerged and then watered as needed with Peters Professional® 20-20-20 fertilizer (Scotts-Sierra Horticulture Products Company, Marysville, OH 43041).

Each small burnet seed has two achenes per hypanthium. After germination the smaller of the two seedlings were removed to ensure only one plant remained in each cone. Small burnet plants were approximately 3 months old when transplanted from the greenhouse to the field.

Trials were transplanted in 2009 and 2010 to obtain two location years of data. The 12 treatments were arranged in a randomized complete block design containing spring and fall treatments with four replications in a split-plot arrangement where herbicide treatment and timing was the whole-plot and genotypes were the sub-plot. Each plot consisted of 12 plants; six Delar and six C-05 plants. A single alfalfa plant was placed between plots within rows and each plot was bordered by a row of Delar to provide a buffer between treatments. Plants within a plot were spaced 0.5 m apart within rows and 1.0 m between each row. Trials were transplanted on May 13, 2009 and May 25, 2010 in fields prepared the previous fall. Hand weeding was done to maintain weed free trials ensuring weed competition did not impact the results.

Herbicide treatments were applied spring and fall in the establishment year. The 12 treatments detailed in Table 3-1 include clopyralid, imazamox, 2,4-DB, metribuzin, aminopyralid, pendimethalin, dimethenamid-P, bromoxynil, dicamba, quinclorac, clethodim, and untreated were applied using a CO_2 pressurized backpack sprayer. The spray boom consisted of 4, 8002 flat fan nozzles spaced 40 cm apart calibrated to deliver 187 L ha^{-1} at 207 kPa at 4.0 Km h^{-1}.

Spring herbicide treatments for trial 1 were applied June 27, 2009. The late treatment date was due to frequent rainfall. At the time of application plants were mostly vegetative with flowering averaging between 10 and 20%. Plant heights were approximately 30 cm for Delar and 25 cm for C-05. Treatments were applied in the early afternoon with 0% cloud cover and a temperature of 26

C. Spring herbicide treatments for trial 2 were applied on July 6, 2010. Treatments were again delayed due to frequent rainfall. Delar plants were 15 cm in height and C-05 plants were 8 cm at the time of treatment. Treatments were applied in the early afternoon with 0% cloud cover and a temperature of 26 C.

Table 3-1. Treatment active ingredient, trade name, and rates applied in small burnet trials.

Treatments[1]	Trade Name	Rate[2]	Field rate
		g ai or ae ha^{-1}	g ha^{-1}
Untreated	Untreated		
Quinclorac	Paramount®	278.6	371
Pendimethalin	Prowl H20®	2128	4480
Metribuzin	Sencor®	560	1120
Imazamox	Raptor®	44.1	350
Dimethenamid-P	Outlook®	945	1260
Dicamba	Banvel®	560	1120
Clopyralid	Transline®	277.2	749
Clethodim	Select max®	135.8	1120
Bromoxynil	Buctril®	280	1120
Aminopyralid	Milestone®	87.5	350
2,4-DB	Butyrac 200®	1120	2240

[1]Imazamox treatment included MSO at 1.0%v/v and AMS at 2.24 kg ha^{-1}. Clethodim treatment included NIS at 0.25% v/v.

[2]All herbicide rates are g ai ha^{-1} except clopyralid, 2,4D-B, aminopyralid, dicamba, and quinclorac which are listed as g ae ha^{-1}.

In preparation for fall treatments and to remove unwanted seed pods, plants to be treated in the fall were cut to uniform height in the last week of August with a mechanical harvestor.

Trial 1, fall treatments were applied November 11, 2009. Delar plants were 20 cm tall with an average width of 57 cm and C-05 plants were 13 cm tall with an average width of 56 cm. Treatments were made in the early afternoon with approximately 20% cloud cover, slightly hazy and the temperature was 16 C. Trial 2 fall treatments were applied November 3, 2010. Delar plants were 18 cm tall with an average width of 56 cm. C-05 plants were 14 cm tall with an average width of 45 cm. The afternoon was slightly hazy, approximately 5% cloud cover and a temperature of 11 C.

When the small burnet plants reached maturity the average height of the Delar plants was 80 cm and the C-05 plants 90 cm. Plant heights tended to be taller than typically observed on rangelands. Delar grows and matures faster than the C-05 genotype as was seen at the time of treatment application where Delar plants were taller and wider than the C-05. At the conclusion of the trials when seed and forage was harvested, plants were taller and forage yields higher for C-05 than Delar plants.

Visual injury was recorded the treatment year (Table 3-2). Seed yield, seed germination, and dry matter yield (DMY) data was collected the growing season after treatment which would be equivalent to the first production year. Visual injury was recorded on a scale of 0 to 100, where 0 = no injury and 100 = complete mortality. Visual ratings were taken 7, 14, and 60 days after treatment (DAT) of the spring timing, and the spring following treatment (approximately 11 months later). Visual ratings for fall applications were made 7 DAT, and the spring following treatment (approximately 6 months after). In both years snowfall occurred within eight days following fall treatments preventing further fall visual ratings (Table 3-2).

Table 3-2. Summary of dates for planting, treatment, visual injury ratings seed harvest and forage harvests.

	2009		2010	
Procedures	Spring	Fall	Spring	Fall
Field planting date	05/13/09	05/13/09	05/25/10	05/25/10
Treatment date	06/27/09	11/11/09	07/06/10	11/03/10
7 DAT evaluation	07/03/09	11/17/09	07/12/10	11/11/10
14 DAT evaluation	07/11/09	Na	07/20/10	Na
60 DAT evaluation	08/27/09	Na	09/01/10	Na
Spring after injury[1]	04/27/10	04/27/10	05/17/11	05/17/11
Seed harvest[2]	07/21/10	07/21/10	07/06/12	07/06/11
Forage Harvest	08/06/10	08/06/10	07/20/11	07/20/11

[1]Visual injury ratings were taken the spring of the year following treatments which is approximately 11 months after spring treatment and 6 months after fall treatment.

[2]C-05 seed was harvest 8/5/10 for trial 1 and 7/19/11 for trial 2.

Spring and fall treatments of each trial were harvested at the same time. Seed of Delar plants were hand harvested July 21, 2010, and July 6, 2011, when seed pods were mature. Seed of C-05 plants were hand harvested August 5, 2010 and July 19, 2011 when seed pods were mature. Because of the later flowering of C-05 plants (approximately 2 weeks) than Delar plants (Table 3-2) seed maturation was also delayed approximately two weeks thus requiring two different harvest times (Table 3-2). Following harvests, seed pods were dried to approximately 11% moisture and seed weights for each plot were determined. Seed was cleaned using a stationary laboratory thresher (Wintersteiger LD 180, Wintertsteiger, Salt Lake City UT, 84116) and an air cleaner (Almaco Air Blast Seed Cleaner, Allen Machine Company, Nevada IA, 50201).

The remaining biomass was harvested August 6, 2010 and July 20, 2011 using a Swift Current plot harvestor with a weigh box (Swift Current, SK, S9H

0H4 Canada). Samples of each sub-plot were dried in an oven at 71 C for 6 days and used to determine the DMY of each sub-plot. Dried seed and stem weights were added to this weight to determine the total DMY of each sub-plot.

Since dormancy is reported to be an issue with small burnet seed requiring an after ripening period, seed was placed in storage for three months after harvest. To determine if a cold treatment affected the germination of the small burnet seed, three seed germination treatments were tested. Frozen and chilled (SGT1), chilled only (SGT2), and non-frozen and non-chilled (SGT3). To conduct these tests four seed samples were randomly chosen. One Delar and C-05 from the spring treatments and one of each from the fall treatments. Untreated checks from spring and fall treatments were also included. Roughly 25 grams of seed of each was placed in a freezer at -80 C for 1 week (SGT1). Two replicates of 50 SGT1 and SGT2 seeds of the selected entries were placed into germination boxes (Acrylic container, Hoffman Manufacturing, Jefferson, OR 97352-9201) on water soaked blotter paper (Steel Blue Blotter Paper, Anchor Paper, St. Paul, MN 55101). The germination boxes were placed in an incubator and chilled for one week at 3 C after which the temperature was increased 3 degrees daily until reaching a temperature of 21 C. The seeds were incubated at 21 C for one week and germinated seeds were counted and removed. After an additional week of incubation, additional germination was determined and the total germinated seed of each entry was combined.

With the same samples, two replicates of 50 seeds were placed in germination boxes on blotter paper and placed in an incubator at 21 C (SGT3).

Germinated seeds were counted 1 and 2 weeks after placing in the incubator. Forty seven percent of the SGT1 seeds germinated. Forty six percent of the SGT2 seeds germinated. Forty six percent of the SGT3 seeds germinated. It was determined SGT1 and SGT2 methods had no effect on the germination of the small burnet seeds.

The germination tests for this study were carried out following the later method (SGT3) without the chilling or freezing and extending germination time as follows. Two samples of 50 seeds of each subplot were tested for germination. Seeds were dusted with a fungicide (Thiram, Sigma-Aldrich Co. St. Louis, MO 63103) to minimize fungal growth and boxes were placed in an incubator at 21 C. Since germination occurs over an extended period, multiple count dates were utilized. The total seed germination after 28 days was reported. If one seed from a hypanthia germinated it was counted germinated. Germinated seeds were removed during counting to simplify subsequent counts.

All data was analyzed using the Proc Mixed procedure of SAS (Littell et al., 2006). Mean comparisons were made among treatments using a Fisher Protected LSD at the $P = 0.05$ level of probability (Steel et al., 1997).

CHAPTER 4

RESULTS AND DISCUSSION

Significant effects were observed for treatments (*P* <0.0001) for visual injury, dry matter yield (DMY), seed yield, and seed germination. This was anticipated due to the broad range of herbicides used. There were also significant treatment x timing interactions (*P* <0.0001) for visual injury, DMY, seed yield, and seed germination. Significant year x treatments interactions were also observed for visual injury, DMY, seed yield and seed germination (*P* <0.0001). Visual injury was less while DMY, seed yield, and seed germination were higher in 2011 (trial 2) compared to 2010 (trial 1). These differences were likely caused by increased precipitation during 2010-11 (Trial 2) (Figure 4-1). There were no changes in rank for visual injury, DMY, seed yield, or seed germination from between the two trials and data was combined over years.

Visual Injury

Visual ratings for spring treatments at 7, 14, and 60 DAT (Table 4-1) and the spring after treatment ratings (11 months after treatments) were significant (*P*<0.0001) (Table 4-2). Visual injury 7 DAT was observed for all spring treatments. Bromoxynil, aminopyralid, imazamox and dicamba treatments were the most injurious with an average injury of 55%. Clethodim, dimethenamid-P, and quinclorac treatments were the least injurious averaging 17%. Visual injury for spring treatments 60 DAT was significant for all but dimethenamid-P and quinclorac (Table 4-1). From 7 DAT to 60 DAT the overall average injury decreased from 38 to 19%. Sixty DAT aminopyralid, imazamox, and 2,4-DB caused the most injury averaging 33% (Table 4-1). Injury from clethodim

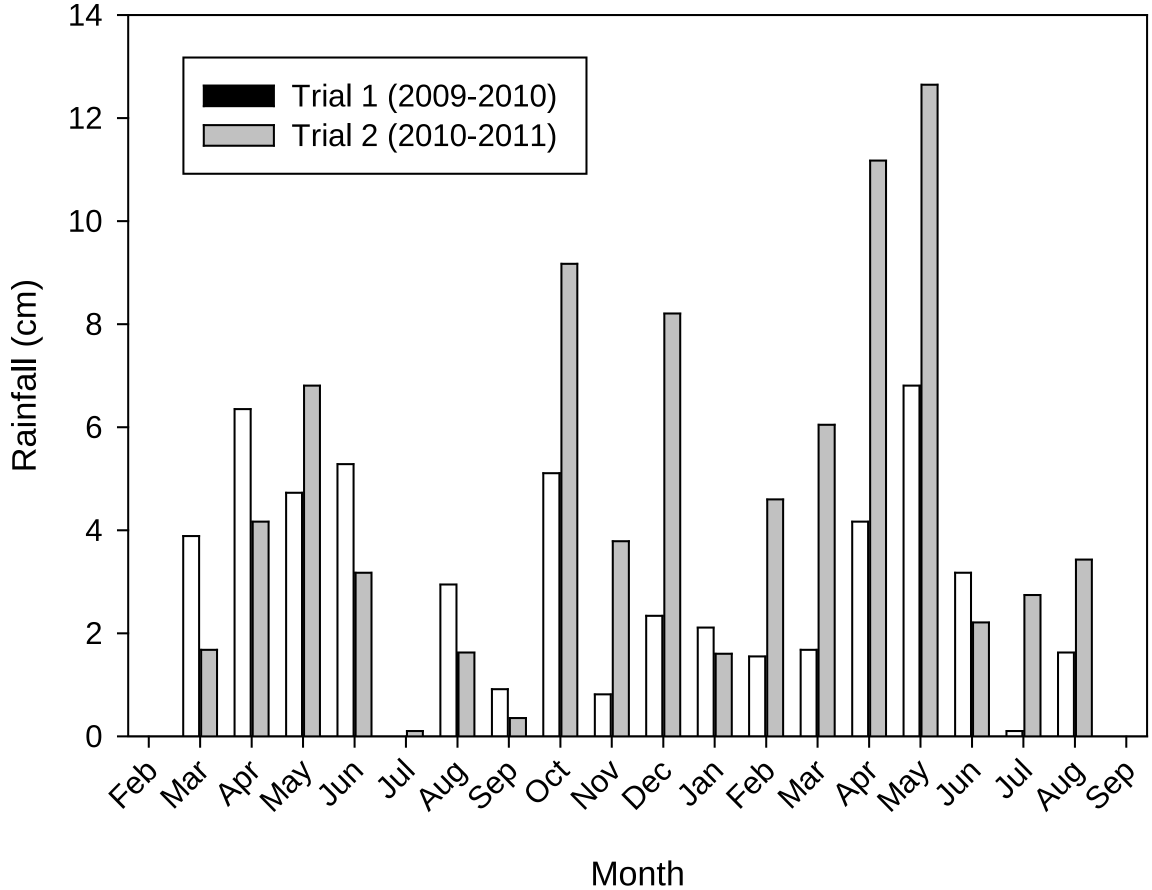

Figure 4-1. Monthly rainfall through the duration of small burnet herbicide tolerance trials, 2009-2010 and 2010-2011

treatments were the lowest 7 DAT of all treatments, did not change 14 or 60 DAT and injury from clethodim treatments were still less than seven of the treatments 60 DAT (Table 4-1). Bromoxynil and dicamba treated plants showed the greatest recovery going from 53%, 7 DAT to 20%, 60 DAT. Based on visual injury, small burnet largely recovers from these treatments within 60 DAT (Table 4-1). No significant visual injury from fall treatments 7 DAT were observed.

Table 4-1. Visual injury 7, 14, and 60 days after treatment (DAT) with spring herbicide applications, 2009 and 2010.

		Injury[1]		
Treatments[2]	Rate[3]	7 DAT	14 DAT	60 DAT
	g ai or ae ha^{-1}	%		
Untreated		0	0	0
Quinclorac	278.6	21	22	7
Pendimethalin	2128	28	29	17
Metribuzin	560	44	43	16
Imazamox	44.1	53	51	29
Dimethenamid-P	945	16	16	5
Dicamba	560	50	49	16
Clopyralid	277.2	32	31	11
Clethodim	135.8	14	14	15
Bromoxynil	280	61	62	19
Aminopyralid	87.5	57	54	43
2,4-DB	1120	47	48	27
LSD (0.05)		11	11	11

[1]Injury rating were on a scale of 0 to 100, with 100 = complete mortality and 0= no injury.

[2]Imazamox treatment included MSO at 1.0%v/v and AMS 2.24 kg ha^{-1}. Clethodim treatment included NIS at 0.25% v/v.

[3]All herbicide rates are g ai ha^{-1} except clopyralid, 2,4D-B, aminopyralid, dicamba, and quinclorac which are listed as g ae ha^{-1}.

Visual injury from spring and fall applied treatments the spring following treatments (11 and 6 months after treatment) were significant (P<0.0001). Injury was greatest in spring and fall applied aminopyralid treatments at 24 and 79% respectively (Table 4-2). Fall applied treatments of Dicamba and imazamox also caused substantial injury at 57 and 31%. Injury from imazamox, pendimethalin, clopyralid, 2,4-DB, metribuzin and bromoxynil spring treatments were also

Table 4-2. Visual injury of small burnet in the spring of the year following treatments, 2010 and 2011

		Injury[1]	
Treatments[2]	Rate[3]	Spring[4]	Fall[5]
	g ai or ae ha^{-1}	%	
Untreated		0	0
Quinclorac	278.6	6	8
Pendimethalin	2128	8	7
Metribuzin	560	11	9
Imazamox	44.1	8	57
Dimethenamid-P	945	1	9
Dicamba	560	4	31
Clopyralid	277.2	11	9
Clethodim	135.8	4	7
Bromoxynil	280	7	7
Aminopyralid	87.5	24	79
2,4-DB	1120	11	12
LSD (0.05)		6	

[1]Injury rating were on a scale of 0 to 100, with 100 = complete mortality and 0 = no injury.
[2]Imazamox treatment included MSO at 1.0%v/v and AMS at 2.24 kg ha^{-1}. Clethodim treatment included NIS at 0.25% v/v.
[3]All herbicide rates are g ai ha^{-1} except clopyralid, 2,4D-B, aminopyralid, dicamba, and quinclorac which are listed as g ae ha^{-1}.
[4] Ratings of spring treatments taken 11 months after treatment.
[5]Ratings of fall treatments taken 6 months after treatment

significant, but much lower averaging 9% (Table 4-2). Injury of the remaining fall treatments were also significant though averaging well below 10% (Table 4-2). Spring treatments of dimethenamid-P, dicamba, clethodim, and quinclorac were similar to the untreated with an average of 4% injury.

Fall treatments of aminopyralid, imazamox, and dicamba were substantially more injurious than the spring treatments of aminopyralid, imazamox, and dicamba. Fall applied aminopyralid and imazamox treatments averaged 52% more injury than the spring applied treatments and fall applied dicamba was 27% more injurious than the spring applied. It is noteworthy that spring treatments of dicamba were similar to the untreated and spring treatments of imazamox were nearly similar to the untreated (Table 4-2). It was also observed that clopyralid, quinclorac, bromoxynil, clethodim, metribuzin, 2,4-DB, and pendimethalin resulted in injury in either or both spring and fall treatments but was much less than aminopyralid, dicamba, and imazamox treatments.

Dry Matter Yield

Genotype x herbicide interactions for dry matter yield (DMY) were significant (P=0.0019). This was not unexpected due to the genetic differences between the two genotypes tested. With the exceptions of bromoxynil, 2,4-DB, and imazamox treatments C-05 consistently out yielded Delar (Table 4-3). Furthermore, for these three treatments, C-05 DMY was less than the untreated suggesting that C-05 may be more sensitive to these treatments than Delar. DMY of aminopyralid treatments of both genotypes were substantially lower than the untreated (Table 4-3).

There was a significant treatment X timing interaction (P<0.0001). Plots treated in the spring with aminopyralid and 2,4-DB had lower DMY averaging 16% less than the spring untreated plots (Table 4-4). Yield from spring treatments of pendimethalin, quinclorac, clopyralid, clethodim, dimethenamid-P, dicamba, and metribuzin were not different from the untreated averaging 4.25 Mg ha^{-1} (Table 4-4).

Table 4-3. Mean dry matter yield (DMY) and seed yield of C-05 and Delar small burnet following 12 herbicide treatments the season following herbicide treatments, 2010 and 2011

		DMY		Seed yield	
Treatments[1]	Rate[2]	C-05	Delar	C-05	Delar
	g ai or ae ha^{-1}	Mg ha^{-1}			
Untreated		4.93	3.92	0.73	1.02
Quinclorac	278.6	4.93	4.17	0.78	1.09
Pendimethalin	2128	4.90	4.15	0.78	1.15
Metribuzin	560	4.73	3.61	0.80	1.04
Imazamox	44.1	3.45	3.40	0.53	0.96
Dimethenamid-P	945	4.49	4.14	0.71	1.14
Dicamba	560	4.33	3.70	0.76	1.06
Clopyralid	277.2	5.04	4.06	0.81	1.07
Clethodim	135.8	4.77	4.05	0.73	1.08
Bromoxynil	280	4.11	4.07	0.66	1.09
Aminopyralid	87.5	3.11	2.06	0.57	0.60
2,4-DB	1120	3.94	4.05	0.67	1.10
LSD (0.05)		0.55		0.14	

[1]Imazamox treatment included MSO at 1.0%v/v and AMS at 2.24 kg ha^{-1}. Clethodim treatment included NIS at 0.25% v/v.
[2]All herbicide rates are g ai ha^{-1} except clopyralid, 2,4D-B, aminopyralid, dicamba, and quinclorac which are listed as g ae ha^{-1}.

Fall applied aminopyralid, imazamox, and dicamba treatments showed substantial reductions in yield and were 67, 36, and 12% lower than the untreated (Table 4-4). DMY from all other fall treatments were not different from the untreated (Table 4-4).

Fall treatments of aminopyralid, imazamox, and 2,4-DB were different from spring treated plots of aminopyralid, imazamox and 2,4-DB. Aminopyralid and imazamox fall treatments reduced yields 61 and 29% respectively when compared with spring treated aminopyralid and imazamox and fall applied treatments of 2,4-DB yielded 12% more than spring treated 2,4-DB plots. All other fall and spring treatments were similar (Table 4-4).

Table 4-4. Mean dry matter yield (DMY) of of small burnet in response to12 spring and fall applied herbicides of small burnet, 2010 and 2011.

		DMY	
Treatments[1]	Rate[2]	Spring	Fall
	g ai or ae ha^{-1}	Mg ha^{-1}	
Untreated		4.43	4.39
Quinclorac	278.6	4.34	4.70
Pendimethalin	2128	4.52	4.50
Metribuzin	560	4.06	4.26
Imazamox	44.1	4.01	2.83
Dimethenamid-P	945	4.18	4.43
Dicamba	560	4.15	3.86
Clopyralid	277.2	4.31	4.77
Clethodim	135.8	4.22	4.58
Bromoxynil	280	3.98	4.18
Aminopyralid	87.5	3.72	1.44
2,4-DB	1120	3.73	4.24
LSD (0.05)		0.49	

[1]Imazamox treatment included MSO at 1.0%v/v and AMS at 2.24 kg ha^{-1}. Clethodim treatment included NIS at 0.25% v/v.
[2]All herbicide rates are g ai ha^{-1} except clopyralid, 2,4D-B, aminopyralid, dicamba, and quinclorac which are listed as g ae ha^{-1}.

When comparing visual injury to DMY there were similarities. Aminopyralid spring treatments caused the most visual injury and DMY was lowest in the spring aminopyralid treatments. Similarly aminopyralid, imazamox, and dicamba treatments caused the greatest visual injury to small burnet plants as well as having the lowest DMY’s of the fall applied treatments.

Seed Yield

Genotype x herbicide interactions for seed yield were significant (*P* =0.0065) (Table 4-3). This was not unexpected because of the large differences between genotypes. Seed yield of the untreated was greater for Delar than C-05 and these differences were consistent across all treatments. Seed yield of C-05 was significantly reduced by the imazamox and aminopyralid treatments while Delar was only reduced by aminopyralid (Table 4-3). It is also noteworthy that the aminopyralid treatments resulted in a greater reduction in seed yield of Delar than C-05, (41 vs 22%).

The timing x herbicide interaction for seed yield was significant (P<0.0001). No spring applied treatments were different from the untreated; however, fall applications of aminopyralid and imazamox reduced seed yield 66 and 33%, respectively (Table 4-5).

Table 4-5. Small burnet seed yield and germination in response to spring and fall applied herbicide treatments, 2010 and 2011

		Seed Yield		Germination	
Treatments[1]	Rate[2]	Spring	Fall	Spring	Fall
	g ai or ae ha^{-1}	— Mg ha^{-1} —		—— % ——	
Untreated		0.90	0.85	64	63
Quinclorac	278.6	0.89	0.94	62	66
Pendimethalin	2128	1.00	0.93	63	61
Metribuzin	560	0.94	0.90	65	62
Imazamox	44.1	0.90	0.57	65	57
Dimethenamid-P	945	0.92	0.92	64	61
Dicamba	560	0.95	0.87	67	58
Clopyralid	277.2	0.92	0.96	66	65
Clethodim	135.8	0.90	0.89	64	62
Bromoxynil	280	0.85	0.89	65	64
Aminopyralid	87.5	0.86	0.29	58	35
2,4-DB	1120	0.84	0.93	68	62
LSD (0.05)		0.15		8	

[1]Imazamox treatment included MSO at 1.0%v/v and AMS at 2.24 kg ha^{-1}. Clethodim treatment included NIS at 0.25% v/v.
[2]All herbicide rates are g ai ha^{-1} except clopyralid, 2,4D-B, aminopyralid, dicamba, and quinclorac which are listed as g ae ha^{-1}.

Plots treated in the spring with aminopyralid and imazamox out-yielded plots treated in the fall with aminopyralid and imazamox by 66 and 36% respectively. All other spring and fall treatments were similar (Table 4-5).

Spring applied treatments which caused visual injury and reduced DMY did not affect seed yield. The fall applied treatments of aminopyralid and imazamox which reduced seed yield, also resulted in the most visual injury and reduced DMY. Conversely, the dicamba treatments which resulted in visual injury and reduced DMY did not affect seed yield.

Seed Germination

There was a significant herbicide x timing interaction for seed germination (P>0.0001). Among the spring applied treatments none differed from the untreated. However, fall applied aminopyralid treatments were 44% less than the untreated. Overall the germination was relatively low averaging only 62% (Table 4-5).

Germination of plots treated in the fall with aminopyralid and dicamba were 40 and 13% less than plots treated in the spring with aminopyralid and dicamba. Germination of all other spring and fall treatments were similar (Table 4-5).

When comparing germination to visual injury, DMY, and seed yield, only the fall applied aminopyralid treatments negatively impacted each. However, at the P=0.07 level, fall treatments of imazamox and dicamba as well as spring treatments of aminopyralid would also be reduced similar to the observations for visual injury, DMY, and seed yield. With clopyralid and aminopyralid in the same chemical family, having similar chemical structures, and weed control spectrum (Bukun et al. 2009), the negative impact of aminopyralid on all traits, whereas clopyralid did not affect DMY, seed yield, or germination was unexpected. However, the results do support Carrithers (1997) report that small burnet is tolerant to clopyralid.

CHAPTER 5

CONCLUSION

This research demonstrated that small burnet can tolerate some herbicides but varies among herbicides tested and is influenced by seasonal application timing. Nearly all herbicides tested such as pendimethalin, metribuzin, dimethenamid-P, bromoxynil, 2,4-DB, clopyralid, clethodim, and quinclorac, show potential for use in small burnet seed production. While some injury was observed, small burnet recovered from the injury caused by these herbicides on both spring and fall treatments. Importantly, seed yield and germination were not impacted by these herbicides.

It was discovered that the timing of applications greatly effects small burnet tolerance. Small burnet recovered better from the spring applications than fall. When considering herbicide applications knowing that the desired plant is tolerant or will recover from treatment damage is a crucial benefit. Effective and safe herbicides will allow control of unwanted plant species in seed fields and grazinglands.

Dicamba should be avoided for fall applications, but may be safe for spring applications. Fall and spring applied treatments of imazamox and aminopyralid reduced DMY, seed yield, and/or viability and should not be used on small burnet.

Visual injury is not a good indicator of reductions in seed yield or seed viability. All herbicide treatments injured the small burnet and all but the aminopyralid and imazamox treatments did not reduce seed yield or lower seed viability.

If a fall or spring herbicide application were needed for weed control there are several herbicides that can be used that would not reduce seed production. These include pendimethalin, metribuzin, dimethenamid-P, bromoxynil, clopyralid, clethodim, and quinclorac. The choice would depend on the weed problem.

In conclusion, results from this study, provides useful information on the herbicide tolerance of small burnet that can potentially be transferred to the field and grazinglands. Further research is needed to evaluate for potential additional environmental and edaphic conditions which may significantly influence small burnet response to herbicides. Efforts must be made to label the herbicides evaluated before they can legally be applied to small burnet.

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