Chapter I

Introduction and Literature Review

The discipline of weed science is based on integrating knowledge of the biological characteristics of troublesome weed species into the development of their most effective control strategies. Chemical weed control is a key component of integrated weed management systems in most crops. Through research, herbicides used in some crops may also fit well into weed management programs in other crops. New herbicides must also be evaluated in order to determine their fit into the marketplace while maximizing their effectiveness and minimizing application rates and costs.

This research addressed herbicide-based weed management programs in potato and winter wheat, as well as the biological characteristics of smooth pigweed (*Amaranthus hybridus* L.). Specific areas of research were: 1) field and laboratory investigations of sulfentrazone for weed management in potato; 2) field, greenhouse and laboratory investigations of the experimental herbicide AE F130060 03 for Italian ryegrass (*Lolium multiflorum* Lam.) management in winter wheat; and 3) field, greenhouse, and growth chamber investigations of growth and reproductive ability of imidazolinone-susceptible and –resistant smooth pigweed.

1. Field and laboratory investigations of sulfentrazone in potato.

Although herbicides have become a major component of potato weed management programs, few herbicides are registered for use in potato. Linuron and metolachlor are often used PRE in various combinations for control of certain grasses and small-seeded broadleaf weeds. Metribuzin may be used PRE or POST for control of annual broadleaf weeds but is limited by potato varietal sensitivity, particularly with POST applications (Kee and Wooten 1994). In addition, heavy reliance on metribuzin in potato has resulted in shifts to weed species that are more tolerant to metribuzin, as well as emergence of triazine-resistant biotypes of species such as common lambsquarters and redroot pigweed (*Amaranthus retroflexus* L.) (Eberlein et al. 1994). Rimsulfuron is also registered for POST applications in potato, but may be ineffective on species such as common ragweed and common lambsquarters when used under dry conditions (Ackley et al. 1996). Although these herbicides are generally effective on several annual grasses and broadleaf weeds, none control all weed species that commonly occur in potato production. In addition, cultivation-intensive management practices commonly used in potato as well as the need for additional weed scouting when using POST herbicides have resulted in grower preference towards PRE herbicides in Virginia potato production (H. P. Wilson, personal communication).

Sulfentrazone is a member of the phenyl triazolinone herbicide group (Theodoridis et al. 1992). Herbicides in this group function through inhibition of protoporphyrinogen oxidase (protox) in plants, a key intermediate in both heme and chlorophyll biosynthesis (Jacobs and Jacobs 1987). Unlike other members of this herbicide group such as the diphenyl ethers, sulfentrazone offers excellent preemergence activity (Dayan et al. 1996). Sulfentrazone is currently registered for weed control in soybean as a prepackaged mixture with chlorimuron and in tobacco as a single entity product (Anonymous 2001). In previous research, sulfentrazone applied preplant incorporated or preemergence controlled several monocotyledonous and dicotyledonous weed species (Vidrine et al. 1996) that often occur in potato production. Currently, there are no known weed species resistant to protox-inhibiting herbicides (Duke et al. 1996); therefore, these herbicides could have an important role in future weed management programs.

Although much research supports soybean and tobacco tolerance to sulfentrazone and its performance in these crops (Fisher et al. 2001; Vidrine et al. 1996), little is known about the tolerance of vegetable crops such as potato to sulfentrazone. Therefore, the objectives of field research were (1) to investigate potato tolerance to sulfentrazone and (2) to evaluate sulfentrazone weed control efficacy in potato weed management programs.

Additional research was conducted in the laboratory to determine the mechanism (s) of sulfentrazone selectivity in potato and certain weed species. Although sulfentrazone controls common lambsquarters at rates as low as 0.11 kg/ha, this herbicide is less effective on jimsonweed (Bailey et al. 2002). Dayan et al. (1996) noted differential responses of sicklepod [*Senna obtusifolia* (L.) Irwin and Barneby] and coffee senna (*Cassia occidentalis* L.) to sulfentrazone and found that tolerance of sicklepod was primarily due to a relatively higher rate of metabolism compared to coffee senna. Although most soybean cultivars are tolerant to sulfentrazone, differential tolerance has also been noted between some soybean cultivars. Differential sulfentrazone tolerance between ‘Stonewall’ and ‘Asgrow 6785’ soybean cultivars was due to differential absorption in the early stages of growth (Li et al. 2000).

The objective of laboratory research was to determine whether differential sulfentrazone tolerance between potato, common lambsquarters, and jimsonweed was due to differential absorption, translocation, and/or metabolism of sulfentrazone in these species.

2. Laboratory, greenhouse, and field investigations of the experimental herbicide AE F130060 03 for Italian ryegrass (*Lolium multiflorum* Lam.) management in winter wheat.

Italian ryegrass is a weed indigenous to winter wheat production in Southern and mid-Atlantic regions of the United States. Wheat grain yield reductions as high as 92% have occurred from competition with Italian ryegrass (Appleby et al. 1976). Liebl and Worsham (1984) reported a 5% grain yield loss for every 10 Italian ryegrass plants/m^2. Competition from Italian ryegrass reduces wheat tillering (Ketchersid and Bridges 1987) and depletes soil nitrogen and phosphorus resources intended for wheat (Perez-Fernandez and Coble 1998). Infestations of Italian ryegrass are common in North Carolina and Virginia wheat fields and often result in field abandonment (A. C. York, North Carolina State University; E. S. Hagood, Virginia Tech, personal communication).

Diclofop-methyl is an aryloxyphenoxypropanoate herbicide that inhibits acetyl coenzyme A carboxylase (ACCase, EC 6.4.1.2), a chloroplastic enzyme essential to fatty acid biosynthesis in susceptible monocot species (Kocher 1984). Diclofop-methyl was registered for selective control of Italian ryegrass in wheat in North Carolina and Virginia in the early 1980’s. Although diclofop has been very effective in controlling Italian ryegrass since its introduction, the repeated use of diclofop-methyl has selected for Italian ryegrass biotypes resistant to this herbicide. Currently, diclofop-resistant Italian ryegrass biotypes infest more than 50% of the wheat hectarage in Virginia and result in net losses in excess of $3.2 million (Hagood 2000). In addition to resistance to diclofop-methyl, many diclofop-resistant Italian ryegrass biotypes also exhibit cross-resistance to other ACCase-inhibiting herbicides such as fenoxaprop-P-ethyl and the cyclohexanedione herbicides tralkoxydim and sethoxydim (Cocker et al. 2001). For these reasons, introduction of herbicides with alternative modes-of-action is essential for profitable wheat production in areas where diclofop-resistant Italian ryegrass populations persist.

Sulfonylurea herbicides differ from ACCase-inhibiting herbicides such as diclofop by inhibiting acetolactate synthase (ALS, EC 4.1.3.18), the enzyme that catalyzes the first parallel reaction in the biosynthesis of the branched chain amino acids valine, leucine, and isoleucine (Ray 1984). Chlorsulfuron is a sulfonylurea herbicide that was registered for use in wheat in some areas of the United States, Europe, and Australia in the early 1980’s following the introduction of diclofop (Levitt et al. 1981). Chlorsulfuron applied at 35 g ai/ha preemergence (PRE) has controlled Italian ryegrass (Griffin 1985). Although rare, at least two Italian ryegrass biotypes in the U.S. are resistant to sulfonylurea herbicides. Taylor and Coats (1996) identified two biotypes of Italian ryegrass from rights-of-ways in Mississippi resistant to sulfometuron where this herbicide had effectively controlled Italian ryegrass previously. One of these biotypes was later determined to be resistant to other sulfonylurea herbicides. In Italy, two biotypes of Italian ryegrass exhibit six- and eight-fold resistance to diclofop and three- and 13-fold resistance to chlorsulfuron (Heap 2002).

Biotypes of diclofop-resistant annual ryegrass (*Lolium rigidum* Gaud.) from Australia also exhibit additional resistance to chlorsulfuron (Matthews et al. 1990). Some of these annual ryegrass biotypes exhibit resistance to every selective postemergence (POST) graminicide registered for use in Australia and are resistant to several herbicides that have not been released (Burnet et al. 1994). The mechanisms of multiple resistance in some of these annual ryegrass biotypes is due to altered herbicide target sites that are less sensitive to inhibition by the herbicides and/or the increased capacity of these biotypes to detoxify the herbicides (Christopher et al. 1992).

AE F130060 03 is an 8.3:1.7 mixture of the experimental sulfonylurea herbicides AE F130060 00 and AE F115008 00. AE F130060 00 (proposed common name mesosulfuron-methyl) is active primarily against monocotyledonous weeds while AE F115008 00 (proposed common name iodosulfuron-methyl-sodium) acts primarily against dicotyledonous weeds. This sulfonylurea mixture has effectively controlled Italian ryegrass and several winter annual dicotyledonous weed species and can be applied to winter wheat when used with the safener AE F107892 (common name mefenpyr diethyl) (Hand et al. 2002). AE F107892 was developed in 1993 as a crop safener for fenoxaprop-P-ethyl, but is also an effective safener for certain other chemical classes (Hopkins 1997).

To date, we are not aware of any reports of any Italian ryegrass biotypes in the U.S. that exhibit multiple resistance to diclofop and sulfonylurea herbicides. Although a similar cross-resistance phenomenon of the magnitude seen in annual ryegrass has not been documented in Italian ryegrass biotypes, Italian ryegrass is physiologically and genetically similar to annual ryegrass (Betts et al. 1992) and the possibility of this occurrence should not be overlooked.

In this research, the potential for differential activity of AE F130060 03 on diclofop-sensitive and –resistant Italian ryegrass biotypes was investigated in initial plant bioassay experiments in the greenhouse and subsequent absorption, translocation, and metabolism experiments in the laboratory. An additional objective was to investigate response of winter wheat to AE F130060 00 with or without the safener AE F107892 in greenhouse and laboratory experiments.

Research was also conducted in numerous field experiments to determine response of diclofop-sensitive and –resistant Italian ryegrass under natural conditions. Objectives of field research were: 1) to compare Italian ryegrass control and wheat response from AE F130060 03 to that from several registered postemergence herbicides; 2) to investigate the influences of AE F130060 03 application timing and rate on Italian ryegrass control and wheat response; and 3) to evaluate tolerance of AE F130060 03 across ten wheat cultivars adapted to Virginia wheat production.

3. Field, greenhouse, and growth chamber investigations of growth and reproductive ability of imidazolinone-susceptible and –resistant smooth pigweed.

At least 60 weed species resistant to acetolactate synthase (EC 4.1.3.18) (ALS)-inhibiting herbicides have been reported within the past 15 years. Recently, *Amaranthus* species have been reported more frequently than other species (Heap 2002). Biotypes of Palmer amaranth (*Amaranthus palmeri* S Wats.) (Horak and Peterson 1995), redroot pigweed (*Amaranthus retroflexus* L.) and prostrate pigweed (*Amaranthus blitiodes* S Wats.) (Saari et al. 1994), common waterhemp (*Amaranthus rudis* Sauer) (Horak and Peterson 1995), livid amaranth (*Amaranthus lividus* L.) and smooth pigweed (Manley et al. 1996; Poston et al.

2000) resistant to ALS-inhibiting herbicides have been reported within the past 6 to 7 years. In all instances, repeated use of ALS-inhibiting herbicides was documented and resistance was due to an altered ALS.

Fitness is defined as the ability of an organism to establish, survive, and reproduce successfully (Silvertown 1982). Ahrens and Stoller (1983) demonstrated that triazine-resistant smooth pigweed produced less shoot biomass and seed dry weight under competitive conditions, fixed less CO_2 under saturated light and CO_2 conditions, and exhibited a significantly lower relative growth rate and net assimilation ratio compared to a triazine-susceptible biotype. Conrad and Radosevich (1979) concluded that triazine-resistant redroot pigweed and common groundsel (*Senecio vulgaris* L.) were less fit than their respective wild types under both competitive and non-competitive conditions. They attributed reduced competitiveness in the resistant biotype to photosynthetic inefficiency and concluded that the triazine resistance trait was only of benefit to the plant where triazine herbicides are repeatedly used. Gressel and Segel (1982) suggest that one possible result of reduced fitness in triazine-resistant weed biotypes is that the selected biotypes may only continue to exist in a population where herbicide selection pressure is great enough to kill the wild type. Based on this premise, reversion to a mostly susceptible population will likely occur over time in the absence of the herbicidal selection agent.

Interestingly, weed biotypes that have developed resistance to ALS inhibitors may not suffer fitness penalties as severe as those observed in triazine resistant weed biotype. Thompson et al. (1994) noted similar growth rates, seed production, and competitiveness in both sulfonylurea-susceptible and –resistant kochia (*Kochia scoparia* (L.) Schrad.). With sulfonylurea-resistant prickly lettuce (*Lactuca serriola* L.), reductions in biomass production compared to the wild type were observed under noncompetitive conditions, but the biotypes grew similarly in competition studies (Alcocer-Ruthling et al. 1992). In smooth pigweed, Poston et al. (2002) found that imidazolinone-susceptible smooth pigweed displayed an advantage in vegetative growth and development over three out of four imidazolinone-resistant biotypes under controlled greenhouse conditions. However, competitive advantages of susceptible smooth pigweed could not be confirmed under field conditions and it was concluded that further studies are required to determine relative growth differences.

Gressel and Segel (1982) have shown that many reproductive factors such as (1) proportion of seeds germinating at a given time, (2) rate of germination, and (3) seed size and seed yield per flower are important in determining whether a wild-type population is more fit than a selected population. Past research comparing fitness of imidazolinone-susceptible and –resistant smooth pigweed under field conditions in Virginia did not document a competitive advantage for susceptible smooth pigweed under field conditions and concluded that further studies comparing competition as well as seed production and germination of smooth pigweed biotypes are warranted (Poston et al. 2002). In this research, work in Virginia was continued to investigate competitive ability, seed production, and seed germination of imidazolinone-susceptible and –resistant smooth pigweed.

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