WHEAT INTERACTIONS WITH ITALIAN RYEGRASS; FORAGE PRODUCTION AND QUALITY IN PURE AND MIXED STANDS OF WHEAT, OATS, AND RYEGRASS; AND HALOSULFURON INTERACTION WITH SOILS

A Dissertation

by

ALEXANDRA CATHRYN CARPENTER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2007

Major Subject: Agronomy

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ABSTRACT

Wheat Interactions with Italian Ryegrass; Forage Production and Quality in Pure and Mixed Stands of Wheat, Oats, and Ryegrass; and Halosulfuron Interaction with Soils. (May 2007)

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A growth room experiment compared seedling growth after nine weeks of two wheat genotypes in pure cultures and mixtures with Italian ryegrass at a low phosphorus (P) level and the P level recommended by soil testing. At the recommended P level in both pure and mixed culture, Mit, a semi-dwarf genotype, had a greater height, leaf area, tiller number, and dry weight of leaves, stems and roots than did Kharkof, a landrace. These results reflected the visual selection criteria for seedling vigor and tillering used in the initial development of the semi-dwarf cultivars.

Field experiments compared total dry matter, calories, and percent crude protein and acid detergent fiber of oats, wheat, and ryegrass in pure culture and mixtures at four locations in central Texas at first clipping, second clipping, and unclipped. Although, forage yield was lower for the first clipping than the second clipping or the unclipped treatment, the first clipping had the best forage quality. There was a strong environmental influence on yield and quality. The best forage was pure wheat at College Station, pure ryegrass at Marlin, the wheat-ryegrass mixture at Temple, and pure oats at

Thrall. Since Temple had the greatest yield of any site, the wheat-ryegrass mixture demonstrated the highest yield potential.

The soil adsorption characteristics of halosulfuron was examined using six soils. Soil adsorption of halosulfuron appeared to be a function of organic matter. Low $K_{f,ads}$ values indicated that a relatively high plant availability of halosulfuron could be available for plant uptake. Sorghum produced in soils with a low organic matter content may experience injury because of the high plant availability.

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I want to express my appreciation to the Department of Soil and Crop Sciences at Texas A&M University for its financial support of my Ph.D. program. I am grateful to all my committee members for their patience in my belated completion of this dissertation during the period of my employment with the University of Missouri Extension Service. Special gratitude is expressed to Dr. Mike Chandler for giving me an understanding of herbicides and weed ecology, to Dr. Scott Senseman for teaching me the ecological dimensions of pesticide applications and the use of his laboratory, to Dr. Travis Miller for giving me field space and providing me with an understanding of my career in extension, to Dr. Norman Borlaug for inspiring me to reach for my star, and to Dr. Rod Bovey for always being friendly and helpful in every meeting. Finally, I want to thank my major professor, Dr. Harry Cralle, for his invaluable help for a period of 11 years in the completion of my Ph.D. degree.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Four key aspects of modern agronomy are the development of new cultivars for seed and forage production, cultivar competition with weeds, cultivar response to fertilization, and the development of herbicides for weed control. Research was conducted to examine the relative competitiveness of an older and a modern wheat (*Triticum aestivum* L.) cultivar in the presence and absence of ryegrass (*Lolium multiflorum* Lam.) at low and high levels of phosphorus nutrition. The comparison of forage production of oats (*Avena sativa* L.), wheat, and ryegrass in pure culture and mixtures in the presence and absence of clipping was studied. The interaction of the herbicide halosulfuron with various soil characteristics was evaluated since grain and forage crops are produced in these soils.

This dissertation follows the style of Weed Science.

CHAPTER II

COMPARATIVE SEEDLING GROWTH OF A SEMI-DWARF CULTIVAR AND A LANDRACE WHEAT IN RESPONSE TO ITALIAN RYEGRASS AND PHOSPHORUS FERTILIZATION

Introduction

The shift from tall landrace populations to semi-dwarf cultivars was an essential component of the worldwide increase in wheat (*Triticum aestivum* L.) yields (Hanson et al. 1982). The semi-dwarf wheats had a greater harvest index and lodging resistance, especially in response to nitrogen fertilization, than did the taller landrace wheat genotypes (Austin et al. 1980). The introduction of semi-dwarf wheat cultivars with enhanced fertilization tripled wheat yields in India from 0.8 tons ha^{-1} in 1959-61 to 2.4 in 1993-95 (Dept. of Agriculture and Cooperation, 2003) However, environmental factors such as weed competition, insects, drought, disease, and nutrient deficiencies continued to limit yield potential worldwide.

Italian ryegrass (*Lolium multiflorum* Lam.) decreased wheat yields in Oregon (Appleby et al. 1976; Appleby and Brewster, 1992) and North Carolina (Liebl and Worsham, 1987). Field studies in central Texas (Stone et al.1999) showed that ryegrass densities of only 40 plants per m^2 reduced wheat yields by as much as 50%. The potential decrease of wheat grain yield by ryegrass competition is important to cental Texas producers in two ways. First, they often face ryegrass as a weed in their grain fields. Second, ryegrass is interseeded with wheat for spring forage production in some fields.

Semi-dwarf wheat cultivars have a greater harvest index than landrace genotypes in high yield environments (Austin et al.1980). Since modern cultivars partition a greater proportion of their photosynthate to reproductive growth and less to vegetative growth, and are shorter at maturity than the landrace genotypes; modern cultivars may be less competitive with weeds than landrace genotypes. Moreover, since landrace genotypes evolved prior to the extensive use of chemical fertilizers and modern cultivars developed in fields provided with commercial fertilization, weeds may be more competitive with modern cultivars than landrace genotypes in nutrient deficient fields.

Phosphorous nutrition is a key component of wheat production. Wheat in western Australia responds well to a small increase in P levels drilled with the seed at planting (Riley et al.1993) and in the southern High Plains of the USA to deep band placement of P (Miller,1998). Phosphorus fertilization is often neglected in wheat production in the Great Plains (Halvorson and Havlin,1992).

A greenhouse experiment used a replacement series design to compare the vegetative growth six weeks after emergence in pure cultures and mixtures of a semi-dwarf winter wheat and Italian ryegrass at a P levels recommended by soil testing and at a low level (Cralle et al. 2003). The relative performance of each species differed between the P treatments in 50%-50% mixtures of the two species. In the 50%-50% mixture at the recommended P treatment, wheat had greater leaf, stem, and root weights than ryegrass. In the 50%-50% mixture of the low P treatment, the two species were very similar in growth, except that ryegrass had about three times more tillers than wheat. While P deficiency limited the growth of wheat less than ryegrass in pure culture, P deficiency did not affect the relative competitiveness of ryegrass compared to wheat in the mixtures. The ability of ryegrass to compete with wheat when P was limiting may have resulted from a difference in root growth. Ryegrass had a greater root length per weight than did wheat in the low P treatment in pure culture and in the 50%-50% mixture. The greater surface area of ryegrass roots likely enhanced the competitiveness of ryegrass relative to wheat in P deficit conditions.

Both wheat and ryegrass have a high uptake rate of P per unit of root length when compared to other species (Classen and Jungk, 1988). Jones et al. (1992) found genetic differences among wheat cultivars in the uptake of P. Comparisons of the uptake efficiency of older and modern wheat cultivars showed greater P efficiency in the modern cultivars due to greater root hair length and smaller root diameter (Gardiner and Christensen, 1990; Horst et al. 1993). The ryegrasses *Lolium multiflorum* Lam. and *Lolium perenne* L. were very effective competitors for P in mixtures with white clover (*Trifolium repens* L.) (Goodman and Collison, 1981, 1982). Italian ryegrass was also an effective competitor with wheat for N (Appleby et al. 1976).

Stone et al. (1998) compared the above- and below-ground interference to a semi-dwarf wheat by Italian ryegrass. Wheat in an above-ground only interaction with ryegrass did not differ from the pure culture wheat controls. But, the below-ground interaction only of the two species reduced wheat height, leaf number, tillering, leaf area, percent total nonstructural carbohydrates in the shoot, and dry weight of leaves, stems, and roots at 45 and 75 DAP compared to controls. Ryegrass roots in this study appeared thinner and more fibrous than that of wheat.

Another greenhouse experiment with sufficiently irrigated controls and a treatment of temporary drought found that water stress enhanced the competitiveness of ryegrass with wheat (Carson et al. 1999). While control ryegrass 14 wk after planting grew better than control wheat in pure culture, wheat produced greater final leaf area and dry stem weight in control mixtures than ryegrass. Watering following drought shifted the relative performance of the two species in mixtures compared to controls. Drought and its relief increased the relative competitiveness of ryegrass compared to controls in mixtures with wheat. During 4 wk of watering following the drought, ryegrass in mixtures grew vigorously and was similar to wheat in all measures except height and dry stem weight.

No studies have examined the relative competitiveness of older and modern wheat cultivars with ryegrass or the effect of ryegrass competition and P levels on their relative growth. The objectives of this study were to compare a landrace genotype and a modern wheat cultivar for seedling growth and competitiveness with ryegrass in response to different levels of P.

Materials and Methods

A growth room experiment was conducted at Texas A & M University in College Station, TX. Two wheat cultivars were planted in pure cultures and mixtures with Italian ryegrass cultivar Marshall. The semi-dwarf cultivar was Mit. The landrace genotype was Kharkof. Kharkof was introduced into the United States in 1873 by Russian immigrants (Brethour et al., 2000). Seed of wheat and ryegrass were germinated on moist filter paper in petri dishes. Seedlings were transplanted into 6.5 L pots providing a wheat density of 8 plants pot^{-1} in two rows separated by 7 cm. The pots were well spaced to avoid pot to pot interaction. Ryegrass seedlings were transplanted simultaneous with wheat at densities of 0 and 8 plants pot^{-1}. Each pot was divided into numbered grids of 4 centimeters squared. The position of each ryegrass seedling into one of the grids was determined by random numbers

Industrially manufactured fritted clay was the growth medium. The clay particles were fused together into larger units of a few millimeters to permit better drainage. The pH was 6.8. There was no organic matter. Soil tests indicated an indigenous P level of 2 mg kg^{-1} . No P was added in this treatment. The recommendation for P to achieve a wheat grain yield goal of 4,800 kg ha^{-1} was 68.4 kg ha^{-1}. This recommended P was supplied at 4g of P pot^{-1} in the form of $Ca(H_2PO_4)_2 \cdot H_2O$. All pots received 1.8 g KNO_3 and 2.2 g NH_3NO_3. Fertilizer was incorporated into the soil by agitation in large plastic cans. Daily temperatures were 25 C during a 14-hr light period and 20 C during a 10-hr dark period. The longer than natural daylight was selected to compensate for the lower the natural light intensity. Flourescent light banks provided about 1000 μmol m^{-2} s^{-1}. Plants were adequately supplied with distilled, deionized water.

At the termination of the experiment, the number of tillers and their heights for each species in a pot were determined. Leaf area was measured with a Li-Cor 3100 Area Meter. Root length was determined before drying with a Comair Root Length Scanner and dry weights of leaves, stems, and roots were measured

The experiment was a randomized complete block design. There were five replications in two runs. Each run was terminated nine wk after seedling transplant. The runs were pooled together for statistical analysis because the experiment run and treatment interaction were not significant. Analysis of variance was conducted with mean separation of treatments determined by LSD ($\alpha<0.05$). All differences discussed were significant at this level.

Results and Discussion

Both genotypes in pure cultures and mixtures grew better at the recommended P level than the low level in all measurements (Tables 1, 2, and 3). Mit and Kharkof had similar growth in the pure cultures at the low P level. Braun et al. (1992) showed that it was very difficult to identify genetic differences in wheat cultivars in poor growing environments. The limitation to growth by P at the low level likely masked the genetic differences in growth potential of Mit and Kharkof. However, at the recommended P level Mit had a greater height, leaf area, tiller number, root length, and dry weight of leaves, stems and roots than did Kharkof. Karimi and Siddique (1991) also found that the vegetative growth rates of modern, semi-dwarf wheat cultivars in Western Australia were greater than those of the older, taller cultivars.

Table 1. Height, tillering, and dry weight of stem of Mit and Kharkof wheat genotypes in pure cultures or mixed cultures with ryegrass and Marshall ryegrass in mixtures with Mit or Kharkof nine weeks after transplanting in low and high P in growth chambers.

Genotype	P level	Mean height of plants of each species	Total tillers of each species	Total stem weight per species
	mg kg^{-1}	cm $plant^{-1}$	number pot^{-1}	g pot^{-1}
Kharkof pure	2	7.7 e[a]	8 f	0.34 e
Mit pure	2	8.8 cd	8 f	0.52 e
Kharkof mixed with ryegrass	2	6.8 f	10 f	0.31 e
Mit mixed with ryegrass	2	8.1 de	8 f	0.49 e
Kharkof pure	6	11.6 b	48 d	3.12 cd
Mit pure	6	12.9 a	72 a	5.29 b
Kharkof mixed with ryegrass	6	12.2 ab	37 e	2.36 d
Mit mixed with ryegrasss	6	12.8 a	52 cd	3.56 c
Ryegrass mixed with Kharkof	2	12.5 a	14 f	0.74 e
Ryegrass mixed with Mit	2	9.2 c	14 f	0.87 e
Ryegrass mixed with Kharkof	6	12.8 a	62 b	6.81 a
Ryegrass mixed with Mit	6	8.8 cd	56 bc	7.32 a
LSD (P = 0.05)		0.9	8	0.77

[a]Means followed by the same letter are not significantly different according to the LSD value.

Table 2. Area and dry weight of leaves of Mit and Kharkof wheat genotypes in pure cultures or mixed cultures with ryegrass and Marshall ryegrass in mixtures with Mit or Kharkof nine weeks after transplanting in low and high P in growth chambers.

Genotype	P level	Combined leaf area of each species	Total leaf weight per species
	mg kg^{-1}	cm^2 pot^{-1}	g pot^{-1}
Kharkof pure	2	71 d[a]	0.53 e
Mit pure	2	122 d	0.88 e
Kharkof mixed with ryegrass	2	63 d	0.50 e
Mit mixed with ryegrass	2	93 d	0.73 e
Kharkof pure	6	1886 b	6.76 b
Mit pure	6	2625 a	9.72 a
Kharkof mixed with ryegrass	6	1301 c	4.98 d
Mit mixed with ryegrasss	6	1828 b	6.3 bc
Ryegrass mixed with Kharkof	2	166 d	0.75 e
Ryegrass mixed with Mit	2	165 d	0.81 e
Ryegrass mixed with Kharkof	6	1876 b	5.88 c
Ryegrass mixed with Mit	6	1388 c	5.67 cd
LSD (P = 0.05)		200	0.82

[a]Means followed by the same letter are not significantly different according to the LSD value.

Table 3. Dry weight and length of root of Mit and Kharkof wheat genotypes in pure cultures or mixed cultures with ryegrass and Marshall ryegrass in mixtures with Mit or Kharkof nine weeks after transplanting in low and high P in growth chambers.

Genotype	P level	Total root weight per species		Total root length of each species	
	mg kg^{-1}	g pot^{-1}		m pot^{-1}	
Kharkof pure	2	0.33	d[a]	25	e
Mit pure	2	0.61	d	45	de
Kharkof mixed with ryegrass	2	0.40	d	62	cd
Mit mixed with ryegrass	2	0.54	d	77	bc
Kharkof pure	6	1.67	c	70	cd
Mit pure	6	3.44	a	157	a
Kharkof mixed with ryegrass	6	1.29	c	104	b
Mit mixed with ryegrass	6	2.56	b	185	a
Ryegrass mixed with Kharkof	2	0.36	d	58	cd
Ryegrass mixed with Mit	2	0.74	d	79	bc
Ryegrass mixed with Kharkof	6	1.72	c	166	a
Ryegrass mixed with Mit	6	2.4	b	172	a
LSD (P = 0.05)		0.54		30	

[a]Means followed by the same letter are not significantly different according to the LSD value.

In mixtures with ryegrass at the low P level, the only difference between the genotypes was the greater height of Mit compared to Kharkof (Tables 1, 2, and 3). At the recommended P level in the mixtures with ryegrass, Mit had a greater leaf area, tiller number, and dry weight of leaves, stems and roots than did Kharkof. Thus, Mit in both pure cultures and mixtures was more responsive to P fertilization than Kharkof.

Ryegrass in mixtures with wheat was more competitive in all measurements at the recommended P than at low level (Tables 1, 2, and 3). The only difference between the growth of ryegrass and its companion wheat at low P was that ryegrass grew taller than either Mit or Kharkof. At the recommended P level in mixtures, Mit had a greater height and leaf area than its companion ryegrass. Conversely, ryegrass had a greater stem weight than its companion Mit in the mixtures. However, ryegrass also had a greater leaf area, tiller number, root length, and dry weight of leaves and stems than its companion Kharkof at the recommended P level. Thus, Mit was more competitive than Kharkof with ryegrass in the mixtures at the recommended P level.

The greater seedling growth and enhanced competitiveness of the semi-dwarf wheat compared to the landrace genotype at the recommended P level reflected the visual selection criteria used in the development of the original semi-dwarf wheat cultivars (N. E. Borlaug, personal communication). The primary criteria at the start of the program was resistance to stem rust (*Puccinia graminis* f. sp. *tritici*). Other selection criteria were seedling vigor, abundant tillering, lodging resistance in response to N fertilization, and large head size with a high number of seeds. Selection for seedling vigor and tillering was reflected in the greater height in pure culture, and the greater leaf area, tiller numbers, and weights of plant parts in both pure cultures and mixtures with ryegrass of Mit compared to Kharkof (Tables 1 and 2). Moreover, Karimi and Siddique (1991) demonstrated a relationship between greater seedling vigor in semi-dwarf wheat cultivars and their increased yields compared to landrace wheat genotypes.

Although landrace wheat genotypes are taller than semi-dwarf cultivars at maturity, the greater seedling vigor of the semi-dwarf wheat cultivars is reflected in their greater height during early vegetative growth than the landrace genotypes. Abundant tillering in the semi-dwarf cultivars contributes to high yields because each tiller can produce a spike. The combined effect of vigorous seedling growth with its initial greater leaf area and height, high plant populations supported by good soil fertility, and increased tillering in semi-dwarf wheat genotypes enhances their competitiveness for light with weeds early in the growing season. Thus, the provision of adequate P is important to enhance the competitiveness of wheat with weeds such as ryegrass. Moreover, further selection for vigorous seedling growth, tillering, and tolerance to high plant populations by plant breeders may assist wheat competitiveness with weeds in the future.

CHAPTER III

WINTER ANNUAL FORAGE PRODUCTION AND QUALITY IN PURE CULTURES AND MIXTURES OF WHEAT, OATS, AND RYEGRASS

Introduction

Oats (*Avena sativa* L.), wheat (*Triticum aestivum* L.), and Italian ryegrass (*Lolium multiflorum* Lam.) are commonly grown in pure and mixed cultures in central Texas for forage production. A common practice is the interseeding of wheat and ryegrass for both forage production and wheat grain yield. Unfortunately, published research does not provide a clear guide to the best choice of forages for producers.

Cherney and Marten (1982) found that wheat grown for forage produced less dry matter that did oats, triticale (a hybrid of wheat and rye), and barley in pure cultures. Morris and Gardner (1958) also found that oats produced more forage than wheat in both favorable and unfavorable growing environments. However, Hubbard and Harper (1949) found less forage production by oats than by rye or wheat. Moreover, there was no difference in yield between mixtures of wheat and oats and pure culture wheat. In another study (Helsel and Thomas, 1987) there was no difference in dry matter production between oats and wheat; oats produced more crude protein than wheat.

Kemp (1974) found a greater forage yield from oats than Italian ryegrass and attributed the difference to a faster establishment and seedling growth of oats. In another study (Azocar and Soto, 1970) ryegrass produced a greater forage yield in pure culture than did wheat or a mixture of the two species. Walker et al. (1990) also found that a mixture of wheat and ryegrass had a similar yield to pure culture wheat.

The frequency of clipping forages for hay production also affected forage production. Zillinsky and McMohan (1974) found that oats clipped for forage three times yielded more dry matter and crude protein than oats clipped only once or twice. The objective of this study was to compare forage production of oats, wheat, and ryegrass in pure culture and mixtures in the presence and absence of clipping.

Materials and Methods

Experiments were conducted from Fall 1996 through Spring 1997 at the Texas A&M University Agronomy Farm near College Station, TX, the Blackland Research Center near Temple, and a farm near Marlin, TX. They were also conducted from the Fall 1997 through Spring 1998 at the Stiles Farm Foundation near Thrall, TX. The soils were a Weswood silt loam (fine-silty, mixed, thermic Fluventic Ustochrept) at College Station, a Crockett loam (fine, montmorilloniti, thermic, Udic Pellusterts) at Marlin, a Houston Black clay (fine, smectitic, thermic Udic Haplusterts) at Temple, and a Burleson clay (fine, montmorillonitic, thermic, Udic.Pellusterts) at Thrall.

Experimental plots were 2.1 by 12.0 m. Planting occurred at all sites occurred between Nov. 1 and Nov. 15. Seed of oats cultivar Bob and wheat cultivar Mit in pure culture was drilled at a rate of 112 and 107 kg ha^{-1}, respectively, into clean-cultivated rows with a 25-cm width to provide a density of 332 and 395 plants m^{-2} for oats and wheat, respectively. Ryegrass cultivar Marshall seed in pure culture was broadcast at a rate of 28 kg ha^{-1} to provide a density of 1402 plants m^{-2}. In mixtures oats was drilled at a rate of 53 kg ha^{-1} to provide a density of 173 oat plants m^{-2} and ryegrass was broadcast at a rate of 14 kg ha^{-1} to provide a density of 673 ryegrass plants m^{-2}. In mixtures wheat was drilled at a rate of 56 kg ha^{-1} to provide a density of 166 wheat plants m^{-2} and ryegrass was broadcast at a rate of 14 kg ha^{-1} to provide a density of 673 ryegrass plants m^{-2}. Nitrogen fertilizer (46-0-0) was broadcast at a rate of 55 kg ha^{-1} at all sites before planting. No irrigation was provided.

Plots were split into a clipped treatment and an unclipped treatment. Clipping occurred at all sites in early March. The height was reduced to 5 to 6 cm by hand harvest. There were two harvests at all locations in the clipped treatment. The second harvest of the clipped plots and the only harvest of the unclipped plots occurred at all sites between May 1 and May 15. Samples were taken by hand harvest from one m^2 area of each plot at each harvest. Samples was dried in an oven at 60 C for 48h before weighing. Yield was measured as total dry matter production per hectare (TDM ha^{-1}) and Megacalories per dry weight (Mcal kg^{-1}). Caloric content is a measure of the energy available in the forage. Forage quality of samples was assessed by the Forage Testing Laboratory at Texas A&M University as percent crude protein (%CP) and percent acid detergent fiber (%ADF). The %CP is an estimate of the provision of nitrogen in the forage. The %ADF is an estimate of the highly indigestible portion of the forage. Higher %CP and lower %ADF are indicators of good forage quality.

At all sites the experimental design was a randomized complete block with a split-plot arrangement with four replications. Main plots were the clipping treatment and sub-plots were the plant culture. Data for the clipped treatment was summed for season-long forage production. Residual plots showed the data to be normally distributed about the mean. Analysis of variance (ANOVA) was performed with interactions and main effects tested at the $\propto = 0.05$ level; means were separated using the LSD method.

Results and Discussion

Since the treatment interactions were significant ($P < 0.05$) in the ANOVA, the results were not pooled. Thus, the results were separated by clipping treatment, plant culture, and site.

College Station site. Yields for both TDM ha^{-1} and Mcal ha^{-1} in the first clipping treatment were lower than those in the second clipping and the unclipped treatment (Tables 4 and 5). But, the first clipping had the best forage quality with a higher %CP and lower %ADF than the other treatments (Tables 6 and 7). Pure ryegrass had the lowest yields in TDM ha^{-1} and Mcal ha^{-1} of any forage in the two clipped and the unclipped treatments. Pure oats and wheat produced the greatest TDM ha^{-1} and Mcal ha^{-1} in the first clipping. Pure wheat and the mixtures had the highest yields in the second clipping. Pure wheat had the lowest %ADF in the second clipping and unclipped treatments. Despite the relatively low %CP in the unclipped treatment, pure wheat appeared to be the best forage at College Station. Ryegrass was clearly the poorest forage at College Station.

Table 4. Total dry matter yield in two clippings and an unclipped treatment of forages at College Station, TX in 1997.

Forage	Total dry matter production		
	First clipping	Second clipping	Unclipped
	--------------------------------kg ha^{-1}------------------------------		
oats	512	1235	2094
ryegrass	174	1090	1143
wheat	465	1571	2101
oats and ryegrass	300	1506	1815
wheat and ryegrass	276	1396	1921
LSD (P = 0.05)	112	237	339

Table 5. Energy yield in two clippings and an unclipped treatment of forages at College Station, TX in 1997.

Forage	Energy production		
	First clipping	Second clipping	Unclipped
	------------------------------Mcal ha^{-1}------------------------------		
ryegrass	567	2294	2566
wheat	1166	3779	4974
oats and ryegrass	661	3446	3938
wheat and ryegrass	675	3349	3994
LSD (P = 0.05)	207	547	406

Table 6. Percent crude protein in two clippings and an unclipped treatment of forages at College Station, TX in 1997.

Forage	Percent crude protein		
	First clipping	Second clipping	Unclipped
	----------------------------------	%	----------------------------------
oats	11.8	9.3	7.3
ryegrass	9.2	9.1	9.4
wheat	13.3	8.6	7.2
oats and ryegrass	11.7	7.9	8.7
wheat and ryegrass	13.7	8.3	6.8
LSD (P = 0.05)	2.2	1.8	1.7

Table 7. Percent acid detergent fiber in two clippings and an unclipped treatment of forages at College Station, TX in 1997.

Forage	Percent acid detergent fiber		
	First clipping	Second clipping	Unclipped
	----------------------------------	%	----------------------------------
oats	21.1	40.5	42.6
ryegrass	18.3	41.4	44.1
wheat	26.7	37.0	39.1
oats and ryegrass	19.5	41.5	43.3
wheat and ryegrass	25.7	39.2	44.1
LSD (P = 0.05)	3.6	1.8	2.3

Marlin site. The first clipping had the poorest forage yields, but the best forage quality among the treatments (Tables 8-11). The wheat-ryegrass mixture had the best yield in Mcal ha^{-1} of any forage in the first clipping. While pure oats produced the lowest yields for TDM ha^{-1} and Mcal ha^{-1} of any forage in the second clipping and the unclipped treatments, pure ryegrass produced the highest yields in these treatments. Although pure ryegrass had the highest %ADF in these treatments, its %CP was not significantly ($P < 0.05$) lower than the other forages. Thus, pure ryegrass was the best forage at Marlin.

Table 8. Total dry matter yield in two clippings and an unclipped treatment of forages at Marlin, TX in 1997.

Forage	Total dry matter production		
	First clipping	Second clipping	Unclipped
	---------------------------------kg ha^{-1}------------------------------		
oats	164	3671	3607
ryegrass	120	6619	8379
wheat	227	4265	4958
oats and ryegrass	169	4372	5410
wheat and ryegrass	128	5483	5608
LSD (P = 0.05)	66	671	835

Table 9. Energy yield in two clippings and an unclipped treatment of forages at Marlin, TX in 1997.

Forage	Energy Production		
	First clipping	Second clipping	Unclipped
	---Mcal ha^{-1}---		
ryegrass	290	17808	18098
wheat	579	11285	11864
oats and ryegrass	430	10561	10991
wheat and ryegrass	710	12410	13161
LSD (P = 0.05)	189	1069	2452

Table 10. Percent crude protein in two clippings and an unclipped treatment of forages at Marlin, TX in 1997.

Forage	Percent crude protein		
	First clipping	Second clipping	Unclipped
	---%---		
oats	23.1	9.3	8.9
ryegrass	25.9	10.9	11.0
wheat	21.9	9.5	9.8
oats and ryegrass	20.6	10.1	9.2
wheat and ryegrass	24.1	10.5	10.1
LSD (P = 0.05)	3.6	2.1	1.6

Table 11. Percent acid detergent fiber in two clippings and an unclipped treatment of forages at Marlin, TX in 1997.

Forage	Percent acid detergent fiber		
	First clipping	Second clipping	Unclipped
	----------------------------------	%	----------------------------------
oats	27.8	42.0	33.6
ryegrass	22.7	46.9	37.2
wheat	30.8	41.2	32.1
oats and ryegrass	30.4	42.1	33.9
wheat and ryegrass	28.1	41.8	32.4
LSD (P = 0.05)	4.6	3.9	2.1

Temple site. The first clipping had the best forage quality, but the poorest forage yields among the treatments (Tables 12-15). Pure wheat was the best producer of dry matter and calories in the first clipping. Pure ryegrass produced the most TDM ha^{-1} in the unclipped treatment and similar to the mixture with wheat in the second clipping. The wheat-ryegrass mixture produced the most Mcal ha^{-1} in the second clipping and unclipped treatment. Forage quality measured as %CP and %ADF for this mixture was similar to the other forages. Thus, the wheat- ryegrass mixture was the best forage at Temple.

Table 12. Total dry matter yield in two clippings and an unclipped treatment of forages at Temple, TX in 1997.

Forage	Total dry matter production		
	First clipping	Second clipping	Unclipped
	--------------------------------kg ha^{-1}------------------------------		
ryegrass	178	6689	8326
wheat	789	5204	4797
oats and ryegrass	356	6215	5932
wheat and ryegrass	555	6818	6803
LSD (P = 0.05)	101	508	689

Table 13. Energy yield in two clippings and an unclipped treatment of forages at Temple, TX in 1997.

Forage	Energy production		
	First clipping	Second clipping	Unclipped
	------------------------------Mcal ha^{-1}------------------------------		
ryegrass	1560	14860	16446
wheat	2019	13172	12287
oats and ryegrass	894	14399	12834
wheat and ryegrass	1420	16190	18953
LSD (P = 0.05)	296	1096	849

Table 14. Percent crude protein in two clippings and an unclipped treatment of forages at Temple, TX in 1997.

Forage	Percent crude protein		
	First clipping	Second clipping	Unclipped
	----------------------------------%	----------------------------------	
oats	31.4	10.0	10.2
ryegrass	28.1	10.6	10.3
wheat	29.9	9.8	10.2
oats and ryegrass	31.0	10.1	10.2
wheat and ryegrass	27.2	10.6	10.1
LSD (P = 0.05)	3.7	2.0	0.9

Table 15. Percent acid detergent fiber in two clippings and an unclipped treatment of forages at Temple, TX in 1997.

Forage	Percent acid detergent fiber		
	First clipping	Second clipping	Unclipped
	----------------------------------%	----------------------------------	
oats	26.9	54.5	40.2
ryegrass	26.1	50.0	48.1
wheat	31.1	57.5	33.2
oats and ryegrass	25.5	52.6	42.6
wheat and ryegrass	30.0	57.1	34.8
LSD (P = 0.05)	2.9	3.3	5.1

Thrall site. The lowest forage yields and the best quality among the treatments was the first clipping treatment (Tables 16-19). Pure wheat had the highest TDM ha^{-1} and Mcal

ha^{-1} at the first clipping. Pure oats had the greatest TDM ha^{-1} and Mcal ha^{-1} of any forage in the second clipping and the unclipped treatments. Its %CP and %ADF were similar to the other forages. Thus, pure oats was the best forage at Thrall.

Table 16. Total dry matter yield in two clippings and an unclipped treatment of forages at Thrall, TX in 1998.

Forage	Total dry matter production		
	First clipping	Second clipping	Unclipped
	--------------------------------kg ha^{-1}------------------------------		
ryegrass	428	1798	3017
wheat	689	3124	3712
oats and ryegrass	456	1869	3501
wheat and ryegrass	580	2622	3593
LSD (P = 0.05)	88	615	412

Table 17. Energy yield in two clippings and an unclipped treatment of forages at Thrall, TX in 1998.

Forage	Energy production		
	First clipping	Second clipping	Unclipped
	------------------------------Mcal ha^{-1}------------------------------		
ryegrass	1067	4598	7700
wheat	1764	7254	8958
oats and ryegrass	1135	4682	8934
wheat and ryegrass	1486	6340	9018
LSD (P = 0.05)	279	1255	377

Table 18. Percent crude protein in two clippings and an unclipped treatment of forages at Thrall, TX in 1998.

Forage	Percent crude protein		
	First clipping	Second clipping	Unclipped
	----------------------------------	%----------------------------------	
oats	30.8	9.2	11.7
ryegrass	24.5	10.7	13.4
wheat	27.8	10.1	11.3
oats and ryegrass	28.0	10.4	11.0
wheat and ryegrass	29.1	10.4	11.0
LSD (P = 0.05)	3.6	2.9	1.3

Table 19. Percent acid detergent fiber in two clippings and an unclipped treatment of forages at Thrall, TX in 1998.

Forage	Percent acid detergent fiber		
	First clipping	Second clipping	Unclipped
	----------------------------------	%----------------------------------	
oats	24.9	48.6	38.4
ryegrass	27.7	50.1	29.4
wheat	33.0	52.9	39.0
oats and ryegrass	27.8	46.3	33.6
wheat and ryegrass	32.3	52.7	35.7
LSD (P = 0.05)	2.8	3.1	5.0

Although, forage yield was lower for the first clipping than the second clipping or the unclipped treatment, the first clipping had the best forage quality with a higher %CP and lower %ADF than the other treatments. There was a strong environmental influence on yield measured as dry matter and energy production and forage quality assessed as crude protein and acid detergent fiber. The best forage was pure wheat at College Station, pure ryegrass at Marlin, the wheat-ryegrass mixture at Temple, and pure oats at Thrall. Since Temple had the greatest yield of any site, the wheat-ryegrass mixture demonstrated the highest yield potential.

CHAPTER IV

HALOSULFURON ADSORPTION AND DESORPTION FROM SIX SOILS

Introduction

Halosulfuron (methyl 5-[[(4,6-dimethoxy-2-pyrimidinyl) amino] carbonylaminosulfonyl] -3-chloro-1-methyl-1-*H*-pyrazole-4-carboxylate) is a sulfonylurea herbicide used postemergence in corn (*Zea maize* L.), sorghum (*Sorghum bicolor* L. Moench), and sugarcane (*Sacchaum officinarum* L.) production for the control of numerous broadleaf weeds and *Cyperus* species. The compound is a weakly acidic herbicide with a pK_a of 3.5 and a low aqueous solubility of 15 mg L^{-1} at pH 5 and 1630 mg L^{-1} at pH 7 (Weed Science Society of America, 2002). Characteristics of the sulfonylureas include low mammalian toxicity, low usage rates (halosulfuron at 35.9 g ha^{-1} in corn and sorghum), a high degree of selectivity, and good control of difficult to control weed species, such as velvetleaf (*Abutilon theophrasti*), pigweed (*Amaranthus* species), ragweed (*Ambrosia* species), and cocklebur (*Xanthium spinosum* L.). Despite the benefits of this new family of herbicides, concerns have developed regarding injury to sorghum. Since adsorption affects the amount of herbicide available for plant uptake, information regarding the adsorptive characteristics of halosulfuron will be useful in determining its root uptake in sorghum.

Numerous studies have examined the adsorption and desorption of various sulfonylurea herbicides. These studies have concluded that adsorption of various sulfonylurea herbicides decreased as soil pH increases, and that desorption increased at high pH values (Beckie and Mercher 1990; Fredrickson and Shea 1986; Goetz et al.

1989; Mersie and Foy 1985; Werkheiser and Anderson 1996).

While general trends in adsorption are consistent for many sulfonylurea herbicides, the magnitude of adsorption may differ greatly between compounds. Studies have also shown a positive correlation between sulfonylurea adsorption and clay content (Gonzalez and Ukrainczyk 1996; Vicari et al. 1996). A positive correlation between soil organic matter content and adsorption was shown for primisulfuron and nicosulfuron, but no such correlation was found for rimsulfuron or chlorsulfuron (Gonzalez and Ukrainczyk 1996; Vicari et al. 1996). While results of soil adsorption studies have been published for many of the sulfonylureas, there is a lack of published data on the adsorption of halosulfuron.

The objective of this study was to characterize the soil adsorption characteristics of halosulfuron.

Materials and Methods

Five of the soils used in this study (Acuff-Estacado sandy clay loam, Bernard clay loam, Houston Black clay, Ships clay, and Victoria sandy clay loam) were obtained from agricultural areas throughout Texas. The Harney silty clay loam was obtained from a sorghum-producing area of Kansas. Samples were obtained from surface horizons, air-dried, ground, and passed through a 2-mm sieve. Physical and chemical characteristics of these soils are described in Table 20.

Table 20. Physical and chemical characteristics of the six soils in this study.

Soil series, texture, and subgroup	Clay	Silt	Sand	OC[a]	pH	CEC[b]
	-------------- (%) ------------					$cmol_c\ kg^{-1}$
Ships clay, very-fine, mixed, active, thermic Chromic Hapluderts	69.2	19.0	11.8	1.18	7.9	39.8
Houston Black clay, very-fine, smectitic, thermic Oxyaquic Hapluderts	54.6	26.4	19.0	1.82	8.5	45.5
Bernard clay loam, fine, smectitic, thermic Vertic Argiaquolls	38.0	18.9	43.1	1.42	6.7	21.2
Victoria silty clay loam, fine, smectitic, hyperthermic Udic Pellusterts	34.8	17.4	47.8	0.95	6.0	21.1
Harney silty clay loam, fine, smectitic, mesic Typic Argiustolls	31.2	58.2	10.6	2.03	6.7	21.1
Acuff Estacado sandy clay loam, fine-loamy, mixed, thermic Aridic Paleustolls	30.2	18.6	51.2	0.66	8.3	14.5

[a] OC - organic carbon.

[b] CEC - cation exchange capacity.

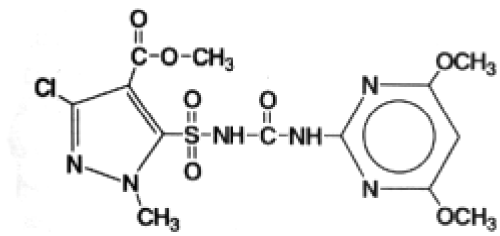

Figure 1. Chemical structure of halosulfuron.

Adsorption was determined by the batch equilibrium method. Analytical grade and ^{14}C-halosulfuron (specific activity of 31 mCi $mmol^{-1}$; labeled at the 4-C of the pyrazole ring) were combined to obtain application rates of 0.023, 0.036, 0.048, and 0.072 μg mL^{-1} (Figure 1). These rates correspond to 0.5x, 0.75x, 1x, and 1.5x rates, based upon a 15.2-cm acre furrow slice. Three g of each soil were placed in 35-ml glass centrifuge tubes. Herbicide and 10-ml 0.01 *N* $CaCl_2$ were added to each soil. Tubes were shaken at 20 - 24° C for 24 h. A preliminary study indicated that halosulfuron had reached equilibrium by 24 h. After shaking, samples were centrifuged at 1400 rpm for 1 h. A 1-ml aliquot of the supernatant for each concentration was removed and added to 6.4-ml scintillation fluid. Quantification of ^{14}C-halosulfuron was made with a Beckman LS 6500 Multi-Purpose Scintillation Counter.

Adsorption isotherms were constructed for each soil using the Freundlich model. A measure of the relative affinity, K_f, was calculated using the linearized Freundlich equation:

$$S = C^{1/n} * K_f$$

where S is the amount adsorbed (mg kg^{-1}), K_f and n are constants and C is the equilibrium concentration (mg L^{-1}). The General Linear Models Procedure of SAS was used to fit the Freundlich equation to the sorption isotherms with $K_{f,\,ads}$ and n_{ads} (adsorption) as fitting parameters. Correlations were performed using the Correlation Procedure of SAS.

Results and Discussion

Statistically significant adsorption isotherms were exhibited in each of the six soils (Table 20). Sorption isotherms for each of the soils were of the C-type (Figures 2 and 3). This indicates constant partitioning across the range of halosulfuron concentrations used in this study. This C-type sorption isotherm is typical of non-ionizable pesticides (Weber 1995); halosulfuron is an acidic compound. Halosulfuron may be a weak enough acid that it behaved as a non-ionizable compound in this study. Furthermore, C-type isotherms are most common at low pesticide concentrations; the maximum rate used in this study may not have been a high enough concentration for halosulfuron to exhibit a pattern of partitioning other than C-type.

Halosulfuron adsorption isotherms and Freundlich constants, $K_{f,ads}$ and $1/n_{ads}$, for each of the soils are presented in Figures 2 and 3 and Table 22, respectively. Freundlich $K_{f,ads}$ values ranged from a low of 0.65 (Victoria) to 0.73 (Harney). Values of $1/n_{ads}$ ranged from 0.71 to 1.02. The order of adsorption of halosulfuron was Harney silty clay loam > Ships clay > Houston Black clay > Bernard clay loam > Acuff Estacado sandy clay loam > Victoria silty clay loam. The greatest adsorption occurred in the Harney silty clay loam, which had the highest organic carbon content of the six soils in the study. The Ships clay also exhibited a strong affinity for halosulfuron, and had the most clay of the soils tested (Table 19). Previous studies have indicated a correlation between organic matter and the adsorption of other sulfonylurea herbicides, primisulfuron and nicosulfuron (Gonzales and Ukrainczyk 1996; Vicari et al. 1996). While this trend was evident in this study, there was no significant correlation between K_f adsorption values and organic carbon content, soil pH, clay content, or cation exchange capacity for any of the soils examined. The lowest adsorption of halosulfuron was observed in the Victoria silty clay loam and the Acuff Estacado sandy clay loam. Both soils have a sand content > 43% and organic carbon content of < 1%.

Table 21. *P* values for adsorption of halosulfuron from the six soils.

Soil	adsorption *p* values[a]
Acuff Estacado sandy clay loam	0.0200
Bernard clay loam	0.0003
Harney silty clay loam	0.0001
Houston Black clay	0.0052
Ships clay	0.0043
Victoria silty clay loam	0.0326

[a] *p* values represent significance of adsorption slopes.

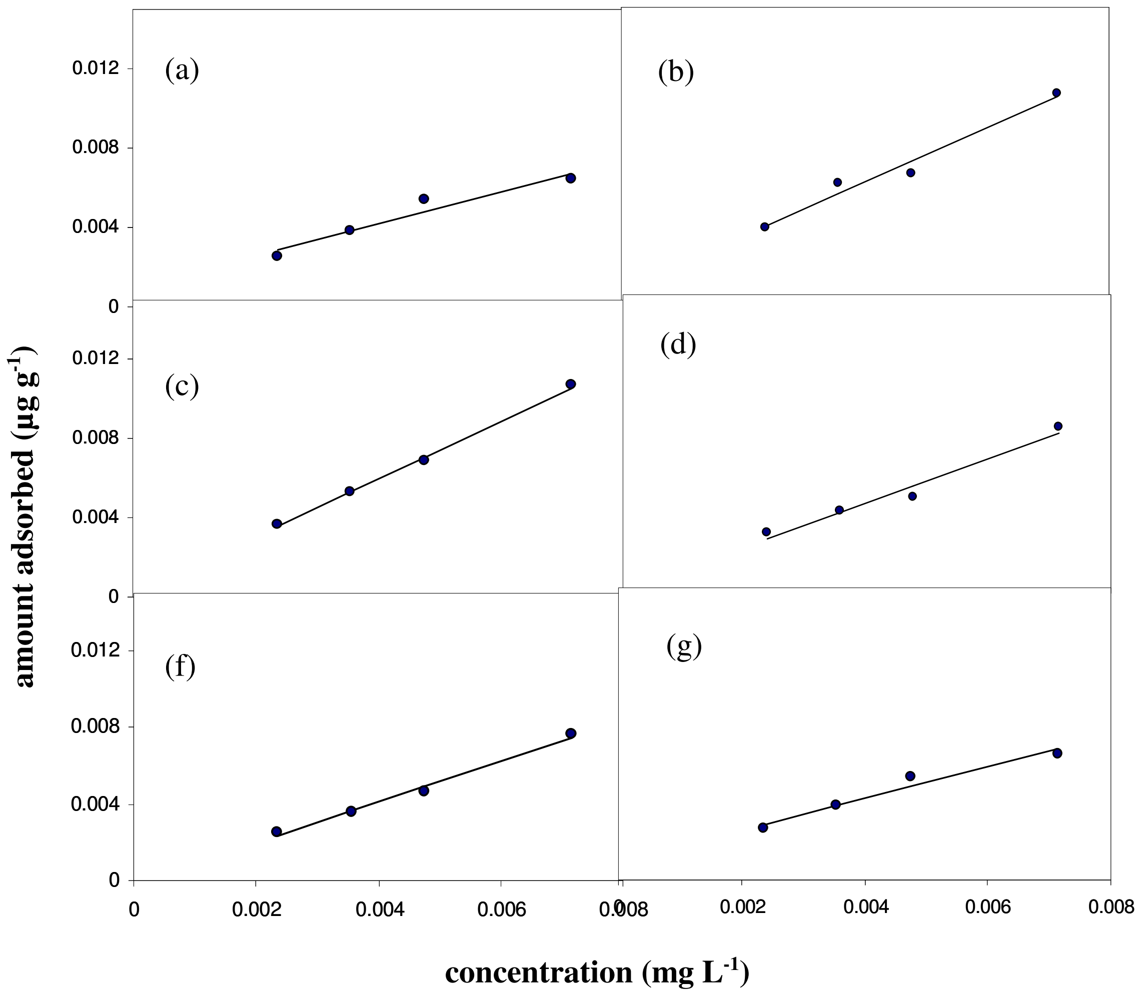

Figure 2. Isotherms for adsorption of halosulfuron from (a) Acuff Estacado sandy clay, (b) Bernard clay loam, (c) Harney silty clay loam, (d) Houston Black clay, (e) Ships clay, and (f)Victoria silty clay loam.

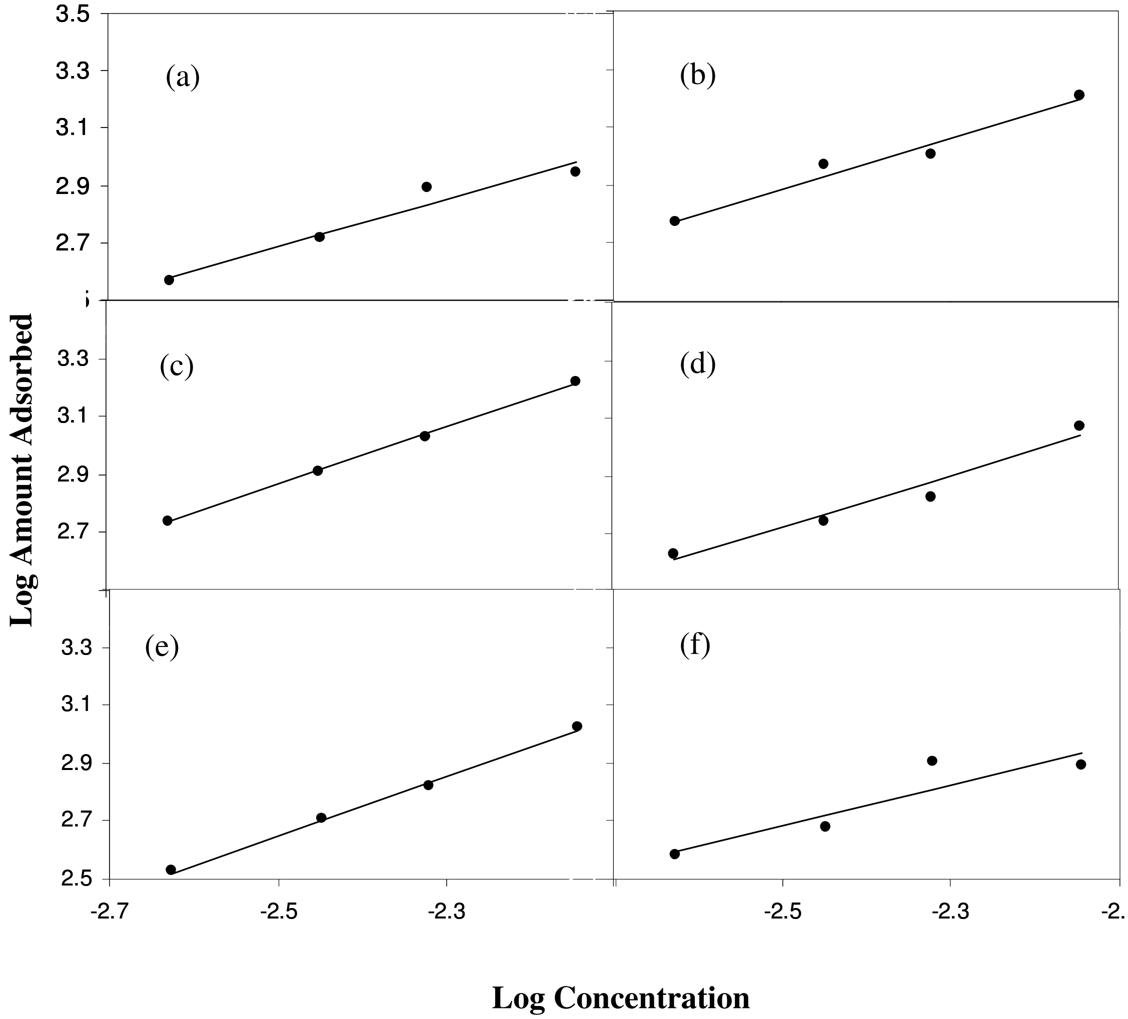

Figure 3. Freundlich adsorption of halosulfuron from (a) Acuff Estacado sandy clay, (b) Bernard clay loam, (c) Harney silty clay loam, (d) Houston Black clay, (e) Ships clay, and (f)Victoria silty clay loam.

Table 22. Freundlich K_f constants for adsorption of halosulfuron from the six soils.

Soil	$^1/n_{ads}$	$K_{f, ads}$ [a]	R^2
Ships clay	1.02*	0.72*	0.99
Houston Black clay	0.89*	0.70*	0.95
Bernard clay loam	0.87	0.70	0.97
Victoria silty clay loam	0.71*	0.65*	0.83
Harney silty clay loam	0.99*	0.73*	0.99
Acuff Estacado sandy clay loam	0.83*	0.68*	0.95

[a] $K_{f, ads}$ - Freundlich K value, representative of affinity of halosulfuron to soil (mL g^{-1}).

* Distribution coefficients are significant at the 0.05 level of probability.

Soil adsorption of halosulfuron in this study appeared to be a function of organic matter although a significant correlation was not determined. Low $K_{f,ads}$ values indicated that a relatively high level of halosulfuron could be available for plant uptake. Thus, sorghum produced on a Victoria silty clay loam or Acuff Estacado sandy clay loam may experience injury because of the low affinity of halosulfuron for these soils.

CHAPTER V

SUMMARY

A growth room experiment compared seedling growth after nine weeks of two wheat genotypes, the semi-dwarf Mit and the landrace Kharkof, in pure cultures at a phosphorus (P) level recommended by soil testing and at a low P level. This experiment also compared Mit in mixed culture with Marshall Italian ryegrass and Kharkof in mixed culture with Marshall Italian ryegrass at a phosphorus (P) level recommended by soil testing and at a low P level. Both cultivars in pure and mixed cultures grew better at the recommended than the low P level in all measurements. Mit and Kharkof response was similar in the pure cultures at the low P level. In mixtures with ryegrass at the low P level, the only difference between the genotypes was that Mit grew taller than Kharkof. However, at the recommended P level Mit in pure culture had a greater height, leaf area, tiller number, root length, and dry weight of leaves, stems and roots than did Kharkof. At the recommended P level in mixtures with ryegrass, Mit also had a greater leaf area, tiller number, and dry weight of leaves, stems and roots than did Kharkof. These results reflected the visual selection criteria for seedling vigor and tillering used in the development of the original semi-dwarf cultivars. Both seedling vigor with its greater initial leaf area and height, and increased tillering in the semi-dwarf wheats enhanced their competitiveness for light with weeds early in the growing season. Thus, the provision of adequate P is important to enhance the competitiveness of wheat with weeds. Moreover, Further selection for vigorous seedling growth, tillering, and tolerance to high plant populations by plant breeders may assist wheat competition with weeds.

Field experiments compared total dry matter, calories, and percent crude protein and acid detergent fiber of oats, wheat, and ryegrass in pure culture and mixtures at four locations in central Texas at first clipping, second clipping, and unclipped. Although, forage yield was lower for the first clipping than the second clipping or the unclipped treatment, the first clipping had the best forage quality with a higher %CP and lower %ADF than the other treatments. There was a strong environmental influence on yield measured as dry matter and energy production and forage quality assessed as crude protein and acid detergent fiber. The best forage was pure wheat at College Station, pure ryegrass at Marlin, the wheat-ryegrass mixture at Temple, and pure oats at Thrall. Since Temple had the greatest yield of any site, the wheat-ryegrass mixture demonstrated the highest yield potential.

The soil adsorption characteristics of halosulfuron was examined using six soils: using Acuff-Estacado sandy clay loam, Bernard clay loam, Houston Black clay, Ships clay, Victoria sandy clay loam, and Harney silty clay loam. Halosulfuron is a sulfonylurea herbicide used postemergence in corn, sorghum, and sugarcane production for the control of numerous broadleaf weeds and *Cyperus* species. Soil adsorption of halosulfuron in this study appeared to be a function of organic matter. Low $K_{f,ads}$ values indicated that a relatively high level of halosulfuron could be available for plant uptake. Sorghum produced on a Victoria silty clay loam or Acuff Estacado sandy clay loam may experience injury because of the low affinity of halosulfuron for these soils.

SOURCES OF MATERIAL

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Comair Root Length Scanner, Commonwealth Aircraft Corp. Ltd., Melbourne, Australia. This company is no longer in business.

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VITA

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