INVESTIGATIONS OF SULFOSULFURON FOR CHEAT (*Bromus secalinus*) CONTROL IN WHEAT (*Triticum aestivum*) AND ROTATIONAL CROP RESPONSE

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INVESTIGATIONS OF SULFOSULFURON FOR CHEAT (*Bromus secalinus*) CONTROL IN WHEAT (*Triticum aestivum*) AND ROTATIONAL CROP RESPONSE

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CHAPTER I

EFFECT OF MON 37500 APPLICATION TIMING ON CHEAT (*Bromus secalinus*) CONTROL, WHEAT (*Triticum aestivum*) INJURY, AND WHEAT YIELD

Effect of MON 37500 Application Timing on Cheat (*Bromus secalinus*) Control, Wheat (*Triticum aestivum*) Injury, and Wheat Yield[1]

JASON P. KELLEY and THOMAS F. PEEPER[2]

Abstract: Sixteen field experiments were conducted across Oklahoma to evaluate the effects of MON 37500 time of application on cheat control, wheat injury, and wheat yield. Wheat injury from MON 37500 when applied preemergence (PRE) was slight and was influenced by cumulative precipitation for 10 d following application. Wheat injury was more frequent with early versus late postemergence (POST) applications and was influenced by wheat growth stage and air temperatures before and after application. Cheat control averaged 75% (n=16 treatments with 4 to 6 replicates) when applied PRE and 88% (n=126 treatments with 4 to 6 replicates) when applied POST. Cheat control from MON 37500 applied POST was negatively influenced by cheat growth stage at application and by the mean low temperatures 0 to 14 and 0 to 21 days prior to application. MON 37500 applied PRE increased yields 52 and 66% in years one and two averaged over eight experiments each year. MON 37500 applied POST increased wheat yields 68 to 69% in years one and two when averaged over all applications in eight experiments each year. Timing applications at 21 to 42 and

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168 d after wheat seeding both years maximized cheat control. Wheat yields were greater from fall POST applications.

Nomenclature: MON 37500, 1-(2-ethlsulfonylimidazo[1,2-a]pyridin-3-ylsulfonyl)-2-(4,6-dimethoxypyrimidin-2-y1)urea; cheat, *Bromus secalinus* L. #[3] BROSE; hard red winter wheat, *Triticum aestivum* L. '2163', '2137', 'Jagger'.

Additional index words: yield reduction.

Abbreviations: POST, postemergence; PRE, preemergence

INTRODUCTION

In 1980, cheat and other winter annual *Bromus* spp. infested over 40% of wheat land in Oklahoma (Greer et al. 1980). In 1987, cheat was listed as being the most common and troublesome weed in Oklahoma wheat (Greer 1988). By 1998, 80% of wheat fields in major wheat producing counties in north central Oklahoma were cheat infested (Barnes et al. 1999), indicating that cheat has become more prevalent in Oklahoma wheat.

Until 1999, wheat growers in the southern Great Plains had four herbicide options for selective *Bromus* sp. suppression in wheat, 1.) chlorsulfuron + metsulfuron, in a 5:1 w/w premix applied PRE, 2.) triasulfuron applied preplant or PRE, 3.) chlorsulfuron + metsulfuron tank mixed with metribuzin applied POST, or 4.) metribuzin applied POST after the wheat has three tillers. Chlorsulfuron +

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

metsulfuron and triasulfuron are most effective against broadleaf weeds and usually only provide minimal *Bromus* sp. suppression. Cultivar restrictions and narrow crop safety margins have limited metribuzin use in Oklahoma (Runyan et al. 1982).

MON 37500, 1-(2-ethlsulfonylimidazo[1,2-a]pyridin-3-ylsulfonyl)-2-(4,6-dimethoxypyrimidin-2-y1)urea; is a recently introduced herbicide for selective *Bromus* sp. and certain broadleaf weed control in wheat. The use rate is 35 g/ha whether applied PRE or POST (Anonymous 2000).

Knowledge of the critical period of weed competition helps producers implement timely herbicide applications to maximize crop yields. In soybean, the critical period of weed competition may start as early as two weeks after emergence (Baysinger and Sims 1991). In spring wheat infested with wild oats, wheat yields declined 14% when wild oats were allowed to compete with wheat beyond the seven-leaf stage (Kirkland 1993). In downy brome infested winter wheat, MON 37500 applied PRE or POST in the fall were more efficacious than MON 37500 applied in the spring (Blackshaw and Hamman 1998) and resulted in higher wheat yields (Geir et al. 1998). In Oklahoma, producers often delay herbicide application until late winter and apply nitrogen fertilizer topdressing and herbicide together. Also weather conditions can hinder fall applications. The effect of delaying MON 37500 application from early fall to late winter on wheat injury, cheat control, and wheat yield has not previously been defined.

The objectives of this research were: 1.) to determine the effect of MON 37500 time of application on wheat injury and cheat control, 2.) to correlate weather factors to wheat injury and cheat control, 3.) to quantify wheat yield loss from delaying MON 37500 from late September or early October until mid-March.

MATERIALS AND METHODS

Field experiments were conducted on Agronomy Research Station fields near Altus, Chickasha, Goodwell, Haskell, Lahoma, Orlando, Perkins, and Stillwater, Oklahoma during the 1996-1997 wheat-growing season and repeated on adjacent sites during 1997-1998 to evaluate the effect of MON 37500 time of application on wheat injury and cheat control. The experimental design was a randomized complete block with four to six replications in each experiment. Plot size was 2.1 by 6.9 or 2.4 by 7.6-m. Soil characteristics for each experiment are listed in Table 1. Experiments were fertilized according to soil tests for a 4000 kg/ha yield goal.

To ensure a uniform population of cheat, locally harvested cheat seed was hand broadcast onto all plots at 50 kg/ha immediately prior to wheat seeding. Cheat seed was incorporated into the top 2.5 to 5.0 cm of soil using a light field cultivator with double rolling baskets. Hard red winter wheat '2163' was seeded in all experiments with the exception of Stillwater 1 and Goodwell 2 which were seeded to 'Jagger' and '2137'. Wheat was seeded into a conventionally tilled seedbed at 67 kg/ha (90, 45, and 50 kg/ha at Chickasha 1, Goodwell 1, and Goodwell 2) using a single or double disk grain drill with 20-cm row spacing (25-cm at Altus 1 and Altus 2) in late September or early October (Table 2). Immediately after wheat seeding, MON 37500 was applied PRE and thereafter, POST treatments were applied on a three-week interval from mid-October until mid-March. All MON 37500 treatments were broadcast at 35 g/ha using a compressed CO_2 backpack sprayer calibrated to deliver 187 L/ha of water carrier. Nonionic surfactant was added to all POST treatments at 0.5% v/v.

Wheat and cheat growth stages were determined at each time of application from ten randomly selected plants of each species (Table 2). Cheat density ranged from 90 plants/m^2 at Goodwell 1 to 270 plants/m^2 at Altus 1, Altus 2, and Haskell 1. Most experiments had low densities of broadleaf weeds present which included; bushy wallflower (*Erysimum repandum* L. # ERYRE), henbit (*Lamium amplexicaule* L. # LAMAM), and flixweed (*Descurainia sophia* (L.) Webb. Ex Prantl # DESSO). MON 37500 very effectively controlled bushy wallflower and flixweed, but not henbit. It is unlikely that the broadleaf weeds significantly influenced wheat yields (Scott et al. 1995).

Wheat injury was visually estimated approximately three weeks after each application using a scale of 0 to 100 where 0 = no injury and 100 = crop death. Cheat control was visually estimated after anthesis using a scale of 0 to 100 where 0 = no control and 100 = complete control. At wheat maturity, a 1.4-m by length-of-plot area was harvested using a small plot combine. The combine separator fan air speed was reduced to retain a large portion of the cheat seed with the wheat grain. Harvested samples were cleaned twice using a small commercial seed cleaner. The first cleaning removed excess chaff and straw from the samples, leaving cheat seed and wheat grain. The second cleaning removed cheat seed and a small amount of cracked or shriveled wheat.

Dockage was defined as the weight loss between the first and second cleaning and was primarily cheat seed. After the second cleaning, test weight and moisture content of each sample were determined. Wheat yields, calculated after the second cleaning, were adjusted to 13.5 percent moisture.

All data were subjected to ANOVA and treatment means separated with protected least significant differences at the P=0.05 level. Cheat control and wheat injury visual ratings were arcsine transformed prior to analysis. Transformation did not affect means separation, therefore original data are presented. Data from all 16 experiments were used to construct simple correlation coefficients between visible wheat injury and cheat control with environmental parameters. Regression analysis was used to examine the influence of application timing on cheat control and wheat yield. Analysis was conducted using SAS version 8.1. Data were pooled across locations, except where precluded by interactions.

RESULTS AND DISCUSSION

Wheat injury. MON 37500 applied PRE did not injure wheat in 14 of 16 experiments. Wheat was injured 3 and 9% at Altus 2 and Haskell 2. Injury was evident as slight, relatively short-lived stunting. It was positively correlated to cumulative rainfall 0 to 10 days after application (r = 0.79, P = 0.0002), but not correlated to soil pH (r = -0.21, P = 0.43), organic matter content (r = 0.05, P = 0.85), clay content (r = -0.04, P = 0.85), or cumulative rainfall 10 d prior to MON 37500 application (r = -0.24, P = 0.35).

Wheat chlorosis from MON 37500 applied POST was most apparent with October and November applications. Injury, in the form of chlorosis, ranged from 0 to 31% in the 16 experiments and was negatively correlated with wheat growth stage at application (Table 3), suggesting that smaller wheat is more likely to be injured by MON 37500 than more developed wheat. Other research has shown that chlorsulfuron injury was negatively correlated to the number of wheat tillers at application (Ferreira et al. 1990). Wheat injury from MON 37500 applied POST was positively correlated to mean high and low temperatures prior to and following application (Table 3). This suggests that when temperatures are warm during October and November, MON 37500 applied POST is more likely to injure wheat. Wheat growth stage and temperature are likely confounded, so distinguishing between temperature effects and growth stage effects is difficult. Temperature fluctuations prior to or following application did not affect wheat injury. Cumulative precipitation 0 to 14 days prior to application was positively correlated to wheat injury. This suggests that wheat is more likely to be injured from MON 37500 applied POST when soil conditions are moist, the temperatures are warm and the wheat is small.

Cheat control. Cheat control from MON 37500 applied PRE ranged from 25 to 99% with a mean of 75% (n=16 treatments, 4 to 6 replications). The only soil property correlated to cheat control was pH ($r = 0.47$ and $P = 0.06$) (Table 4). Cumulative rainfall 0 to 3 d prior to MON 37500 application($r= -0.61$, $P=0.01$) and rainfall 0 to 3 d after application ($r= -0.62$, $P=0.01$) both influenced cheat control. This suggests that when planting wheat into moist soil, cheat may emerge prior to activating rainfall and thus reduce control. It also suggests that rainfall greater than needed for activation may reduce cheat control.

MON 37500 applied POST controlled cheat 7 to 100% with a mean of 88% (n=126 treatments, 4 to 6 replications). Cheat growth stage, defined using the Zadok scale, at time of application was negatively correlated ($P = 0.02$) to cheat control (Table 3). This suggests that small cheat is easier to control than larger cheat. Using data from all experiments, mean low temperatures 0 to 14 days and 0 to 21 days prior to application were positively correlated to cheat control. This suggests that cool temperatures reduce cheat control (Table 3).

A cubic response was found between cheat control and timing of POST MON 37500 applications in both year one ($Y = 4E-05x^3 - 0.0116x^2 + 0.8717x + 74.893$, $R^2 = 0.78$) and year two ($Y = 4E-05x^3 - 0.0098x^2 + 0.6046x + 82.202$, $R^2 = 0.56$) (Figure 1). Cheat control was maximized by MON 37500 applied POST at 21 to 42 d after wheat seeding. Cheat control generally declined from 64 d after wheat seeding and was lowest in late January, then increased in mid-February and March. It is likely that cheat control declined during December and January air temperatures are at their lowest at that time of year. During this time, cheat is often not actively growing and leaves are often necrotic from freezing weather and less likely to absorb applied MON 37500. Temperatures warm through February and March, cheat resumes active growth and control increases.

These results agree with research in Kansas on downy brome control with MON 37500 where downy brome control was greatest from PRE and early fall applications and least from late December treatments. In that research MON 37500 was not applied during January. Downy brome control increased in March as temperatures warmed (Stahlman and Geier 2000).

Wheat Yield. Averaged over experiments, wheat yields were increased 52 and 66% by MON 37500 applied PRE in year 1 and 2 and 68 and 69% when applied POST in year 1 and 2. Mean wheat yields of MON 37500 treated wheat were 2490 and 2640 kg/ha in year one and two.

A quadratic relationship was found between wheat yield increase and application timing in year one ($Y = -0.0039x^2 + 0.6063x + 72.993$, $R^2 = 0.61$) and year two ($Y = -0.0019x^2 + 0.1105x + 81.588$, $R^2 = 0.98$) (Figure 2). In year one, a freeze in mid-April when wheat was in the boot stage reduced wheat yield potential. In both years maximum wheat yield increase was obtained from MON 37500 applied POST 21 to 64 d after wheat seeding.

Thus it is essential to control cheat in the fall to maximize wheat yields. Wheat yields declined after allowing cheat to compete with wheat for approximately 12 weeks in year one and only 3 to 6 weeks in year two.

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Table 1. Soil series, classification, and characteristics[a] in 16 experiments.

Experiment	Series	Classification	OM	Sand	Silt	Clay	pH	CEC
			%					meq/100g
Altus 1	Holister	Fine, mixed, thermic Pachic Paleustolls	1.3	34	33	33	7.5	19.8
Altus 2	"	"	1.4	35	32	33	7.1	21.6
Chickasha 1	Dale	Fine-silty, mixed, thermic Pachic Haplustolls	1.2	39	50	11	6.4	12.5
Chickasha 2	"	"	1.2	39	50	11	6.4	12.5
Goodwell 1	Richfield	Fine, montmorillonitic, mesic, Aridic Arguistolls	1.9	38	38	24	7.4	25.3
Goodwell 2	"	"	1.5	39	35	26	7.0	24.7
Haskell 1	Taloka	Fine, mixed, thermic Mollic Albaqualfs	1.0	37	57	6	5.0	8.3
Haskell 2	"	"	1.3	45	43	12	5.0	9.2
Lahoma 1	Grant	Fine-silty, mixed, thermic Udic Haplustolls	1.2	31	46	23	5.7	15.1
Lahoma 2	"	"	1.3	39	40	21	6.1	13.3
Orlando 1	Port	Fine-silty, mixed thermic Cumulic Haplustolls	1.4	34	46	20	5.4	12.9
Orlando 2	"	"	1.0	53	32	15	5.1	10.4

Table 1. Continued.

Perkins 1	Teller	Fine-loamy, mixed, thermic Udic Argiustolls	1.0	53	36	11	6.3	8.3
Perkins 2	"	"	0.9	58	33	9	5.8	7.6
Stillwater 1	Norge	Fine-silty, mixed, thermic Udic Paleustolls	1.5	49	31	20	5.3	16.1
Stillwater 2	"	"	1.5	49	31	20	5.3	16.1

[a] OM = Organic matter, CEC = cation exchange capacity

Table 2. Wheat seeding dates and wheat and cheat growth stages 21, 42, 84, and 168 days after wheat seeding in 16 experiments.

	Wheat	Growth stages at selected intervals after seeding (days)							
Experiment	seeded	Wheat				Cheat			
		21	42	84	168	21	42	84	168
Altus 1	10-01-96	3 leaves	3 tillers	7 tillers	Jointed	PRE	3 leaves	4 tillers	Jointed
Chickasha 1	10-17-96	2 leaves	1 tiller	3 tillers	Jointed	1 leaf	3 leaves	3 tillers	13 tillers
Goodwell 1	10-09-96	Spike	2 tillers	3 tillers	6 tillers	PRE	1 leaf	2 tillers	4 tillers
Haskell 1	10-04-96	2 leaves	4 tillers	5 tillers	6 tillers	1 leaf	1 tiller	3 tillers	12 tillers
Lahoma 1	09-30-96	2 leaves	4 tillers	7 tillers	12 tillers	1 leaf	2 tillers	3 tillers	10 tillers
Orlando 1	09-24-96	1 leaf	4 tillers	10 tillers	Jointed	2 leaves	1 tiller	12 tillers	10 tillers
Perkins 1	09-23-96	1 tiller	4 tillers	10 tillers	Jointed	3 leaves	2 tillers	8 tillers	Jointed
Stillwater 1	10-04-96	1 leaf	1 tiller	9 tillers	Jointed	1 leaf	3 leaves	3 tillers	Jointed
Altus 2	10-07-97	1 leaf	2 tillers	3 tillers	Jointed	1 leaf	3 leaves	2 tillers	Jointed
Chickasha 2	10-01-97	3 leaves	3 tillers	8 tillers	Jointed	Spike	2 leaves	7 tillers	Jointed

Table 2. Continued.

Goodwell 2	10-15-97	1 leaf	1 leaf	2 leaves	2 tillers	PRE	PRE	2 leaves	2 tillers
Haskell 2	10-02-97	2 leaves	4 tiller	7 tillers	Jointed	1 leaf	2 tillers	6 tillers	10 tillers
Lahoma 2	09-30-97	3 leaves	4 tiller	10 tillers	Jointed	1 leaf	1 tiller	4 tillers	Jointed
Orlando 2	10-01-97	1 leaf	1 tiller	7 tillers	Jointed	1 leaf	1 tiller	7 tillers	Jointed
Perkins 2	09-29-97	2 leaves	1 tiller	5 tillers	Jointed	2 leaves	1 tiller	5 tillers	Jointed
Stillwater 2	09-29-97	1 leaf	1 tiller	5 tillers	Jointed	1 leaf	1 tiller	4 tillers	Jointed

Table 3. Simple linear correlation coefficients (r) for correlation of selected parameters with wheat injury and cheat control from MON 37500 applied postemergence in 16 experiments.

	r^a	
Parameter	Wheat injury	Cheat control
Wheat growth stage (Zadok scale)	-0.31***	-0.18**
Cheat growth stage (Zadok scale)	-0.34***	-0.20**
Mean temperature on application day	0.32***	0.07
Mean high temperature 0 to 3 days prior to application	0.27***	0.10
Mean high temperature 0 to 7 days prior to application	0.30***	0.12
Mean high temperature 0 to 14 days prior to application	0.47***	0.16
Mean high temperature 0 to 21 days prior to application	0.51***	0.14
Mean high temperature 0 to 3 days after application	0.23***	0.04
Mean high temperature 0 to 7 days after application	0.25***	0.04
Mean high temperature 0 to 14 days after application	0.24***	0.08
Mean high temperature 0 to 21 days after application	0.22***	0.07

Table 3. Continued.

Mean low temperature 0 to 3 days prior to application	0.27***	0.08
Mean low temperature 0 to 7 days prior to application	0.39***	0.13
Mean low temperature 0 to 14 days prior to application	0.51***	0.15*
Mean low temperature 0 to 21 days prior to application	0.51***	0.14*
Mean low temperature 0 to 3 days after application	0.08	0.01
Mean low temperature 0 to 7 days after application	0.26**	0.06
Mean low temperature 0 to 14 days after application	0.30***	0.07
Mean low temperature 0 to 21 days after application	0.31***	0.06
Summed diurnal temperature fluctuation 0 to 3 days prior to application	-0.02	0.06
Summed diurnal temperature fluctuation 0 to 7 days prior to application	-0.12	-0.01
Summed diurnal temperature fluctuation 0 to 14 days prior to application	-0.05	0.03
Summed diurnal temperature fluctuation 0 to 3 days after application	0.03	-0.04
Summed diurnal temperature fluctuation 0 to 7 days after application	0.07	-0.01
Summed diurnal temperature fluctuation 0 to 14 days after application	-0.02	0.05

Table 3. Continued.

Cumulative precipitation 0 to 3 days prior to application	0.17*	-0.03
Cumulative precipitation 0 to 7 days prior to application	0.12	0.10
Cumulative precipitation 0 to 14 days prior to application	0.19**	0.10
Cumulative precipitation 0 to 21 days prior to application	0.10	0.08
Cumulative precipitation 0 to 3 days after application	-0.04	-0.12
Cumulative precipitation 0 to 7 days after application	-0.05	-0.26***
Cumulative precipitation 0 to 14 days after application	0.06	-0.24***
Cumulative precipitation 0 to 21 days after application	-0.03	-0.17**
Soil temperature at 10-cm on day of application	0.44***	0.10

[a]*, **, and *** indicate significance at the 0.01, 0.05, and 0.01 levels, respectively.

Table 4. Simple linear correlation coefficients of selected parameters with cheat control from MON 37500 applied PRE in 16 experiments.

Variable	r[a]
Soil pH	0.47*
Soil organic matter content	0.17
% Clay	0.19
CEC	0.35
Cumulative rainfall 0 to 3 days prior to application	-0.61***
Cumulative rainfall 0 to 7 days prior to application	-0.04
Cumulative rainfall 0 to 14 days prior to application	-0.49*
Cumulative rainfall 0 to 21 days prior to application	-0.33
Cumulative rainfall 0 to 3 days following application	-0.62***
Cumulative rainfall 0 to 7 days following application	-0.12
Cumulative rainfall 0 to 14 days following application	-0.04
Cumulative rainfall 0 to 21 days following application	-0.07

[a] * and *** indicate F test significance at P = 0.1 and 0.01.

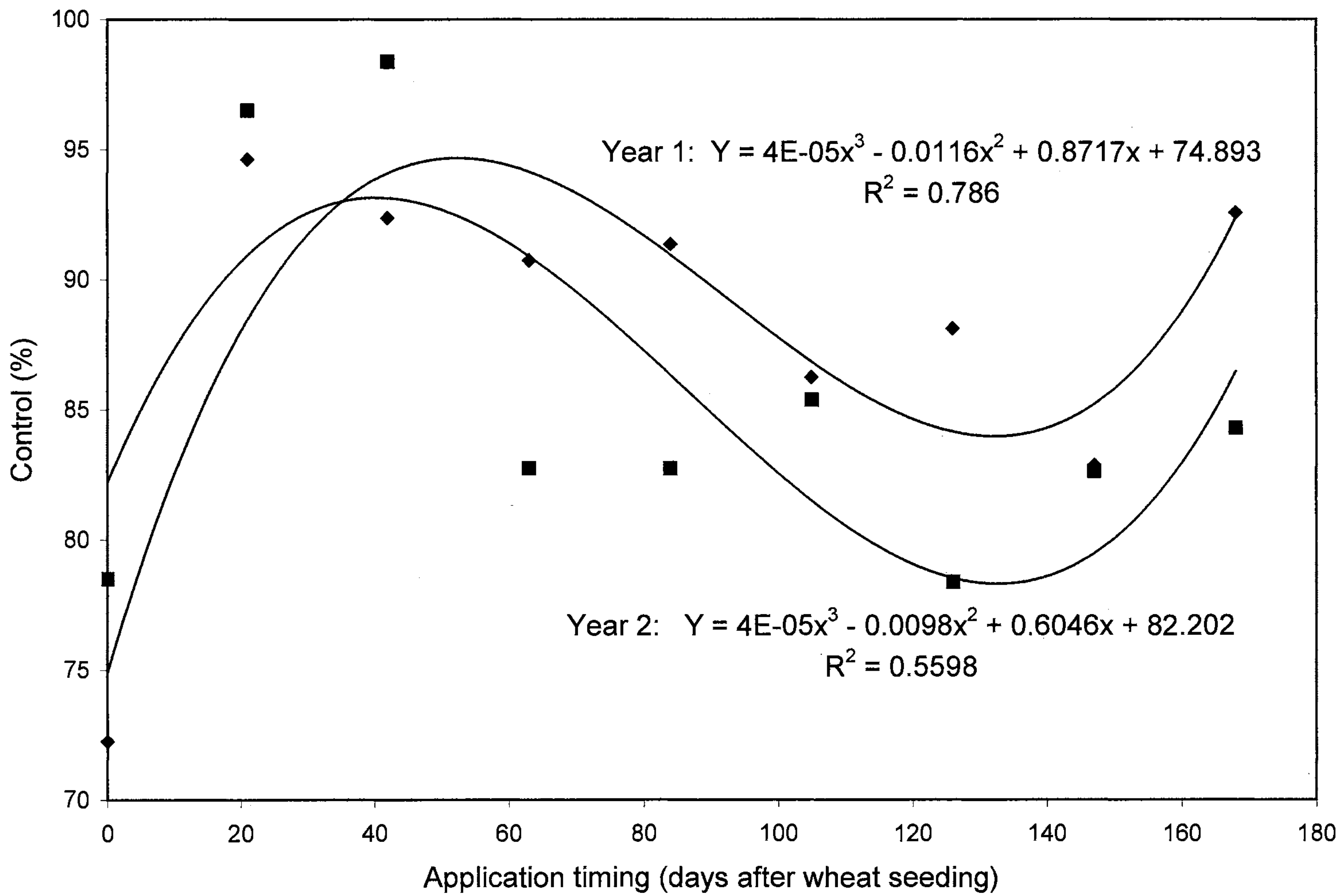

Figure 1 . Effect of MON 37500 application timing on cheat control pooled over 8 locations per year in 1996-1997 and 1997-1998.

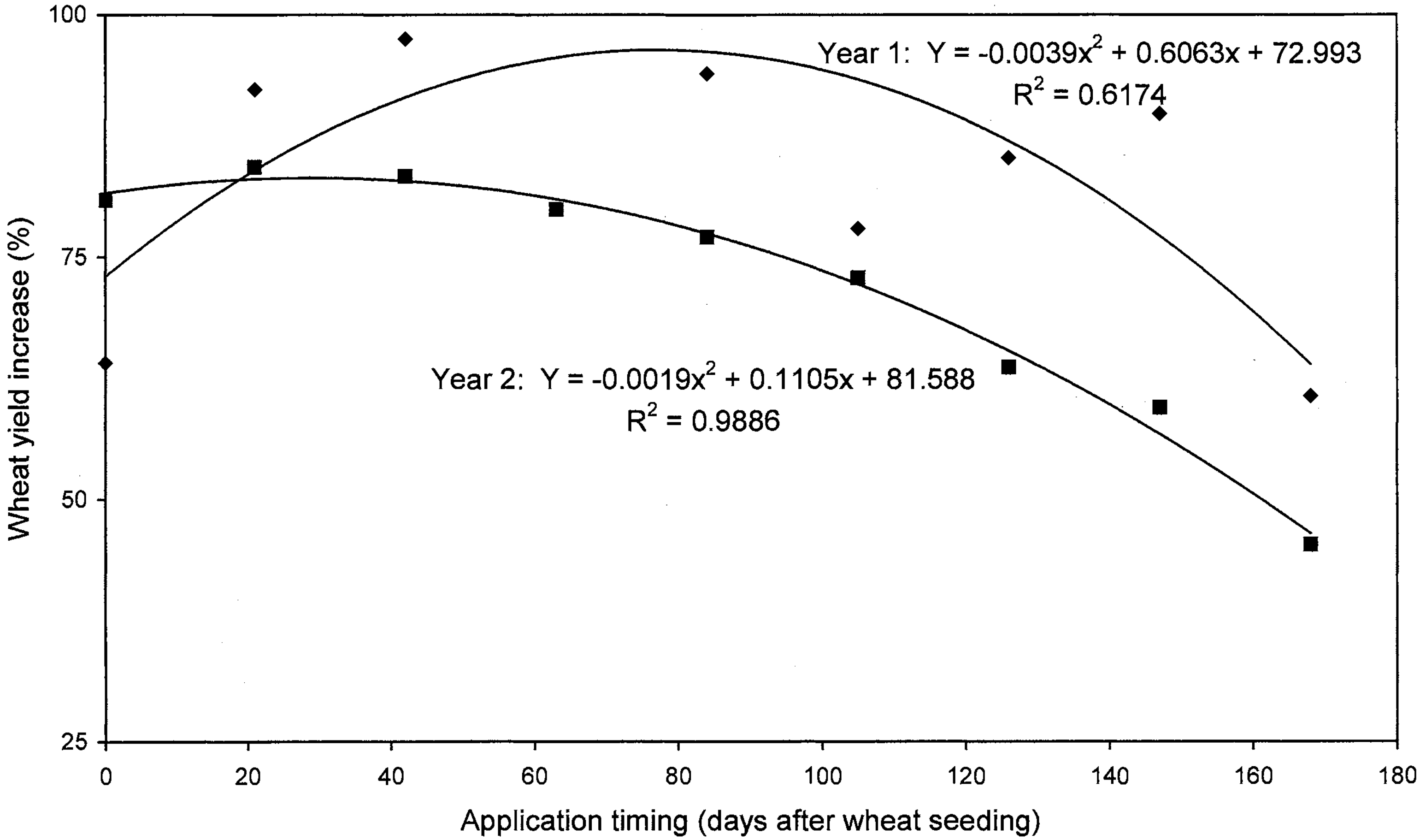

Figure 2. Effect on wheat yield of MON 37500 application timing pooled over 8 locations per year in 1996-1997 and 1997-1998.

CHAPTER II

GRAIN SORGHUM (*Sorghum bicolor*)

RESPONSE TO MON 37500

Grain Sorghum (*Sorghum bicolor*) Response to MON 37500[1]

JASON P. KELLEY and THOMAS F. PEEPER[2]

Abstract: Field experiments were conducted on Agronomy Research Stations across Oklahoma to evaluate grain sorghum response to residual MON 37500. MON 37500 was applied to hard red winter wheat at 35 g ai/ha at three-week intervals beginning with a preemegence (PRE) application in late September or early October and continuing with postemergence (POST) applications until mid-March. Timing of MON 37500 application did not affect grain sorghum injury or yield in any experiment. MON 37500 reduced yields of double crop grain sorghum seeded no-till 3 to 9 months after treatment (MAT) in 11 of 15 experiments, and in 3 of 12 experiments the yield of grain sorghum seeded 14 to 20 MAT was reduced by 14 to 60%. Soil pH and cumulative precipitation from MON 37500 application until grain sorghum seeding were related to grain sorghum injury from residual MON 37500.

Nomenclature: MON 37500, 1-(2-ethlsulfonylimidazo[1,2-a]pyridin-3-ylsulfonyl)-3-(4,6-dimethoxypyrimidin-2-y1)urea; grain sorghum, *Sorghum bicolor* (L.) Moench 'NC+5c35', 'Pioneer 8699', 'Pioneer 8446', 'Pioneer 8500'.

Additional index words: Soil pH, precipitation.

Abbreviations: MAT, months after treatment, POST, postemergence; PRE, preemergence, OM, organic matter.

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INTRODUCTION

MON 37500 (proposed common name sulfosulfuron) is a recently introduced sulfonlyurea herbicide for selective control of *Bromus* sp. and certain broadleaf weeds in wheat (*Triticum aestivum*). The label specifies that only winter wheat or spring wheat may be seeded for one year following MON 37500 application after which a field bioassay should be performed if crops other than wheat are to be seeded (Anonymous 2000).

As with other sulfonylurea herbicides (Ahrens 1994), the water solubility of MON 37500 is pH dependent. MON 37500 is degraded both microbially and by acid hydrolysis with rapid hydrolysis occurring in moist, low pH soils (Hatzios 1998). MON 37500 is considered somewhat persistent with a reported field half-life of 14 to 75 d (Hatzios 1998), suggesting that low levels of residues could persist in the soil to injure certain crops one to three years after application, depending on soil and climate (Hatzios 1998). With similar half-life and chemical properties, it could be postulated that MON 37500 would persist in a similar manner as chlorsulfuron and other residual sulfonlyurea herbicides.

Soil moisture and temperature influence persistence of sulfonylurea herbicides. Increasing the soil temperature from 20 C to 30 C increased chlorsulfuron degradation 2 to 3 times (Walker and Brown 1983). Metsulfuron degradation was twice as rapid at 24 C versus 8 C (Anderson 1985). Increasing soil moisture content from 6 to 12% increased chlorsulfuron degradation rate two fold (Walker and Brown 1983).

Grain sorghum seeded approximately 18 MAT was injured by MON 37500 in Nebraska and Wyoming, but not Kansas (Lyon et al. 2001). These differences in response between states were attributed to greater soil organic matter content, greater precipitation, and a longer frost free season in Kansas. In other rotational crop research in Kansas, MON 37500 reduced grain sorghum yields 0 and 80% at two locations (Geier et al.1999).

In Idaho, Oregon, and Washington, barley, canola, and pea were injured by residual MON 37500. Differences in injury between locations were attributed in part to differences in precipitation, soil organic matter content, and soil pH (Shinn et. al). Rainbolt et al., 2001 also attributed differences in rotational crop injury from residual MON 37500 to differences in precipitation, soil pH, and soil organic matter content. In Canadian soils with soil organic matter content from 1.8 to 10.3% and soil pH from 5.1 to 8.0, canola and barley response to MON 37500 and triasulfuron were correlated with soil organic matter content and soil pH (Moyer and Hamman 2001).

Wheat is the primary grain crop grown in Oklahoma. In 2000, there were approximately 2.5 million ha of wheat seeded in Oklahoma (Bartlett 2001) of which 42% were treated with a herbicide (Anonymous 1999). However, grain sorghum production has been increasing. In 2000, grain sorghum was seeded on 182,000 ha in Oklahoma (Bartlett 2001) and it is frequently grown in rotation with wheat.

The objectives of this research were: 1) to determine whether the timing of MON 37500 application to wheat affected the response of double-crop or second year grain sorghum, 2) to determine the effect of soil characteristics and environmental conditions on the response of grain sorghum to residual MON 37500.

MATERIALS AND METHODS

Field experiments were established in the fall of 1996 on Agronomy Research Stations near Altus, Chickasha, Goodwell, Haskell, Lahoma, Orlando, Perkins, and Stillwater, Oklahoma, and repeated at adjacent sites beginning in 1997 to evaluate grain sorghum response to MON 37500. The experimental design at each site was a randomized complete block with four to six replications. Plot was 2.1 by 6.9 or 2.4 by 7.6-m. Soil characteristics for each experiment are listed in Table 1.

In each experiment, cheat (*Bromus secalinus* L. #[3] BROSE) was hand broadcast onto all plots at 50 kg/ha and incorporated into the top 2.5 to 5.0 cm of soil with a light field cultivator with double rolling baskets immediately prior to wheat seeding. Hard red winter wheat '2163' was seeded in all experiments, except for Stillwater 1 and Goodwell 2, which were seeded to 'Jagger' and '2137'. Wheat was seeded into a conventionally tilled seedbed at 67 kg/ha (Chickasha 1, Goodwell 1, and Goodwell 2, 90, 45, and 50 kg/ha, respectively) using a single or double disk grain drill with 20-cm (25-cm in Altus 1 and Altus 2) row spacing in

[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

late September or early October. Immediately after wheat seeding, MON 37500 was applied preemergence (PRE) and thereafter applied postemergence (POST) on a three week interval, from mid-October until mid-March (Table 2). All MON 37500 treatments were broadcast at 35 g/ha using a compressed CO_2 backpack sprayer calibrated to deliver 187 L/ha of spray volume. Nonionic surfactant was added to all POST treatments at 0.5% v/v.

Wheat was harvested at maturity in June of 1997 and 1998 using a small plot combine. Immediately after wheat harvest two 76-cm wide rows of Pioneer '8699' or '8446' fluxofenium-treated double crop grain sorghum were no-till seeded no-till down the length of each plot at 124,000 seeds/ha using a two-row no-till planter with row cleaners. In the Altus 1 full season experiment and Altus 2 double crop experiment, short season grain sorghum (NC+5c35) was seeded due to drought-delayed planting. Immediately thereafter glyphosate and alachlor were applied at 1.1 and 2.2 kg ai/ha. Nitrogen fertilizer was broadcast at 110 kg of N/ha.

The following spring full season grain sorghum was seeded in eight (1998) and four (1999) of the experiments in May or early June (Altus 1 was seeded August 3, 1998). In 1999, only experiments where appreciable double crop grain sorghum injury was seen were reseeded to full season grain sorghum.

Full season grain sorghum 'Pioneer '8500' or 'Pioneer 8446' (fluxofenium-treated) was seeded using the same procedures as used for the double crop grain sorghum. Glyphosate and alachlor were broadcast at 1.1 and 2.2 kg/ha immediately after grain sorghum seeding. Nitrogen was surface applied at 110 kg/ha after crop seeding.

Effects on emergence were determined by counting grain sorghum plants in each plot soon after emergence. Grain sorghum injury was visually estimated early in the growing season using a scale of 0 to 100 where 0 = no crop injury and 100 = crop death. Heights of two to five randomly selected plants per plot were measured at the highest growing point at mid-season or at crop maturity. Panicles per plot were counted at crop maturity. At maturity, grain sorghum was harvested with a small plot combine in 9 of 15 double crop experiments and 11 of 12 full season experiments. In the other experiments, drought stress prevented grain formation and plant biomass was harvested from a portion of each plot.

During the winter months following harvest of the double crop grain sorghum, glyphosate was applied broadcast at 1.1 kg/ha to kill volunteer wheat and cheat. Plots were otherwise undisturbed until the full season grain sorghum was seeded. Irrigation was used only for the Altus 1 full season and the Altus 2 double crop experiments, which were flood irrigated once one wk prior to grain sorghum seeding with approximately 15-cm of water. This was done to avoid loss of the experiment due to drought.

All data were subjected to ANOVA and means separated by Fisher's protected LSD test at P=0.05 level. Visual ratings were arcsine transformed prior to analysis, but transformation had no effect on means separation. Therefore, data are presented in original form. Correlation and regression analyses were conducted using SAS version 8.1.

RESULTS AND DISCUSSION

Double crop grain sorghum. MON 37500 time of application to wheat had no effect ($P = 0.06$ to 1.00) on injury of double-cropped grain sorghum in any of the fifteen experiments. Grain sorghum injury varied greatly with location. Pooled over MON 37500 application timing within locations, a quadratic relationship was found between soil pH and visual injury ($Y = -12.298x^2 + 181.27x - 570.02$, $R^2 = 0.51$), Figure 1. Mean cumulative precipitation from MON 37500 application to grain sorghum seeding affected grain sorghum injury ($Y = -1.29x + 116.08$, $R^2 = 0.20$), Figure 2 and a weak quadratic response was found between the number of precipitation events greater than 0.25 cm and grain sorghum injury ($Y = 0.0051x^2 - 1.7448x + 125.8$, $R^2 = 0.18$), Figure 3. The Altus 2 experiment was omitted from regression analysis due to the late seeding date.

Pooled over MON 37500 application timing, a quadratic relationship was found between soil pH and yield ($Y = 9.4363x^2 - 151.05x + 604.14$, $R^2 = 0.65$), Figure 4. There was a linear relationship between mean cumulative precipitation from MON 37500 application to grain sorghum seeding and the natural log of yield ($Y = 0.1167x - 1.16142$, $R^2 = 0.65$), Figure 5. A weaker linear relationship was found between the number of precipitation events greater than 0.25 cm and yield ($Y = 1.7939x - 25.899$, $R^2 = 0.31$), Figure 6. The relationship between the number of precipitation events greater than 0.25 cm to grain sorghum injury and yield was not as strong as the relationship between cumulative precipitation from application to seeding, suggesting that cumulative precipitation is more important for MON 37500 degradation than the number of precipitation events.

Mean high temperature from MON 37500 application to grain sorghum seeding was not correlated to yield (r = -0.45, P=0.10). Soil cation exchange capacity (CEC) was correlated to yield (r = -0.53, P = 0.04). Soil pH was also correlated to CEC (r = 0.70, P = 0.005). In these experiments, soils with the highest CEC, tended to have lower yield, thus it appears that the soil pH was masking CEC effects. Rainfall and pH were also highly correlated (r = -0.63, P=0.01). This was expected since soils that form under higher rainfall conditions generally have low pH values. Soil organic matter content was not correlated to yield (r = -0.28, P = 0.32). The lack of a detectable correlation between soil organic matter content and yield may be related to the narrow range in organic matter contents (0.9 to 1.9%).

Full season grain sorghum. MON 37500 time of application to wheat had no effect on injury or yields in any experiment. Averaged over application timing, MON 37500 did not reduce grain sorghum yield in any of the eight experiments initiated in 1996 (planted in 1998). Early season injury was seen at Goodwell 1, but did it not affect plant density (P = 0.84), mature plant height (P = 0.10), or grain yield (P = 0.20). Of the experiments initiated in 1997, four experiments were seeded to full season grain sorghum in 1999. Of these, yields were reduced 14, 19, and 60%, respectively, at Altus 2, Lahoma 2, and Goodwell 2. Yields were not affected by residual MON 37500 at Perkins 2. At Goodwell 2, grain sorghum was severely injured and plant density, mature plant height, and panicle density were all reduced. At Altus 2 and Lahoma 2 only very slight visual injury was seen and plant density, mature plant height, and panicle density were not affected by MON 37500.

Pooled over MON 37500 application timing, there was a weak linear relationship between visual injury and soil pH ($Y = 9.1169x - 49.623$, $R^2 = 0.18$), Figure 7. There was a stronger linear relationship between visual injury and mean cumulative precipitation from MON 37500 application to grain sorghum seeding ($Y = -0.3513X + 50.661$, $R^2 = 0.43$), Figure 8.

Pooled over MON 37500 application timing there was a linear relationship between soil pH and yield ($Y = -12.632x + 164.22$, $R^2 = 0.34$), Figure 9. There was a linear relationship between yield and mean cumulative precipitation from MON 37500 application to grain sorghum seeding, ($Y = 0.3182x + 47.763$, $R^2 = 0.45$), Figure 10.

Mean high temperature from MON 37500 application to seeding was not correlated to yield ($r= 0.05$, $P = 0.87$). As with the double crop grain sorghum, CEC was correlated to yield ($r = -0.66$, $P = 0.02$) and organic matter content did not influence yield ($r = -0.46$, $P = 0.15$).

These experiments suggest that soil pH and precipitation were the primary factors influencing MON 37500 persistence. This is in agreement with Shinn et al. 1998 and Rainbolt et al. 2001. In these experiments little or no apparent degradation of MON 37500 occurred during the winter months, as evidenced by a complete lack of application timing effects in any experiment. Planting double crop grain sorghum after application of MON 37500 to wheat will very likely result in severe grain sorghum injury. Injury to grain sorghum seeded the next season will vary with soil pH and precipitation.

ACKNOWLEDGEMENTS

The authors would like to thank R. Thacker, J.C. Banks, T. Pickard, L. Bohl, and G. Strickland for their valuable assistance with this research. Monsanto Company provided partial financial support.

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Table 1. Soil series, classification, and characteristics[a] for all experiments.

Experiment	Series	Classification	OM	Sand	Silt	Clay	pH	CEC
			%	%	%	%		meq/100g
Altus 1	Holister	Fine, mixed, thermic Pachic Paleustolls	1.3	34	33	33	7.5	19.8
Altus 2	"	"	1.4	35	32	33	7.1	21.6
Chickasha 1	Dale	Fine-silty, mixed, thermic Pachic Haplustolls	1.2	39	50	11	6.4	12.5
Goodwell 1	Richfield	Fine, montmorillonitic, mesic, Aridic Arguistolls	1.9	38	38	24	7.4	25.3
Goodwell 2	"	"	1.5	39	35	26	7.0	24.7
Haskell 1	Taloka	Fine, mixed, thermic Mollic Albaqualfs	1.0	37	57	6	5.0	8.3
Haskell 2	"	"	1.3	45	43	12	5.0	9.2
Lahoma 1	Grant	Fine-silty, mixed, thermic Udic Haplustolls	1.2	31	46	23	5.7	15.1
Lahoma 2	"	"	1.3	39	40	21	6.1	13.3
Orlando 1	Port	Fine-silty, mixed thermic Cumulic Haplustolls	1.4	34	46	20	5.4	12.9
Orlando 2	"	"	1.0	53	32	15	5.1	10.4
Perkins 1	Teller	Fine-loamy, mixed, thermic Udic Argiustolls	1.0	53	36	11	6.3	8.3

Table 1. Continued.

Perkins 2	"	"	0.9	58	33	9	5.8	7.6
Stillwater 1	Norge	Fine-silty, mixed, thermic Udic Paleustolls	1.5	49	31	20	5.3	16.1
Stillwater 2	"	"	1.5	49	31	20	5.3	16.1

[a] OM = Organic matter, CEC = Cation exchange capacity

Table 2. MON 37500 application dates in 15 experiments.

Experiment	Application Dates								
	1	2	3	4	5	6	7	8	9
Altus 1	10-01-96	10-15-96	11-04-96	11-26-96	12-16-96	01-20-97	01-29-97	02-17-97	03-10-97
Chickasha 1	______	10-17-96	11-07-96	11-26-96	12-16-96	01-06-97	01-31-97	02-18-97	03-10-97
Goodwell 1	10-09-96	10-18-96	11-08-97	11-27-96	12-16-96	01-17-97	01-31-97	02-20-97	03-14-97
Haskell 1	10-04-96	10-16-96	11-08-96	12-01-96	12-16-96	01-06-97	01-29-97	02-19-97	03-10-97
Lahoma 1	09-30-96	10-16-96	11-05-96	11-26-96	12-16-96	01-06-97	01-31-97	02-18-97	03-10-97
Orlando 1	09-24-96	10-15-96	11-05-96	11-27-96	12-16-96	01-06-96	01-29-97	02-18-97	03-10-97
Perkins 1	09-23-96	10-15-96	11-05-96	11-25-96	12-16-96	01-06-97	01-29-97	02-18-97	03-10-97
Stillwater 1	10-4-96	10-15-96	11-05-96	11-25-96	12-16-96	01-06-97	01-29-97	02-18-97	03-10-97
Altus 2	10-07-97	10-13-97	11-05-97	11-24-97	12-15-97	01-05-98	01-26-98	02-18-98	03-10-97
Goodwell 2	______	10-15-97	11-03-97	11-24-97	12-15-97	01-05-98	01-26-98	02-20-98	03-13-98
Haskell 2	10-02-97	10-17-97	11-07-97	11-24-97	12-19-97	01-15-98	01-28-98	02-19-98	03-10-98
Lahoma 2	09-30-97	10-15-97	11-06-97	11-25-97	12-17-97	01-09-98	01-30-98	02-17-98	03-23-98

Table 2. Continued.

Orlando 2	10-01-97	10-15-97	11-04-97	11-25-97	12-16-97	01-10-98	01-30-98	02-16-98	03-24-98
Perkins 2	09-29-97	10-16-97	11-04-97	11-26-97	12-15-97	01-09-98	01-30-98	02-16-98	03-23-98
Stillwater 2	09-29-97	10-16-97	11-04-97	11-25-97	12-16-97	01-09-98	01-30-98	02-16-98	03-24-98

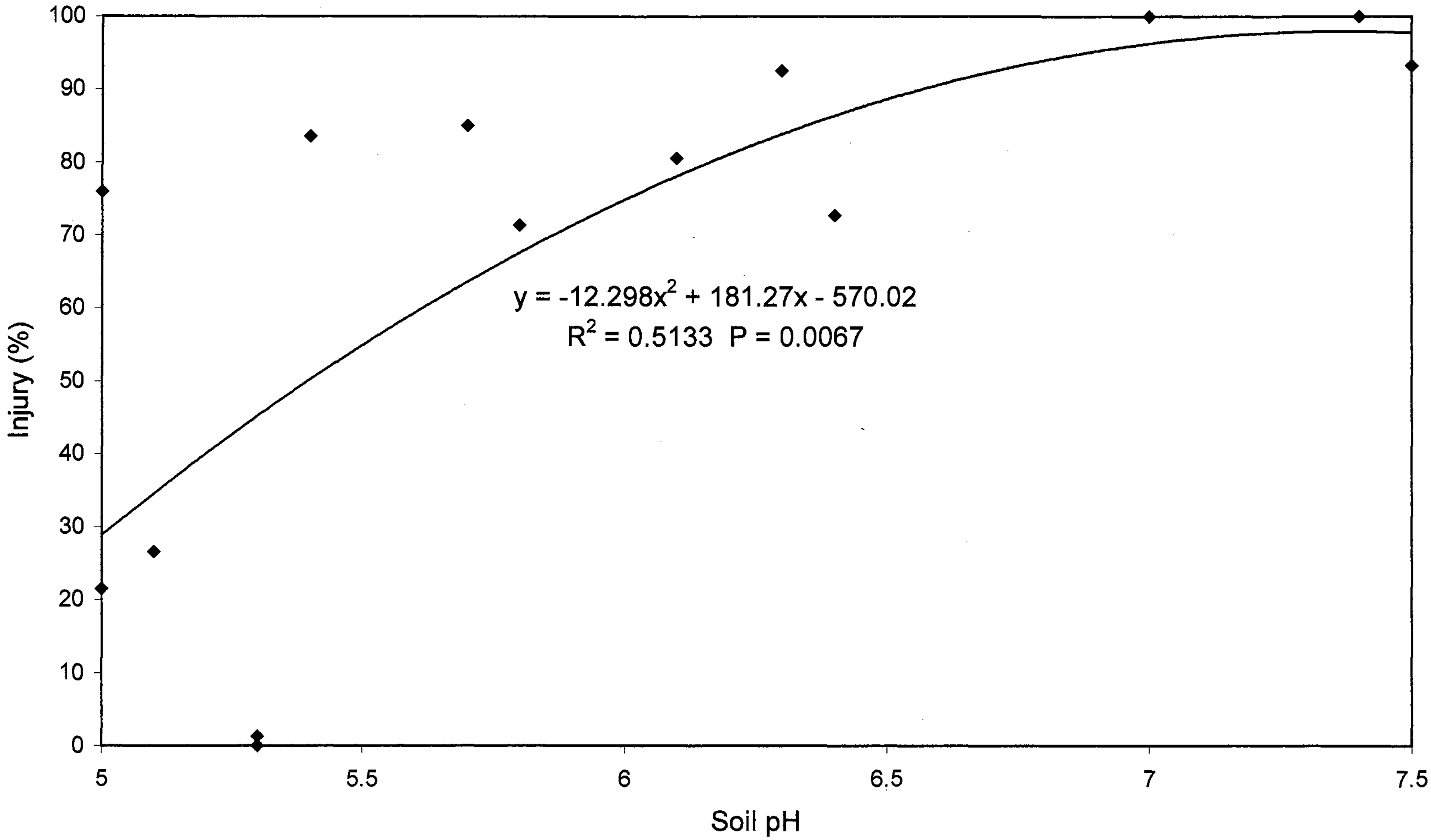

Figure 1. Effect of soil pH on double crop grain sorghum injury in 14 experiments.

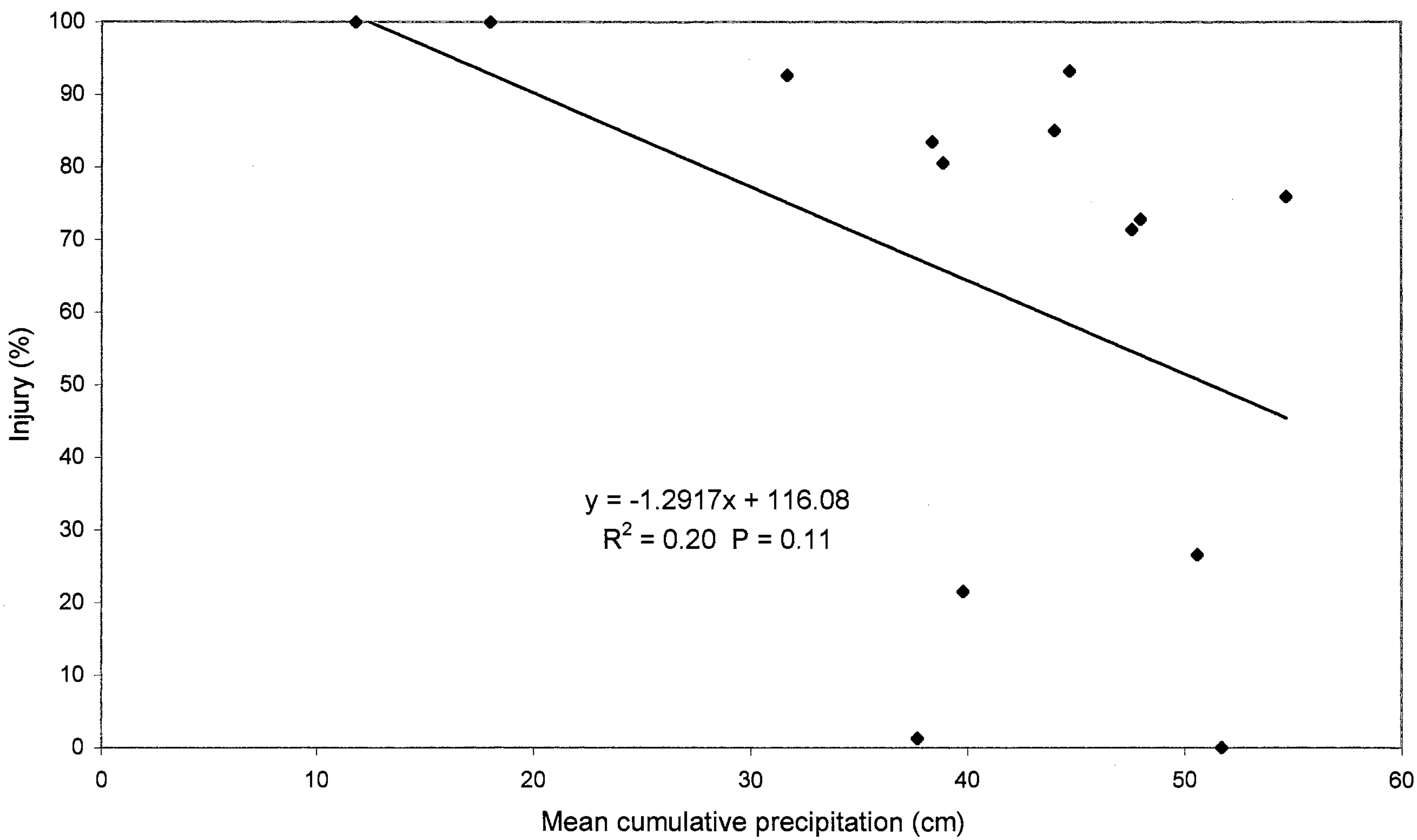

Figure 2. Effect of mean cumulative precipitation from MON 37500 application to seeding on double crop grain sorghum visual injury in 14 experiments.

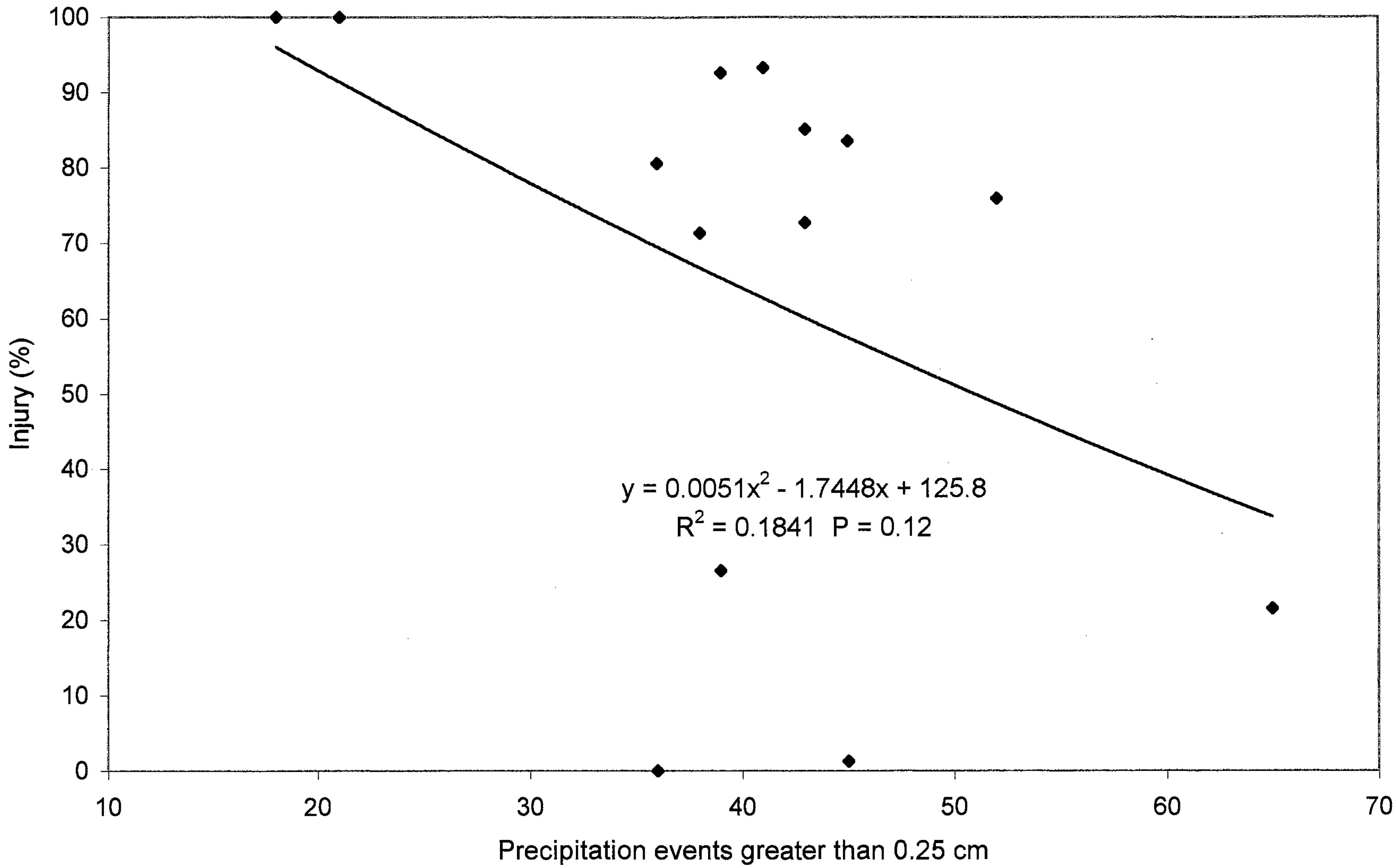

Figure 3. Effect of the number of precipitation events greater than 0.25 cm on double crop grain sorghum injury in 14 experiments.

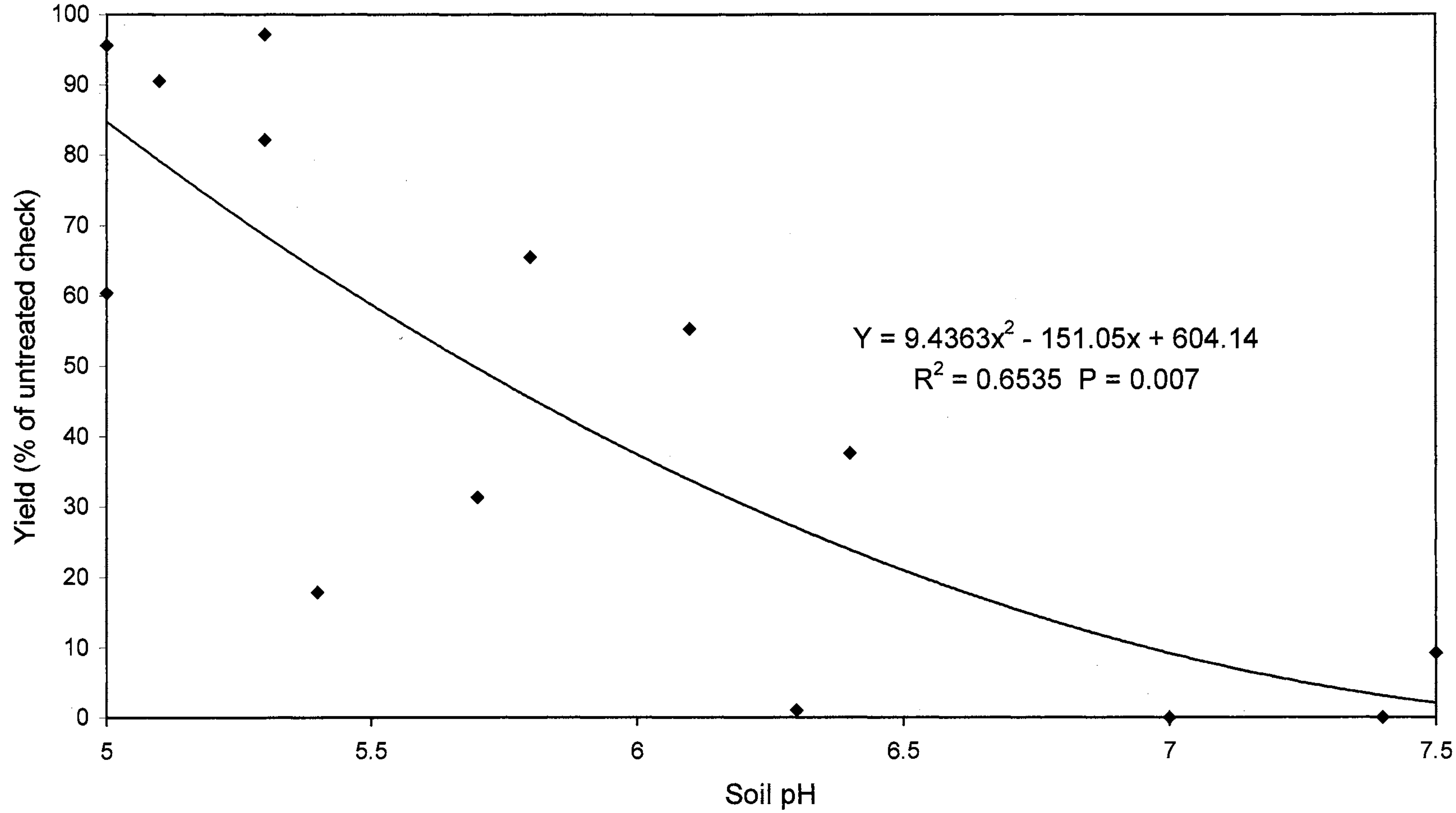

Figure 4. Effect of soil pH on yield of double crop grain sorghum in 14 experiments.

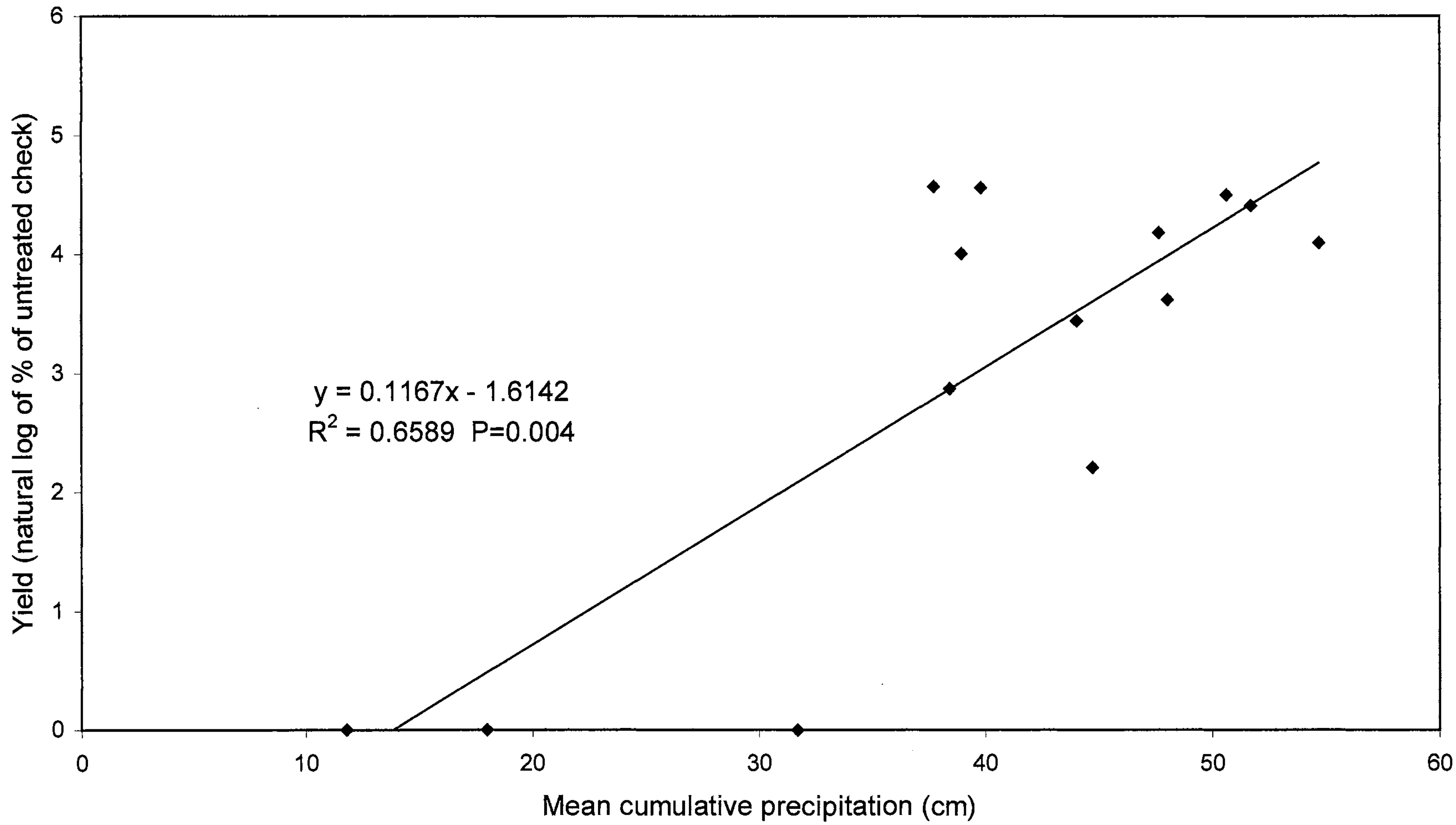

Figure 5. Effect of cumulative precipitation from MON 37500 application to seeding on yield of double crop grain sorghum in 14 experiments.

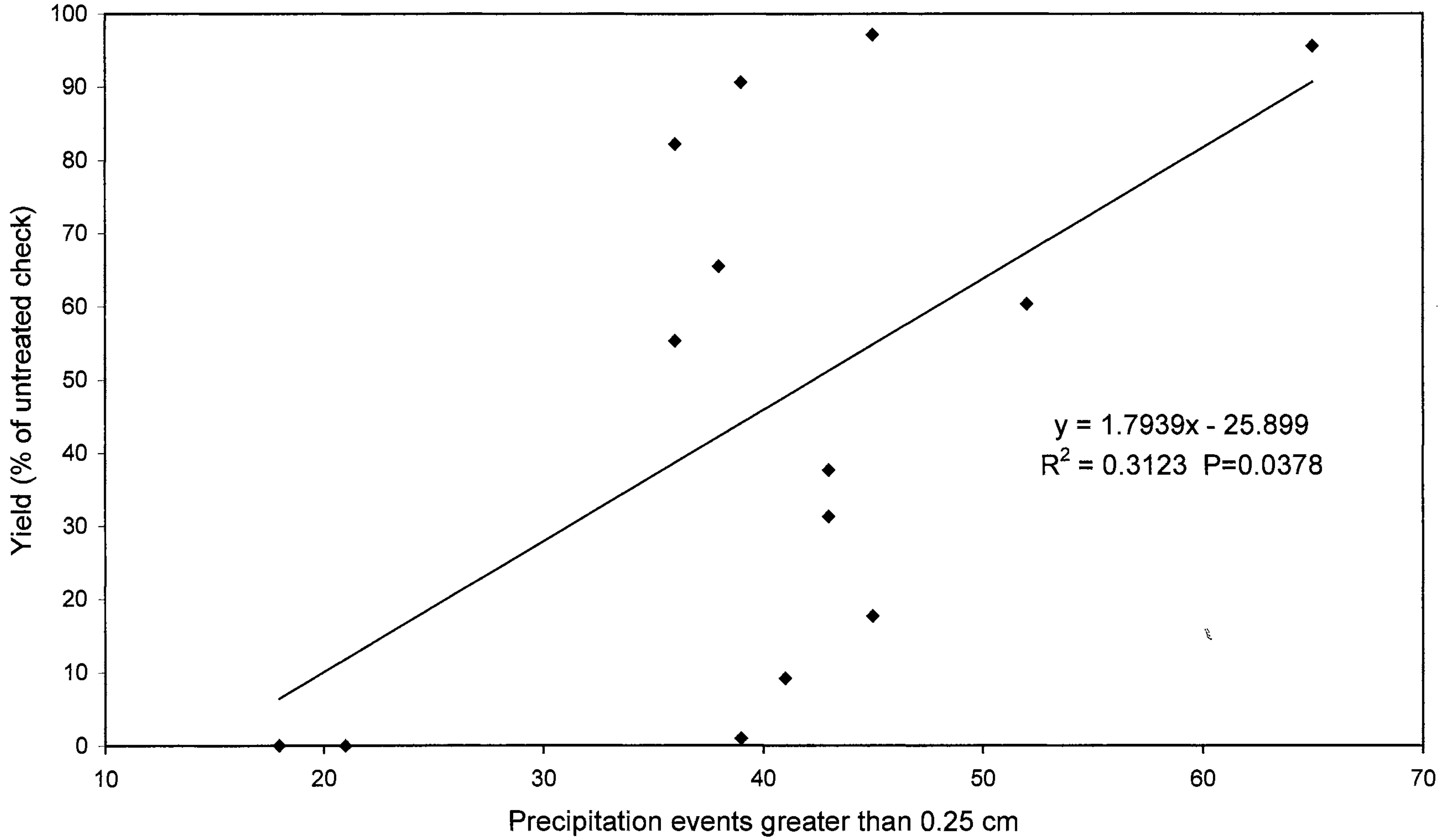

Figure 6. Effect of the number of precipitation events greater than 0.25 cm on yield of double crop grain sorghum in 14 experiements.

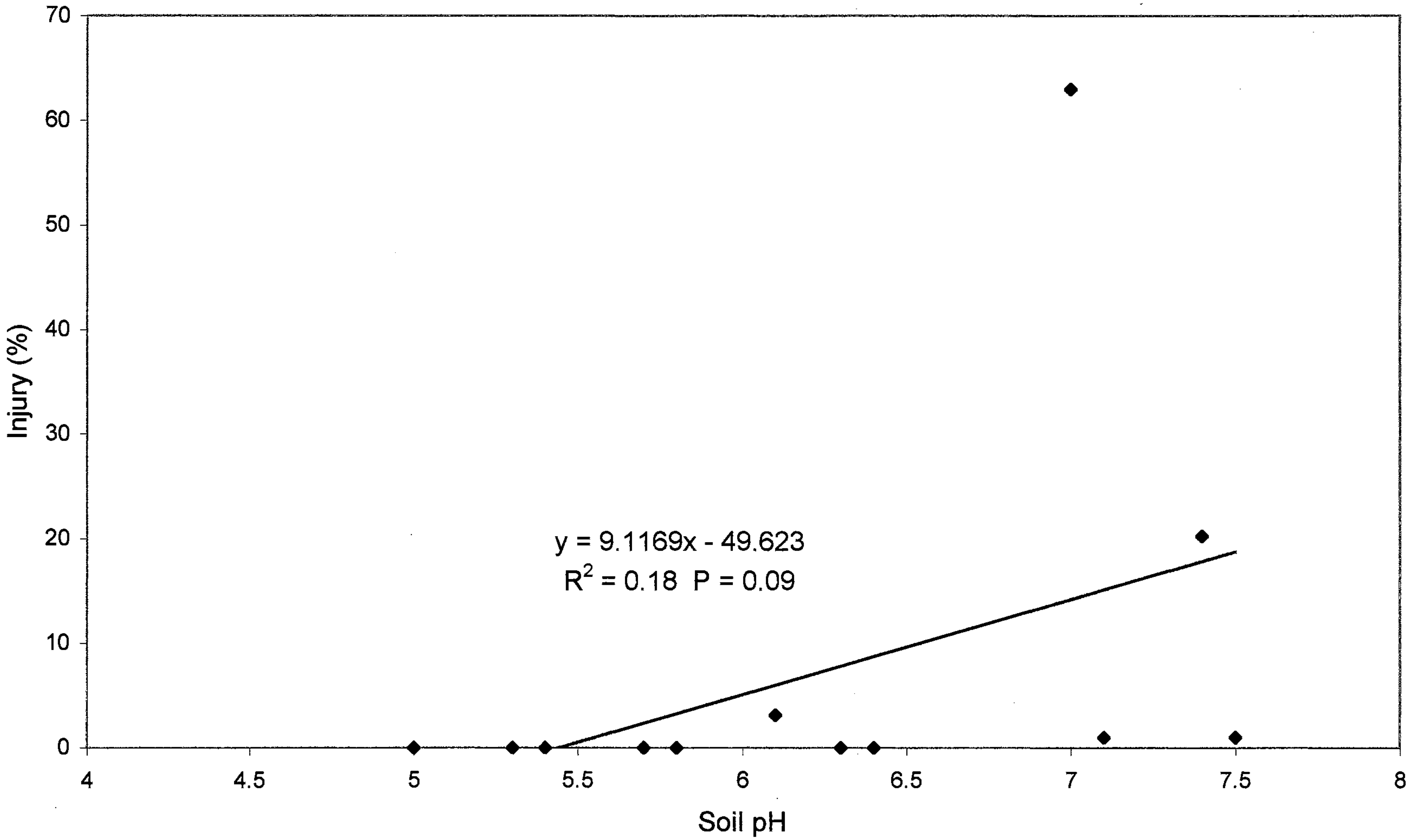

Figure 7. Effect of soil pH on injury of full season grain sorghum in 11 experiments.

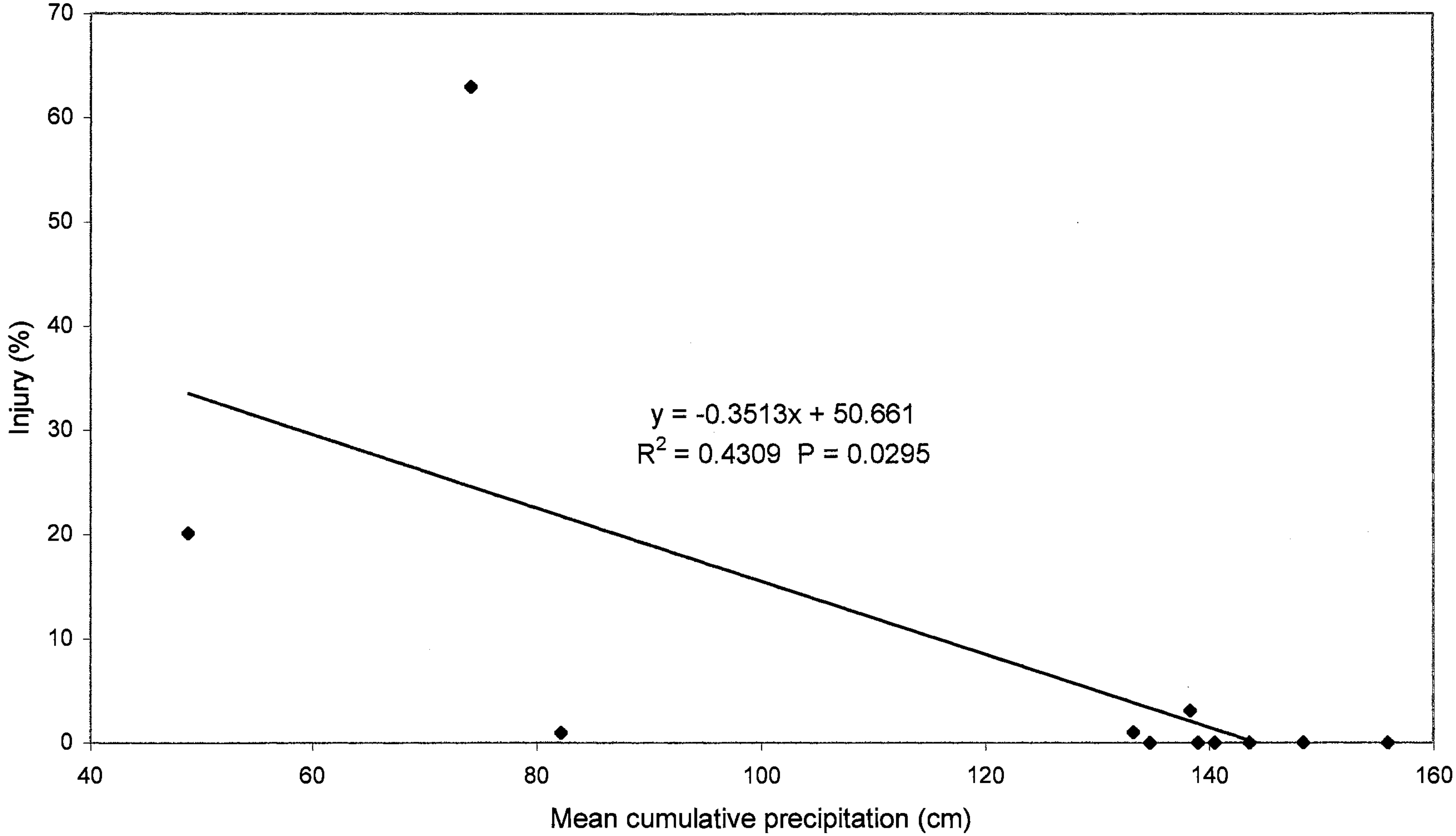

Figure 8. Effect of cumulative precipitation from MON 37500 application to seeding on full season grain sorghum injury in 11 experiments.

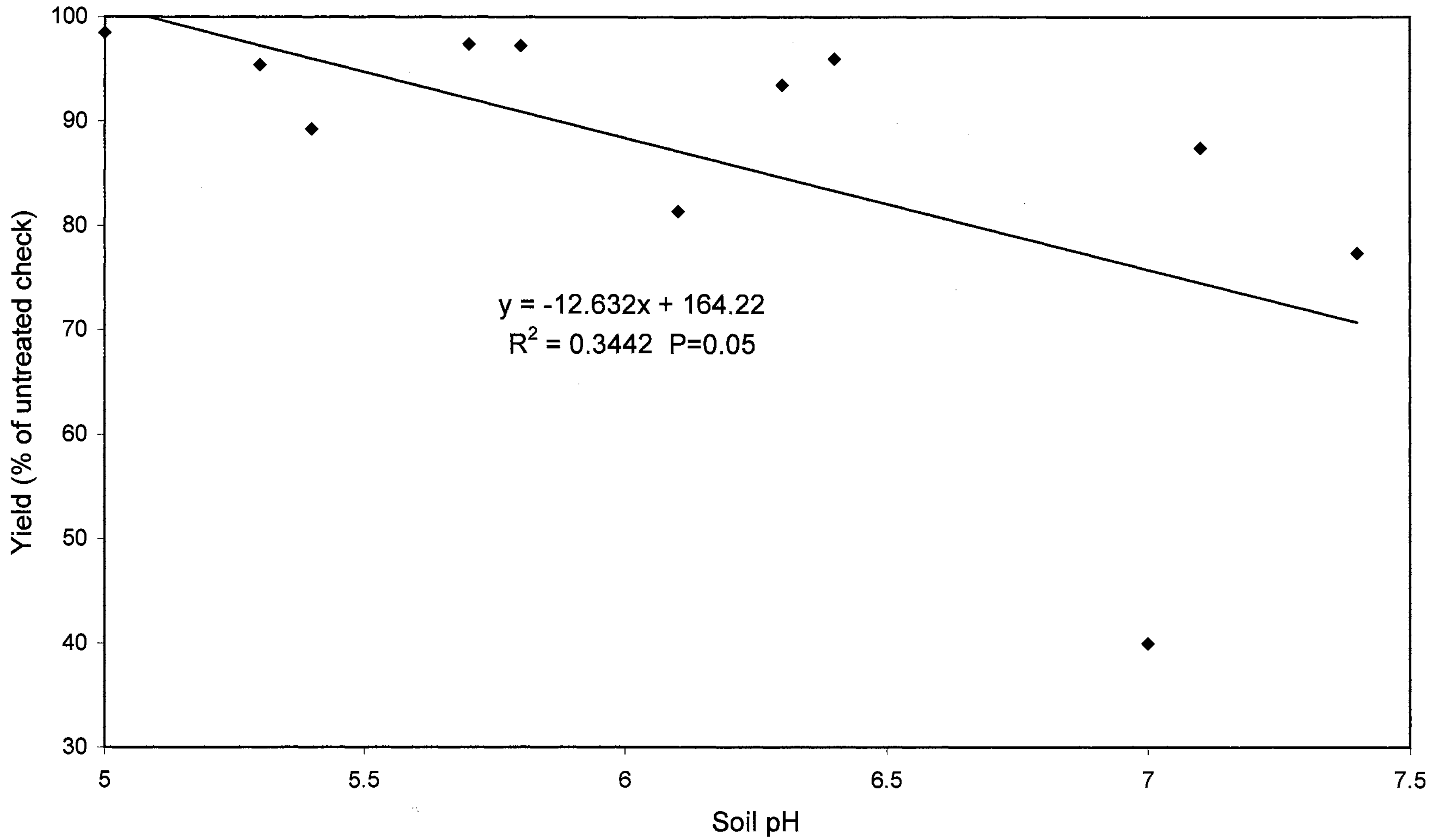

Figure 9. Effect of soil pH on yield of full season grain sorghum in 11 experiments.

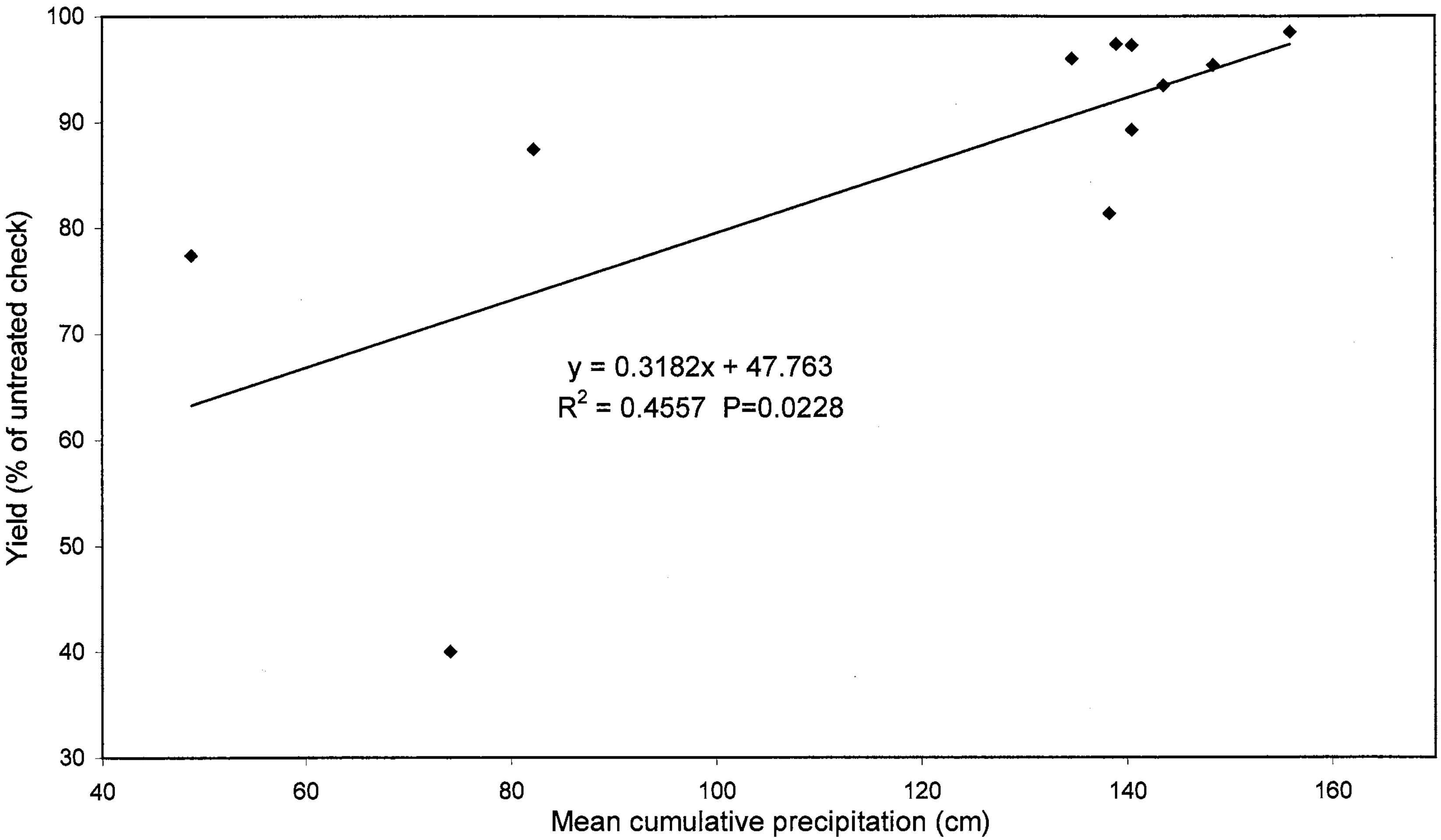

Figure 10. Effect of cumulative precipitation from MON 37500 application to seeding on yield of full season grain sorghum in 11experiments.

CHAPTER III

WHEAT (*Triticum aestivum*) AND ROTATIONAL CROP RESPONSE TO MON 37500

Wheat (*Triticum aestivum*) and Rotational Crop Response to MON 37500[1]

JASON P. KELLEY and THOMAS F. PEEPER[2]

Abstract. Field experiments were conducted in northcentral Oklahoma to evaluate the effects of MON 37500 applied to wheat at 35, 70, and 140 g ai/ha on rotational crops seeded no-till 16 to 29 months after treatment (MAT). Wheat yields were not reduced by MON 37500 at site 1, but were decreased 6, 11, and 24% by 35, 70, and 140 g/ha, respectively, at site 2. Wheat yield reductions at site 2 were attributed to late seeding, small wheat growth stage, and cool, wet weather during the month of application. Corn and soybean seeded approximately 16 MAT were not visibly injured by MON 37500 at any rate at either site. Grain sorghum seeded 17 MAT was visibly injured by MON 37500 at 70 and 140 g/ha at site 1 (soil pH = 6.4), and 140 g/ha reduced grain yield 58%. Grain sorghum was not visibly injured at site 2 (soil pH = 5.0), when seeded 17 MAT. Grain sorghum seeded 29 MAT was not injured at either site. Sunflower seeded 17 MAT at site 1 was visibly injured by MON 37500 at 140 g/ha and yield was reduced 17%. At site 2, sunflowers seeded 17 MAT were not affected by MON 37500. Sunflower seeded 29 MAT was not injured at either site.

Nomenclature: MON 37500, 1-(2-ethlsulfonylimidazo[1,2-*a*]pyridin-3-ylsulfonyl)-3-(4,6-dimethoxypyrimidin-2-yl)urea; corn, *Zea mays* L. 'Dekalb 566'; grain

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[1] Received for publication _________, and in revised form ______________.

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sorghum, *Sorghum bicolor* (L.) Moench 'Dekalb 36', 'Pioneer 8500'; soybean, *Glycine max* (L.) 'Asgrow 3701'; sunflower, *Helianthus annuus* L. 'Dekalb 3872', 'Pioneer 6451'; winter wheat, *Triticum aestivum* L. '2163,' 'Tonkawa'.

Additional index words: soil pH, precipitation, crop injury.

Abbreviations: MAT, months after treatment, PRE, preemergence, POST, postemergence.

INTRODUCTION

MON 37500, a sulfonylurea herbicide, registered for selective control of *Bromus* sp. and certain broadleaf weed in 1999. Its single use rate is 35 g/ha whether applied PRE or POST. MON 37500 and chlorsulfuron have similar pK_a values of 3.51 and 3.6 at 25 C, thus the water solubility is affected by pH. Water solubility of MON 37500 is 18, 1627, and 482 ppm at pH 5, 7, and 9, respectively (Hatzios 1998), compared to chlorsulfuron water solubility of 587 and 31800 ppm at pH 5 and 7 (Ahrens 1994). MON 37500 is degraded microbially and by acid hydrolysis with rapid hydrolysis in low pH soils (Hatzios 1998). MON 37500 has a reported field half-life of 14 to 75 d, depending on the climate and soil type (Hatzios 1998), compared to 28 to 42 d for chlorsulfuron, which is also dependent on climate and soil type (Ahrens 1994).

Much research has been conducted on the persistence of chlorsulfuron and its effects on rotational crops. Mersie and Foy 1985, found that soil organic matter content was the soil variable most negatively correlated to chlorsulfuron phytoxicity, whereas there was little relationship between clay content and chlorsulfuron photoxicity (Anderson and Humburg 1987). In Colorado, chlorsulfuron bioactivity was most influenced by soil pH and organic matter content (Anderson and Humburg 1987). In other research (Anderson and Barrett 1985) soil temperature, pH, and soil texture greatly influenced chlorsulfuron persistence.

In rotational crop studies in Idaho, Oregon, and Washington, (Shinn et al. 1998) barley, pea, and canola were visibly injured by 18, 36, and 72 g/ha of MON 37500 applied 12 or 16 months prior to rotational crop seeding. Differences in rotational crop injury between locations were attributed in part to differences in precipitation, soil pH, and soil organic matter (Shinn, et al. 1998). Rainbolt, et al. 2001, reported similar results with MON 37500. In greenhouse experiments, using Canadian soils with a soil organic matter content of 1.8 to 10.3% and pH of 5.1 to 8.0, the concentrations of MON 37500 and triasulfuron that reduced canola and barley growth 50% were correlated to soil organic matter content and pH (Moyer and Hamman 2001)

The current product label specifies that only wheat may be seeded for one year following an application of MON 37500 to wheat (Anonymous 2000). A bioassay is recommended if crops other than wheat are to be planted (Anonymous 2000). Changes in federal legislation have encouraged crop diversification. Thus as traditional wheat growers seek to diversify crops, additional information is needed concerning risks of crop injury from residual MON 37500 applied to wheat. Since little was known about the persistence of MON 37500 and how it might affect rotational crops in the Southern Great Plains, this research was conducted to determine the response of crops commonly grown in the Great Plains to residual MON 37500. High rates of MON 37500 were included to determine the margin of safety for crops seeded 16 to 29 MAT.

MATERIALS AND METHODS

Field experiments were conducted on the Perkins Agronomy Research Station near Perkins, Oklahoma (site 1) and on a producers field near Enid, Oklahoma (site 2) to evaluate the response of corn, grain sorghum, soybean, and sunflower to MON 37500 applied to wheat at 35, 70, and 140 g ai/ha 16 to 29 months prior to seeding. Soil characteristics for each location are listed in Table 1.

Adjacent experiments were established for each crop. The experimental design was a randomized complete block and plot size was 4.6 by 7.6-m. Treatments were replicated four times (12 for grain sorghum). Hard red winter wheat '2163' was seeded October 3, 1997 at site 1 at 67 kg/ha and 'Tonkawa' hard red winter wheat was seeded October 31, 1997 at 90 kg/ha at site 2 into conventionally tilled seedbeds using a single disk grain drill with eight-inch row spacing.

On November 18, 1997 at site 1 and December 17, 1997 at site 2, MON 37500 was applied at 35, 70, and 140 g/ha to four adjacent experiments per site. All treatments were applied using a CO_2 pressurized backpack sprayer calibrated to deliver 187 L/ha spray volume. Nonionic surfactant was added to the water carrier at 0.5% v/v. At application, wheat at site 1 had 4 to 6 tillers, while wheat at site 2 had 2 to 4 leaves. Henbit (*Lamium amplexicaule* L) was the dominant weed at both sites with a density of 2 to 10 plants/m^2.

At wheat maturity, a 1.4 by 7.6-m portion of each plot was harvested with a small plot combine. Harvested samples were recleaned with a small commercial seed cleaner to remove chaff and grain yields were adjusted to 13.5 % moisture. Wheat not harvested with the small plot combine was harvested with a conventional combine with a straw spreader. After wheat harvest, wheat stubble was left undisturbed. Glyphosate at 1.1 kg/ha was applied in mid-July and mid-November, 1998 for volunteer wheat and/or summer annual weed control.

On April 6 or 9, 1999, glyphosate was applied at 1.1 kg/ha to all plots. Six rows each of soybean 'Asgrow 3701 RR' or corn 'Dekalb 566 RR' were seeded no-till using a two row no-till planter at 470,000 seeds/ha (soybean) and 54,000 seeds/ha (corn) in 76-cm rows into appropriate plots. Immediately after seeding, alachlor was applied at 2.2 kg/ha to the seeded plots. Glyphosate at 1.1 kg/ha was reapplied on May 24 after which no additional weeds appeared. Nitrogen fertilizer was broadcast at 140 kg/ha onto all experiments.

On May 24 or 25, 1999, glyphosate was broadcast at 1.1 kg/ha to grain sorghum and sunflower experiments. Six rows each of grain sorghum 'Pioneer 8500' or sunflower 'Pioneer 6451' were then seeded no-till into appropriate plots at 131,000 seeds/ha (grain sorghum) and 64,000 seeds/ha (sunflower). Both grain sorghum and sunflower were seeded on 76-cm row spacing. Immediately after seeding, alachlor was applied at 2.2 kg/ha to the grain sorghum plots. At site 2, sethoxydim was applied at 0.45 kg/ha on June 22, 2000 to control large crabgrass (*Digitaria sanguinalis* L.).

In late winter of 2000 and mid-May, 2000, glyphosate was broadcast at 1.1 kg/ha for winter annual weed control to all experiments. On May 11 or 16, 2000, six rows each of grain sorghum 'Dekalb 36' (131,000 seeds/ha) or sunflower 'Dekalb 3872' (64,000 seeds/ha) were seeded no-till into appropriate plots. Both crops were seeded in 76-cm rows. Immediately after seeding, alachlor was applied at 2.2 kg/ha to grain sorghum plots. Nitrogen fertilizer was broadcast at 140 kg/ha after crop seeding.

Plants in the two center rows of each plot were counted soon after emergence. Crop injury was visually estimated within 1 month of crop emergence using a scale of 0 to 100, where 0 = no injury and 100 = crop death. Height of three to five randomly selected crop plants were measured in each plot at mid-season or at crop maturity. Both years, at crop maturity, the center two rows of each six-row plot were harvested with a small plot combine. Harvested grain sorghum, soybean, and sunflower samples were recleaned with a small commercial seed cleaner to remove chaff. Corn, grain sorghum, and soybean yields were adjusted to 13.5% moisture, and sunflower yields were adjusted to 10% moisture. The remaining four rows of each plot were combine harvested.

The 30-year average annual precipitation at site 1 and site 2 is 893 and 823 mm. Precipitation during 1998 was 11 and 4 percent above average at site 1 and site 2 and in 1999 was 14 and 35 percent above average. At site 1, in 1998 and 1999 mean air temperature was 16.8 and 16.4 C, which was warmer than the 30-year average temperature of 15.0 C. Mean air temperature during 1998 and 1999 was 15.7 and 15.1 C at site 2, which was near the 30-year average of 15.6 C. Thus mean environmental conditions would have been as favorable or more favorable than normal for microbial degradation of MON 37500.

All data were subjected to analysis of variance and means separated by Fisher's protected LSD test at P=0.05 level. Visual ratings were arcsine transformed prior to analysis, but had no effect on means separation. Therefore visual ratings are presented in original form.

RESULTS AND DISCUSSION

Wheat. Since the wheat was nearly weed free with henbit present only at low densities, it is unlikely that weeds affected wheat yield (Scott and Peeper, 1994). MON 37500 did not reduce wheat yields, compared to the untreated check at site 1 (Table 2). At site 2, wheat yield was reduced 6, 11, and 24% by MON 37500 at 35, 70, and 140 g/ha, respectively.

Wheat at site 1 had 4 to 6 tillers, while wheat at site 2 had only 2 to 4 leaves at application. At site 2 temperatures were slightly cooler than the 30-year average and precipitation was more than four times the 30-year average for the month of application. Within 7 d of application at site 2, precipitation totaled 74 mm. At site 1, temperatures were also slightly lower than the 30-year average, but precipitation during the month of application was 50% below the 30-year average. In greenhouse experiments, Geier et al. 1999 found that MON 37500 injured wheat more when soil moisture was 20% (w/w) compared to 7 and 14%

and was due to increased herbicide uptake by plants under moist conditions. In Canada, downy brome infested winter wheat, yields increased as MON 37500 rate increased up to 40 g/ha. Rates at or above 40 g/ha in some instances reduced wheat grain yields (Blackshaw and Hamman 1998).

Corn and Soybean. MON 37500 caused no visible injury and had no effect (P=0.40 to 0.86) on crop density, plant height, and grain yield of corn and soybean seeded approximately 16 MAT at site 1 or 2. (data not shown). Mean corn grain yields were 4840 and 3,580 kg/ha at site 1 and 2. These grain yields are typical for dryland corn production for these areas. Soybean grain yields were 950 and 1350 kg/ha and were similar to mean yield for these counties (1265 kg/ha) in 1999 (Bartlett 2000).

The lack of corn or soybean injury or yield reductions suggest that with average temperature and precipitation there is at least a 3 fold margin of safety when soil pH is between 5.0 and 6.4 for planting corn and soybean approximately 16 months after MON 37500 applications.

Grain sorghum. At site 1, plant density was not affected by MON 37500 applied 17 MAT, but plant height was reduced 30% and grain yield reduced 58% by MON 37500 at 140 g/ha (Table 3). Grain sorghum was visually injured 20 and 62% by 70 and 140 g/ha. Thus there was only a one-fold margin of safety. Grain sorghum seeded approximately 17 MAT was not visibly injured by any MON 37500 treatment at site 2and there were no differences in plant density (P = 0.14), plant height (P = 0.92), and grain yield (P = 0.87) (Table 3). This suggests that when soil pH is 5.0 there was at least a 3-fold margin of safety.

MON 37500 had no effect on plant density (P = 0.33 and 0.51), mature plant height (P = 0.56 and 0.94), or grain yield (P = 0.06 and 0.23) of grain sorghum when seeded 29 MAT at either site (data not shown). Grain sorghum yields at site 1 increased with increasing MON 37500 rates. This suggests that either the grain sorghum residue in productive plots from the previous year reduced yields or that grain sorghum severely injured the previous year utilized less water and available nutrients, thus causing increasing yields in the subsequent crop. Grain yields of the grain sorghum seeded 29 MAT averaged 3,040 and 5,520 kg/ha at Enid and Perkins.

Sunflower. MON 37500 did not affect sunflower stand density, when seeded 17 MAT, but 140 g/ha caused visible injury, reduced plant height 8%, and reduced grain yields 17% at site 1. MON 37500 treatments had no effect on stand density or plant height and did not visibly injure sunflower when seeded 17 MAT at site 2 (Table 4). Sunflower grain yields were not affected by MON 37500 treatments, but low due to an infestation of sunflower headclipping weevils (*Haplorhynchites aeneus*), which reduced grain yield approximately 90% (CV 45%). (Table 4).

MON 37500 treatments did not affect plant density (P = 0.11 and 0.49), mature plant height (P = 0.91 and 0.80), and grain yield (P = 0.77 and 0.51) of sunflowers seeded 29 MAT at site 1 or 2 (data not shown). Sunflower grain yields in 2000 averaged 1270 and 670 kg/ha at site 1 and 2. In these experiments, at site 1 there was a 2 fold margin of safety, while at site 2 there was a 3 fold margin of safety when sunflowers were seeded 17 months after initial MON 37500 treatment.

Thus, corn and soybean seeded 16 MAT were not injured by the labeled rate of MON 37500 (35 g/ha) at either site. Therefore corn and soybean could likely be safely seeded 16 months after MON 37500 application of 35 g/ha when soil pH is between 5.0 and 6.4. MON 37500 applied at 140 g/ha injured sunflower when seeded 17 MAT when soil pH was 6.4, but not 5.0 and was not injured on either soil when seeded 29 MAT. Therefore sunflower could be safely seeded 17 MAT when soil pH was between 5.0 and 6.4. However, the margin of safety on the higher pH soil would be less. Grain sorghum was injured by 70 and 140 g/ha of MON 37500 when seeded 17 MAT when soil pH was 6.4 but not 5.0. Grain sorghum was not injured on either soil when seeded 29 MAT. Therefore, grain sorghum can be seeded 17 MAT when soil pH is between 5.0 and 6.4, but the margin of safety level on soils with pH of 6.4 would be marginal. Grain sorghum seeded 29 MAT should not be injured in these soils if precipitation is normal.

The soil pH of most Oklahoma wheat land (66%) is between 5.0 and 6.4, (Zhang 2000), but areas in western Oklahoma and the Western Great Plains have soil pH exceeding 6.4. Additional research is needed to determine whether rotational crop injury would occur on soils with pH higher than 6.4 or if precipitation was lower than average.

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Table 1. Sites, soil characteristics, MON 37500 application date, rotational crop seeding dates, and crops seeded.

	Soil					Date	Date	
Site	Series	pH	Texture	OM	CEC	applied	seeded	Crops
				%	meq/100g			
Enid	Pond Creek[a]	5.0	Loam	1.2	10.8	12-17-97	04-09-99	Corn and soybean
							05-24-99	Grain sorghum and sunflower
							05-11-00	Grain sorghum and sunflower
Perkins	Teller[b]	6.4	Sandy loam	0.7	6.8	11-18-97	04-06-99	Corn and soybean
							05-25-99	Grain sorghum and sunflower
							05-16-00	Grain sorghum and sunflower

[a] Fine-silty, mixed thermic Udic Argiustoll

[b] Fine-loamy, mixed thermic Udic Argiustoll

Table 2. Effect of MON 37500 application rate on visible wheat injury at harvest, grain yield, and grain moisture at Enid and Perkins.

	Enid			Perkins		
MON 37500	Injury	Yield	Moisture	Injury	Yield	Moisture
g/ha	%	kg/ha	%	%	kg/ha	%
0	0	4,380	10.70	0	3,450	10.0
35	13	4,090	10.60	0	3,580	9.9
70	19	3,860	10.60	0	3,410	9.9
140	38	3,320	10.60	0	3,370	9.8
LSD 0.05	3	130	0.08	NSD	160	NSD

Table 3. Effect of MON 37500 application rate on injury, plant density, plant height, and yield of grain sorghum seeded 17 MAT at Enid and Perkins.

	Enid				Perkins			
MON 37500	Injury	Plants	Height	Yield	Injury	Plants	Height	Yield
g/ha	%	no./m^2	cm	kg/ha	%	no./m^2	cm	kg/ha
0	0	10.3	97	3,510	0	8.2	116	2,360
35	0	10.8	96	3,540	2	8.0	115	2,270
70	0	10.4	95	3,480	20	8.1	110	2,280
140	0	10.6	95	3,450	62	8.0	81	990
LSD 0.05	NSD	NSD	NSD	NSD	7	NSD	9	360

Table 4. Effect of MON 37500 application rate on injury, plant density, plant height, and yield of sunflower seeded 17 MAT at Enid and Perkins.

	Enid				Perkins			
MON 37500	Injury	Plants	Height	Yield	Injury	Plants	Height	Yield
g/ha	%	no./m^2	cm	kg/ha	%	no./m^2	cm	kg/ha
0	0	3.9	133	180	0	3.3	140	835
35	0	3.6	133	140	1	3.7	138	890
70	0	4.2	134	140	0	3.2	141	810
140	0	4.0	136	150	14	3.1	129	700
LSD 0.05	NSD	NSD	NSD	NSD	5	NSD	6	90

CHAPTER IV

ROTATIONAL CROP RESPONSE TO CONSECUTIVE ANNUAL MON 37500 APPLICATIONS

Rotational Crop Response to Consecutive Annual MON 37500 Applications[1]

JASON P. KELLEY and THOMAS F. PEEPER[2]

Abstract: Field experiments were conducted in the northcentral, southwest, and panhandle regions of Oklahoma on soils with pH of 5.0, 7.0, and 7.8, respectively, to evaluate rotational crop response to consecutive annual MON 37500 applications. MON 37500 was applied at 35 g ai/ha in December of 1996, 1997, and 1998 to growing wheat. Potential rotational crops for each region were seeded no-till in the spring or summer of 1997, 1998, and 1999. Corn was injured when seeded into pH 5.0 and 7.8 soils four to five months after MON 37500 application. Corn seeded 16 to 17 months after MON 37500 application was not injured where soil pH was 5.0, but was visibly injured where soil pH was 7.8. Corn injury was greater from three consecutive annual applications than from a single application of MON 37500 where soil pH was 7.8. MON 37500 did not reduce cotton lint or biomass yield. Grain sorghum was visibly injured when seeded five to eight months after MON 37500 application at all sites. Where soil pH was 7.8, grain sorghum injury was greater after consecutive annual MON 37500 applications than after single applications. Differences in rotational crop injury among locations were attributed to soil pH differences.

Nomenclature: MON 37500, 1-(2-ethylsulfonylimidazol[1,2-*a*]pyridin-3-ylsulfonyl)-3-(4,6-dimethoxypyrimidin-2-yl)urea; corn, *Zea mays* L. 'Dekalb

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566';'Pioneer 3167'; cotton, *Gossypium hirsutum* L. 'Paymaster 1220 BGRR' and 'Paymaster 1244BGRR'; grain sorghum, *Sorghum bicolor* (L.) Moench 'Pioneer 8446', 'Pioneer 8500', 'Pioneer 8699', 'NC+ 5C35'.

Additional index words: Soil pH, persistence, precipitation.

Abbreviations: MAT, months after application.

INTRODUCTION

MON 37500 is a recently introduced sulfonlyurea herbicide for selective control of *Bromus* sp. and certain broadleaf weed control in wheat. The MON 37500 label specifies that only winter or spring wheat may be seeded for one year following application of MON 37500 and after one year a bioassay should be performed before seeding crops other than wheat (Anonymous 2000).

As in the case with other sulfonylurea herbicides (Ahrens 1994), the water solubility of MON 37500 is pH dependent. It has a reported pKa of 3.51 and is degraded microbially and by acid hydrolysis (Hatzios 1998). MON 37500 has a reported half-life of 14 to 75 days in the field (Hatzios 1998), compared to 28 to 42 d for chlorsulfuron (Ahrens 1994). Thus, it is considered somewhat persistent and low levels can persist long enough to injure sensitive crops one to three years after application, depending on soil and climate (Hatzios 1998).

Like MON 37500, chlorsulfuron (pKa = 3.6) degrades both microbially and by acid hydrolysis. Persistence of chlorsulfuron in Colorado was best explained by variation in soil pH, soil organic matter, and number of precipitation events (Anderson and Humburg 1987). In South Dakota, corn, flax, grain sorghum, soybeans, and sunflowers were all injured when seeded 12 months after chlorsulfuron application, and magnitude of injury varied with site. Differences in injury between sites were attributed to soil pH (Peterson and Arnold 1985). In Canada, sugar beet and lentils were injured by chlorsulfuron >5 yr after application (Moyer et al. 1990). In Greece, chlorsulfuron applied three consecutive years did not increase rotational crop injury at three of four sites compared to a single application. At the fourth site, where precipitation was low, accumulation of chlorsulfuron could not be ruled out (Vicari, et al 1994).

Grain sorghum seeded approximately 18 MAT was injured by MON 37500 in Nebraska and Wyoming, but not Kansas (Lyon et al. 2001). Differences in grain sorghum response between states was attributed to greater soil organic matter content, greater precipitation, and a longer frost free season in Kansas (Lyon et al. 2001). In Idaho, Oregon, and Washington, barley, canola, and pea were injured by residual MON 37500. Differences in injury levels between locations were related in part, to differences in precipitation, soil organic matter and pH (Shinn et al. 1998). Rainbolt et al. 2001 also attributed differences in rotational crop injury from MON 37500 was attributed to the same factors. In growth chamber studies, using Canadian soils with soil organic matter content from 1.8 to 10.3% and soil pH from 5.1 to 8.0, the concentrations of MON 37500 and triasulfuron that reduced canola and barley by 50% were best correlated with soil organic matter content and pH (Moyer and Hamman 2001).

Winter wheat is the primary grain crop grown in Oklahoma, with approximately 2.6 million ha seeded annually (Bartlett 2001). Corn, cotton, and grain sorghum are rotational crops that may follow wheat that has been treated with MON 37500. In 1999 there were 174,000, 97,000, and 178,000 ha of corn, cotton, and grain sorghum, respectively, seeded in Oklahoma (Bartlett 2001). However, there were 174, 000, 97,000, and 178,000 ha of corn, cotton, and grain sorghum, respectively, seeded in Oklahoma in 1999 (Bartlett 2001). These crops may follow wheat that has been treated with MON 37500.

The objectives of this research were to determine the extent of corn, cotton, and grain sorghum injury by MON 37500 in three major cropping environments of the Southern Great Plains and to determine whether consecutive annual MON 37500 applications caused greater rotational crop injury than a single application.

MATERIALS AND METHODS

Three-year field experiments were conducted near Altus, Oklahoma, in the Central Red Rolling Plains, near Enid, Oklahoma, in the Central Rolling Red Prairies, and near Goodwell, Oklahoma in the Southern High Plains (Gray and Galloway 1959) to determine whether MON 37500 persistence would result in more crop injury from consecutive annual applications than from a single a application. Soil characteristics of each location are listed in Table 1. The 30-year average precipitation is 650, 820, and 450 mm at Altus, Enid, and Goodwell, respectively. Weather collection stations were located on site at Altus and Goodwell, and located approximately 11 km from the Enid site. Yearly cumulative precipitation for each site is listed in Table 1.

The experimental design was a randomized complete block design with four replicates. Treatments were paired so that each MON 37500-treated plot was adjacent to an untreated control plot. Plot size ranged from 6.1 by 9.1 m to 12.2 by 9.1 m, depending on experimental area available and the number of rotational crops included in a site. Grain sorghum was included at all sites, whereas corn and cotton were included at two sites where these crops are adapted. Herbicide treatments included MON 37500 applied in water carrier to growing wheat at 35 g/ha plus 0.5% v/v nonionic surfactant in December of 1996, 1997, or 1998, in both 1996 and 1997, and in three consecutive years, i.e. 1996, 1997, and 1998, using a CO_2 pressurized backpack sprayer. Spray volume was 187 L/ha. In late March or April of 1997, 1998, and 1999, glyphosate was applied at 1.1 kg/ha to kill the wheat and simulate crop failure. Rotational crops were then seeded no-till later in the spring or summer of each year. Rotational crops seeded, seeding dates, variety or hybrid, and seeding rates are listed in Table 2.

Four or six rows of each rotational crop were seeded no-till into appropriate plots using a two-row no-till planter with 76-cm row spacing. Immediately thereafter alachlor and glyphosate were broadcast at 2.2 and 1.1 kg/ha. Nitrogen fertilizer was broadcast applied either as topdress to the wheat or broadcast surface applied immediately after crop seeding.

Plants from the two center rows of each crop were counted soon after emergence. Rotational crop injury was visually estimated throughout the growing season using a scale of 0 to 100, where 0 = no injury and 100 = crop death. Heights of two to five plants were measured in each plot at mid-season or at crop maturity. Grain sorghum panicles in the two center rows of each plot were counted at maturity. The center two rows of grain sorghum and corn plots were harvested with a small plot combine to determine grain yield. The remaining rows of corn and grain sorghum were then harvested. The two center rows of cotton were hand harvested or picked with a small plot cotton picker and the stalks and remaining rows were rotary mowed. Immediately after harvest of the latest maturing crop each year, the entire experiment was lightly tilled with a field cultivator or disk and hard red winter wheat was seeded. At Goodwell, irrigation furrows were rebuilt using a bedder each year before wheat seeding.

Harvested grain sorghum samples were recleaned once using a small commercial seed cleaner to remove excess glumes from the grain. Corn and grain sorghum yields were adjusted to 13.5 percent moisture. Harvested cotton samples were deburred, ginned, and lint and seed yields were determined. Fiber quality was measured by a public laboratory[3] using HVI (High Volume Instrument) procedures. Fiber qualities measured included; micronaire, length, uniformity, strength, leaf grade, Rd, and +b (Anonymous 1997).

In 1998 at Altus, rotational crop planting was delayed until August 3 because of drought conditions. Prior to seeding, a dam was built around the experiment and over two days, approximately 30 cm of water was flood applied to the experiment. Water movement was slow across the plots and no visible soil movement occurred. Due to the late seeding, the cotton did not mature before a killing frost, therefore plant biomass was harvested and weighed.

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[3] International Textile Center, 1001 East Loop 289, Lubbock, TX 79403

At Goodwell, in 1997 and 1998, grain sorghum grain was not harvested because of severe bird damage. Instead, grain sorghum panicles were clipped from one row per plot and weighed.

Visual injury ratings were subjected to arcsine transformations. The transformation had no effect on means separation, therefore original data are presented. Data were not pooled across years or locations because of the different environments. Differences in paired data groups (treated and untreated) were distinguished by using paired F-tests. All computations were conducted using SAS version 8.1.

RESULTS AND DISCUSSION

Corn. Corn density was not affected by MON 37500 when seeded four MAT at Enid in any year. Corn density was reduced when seeded 5 MAT in 1997 and 1999 at Goodwell (Table 3). Plant height was reduced only in 1997 at Enid and all three years at Goodwell by MON 37500 applied four to five prior to corn seeding. Corn was visually injured 10 to 40% at Enid and 69 to 93% at Goodwell by MON 37500 applied four to five months prior to corn seeding. Yield of corn seeded four MAT in 1998 and 1999 at Enid, and all three years at Goodwell was reduced by MON 37500.

Corn seeded 16 MAT at Enid was not affected by MON 37500 in either year (Table 3). At Goodwell, corn seeded 17 MAT was visually injured both years and grain yields were reduced in 1998. Plant height and density were not affected by

MON 37500 applied 17 months prior to seeding. Corn seeded 28 or 29 MAT was not affected by MON 37500 at either site.

MON 37500 applied 4 and 16, 16 and 28, or 4, 16, and 28 MAT did not cause greater corn injury than a single MON 37500 treatment applied 4 months prior to corn seeding at Enid. This suggests that at Enid, MON 37500 was not persisting into the next growing season. At Goodwell, corn seeded after MON 37500 was applied 5 and 17, and 5, 17, and 29 MAT exhibited greater injury than a single application 5 months prior to seeding, suggesting that a portion of MON 37500 persisted more than 12 months.

Thus, a restriction against seeding corn as a rotational for 16 months following a MON 37500 application should be adequate for an environment similar to that at Enid, since no visible injury or yield reductions occurred, even after two consecutive annual applications. A 29-month planting restriction would appear necessary in higher soil pH, low rainfall areas such as the Southern High Plains.

Cotton. Cotton at Altus was slightly stunted by MON 37500 (10%) at 21 d after seeding in 1997, but injury was not visible later in the growing season. Lint yields averaged 680 and 890 kg/ha at Altus and Enid in 1997. MON 37500 treatments caused no other visible injury at either site in any of the three years and had no effect on stand density, plant height, lint or seed yield or fiber quality parameters. The lack of cotton injury from single or repeated application of MON 37500 indicates that cotton could be safely seeded 6 mo. following MON 37500 applications with little concern for crop injury when soil pH ranged from 5.0 to 7.0.

Grain sorghum. MON 37500 visibly injured grain sorghum 35 to 100% when seeded 5 to 8 MAT at each site in 1997, 1998, and 1999 (Table 4). Grain sorghum density was reduced by MON 37500 applied 5 to 8 MAT every year at Goodwell, two of three years at Altus, and one year at Enid (Table 4). Yields of grain sorghum seeded 5 to 8 MAT were reduced at all sites every year (Table 4).

Yields of grain sorghum seeded approximately 1.5 years after treatment were not reduced at Enid or Altus in 1998 and 1999. At Goodwell, grain sorghum yields were reduced in 1998, but not 1999. Grain sorghum yields were not affected by MON 37500 when seeded 29 or 30 MAT at any site.

MON 37500 applied 8 and 20 months or 6, 18, and 30 months prior to seeding did not appear to cause greater injury than a single application 6 or 8 months prior to seeding at Altus. At Enid, MON 37500 applied 5 and 17, or 5, 17, and 29 months prior to seeding did injure grain sorghum more than a single application 5 months prior to seeding. Grain sorghum injury was greater at Goodwell when MON 37500 was applied both 17 and 29 months prior to seeding than when applied once 17 or 29 months before seeding. Grain sorghum yield was reduced 100% by MON 37500 treatment sequences that included an application 5 months prior to seeding. Thus, it appears that a portion of the applied MON 37500 was persisting at least 17 months at Goodwell. A 16 to 20 month planting restriction for grain sorghum would seem necessary for grain sorghum at Enid and Altus. In the panhandle region, a planting restriction of 29 months would be necessary.

At each location and year (n = 9), soil pH was negatively correlated with yield of grain sorghum (r = -0.904, P = 0.0008). Neither soil organic matter content, sand, silt, or clay content, nor CEC were correlated to grain sorghum yield. Rainfall was marginally negatively correlated with grain sorghum yield (p=0.12). This research suggests that soil pH and precipitation were likely the primary factors influencing MON 37500 persistence. This is in agreement with Shinn et al. 1998 and Rainbolt et al. 2001.

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Table 1. Soil characteristics and precipitation at each site.

Site	Series	Texture	pH	OM	Sand	Silt	Clay	CEC	Precipitation		
									1997	1998	1999
				———	——— %	———	———	meq/100g	———	——— cm	———
Altus	Tillman-Hollister[a]	Clay-loam	7.0	1.4	37	32	31	19.9	108	46	68
Enid	Pond Creek[b]	Loam	5.0	1.2	45	39	16	10.8	104	125	111
Goodwell	Richfield[c]	Loam	7.8	1.3	42	42	16	21.4	38	51	41

[a] Fine, mixed, thermic Pachic Paleustolls

[b] Fine-silty, mixed, thermic, Udic Argiustolls

[c] Fine, montmorillonitic, mesic, Aridic Argiustolls

Table 2. Dates MON 37500 applied, wheat growth stage, rotational crops seeded and variety or hybrid, date rotational crops seeded, seeding rate, date rotational crops harvested, and dates wheat was seeded.

			Rotational crops				
Site	MON 37500 applied	Wheat stage	Variety or hybrid	Seeded	Seeding rate	Harvest date	Wheat seeded
					no./ha		
Altus	12-12-96	5 to 9 tl	Cotton 'Paymaster 1244 BGRR'	05-20-97	123,000	08-27-97	10-20-97
			Grain sorghum 'Pioneer 8699'	05-20-97	123,000	10-20-97	
	12-05-97	2 lf to 3 tl	Cotton 'Paymaster 1220 BGRR'	08-03-98	215,000	11-16-98	11-17-98
			Grain sorghum 'NC+ 5c35'	08-03-98	140,000	11-16-98	
	12-14-98	1 to 3 lf	Cotton 'Paymaster 1220 BGRR'	06-09-99	125,000	11-15-99	________
			Grain sorghum 'Pioneer 8500'	06-09-99	140,000	10-14-99	
Enid	12-09-96	4 to 12 tl	Corn 'Pioneer 3167'	04-14-97	49,000	09-17-97	11-20-97
			Cotton 'Paymaster 1244 BGRR'	05-15-97	120,000	11-20-97	
			Grain sorghum 'Pioneer 8699'	05-12-97	120,000	09-17-97	

Table 2. Continued.

	12-01-97	2 to 4 lf	Corn 'Pioneer 3167'	04-13-98	49,000	10-23-98	10-26-98
			Cotton 'Paymaster 1220 BGRR'	05-14-98	215,000	10-23-98	
			Grain sorghum 'Pioneer 8446'	05-14-98	140,000	09-18-98	
	12-02-98	3 lf to 1 tl	Corn 'DK 566 RR'	04-06-99	49,000	08-26-99	________
			Cotton 'Paymaster 1220 BGRR'	05-24-99	195,000	11-12-99	
			Grain sorghum 'Pioneer 8500'	05-24-99	140,000	09-10-99	
Goodwell	12-16-96	3 to 6 tl	Corn 'Pioneer 3162'	05-16-97	69,000	10-15-97	10-15-97
			Grain sorghum 'Pioneer 8699'	06-17-97	195,000	10-15-97	
	12-16-97	2 to 3 lf	Corn 'Pioneer 3167'	05-13-98	74,000	09-29-98	09-29-98
			Grain sorghum 'Pioneer 8446'	05-13-98	220,000	09-29-98	
	12-15-98	2 to 9 tl	Corn 'DK 566 RR'	05-19-99	83,000	09-23-99	________
			Grain sorghum 'Pioneer 8500'	05-19-99	230,000	10-26-99	

Table 3. Effect of MON 37500 applied 4 to 5, 16 to 17, and/or 28 to 29 months prior to corn seeding.

Site	Year	MON 37500 applied	Plants		Injury		Height		Yield	
		MBS[a]	no./m^2		%		cm		kg/ha	
			Trt[b]	Unt[c]	Trt	Unt	Trt	Unt	Trt	Unt
Enid	1997	4	3.3	4.1	10***	0	78**	92	3,280	3,530
	1998	4	4.2	5.0	40***	0	135	135	210*	450
	1999	4	3.3	3.5	33***	0	127	138	2,210*	3,330
	1998	16	4.7	4.9	0	0	140	144	550	610
	1999	16	4.2	4.3	0	0	199	208	3,390	3,960
	1999	28	4.6	4.6	0	0	210	210	5,020	4,160
	1998	4, 16	5.2	4.7	50***	0	133*	148	440	630
	1999	16, 28	3.0	3.2	0	0	204	210	3,410	2,830
	1999	4, 16, 28	3.7	3.7	23***	0	189***	205	2,270	3,110

Table 3. Continued.

Good[d]	1997	5	4.4	4.9	79***	0	133***	165	250***	3,270
	1998	5	3.6***	4.3	93***	0	134***	205	130***	5,470
	1999	5	6.2**	7.5	69***	0	81***	145	2,680*	5,300
	1998	17	4.1	4.3	20***	0	191	194	2,930*	4,730
	1999	17	7.3	7.3	8	0	211	208	5,390	5,430
	1999	29	7.8	7.5	0	0	213	211	4,900	5,400
	1998	5, 17	3.2***	4.4	96***	0	106***	199	50***	5,070
	1999	17, 29	7.6	7.3	18***	0	197	204	4,530	4,800
	1999	5, 17, 29	4.6***	7.0	86***	0	135***	207	1,040***	5,150

*, **, *** signifies significant differences between treated and untreated at 0.1, 0.05, and 0.01 probability level, respectively.

[a] MBS = Months before seeding

[b] Trt = Treated

[c] Unt = Untreated

[d] Good = Goodwell

Table 4. Effect of MON 37500 applied 5 to 8, 18 to 20, and/or 29 to 30 months prior to grain sorghum seeding.

Site	Year	MON 37500 applied	Plants		Injury		Height		Panicles		Yield[d]	
		MBS[a]	no./m^2		%		cm		no./m^2		kg/ha	
			Trt[b]	Unt[c]	Trt	Unt	Trt	Unt	Trt	Unt	Trt	Unt
Altus	1997	5	2.7***	9.8	90***	0	52***	102	5.1***	21.7	50***	3,400
	1998	8	9.3	10.4	40***	0	80	88	6.8	9.3	650**	1,670
	1999	6	0.0***	6.6	100***	0	0***	93	0.2***	6.0	10***	1,510
	1998	20	9.2	8.9	0	0	87	88	8.0	8.7	1,530	1,860
	1999	18	4.3**	6.9	33**	0	81	88	4.2***	7.1	1,140	1,590
	1999	30	7.2	7.2	0	0	88	91	7.2	7.5	1,660	1,870
	1998	8, 20	7.2	9.2	50***	0	72**	88	5.1**	9.3	490**	1,750
	1999	18, 30	7.8	8.1	28	0	85	91	7.0	8.1	1,540	1,480
	1999	6, 18, 30	0.0***	6.5	100***	0	10***	86	0.4***	6.6	0***	1,370

Table 4. Continued.

Enid	1997	5	4.9***	7.6	38***	0	89***	110	8.0*	9.4	3,730*	5,210
	1998	5	9.4	10.5	59***	0	81**	97	5.4***	9.3	990***	2,190
	1999	5	10.5	10.7	35***	0	58	63	7.0***	11.0	2,220**	3,080
	1998	17	10.9	10.2	0	0	96	94	10.1	10.0	2,250	2,350
	1999	17	9.0	8.8	3	0	85*	105	12.1	10.4	3,430	3,830
	1999	29	8.7	9.4	0	0	99	95	12.5	11.3	4,280	3,760
	1998	5, 17	10.0	10.5	63***	0	79***	98	5.3***	10.0	920***	2,370
	1999	17, 29	11.0	10.7	0	0	68	66	11.5	10.7	2,710	3,030
	1999	5, 17, 29	9.3	8.7	58***	0	53*	74	7.5**	10.2	1,500***	3,670
Good	1997	6	8.9***	16.1	75***	0	46***	120	0.3***	20.7	70***	5,210
	1998	5	0.7***	14.2	100***	0	0***	117	0***	12.9	0***	3,540
	1999	5	2.3***	11.7	100***	0	0***	119	0***	16.0	0***	6,160
	1998	17	10.1	12.4	61***	0	104***	120	6.9***	13.2	1,180***	2,980
	1999	17	9.8	9.5	14***	0	81	90	15.6	15.3	5,030	5,350

Table 4. Continued

1999	29	11.8	12.0	3	0	121	124	17.5	16.3	5,080	5,890
1998	5, 17	0.5***	14.9	100***	0	0***	118	0***	13.0	0***	3,110
1999	17, 29	7.6*	10.2	68***	0	80***	120	7.3***	16.2	2,430***	6,270
1999	5, 17, 29	0.1***	10.0	100***	0	0***	121	0***	15.5	0***	5,170

*, **, and *** signifies differences between treated and untreated at the 0.10, 0.05, and 0.01 probability level, respectively

[a] MBS = Months before seeding

[b] Trt = Treated

[c] Unt = Untreated

[d] Yields at Goodwell in 1997 and 1998 were panicle biomass

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VITA

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Doctor of Philosophy

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