EVALUATION OF QUINCLORAC FOR CHEAT (*Bromus secalinus* L.) CONTROL IN WINTER WHEAT (*Triticum aestivum* L.)

By

LORA M. FRANETOVICH

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aestivum L.)

Thesis Approved:

Thomas F. Peeper

Thesis Adviser

Kevin J. Donnelly

Jimmy F. Stritzke

Thomas C. Collins

Dean of the Graduate College

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This thesis is a manuscript to be submitted for publication in Weed Technology, a Weed Science Society of America publication.

EVALUATION OF QUINCLORAC FOR CHEAT (*Bromus secalinus* L.) CONTROL IN WINTER WHEAT (*Triticum aestivum* L.)

Evaluation of Quinclorac for Cheat (*Bromus secalinus*) Control in Winter Wheat (*Triticum aestivum*)[1]

LORA M. FRANETOVICH and THOMAS F. PEEPER[2]

Abstract. Fifteen field experiments and two controlled environment experiments were conducted to evaluate quinclorac for cheat control in winter wheat. Quinclorac at 560 and 1120 g ha^{-1} applied to tillered wheat controlled cheat 93 to 100% but injured wheat and, at one of four sites, reduced yield. In contrast, pooled over four experiments and four application times, quinclorac at 420 g ha^{-1} and 560 g ha^{-1} controlled cheat only 20 and 31%. Quinclorac at 420 g ha^{-1} plus chlorsulfuron:metsulfuron (5:1) at 35 g ha^{-1} applied PRE increased yield at one of three sites. At two of three sites, averaged over chlorsulfuron:metsulfuron rates, quinclorac at 280 and 420 g ha^{-1} applied POST, increased wheat yield. In cultivar tolerance experiments, 'Chisholm' and 'TAM 200' yields were reduced more than 50% at one of three sites. Yields of 'Mesa', 'Cimarron' and '2180' were not

[1]Approved for publication and in revised form by the Director, Oklahoma Agric. Exp. Sta., Oklahoma State Univ., Stillwater, OK 74078. This research was supported under project H-1644.

[2]Grad. Res. Asst. and Prof., respectively, Dep. Agron. Oklahoma State Univ., Stillwater, OK 74078.

affected by quinclorac at any site. In a greenhouse, quinclorac plus chlorsulfuron:metsulfuron reduced the dry root weight of cheat. In a laboratory, quinclorac plus crop oil concentrate consistently reduced wheat leaf area and suppressed cheat. Quinclorac plus different additives and two pesticides reduced the leaf area of cheat. **Nomenclature:** Chlorsulfuron, 2-chloro-N-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide; metsulfuron, 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-y)amino]carbonyl]amino]sulfonyl]benzoic acid; quinclorac, 3,7-dichloro-8-quinolinecarboxylic acid; cheat, *Bromus secalinus* L. #[3], BROSE; wheat, *Triticum aestivum* L. em Thell.

Additional index works: Synergism, chlorsulfuron, metsulfuron, application timing, BROSE.

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[3]Letters following this symbol are a WSSA approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

INTRODUCTION

Several *Bromus* spp. can be serious weeds in winter wheat in North America (15). Although many fields contain two or more *Bromus* species, cheat is most common in the Southern Great Plains while downy brome (*Bromus tectorum* L.) is the major weed problem in wheat in the western United States (15). These winter annuals thrive in "reduced tillage" or "conservation tillage" winter wheat production systems. Current "conservation compliance" regulations imposed by government farm policy will likely increase *Bromus* spp. infestations nationwide (15).

Numerous herbicides have been evaluated over the years for *Bromus* spp. control in winter wheat but with variable results. Propham (1-methylethyl phenylcarbamate) or TCA (trichloroacetic acid) applied POST controlled downy brome 85% with no wheat yield reduction (20). However, the following year, with similar conditions, 50% wheat injury was observed.

Cyanazine [2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile], ethyl-metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(ethylthio)-1,2,4-triazin-5(4*H*)-one], and metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] have been investigated for selective control of *Bromus* spp. in wheat. Cyanazine, when applied to small cheat, suppressed it enough to increase wheat yields 79% (1). Cyanazine was registered for cheat suppression in Oklahoma, but the registration has not been renewed because control was variable and the herbicide has a full season grazing restriction. Metribuzin has been effectively used for control of *Bromus* spp. in wheat (21).

However, a narrow margin of crop safety and variety restrictions have limited its use. Ethyl-metribuzin, the ethylthio analog of metribuzin, selectively controlled cheat, downy brome, and rescuegrass (*Bromus catharticus* Vahl) when applied POST before wheat tillering (22), but is no longer being developed.

More recently, a 5:1 premix of chlorsulfuron:metsulfuron (chlor:met)[4], has been registered for cheat suppression in winter wheat when applied PRE or when applied POST with metribuzin. This product, applied PRE, suppresses cheat 40 to 60% and can increase wheat yield (9).

Quinclorac is a broad-spectrum quinolinecarboxylic acid herbicide (3) that selectively controls barnyardgrass [*Echinochloa crus galli* (L.) Beauv.] in rice (*Oryza sativa* L.) (5, 8, 24), and controls both grasses and broadleaves in corn (*Zea mays* L.), small grains, sorghum (*Sorghum bicolor* L. Moench) , and turfgrass (10, 13, 16, 17, 19, 26, 27, 28). It is currently registered for PRE and POST weed control in rice. The primary target in rice is barnyardgrass which is controlled with 220 g ai ha^{-1} applied PPI or delayed PRE (18), and 140 to 560 g ha^{-1} applied PRE and POST depending on soil conditions (23). Quinclorac is a hormone-type herbicide with a possible additional mode of action yet to be identified (2). It is primarily absorbed by roots, but can be absorbed by leaves and translocated both basipetally and acropetally. As a result, quinclorac is most effective when used on

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[4]Abbreviations: chlor:met = chlorsulfuron:metsulfuron; PARS = Perkins Agronomy Research Station; LBRA = Lake Carl Blackwell Research Area; SCRS = South Central Research Station; NCRS = North Central Research Station; NARS = North Agronomy Research Station; DAT = days after treatment.

moist soils or when leached into the root zone (2, 11), and it is often tank mixed with other herbicides for broader-spectrum weed control in rice.

Control of smooth crabgrass [*Digitaria ischaemum* (Schreb.) Muhl.] and goosegrass [*Eleusine indica* (L.) Gaertn.] in turf with quinclorac at 450 to 680 g ha^{-1} was poor (6, 7). Quinclorac + 2,4-D [2,4-dichlorophenoxyacetate] low volatile ester injured sorghum more than either applied alone or quinclorac plus dicamba [2-Methoxy-3,6-dichlorobenzoic acid] (14). Quinclorac has also been investigated for annual grass control in wheat in Canada, Idaho, and North Dakota (12, 13, 16, 17, 26, 27). Much of that work has focused on selection of an optimum oil additive for POST applications. In the field, wheat yields were not affected by quinclorac applied alone, with petroleum oil, or with once-refined or methylated soybean (*Glycine max* Merrill) oils. In greenhouse experiments, quinclorac at 280 to 1100 g ha^{-1}, applied to foliage alone, or with petroleum oil, once-refined soybean or sunflower (*Helianthus annuus* L.) oil, methylated soybean or sunflower oil, or with surfactant did not injure 'Marshall' spring wheat (12, 17) In that work, when applied to seedling wheat, quinclorac alone or with methylated rapeseed (*Brassica napus* var. *annua Koch*) oil adjuvant did not reduce fresh foliage weights of six winter wheat cultivars. In the field, wheat was injured <5% when quinclorac at 560 g ha^{-1} was applied at tillering (12). Also, no measurable detrimental effect on wheat was detected when quinclorac at 1500 g ha^{-1} was incorporated in the soil above the seed (25).

Thus, quinclorac has controlled a wide range of weeds, and wheat appears to have substantial tolerance. However, wheat tolerance may depend on growth stage at the time of application. The objectives of this research were to evaluate quinclorac for selective cheat control in winter wheat; to evaluate quinclorac plus other hormone-type herbicides for synergistic or antagonistic responses; and to evaluate the effect of quinclorac plus various additives on wheat and cheat in a laboratory.

MATERIALS AND METHODS

General. Field experiments were conducted in Oklahoma during the 1990-91 and 1991-92 winter wheat crop seasons to evaluate quinclorac for selective cheat control. All plots were seeded with '2157' hard red winter wheat at 67 kg ha^{-1} except as noted below. The wheat was drill planted 1.3 to 5.1 cm deep in moist soil in conventionally prepared seedbeds with little or no crop residue. Fertilizer was applied in accordance with soil test recommendations for 4040 kg ha^{-1} yield goals.

Locally collected cheat seed was hand broadcast at 50 kg ha^{-1} in 1990-91 and 70 to 90 kg ha^{-1} in 1991-92 and incorporated 5 to 8 cm deep before planting wheat using a light field cultivator with rolling baskets both years. All herbicide treatments were applied with a CO_2-pressurized backpack sprayer in a total volume of 190 L ha^{-1}. Untreated weedy checks were included in all experiments. The dates seeded, dates of herbicide application, cheat densities, and soil information for all experiments except the cultivar tolerance comparisons are in Table 1. Rainfall intervals for all sites are presented in Table 2.

Propiconazole (1-[[2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl]methyl]-1*H*-

1,2,4-triazole) at 130 g ai ha^{-1} was applied to all 1991-92 experiments for control of powdery mildew (*Erysiphe graminis* DC. ex Marat. f sp. *tritici* E. Marchal) and leaf rust (*Puccinia recondita* Rob. ex Desm. f sp. *tritici* Mains). In some cases dimethoate (O, O-dimethyl S-[-N-(methylcarbamoyl)methyl] phosphorodithioate) at 420 g ai ha^{-1} was applied with propiconazole for greenbug (*Schizaphis graminum* Rondani) control.

Cheat control and/or wheat injury were visually estimated using a scale of 0 to 100%. Cheat control was visually estimated before harvest in 1991, and in early spring in 1992. Yield samples were obtained from all experiments by harvesting a 1.5 m by 6.1 or 7.6 m area from each plot with a small plot combine adjusted to retain cheat seed with the harvested grain. The harvested samples were cleaned with a small commercial seed cleaner, removing chaff, straw and cheat. Weight lost by the cleaning process was considered an estimate of dockage. Grain yields were adjusted to 13.5% moisture and all data were statistically analyzed and means separated with protected LSD tests at the 0.05 probability level. Visual control data were subjected to arcsin transformations prior to analysis.

Applications to tillered wheat. Three experiments were conducted at the Agronomy Research Station near Perkins, OK, (PARS)[4] in 1990-91, and one experiment was conducted at the Agronomy Research Station, near Stillwater, OK, (SARS)[4] in 1991-92, to evaluate cheat control with quinclorac applied to tillered wheat. The design for each experiment was a randomized complete block with three or four replicates.

The cultivar used at PARS-1 and PARS-2 was 2157, and 'Chisholm' was planted at PARS-3. Quinclorac at 560 and 1100 g ha^{-1} plus the additive BCH 864 01S[5] (chemistry not available) at 3.5 L ha^{-1} was applied when the wheat had three to five tillers at PARS-1, seven to eight tillers at PARS-2, and four to six tillers at PARS-3. The cheat had two to seven tillers at PARS-1, three to eight tillers at PARS-2, and three to five tillers at PARS-3. Ethyl-metribuzin at 1120 g ai ha^{-1} was applied when the wheat had one to five leaves at PARS-1 and metribuzin at 420 g ha^{-1} was applied when the wheat had three to six tillers at PARS-2 and PARS-3. The cheat density was 110 to 160 plants per m^2 at all sites.

The 1991-92 experiment at SARS was seeded with 'Karl' hard red winter wheat. Quinclorac at 280 and 560 g ha^{-1} plus a modified oil additive[6] at 2.3 L ha^{-1} was applied when the wheat had two to four tillers and the cheat had one to two leaves. The cheat density was about 160 plants per m^2.

Application timing experiments. Four experiments were conducted in 1991-92 to evaluate the effect of quinclorac application timing on cheat control and crop injury. Experiments were conducted at the South Central Agronomy Research Station (SCRS)[4] near Chickasha, OK; the North Central Agronomy Research Station (NCRS)[4] near Lahoma, OK; the North Agronomy Research Station (NARS)[4] near Stillwater, OK; and at the Lake Carl Blackwell Agronomy Research Area (LBRA)[4] near Orlando, OK. An additional experiment was conducted at LBRA at a cheat-free site adjacent to the above mentioned

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[5]Experimental additive. BASF Corp., Parsippany, NJ 07054.

[6]Sun-it II modified oil additive. Available from Agsco, Inc., Grand Forks, ND 58206-0458.

experiment.

Quinclorac at 420 and 560 g ha^{-1} was applied PPI, PRE, before tillering, and when the wheat had two to eight tillers at each site except at NARS where only 420 g ha^{-1} was applied to tillered wheat. The cheat had one to two leaves at the early POST timing and one to four leaves at the late POST timing. The PPI treatments were applied and incorporated with one pass of a light field cultivator with double rolling baskets operated 3 to 4 cm deep after the cheat seed was incorporated. All POST treatments included the modified oil additive at 2.3 L ha^{-1}. Metribuzin at 420 g ai ha^{-1} was applied to tillered wheat as a standard. Fall armyworm (*Spodoptera frugiperda* Smith) damage to part of the experiment at NCRS when the wheat was in the seedling stage necessitated deletion of two replicates of every treatment and all replicates of quinclorac at 560 g ha^{-1} applied PPI and metribuzin at 420 g ha^{-1}. Data from the remaining treatments were then analyzed using a completely randomized design.

Combinations with chlorsulfuron:metsulfuron. Three experiments were conducted to evaluate the efficacy of quinclorac at 0, 280 and 420 g ha^{-1} tank mixed with chlor:met at 0, 18 and 35 g ai ha^{-1} applied PRE and POST to wheat with two to five leaves and cheat with one to three leaves. The experimental design was a randomized complete block with a factorial arrangement of treatments and an added check, with four replicates. Factors included application timing, quinclorac rate, and chlor:met rate. The experiment at NCRS was planted with a double disk drill and replanted without tillage, on October 16 with a chisel opener drill. Replanting was necessary due to severe stand reduction from fall armyworms.

Using data from the four application timing experiments where cheat was present and the three combinations with chlor:met experiments, simple linear correlation coefficients were calculated between visible cheat control from quinclorac at 420 g ha^{-1} applied PRE and before tillering and selected soil and environmental parameters. Correlation significance was determined using standard F tests.

Cultivar tolerance. Experiments were conducted in 1991-92 at PARS and LBRA to evaluate the tolerance of nine hard red winter wheat cultivars to quinclorac. The experimental design for both experiments was a randomized complete block with a factorial arrangement of treatments and four replicates. The two factors were herbicide treatment and wheat cultivar. The cultivars, including Chisholm, 'Newton', 'TAM 101', 'TAM 200', Karl, 'Mesa', 'Cimarron', '2180', and 'Arapahoe', were seeded October 3 at PARS and November 21 at LBRA. Quinclorac at 280 and 560 g ha^{-1} plus the modified oil additive at 2.3 L ha^{-1} were applied to wheat with one to three leaves on December 9 at LBRA and 2.5 cm of rain fell two d after treatment (DAT)[4]. At PARS, the same treatments were applied October 15 to wheat with two leaves. Eleven DAT 7.1 cm of rain fell. The experiment at PARS contained no weeds, however, triasulfuron [2-(2-chloroethoxy)-N-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide] at 0.03 kg ai ha^{-1} was applied at LBRA in March to control broadleaf weeds. A scattered population of cheat was also present.

A third experiment was planted with the same cultivars on October 15 with a cone seeder at SARS. The experimental design was a randomized complete block with a factorial arrangement of treatments and two replicates. A 1.2 m by 1.5 m area was harvested from each plot with a small plot combine and samples were cleaned and evaluated as explained previously. Quinclorac at 280 and 560 g ha^{-1} plus the modified oil additive at 2.3 L ha^{-1} were applied on November 21 to wheat with two leaves. The experiment received 3 cm of rain 21 DAT. No weeds were present.

Synergism experiments. Greenhouse experiments were conducted to evaluate quinclorac plus other pesticides for synergistic responses. Ten cheat seeds per pot were planted 0.6 cm deep in 10-cm diameter round pots 14-cm tall containing 950 g of a sandy clay loam top soil (pH = 5.8, organic matter content = 1.5 %). The experimental design was a randomized complete block with four replicates per run. After seeding on May 29 and July 31 for the two runs of the experiment, the cheat was grown in a greenhouse without supplemental light. Pots were watered from the bottom until the treatments were applied, after which daily watering was from the top. Twenty d after planting, when the cheat had three leaves, each pot was thinned to four cheat plants and quinclorac at 140, 280, and 560 g ha^{-1}; 2,4-D low volatile ester at 140 g ae ha^{-1}; MCPA [(4-chloro-2-methylphenoxy)acetic acid] at 140 g ae ha^{-1}; dicamba at 35 g ae ha^{-1}; picloram [4-Amino-3,5,6-trichloropicolinic acid] at 9 g ae ha^{-1}; chlor:met at 18 g ha^{-1}; and esfenvalerate [(S)-cyano(3-phenoxyphenyl)methyl(S)-4 chloro-alpha-(1-methylethyl)benzene acetate] at 560 g ai ha^{-1} were applied. Additional treatments included quinclorac at 280 g ha^{-1} mixed with each of the other pesticides and an untreated check. All treatments included the modified oil additive at 2.3 L ha^{-1}. Treatments were applied with a CO_2-pressurized sprayer in a total volume of 190 L ha^{-1}.

Ten DAT the width and length of the fourth leaf of each cheat plant was measured. Twenty DAT the height of the cheat canopy, total leaf area of each plant, and root fresh and dry weights were determined.

From the above data, expected response values for pesticide combinations were calculated by the mathematical method described by Colby (4). All responses were converted to percent-of-check; the product of the percent-of-check responses provided by the two pesticides applied individually was divided by 100. This value was compared to the actual observed response of the two pesticides applied as a tank mix. The expected and observed responses were then statistically analyzed and means separated with least significant differences (LSD) at the 0.05 level. When the observed values were less than the expected, the tank mixture was synergistic. When the observed value was greater than the expected, the activity on cheat of the tank mixture was antagonistic and when there were no differences between the observed and expected values, the tank mixture produced an additive response.

Additive experiments. An experiment was conducted in a laboratory to evaluate the influence of selected additives on quinclorac activity. Pots were prepared as described above except that wheat and cheat were both planted in each pot. Pots were planted on January 12 and February 9 for two runs of the experiment and were arranged in a randomized complete block design, with five and three replicates, respectively. The plants were grown under artificial light (220

$\mu E\ m^{-2}\ s^{-1}$) with twelve hour days in a temperature range of 21 to 37 C. Wheat (2157) and cheat seeds were pregerminated for four and five d prior to planting. Five seeds of each species were planted in each pot and 16 d after planting the pots were thinned to three of each species and the treatments were applied. Treatments included quinclorac at 280 g ha^{-1} applied alone and with eight additives when the wheat had two to three leaves and the cheat had one to two leaves . Quinclorac at 280 g ha^{-1} plus chlor:met at 18 g ha^{-1} and quinclorac at 280 g ha^{-1} plus esfenvalerate at 560 g ha^{-1} were also included, each with the modified oil additive at 2.3 L ha^{-1}.

Fourteen DAT wheat and cheat injury were visually estimated. Twenty-one DAT the leaf area of each plant was measured using a leaf area meter, and the fresh and dry foliage weights of each plant were determined after clipping at the soil surface. All data were statistically analyzed and means separated with least significant differences (LSD) at the 0.05 level. Visual control data were subjected to arcsin transformations prior to analysis.

RESULTS AND DISCUSSION

Applications to tillered wheat. In all three experiments located at PARS, cheat was controlled 90% or greater when quinclorac at 560 and 1120 g ha^{-1} was applied (Table 3). Cheat control was 68 and 93% with quinclorac at 280 and 560 g ha^{-1} at SARS. No wheat injury was noted at any of the PARS experiments until the wheat had headed. At that time, the wheat in PARS-1 and PARS-2 treated with quinclorac had rolled, erect leaves compared to the lax leaves on untreated plants, and the wheat was slightly chlorotic. At SARS, quinclorac at 560 g ha^{-1} injured wheat 10%. This injury was characterized by onion-leafing which was still present before harvest, with some bent heads.

Grain yield was not affected by any of the treatments at PARS-1, however yield was reduced by quinclorac at PARS-2 (Table 3). AT PARS-3, only ethyl-metribuzin affected grain yield, and at SARS, yield was increased by quinclorac at 280 g ha^{-1} more than by quinclorac at 560 g ha^{-1}. Neither increased yield as much as metribuzin.

Dockage was relatively low in all of the PARS experiments and was not affected by any of the herbicide treatments. However, in agreement with the yield data, dockage was reduced with all herbicide treatments at SARS.

Application timing experiments. In these five experiments, there were no interactions associated with location or application timing in the visual estimates of cheat control. Thus, the data were pooled across these factors. Averaged over location and application timings, quinclorac at 420 g ha^{-1} and 560 g ha^{-1} controlled cheat 20 and 31%, respectively, showing a significant rate response. Averaged over location and herbicide treatment, quinclorac applied PPI, PRE, early POST, and late POST controlled cheat 22, 27, 19, and 33%, respectively. Analysis of the transformed data indicated that cheat control with quinclorac applied late POST was better than with quinclorac applied PPI or early POST.

No wheat injury was visually detected throughout the growing season with any of the treatments at LBRA-1, NCRS or SCRS. At NARS, metribuzin at 420 g ha^{-1} caused 15% chlorosis soon after application, but no injury was visible at harvest. At LBRA-2, quinclorac at 560 g ha^{-1} applied to tillered wheat caused 10% injury evident as onion-leafing or leaf rolling, and wheat heads which were bent or hooked in appearance, frequently with trapped awns.

Grain yield at LBRA-1 was increased when quinclorac at 420 and 560 g ha^{-1} was applied to tillered wheat (Table 4). Grain yield was not affected by any herbicide treatments at SCRS. At LBRA-2 quinclorac at 560 g ha^{-1} applied to tillered wheat reduced yield compared to quinclorac at 420 and 560 g ha^{-1} applied before tillering. Also, quinclorac at 420 g ha^{-1} applied before tillering reduced yield compared to the same rate applied to tillered wheat. At NCRS and NARS, only quinclorac at 560 g ha^{-1} and metribuzin at 420 g ha^{-1} increased yield, respectively. Dockage, pooled over locations and application timings was not affected by quinclorac.

Combinations with chlorsulfuron:metsulfuron. Because of interactions with location the data were analyzed by location. There was no three-way interaction in the visual cheat control data from SCRS. Averaged over quinclorac rate and chlor:met rate, cheat control increased ($P = 0.05$) from 32% with herbicides applied PRE to 39% when herbicides were applied POST. When pooled over chlor:met treatments, cheat control increased ($P = 0.05$) from 25% with no quinclorac applied PRE to 40 and 41% when quinclorac at 420 g ha^{-1} was applied PRE or POST, respectively.

At NCRS , there were no interactions. Cheat control, averaged over chlor:met treatments and application times, increased ($P = 0.05$) from 38 and 40% when quinclorac at 280 and 420 g ha^{-1} was applied, to 53% when no quinclorac was applied. When averaged over quinclorac treatments cheat control increased (P = 0.05) from 17 to 48 to 55 % when chlor:met was applied at 0, 18 and 35 g ha $^{-1}$.

At NARS, there was an interaction between chlor:met treatment and the time of application. Averaged over quinclorac treatments, chlor:met at 18 and 35 g ha^{-1} applied POST controlled cheat 45 and 50%, respectively, compared to 8 to 18% with other treatments, which was a significant increase.

No wheat injury was detected at either SCRS or NCRS. However, at NARS chlor:met at 35 g ha^{-1} applied both PRE and POST was stunting the wheat 10% in January. No injury was detected at harvest.

At SCRS, there were three-way interactions among quinclorac rate, chlor:met rate, and application timing for grain yield and dockage. When applied PRE, only quinclorac at 420 g ha^{-1} plus chlor:met at 35 g ha^{-1} increased yield (Table 5). When applied POST, quinclorac at 280 g ha^{-1} plus chlor:met at 35 g ha^{-1}, and quinclorac at 420 g ha^{-1} plus chlor:met at 18 g ha^{-1} increased yield.

A two-way interaction between quinclorac rate and application timing averaged over chlor:met rate was detected at both NCRS and NARS (P = 0.10). At both sites yield was increased with all treatments. At NCRS averaged over chlor:met rates, quinclorac at 280 and 560 g ha^{-1} applied POST increased grain yield more than other treatments. At NARS, averaged over chlor:met rates, quinclorac at 280 and 420 g ha^{-1} increased yield more when applied POST than when applied PRE.

At SCRS, an interaction between quinclorac, chlor:met, and timing on dockage was detected at the 0.10 level of significance. Dockage was decreased with quinclorac at 420 g ha^{-1} alone, and with quinclorac at 420 and 560 g ha^{-1} plus chlor:met at 35 g ha^{-1} applied PRE. Of the POST treatments applied, only chlor:met at 18 g ha^{-1} did not reduce dockage.

Dockage at NCRS and NARS exceeded 50% in the weedy checks, indicating very heavy cheat infestations. At these sites, a two-way interaction between quinclorac treatment and application timing averaged over chlor:met treatments was detected in the dockage data. At NCRS, all treatments reduced dockage except the chlor:met treatments without quinclorac applied POST. In agreement with the yield data averaged over chlor:met treatments, quinclorac at 280 and 420 g ha^{-1} applied POST decreased dockage more than other treatments. At NARS, all treatments reduced dockage. Averaged over chlor:met treatments quinclorac at 420 g ha^{-1} applied PRE decreased dockage more than quinclorac at 0 or 280 g ha^{-1} applied PRE and quinclorac at 420 g ha^{-1} applied POST decreased dockage the most.

Attempts to correlate the data from quinclorac at 420 g ha^{-1} applied PRE in four of the application timing experiments and the three combination experiments with various factors were not very successful. Neither d from planting to treatment application nor wheat planting depth was correlated with cheat control ($r = 0.07$, $r = -0.06$). Correlations between cheat control and rainfall received 0 to 3, 3 to 7, 7 to 14, 14 to 21, 0 to 7, 0 to 14, and 0 to 21 DAT revealed that rainfall received 14 to 21 d after application was positively correlated with cheat control ($r = 0.88$, $P = 0.01$). No correlation was found with other rainfall data.

Soil pH was positively correlated with cheat control ($r = 0.81$, $P = 0.03$) from quinclorac at 420 g ha^{-1} applied PRE, indicating that greater control should be expected as soil pH increases.

Cheat control from the same seven experiments with quinclorac at 420 g ha^{-1} applied POST was not correlated with rainfall amounts received during any of the intervals or d from planting to treatment. Cheat growth stage at the time of application was negatively correlated with cheat control ($r = -0.67$, $P = 0.10$), indicating that greater control should be expected on smaller plants.

Cultivar tolerance experiments. At SARS, there was an interaction of cultivar and quinclorac treatment on grain yield (Table 6). Quinclorac at 280 g ha^{-1} decreased yield only on the cultivar Chisholm. However, quinclorac at 560 g ha^{-1} reduced yields of all cultivars except Mesa, Cimarron, and 2180. Chisholm and TAM 200 yields were reduced more than 50% compared to their respective checks.

At LBRA, quinclorac treatments had no affect on any cultivar, while at PARS, averaged over cultivars, yields were increased from 2200 kg ha^{-1} in the check to 2360 and 2410 kg ha^{-1} (LSD 0.05 = 155) when quinclorac at 280 and 560 g ha^{-1} was applied, respectively. The PARS site was weed free in all plots the entire season, but some cultivars lodged severely before harvest. Lodging varied from 2 to 76% depending on cultivar, and averaged over cultivar, 54% of the wheat was completely lodged. Averaged over cultivar, quinclorac at 560 g ha^{-1} reduced lodging to 33%. The differences in yield may have resulted from differences in harvesting efficiency.

Synergism experiments. In the greenhouse, quinclorac alone or in combination with all pesticides except MCPA reduced the leaf area of cheat in the first run of the experiment (Table 7). In the second run, quinclorac plus each of the pesticides reduced the leaf area, as did chlor:met alone. In both runs, quinclorac plus chlor:met reduced the dry root weight of cheat. In contrast, MCPA and esfenvalerate increased the dry root weight in the first run. A synergistic response with respect to leaf area reduction was determined with mixes of quinclorac and dicamba, esfenvalerate, picloram, or chlor:met. The same was determined in the second run with quinclorac and dicamba, esfenvalerate and 2,4-D. Synergism was also determined on root weight reduction in the first run with quinclorac and esfenvalerate. None of the combinations were antagonistic. Thus, mixes of quinclorac with dicamba or esfenvalerate consistently decreased the leaf area of cheat more than could be attributed to additive effects, and quinclorac plus esfenvalerate decreased the dry root weight of cheat in one run more than would be expected from additive effects.

Additive experiments. Injury to the wheat was typical to that noticed in field experiments in that the leaves were rolled. Quinclorac plus any additive or the two pesticides reduced the leaf area of wheat in both runs except that leaf area was not reduced in the first run with one of the non-ionic silicone surfactants[7] (Table 8). Quinclorac alone did not reduce wheat foliage dry weight in either run. None of the adjuvants significantly affected quinclorac activity. Quinclorac plus chlor:met severely injured the wheat in both runs.

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[7]Tegopren 5878, a polyether-polymethylsiloxane-copolymer. Goldschmidt Chemical Corp., Hopewell, VA 23860.

Pooled across runs, all treatments reduced the leaf area of cheat. Of the additives, only BCH 864 01S reduced cheat leaf area more than quinclorac alone. All treatments except quinclorac alone and with the modified oil additive reduced cheat dry weights in both runs. The quinclorac plus chlor:met combination reduced cheat leaf area more than other treatments. Thus, there was evidence that BCH 864 01S, the additive used in the applications to tillered wheat studies at PARS during 1990-91 was a more effective additive than the modified oil additive used in all field studies in 1991-92.

This research indicates that cheat control with quinclorac is variable, however control appears to be greater at later application timings. Quinclorac at 140 and 280 g ha^{-1} proved ineffective on cheat, while quinclorac at 420, 560, and 1120 g ha^{-1} caused onion-leafing to develop on cheat plants. Tank mixes of quinclorac plus chlor:met increased yields more than either of the herbicides used alone in one of three experiments.

Little crop injury was observed throughout the field experiments, indicating wheat tolerance to quinclorac. However, in cultivar tolerance studies, some wheat cultivars appeared much more sensitive than others.

Greenhouse experiments indicated that combinations of quinclorac and some growth regulating type pesticides are synergistic on cheat with respect to leaf area and dry root weight. Additional experiments showed differences in activity of quinclorac on wheat and cheat when different additives were used including BCH 864 01S and a modified oil additive, the two additives used in field experiments.

The variable results obtained throughout this research imply the need for further investigations of proper timing, ideal use rates, and possible tank mix combinations, to fully understand quinclorac and its place as a possible cheat control herbicide.

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Table 1. Sites, dates of seeding and herbicide applications, cheat densities, and soil characteristics for twelve cheat control experiements.

Experiment	Site	Date seeded	Quinclorac applications: 1-5 leaves	Quinclorac applications: 2-8 tillers	Metribuzin application	Cheat density	Soil: Tex[a]	Soil: pH	Soil: OM[a]
						plant m^{-2}			%
Application to tillered wheat	PARS-1[a]	Sep 28, 90		Nov 30, 90	Oct 30, 90[b]	110	L	4.9	1.4
	PARS-2	Sep 28, 90		Nov 30, 90	Nov 17, 90	160	L	4.8	1.4
	PARS-3	Oct 04, 90		Nov 30, 90	Nov 01, 90[b]	110	L	5.2	1.1
	SARS[a]	Oct 10, 91		Nov 21, 91	Dec 06, 91	220	L	5.5	1.7
Application timing	LBRA-1[a]	Oct 01, 91[cd]	Oct 16, 91	Dec 06, 91	Jan 10, 92	480	L	5.6	1.2
	LBRA-2	Oct 01, 91[cd]	Oct 16, 91	Dec 06, 91	Jan 10, 92	0	L	5.6	1.2
	NARS[a]	Sep 17, 91[cd]	Sep 30, 91	Oct 11, 91	Nov 25, 91	460	SCL	6.3	1.6
	NCRS[a]	Sep 19, 91[cd]	Oct 03, 91	Oct 15, 91	Jan 03, 92	220	L	6.1	1.5
	SCRS[a]	Oct 08, 91[cd]	Oct 18, 91	Nov 21, 91	Jan 30, 92	480	CL	6.7	1.9
Combinations with chlorsulfuron: metsulfuron	NARS	Oct 17, 91[d]	Nov 27, 91			610	SCL	6.2	1.5
	NCRS	Sep 19, 91[de]	Jan 03, 91			270	L	6.5	1.6
	SCRS	Oct 08, 91[d]	Oct 18, 91			480	L	7.6	1.1

Table 1. Continued.

[a]Abbreviations used: LBRA = Lake Carl Blackwell Research Area; NARS = North Agronomy Research Station; NCRS = North Central Research Station; SCRS = South Central Research Station; PARS = Perkins Agronomy Research Station; SARS = Stillwater Agronomy Research Station; Tex = texture; OM = organic matter.

[b]Standard treatment was ethyl-metribuzin.

[c]PPI treatments were applied on this date.

[d]PRE treatments were applied on this date.

[e]Experiment was replanted on October 16, 1992.

Table 2. Intervals from application to precipitation of 1.3 cm or more.

	Quinclorac applications				Standard
Experiment	PPI	PRE	1-4LF[a]	2-8TL[a]	treatment
	d				
LBRA[a]	25	25	10	5	3
NARS[a]	1	1	26	15	17
NARS	-	9	15	-	-
NCRS	39	39	25	13	-
NCRS[a]	-	39	19	-	-
PARS-1[a]	-	-	-	27	12
PARS-2	-	-	-	27	17
PARS-3	-	-	-	27	3
SARS[a]	-	-	-	21	6
SCRS[a]	20	20	10	21	25
SCRS	-	20	10	-	-

[a]Abbreviations used: LF = leaves; TL = tillers; LBRA = Lake Carl Blackwell Research Area; NARS = North Agronomy Research Station; NCRS = North Central Agronomy Research Station; PARS = Perkins Agronomy Research Station; SARS = Stillwater Agronomy Research Station; SCRS = South Central Research Station.

Table 3. Cheat control, grain yield, and grain dockage in four experiments with applications to tillered wheat.

			Location			
Response	Treatment	Rate	PARS-1[a]	PARS-2	PARS-3	SARS[a]
		g ha^{-1}	%			
Cheat control	Quinclorac	280	-	-	-	68
	Quinclorac	560	93	90	97	93
	Quinclorac	1120	97	93	100	-
	Metribuzin	420	-	97	-	94
	Ethyl-metribuzin	1120	58	-	93	-
	Check		0	0	0	0
	LSD (0.05)		8	10	3	16
			kg ha^{-1}			
Grain yield	Quinclorac	280	-	-	-	2990
	Quinclorac	560	1270	810	1140	2560
	Quinclorac	1120	1260	670	1130	-
	Metribuzin	420	-	1240	-	3420
	Ethyl-metribuzin	1120	1530	-	2170	-
	Check		1510	1110	1570	2020
	LSD (0.05)		NSD	220	560	300
			%			
Grain dockage	Quinclorac	280	-	-	-	9
	Quinclorac	560	4	8	9	7
	Quinclorac	1120	3	9	6	-
	Metribuzin	420	-	9	-	5
	Ethyl-metribuzin	1120	4	-	6	-

Table 3. Continued.

Check	6	11	11	35
LSD (0.05)	NSD	NSD	NSD	6

[a]Abbreviations used: PARS = Perkins Agronomy Research Station; SARS = Stillwater Agronomy Research Station.

Table 4. Interactions of quinclorac and application timing on grain yield and dockage in five experiments.

Treatment	Rate	Timing	Grain yield					Grain dockage
			Locations					
			LBRA-1[a]	LBRA-2	NARS[a]	NCRS[a]	SCRS[a]	Mean
	g ha^{-1}		kg ha^{-1}					%
Quinclorac	420	PPI	1330	1820	500	760	1220	32
Quinclorac	560		1180	1740	490	-	1380	32
Quinclorac	420	PRE	1260	1830	530	780	1530	32
Quinclorac	560		1390	1760	530	960	1390	30
Quinclorac	420	1-4LF	1330	1900	500	680	1440	32
Quinclorac	560		1580	1860	500	1040	1380	28
Quinclorac	420	2-8TL	1760	1650	400	880	1090	30
Quinclorac	560		1960	1610	-	1140	1360	17
Metribuzin	420	3-19TL	1610	1780	1010	-	1100	18
Check			1300	1720	500	850	1140	34
LSD (0.05)			400	220	120	280	NSD	NSD

Table 4. Continued.

[a]Abbreviations used: LBRA = Lake Carl Blackwell Research Area; NARS = North Agronomy Research Station; NCRS = North Central Research Station; SCRS = South Central Research Station.

Table 5. Interactions of quinclorac, chlorsulfuron:metsulfuron, and timing on grain yield and dockage of wheat at three locations.

		SCRS[a]						NCRS[a]		NARS[a]	
		Application timing									
		PRE			POST			PRE	POST	PRE	POST
	Quinclorac	Chlorsulfuron:metsulfuron (g ha^{-1})									
Response	rate	0	18	35	0	18	35	mean	mean	mean	mean
	g ha^{-1}	kg ha^{-1}									
Grain yield	0	-	1390	1590	-	1520	1480	960	930	1020	1080
	280	1420	1440	1440	1580	1500	1900	940	1070	800	1160
	420	1420	1220	1850	1620	1910	1340	910	1110	970	1230
	Check	1450						810		580	
LSD (0.05)		380						80		NS	
LSD (0.10)										100	
		%									
Grain dockage	0	-	20	15	-	16	14	62	64	39	37
	280	17	16	11	13	12	8	56	40	42	21

Table 5. Continued.

	420	14	16	11	14	8	12	60	36	34	16
	Check			——— 19 ———				——— 70 ———		——— 51 ———	
LSD (0.05)				——— NS ———				——— 6.5 ———		——— 4.8 ———	
LSD (0.10)				——— 3.5 ———							

[a]Abbreviations used: SCRS = South Central Research Station; NCRS = North Central Research Station; NARS = North Agronomy Research Station.

Table 6. Interactions of cultivar and quinclorac on grain yield at three locations.

	SARS[a]			LBRA[a]	PARS[a]
	Quinclorac rates (g ha^{-1})				
Cultivar	0	280	560	Mean	Mean
	kg ha^{-1}				
Arapahoe	2300	2450	1540	1680	2260
Chisholm	3450	2200	1500	1870	2790
Cimarron	2440	2540	2160	1820	2620
Karl	2680	2330	1570	1690	2730
Mesa	1810	2040	1720	2020	2430
Newton	2060	1690	1130	1220	1450
TAM 101	2500	2910	1640	1100	1840
TAM 200	2200	2200	970	1100	2190
2180	2190	2380	2270	1130	2600
LSD (0.05)	390			370	270

[a]Abbreviations used: SARS = Stillwater Agronomy Research Station; LBRA = Lake Carl Blackwell Research Area; PARS = Perkins Agronomy Research Station.

Table 7. Leaf area and root dry weight of cheat in two greenhouse experiments.

Treatment	Rate	Run 1				Run 2			
		Leaf area[b]		Root wt		Leaf area		Root wt	
		Quinclorac (g ha^{-1})							
		0	280	0	280	0	280	0	280
	g ha^{-1}	— cm^2 —		— g —		— cm^2 —		— g —	
Quinclorac	280	145	103	2.8	2.20	154	120	1.1	0.70
2,4-D	140	112	84	1.6	1.70	149	74[+]	0.7	0.70
MCPA	140	154	119	5.9	1.50	156	91	1.4	0.90
Dicamba	35	148	85[+]	2.8	1.00	156	85[+]	1.5	0.70
Picloram	0.9	167	99[+]	2.2	3.40	160	95	1.3	1.10
Chlor:met[a]	18	162	30[+]	1.9	0.30	91	71	0.4	0.30
Esfenvalerate	560	168	62[+]	5.3	1.40[+]	155	58[+]	1.4	0.50
LSD (0.05)		— 35 —		— 2.5 —		— 37 —		— 0.7 —	

[a]Chlor:met = chlorsulfuron:metsulfuron (5:1).

[b]Positive sign = synergism.

Table 8. Effect of quinclorac at 280 g ha^{-1} applied alone and with each of eight different additives on leaf area and dry weight of wheat and cheat in a laboratory.

		Wheat				Cheat		
		Leaf area		Dry weight		Leaf area	Dry weight	
Additive	Rate	Run 1	Run 2	Run 1	Run 2	Mean	Run 1	Run 2
	% v/v	—— cm^2 ——		—— g ——		cm^2	g	g
None	-	36	52	0.23	0.33	9	0.04	0.07
Non-ionic silicone surfactant[a]	0.1	39	49	0.25	0.31	11	0.05	0.05
Non-ionic silicone surfactant[a]	0.1	36	59	0.24	0.37	9	0.04	0.06
Non-ionic silicone surfactant[a]	0.1	32	50	0.20	0.30	7	0.04	0.05
Ag-98[b]	0.25	38	50	0.26	0.30	7	0.05	0.06
	L ha^{-1}							
Crop oil concentrate[c]	2.3	34	54	0.22	0.33	7	0.03	0.05
Modified oil additive[d]	2.3	35	53	0.23	0.34	7	0.03	0.07
Modified vegetable oil[d]	2.3	31	53	0.21	0.33	7	0.04	0.06
BCH 864 01S[e]	2.3	31	57	0.21	0.36	5	0.04	0.04

Table 8. Continued

	g ha^{-1}							
Chlor:met[f,g]	18	11	15	0.10	0.10	2	0.01	0.03
Esfenvalerate[g]	560	32	55	0.22	0.34	5	0.03	0.03
Check		52	69	0.28	0.36	17	0.08	0.09
LSD (0.05)		9	11	0.06	0.08	3	0.02	0.03

[a]Tegopren 5840, Tegopren 5878, and Silwet L-77 non-ionic silicone surfactants, respectively. Available from Goldschmidt Chemical Corp., Hopewell, VA 23860 and Union Carbide Chemicals and Plastics Co., Inc., Danbury, CT 06817-0001, respectively.

[b]Alkylaryl polyoxyethylene glycols non-ionic surfactant. Available from Rohm and Haas Co., Philadelphia, PA 19105.

[c]Crop oil concentrate. Available from Cornbelt Chemical Co., Inc., McCook, NE 69001.

[d]Sun-it II modifield oil additive and Scoil modified vegetable oil plus emulsifier, respectively. Available from Agsco, Inc., Grand Forks, ND 58206-0458.

[e]Experimental additive available from BASF Corp., Parsippany, NJ 07054.

[f]Abbreviations: Chlor:met = chlorsulfuron:metsulfuron (5:1).

[g]Treatments included Sun-it II at 2.3 L ha^{-1}.

VITA

Lora M. Franetovich

Candidate for the Degree of

Master of Science

Thesis: EVALUATION OF QUINCLORAC FOR CHEAT (*Bromus secalinus* L.) CONTROL IN WINTER WHEAT (*Triticum aestivum* L.)

Major Field: Agronomy

Biographical:

Personal Data: Born in Minehill, New Jersey, July 23, 1969, the daughter of Paul and Sandy Franetovich.

Education: Graduated from Bethel High School, Shawnee, Oklahoma, in May 1987; received Bachelor of Science degree in Agronomy from Oklahoma State University, May 1991; completed requirements for the Master of Science degree in Agronomy at Oklahoma State University in May, 1993.

Professional Experience: Graduate Research Assistant, Department of Agronomy, Oklahoma State University, May 1991 to May 1993. Office Assistant, Department of Agronomy, OSU, August 1990 to May 1991. Summer Intern, E. I. DuPont de Nemours & Co., Inc., Agric. Prod. Dept., May 1990 to August 1990. Laboratory Assistant, Department of Agronomy, OSU, May 1989 to May 1990. Check-out supervisor and register operator, K-Mart, Shawnee, OK, September 1986 to May 1989.

Professional Organizations:
Southern Weed Science Society
Weed Science Society of America
American Society of Agronomy
Crop Science Society of America