EFFECTS OF FIVE COOL-SEASON ANNUAL GRASSES ON HARD RED WINTER WHEAT GRAIN YIELD AND QUALITY

By

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THESIS FORMAT

This thesis was formatted to facilitate publication in *Weed Science*,

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Chapter I

Effects of Five Cool-Season Annual Grasses on Hard Red Winter Wheat. I. Grain Yield

Effects of Five Cool-Season Annual Grasses on Hard Red Winter Wheat.

I. Grain Yield

Cheat, feral rye, Italian ryegrass, jointed goatgrass, and wild oats are common weeds of hard red winter wheat in Oklahoma. Field experiments were conducted near Altus, Perkins, Stillwater, and Lahoma, OK to quantify the wheat grain yield losses resulting from season-long interference of those weeds with wheat. Plots at each location were seeded with one of the five above mentioned weed species at one of seven seeding rates. Weed seed were broadcast over plots, incorporated with shallow tillage, and then wheat was planted in all plots at a rate of 84 kg ha^{-1}. Rainfall received within 10 days after planting influenced the time of weed emergence relative to wheat emergence which influenced the weeds' abilities to reduce crop yields; therefore, yield losses varied significantly within weed species across locations. Wheat grain yield and yield loss were regressed as a function of weed density for each weed species at each location using a rectangular hyperbolic regression model. In addition, the regression equations were used to estimate yield losses caused by each weed at each location at a density of 30 plants m^{-2}. Because density was held constant, those yield losses could be compared across weed species within each location. At Stillwater, where wheat yield was reduced the most, the regression equations (at a density of 30 plants m^{-2}) estimated yield losses of 33.0 (cheat), 84.3 (feral rye), 46.4 (Italian ryegrass), 24.8 (jointed goatgrass), and 41.4% (wild oats). Maximum observed weed densities recorded at Stillwater were 51 (cheat), 56 (feral rye), 71 (Italian ryegrass), 60 (jointed goatgrass), and 78 (wild oats) plants m^{-2}, and the corresponding yield losses were 39.7, 94.6, 77.3, 32.8, and 52.2%, respectively. At

Lahoma, where wheat yield was reduced the least, the regression equations (at a density of 30 plants m^{-2}) estimated yield reductions of 15.1 (cheat), 36.4 (feral rye), 13.5 (Italian ryegrass), 23.2 (jointed goatgrass), and 20.9 % (wild oats). Maximum weed densities recorded at Lahoma were 34 (cheat), 46 (feral rye), 51 (Italian ryegrass), 126 (jointed goatgrass), and 34 (wild oats) plants m^{-2}, and the corresponding yield losses were 13.4, 35.5, 11.7, 17.7, and 21.1%, respectively.

Nomenclature: Cheat, *Bromus secalinus* L., BROSE; feral rye, *Secale cereale* L. SECCE; Italian ryegrass, *Lolium multiflorum* Lam., LOLMU; jointed goatgrass, *Aegilops cylindrica* Host, AEGCY; wild oats, *Avena fatua* L., AVEFA; wheat, *Triticum aestivum* L. 'Jagger'.

Key words: Weed competition; weed density; weed interference; wheat yield loss; wheat yield loss threshold.

In 2006 the United States produced 18.6 million metric tons of hard red winter wheat, and Oklahoma produced 11.8% of that total on 1.3 million ha (USDA–NASS 2006). Approximately 98% of the wheat produced in the state is hard red winter wheat (USDA–NASS 2006); therefore, "wheat" in this paper will refer to that type of wheat, unless specified otherwise. Because wheat production is so important to the United States and, specifically, to Oklahoma, scientists must learn how to effectively manage the yield-limiting factors of wheat production, such as weeds, and communicate that information to others. Weeds reduce crop yields by what is often called "competition"; however, the term "interference" is more appropriate because it encompasses all of the effects that weeds have on crops. Interference is "...an all-inclusive term that denotes all the direct effects that one plant might impose on another, such as competition, allelopathy, parasitism, and indirect effects (usually unknown) without referring to any one effect in particular" (Anderson 1996).

Cheat, feral rye, Italian ryegrass, jointed goatgrass, and wild oats are among the 10 most common and 10 most troublesome weeds of wheat in Oklahoma (Webster 2004). Cheat is the most prevalent grassy weed of wheat in Oklahoma (Justice et al. 1993), and cheat interference in wheat causes losses by reducing forage and grain yields, delaying harvest operations, and increasing dockage (Ratliff and Peeper 1987). A 1998 survey revealed that in three of Oklahoma's largest wheat-producing counties (i.e., Alfalfa, Garfield, and Kingfisher), 70 to 89% of production fields were infested to some degree with cheat (Barnes et al. 1999). No published data were found that related cheat interference to wheat yield loss; however, an experiment investigating the control of cheat with the experimental herbicide MON 37500 reported that cheat densities of 90 to 270 plants m^{-2} and a mean cheat control of 88% resulted in yield increases of up to 69% compared to the untreated check (Kelley and Peeper 2003). Assuming that the herbicide caused no yield loss due to crop injury, this suggests that cheat plants at that density can reduce wheat yield by 69%.

Feral rye is also a significant weed problem in the wheat-producing regions of the United States, including Oklahoma (Roberts et al. 2001). In 1994, feral rye, jointed goatgrass, and downy brome (*Bromus tectorum* L.) infested approximately 0.5 million ha of wheat in Colorado (Stump and Westra 1994). In southwest Montana, feral rye interference reduced wheat yield by more than 50% (Coble and Fay 1985); and in Oregon, season-long interference with 194 feral rye plants m^{-2} reduced wheat yield 69% (Rydrych 1987). Barnes and Putnam (1986) reported that feral rye has allelopathic properties.

Shortly after Italian ryegrass was introduced as a forage crop into Oklahoma, it became a prevalent weed in wheat throughout the state (Barnes et al. 2001). Appleby et al. (1976) in western Oregon found that wheat yield reductions in semidwarf cultivars were 24 and 39% at Italian ryegrass densities of 39 and 99 plants m^{-2}, respectively. Hashem et al. (1998) conducted similar research in Oregon and reported that Italian ryegrass densities of 25 and 400 plants m^{-2} reduced wheat yields 42 and 92%, respectively.

A 1988 survey of weed scientists revealed that jointed goatgrass infested approximately 1.2 million ha of all classes of winter wheat in the United States and that the weed was a significant problem in small grains production in Colorado, Kansas, New Mexico, Oklahoma, Oregon, Utah, Washington, and Wyoming (Donald and Ogg 1991).

Anderson (1993) in Colorado reported that interference from 18 jointed goatgrass plants m^{-2} reduced wheat yield 27%. A comprehensive literature review of jointed goatgrass publications cites an immediate need for additional research, including yield reduction data relative to jointed goatgrass density (Donald and Ogg 1991).

Wild oats first entered southwest Oklahoma from north central Texas in the early 1970s and has since spread to the northern boundary of Oklahoma (Geis 1994). Martin et al. (1987) in Australia reported that when wheat was seeded at 11 kg ha^{-1}, wild oats densities of 23 and 336 plants m^{-2} reduced yields 28 and 77%, respectively. When wheat was seeded at 88 kg ha^{-1}, wild oats densities of 11 and 238 plants m^{-2} reduced yields 11 and 44%, respectively. Increasing wheat density marginally decreased the yield-reducing effects of wild oats, although yield losses still increased as wild oats density increased.

In Oklahoma, the most recent weed interference experiments have been conducted with cotton (*Gossypium hirsutum* L.) (Wood et al. 2002), peanut (*Arachis hypogaea* L.) (Farris and Murray 2006), and sorghum (*Sorghum bicolor* (L.) Moench.) (Moore et al. 2004), but no such research has been conducted with wheat. The objective of this research was to quantify the wheat grain yield losses resulting from interference with the five previously discussed weeds. Ultimately, the findings will aid scientists, agronomists, and wheat producers in making well-informed weed-management decisions by allowing them to estimate the yield impacts that those weeds may cause.

Materials and Methods

Field experiments were conducted on agricultural experiment stations near Altus, Perkins, and Stillwater, OK in 2004-2005 and near Lahoma and Perkins, OK in 2005-2006. Experiments were conducted on a Tillman clay loam (fine, mixed, superactive, thermic Vertic Paleustolls) at Altus, a Teller fine sandy loam (fine-loamy, mixed, active, thermic Udic Argiustolls) at Perkins, an Easpur loam (fine-loamy, mixed, superactive, thermic Fluventic Haplustolls) at Stillwater, and a Pond Creek silt loam (fine-silty, mixed, superactive, thermic Pachic Argiustolls) at Lahoma. Soil pH was 7.1 at Altus, 6.7 at Perkins in 2004-2005, 7.1 at Stillwater, 5.9 at Lahoma, and 6.0 at Perkins in 2005-2006. Organic matter content was 0.9% at Altus, 0.7% at Perkins in both seasons, 0.6% at Stillwater, and 1.5% at Lahoma.

Approximately 1 mo prior to planting, soil samples were taken at each location and submitted to a soil analytical laboratory[1] to determine the fertilizer requirements to reach a 3360 kg ha^{-1} yield goal. Each location was then fertilized based on the results of those laboratory analyses.

Members of the grass (Poaceae) family produce a one-seeded, indehiscent fruit, known as a “caryopsis” (Tyrl et al. 2002). For simplicity, caryopses are referred to hereafter as “seed”, even though the term is botanically incorrect. To establish weed populations, the appropriate species and number of seed were broadcast over a plot with a cone seeder-style grain drill immediately prior to wheat planting. The seed delivery tubes were removed from the grain drill’s furrow openers and fastened to the frame of the drill at equal distances from each other. The bottoms of the tubes were approximately 25 cm above the soil surface; and as the seed were metered out of the cone seeder, they flowed through the tubes and landed on the soil surface in a relatively uniform distribution pattern. After weed seed were broadcast, they were incorporated into the soil to a depth of approximately 1 cm with an S-tine cultivator with rolling baskets.

The wheat cultivar ‘Jagger’ was planted at a rate of 84 kg ha^{-1} to establish a crop stand of approximately 2.5 million plants ha^{-1}. In 2004-2005, planting occurred on October 6 at Stillwater, October 18 at Perkins, and October 20 at Altus. In 2005-2006, planting was accomplished on September 21 at Perkins and October 12 at Lahoma. The experimental design was a randomized complete block with four replications of each treatment. Plots were 7 rows (1.3 m) wide by 12.2 m long with 19-cm row spacing.

In 2004-2005, seed of all weed species were broadcast at rates of 28, 56, 112, and 224 seed m^{-2}. In 2005-2006, cheat, Italian ryegrass, and jointed goatgrass were seeded at rates of 28, 56, 112, 224, 448, 672, and 896 seed m^{-2}; wild oats at rates of 14, 28, 56, 112, 224, 448, and 672 seed m^{-2}; and feral rye at rates of 7, 14, 28, 56, 112, 224, and 448 seed m^{-2}. Experiments also included a weed-free treatment. In both years, weed populations were quantified 150 days after emergence by counting the number of weeds in 0.2 m^2 (the area between adjacent wheat rows for a length of 1 m). To increase precision of the weed density data, counts were conducted at two randomly selected sites within each plot, and the mean of those two observations was used as weed density.

To eliminate end-row effects, grain was harvested from 9.1 m of the 12.2 m plots. The remainder of the plot length was destroyed by mowing 1.55 m of wheat from each end of the plots immediately prior to harvest. Wheat was harvested with a plot combine; and in 2004-2005, harvest occurred on June 7 at Stillwater, June 8 at Perkins, and June 9 at Altus. In 2005-2006, wheat was harvested on May 30 at Perkins and June 6 at

Lahoma. Grain yield and moisture content were measured in the field; and grain was placed in storage so that quality factors could be measured later at the Oklahoma State University Stored Products Research and Education Center[2]. Dockage and foreign material were subtracted from plot yields, and yields were adjusted to 12% moisture before data analyses. Procedures used for measuring grain quality followed the official standards set forth by the United States Department of Agriculture-Federal Grain Inspection Service (USDA–FGIS 2004). A detailed description of those quality factors and the procedures used to measure them are included in an accompanying publication on the effects of weed interference on wheat grain quality (Fast et al. 2007).

Statistical Analyses

Variability in wheat grain yield and yield loss prevented pooling of the data across locations; therefore, each experiment was analyzed separately. Wheat yield and yield loss were regressed as a function of weed density. Percentage yield loss was calculated by subtracting plot yield from the maximum potential yield, dividing by the maximum potential yield, and multiplying by 100. Maximum potential yield was the mean of the four highest yields from the experiment (the highest yield from each replication of treatments). By using the maximum potential yield instead of the yield from the weed-free treatment, the number of negative yield loss values was reduced and the fit of the regression models improved. Use of maximum potential yield instead of the weed-free yield has been implemented by others (Jasieniuk et al. 1999; Jasieniuk et al. 2001). Linear regression models fit the data very poorly, and quadratic models predicted a biologically unrealistic increase in wheat yield (or decrease in yield loss) as weed densities neared their maximum value. These problems were consistent with statements by Cousens (1991) that linear models are "only appropriate at low densities" and that quadratic models produce "a biologically implausible turning point". To avoid those problems, a rectangular hyperbolic regression model was fit to the data. Cousens (1985) developed this model and used samples of data from the literature to demonstrate that the model was appropriate for explaining the relationship between weed interference and crop yield. Yield as a function of weed density was modeled using Equation 1 (Cousens 1988).

$$Y = B[1 - ID/(1 + ID/A)] \qquad [1]$$

Where Y is the crop yield, B is the maximum potential yield, I is the decrease in yield per unit increase in weed density (the initial slope of the curve), D is the weed density, and A is the asymptote for yield (the yield as weed density approaches infinity). Yield loss was modeled using Equation 2 (Cousens 1985).

$$Y_L = (ID)/[1 + (ID/A)] \qquad [2]$$

Where Y_L is the yield loss (%), I is the yield loss per weed as weed density approaches zero (the initial slope of the curve), D is the weed density, and A is the upper asymptote for yield loss (the percent yield loss as weed density approaches infinity). Parameter estimates for both models were determined using the Gauss-Newton least squares estimation method via the NLIN procedure in SAS (SAS 2002). The rectangular hyperbolic regression model has been used in numerous publications to relate weed density to crop yield loss with several weed vs. crop species (Askew and Wilcut 2001; Clewis et al. 2001; Harrison et al. 2001; Jasieniuk et al. 2001; Martin et al. 1987; Pester et al. 2000; Webster et al. 2000). Wheat yield and yield loss were modeled because yield loss models do not provide information about wheat yields of experiment locations relative to each other.

Results and Discussion

Wheat grain yield and yield losses varied significantly for each weed species across locations; therefore, regression models were calculated at each location. Those models are provided in Figure 1 (cheat), Figure 2 (feral rye), Figure 3 (Italian ryegrass), Figure 4 (jointed goatgrass), and Figure 5 (wild oats). To compare the relative interference of these weeds with wheat, regression equations were used to estimate yield losses caused by each weed at each location at a density of 30 plants m^{-2} (Table 1). Because a common density was used, they can be compared across weeds within each location.

At Altus, yield losses predicted at a weed density of 30 plants m^{-2} ranged from 15.7 to 36.4% (Table 1). Feral rye predicted the greatest reduction of 36.4% and was followed by wild oats (22.3%), cheat (19.7%), Italian ryegrass (15.7%), and jointed goatgrass (15.7%). Maximum weed densities actually observed were 80 (feral rye), 107 (wild oats), 73 (cheat), 83 (Italian ryegrass), and 130 plants m^{-2} (jointed goatgrass); and the corresponding yield losses were 68.2, 33.1, 26.8, 19.3, and 21.0%, respectively.

Yield losses expected with 30 weeds m^{-2} ranged from 15.2 to 45.5% at Perkins in 2004-2005 (Table 1). The largest yield loss was estimated for feral rye (45.5%) with wild oats, jointed goatgrass, cheat, and Italian ryegrass expected to reduce yield by 23.2 to 15.2%, a range of 8.0%. Maximum weed densities recorded were 69 (feral rye), 93 (wild oats), 170 (jointed goatgrass), 76 (cheat), and 88 plants m^{-2} (Italian ryegrass). The resulting yield losses were 65.6, 30.2, 19.0, 17.0, and 21.6%, respectively.

At Stillwater, yield reductions attributable to weeds at a density of 30 plants m^{-2} ranged from 24.8 to 84.3% (Table 1). Feral rye predicted the largest yield reduction of 84.3% followed by Italian ryegrass (46.4%) and wild oats (41.4%) which in turn were greater than cheat (33.0%) and jointed goatgrass (24.8%). Maximum weed densities recorded at Stillwater were 56 (feral rye), 71 (Italian ryegrass), 78 (wild oats), 51 (cheat), and 60 (jointed goatgrass) plants m^{-2}; and the corresponding yield losses were 94.6, 77.3, 52.2, 39.7, and 32.8%, respectively.

At Lahoma, yield losses attributable to weeds at a density of 30 plants m^{-2} ranged from 13.5 to 36.4% (Table 1). Feral rye predicted the largest yield reduction of 36.4% followed by jointed goatgrass (23.2%) and wild oats (20.9%). Cheat and Italian ryegrass predicted yield losses of 15.1 and 13.5%, respectively. Maximum weed densities recorded were 46 (feral rye), 126 (jointed goatgrass), 34 (wild oats), 34 (cheat), and 51 (Italian ryegrass) plants m^{-2}, and the corresponding yield losses were 35.5, 17.7, 21.1, 13.4, and 11.7%, respectively.

At Perkins 2005-2006, yield losses predicted with 30 weeds m^{-2} ranged from 10.1 to 29.4% (Table 1). The largest yield losses were estimated for feral rye (29.4%) and cheat (21.2%). Italian ryegrass, wild oats, and jointed goatgrass were expected to reduce yield by 16.6, 13.9, and 10.1%, respectively. Maximum weed densities recorded were 76 (feral rye), 89 (cheat), 158 (Italian ryegrass), 120 (wild oats), and 190 plants m^{-2} (jointed goatgrass), and the corresponding yield losses were 35.9, 26.8, 24.5, 32.3, and 36.6%, respectively.

Mean yield losses were apparently the greatest at locations that received the most rainfall within 10 days after planting (DAP). Rainfall histograms for each location are provided in Figure 6. The mean yield loss for each location was calculated by summing yield losses across treatments and dividing by the number of treatments in that experiment. Mean yield loss was regressed as a function of total rainfall within 10 DAP. As early rainfall increased, mean yield loss also increased (Figure 7). Differences in the planting depths of wheat and weed seed probably explain why rainfall significantly affected the yield losses at each location. Wheat was planted to a depth of approximately 3 cm, where soil moisture was adequate for germination and emergence. Weed seed were incorporated to a depth of approximately 1 cm, where soil moisture was inadequate. Therefore, weed emergence required rainfall; and wheat emergence did not. Resultantly, at locations that received very little rainfall (e.g., Lahoma), the wheat emerged earlier than the weeds. At locations that received a greater amount of early rainfall (e.g., Stillwater), the wheat and weeds emerged at approximately the same time. Pavlychenko (1937) noted that when crop and weed plants grow together, they simultaneously utilize available resources, and the development of both species is lessened. At locations where wheat emerged earlier than the weeds, the wheat had a competitive advantage and was able to utilize a greater proportion of the available resources than the weeds; therefore, yield losses caused by weeds were relatively small. At locations where wheat and weeds emerged at similar times, the wheat's competitive advantage was reduced, and the wheat and weeds were competing to utilize similar quantities of resources, which resulted in greater yield losses. Several authors have published data that support the hypothesis that the time of weed emergence relative to crop emergence significantly affects the severity of yield losses caused by weeds (Bosnic and Swanton 1997; Chikoye et al. 1995; Dieleman et al. 1995; Knezevic et al. 1997; O'Donovan et al. 1985).

The five weed species included in this research are capable of significantly reducing wheat yield; the severity of the yield loss is dependent on species and density of weeds present and on rainfall within 10 DAP. When making weed management decisions, one should consider yield and grain quality reductions that occur as a result of weed interference with wheat. In an accompanying publication (Fast et al. 2007), the grain quality reductions and resulting price discounts caused by the five weeds included in this paper are quantified.

Sources of Materials

[1] Soil, Water & Forage Analytical Laboratory, Oklahoma State University, 045 Agricultural Hall, Stillwater, OK 74078.

[2] Stored Products Research and Education Center, Oklahoma State University, 305 South Range Road, Satillwater, OK 74074.

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TABLE 1. Wheat grain yield losses estimated by the regression equation[a] for each weed at each location at a density of 30 plants m^{-2}.

	2004-2005			2005-2006	
Weeds	Altus	Perkins	Stillwater	Lahoma	Perkins
			% yield losses		
Cheat	19.7	16.6	33.0	15.1	21.2
Feral rye	36.4	45.5	84.3	36.4	29.4
Italian ryegrass	15.7	15.2	46.4	13.5	16.6
Jointed goatgrass	15.7	18.3	24.8	23.2	10.1
Wild oats	22.3	23.2	41.4	20.9	13.9

[a] Regression equations, graphs, and R^2 values are provided in Figure 1 (cheat), Figure 2 (feral rye), Figure 3 (Italian ryegrass), Figure 4 (jointed goatgrass), and Figure 5 (wild oats).

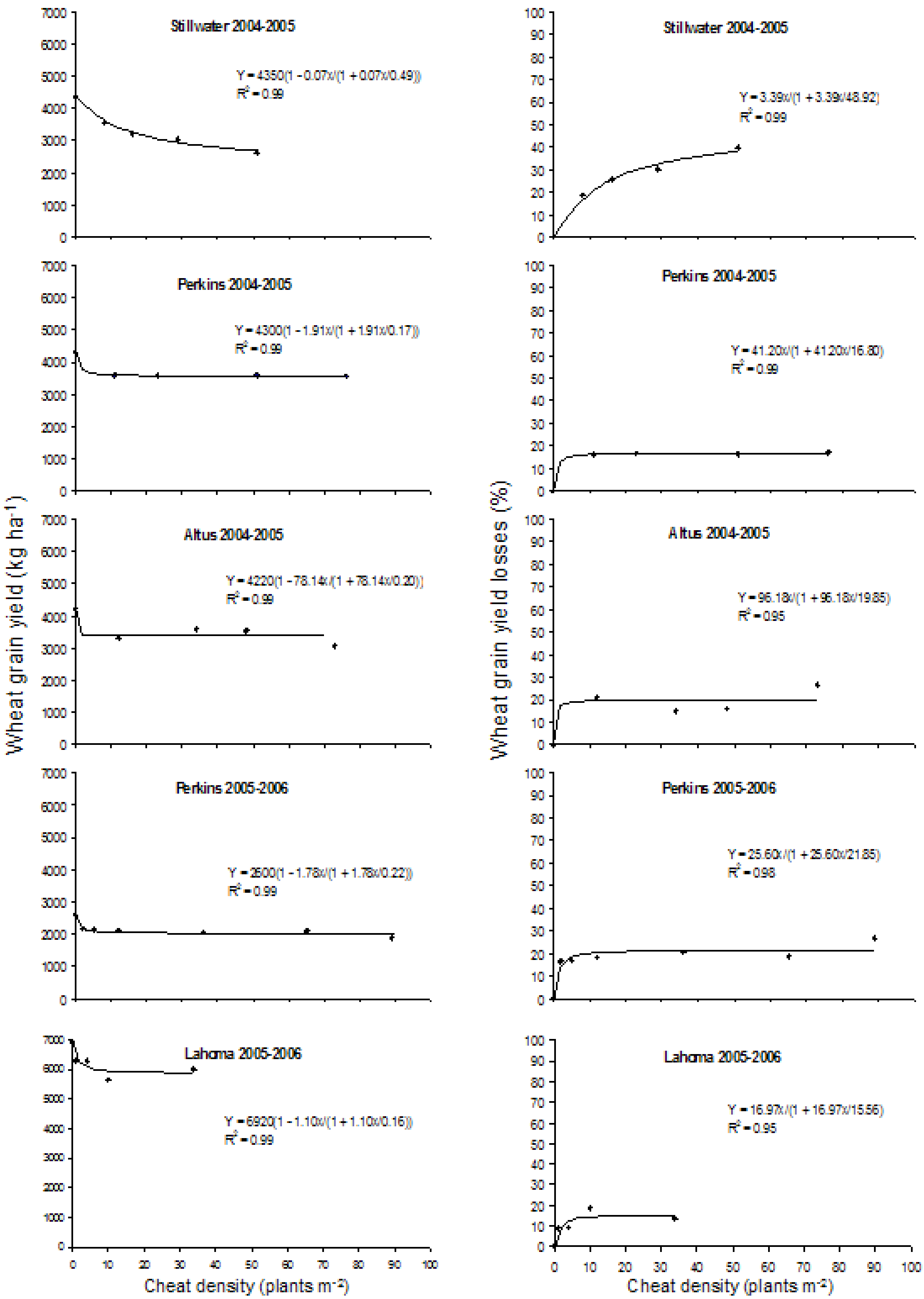

Figure 1. Wheat grain yield and yield losses as a function of cheat density. Cheat densities were quantified 150 days after emergence.

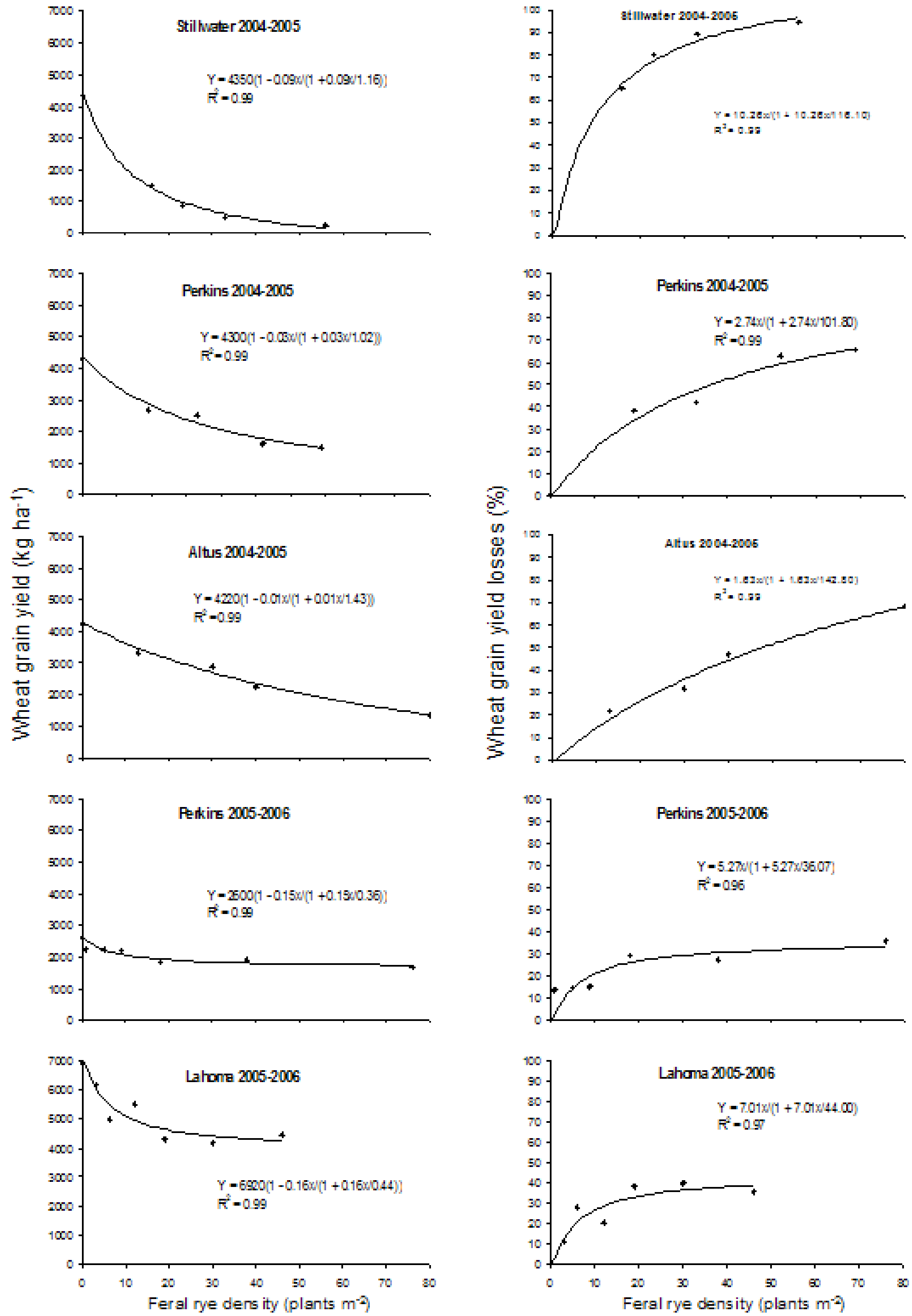

Figure 2. Wheat grain yield and yield losses as a function of feral rye density. Feral rye densities were quantified 150 days after emergence.

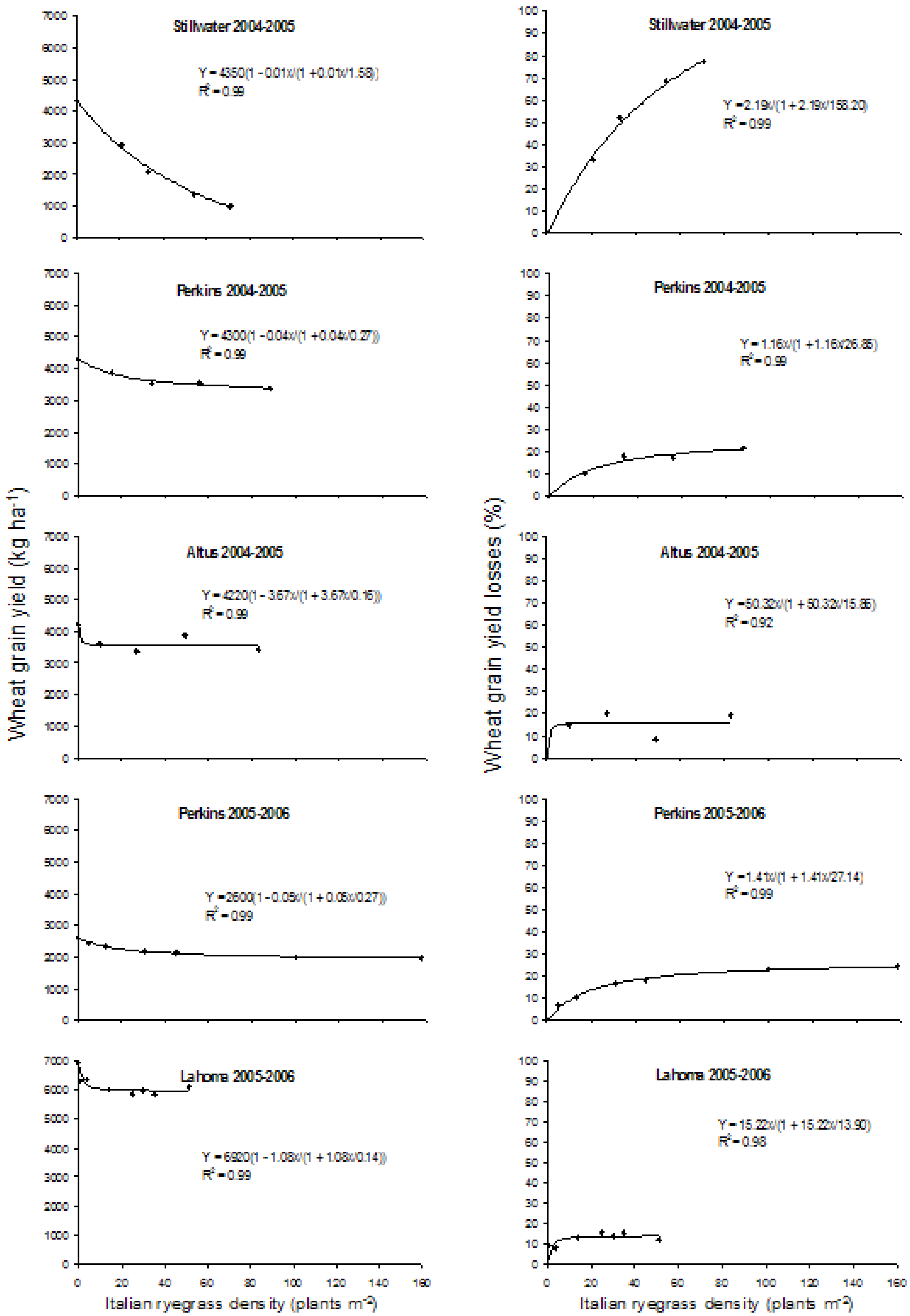

Figure 3. Wheat grain yield and yield losses as a function of Italian ryegrass density. Italian ryegrass densities were quantified 150 days after emergence.

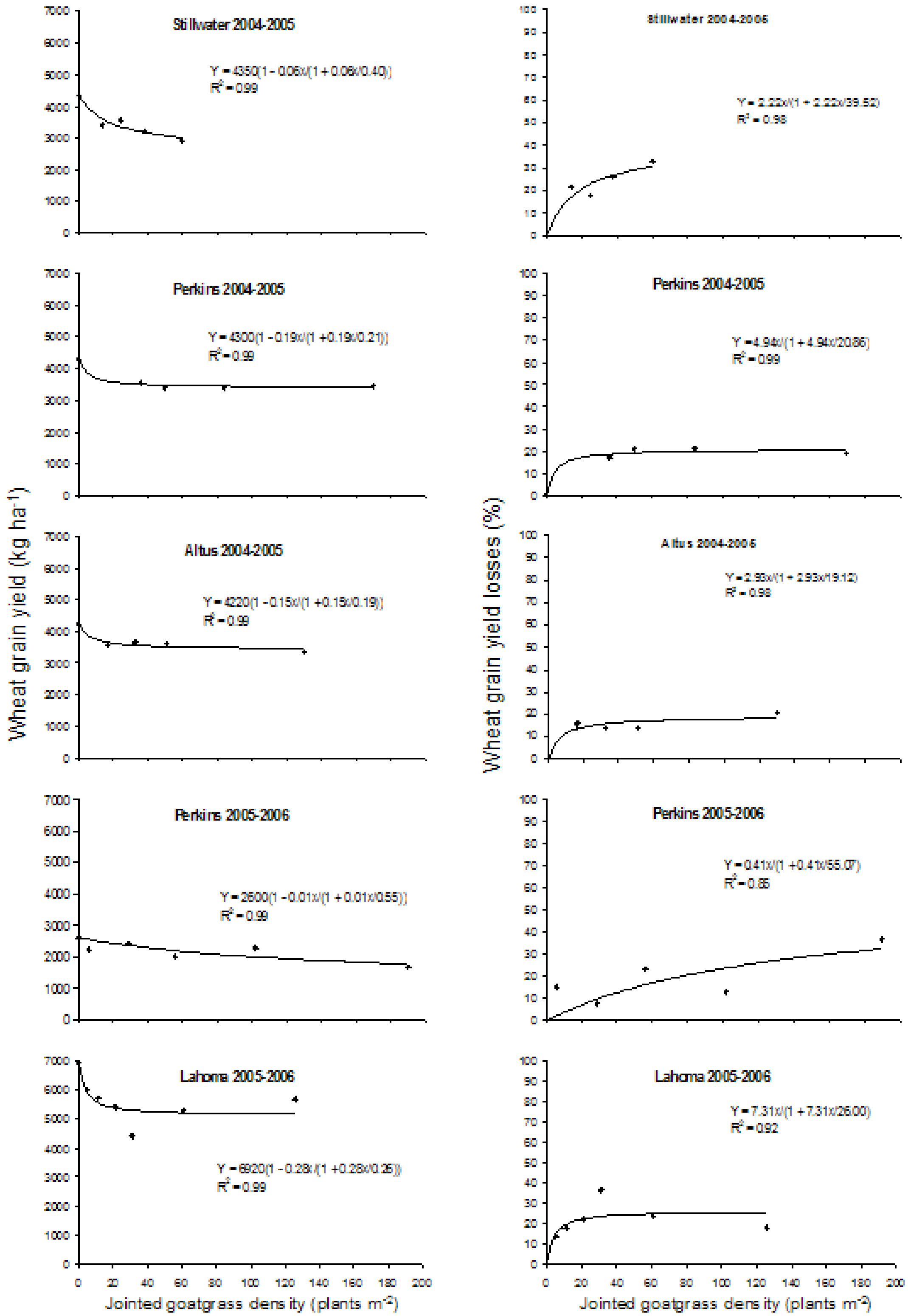

Figure 4. Wheat grain yield and yield losses as a function of jointed goatgrass density. Jointed goatgrass densities were quantified 150 days after emergence.

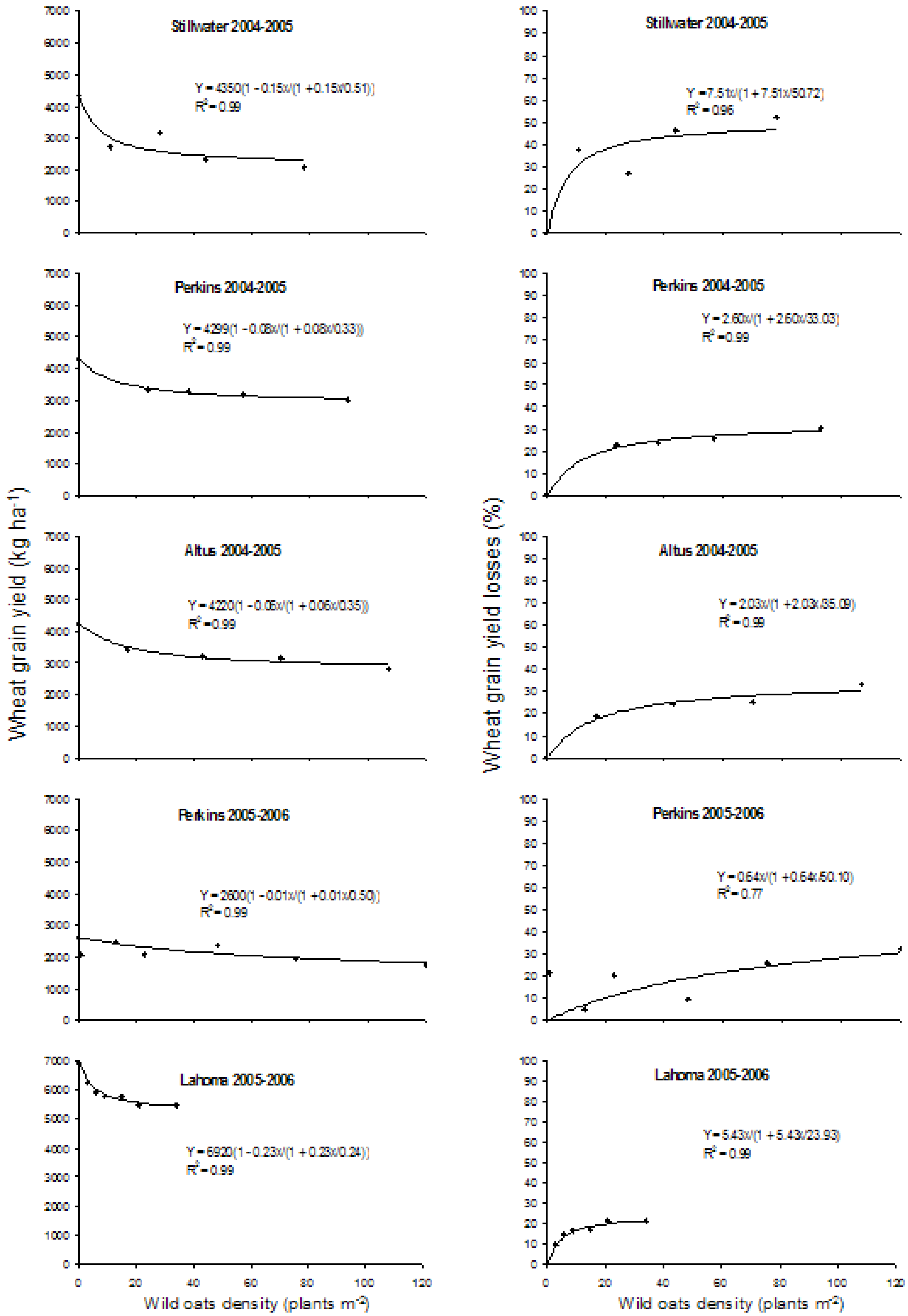

Figure 5. Wheat grain yield and yield losses as a function of wild oats density. Wild oats densities were quantified 150 days after emergence.

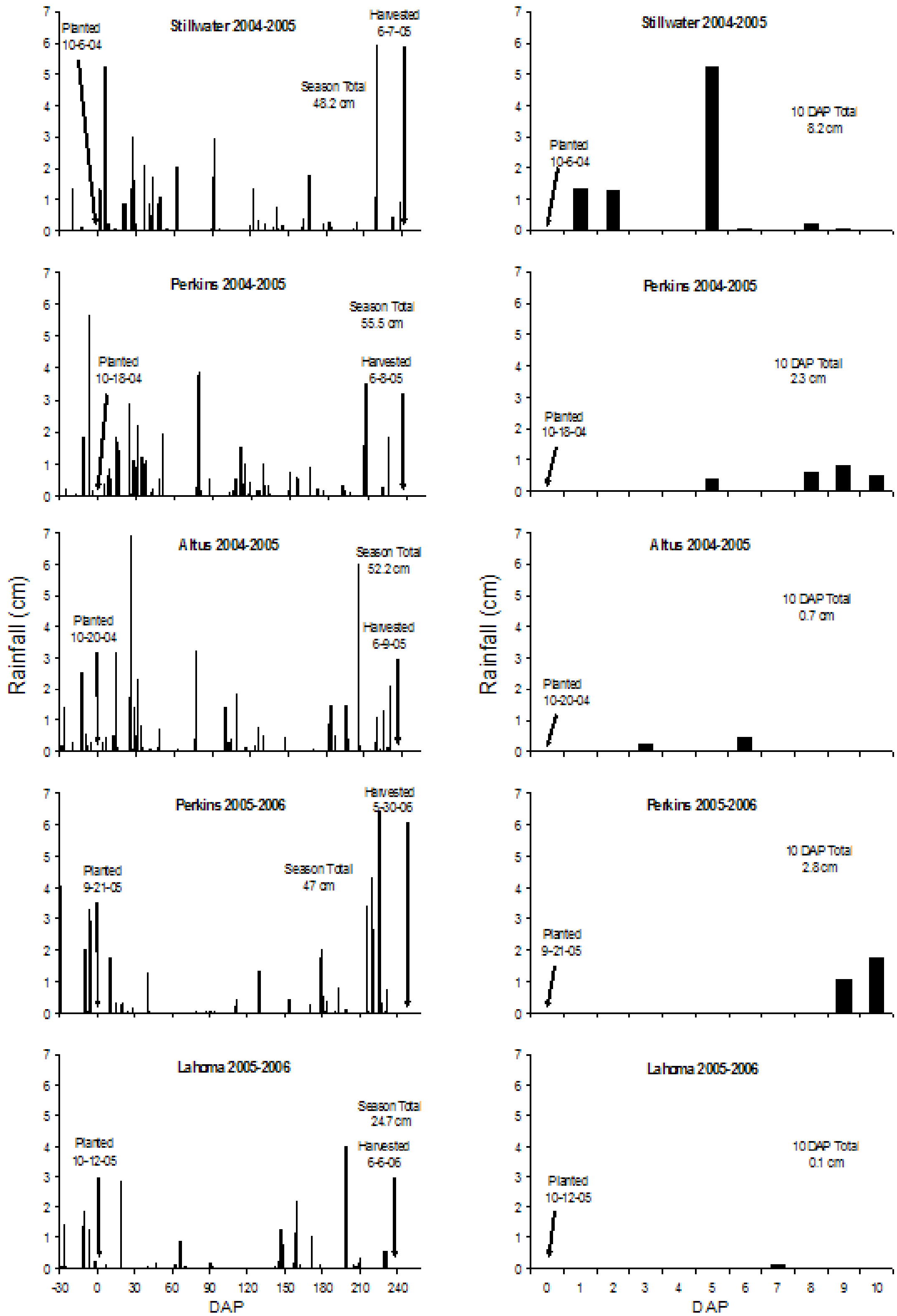

Figure 6. Rainfall histograms for each location for the season and for the 10 days after planting (DAP).

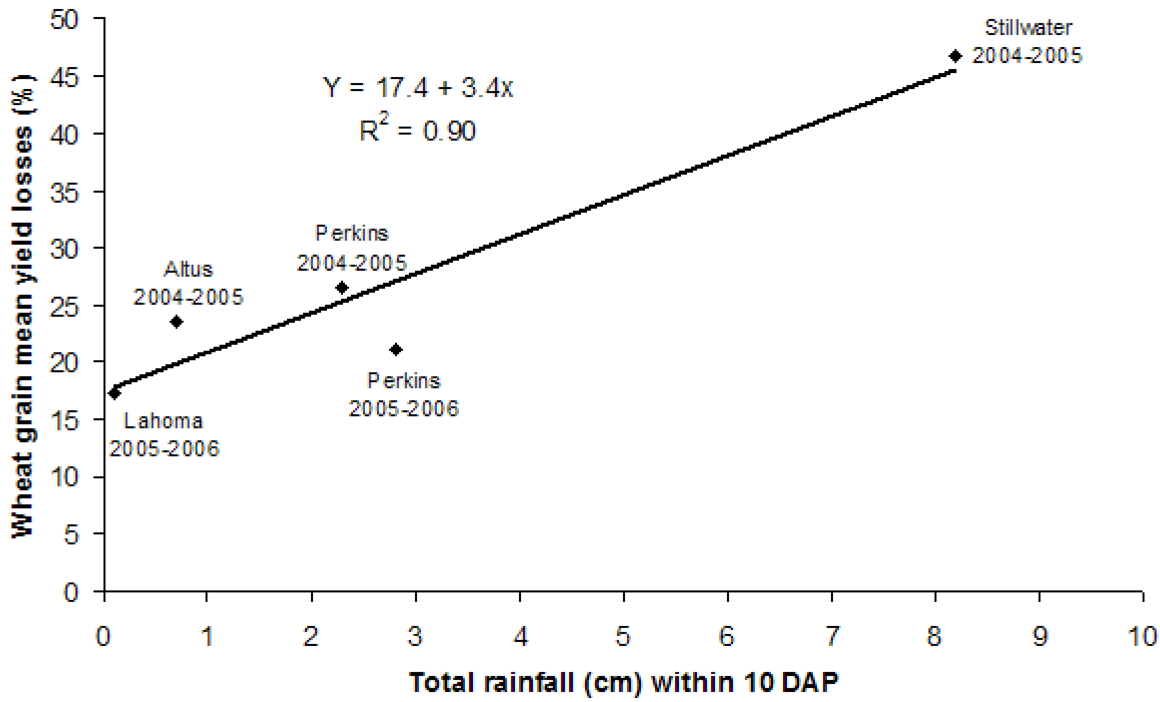

Figure 7. Mean wheat grain yield losses at each location as a function of rainfall received within 10 days after planting (DAP). Mean yield losses were calculated by summing treatment yield losses and dividing by the number of treatments in that experiment.

Chapter II

Effects of Five Cool-Season Annual Grasses on Hard Red Winter Wheat.

II. Grain Quality

Effects of Five Cool-Season Annual Grasses on Hard Red Winter Wheat.

II. Grain Quality

Field experiments were conducted near Altus, Perkins, Stillwater, and Lahoma, OK to quantify the wheat grain quality reductions and price discounts resulting from cheat, feral rye, Italian ryegrass, jointed goatgrass, and wild oats interference with hard red winter wheat. Plots were seeded with one of the five above mentioned weed species at one of seven seeding rates and wheat was planted in all plots at a rate of 84 kg ha^{-1}. Weed populations were quantified, wheat was harvested, wheat grain moisture, shrunken and broken kernels, dockage, foreign material, and test weight were measured, and wheat grade and price discounts were determined. Quality factors and price discounts were regressed as a function of weed density for each species at each location. In addition, regression equations were used to estimate quality reductions and price discounts caused by each weed species at each location at a density of 30 plants m^{-2}. Because density was held constant, those quality reductions and price discounts could be compared across weed species within each location. At Stillwater (at a density of 30 plants m^{-2}), the regression models predicted that no weed species significantly affected moisture. Feral rye significantly increased shrunken and broken kernels and foreign material; and cheat, feral rye, and Italian ryegrass significantly increased dockage and significantly reduced grade. Estimated price discounts were 519.9 (feral rye), 72.9 (cheat), 48.7 (Italian ryegrass), 39.3 (wild oats), 32.1 (jointed goatgrass), and 22.0 cents $hectoliter^{-1}$ (c hl^{-1}) (weed-free treatment). At Lahoma (at a density of 30 plants m^{-2}), the regression models predicted that no weed species significantly affected moisture and shrunken and broken kernels. The

models also predicted that cheat and jointed goatgrass significantly increased dockage; and feral rye significantly affected foreign material and test weight. Feral rye also caused a significant decrease in grade. Estimated price discounts were 173.1 (feral rye), 18.8 (cheat), 15.2 (jointed goatgrass), 12.8 (Italian ryegrass), 7.5 (wild oats), and 1 c hl^{-1} (weed-free treatment).

Nomenclature: Cheat, *Bromus secalinus* L., BROSE; feral rye, *Secale cereale* L. SECCE; Italian ryegrass, *Lolium multiflorum* Lam., LOLMU; jointed goatgrass, *Aegilops cylindrica* Host, AEGCY; wild oats, *Avena fatua* L., AVEFA; wheat, *Triticum aestivum* L. 'Jagger'.

Key words: Dockage; foreign material; grain grade; grain moisture content; grain quality; shrunken and broken kernels; test weight; weed competition; weed density; weed interference; wheat quality.

In 2006 the United States produced 18.9 million metric tons of hard winter wheat, and Oklahoma produced 11.6% of that total (USDA–NASS 2006). A substantial portion of the hard winter wheat produced in the U.S. is exported (USDA–ERS 2006); therefore, it is important that the quality of wheat produced in the U.S. either meets or exceeds the expectations of international buyers to ensure continued trade.

Grain quality is accurately and consistently measured and described with the use of a system developed by the United States Department of Agriculture-Federal Grain Inspection Service. This system is used to assign grain a quality grade, which is determined by comparing eight grade-determining factors to a set of standards (Table 1). The eight grade-determining factors are measured using standardized techniques and equipment, and they include test weight (grain density), foreign material, shrunken and broken kernels, heat damaged kernels, total damaged kernels, foreign material, shrunken and broken kernels, total defects, wheat of other classes, and contrasting classes (USDA–FGIS 2005). Grades for wheat are U.S. No. 1, 2, 3, 4, 5, and U.S. Sample grade. U.S. No.1 wheat is wheat of the highest quality; therefore, grain quality decreases as grade increases numerically. Hereafter, a numerical increase in grade will be referred to as a decrease in grade because of the corresponding decrease in grain quality. Grain moisture and dockage are not grade-determining factors; however, maximum acceptable values of each are usually specified in the sales contract when wheat is traded (U.S. Wheat Associates 2002).

Grain merchandisers typically offer producers a price for U.S. No. 1 wheat that contains no dockage and has a moisture content at or below 13.5%. If wheat does not meet these quality specifications, the offered price is discounted. Discounts are determined using tables that contain ranges of values of each quality factor and the discount that corresponds to each range. An example of a discount table used by a grain merchandiser in Oklahoma is provided in Table 2. Because reductions in grain quality have the potential to significantly reduce the selling price of wheat, it is important that producers intensively manage production factors, such as weeds, that affect wheat grain quality.

Cheat, feral rye, Italian ryegrass, jointed goatgrass, and wild oats are among the 10 most common and 10 most troublesome weeds of wheat in Oklahoma (Webster 2004). Weed interference negatively affects wheat grain quality by decreasing test weight and increasing moisture content, dockage, foreign material, shrunken and broken kernels, and grade. In Kansas, wheat samples were taken from 26 combines, and the average dockage of the samples was 4.2% (Herrman et al. 1997). Ferreira et al. (1990) in Oklahoma found that when wheat was infested with approximately 116 cheat plants m^{-2}, dockage values ranged from 5.1 to 24%. Barnes et al. (2001) in Oklahoma found that wheat infested with 105 and 160 cheat plants m^{-2} resulted in dockage values of 11.4 and 19.3%, respectively. Yenish and Young (2004) noted that jointed goatgrass spikelets are capable of causing economic losses by contaminating harvested grain and reducing test weight. No published data were found that relate feral rye, Italian ryegrass, or wild oats interference to reductions in wheat grain quality. The objective of this research was to quantify the wheat grain quality reductions and price discounts that result from interference of the five above mentioned weeds with wheat.

Materials and Methods

Field experiments were conducted at agricultural experiment stations near Altus, Perkins, and Stillwater, OK in 2004-2005 and near Lahoma and Perkins, OK in 2005-2006 to quantify the yield losses, grain quality reductions, and price discounts caused by weed interference with wheat. The yield loss data are presented in a companion publication (Fast et al. 2007), which contains all of the experimental details, except for the following materials and methods that were used to measure grain quality factors. Please refer to our companion publication for all other experimental details (Fast et al. 2007).

Grain quality factors were measured using the techniques and equipment standardized by the United States Department of Agriculture-Federal Grain Inspection Service (USDA–FGIS 2004). After wheat was harvested, a 1500 g representative sample (referred to hereafter as the work sample) was obtained from the yield of each plot using a sample divider[1]. Work samples were processed with a mechanical grain dockage tester[2], which separated the dockage and shrunken and broken kernels from the work sample. Dockage separation was weighed and discarded, and shrunken and broken kernel separation was weighed and mixed back into the work sample. Test weight was then measured by obtaining a 1.101 l subsample from the work sample using a standard test weight measure[3]. The subsample was weighed and converted from g 1.101 l^{-1} to kg $hectoliter^{-1}$ (kg hl^{-1}). Foreign material content was determined by obtaining a 150 g subsample from the work sample, manually removing the shrunken and broken kernels with an oblong-hole sieve[4], and examining the subsample visually for foreign material. If foreign material was detected, a 50 g subsubsample was obtained from the subsample.

Foreign material was then manually separated from the subsubsample and weighed. Dockage, shrunken and broken kernels, and foreign material were converted to percentages by dividing the weight of the separation by the original weight of the sample and multiplying by 100. Grade was then determined by comparing the values of the quality factors to the standards in Table 1. Wheat grain price discounts caused by each quality factor were then determined using Table 2, which contains price discounts used by a grain merchandiser in Oklahoma (Peavey Company, personal communication). Discounts caused by each quality factor were summed to obtain the total price discount caused by each weed at each recorded density.

Statistical Analyses

Variability in quality reductions and total price discounts prevented pooling of the data across locations; therefore, foreign material, test weight, shrunken and broken kernels, dockage, moisture content, and total price discount were regressed as a function of weed density for each weed species at each location. Linear and quadratic models were fit to the data via the REG procedure in SAS (SAS 2002), and the model that provided the best fit was used. Because grade is a discrete variable, it could not be regressed; therefore, grades and their corresponding weed densities were plotted as line graphs.

Results and Discussion

Models relating wheat grain moisture content, dockage, shrunken and broken kernels, foreign material, test weight, grade, and price discount to weed density for each weed species at each location are provided in Figures 1 and 2 (cheat), 3 and 4 (feral rye), 5 and 6 (Italian ryegrass), 7 and 8 (jointed goatgrass), and 9 and 10(wild oats). To compare the effects of these weeds on wheat grain moisture content, shrunken and broken kernels, dockage, foreign material, test weight, and total price discount, regression equations were used to estimate the value of each factor at a density of 30 plants m^{-2}. Because a common density was used, those values can be compared across species within each location. It was concluded that a weed species (at a density of 30 plants m^{-2}) significantly affected a grain quality factor if the wheat price discount caused by that weed was greater than the price discount that wheat from the weed-free treatment received.

At Altus (Table 3), wheat from the weed-free treatment was 10% moisture, 0.7% shrunken and broken kernels, 0.8% dockage, 0% foreign material, had a test weight of 77.8 kg hl^{-1} and a grade of U.S. No. 1, and was discounted 2.0 c hl^{-1}. The regression models predicted that, at a density of 30 plants m^{-2}, none of the five weed species significantly affected moisture, shrunken and broken kernels, or test weight. Cheat, jointed goatgrass, and Italian ryegrass significantly increased dockage; and feral rye significantly increased foreign material. Jointed goatgrass and wild oats did not affect grade. Cheat and Italian ryegrass decreased grade to U.S. No. 2; and feral rye decreased it to U.S. Sample grade. Feral rye had the greatest predicted price discount of 155.6 c hl^{-1}; and cheat, Italian ryegrass, jointed goatgrass, and wild oats estimated discounts of 9.2, 8.2, 4.5, and 2.4 c hl^{-1}, respectively.

At Perkins 2004-2005 (Table 3), wheat from the weed-free treatment was 9.8% moisture, 1% shrunken and broken kernels, 2% dockage, 0% foreign material, had a test weight of 76.6 kg hl^{-1} and a grade of U.S. No. 2, and was discounted 9.0 c hl^{-1}. The regression models predicted that, at a density of 30 plants m^{-2}, moisture and test weight were not significantly affected by any of the five weed species; and shrunken and broken kernels, foreign material, and grade were significantly affected by feral rye. All weed species caused a significant increase in dockage. Feral rye had the largest estimated total price discount of 182 c hl^{-1}; and those of wild oats, jointed goatgrass, Italian ryegrass, and cheat were 19.4, 19.2, 14.8, and 6.1 c hl^{-1}, respectively.

At Stillwater (Table 3), wheat from the weed-free treatment was 8.6% moisture, 1.6% shrunken and broken kernels, 2.3% dockage, 0% foreign material, had a test weight of 73.1 kg hl^{-1} and a grade of U.S. No. 3, and was discounted 22.0 c hl^{-1}. At a weed density of 30 plants m^{-2}, the regression models predicted that moisture and test weight were not significantly affected by any of the five weed species. Shrunken and broken kernels and foreign material were significantly affected by feral rye. Additionally, the models predicted that cheat, feral rye, and Italian ryegrass caused dockage to increase significantly; and jointed goatgrass and wild oats did not. Jointed goatgrass and wild oats did not effect grade. Cheat and Italian ryegrass decreased grade to U.S. No. 4; and feral rye decreased it to U.S. Sample grade. Feral rye had the greatest predicted total price discount of 519.9 c hl^{-1}; and those of cheat, Italian ryegrass, jointed goatgrass, and wild oats were 72.9, 48.7, 32.1, and 39.3 c hl^{-1}, respectively.

At Lahoma (Table 3), wheat from the weed-free treatment was 8.5% moisture, 1% shrunken and broken kernels, 0.3% dockage, 0% foreign material, had a test weight of 76.8 kg hl^{-1} and a grade of U.S. No. 2, and was discounted 1.0 c hl^{-1}. The regression models (at a density of 30 plants m^{-2}) predicted that none of the five weed species significantly affected moisture, shrunken and broken kernels, or test weight. Additionally, the models predicted that feral rye significantly increased foreign material and significantly decreased grade; and that cheat and jointed goatgrass significantly increased dockage. Feral rye had the greatest estimated total price discount of 173.1 c hl^{-1}; and cheat, Italian ryegrass, jointed goatgrass, and wild oats had estimates of 18.8, 12.8, 15.2, and 7.5 c hl^{-1}, respectively.

At Perkins 2005-2006 (Table 3), wheat from the weed-free treatment was 8.9% moisture, 2% shrunken and broken kernels, 1.2% dockage, 0% foreign material, had a test weight of 76.8 kg hl^{-1} and a grade of U.S. No. 2, and was discounted 5.0 c hl^{-1}. The regression models predicted that, at a density of 30 plants m^{-2}, moisture, shrunken and broken kernels, and test weight were not significantly affected by any of the five weed species. Feral rye significantly increased foreign material and significantly decreased grade; and cheat and wild oats significantly increased dockage. Feral rye had the greatest estimated total price discount of 100.2 c hl^{-1}; and cheat, Italian ryegrass, jointed goatgrass, and wild oats had estimated discounts of 14.3, 13.5, 17.9, and 24.4 c hl^{-1}, respectively.

Wheat grain quality reductions and price discounts were apparently the greatest at locations that received the most rainfall within 10 days after planting (DAP). Rainfall histograms for each location are provided in Figure 11. The mean total price discount for each location was calculated by summing total price discounts across treatments and dividing by the number of treatments in that experiment. Mean total price discount was regressed as a function of total rainfall within 10 DAP. As early rainfall increased, mean total price discount also increased (Figure 12). Differences in the planting depths of wheat and weed seed probably explain why early rainfall significantly affected the quality reductions and price discounts that occurred at each location. Wheat was planted to a depth of approximately 3 cm, where soil moisture was adequate for germination and emergence. Weed seed were incorporated to a depth of approximately 1 cm, where soil moisture was inadequate. Therefore, weed emergence required rainfall; and wheat emergence did not. Resultantly, at locations that received very little early rainfall (e.g., Lahoma), the wheat emerged earlier than the weeds. At locations that received a greater amount of early rainfall (e.g., Stillwater), the wheat and weeds emerged at approximately the same time. Pavlychenko (1937) stated that when crop and weed plants grow together, they utilize available resources, and the development of both species is lessened. We concluded that at locations where the wheat emerged much earlier than the weeds, the wheat had a competitive advantage and was able to utilize a greater proportion of the available resources than the weeds; therefore, wheat grain quality reductions and price discounts were minimal. At locations where wheat and weeds emerged at approximately the same time, the wheat and weeds were competing to utilize similar quantities of resources; therefore, wheat grain quality reductions and price discounts were more severe.

The five weed species included in this research are capable of causing significant wheat grain quality reductions and price discounts. The severity of grain quality reductions is dependent on species and density of weeds present and on rainfall within 10 DAP. When making weed-management decisions, one should consider grain quality and yield reductions that result from weed interference with wheat. In an accompanying publication (Fast et al. 2007), the yield losses caused by the five weeds included in this paper are quantified.

Sources of Materials

[1]Boerner Divider, Seedburo Equipment Co., 1022 W. Jackson Blvd., Chicago, IL 60607.

[2]MCI Kicker mechanical grain dockage tester, Mid-Continent Industries, 1801 SE 9th St., Newton, KS 67114.

[3]Standard test weight measure, Ohaus Scale Corp., P.O. Box 2033, Pine Brook, NJ 07058.

[4]Seive (1.626 by 9.545 mm oblong-hole), Seedburo Equipment Co., 1022 W. Jackson Blvd., Chicago, IL 60607.

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TABLE 1. Grain grading standards for test weight, foreign material, and shrunken and broken kernels (USDA-FGIS 2005). Wheat contained no heat damaged kernels, wheat of other classes, or contrasting classes; therefore, these factors were not included in the table.

Grade	Test weight[a]	Foreign material[b]	Shrunken and broken kernels[b]
	kg hectoliter^{-1}	—— % ——	
U.S. No. 1	77.3	0.4	3.0
U.S. No. 2	74.7	0.7	5.0
U.S. No. 3	72.2	1.3	8.0
U.S. No. 4	69.6	3.0	12.0
U.S. No. 5	65.7	5.0	20.0
U.S. Sample grade	< 65.7	> 5.0	> 20.0

[a] Minimum limits.
[b] Maximum limits.

TABLE 2. Discount table used by a grain merchandiser in Oklahoma (Peavey Company, personal communication).

Quality factor	Value range	Discount
		c hl^{-1}
Test weight[a]	> 74.6	0.0
	74.5 - 70.8	2.0
	70.7 - 69.5	4.0
	< 69.5	nstr[c]
Grade	U.S. No. 1	0.0
	U.S. No. 2	1.4
	U.S. No. 3	8.5
	U.S. No. 4	17.0
	U.S. No. 5	25.6
	U.S. Sample grade	34.0
Foreign material[b]	1.1 - 5.0	2.8
	5.1 - 10.0	14.2
	> 10.0	nstr
Moisture content[b]	< 13.6	0.0
	13.6 - 13.7	5.7
	13.8 - 14	11.4
	14.1 - 14.2	17.0
	14.3 - 14.5	22.7
Dockage[b]	< 1.1	0.0
	1.1 - 2.0	5.7
	2.1 - 3.0	11.4
	3.1 - 10.0	2 for each 0.5%
	> 10.0	ntsr

[a] kg $hectoliter^{-1}$.

[b] %.

[c] nstr, negotiable and subject to rejection.

Table 3. Estimated moisture, shrunken and broken kernels, dockage, foreign material, test weight, grade, and total price discount. Values were estimated using the regression equation[a] for each quality factor at a density of 30 plants m^{-2}.

Location	Weeds	Moisture	Shrunken and broken kernels	Dockage	Foreign material	Test weight	Grade[b] (plants m^{-2})	Total price discount
		%				kg $hectoliter^{-1}$	U.S. No.[c]	cents $hectoliter^{-1}$
Altus 2004-2005	weed-free	10.0	0.7	0.8	0.0	77.8	1 (0)	2.0
	cheat	12.1	0.9	11.3	0.0	77	2 (27)	9.2
	feral rye	10.4	1.2	1.0	23.3	76.4	S (30)	155.6
	Italian ryegrass	11.3	0.9	1.4	0.0	76.8	2 (27)	8.2
	jointed goatgrass	11.2	0.8	1.5	0.0	77.4	1 (37)	4.5
	wild oats	11.1	0.8	0.9	0.0	77.5	1 (43)	2.4
Perkins 2004-2005	weed-free	9.8	1.0	2.0	0.0	76.6	2 (0)	9.0
	cheat	9.7	1.3	2.2	0.0	76.4	2 (26)	6.1
	feral rye	10.6	3.3	2.1	30.3	74.8	S (29)	182
	Italian ryegrass	11.0	1.0	2.6	0.0	76.1	2 (34)	14.8
	jointed goatgrass	10.1	1.0	3.0	0.0	76.4	2 (36)	19.2
	wild oats	10.3	1.0	3.1	0.0	76.3	2 (24)	19.4
Stillwater 2004-2005	weed-free	8.6	1.6	2.3	0.0	73.1	3 (0)	22.0
	cheat	9.4	2.9	10.0	0.0	71.5	4 (29)	72.9
	feral rye	9.9	4.4	9.6	79.8	71.1	S (33)	519.9
	Italian ryegrass	11.1	1.9	8.4	0.0	71.2	4 (33)	48.7
	jointed goatgrass	8.6	2.1	1.9	0.0	73.4	3 (25)	32.1
	wild oats	9.4	1.7	0.6	0.0	72.6	3 (28)	39.3
Lahoma 2005-2006	weed-free	8.5	1.0	0.3	0.0	76.8	2 (0)	1.0
	cheat	8.9	1.1	8.9	0.0	76.5	2 (34)	18.8
	feral rye	9.0	1.5	0.5	27.2	74.9	S (30)	173.1
	Italian ryegrass	8.4	1.2	0.2	0.0	76.7	2 (30)	12.8
	jointed goatgrass	8.6	1.4	1.8	0.0	76.6	2 (31)	15.2
	wild oats	9.0	1.3	0.6	0.0	76.5	2 (34)	7.5
Perkins 2005-2006	weed-free	8.9	2.0	1.2	0.0	76.8	2 (0)	5.0
	cheat	10.0	2.3	10.0	0.0	76.6	2 (36)	14.3
	feral rye	11.2	2.4	1.9	10.6	75.5	S (38)	100.2
	Italian ryegrass	9.6	2.4	2.5	0.0	76.4	2 (31)	13.5
	jointed goatgrass	9.0	2.2	3.0	0.0	76.7	2 (29)	17.9
	wild oats	11.9	2.4	3.1	0.0	76.3	2 (23)	24.4

[a] Regression equations, graphs, and R^2 values are provided in Figures 1 and 2 (cheat), 3 and 4 (feral rye), 5 and 6 (Italian ryegrass), 7 and 8 (jointed goatgrass), and 9 and 10 (wild oats).

[b] Grade could not be regressed because it is a discrete variable; therefore, the weed density that was nearest to 30 plants m^{-2} and the corresponding grade are provided in the table. The number in parentheses to the right of the grade is the weed density in plants m^{-2}.

[c] S, U.S. Sample grade.

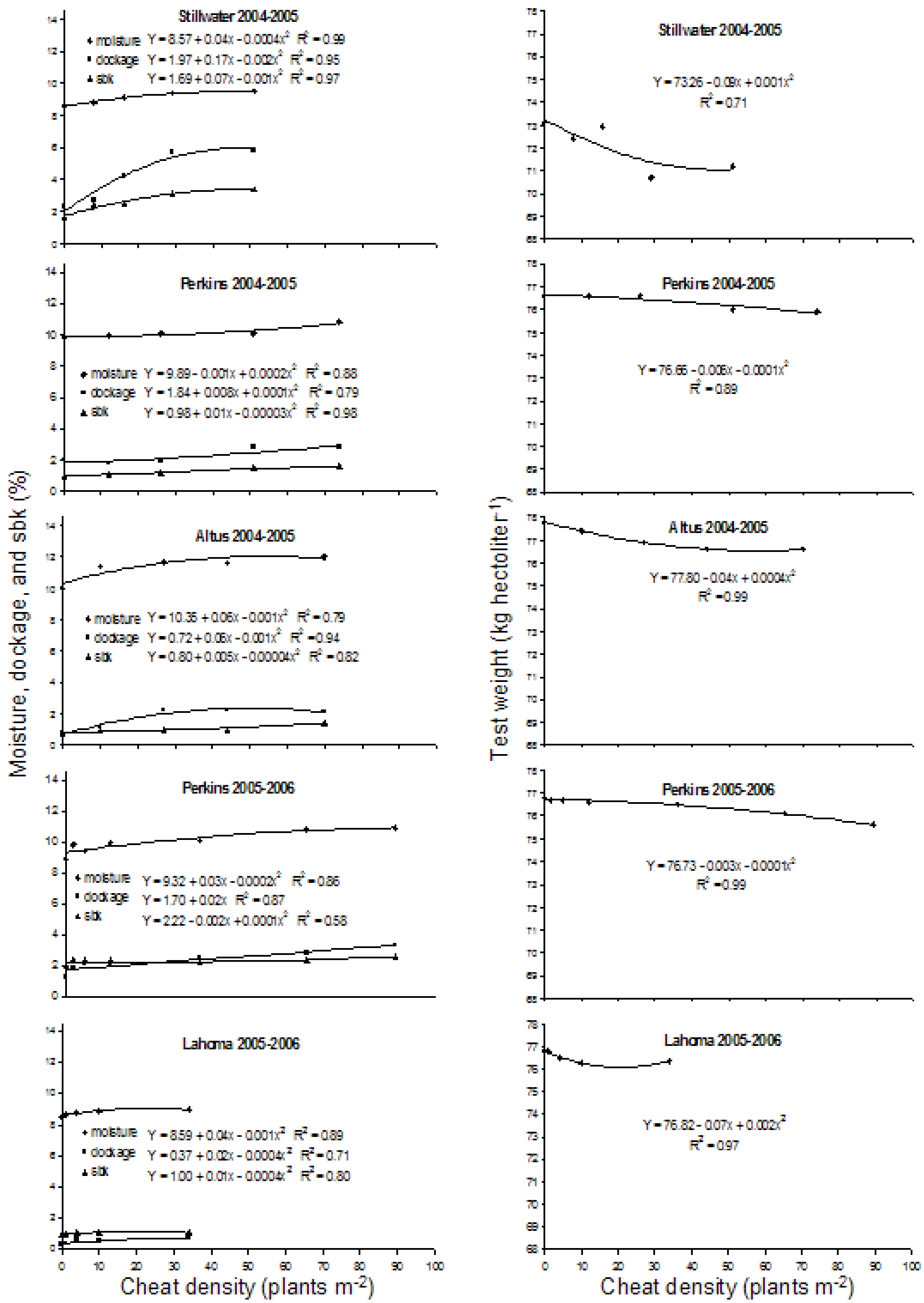

Figure 1. Wheat grain moisture, dockage, shrunken and broken kernels (sbk), and test weight as a function of cheat density. Cheat densities were quantified 150 days after emergence.

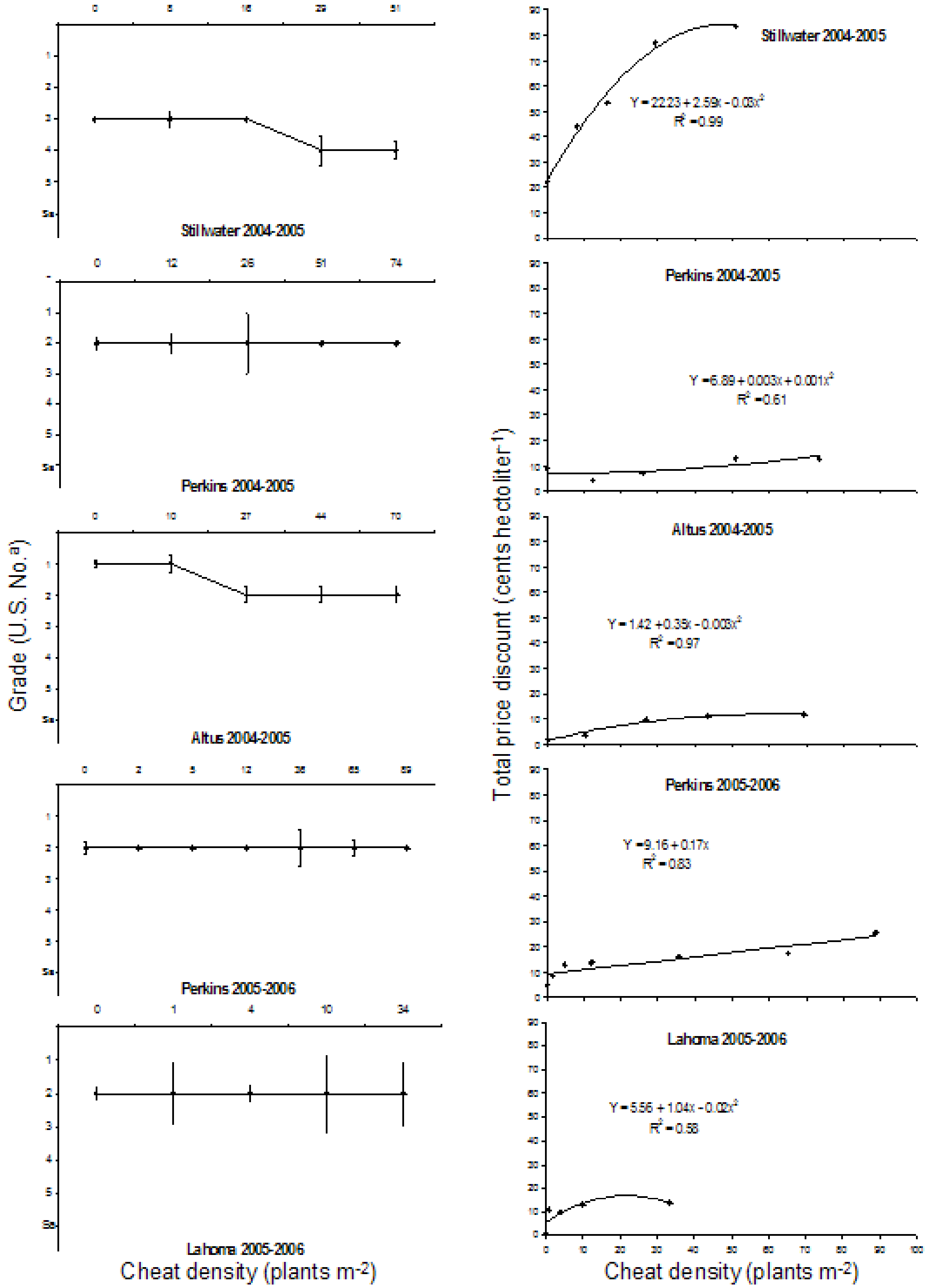

Figure 2. Effect of cheat density on grain grade (bars represent standard error of the mean) and total price discount as a function of cheat density. Cheat densities were quantified 150 days after emergence.

[a] Sa, U.S. Sample grade.

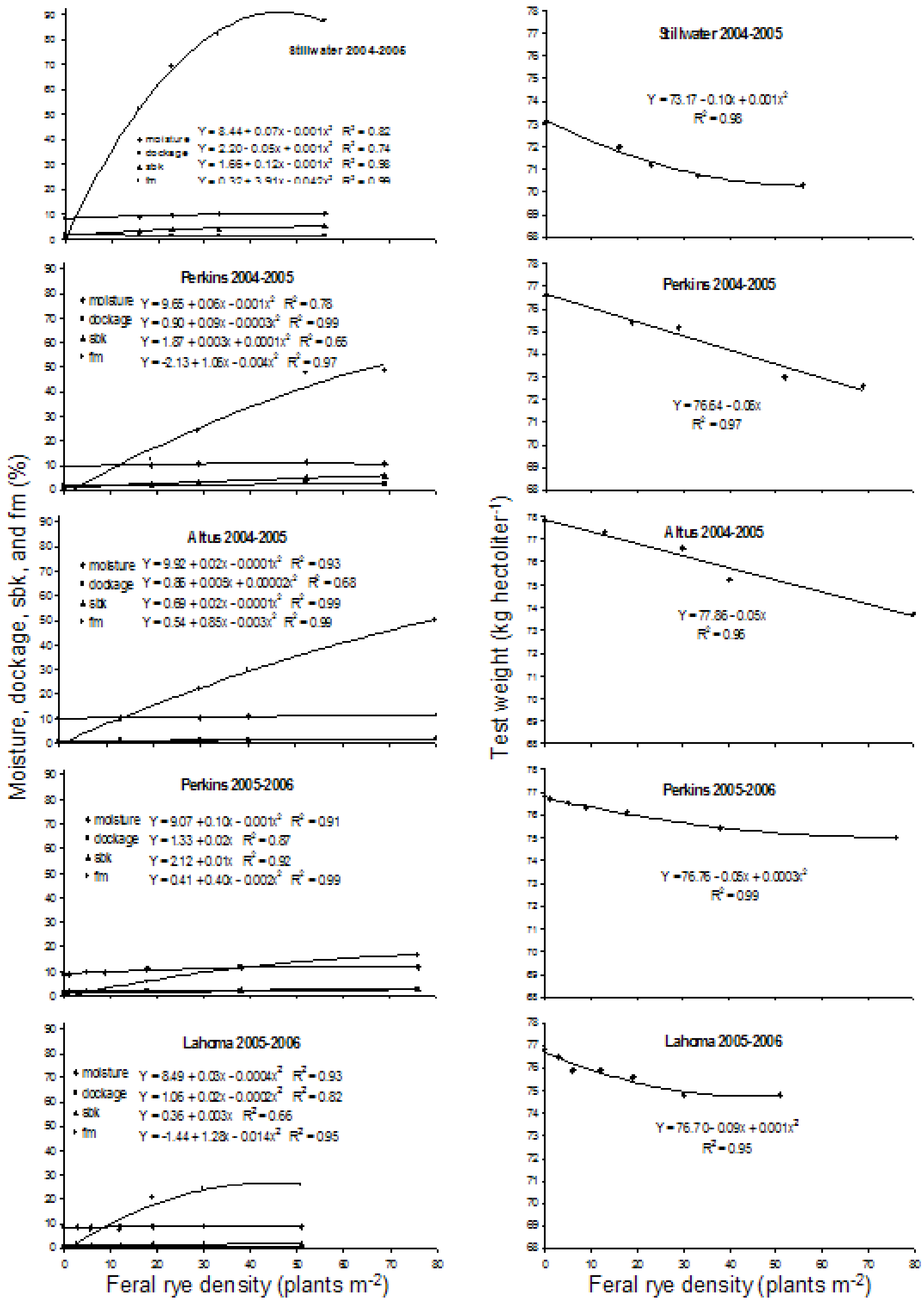

Figure 3. Wheat grain moisture, dockage, shrunken and broken kernels (sbk), foreign material (fm), and test weight as a function of feral rye density. Feral rye densities were quantified 150 days after emergence.

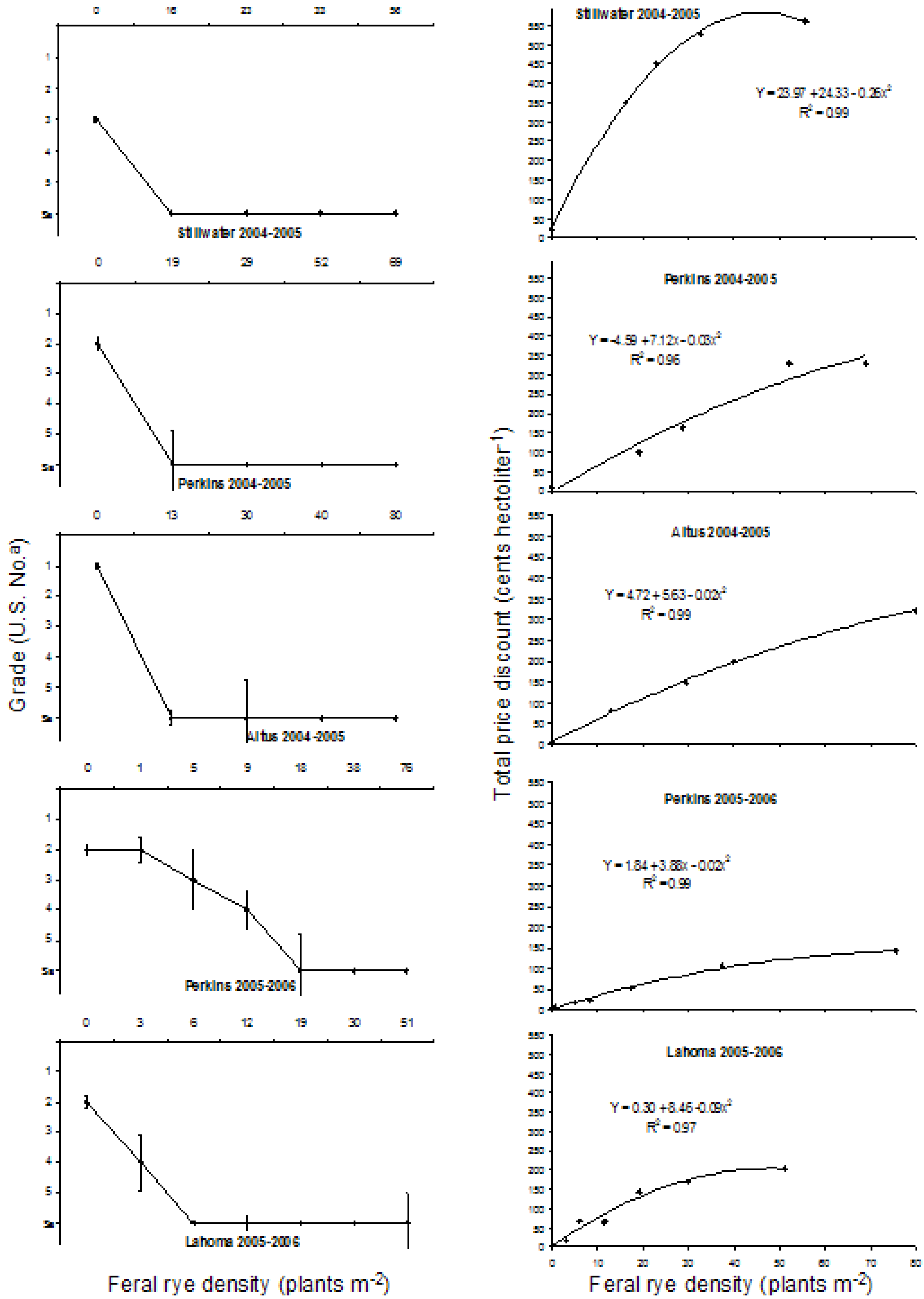

Figure 4. Effect of feral rye density on grain grade (bars represent standard error of the mean) and total price discount as a function of feral rye density. Feral rye densities were quantified 150 days after emergence.

[a] Sa, U.S. Sample grade.

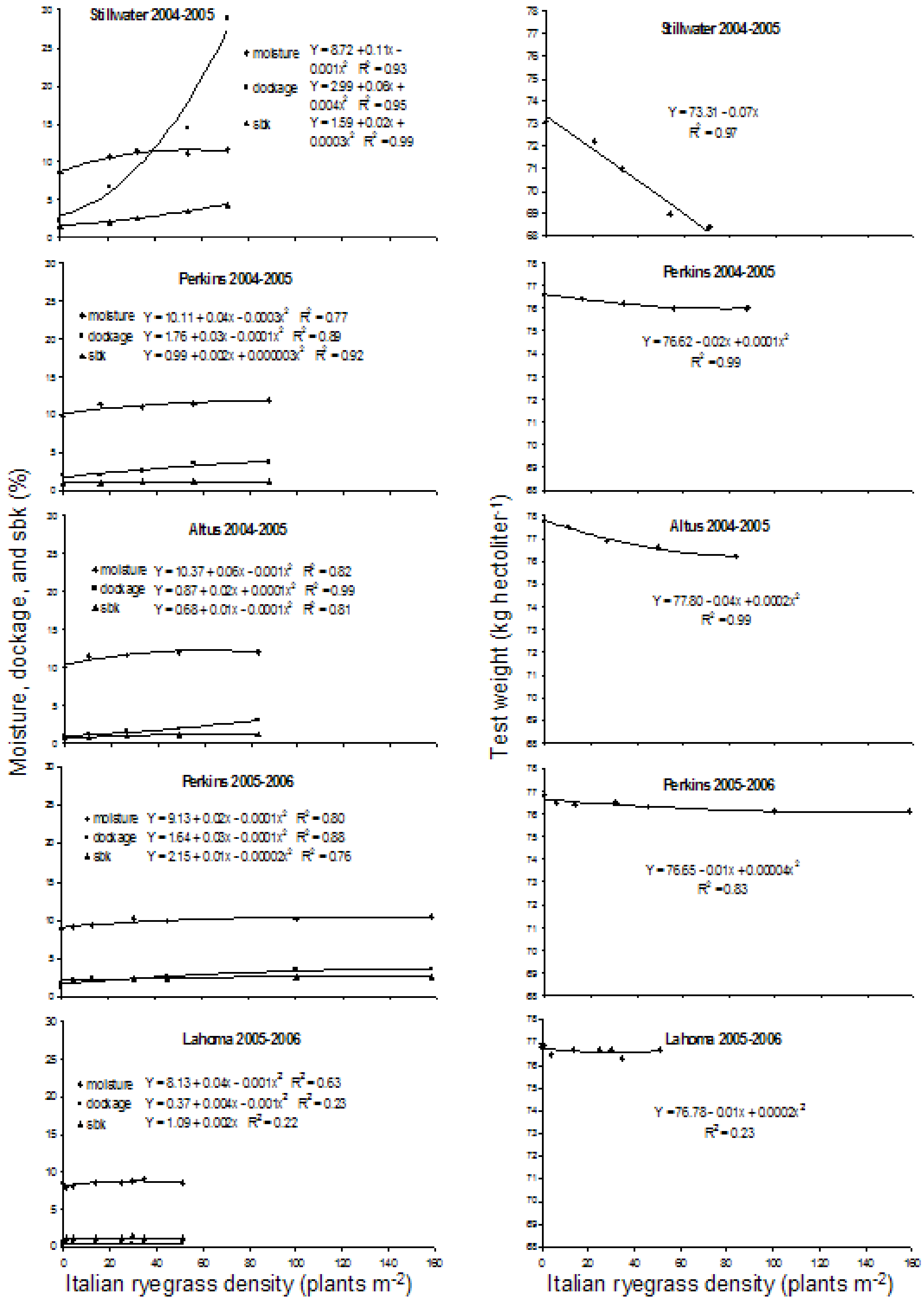

Figure 5. Wheat grain moisture, dockage, shrunken and broken kernels (sbk), and test weight as a function of Italian ryegrass density. Italian ryegrass densities were quantified 150 days after emergence.

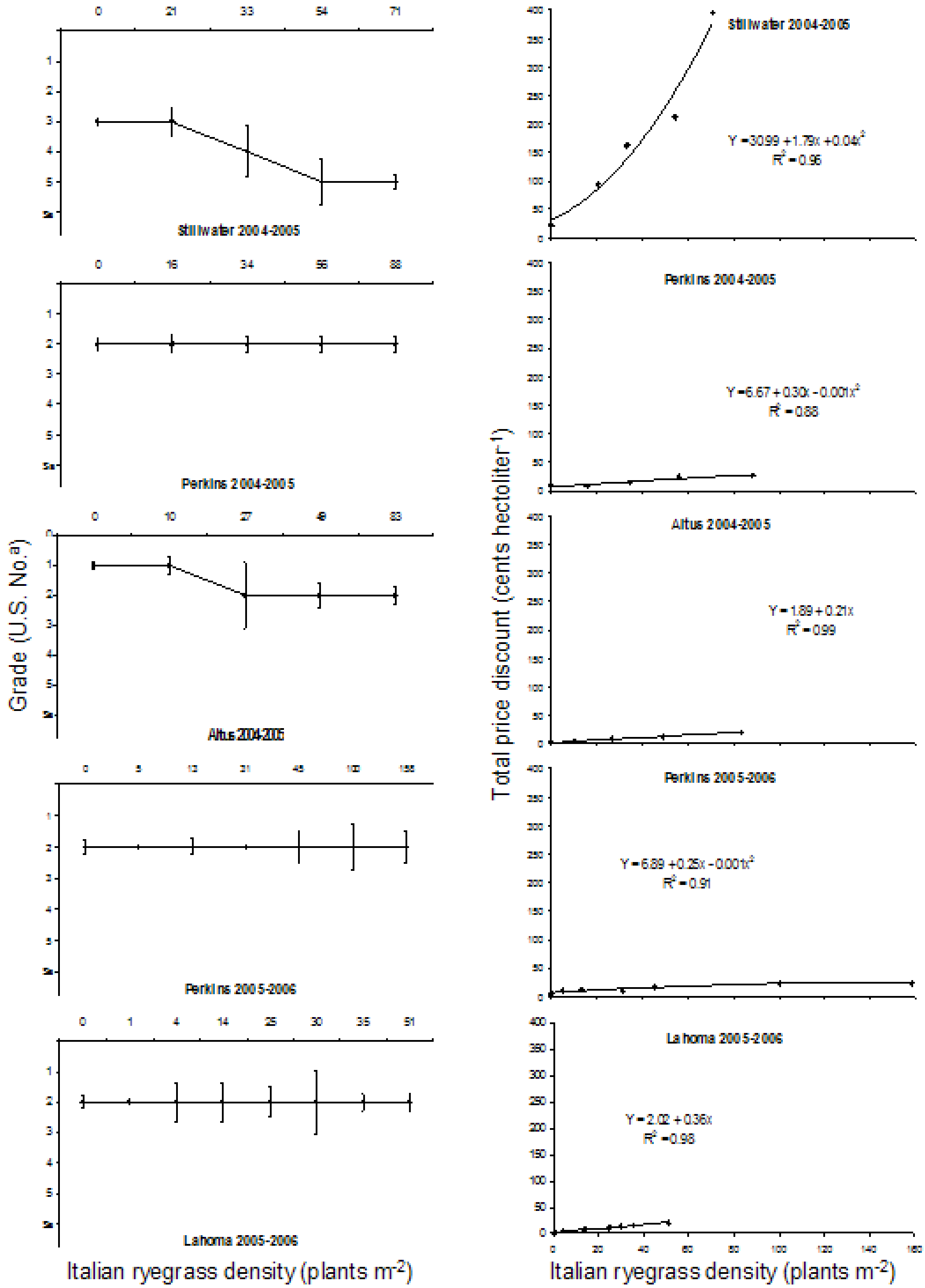

Figure 6. Effect of Italian ryegrass density on grain grade (bars represent standard error of the mean) and total price discount as a function of Italian ryegrass density. Italian ryegrass densities were quantified 150 days after emergence.

[a] Sa, U.S. Sample grade.

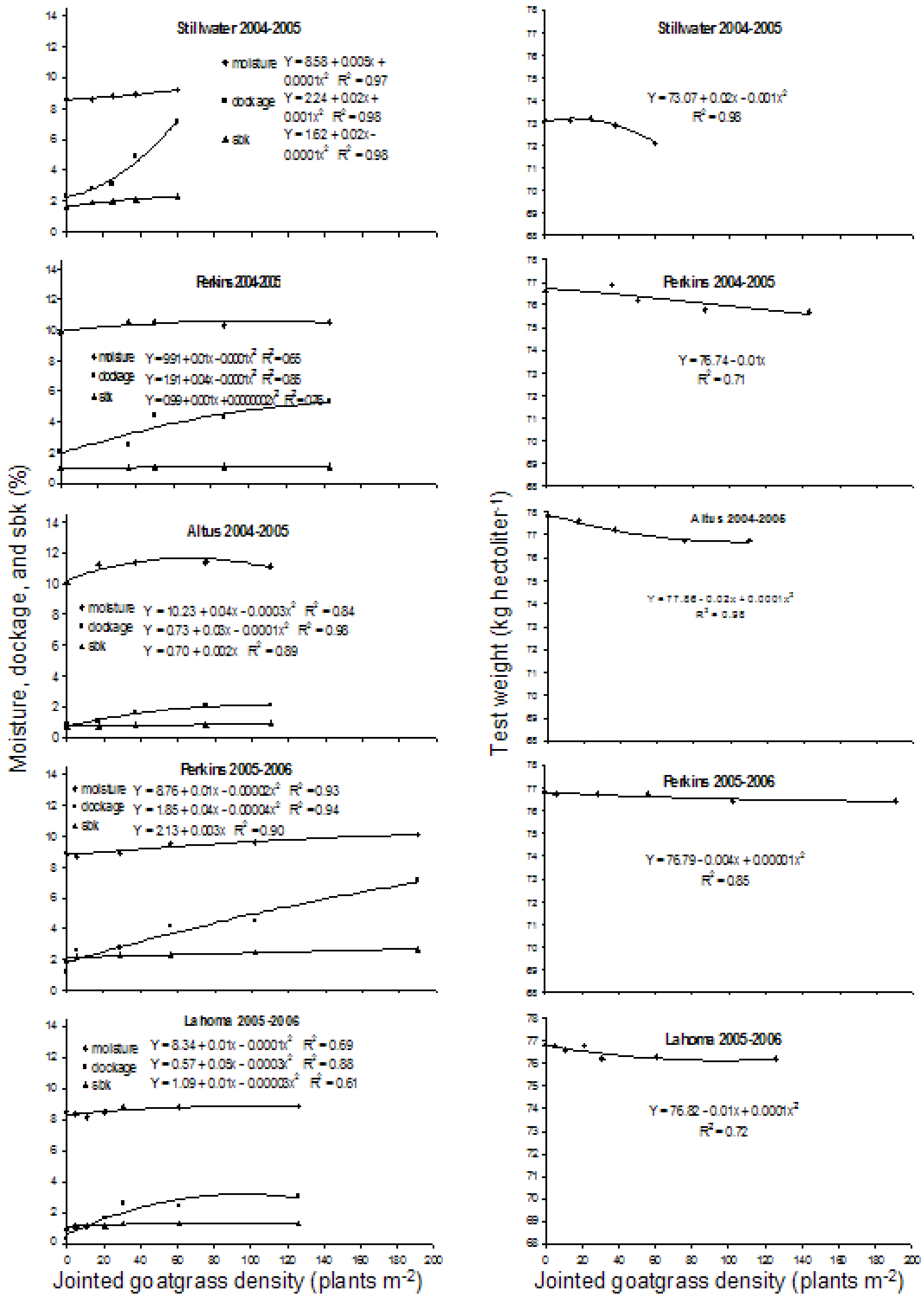

Figure 7. Wheat grain moisture, dockage, shrunken and broken kernels (sbk), and test weight as a function of jointed goatgrass density. Jointed goatgrass densities were quantified 150 days after emergence.

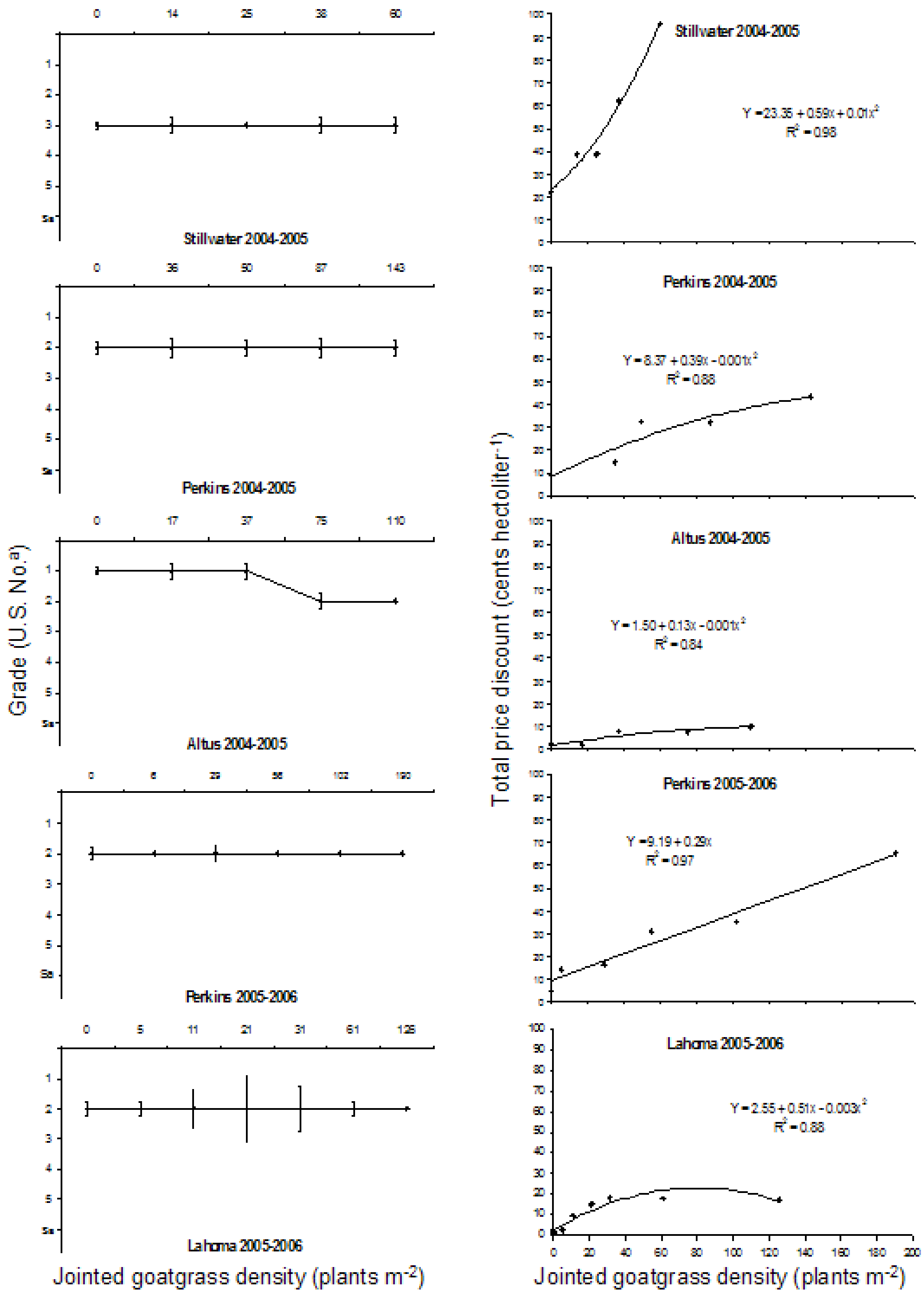

Figure 8. Effect of jointed goatgrass density on grain grade (bars represent standard error of the mean) and total price discount as a function of jointed goatgrass density. Jointed goatgrass densities were quantified 150 days after emergence.

[a] Sa, U.S. Sample grade.

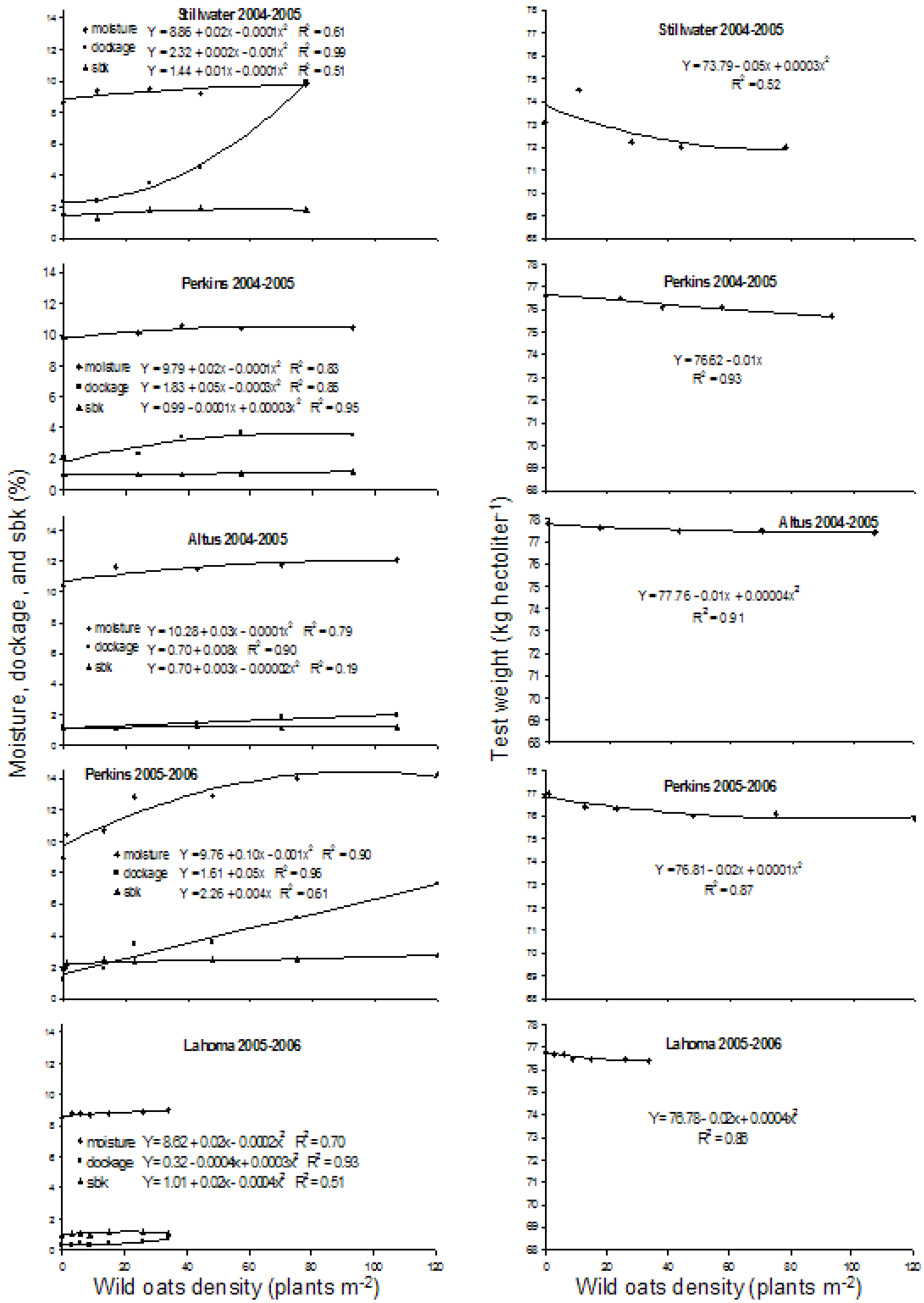

Figure 9. Wheat grain moisture, dockage, shrunken and broken kernels (sbk), and test weight as a function of wild oats density. Wild oats densities were quantified 150 days after emergence.

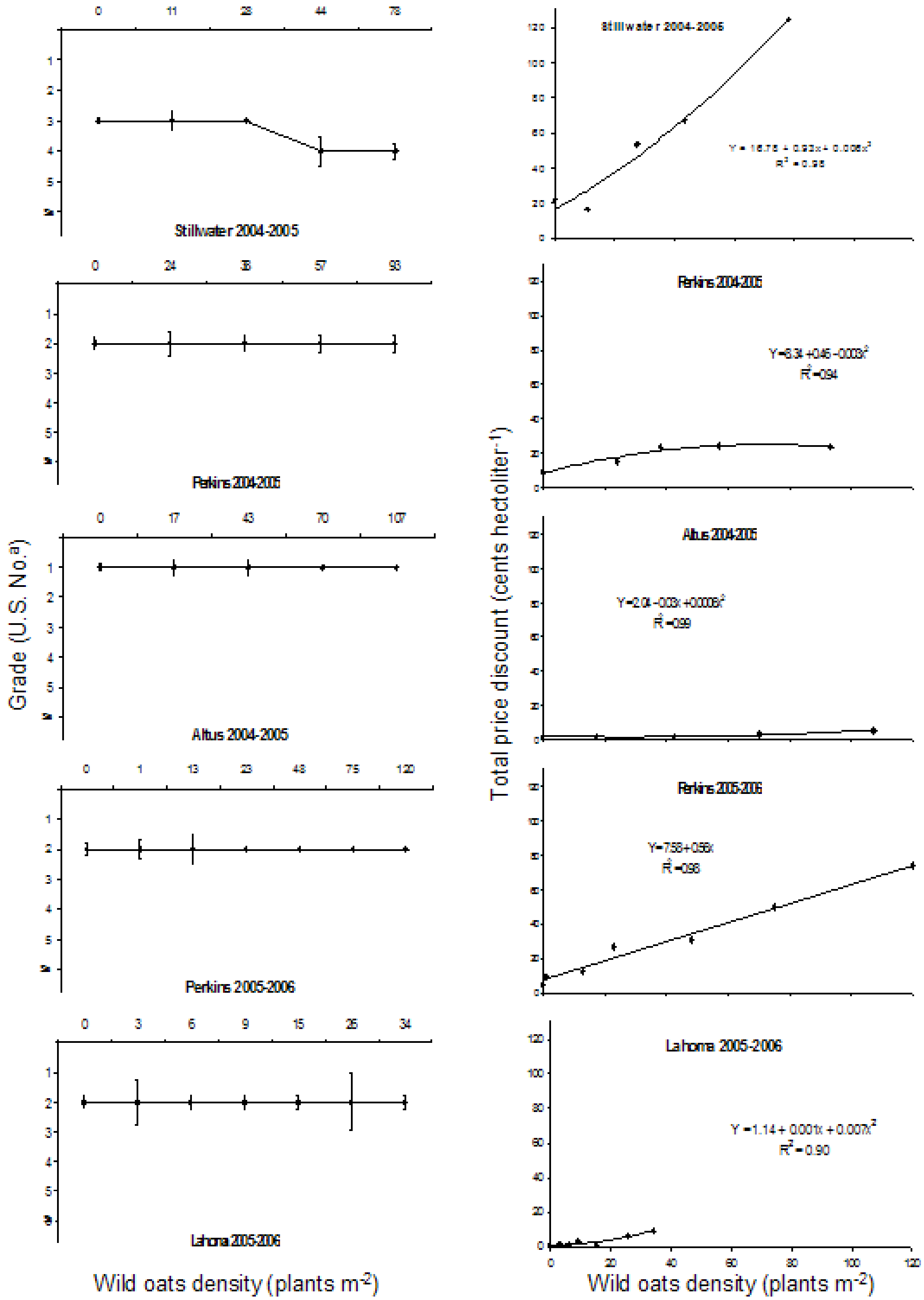

Figure 10. Effect of wild oats density on wheat grain grade (bars represent standard error of the mean) and total price discount as a function of wild oats density. Wild oats densities were quantified 150 days after emergence.

[a] Sa, U.S. Sample grade.

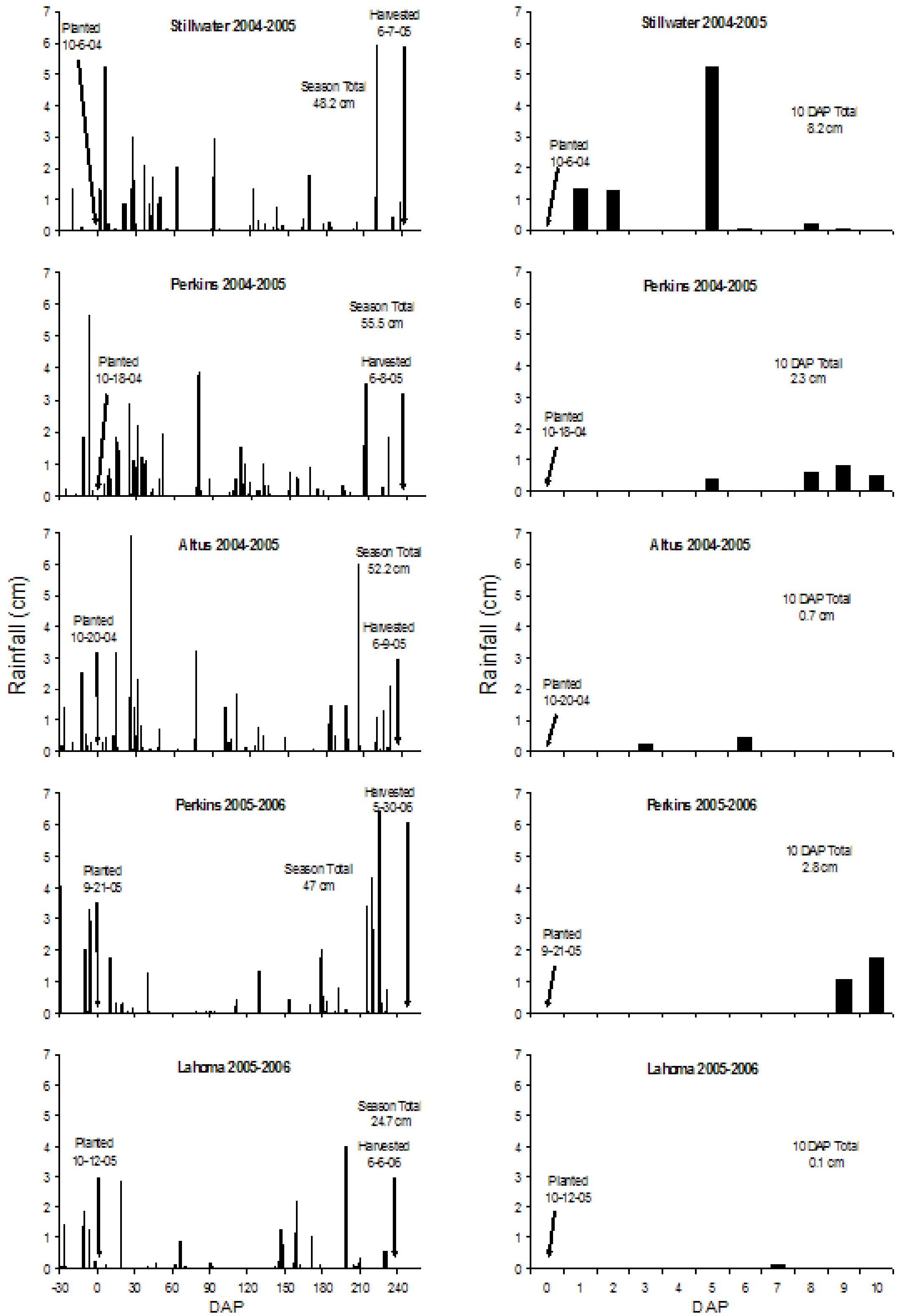

Figure 11. Rainfall histograms for each location for the season and for the 10 days after planting (DAP).

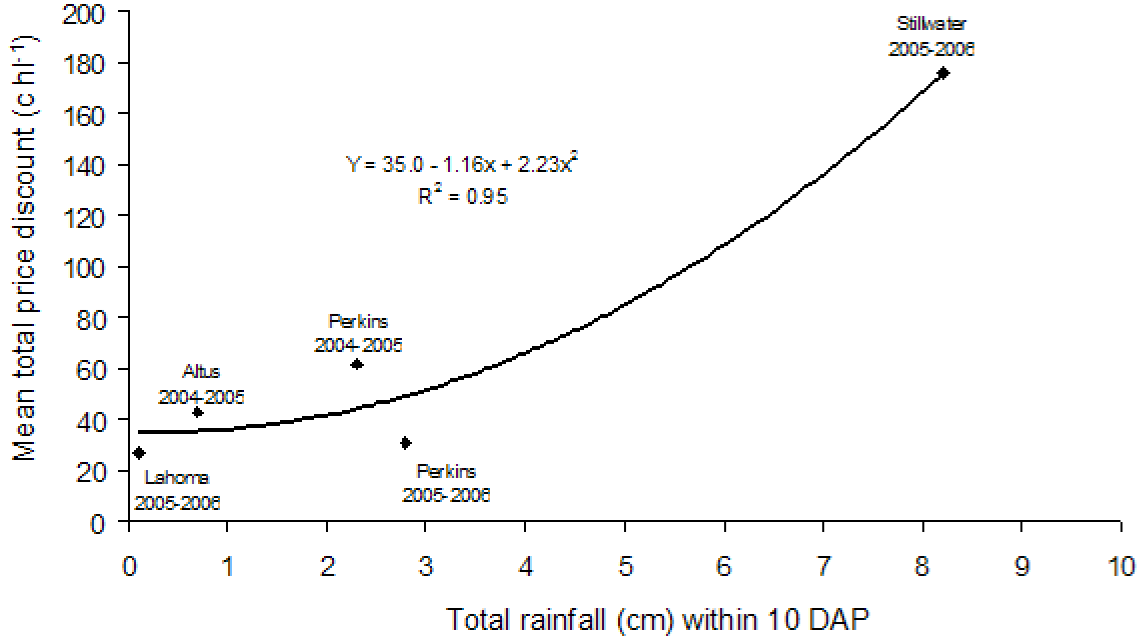

Figure 12. Mean total price discount as a function of rainfall received within 10 days after planting (DAP). Mean total price discounts were calculated by summing the total price discounts of all treatments and dividing by the number of treatments in that experiment.

VITA

Brandon James Fast

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF FIVE COOL-SEASON ANNUAL GRASSES ON HARD RED WINTER WHEAT GRAIN YIELD AND QUALITY

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Name: Brandon James Fast Date of Degree: May, 2007

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Title of Study: EFFECTS OF FIVE COOL-SEASON ANNUAL GRASSES ON HARD RED WINTER WHEAT GRAIN YIELD AND QUALITY

Pages in Study: 58 Candidate for the Degree of Master of Science

Major Field: Plant and Soil Sciences

Scope and Methods of Study: Chapter I: Cheat, feral rye, Italian ryegrass, jointed goatgrass, and wild oats are common and troublesome weeds of hard red winter wheat in Oklahoma. Field experiments were conducted to quantify the wheat grain yield losses caused by interference of those weeds with wheat. Data collected were weed density and wheat grain yield. Chapter II: In addition to reducing wheat grain yield, the five above mentioned weeds affect wheat grain quality. The field experiments were also conducted to quantify the wheat grain quality reductions and price discounts that occur as a result of weed interference. Data collected were wheat grain moisture content, test weight, foreign material, shrunken and broken kernels, dockage, grade, and price discount.

Findings and Conclusions: Chapter I: All five weeds included in these experiments are capable of significantly reducing wheat grain yield. The weeds and their density plus the amount of rainfall a location receives within 10 days after planting significantly affected the severity of the yield losses caused by weeds. Observed yield losses caused by cheat, feral rye, Italian ryegrass, jointed goatgrass, and wild oats were as high as 39.7, 94.6, 77.3, 36.6, and 52.2%, respectively. Chapter II: These five weeds are also capable of causing significant wheat grain quality reductions and price discounts. As was the case with yield loss, wheat grain quality was significantly affected by the weed and density of weeds present, as well as the amount of rainfall a location receives within 10 days after planting. Price discounts caused by cheat, feral rye, Italian ryegrass, jointed goatgrass, and wild oats were as high as 84, 560, 395, 96, and 125 cents hectoliter^{-1}.

CO-ADVISERS' APPROVAL:____