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Optimum Stand Density of Spring Triticale for Grain Yield and Alfalfa Establishment

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Abstract

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Keywords

triticale, grain, alfalfa, feed crops, companion crops

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ABSTRACT

Triticale (×*Triticosecale* Wittmack) has potential as a feed crop in the north central United States and could also function as a companion crop for alfalfa (*Medicago sativa* L.) establishment. The objectives of this research were to assess the suitability of a short-statured spring triticale as a companion crop and determine optimum triticale seeding rates for grain yield and alfalfa establishment. Spring triticale 'Trimark 37812' and alfalfa were grown in companion at Ames and Sioux Center, IA during 2004 and 2005. Triticale was seeded at 198, 297, 396, 495, and 594 pure live seeds (PLS) m–2 and alfalfa was seeded at 600 PLS m–2. The grain yield response to changes in stand density was quadratic with maximum yield occurring at 516 plants m–2. A plant density of 325 plants m–2 and a seeding rate of 374 seeds m–2 resulted in maximum profit. The grain yield at the stand density for maximum profit was 4.4 Mg ha–1. Increasing the triticale seeding rate had no effect on alfalfa stand density or dry matter yield. Alfalfa stand densities exceeded the 130 plants m–2 threshold required for maximum long-term productivity suggesting the short-statured spring triticale cultivar used in this study was well suited for companion cropping with alfalfa.

Use of a companion crop has been the most common alfalfa establishment method in the north central United States and has been used to establish the majority of alfalfa fields in this region (Tesar and Marble, 1988; Simmons et al., 1992; S.K. Barnhart, personal communication, 2007). Companion cropping typically involves simultaneous planting of spring cereal grains and alfalfa. The rapid early establishment of cereal grains protects against soil erosion and suppresses weeds during the time the slower growing alfalfa establishes. The cereal companion crop also provides forage, grain, and bedding during the establishment year. In a survey of Minnesota alfalfa producers, protection against soil erosion was the most important reason given for using a companion crop (Simmons et al., 1992). Production of grain, straw, or forage was of less importance and weed suppression was of intermediate importance. Companion cropping has endured as a practice for alfalfa establishment even though herbicides reduce the need of a companion crop for weed suppression (Brink and Marten, 1986; Sheaffer et al., 1988).

Producers using spring cereal grains for alfalfa establishment have concerns about negative competitive effects of companion crops on the interseeded alfalfa (Simmons et al., 1992). Oat (*Avena sativa* L.) is the companion crop of choice because it is less competitive with alfalfa for light, soil moisture, and nutrients than other cereal grains (Bula et al., 1954; Klebesadel and Smith, 1959; Nickel et al., 1990). To minimize competition with alfalfa, short-statured and early-maturing cereal grains are preferred as companion crops (Simmons et al., 1992) and low seeding rates are recommended (Lanini et al., 1991; Hall et al., 2004a). Lodging of the cereal grain was identified as a major limitation to using a companion crop for alfalfa establishment (Simmons et al., 1992). Problems with lodging could be alleviated with shorter and earlier maturing cereal grain cultivars (Simmons et al., 1995). When surveyed, producers reacted favorably to using a dwarf cereal grain as a companion crop to reduce lodging potential as well as reduce competition with alfalfa seedlings (Simmons et al., 1992).

Triticale has potential for introduction into the livestock-rich north central U.S. region because of its high yields and its high feed value for livestock relative to other cereal grains (Myer and Lozano del Rio, 2004). The major market for grains in the north central United States is for feed for swine (*Sus scrofa domestica*), beef (*Bos taurus*), chicken (*Gallus domesticus*), and turkey (*Meleagris gallopavo*). Research has shown grain from modern triticale varieties is an excellent replacement for corn as animal feed, and because of its high crude protein and lysine content, has feed values as high as or higher than other cereal grains (Hale et al., 1985; Hill and Utley 1989; Myer et al., 1990; Smith et al., 1994). It has been estimated that triticale is planted on more than 3.3 million hectares worldwide (International Triticale Association, 2003; Food and Agriculture Organization, 2005), but it has received relatively little attention as a grain crop in the north central United States. Short-statured, early-maturing spring triticale could offer an alternative for companion cropping with alfalfa, while simultaneously producing a high quality feed grain.

Research in Manitoba identified the best spring triticale seeding rate for grain yield as 100 kg ha–1 (Larter et al., 1971). However, breeding efforts have considerably improved triticale in the last 35 yr. Suitable spring triticale seeding rates for alfalfa establishment have not been identified for the north central U.S. conditions. The objectives of our research were to assess the suitability of a short-statured, grain-type, spring triticale as a companion crop for alfalfa and determine triticale seeding rates for maximizing grain yield, profit, and alfalfa establishment.

MATERIALS AND METHODS

Plant Culture and Experimental Treatments

Spring triticale 'Trimark 37812' and alfalfa 'Mycogen 4375LH' were grown in companion at two locations during the 2004 and 2005 seasons.1 Trimark 37812 is a short-statured, early maturing cultivar developed by Resource Seeds, Inc., Gilroy, CA. It averaged 76 cm in height at full head extension and was the earliest maturing of 21 cultivars tested in Iowa State University variety performance tests during 2002, 2003, and 2004 (Gibson et al., 2004). Trimark 37812 reached heading 5 d earlier than the mean of all cultivars tested. The seed for this experiment was obtained from ProGene Plant Research, Othello, WA.

Triticale seeding rates were 198, 297, 396, 495, and 594 PLS m–2. The triticale had 24,700 seeds kg–1 and 99% pure live seed. Alfalfa (405,720 seeds kg–1) was planted at 680 total (16.8 kg ha–1) and 600 PLS m–2. The experiment was conducted in 2004 and 2005 at the Iowa State University (ISU) Agronomy and Agricultural and Biosystems Engineering Research Farm near Ames (42.0°N, 93.6°W) in central Iowa and the Dordt College Ag Stewardship Center near Sioux Center, Iowa (43.1°N, 96.2°W) in northwest Iowa. The experimental layout was a randomized complete block with four replicates for each location in each year. The experimental unit was a plot containing an individual triticale seeding rate treatment within a location and year. Table 1 contains dates for field and data collection activities.

Soybean [*Glycine max* (L.) Merr.] was the previous crop at both sites in both years. Predominate soil types were Nicollet loam (fine-loamy, mixed, superactive, mesic Aquic Hapludolls) in 2004 and Clarion loam (fine-loamy, mixed, superactive, mesic Typic Hapudolls) in 2005 at Ames and Galva and Primghar silty clay loams (fine-silty, mixed, superactive, mesic Typic Hapudolls) in both 2004 and 2005 at Sioux Center. Soil samples were collected to a 15-cm depth at each field site. Soil pH, P, using the Bray and Kurtz P-1 test, available K, and organic matter (OM) using dry combustion were determined with the methods described in Brown (1998). Soil test levels at Ames indicated pH 7.4, 10 mg P kg–1, 125 mg K kg–1, and 84 g kg–1 OM in 2004 and pH 6.8, 28 mg P kg–1, 130 mg K kg–1, and 30 g kg–1 OM in 2005.

Soil tests at Sioux Center indicated pH 7.0, 31 mg P kg–1 205 mg K kg–1, and 35 g kg–1 OM in 2004 and pH 6.3, 47 mg P kg–1, 301 mg K kg–1, and 35 g kg–1 OM in 2005.

The field near Ames in 2004 was prepared for planting by broadcasting 9 kg N, 12 kg P, 22 kg K ha–1 followed directly with one pass of a tandem disc on 24 Sept. 2003 and one pass of a culti-pack roller on the day of planting the following spring. Forty-five kilograms of N in the form of urea were topdressed onto the field on 31 Mar. 2004. The field near Ames in 2005 was prepared with one pass of a combination field cultivator and tine-harrow in the spring. Forty-five kilograms of N in the form of urea were topdressed onto the field on 2 Apr. 2005. The sites near Sioux Center were field cultivated once and harrowed once on the day of planting in both 2004 and 2005. No fertilizer or lime were applied before planting the triticale at Sioux Center.

The triticale and alfalfa were planted simultaneously using commercial grain drills with 19-cm row spacing, except at Sioux Center in 2005 when alfalfa was broadcast seeded using an 18.3-m boom and 33 kg ha–1 muriate of potash (KCL) as a carrier. Planting at Sioux Center was followed by one pass of a culti-packer roller. Plots sizes at Ames were 3.8 m wide by 27.4 m long in 2004 and 3.8 m wide by 60.8 m long in 2005. Plot sizes at Sioux Center were 7.3 m wide by 39.2 m long in 2004 and 7.3 m by 30.3 m long in 2005.

Data Collection

Triticale plant density was counted directly in the field at both locations (Table 1). Plants were counted in three randomly selected 0.38-m2 areas within each triticale seeding rate plot. Photosynthetically active radiation (PAR) interception by the triticale within each plot was determined shortly after full head extension of the triticale using an AccuPAR Linear PAR Ceptometer, Model PAR-80 (Decagon Devices, Inc., Pullman, WA). Measurements were obtained by placing the ceptometer diagonally across three cereal grain rows. Measurements were collected under full sunlight between 1130 and 1400 h just above the alfalfa at 48 cm above the soil surface. Percent light interception was calculated by dividing the average of six below canopy PAR readings by one above canopy reading and multiplying by 100.

Spikes m–2 for each triticale seeding rate were counted from two 0.38-m2 areas collected in each plot before grain harvest. Kernels spike–1 were determined at Ames in 2004 and 2005 and Sioux Center in 2005 by counting the number of kernels from each of the spike samples collected from the 0.38-m2 areas. Thousand-kernel weight for each cereal grain seeding rate treatment was determined for each plot by weighing two 1000-kernel subsamples obtained from a 1-kg sample collected during harvest. Kernels spike–1 for Sioux Center in 2004 were calculated from the total yield, spikes m–2, and 1000-kernel weight data.

Triticale grain was machine harvested at Ames using a Massey Ferguson Model 25 combine (Sampo Rosenlew Ltd., Pori, Finland). The harvested area was 3.4 m wide by 27.4 m long in 2004 and 3.4 m wide by 56.8 m long in 2005. Grain yield for each triticale seeding rate was determined using an electronic scale integrated into the combine. Straw was baled and removed within 24 h of grain harvest. The remaining stubble and alfalfa shoots were removed at 6 cm above the soil surface with a flail chopper. Triticale at Sioux Center was cut 20 cm above the soil surface with a swather, machine harvested with a Case IH Model 2166 combine (Case IH, Racine, WI), and weighed in a wagon with an electronic scale. The harvested area was 3.65 m wide by 39.2 m long in 2004 and 7.0 m wide by 30.3 m long in 2005. Straw was baled and removed the day after grain harvest. Final grain yields at both Ames and Sioux Center were adjusted to 135 g kg–1 moisture.

Grain volume weight and moisture concentration were determined using a grain analysis computer (Model GAC2100, Dickey-John, Auburn, IL). Grain N concentration was analyzed using the Dumas combustion method (AOAC International, 2000). Crude protein concentration of the grain was calculated by multiplying percent N by 6.25.

Alfalfa plants were excavated in two areas per plot to determine alfalfa stand density approximately 10 d after triticale grain harvest. Sampling area was 0.25 m2 for Ames in 2004 and 2005 and Sioux Center in 2005 and 0.09 m2 at Sioux Center in 2004. Alfalfa dry matter production was measured 6 wk after triticale harvest in Ames by harvesting with a flail chopper into a wagon with electronic weighing equipment. Cutting height was approximately 6 cm and harvested area per plot was 1.8 m wide by 27.4 m long in 2004 and 1.8 m wide by 60.8 m long in 2005. Two 1-kg subsamples were collected from each plot, weighed, dried to constant weight in a forced air oven at 60°C, and reweighed to determine moisture content. Alfalfa dry matter was not measured at Sioux Center.

The daily minimum air temperature, maximum air temperature, and rainfall were recorded for 2004 and 2005 using weather stations at each location. The mean weather conditions for each site were determined using means from 1951 to 2005 from the Iowa Environmental Mesonet (2006). Daily rainfall measurements at Ames did not include frozen precipitation, which was not measured.

Statistical Analysis

Second-order polynomial equations were fit to the response of measured variables to seeding rate for all experimental units. Analysis of variance procedures and F-tests using PROC GLM of SAS (SAS Institute, 2006) were used to determine if the quadratic and linear components of the second-order polynomial equations were significant and if the quadratic and linear components differed across years and locations. Because interactions of year and location with the quadratic components were not significant, a second statistical analysis was performed with these interactions removed from the model. Separation of year and location means was performed for parameters that did not change with seeding rate (linear and quadratic components were not significant) by analyzing the means for all seeding rates using the lsmeans statement and Tukeys mean separation. Type III sums of squares were used for all statistical calculations and a significance level of $P \leq 0.05$ was used for all statistical tests.

Partial Budget Analysis

A partial budget analysis was conducted to determine the triticale stand density and seeding rate that optimized profit. Triticale seed averaged 24,700 seeds kg–1 and cost $0.55 kg–1. There are few established cash markets and no official price reports for triticale grain. The most readily available current market for triticale in the north central United States is as a corn substitute in livestock feed. Triticale grain is priced similarly to corn in the southeast United States (Fohner and Sierra, 2004). Therefore, the average 10-yr National Agricultural Statistics Service (NASS) corn price ($0.0811 kg–1) in Iowa was used to calculate triticale value. The seeding rate for maximum profit occurred where the difference between seed cost ha–1 and gross return ha–1, calculated as yield multiplied by price, was greatest.

RESULTS AND DISCUSSION

Daily rainfall and average daily air temperatures during the growing season are presented in Fig. 1 and 2. At Ames, air temperatures for the duration of the growing season were 0.5°C below the 55-yr average in 2004 and 0.5°C above average in 2005. Total rainfall during the growing season was 50 mm above the 55-yr average in 2004 and 40 mm above average in 2005. At Sioux Center, air temperatures were 0.2°C above the 55-yr average in 2004 and 1.3°C above average in 2005. Rainfall was 100 mm below the 55-yr average in 2004 and 78 mm below average in 2005.

Triticale stand densities increased linearly with seeding rate at both sites in both years (Fig. 3). Stand density was 87% of the seeding rate when averaged for years, locations, and seeding rate. Stand densities were generally 70 to 100% of the seeding rates at Ames in 2004 and 2005 and Sioux Center in 2005. Stand densities at Sioux Center in 2004 were greater than the seeding rates for the 198, 297, and 396 seeds m–2 treatments. The stand densities for these three seeding rates were 39, 11, and 18% greater than the intended seeding rates, respectively. Stand densities were 97 and 91% of the 495 and 594 seeds m–2 seeding rates, respectively, at Sioux Center in 2004.

The quadratic component of the equations fit to the relationship between the measured parameters (grain yield, yield components, etc.) and stand density was not statistically different across years and locations for all parameters measured, indicating the curvature of the response to stand density was similar for the four site years (data not shown). Therefore, all statistical analyses and interpretations were performed with the interactions of the quadratic component with year and location removed from the model. This second model was used to test the significance of the quadratic term as well as the linear term and the interactions of the linear term with year and location.

The response of grain yield to changes in stand density was quadratic (Fig. 4). The maximum grain yield of 4.53 Mg ha–1 was attained at a stand density of 516 plants m–2. However, 95% of the maximum grain yield was attained at 341 plants m–2 indicating there was a broad plateau in the quadratic response of grain yield to stand density. The response of spikes m–2 to stand density was linear and positive. However, the response of spikes plant–1 to stand density was quadratic with a minimum of 1.2 spikes plant–1 attained at a stand density of 564 plants m–2.

There were no changes in kernels spike–1, kernel weight, grain volume weight, or grain protein concentration with increases in triticale stand density (data not shown). The lack of change in kernels spike–1 or kernel weight with stand density indicated that the relationship between stand density and grain yield was exclusively controlled by the increase in spikes m–2 that occurred with greater stand densities. The grain yield plateau that occurred at greater stand densities was caused by a reduction in the number of spikes plant–1 to levels that were just above one per plant.

The stand density producing maximum profit was 325 plants m–2 as determined by partial budget analysis (Fig. 5). This corresponded with a seeding rate of 374 seeds m–2, based on an average of 87% of the seed-producing plants in this study. The average grain yield at the stand density for maximum profit was 4.4 Mg ha–1. Recommended seeding rates for other spring small grains in the north central United States are 150 to 300 seeds m–2 for barley (*Hordeum vulgare* L.; Baldridge et al., 1985), 240 to 360 seeds m–2 for oat (Marshall et al., 1992), and 200 to 250 seeds m–2 for spring wheat (*Triticum aestivum* L.; Paulsen, 1987; Carr et al., 2003). The 374 seeds m–2 rate required for maximum profit of spring triticale in the current study was greater than the recommended seeding rates for barley, oat, and wheat. The high stand density required for maximizing spring triticale grain yield in the current study appears to be related to tiller production in the selected cultivar.

Year and location differences in grain yield, spikes m–2, spikes plant–1, kernels spike–1, kernel weight, grain volume weight, and grain protein are presented in Table 2 and provide insight into the productivity level of spring triticale in the environments of this study. Average grain yield ranged from 3.9 to 4.7 Mg ha–1 and was greater in 2005 than 2004. The interaction of year and location was significant for both spikes m–2 and spikes plant–1. Both had similar quantities for the 2 yr at Ames, but had greater quantities in 2004 than 2005 at Sioux Center. Kernels spike–1 were generally around 33, except at Sioux Center in 2004 when they were 25. Kernel weight averaged 29 mg kernel–1 with little variability among the years and locations. Grain volume weight was less and grain protein concentration was greater in 2004 than 2005. Grain protein concentration was greater at Sioux Center than Ames.

The year and location differences were likely caused by variation in temperature and rainfall. Spikes m–2 and spikes plant–1 were greater at Sioux Center (the more northerly and cooler environment) than Ames. The greatest number of spikes was initiated in the relatively cool temperatures at Sioux Center in April 2004. Fewer kernels spike–1 at Sioux Center in 2004 may have been a compensatory response to the greater number of spikes plant–1, a phenomenon common in small grains (Paulsen, 1987). Extended periods of cool, cloudy weather in June and July 2004 were conducive to fungal disease infection and preharvest sprouting, which reduced grain yields. Infection by septoria leaf blotch (*Septoria* spp.; Wiese, 1987) and fusarium head blight (*Fusarium* spp.; Wiese, 1987) was observed at both Ames and Sioux Center in 2004.

There was no change in alfalfa stand density at triticale harvest or alfalfa dry matter yield at the end of the summer as triticale stand density increased (data not shown). Alfalfa stand densities and yield were greater in 2004 than in 2005 (Table 2). Stand densities (plants m–2) were 36 and 28% of the 600 alfalfa PLS m–2 in 2004 and 2005, respectively. This was most likely due to 2004 being cooler and wetter than 2005. According to Hall et al. (2004a), it is common for no more than a third of sown alfalfa seeds to produce seedlings. The alfalfa stand densities in the establishment year produced in this study exceeded the 100 to 130 plants m–2 required to maximize alfalfa dry matter yield for multiple years following establishment (Bolger and Meyer, 1983; Volenec et al., 1987; Hall et al., 2004b).

Light interception by the triticale canopy increased linearly with stand density in both years (Fig. 6). There were no differences in light interception for the two study locations. At the stand density for maximum profit (325 plants m–2), light interception by the triticale canopy at full plant height was 35 to 50% of incident PAR. Therefore, 50 to 65% of the incident PAR was transmitted to the alfalfa seedlings. Simmons et al. (1995) found that PAR available to alfalfa seedlings at full height of oat and barley differed between semidwarf and standard height cultivars. Photosynthetically active radiation available to alfalfa seedlings was only 28 to 44% in standard height barley and 38 to 60% in standard height oat. It increased to 38 to 59% in semidwarf barley and 45 to 70% in semidwarf oat. Alfalfa dry matter was slightly higher when grown with semidwarf barley or oat genotypes than with standard-height cultivars. Alfalfa seedling establishment was similar among semidwarf and standard-height cultivars (Simmons et al., 1995).

The short-statured, early-maturing spring triticale cultivar used in this study was an effective companion crop for alfalfa establishment. It was grown as a grain crop while maintaining a sparse leaf canopy that limited interference with young alfalfa seedlings. Dense companion crop growth, lodging, and growing small grain companion crops to grain are all associated with mortality of alfalfa seedlings (Brink and Marten, 1986). A common recommendation for optimum alfalfa stands with companion seedings is to manage the field to the advantage of the alfalfa rather than the companion crop (Hall et al., 2004a). Use of short-statured, sparse-tillering spring triticale cultivars like the one used in this study could allow grain production with reduced risk of alfalfa stand loss. They could be managed for maximum grain production without negatively influencing the alfalfa. Unlike more traditional standard-height small grain cultivars, short-stature and sparse tillering allow application of N fertilizer with little concern for lodging.

Spring triticale has potential as a useful companion crop for alfalfa establishment. However, its adoption may be limited in the near-term by susceptibility to fusarium head blight (FHB; *Fusarium graminearum*), ergot caused by *Clavicep purpurea*, and pre-harvest sprouting. All three of these are sporadic, but serious problems that occur with high rainfall conditions. Better resistance to FHB, ergot, and preharvest sprouting should be incorporated into short-statured, grain-type cultivars to make spring triticale a more viable crop for companion cropping with alfalfa in the north central United States.

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Table 1. Dates of field activities and data collection for spring triticale and alfalfa grown at two Iowa locations in two growing seasons.

Activity	Ames		Sioux Center	
	2004	2005	2004	2005
Soil preparation	29 Sept. 2003	22 Mar.	27 Mar.	4 Apr.
Planting	23 Mar.	29 Mar.	27 Mar.	4 Apr.
Triticale stand density	16 Apr.	11 Apr.	11 May	26 June
Alfalfa stand density (spring)	22 Apr.	28 Apr.	11 May	20 May
Light interception	12 June	17 June	19 June	16 June
Sampling triticale yield components	16 July	14 July	25 July	18 July
Triticale harvest	19 July	14 July	27 July	23 Jul
Alfalfa stand density (post triticale harvest)	29 July	27 July	6 Aug.	1 Aug.
Alfalfa harvest	1 Sept.	24 Aug.	–	–

Table 2. Year and location differences in productivity measurements for spring triticale and interseeded alfalfa at Ames and Sioux Center, IA, in 2004 and 2005. The data for each year and location were averaged for seeding rates of 198, 297, 396, 495, and 594 pure live seeds m^{-2}.

		Triticale							Alfalfa	
Year	Location	Grain yield	Spikes m^{-2}	Spikes plant^{-1}	Kernels spike^{-1}	Kernel weight	Grain volume weight	Grain protein	Stand density†	Dry matter‡
		Mg ha^{-1}				mg kernel^{-1}	kg hL^{-1}	g kg^{-1}	plants m^{-2}	Mg ha^{-1}
2004	Ames	3.9	454	1.48	34	28	67.5	117	195	3.0
	Sioux Center	3.8	591	1.84	25	28	65.0	141	239	–
2005	Ames	4.3	461	1.43	30	31	73.7	112	137	2.1
	Sioux Center	4.7	526	1.66	34	30	72.1	123	202	–
HSD (0.05) year, location§		ns¶	59	0.19	3	1	ns	5	30	–
HSD (0.05) year#		0.1	ns	0.10	2	ns	0.5	3	16	0.2
HSD (0.05) location††		ns	ns	0.10	ns	ns	ns	3	ns	–

† Counted approximately 10 d after triticale harvest.

‡ Alfalfa dry matter was not determined at Sioux Center. Alfalfa dry matter was determined at Ames on 24 Aug. 2005 and 1 Sept. 2005.

§ Tukey's honest significant difference for comparing means across years and locations.

¶ ns = not significant, $P > 0.05$.

Tukey's honest significant difference for comparing means of the 2 yr averaged by location.

†† Tukey's honest significant difference for comparing means of the two locations averaged by year.

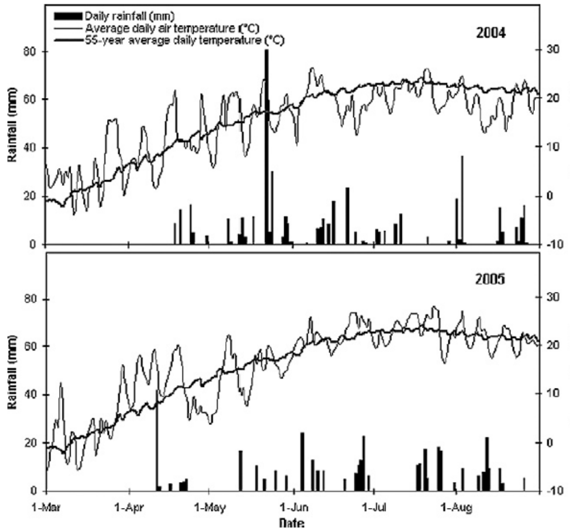

Fig. 1. Average daily air temperature and rainfall from 1 March to 31 August at the Agronomy and Agricultural and Biosystems Engineering Research Farm near Ames in 2004 and 2005 and the long-term average daily air temperature.

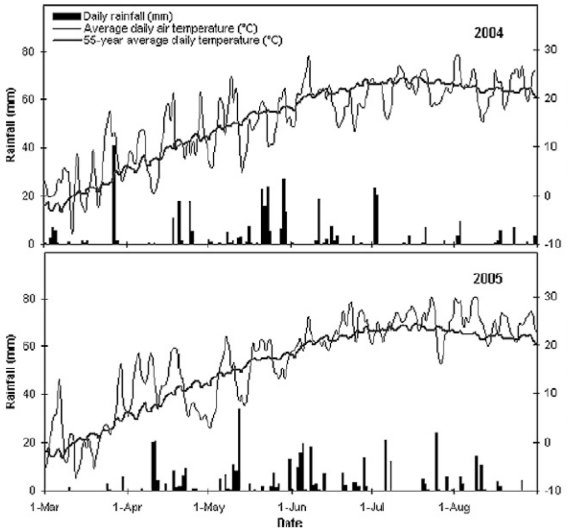

Fig. 2. Average daily air temperature and rainfall from 1 March to 31 August for Sioux Center, IA, in 2004 and 2005 and the long-term average daily air temperature.

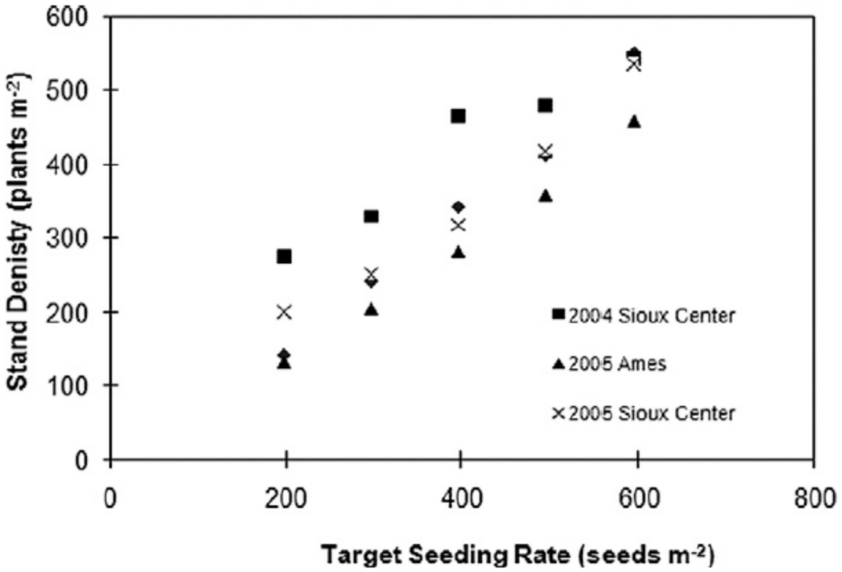

Fig. 3. Spring triticale stand density from target seeding rates of 198, 297, 396, 495, and 594 pure live seeds m^{-2} at Ames and Sioux Center, IA in 2004 and 2005.

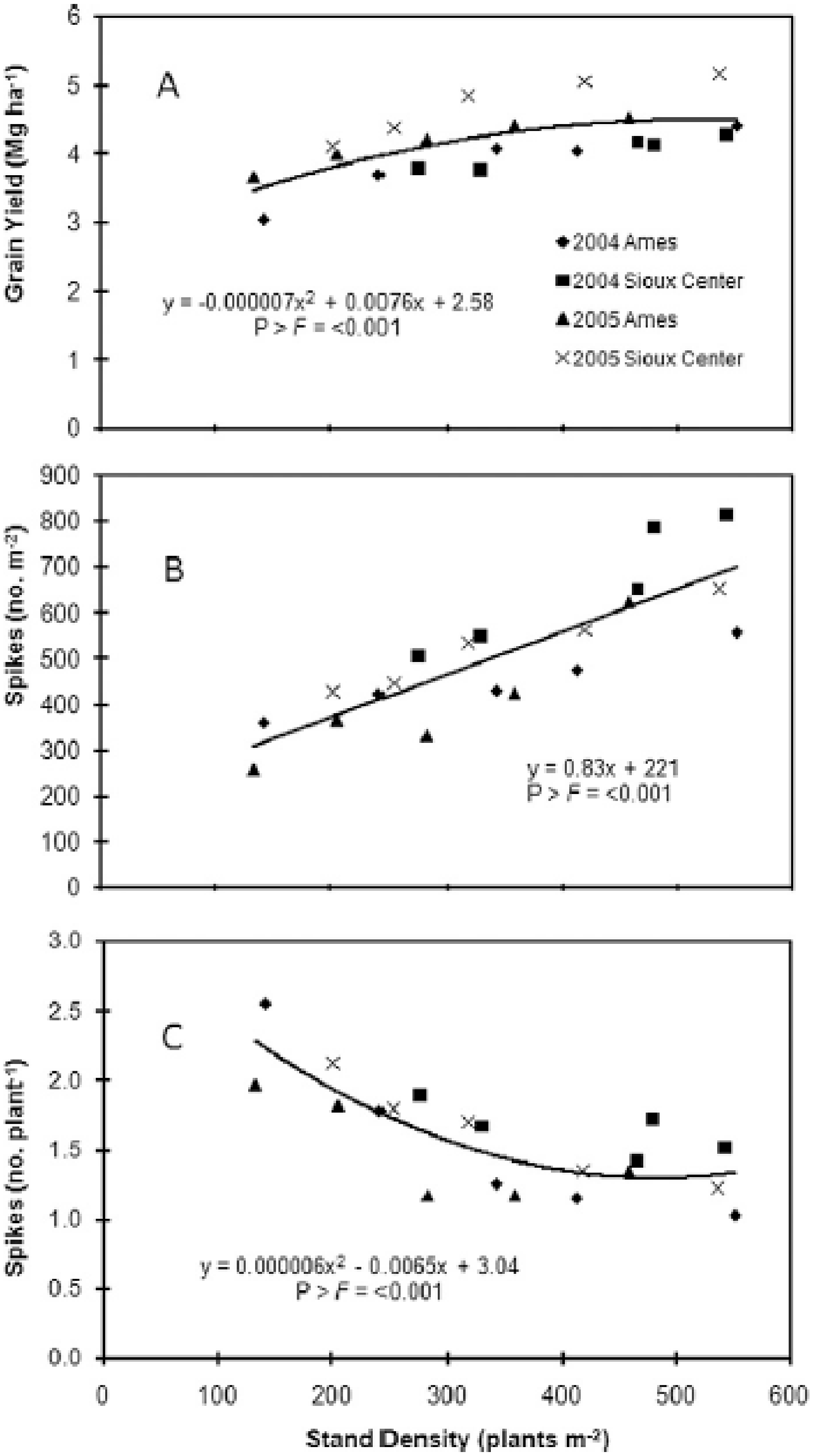

Fig. 4. Response of spring triticale grain yield (A), spikes m^{-2} (B), and spikes $plant^{-1}$ (C) to stand density at Ames and Sioux Center, IA in 2004 and 2005.

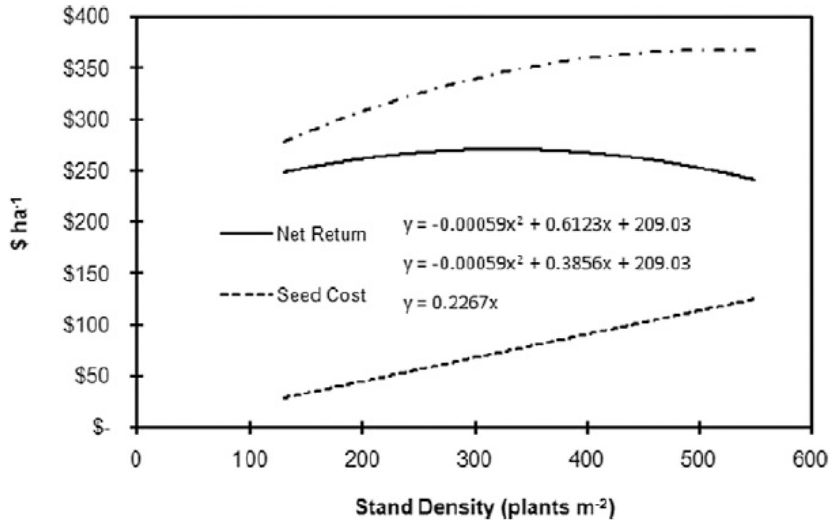

Fig. 5. Stand density effects on gross return, net return, and seed cost of spring triticale at \$0.55 kg^{-1} of seed, 24,700 seeds kg^{-1}, 87% emergence, and triticale grain price of \$0.0811 kg^{-1}. The stand density for maximum profit (greatest net return) occurred at 325 plants m^{-2}. Data were averaged for triticale planted at Ames and Sioux Center, IA in 2004 and 2005.

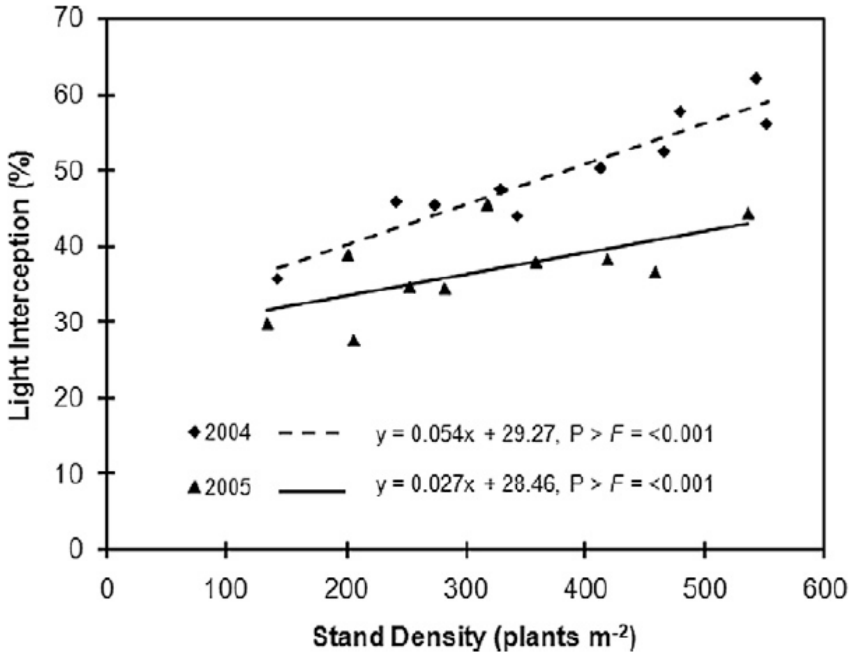

Fig. 6. The relationship between spring triticale stand density and photosynthetically active radiation intercepted by the plant canopy. Measurements were taken on 12 June 2004 and 17 June 2005 at Ames, IA and 19 June 2004 and 16 June 2005 at Sioux Center, IA. Data were averaged across locations.