EFFECT OF SIMULATED GRAZING INTENSITY

ON DUAL-PURPOSE WINTER WHEAT

(*TRITICUM AESTIVUM* L.) GRAIN YIELD

IN OKLAHOMA

By

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ABSTRACT

Dual-purpose winter wheat growth and grain yield are influenced by cattle stocking density and variety selection. The objectives of this study were to determine the effect of mowing height on winter wheat grain yield, determine which growth habit has the least negative yield response to grazing, and determine the potential to use NDVI as a means of monitoring crop canopy closure. Grazing intensity was simulated at Stillwater and Lahoma, OK by mowing wheat to heights of 3, 7.5, and 12 cm at approximately four-week intervals. Mowing was initiated in early November and terminated at first hollow stem in the spring. Canopy closure was obtained using digital photography, and NDVI was measured with a handheld sensor. Canopy closure and NDVI measured throughout the grazing season were positively correlated with mowing height. Regression analysis determined NDVI could be used as a substitute for canopy closure when determining the impact of grazing on wheat growth (R^2=0.93). Relative grain yield had an asymptotic response to canopy closure and NDVI measurements taken prior to winter dormancy and at grazing termination. The 3-cm mowing height reduced grain yield of Fuller by 26%, but reduced grain yield of Overley by 39%, compared with the non-defoliated treatments. The results of this study indicate that there is a grain yield loss associated with grazing wheat, yield loss is greater at high grazing intensities, and grain yield of Fuller was not as negatively impacted by grazing as compared to Overley due to the effect of growth habit.

CHAPTER I

INTRODUCTION

Wheat contributes immensely to the agricultural economy of the southern Great Plains. Hard red winter wheat (*Triticum aestivum* L.) is Oklahoma's largest cash crop and is sown on approximately 2.4 million hectares annually. The winter climate of Oklahoma has few snow-covered days, making it one of the unique areas of the world that can accommodate dual-purpose production of winter cereals. Hard red winter wheat is considered a valuable forage source because it provides nutrient rich forage during a season when lush green vegetation is at a deficit. In this production system wheat is sown in early to mid September to allow for adequate fall growth to support winter grazing. Cattle are allowed to graze wheat pasture when crown root development and biomass accumulation are adequate to support grazing. This varies depending on weather conditions, but usually occurs 45-60 days after planting. Wheat is grazed throughout the winter months and at grazing termination calves are shipped to feedlots and fed to slaughter weight. It is estimated that one half of Oklahoma wheat hectares are used for dual-purpose wheat production (True et al., 2001). Growers favor this system because it offers a diversified and stable income stream generated from both both cattle and grain (Redmon et al., 1995).

Previous studies have evaluated the influence of grazing and simulated grazing on grain yield. Arzadun et al. (2006) conducted a study in Argentina evaluating simulated grazing heights of 3 cm, 7 cm, and no simulated grazing on three varieties differing in morphological and physiological growth. They found that grain yield did not differ between 3 and 7-cm clipped treatments, but yield was less in the clipped treatments than in the non-clipped treatments. Other studies reported that mechanical clipping had little or no effect on grain yield and in some cases caused a grain-yield increase (Christiansen et al., 1989; Redmon et al., 1995). Holliday (1956) found that grazing wheat with live cattle caused a decrease in grain yield. Winter and Thompson (1990) determined a 20% decrease in yield associated with grazing in a three-year study; however, Holman et al. (2009) found that grazing caused little reduction in grain yield and occasionally an increase. A six-year study conducted in Bushland, Texas used live cattle for grazing and found grazing to have a negative impact on grain yield in only one year, and favorable precipitation leading to compaction was thought to be the cause of the yield reduction (Baumhardt et al., 2009). Winter and Musick (1991) conducted a similar study at the same location and found that semi-dwarf wheat grain yield in an irrigated system was reduced by 2.18 Mg ha^{-1} compared to the non-grazed plots. The irrigated conditions in the Winter and Musick (1991) study could have led to compaction and been the cause of yield loss, similar to the findings of Baumhardt et al. (2009). Although these studies show grazing to have positive and negative effects on grain yield, Oklahoma state averages suggest lower grain yields in dual-purpose systems (Edwards et al., 2011).

Grazing termination date greatly influences grain yield in a dual-purpose production system. The proper growth stage to cease grazing is first hollow stem which occurs just after Feekes growth stage 5 (Large, 1954). First hollow stem occurs when wheat has 1.5 cm of hollow stem present below the developing wheat head (Edwards and Horn, 2010). Years of research have found that this date is optimum to offset competing objectives of grain yield and weight gain in a dual-purpose enterprise. Grain yield reductions from clipping at early joint have been found to be minimal, indicating that a significant amount of forage can be removed during the appropriate time of the grazing season with minimal effect on subsequent grain yield (Dunphy et al, 1982). Holman et al. (2009) found that grazing had no effect on grain yield when cattle were removed before first hollow stem, but when grazing continued past first hollow stem there was a 23% decrease in grain yield. Several additional studies suggest that winter wheat can be grazed in the fall and spring and have little effect on grain yield as long as grazing is ceased by first hollow stem, soil moisture is readily available, and sound management practices are implemented (Khalil et al., 2002; Redmon et al., 1996; Virgona et al., 2006).

Maximizing profit for both portions of a dual-purpose system is challenging and requires intensive management, but management in a dual-purpose system is frequently directed towards the stocker cattle portion of the enterprise. The best way to ensure the greatest weight gain from stocker cattle is to increase stocking densities to the carrying capacity of wheat pasture. Previous studies have found a negative correlation between stocking density and grain yield. Arzadun et al. (2003) determined that grain yield increased by approximately 400 kg ha^{-1} when grazing intensity was reduced from 3 heifers ha^{-1} (high) to 1.5 heifers ha^{-1} (low). Generally, stocking rates are initially determined from the quantity of fall biomass, and adjustments to these rates are made when biomass falls below what is required to maintain a constant weight gain on stocker cattle. A study using sheep for grazing determined pastures grazed more intensely and for longer durations never reached full canopy closure, resulting in yield decreases of up to 33% in these pastures (Virgona et al., 2006). Research has proven that to obtain maximum grain yield from semi-dwarf wheat varieties there must be maximum leaf area at anthesis (Redmon et al., 1995; Arzadun et al., 2003). Unfortunately, light interception is often ignored due to the difficulty of obtaining accurate measurements (Purcell, 1999).

Leaf area index (LAI) of grazed winter wheat has been found to increase rapidly post grazing but never reach the LAI of ungrazed plants, resulting in approximately a 38% decrease in LAI (Winter and Thompson, 1990; Harrison et al., 2010). Lower LAI in grazed plants can translate into reduced plant water stress due to less canopy evaporative demand (Harrison et al., 2010). Kelman and Dove (2009) found less water to be depleted in the 0-0.6 m zone in intensely-grazed plots, and Virgona et al. (2006) determined that grazed crops used less water during and directly after grazing than the ungrazed treatments. This information provides a partial explanation of the variability of grazing on grain yield among years.

Total leaf area influences the ability of a wheat plant to intercept sunlight, which affects plant growth and grain yield (Shibles and Weber, 1965; Sinclair and Muchow, 1999; Monteith, 1977). Stocking densities on winter wheat affect the amount of foliage present at grazing termination and influence plant growth and grain yield post grazing. Miller et al. (2010) conducted a study evaluating grain yield as a function of dry matter (DM) production and found that non-grazed plots had an end grazing DM residual of 940 kg ha^{-1} compared to 520 kg ha^{-1} for the grazed treatments. They concluded that dual purpose wheat can be continuously grazed to 500 kg DM ha^{-1} residual at stem elongation without a reduction in grain yield.

In this study, canopy closure values were obtained for different grazing intensities using digital photography. Purcell (2000) analyzed canopy closure measurements for soybean and compared measurements taken by a 1-m line-quantum sensor to results from digital imagery analysis and found that crop canopy light interception was directly proportional to canopy closure percentage. His study demonstrated that canopy closure measurement using digital imagery analysis was more simplistic than other methods and was a very accurate means of determining crop canopy light interception. Digital photography was also tested against other methods in determining turfgrass coverage (Richardson et al., 2001). The results provided by Richardson et al. (2001) showed that digital imagery analysis precisely measured turfgrass coverage and was capable of distinguishing the smallest differences in coverage. Richardson et al. (2001) concluded that digital imagery analysis was the most effective in determining the amount of green turf. Additionally, crop biomass was characterized by a hand-held normalized difference vegetation index (NDVI) sensor. Previous research confirmed that winter wheat grain yield potential can be accurately predicted from NDVI measurements taken at Feekes growth stage 4 and 5 (Raun et al., 2001). Many producers have access to hand-held NDVI sensors for use in predicting grain yield response to nitrogen fertilization. The comparison of NDVI measurements to canopy closure values acquired by digital photography will determine if a handheld NDVI sensor can also be used by producers to accurately predict canopy closure values on grazed wheat throughout the growing season. A long term goal of this research is the use of mid-season NDVI values to determine appropriate stocking densities for maximizing hard red winter wheat grain yield in a dual-purpose production system

Many studies have evaluated grazing effects on wheat grain yield; however, a literature review revealed no research on grazing intensity has been found to relate mid-season canopy closure or NDVI values to grain yield. The central hypotheses of this study are wheat yield response to simulated grazing will be affected by simulated grazing intensity and plant growth habit; and NDVI measurement of crop canopy closure will closely follow crop canopy closure as determined by digital photography.

Objectives

1) Determine the effect of mowing height on winter wheat grain yield.

2) Determine which growth habit has the least negative yield response to grazing.

3) Determine the potential to use NDVI as a means of monitoring crop canopy closure.

CHAPTER II

METHODOLOGY

Establishment

This three-year study was initiated during the 2008-2009 growing season at Stillwater, OK (36^{o}8'4.54"N, 97^{o}6'12.83"W, elevation 270 m) on an Easpur Loam (fine loamy, mixed, superactive, thermic Fluventic Haplustolls). A second site was established in the 2009-2010 growing season near Lahoma, OK (36^{o}23'20.80"N, 98^{o}6'28.21"W, elevation 390 m) on a Grant Silt Loam (fine-silty, mixed, superactive, thermic Udic Argiustolls). The experiment area at both locations received several pre-plant tillage operations each year for weed control, incorporation of crop residue from the previous year, and seedbed preparation just prior to planting. Experimental design was a full factorial arrangement of a randomized complete block (RCBD) with four replications (blocks). Main effects were variety (Fuller and Overley) and simulated grazing intensity (mowing treatments of 3 cm, 7.5 cm, 12 cm, and a non-treated control). Fuller was chosen because it has a planophile growth habit and Overley has an erectophile growth habit. Planophile is a prostrate type of growth or horizontal leaf orientation. Erectophile defines a plant with vertical leaf orientation. Monteith (1977) found that horizontal leaf orientation intercepts more light at small leaf area values and erect leaves intercept more light at higher leaf area values. Plant growth habit influences the leaf angle distribution, which affects the plant’s ability to reflect, transmit, and absorb solar radiation.

Individual plot size was 1.2 m wide by 5.2 m long with 15-cm row spacing. Replications were separated by a 3-m alley.

Fertility

Nitrogen (urea) was applied pre-plant each year with a broadcast spreader and incorporated. Quantity applied varied depending on soil test results, but was sufficient to have approximately 100 kg ha^{-1} soil nitrogen present at planting to ensure that nitrogen was not a limiting factor in wheat growth. In addition, a topdress application of nitrogen was made in the spring at both locations to prevent late-season N limitation (Table 1).

Table 1. Topdress nitrogen fertilizer applications for simulated grazing research studies at Stillwater and Lahoma, OK.

Location	Date	Quantity (kg N ha^{-1})	Source
Stillwater	5 February 2009	90	Urea (46-0-0)
Stillwater	10 March 2010	50	UAN (32-0-0)
Stillwater	4 March 2011	135	Urea (46-0-0)
Lahoma	N/A	N/A	N/A
Lahoma	10 March 2011	90	Urea (46-0-0)

N/A quantity applied in the fall combined with the soil residual was sufficient to ensure non-limiting N fertility.

Planting

Wheat was sown 15 September 2008, 21 September 2009, and 15 September 2010 at Stillwater and 15 September 2009 and 13 September 2010 at Lahoma using a Hege small-plot, conventional drill (Wintersteiger, Salt Lake City, UT). Planting density was 3.7 million seeds ha^{-1} or approximately 120 kg seed ha^{-1}. Soil test phosphorus indices ranged from 48 to 57 at Stillwater and 59 to 70 at Lahoma. An in-furrow application of 56 kg ha^{-1} diammonium phosphate (DAP) was applied at planting. Plots at the Lahoma site in 2009 were irrigated with pulse-action lawn sprinklers shortly after sowing to obtain uniform plant emergence.

Mowing

Stand counts were taken at emergence in the control plots (n=8) at both locations to determine percent emergence. Digital photographs of each plot were taken at approximately two-week intervals between emergence and grazing initiation. Simulated grazing was initiated in early November or approximately 6-7 weeks after emergence using a rotary-blade, self-propelled mower with bagging attachment.

Prior to the first mowing treatment, forage was measured from the 3-cm mowing height plots in each replication. Forage was measured by hand-clipping two, 1-m by one-row samples at a 3-cm clipping height. Forage clippings were dried at approximately 50C^{o} for 7-10 days and weighed to obtain biomass at mowing initiation. Plots were mowed at a regrowth threshold of approximately 5 cm throughout the grazing season; therefore, mowing operation timing varied among years and location (Table 2). Mowing continued until first hollow stem the following spring.

Table 2. Mowing dates for simulated grazing intensity treatments at Stillwater and Lahoma, OK.

Location	**Season**	**Mowing Dates**				
		1	**2**	**3**	**4**	**5**
Stillwater	2008-2009	10/30/08	11/20/08	2/5/09	2/26/09	–
Stillwater	2009-2010	11/5/09	11/24/09	12/14/09	2/15/10	3/5/10
Stillwater	2010-2011	11/22/10	12/8/10	2/22/11	–	–
Lahoma	2009-2010	11/5/09	11/19/09	12/14/09	2/17/09	3/6/10
Lahoma	2010-2011	11/8/10	11/22/10	12/9/10	2/22/11	–

Canopy Closure and NDVI

Digital photographs were taken from the front 1/3 of each plot before and after each mowing treatment using a method similar to that described by Purcell (2000). Pictures were taken from above with the camera lens pointing down encompassing approximately 1 m^2 of the plot. The camera was mounted on a monopod attached to a piece of polyvinyl chloride (PVC) pipe. The mount was 1 m above the soil surface and the camera was inclined from the horizon to prevent the PVC pipe from being included in the picture. Digital photographs were batch analyzed using SigmaScan Pro (v. 5.0, systat software, Point Richmond, CA) (Karcher and Richardson, 2005). The software has selectable options defining hue and saturation values. Setting hue and saturation values selectively included the green pixels in the digital image (Purcell, 2000). For this study hue was set for the range 40 to 140, and saturation was set for the range 15 to 100. The output of the program is fractional canopy coverage defined as the number of scanned pixels divided by the total number of pixels per image (Purcell, 2000). NDVI measurements were taken using GreenSeeker™ sensor (model 505, NTech Industries, Ukiah, CA) before and after each mowing treatment.

A line quantum sensor (LI–191SA, Li-Cor, Lincoln, Neb.) was used at anthesis to quantify maximum insolation by wheat. Insolation measurements were not taken at the Stillwater location in 2009, but were taken in 2010 and 2011 at Stillwater and Lahoma sites. Percent insolation was determined by measuring photosynthetically active radiation above and below the canopy within one hour of solar noon in unobstructed sunlight. The below canopy reading was made between the center two drill rows in the front 1/3 of each plot.

Herbicide and Fungicide Applications

To control broadleaf weeds 0.56 kg ha^{-1} MCPA was applied directly after grazing termination in 2009 at the Stillwater location. An application of 0.033 kg ha^{-1} lambda-cyhalothrin was made 7 October 2009 at Stillwater to control fall armyworm (*Spodoptera frugiperda*) and grasshopper (*Melanoplus differentialis*). Due to early-season broadleaf weeds and annual ryegrass infestation 0.42 kg ha^{-1} MCPA and 0.12 kg ha^{-1} pinoxaden were applied 5 November 2009 at the Lahoma site. An application of 0.56 kg ha^{-1} MCPA and 0.026 kg ha^{-1} lambda-cyhalothrin was made 2 October 2010 at Lahoma and 4 October 2010 at Stillwater to control broadleaf weeds and fall armyworm. Additionally, 0.011 kg ha^{-1} chlorsulfuron, 0.002 kg ha^{-1} metsulfuron-methyl and 0.42 kg ha^{-1} MCPA were applied 18 February 2011 at Lahoma to control winter annual grass and spring emerged broadleaf weeds. Fungicide was not applied in 2009 at the Stillwater location. To prevent grain yield reduction from foliar disease, 0.09 kg ha^{-1} propiconazole and trifloxystrobin at Feekes growth stage 10.1 (Large, 1954) on 14 April 2010 at Stillwater and 15 April 2010 at Lahoma. Due to delayed heading dates caused by the 3-cm mowing treatment at the Stillwater site, fungicide was not applied on these plots until 21 April 2010. On 19 April 2011 0.085 kg ha^{-1} pyraclostrobin and 0.053 kg ha^{-1} metconazole were applied at Stillwater and Lahoma.

A freeze occurred in early April 2009 and damage was assessed by counting total stems and total live heads in 1 m of row from each plot. Percent damage per plot was calculated by 1-(total live heads/total stems). To assess shatter damage from a hailstorm at the Lahoma site in 2011, visual ratings were made prior to harvest. Harvest index samples were taken from 1 m of an inner row of each plot just prior to harvest. Samples were clipped just above the soil surface, dried, and weighed. Samples were then threshed with a Hege small plot combine to determine grain weight of the sample and 100 seed weight. Plots were harvested 19 June 2009, 22 June 2010, and 3 June 2011 at Stillwater and 11 June 2010 and 8 June 2011 at Lahoma with a Hege self-propelled small-plot combine.

Statistical Analysis

Grain yield, fertile spikes, seeds head^{-1}, percent insolation, fractional canopy closure, and NDVI data were analyzed using SAS software (SAS Institute, 2004). Analysis of variance was performed using PROC MIXED with a slice option to detect differences among the interactions of variety and mowing height main effects. Data was analyzed by location holding year as a random variable. Grain yield, fertile spikes, and seeds head^{-1} data for the 2008-2009 growing season at Stillwater was analyzed separately due to the influence of the spring 2009 freeze. Replication 1 was dropped in the analysis of grain yield and seeds head^{-1} at Stillwater for 2010-2011 due to extensive pest damage. Regression analysis was performed to detect the correlation between fractional canopy closure derived by digital photography and NDVI using SigmaPlot 9 (Systat Software, 2004). Additionally, regression analysis was used to determine the relationship of relative grain yield to fractional canopy closure and NDVI measurements taken prior to winter dormancy and at grazing termination. Relative yield was determined by location and year by expressing yield of each plot relative to the yield produced by the non-defoliated treatment.

Table 3. Day of year (DOY) canopy closure and NDVI measurements were taken at Stillwater and Lahoma, OK during the 2009-2010 and 2010-2011 production seasons.

Prior to winter dormancy			Grazing termination		
Year	**Location**	**DOY**	**Year**	**Location**	**DOY**
2009	Stillwater	348	2010	Stillwater	64
2010	Stillwater	342	2011	Stillwater	53
2009	Lahoma	348	2010	Lahoma	65
2010	Lahoma	343	2011	Lahoma	53

CHAPTER III

RESULTS AND DISCUSSION

Stillwater 2008-2009 Yield and Yield Components

During the 2008-2009 growing season at Stillwater the number of fertile spikes m^{-1} varied across mowing heights (Fig. 1). Freeze damage had a negative impact on fertile spikes m^{-1}, and less freeze damage was observed in the 3, 7.5, and 12-cm mowing height treatments than the non-defoliated treatment. This was probably the result of delayed heading within simulated grazing, as previous studies found that grazing leads to delayed heading dates which would be advantageous in the case of a spring freeze event (Winter and Thompson, 1990; Virgona et al., 2006). The increased freeze damage in nongrazed plots is further evidenced by approximately 15 fewer fertile spikes m^{-1} in the nongrazed plots than the 3-cm mowing height treatment. Variety had no impact on fertile spikes m^{-1} except at the 12-cm mowing height. Neither mowing height nor variety affected seeds $head^{-1}$ at Stillwater in 2008-2009 (data not shown).

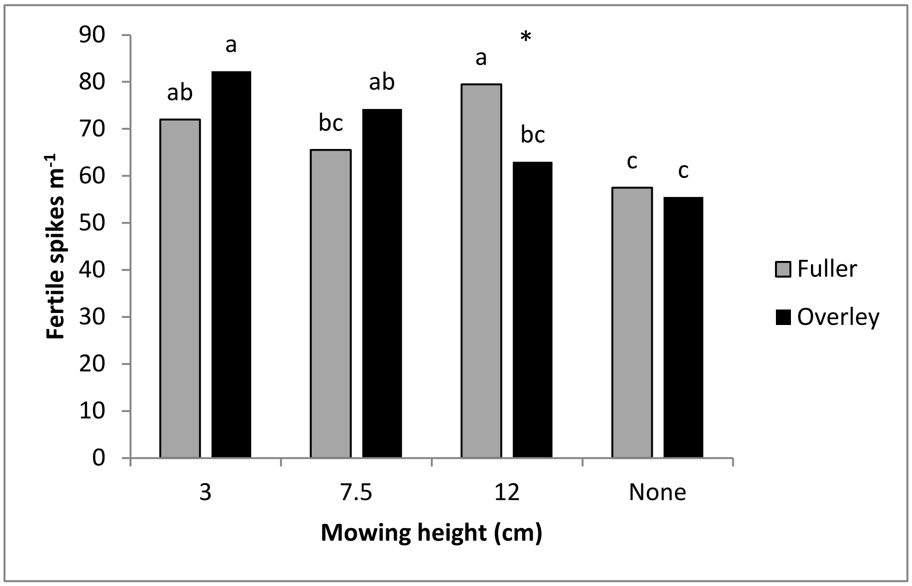

Figure 1. Least squares mean of fertile spikes m^{-1} of row as affected by mowing height and variety at Stillwater during the 08-09 growing season. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

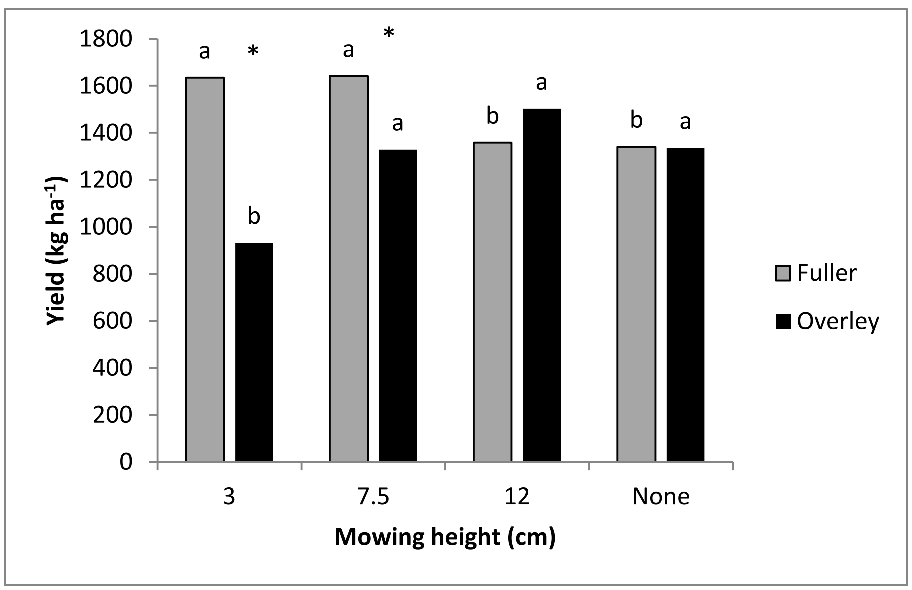

Figure 2. Least squares mean of grain yield as affected by mowing height and variety at Stillwater during the 08-09 growing season. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

The 3 and 7.5-cm mowing height treatments yielded approximately 300 kg ha^{-1} more than the 12-cm and non-defoliated treatments for Fuller, and yields for Fuller were greater than Overley at the 3 and 7.5-cm mowing heights (Fig. 2). Conversely, mowing seemed to decrease the yield of Overley. Although Overley had more fertile spikes m^{-1} at the 3-cm mowing height than the less intense simulated grazing treatments, grain yield was the lowest for this treatment. The negative impact of simulated grazing on the grain yield of Overley was probably due to its erect growth habit and the contrasting response of Fuller grain yield to simulated grazing.

Stillwater 2009-2011 Light Interception

There was an inverse relationship for light interception between mean canopy closure and simulated grazing intensity at Stillwater (Fig. 3). Fuller maintained higher canopy closure than Overley at the 3 and 7.5-cm mowing height treatments, which was probably the result of the more prostrate growth habit of Fuller being less affected by mowing as compared to the more erect growth habit of Overley. Results for NDVI at Stillwater were similar to those for fractional canopy closure (Fig. 4). The 3-cm mowing height had the lowest NDVI across variety and with each incremental increase in mowing height there was an approximate 0.1 increase in NDVI. Maximum NDVI was obtained in the 12-cm and non-defoliated treatments. It is also important to note that Overley had significantly lower NDVI values across all mowing heights as compared to Fuller; whereas varietal differences for canopy closure were only present in the two most intensive simulated grazing treatments. Similar studies have reported a decrease in leaf area index in grazed wheat compared with nongrazed (Winter and Thompson, 1990; Harrison et al., 2010).

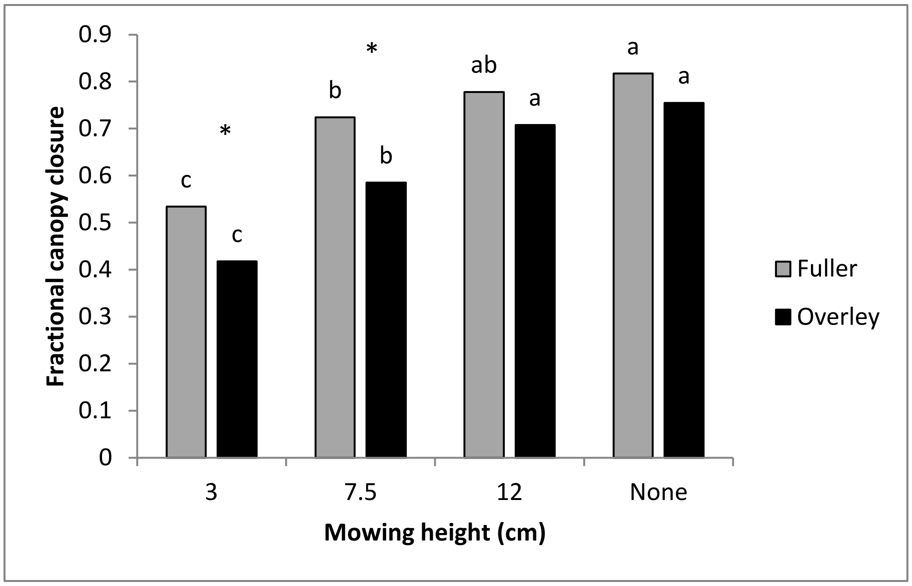

Figure 3. Least squares mean of fractional canopy closure via digital photography measured from mowing initiation to mowing termination as affected by mowing height and variety at Stillwater averaged across the 08-09, 09-10, and 10-11 growing seasons. Bars within varieties with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

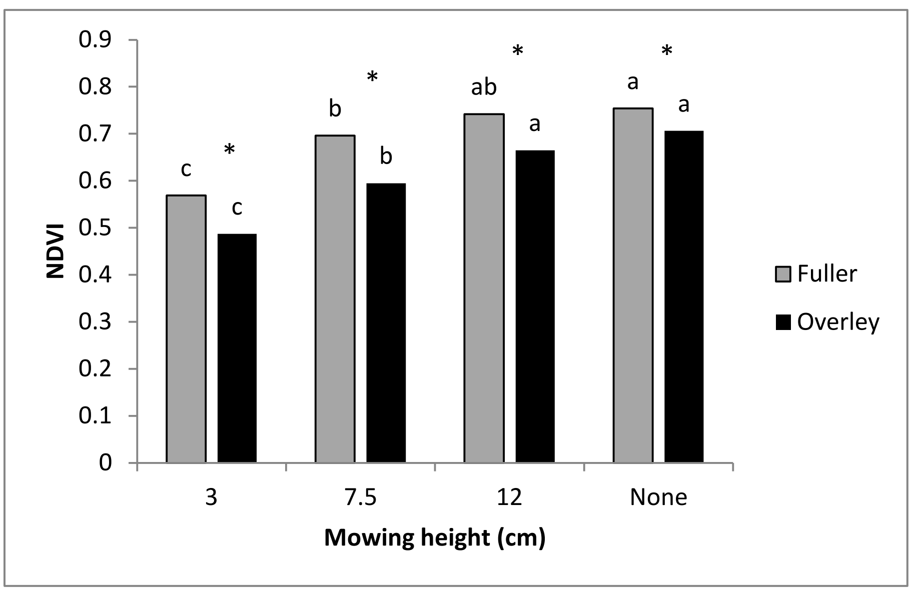

Figure 4. Least squares mean of NDVI measured from mowing initiation to mowing termination as affected by mowing height and variety at Stillwater averaged across the 08-09, 09-10, and 10-11 growing seasons. Bars within varieties with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

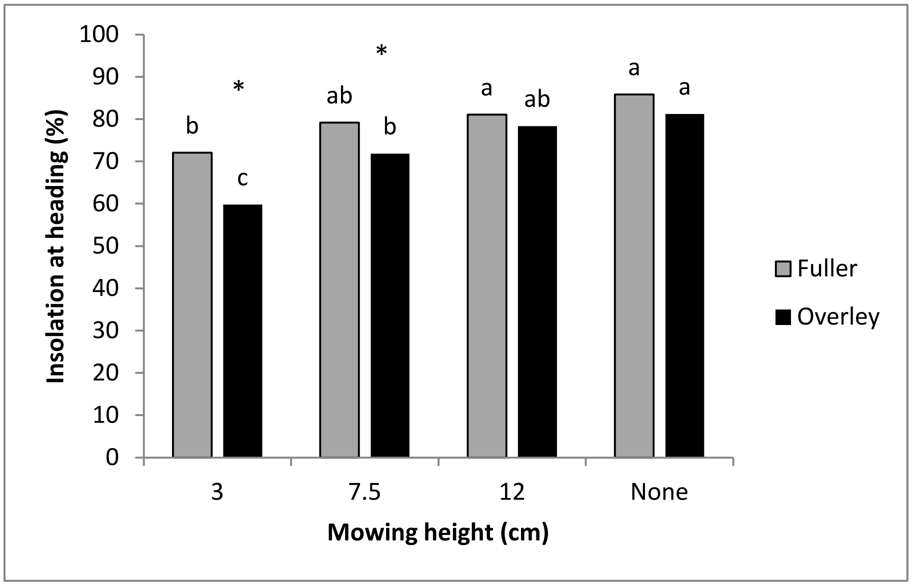

Figure 5. Least squares mean of percent insolation as affected by mowing height and variety at Stillwater during the 09-10 and 10-11 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

Research has found that complete insolation by the crop canopy at anthesis is required to reach maximum yield (Redmon et al., 1995; Arzadun et al., 2003); however, none of our treatments reached 100% insolation. The 3-cm mowing height intercepted significantly less PAR than the 12-cm and non-defoliated treatments for Fuller (Fig. 5). The 3-cm mowing height significantly reduced intercepted PAR compared to all other treatments in Overley, and the 7.5-cm treatment resulted in less insolation than the non-defoliated treatment. Overley produced less insolation at the 3 and 7.5-cm mowing height treatments compared to Fuller. This was likely due to the negative effect of mowing on the erect growth habit of Overley. These findings are supported by the data of Harrison et al. (2010), which suggested when wheat is grazed too intensely the crop is unable to recover the leaf area necessary to intercept maximum quantities of PAR.

Stillwater 2009-2011 Yield Components

In contrast to the 2008-2009 season when freeze affected fertile spikes, the lowest mowing height had significantly fewer fertile spikes m^{-1} in both varieties for the 2009-2011 growing seasons (Fig. 6). Response of fertile spikes to simulated grazing was similar across varieties, with fertile spike count increasing by 20 spikes as mowing height increased from 3 cm to 7.5 cm. Fertile spikes m^{-1} did not change once mowing height reached 7.5-cm, suggesting that the 7.5-cm mowing height was sufficient to maintain maximum fertile spikes m^{-1}. Overley had significantly fewer fertile spikes than Fuller in the non-defoliated treatment and the 3 and 7.5-cm mowing height treatments, indicating a tendency for Overley to produce fewer fertile spikes than Fuller.

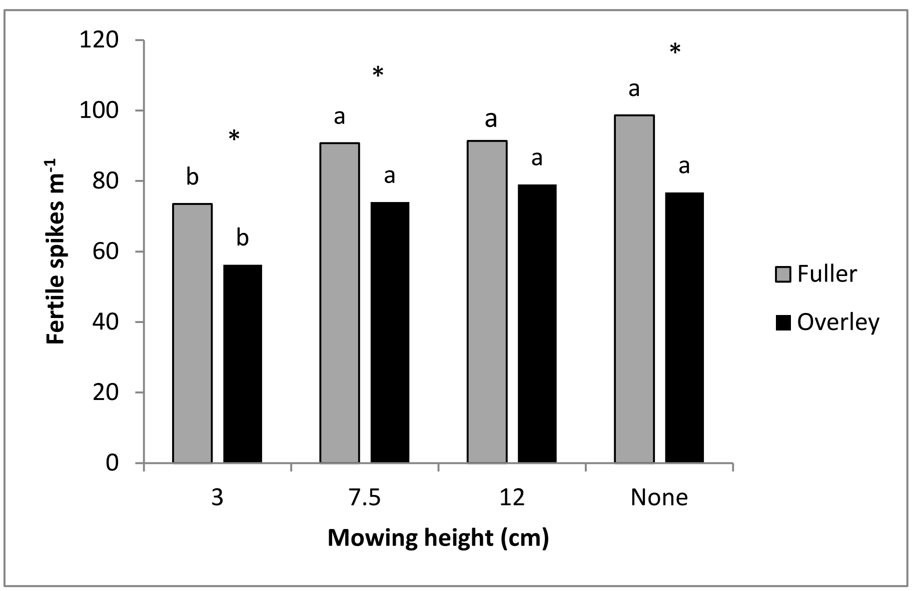

Figure 6. Least squares mean of fertile spikes m^{-1} as affected by mowing height and variety at Stillwater during the 09-10 and 10-11 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

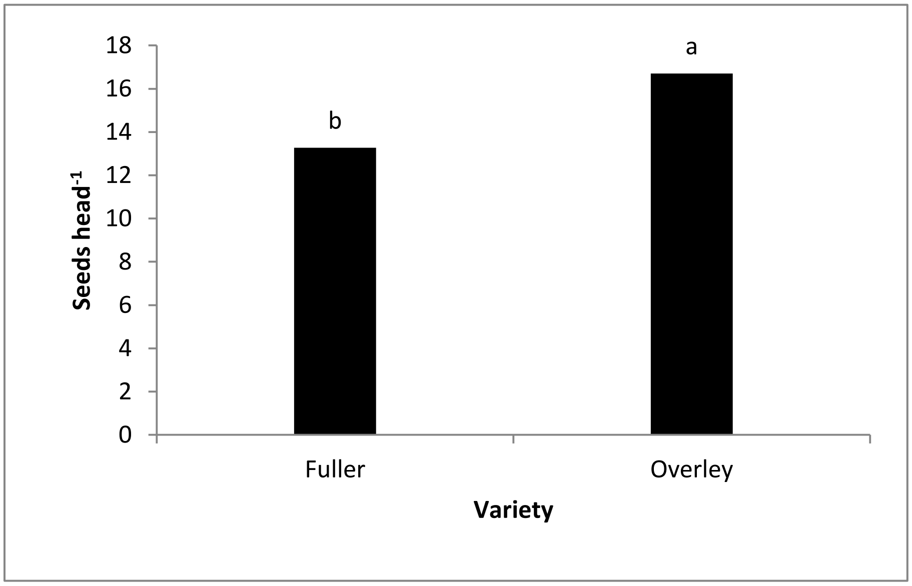

Figure 7. Least squares mean of seeds head^{-1} as affected by variety at Stillwater averaged across mowing height for the 09-10 and 10-11 growing seasons. Different letter indicates significance at (α=0.05).

There were no significant differences for seeds head^{-1} for the main effect of mowing height or the interaction of variety and mowing height. Overley filled approximately 17 seeds head^{-1} compared with the 13 seeds head^{-1} filled by Fuller (Fig. 7). The cause of the difference in number of seeds head^{-1} is unknown but is hypothesized to be attributed to varietal characteristics.

Stillwater 2009-2011 Grain Yield

Variety did not affect grain yield at Stillwater during the 2009-2011 growing seasons suggesting that growth habit had no influence on grain yield at this location (Fig. 8). Drought stress negatively affected grain yield during the 2010 and 2011 growing season and may have been a confounding factor influencing results. The 3-cm mowing height reduced grain yield by approximately 1000 kg ha^{-1} compared with non-defoliated plots. It is important to note that decreasing simulated grazing intensity from a 3-cm to 7.5-cm mowing height increased grain yield and also increased insolation by the canopy.

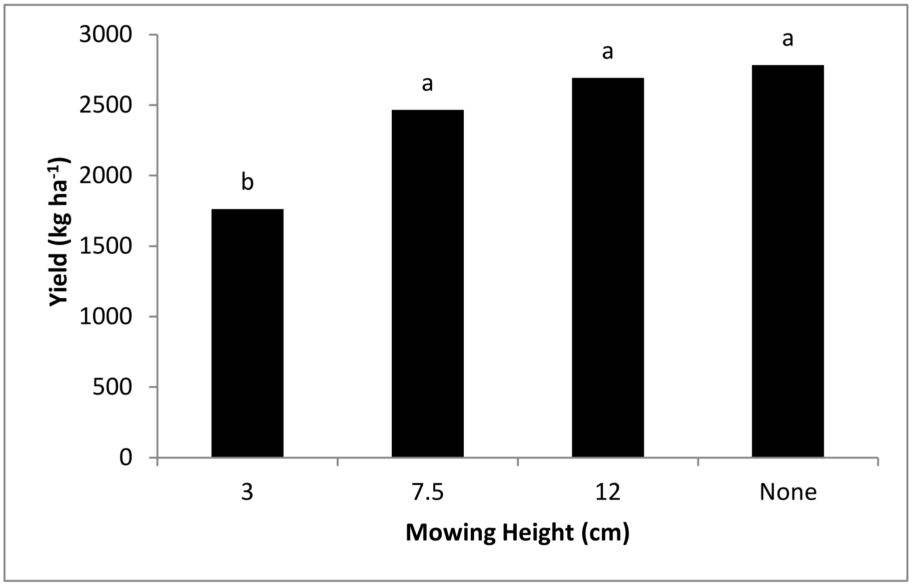

Figure 8. Least squares mean of grain yield as affected by mowing height at Stillwater during the 09-10 and 10-11 growing seasons. Bars with the same letter are not significantly different (α=0.05).

Lahoma 2009-2011 Light Interception

Results for fractional canopy closure at Lahoma were similar to those from Stillwater (Figs. 3 and 9). The 3-cm mowing height reduced canopy closure of Fuller, but the prostrate growth habit of this variety allowed enough leaf area to remain at the 7.5-cm mowing height for canopy closure to be equal to the 12-cm and non-defoliated treatment (Fig. 9). In contrast, canopy closure for Overley at the 7.5-cm treatment was significantly lower than the 12-cm and non-defoliated treatments and decreased an additional 0.2 at the 3-cm mowing height. Fuller had significantly higher canopy closure at the 3 and 7.5-cm mowing heights as compared to Overley, which was probably an effect of growth habit.

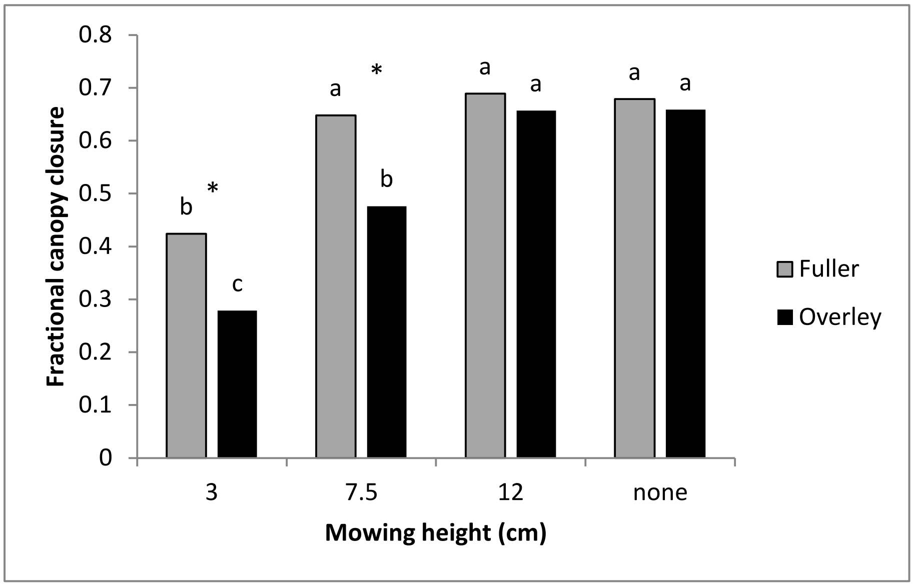

Figure 9. Least squares mean of fractional canopy closure via digital photography measured from mowing initiation to mowing termination as affected by mowing height and variety at Lahoma averaged across the 09-10 and 10-11 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

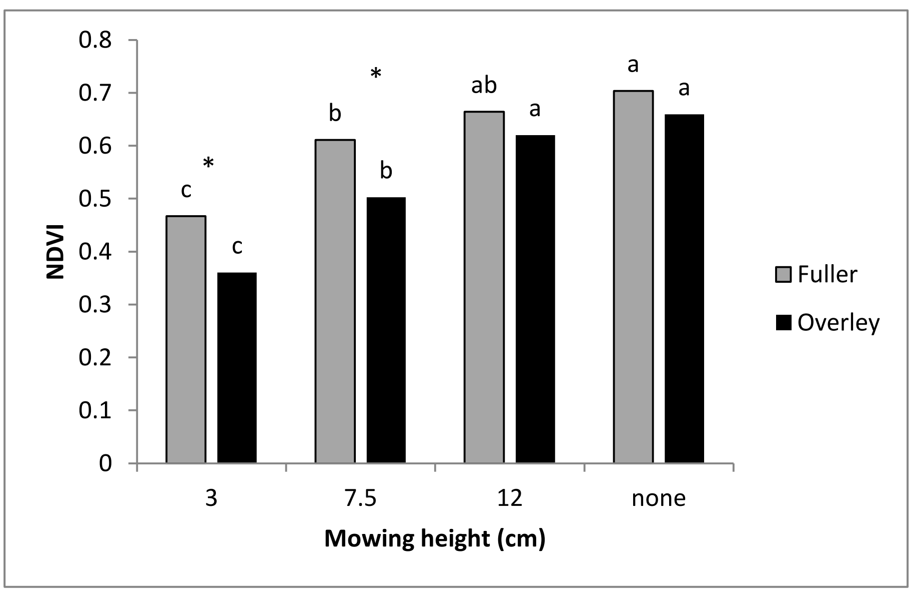

Figure 10. Least squares mean of NDVI measured from mowing initiation to mowing termination as affected by mowing height and variety at Lahoma averaged across the 09-10 and 10-11 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly

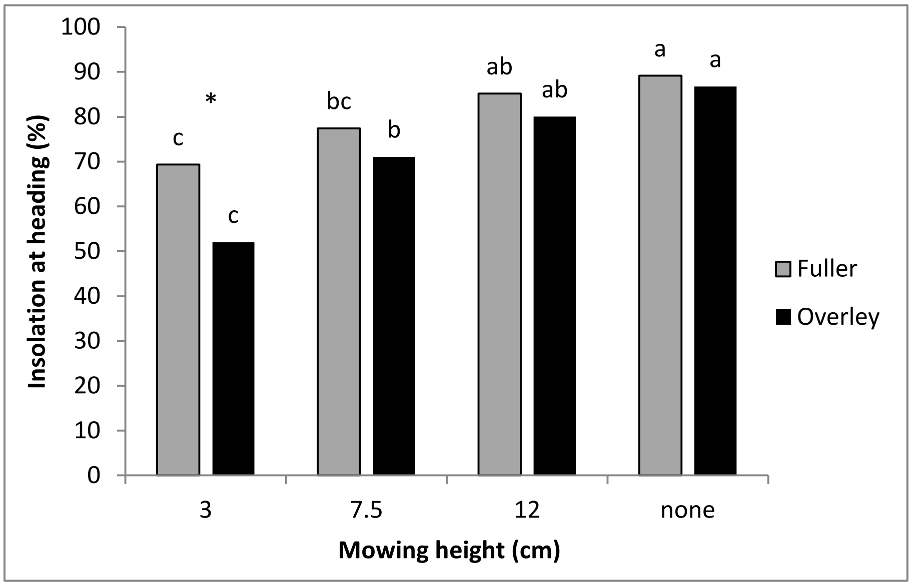

Figure 11. Least squares mean of percent insolation as affected by mowing height and variety at Lahoma during the 09-10 and 10-11 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

The response of NDVI to simulated grazing and cultivar at Lahoma was similar to fractional canopy closure. NDVI was lowest for both varieties at the 3-cm mowing height and increased as mowing height increased (Fig. 10). NDVI of Overley was significantly lower than Fuller at the 3 and 7.5-cm mowing heights throughout the grazing season (data not shown). Differences in NDVI between varieties at this location resulted from prostrate versus erect growth habit. The similarities between canopy closure and NDVI at both locations implies that mowing height and variety influence leaf area during the grazing season at different environments.

Mowing height and growth habit affected the amount of leaf area available to intercept sunlight at anthesis (Fig. 11). Percent insolation was not different for Fuller between the 3 and 7.5-cm mowing heights or between the 7.5 and 12-cm mowing heights, but the 3 and 7.5-cm mowing height treatments had less total leaf area at anthesis than the non-defoliated treatment (Fig. 11). The 3-cm mowing height treatment reduced insolation by 20% in Fuller compared with the non-defoliated treatment. Similar to Stillwater, mowing had a greater impact on percent insolation for Overley than for Fuller at Lahoma. There was a 20% reduction in insolation for Overley when mowing height was reduced from 7.5 to 3 cm and approximately a 40% reduction compared with the non-defoliated treatment. This suggests that an erect growth habit wheat variety does not recover leaf area quickly enough between grazing termination and anthesis to achieve maximum insolation, which is essential to maximize grain yield.

Lahoma 2009-2011 Yield Components

Fertile spikes, like many other components measured in this study, exhibited similar trends at both locations. The 3-cm mowing height reduced fertile spikes by approximately 30 spikes for both varieties as compared to the 7.5-cm mowing height (Fig. 12). Number of fertile spikes was not affected at mowing heights greater than 7.5 cm. Production of fertile spikes m^{-1} was lower for Overley across all treatments, which indicates that fewer fertile spikes is a varietal characteristic of Overley.

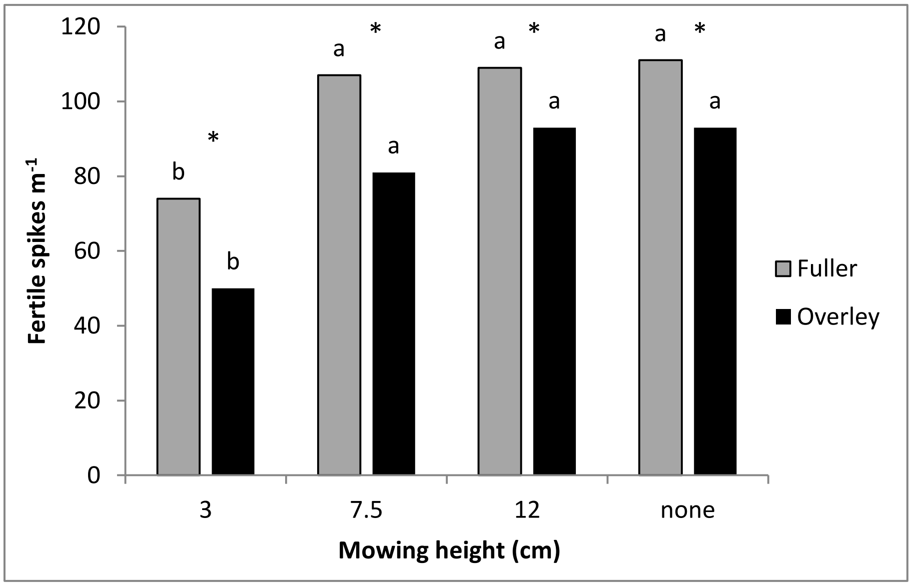

Figure 12. Least squares mean of fertile spikes as affected by mowing height and variety at Lahoma during the 09-10 and 10-11 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

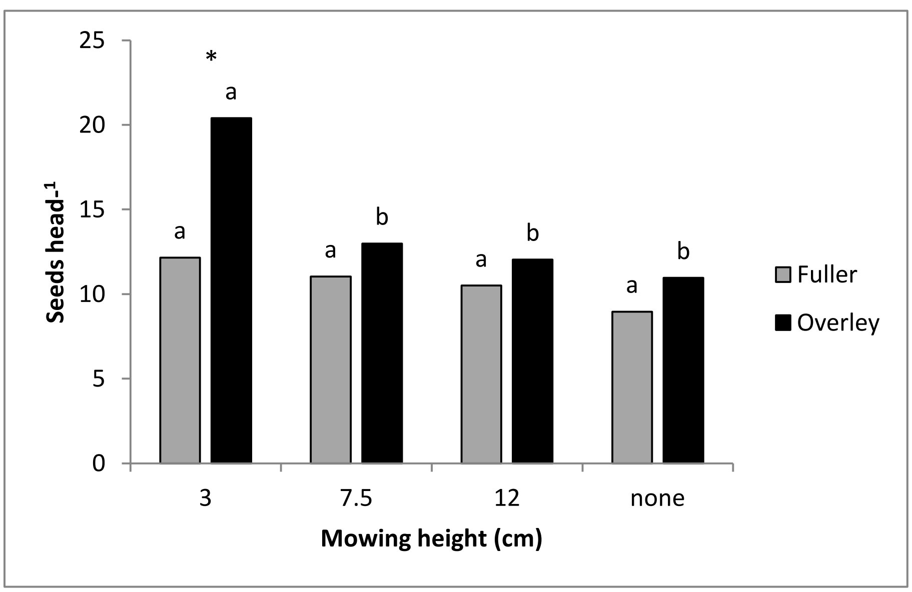

Figure 13. Least squares mean of seeds head^{-1} as affected by mowing height and variety at Lahoma during the 09-10 and 10-11 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

In contrast to Stillwater, mowing height affected seeds head^{-1} at Lahoma. The Overley 3-cm mowing height had the lowest fertile spikes of all treatments but had more seeds head^{-1} than all other treatments analyzed (Fig. 13). Fewer fertile spikes reduce the amount of inter-plant competition, allowing more water and nutrient availability to produce seed, which was probably the cause of more seeds head^{-1}. Mowing height had no effect on Fuller.

Lahoma 2009-2011 Grain Yield

Fuller yielded 470 kg ha^{-1} and 540 kg ha^{-1} more than Overley at the 3 and 12-cm mowing heights, respectively. The two varieties yielded equally in the 7.5-cm mowing height and non-defoliated treatments (Fig.14). The 3-cm mowing height plots resulted in the greatest yield decrease for both varieties, and yields increased as mowing height increased. In contrast to the study conducted by Arzadun et al. (2006), we found grain yield to be less in the 3-cm mowing height compared with the 7.5-cm treatment. Slightly lower numeric grain yields for the non-defoliated treatment compared with the 12-cm mowing height is supported by previous research which suggests higher yields in later planting dates for wheat that is not grazed (Epplin et al., 2000; Hossain et al., 2003; Edwards et al., 2011). Grain yield at Lahoma was reduced by a severe hailstorm 23 May 2011. Overley had equal grain yield for the non-defoliated, 12, and 7.5-cm treatments; however, the 3-cm mowing height reduced grain yield by 39% compared to the Overley . The 3-cm mowing height reduced yield by 33% as compared to the 12-cm treatment in Fuller. Decreases in grain yield for the 3-cm treatment were attributed to lower canopy closure throughout the grazing season and less percent insolation at anthesis.

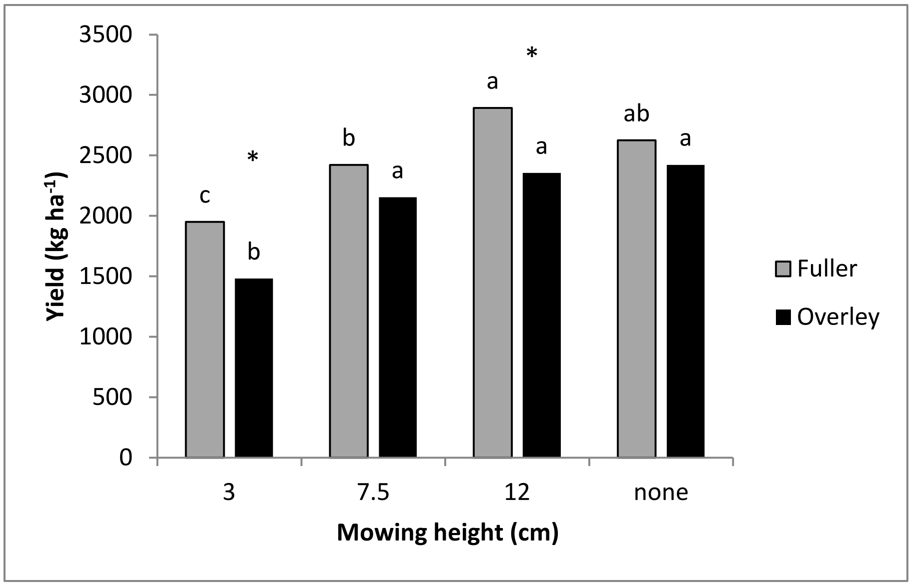

Figure 14. Least squares mean of grain yield as affected by mowing height and variety at Lahoma during the 09-10 and 10-11 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

Canopy Closure vs. NDVI

Previous research indicated that the digital photography method is an accurate means of determining canopy closure (Purcell, 2000). This study examined the relationship of NDVI to fractional canopy closure determined by digital imagery analysis during the grazing season across all locations and years for the treatments receiving mowing. Figures reported by Freeman et al. (2003) illustrate the insensitivity of the GreenSeeker sensor at NDVI values greater than 0.82 due to a peak in red adsorption. For this reason, control plots were dropped in the linear regression analysis between canopy closure and NDVI. Results from linear regression showed a strong relationship (R^2=0.93) between NDVI and fractional canopy closure (Fig. 15). Raun et al. (2001) found that a hand held NDVI sensor accurately predicted wheat grain yield potential, but the results from this study indicate that the sensor could also be used as a substitute for canopy closure when determining grazing impact in a dual-purpose system.

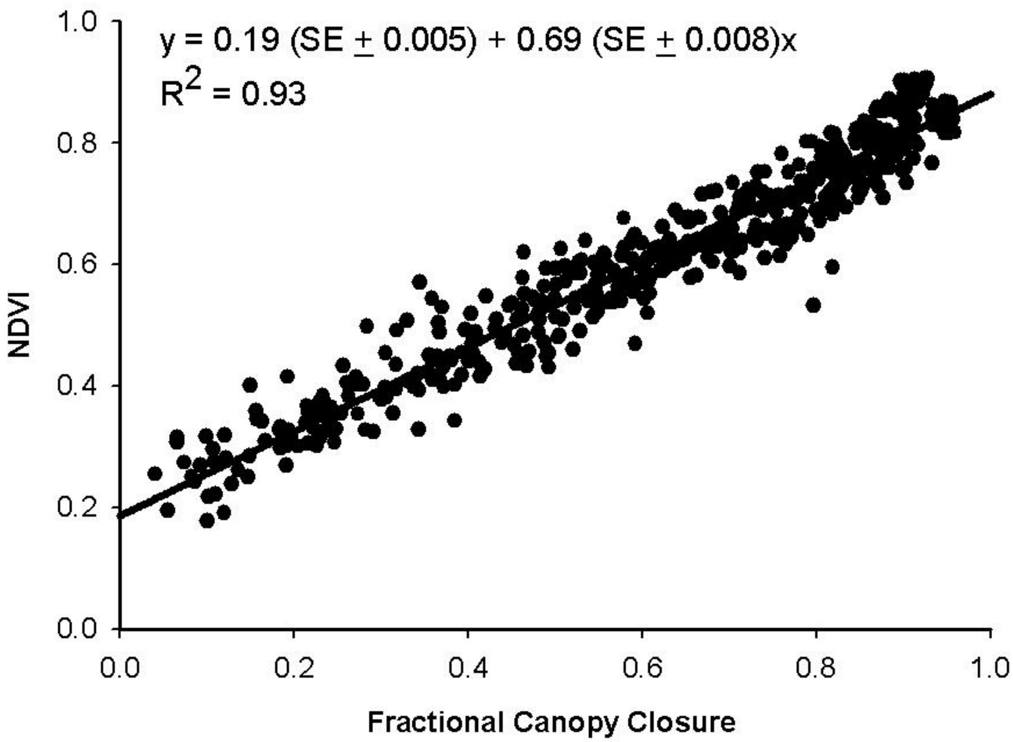

Figure 15. Relationship between fractional canopy closure via digital photography and NDVI via GreenSeeker sensor taken throughout the grazing season during 08-09, 09-10, and 10-11 production seasons at Stillwater and during 09-10 and 10-11 production seasons at Lahoma, OK.

Canopy Closure Prior to Winter Dormancy vs Relative Yield

Relative yield was expressed as a nonlinear function of canopy closure measurements taken prior to winter dormancy. Asymptotic relative grain yield predicted by the equation is 1.03 (Fig. 16). Assuming 95% of the asymptotic relative yield could be achieved, maximum attainable relative yield was 0.98. Maximum attainable relative yield of 0.98 corresponds to a canopy closure value of 0.53 at the onset of winter dormancy. Canopy closure below this level at the onset of winter dormancy would likely result in grain yield reductions. Approximately 93% of all the 3-cm mowing height data points were below the critical canopy closure value of 0.53. With the majority of the 3-cm mowing height treatments having low canopy closure prior to winter dormancy, it can be assumed that high intensity grazing negatively impacts canopy closure even in times of active growth. Although growth habit had little effect on the ability of canopy closure to remain above the critical level of 0.53 at the 3-cm mowing height, Fuller produced greater grain yield than Overley at the 3-cm mowing height at Lahoma (Fig. 14). Growth habit had a greater effect in the relationship of relative yield to canopy closure at the 7.5-cm mowing height. Approximately 73% of the 7.5-cm mowing height treatments below the critical canopy closure of 0.53 were associated with Overley. Both varieties had sufficient canopy closure to reach maximum yield once mowing reached a height of 12-cm. The 3 and 7.5-cm mowing heights had a greater impact on the canopy closure of Overley prior to winter dormancy than that of Fuller. This indicates an erect growth habit is unable to retain sufficient canopy closure to achieve maximum relative grain yield when subjected to intense and moderate grazing intensities.

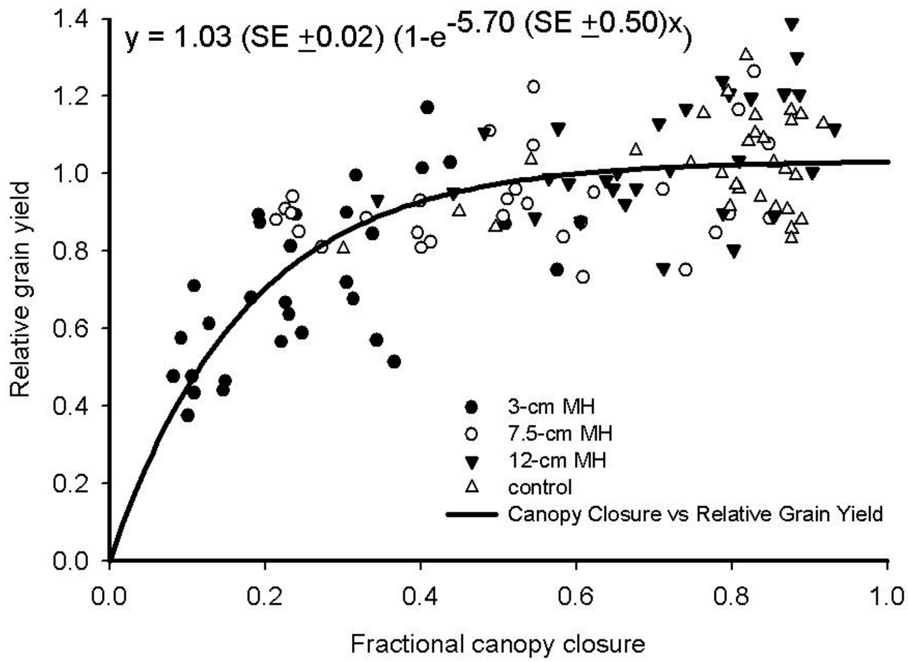

Figure 16. Relative grain yield of Fuller and Overley as a function of canopy closure prior to winter dormancy at Stillwater and Lahoma, OK during the 09-10 and 10-11 production seasons.

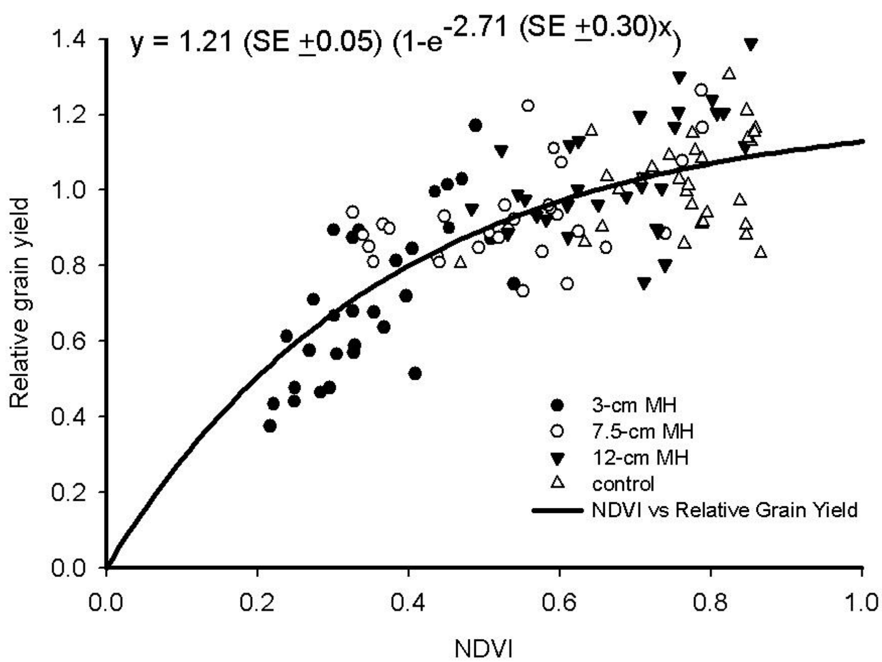

Figure 17. Relative grain yield of Fuller and Overley as a function of NDVI prior to winter dormancy at Stillwater and Lahoma, OK during the 09-10 and 10-11 production seasons.

The comparison of relative grain yield to NDVI determined an asymptotic relative grain yield of 1.21 (Fig. 17). Asymptotic relative yield predicted by the equation is greater for NDVI as compared to canopy closure and is attributed to the yield plateau being reached more slowly in the NDVI equation. As discussed previously, the control plots have large amounts of leaf area causing a peak in red adsorption and is the reason for the yield plateau being reached more slowly. Achieving 95% of the asymptotic relative yield would require a NDVI of 1.1, which is greater than the maximum NDVI that can be accurately predicted. Therefore, maximum relative yield was assumed to be 1.0. Reaching maximum relative yield of 1.0 would require NDVI of 0.64 or greater prior to winter dormancy. Substantial decreases in grain yield were observed when NDVI fell below 0.64 prior to winter dormancy. The majority of the 12-cm and nongrazed control treatments had NDVI values above 0.64 and was able to maintain enough leaf area throughout the grazing season to reach maximum relative yield. Approximately 66% of the 3-cm mowing height treatments had relative yield less than 0.8. This further emphasizes the negative impact of intense grazing on grain yield. Differences between varieties are similar to the differences observed in the canopy closure to relative yield comparison (Fig. 16). Fuller maintained higher NDVI values in the 3 and 7.5-cm mowing height treatments as compared to Overley, suggesting that a prostrate growth habit may be better suited for intense and moderate grazing scenarios.

Canopy Closure at Grazing Termination vs. Relative Yield

A strong relationship existed between canopy closure measurements taken at grazing termination and relative grain yield for both varieties across all locations and years (Fig. 18). Assuming 95% of the asymptotic relative yield (1.07) could be achieved, maximum attainable relative yield of both varieties was 1.0, which would be achieved by 0.62 fractional canopy closure at grazing termination. Yield reductions were observed when grazing reduced fractional canopy closure to values less than 0.62 at grazing termination. Approximately 90% of all the 3-cm mowing height plots had canopy closure less than 0.62. Although Fuller had greater canopy closure at the 3-cm mowing height, few plots possessed the canopy closure necessary to reach maximum yield at the 3-cm mowing height. The majority (58%) of the 7.5-cm mowing height plots with canopy closure less than 0.62 were Overley, indicating growth habit has more influence on the relationship of canopy closure to relative yield at the 7.5-cm mowing height as compared to the 3-cm mowing height. Many of the 12-cm mowing height treatments and nongrazed control plots of both varieties had canopy closure sufficient to achieve maximum attainable yield. Differences in canopy closure between the two varieties suggest that lower grazing intensity is required for Overley to possess the canopy closure needed at grazing termination to reach maximum attainable relative yield.

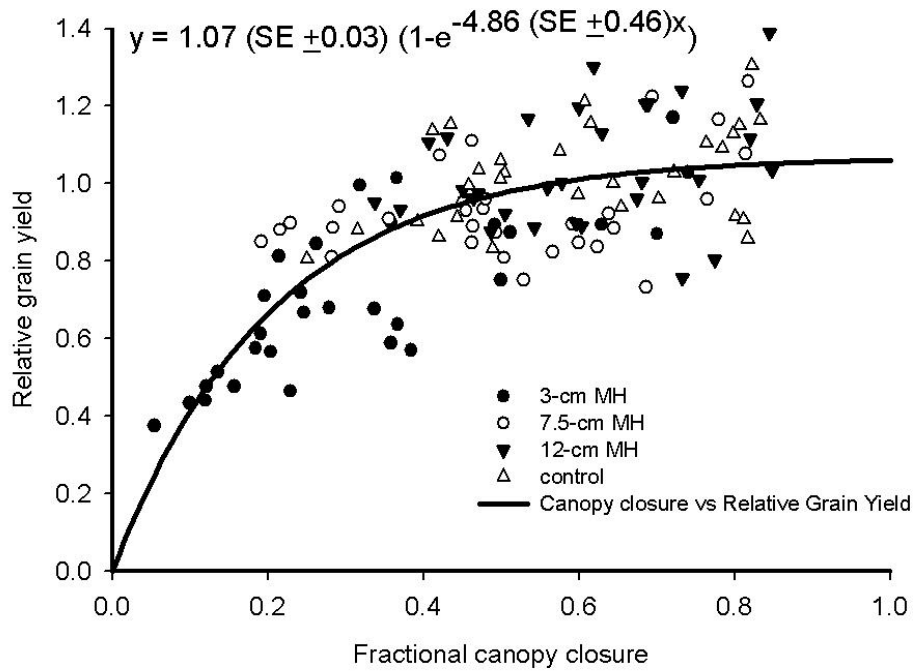

Figure 18. Relative grain yield of Fuller and Overley as a function of canopy closure at grazing termination at Stillwater and Lahoma, OK during the 09-10 and 10-11 production seasons.

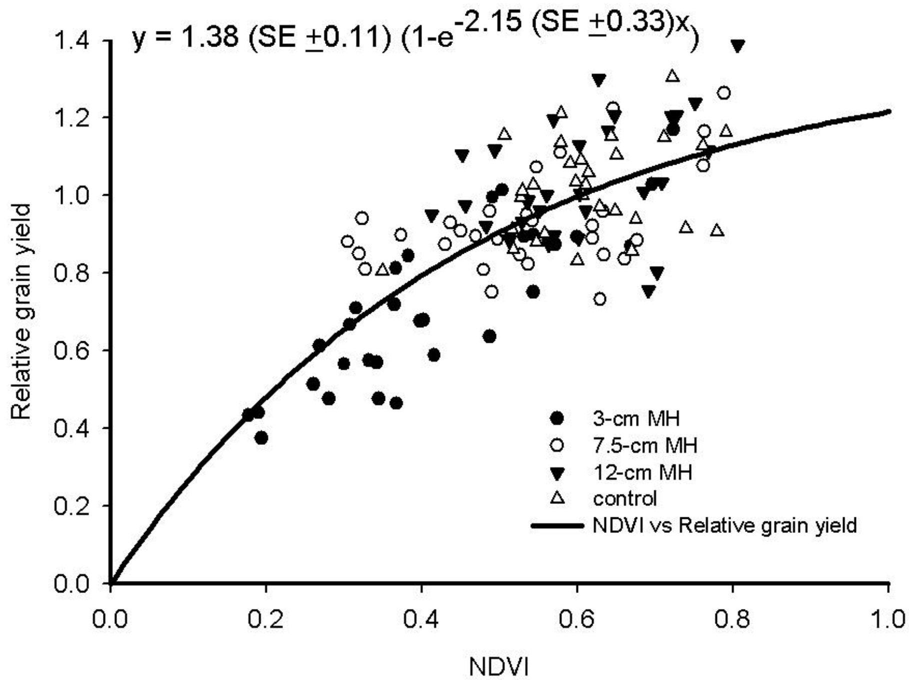

Figure 19. Relative grain yield of Fuller and Overley as a function of NDVI at grazing termination at Stillwater and Lahoma, OK during the 09-10 and 10-11 production seasons.

The equation for the comparison of relative grain yield to NDVI at grazing termination predicted an asymptotic relative yield of 1.38 (Fig. 19). Achieving 95% of the asymptotic relative yield would require an NDVI value outside of the range of what can be accurately predicted by the handheld NDVI sensor. Therefore, maximum attainable relative yield for both varieties was assumed to be 1.0. Achieving relative yield of 1.0 requires NDVI to be 0.60 or greater at grazing termination. Similar to NDVI prior to winter dormancy (Fig. 17), the equation describing yield as a function of NDVI at grazing termination was slow to reach a yield plateau due to the insensitivity of the handheld sensor at NDVI values greater than 0.82. Results of the relationship of NDVI to relative yield were similar to the relationship of canopy closure to relative yield (Fig 18), which is expected considering the strong correlation (R^2=0.93) of NDVI and canopy closure. The majority (>90%) of the 3-cm mowing height treatments for either variety possessed NDVI values lower than those required to reach maximum attainable yield. The effect of growth habit on leaf area is evident as Overley had approximately 50% more plots with NDVI below 0.60 as compared to Fuller. Substantial yield losses are incurred when NDVI falls below 0.60, indicating the inability of these wheat plants to recover the leaf area needed for maximum yield.

CHAPTER IV

CONCLUSIONS

Canopy closure and NDVI measurements taken throughout the grazing season were positively correlated with mowing height regardless of year or location. Fractional canopy closure and NDVI were lowest for the 3-cm mowing height and increased as mowing height increased. These results are consistent with what is expected during the growing season in an actual live cattle grazing environment. It is expected that in a high intensity environment less leaf area would be present resulting in less canopy closure, and as grazing intensity is decreased canopy closure would increase. Growth habit also had an effect on canopy closure and NDVI. Fuller exhibited greater fractional canopy closure and NDVI values for all treatments and was significantly higher than Overley for the 3 and 7.5-cm heights at both locations. Insolation percentages measured at heading showed the same trend as fractional canopy closure and NDVI at both locations, indicating the negative effect of mowing on total leaf area persisted from mowing termination to anthesis.

Number of fertile spikes m^{-1} was positively correlated with mowing height across locations and years with the exception of 2008-2009. Seeds $head^{-1}$ had no impact on grain yield at either location; however, it is noteworthy that Overley produced more seeds $head^{-1}$ than Fuller at Stillwater, and the 3-cm mowing height increased seeds $head^{-1}$ of Overley at Lahoma.

Previous research has reported mixed results regarding the effect of grazing on grain yield, but results from this study determined that simulated grazing decreased grain yield at both locations for the 2009-2011 growing seasons. Mowing height affected grain yield differently during the 2008-2009 season as compared to the 2009-2011 growing seasons at Stillwater due to a freeze which altered the number of fertile spikes. When analyzing grain yield by location, we found that only mowing height had a significant effect at Stillwater. Grain yield at Stillwater was reduced by the 3-cm mowing height treatment. Results at Lahoma found a growth habit by mowing height interaction. Fuller was not as negatively impacted by simulated grazing as compared to Overley, yielding 470 kg ha^{-1} and 540 kg ha^{-1} higher at mowing heights of 3 and 12-cm, respectively.

Grain yield at both locations was strongly correlated to canopy closure, NDVI, and percent insolation. At the 3-cm mowing height canopy closure, NDVI, and percent insolation were lowest as was grain yield. This suggests that grain yield was decreased due to inadequate leaf area for sunlight interception.

Previous studies have determined that digital photography is an accurate and simplistic method for determining crop canopy closure (Purcell, 2000). Handheld NDVI sensors, which are increasing in popularity for the use of determining topdress nitrogen applications, exhibited a strong correlation (R^2=0.93) with fractional canopy closure via digital photography in this study. This indicates that NDVI can be used as a substitute for crop canopy closure.

Relative yield exhibited an asymptotic relationship with fractional canopy closure and NDVI measured at grazing termination. According to this study, maximum attainable relative yield of 1.0 was realized when fractional canopy closure reached 0.62. Differences in canopy closure between the two growth habits indicated less intense grazing was required for Overley to maintain the same canopy closure as Fuller. When using the same maximum attainable relative grain yield of 1.0, an NDVI of 0.60 was required for both varieties. Grain yield significantly decreased when canopy closure or NDVI fell below the previously mentioned values. Additionally, canopy closure and NDVI measurements taken prior to winter dormancy was compared to relative yield. Results from this analysis showed that Fuller and Overley required canopy closure of 0.53 prior to winter dormancy to reach maximum attainable relative grain yield of 0.98. A NDVI value of 0.64 or greater prior to winter dormancy produced a maximum attainable relative yield of 1.0 for both varieties.

Results from this study are in accordance with Oklahoma state averages suggesting that grazing reduces grain yield (Edwards et al., 2011). This study determined that a prostrate growth habit maintained higher canopy closure throughout the grazing season compared to an erect growth habit and that grain yield was a function of maximum canopy closure. The models comparing canopy closure and NDVI to grain yield (Fig. 16-19) provide producers an estimate of the values needed to achieve maximum yield. Further research determining the effect of simulated grazing intensity on grain yield and the relationship of canopy closure to grain yield is needed to encompass more years and additional wheat varieties.

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APPPENDICES

Table A1. Average percent freeze damage for each treatment at Stillwater,

Treatment	Damage (%)
Fuller non-treated	60
Fuller 3 cm	42
Fuller 7.5 cm	50
Fuller 12 cm	51
Overley non-treated	61
Overley 3 cm	33
Overley 7.5 cm	46
Overley 12 cm	55

Table A2. Average percent shatter due to hail 23 May 2011 at Lahoma, OK

Treatment	Shatter (%)
Fuller non-treated	15
Fuller 3 cm	10
Fuller 7.5 cm	10
Fuller 12 cm	13
Overley non-treated	50
Overley 3 cm	20
Overley 7.5 cm	30
Overley 12 cm	38

Table A3. Mean quantity of forage (kg ha^{-1}) for the 3-cm mowing height plots of each variety at grazing initiation during all years at Stillwater and Lahoma, OK.

Year	Location	Variety	Forage (kg ha^{-1})
2008	Stillwater	Fuller	740
2008	Stillwater	Overley	949
2009	Stillwater	Fuller	1761
2009	Stillwater	Overley	1820
2010	Stillwater	Fuller	1803
2010	Stillwater	Overley	1864
2009	Lahoma	Fuller	1118
2009	Lahoma	Overley	1387
2010	Lahoma	Fuller	2851
2010	Lahoma	Overley	3233

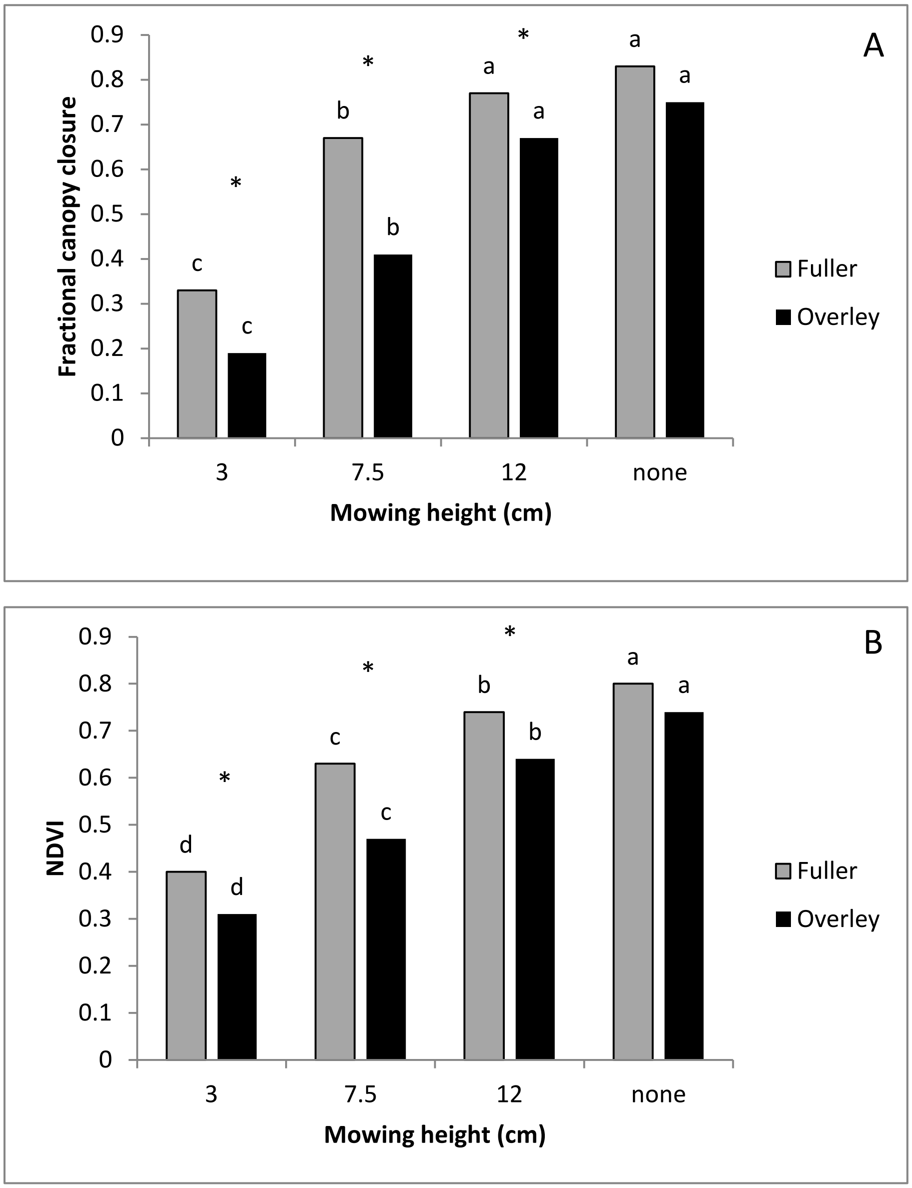

Figure 1. (A)Fractional canopy closure via digital photography taken prior to winter dormancy as affected by mowing height and variety across both locations during the 2009-2011 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).(B) NDVI taken prior to winter dormancy as affected by mowing height and variety across both locations during the 2009-2011 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

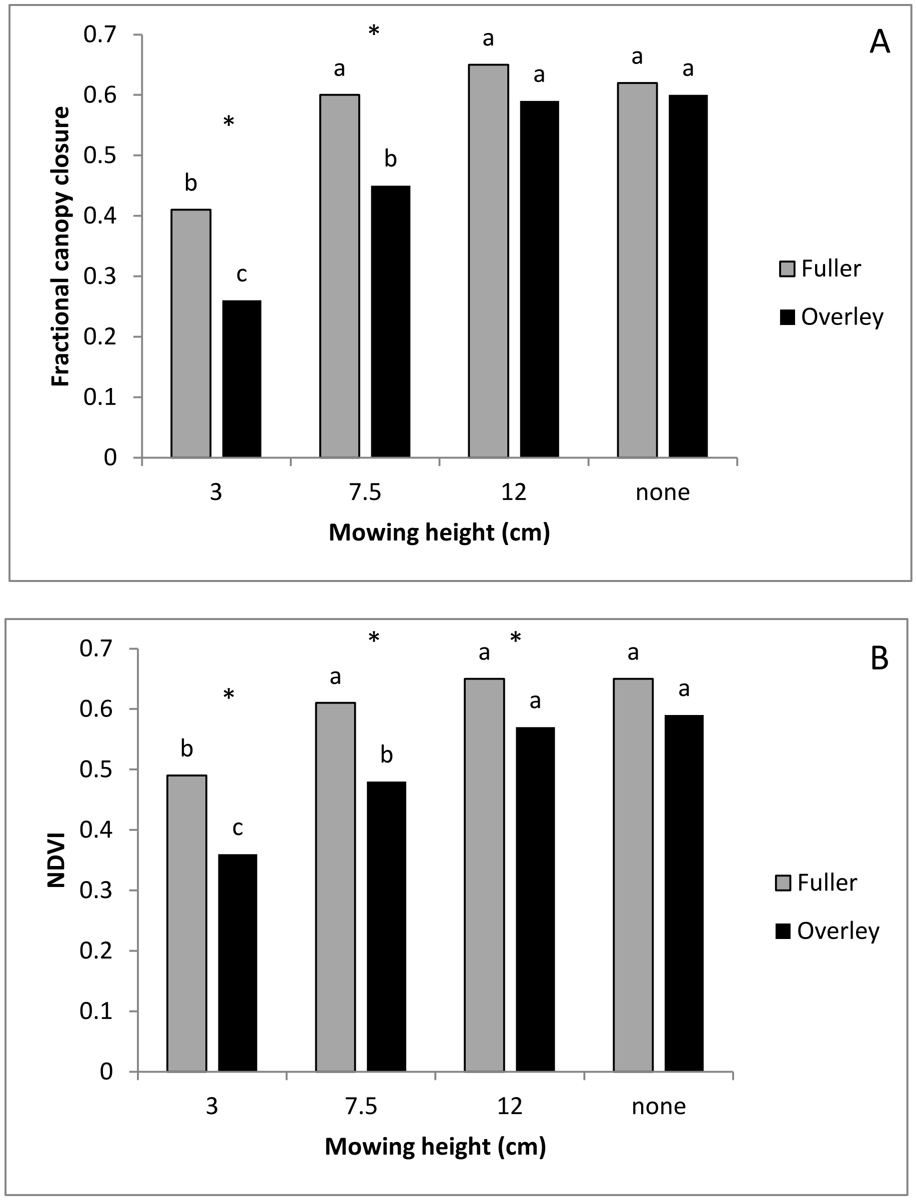

Figure 2. (A)Fractional canopy closure via digital photography taken at grazing termination as affected by mowing height and variety across both locations during the 2009-2011 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).(B) NDVI taken at grazing termination as affected by mowing height and variety across both locations during the 2009-2011 growing seasons. Bars within variety with the same letter are not significantly different (α=0.05). Bars within mowing height with an asterisk are significantly different (α=0.05).

Table A4. Fractional canopy closure and NDVI data at Stillwater during the 2008-2009 growing season.

			Fractional canopy closure				NDVI			
Year (grain)	Variety	Mowing Height (cm)	DOY 304	DOY 325	DOY 36	DOY 57	DOY 304	DOY 325	DOY 36	DOY 57
2009	Fuller	None	0.68	0.88	0.68	0.86	0.64	0.85	0.66	0.76
2009	Fuller	3	0.68	0.83	0.63	0.78	0.65	0.71	0.59	0.68
2009	Fuller	7.5	0.77	0.88	0.72	0.88	0.65	0.80	0.69	0.77
2009	Fuller	12	0.74	0.89	0.71	0.89	0.72	0.87	0.69	0.80
2009	Overley	None	0.63	0.85	0.67	0.82	0.61	0.80	0.64	0.72
2009	Overley	3	0.60	0.68	0.45	0.60	0.59	0.72	0.53	0.54
2009	Overley	7.5	0.56	0.73	0.53	0.73	0.62	0.73	0.59	0.66
2009	Overley	12	0.55	0.81	0.62	0.78	0.58	0.78	0.63	0.73
2009	Overley	3	0.66	0.70	0.40	0.58	0.67	0.64	0.52	0.57
2009	Overley	7.5	0.70	0.82	0.53	0.77	0.66	0.81	0.61	0.72
2009	Overley	None	0.73	0.92	0.61	0.84	0.69	0.84	0.67	0.74
2009	Fuller	3	0.82	0.86	0.50	0.77	0.68	0.76	0.59	0.67
2009	Fuller	12	0.72	0.91	0.65	0.89	0.71	0.86	0.67	0.78
2009	Fuller	7.5	0.68	0.87	0.59	0.83	0.64	0.81	0.65	0.76
2009	Overley	12	0.63	0.88	0.65	0.87	0.62	0.82	0.68	0.75
2009	Fuller	None	0.77	0.91	0.70	0.89	0.65	0.86	0.71	0.80
2009	Overley	7.5	0.62	0.76	0.63	0.76	0.59	0.78	0.62	0.70
2009	Overley	None	0.66	0.88	0.70	0.85	0.61	0.84	0.69	0.77
2009	Overley	3	0.56	0.72	0.59	0.71	0.62	0.69	0.61	0.64
2009	Overley	12	0.53	0.80	0.69	0.82	0.60	0.79	0.67	0.75
2009	Fuller	None	0.55	0.86	0.66	0.84	0.65	0.82	0.70	0.81
2009	Fuller	3	0.56	0.67	0.61	0.76	0.60	0.71	0.63	0.71
2009	Fuller	12	0.65	0.87	0.72	0.86	0.63	0.81	0.71	0.82
2009	Fuller	7.5	0.61	0.82	0.71	0.82	0.61	0.77	0.70	0.80
2009	Overley	12	0.71	0.88	0.69	0.87	0.63	0.77	0.68	0.74
2009	Fuller	12	0.82	0.92	0.72	0.91	0.72	0.87	0.71	0.86
2009	Overley	7.5	0.82	0.88	0.67	0.84	0.70	0.77	0.68	0.75
2009	Overley	3	0.63	0.73	0.52	0.66	0.64	0.65	0.59	0.63
2009	Fuller	7.5	0.79	0.90	0.75	0.90	0.71	0.84	0.71	0.82
2009	Fuller	None	0.78	0.90	0.73	0.87	0.74	0.89	0.71	0.88
2009	Overley	None	0.78	0.89	0.72	0.86	0.70	0.84	0.71	0.79
2009	Fuller	3	0.85	0.88	0.65	0.83	0.72	0.81	0.67	0.78

Table A5. Yield component data at Stillwater during the 2008-2009 growing season.

Year (grain)	Variety	Mowing Height (cm)	Forage at grazing initiation (kg ha^{-1})	Total spikes m^{-1}	Fertile spikes m^{-1}	Dead (%)	Total biomass (g m^{-1})	HI Seed weight (g m^{-1})	100 Seed weight (g)	Seeds head^{-1}	Yield (kg ha^{-1})
2009	Fuller	None		138	43	69	143	18.6	1.81	23.9	1181
2009	Fuller	3	755	118	64	46	80	21.5	2.22	15.1	1239
2009	Fuller	7.5		142	65	54	136	27.5	1.9	22.2	1508
2009	Fuller	12		141	72	49	101	26.3	2.2	16.6	1368
2009	Overley	None		146	54	63	100	18.0	1.93	17.3	1122
2009	Overley	3	775	123	72	41	78	19.3	1.76	15.3	690
2009	Overley	7.5		153	69	55	107	20.0	1.92	15.1	1274
2009	Overley	12		126	57	55	95	20.9	2.26	16.2	1251
2009	Overley	3	899	105	78	26	82	21.8	1.93	14.5	1029
2009	Overley	7.5		105	65	38	105	23.1	2.04	17.4	1426
2009	Overley	None		150	59	61	130	23.2	2	19.6	1461
2009	Fuller	3	571	106	73	31	93	21.9	2.25	13.3	1566
2009	Fuller	12		175	95	46	164	31.2	2.05	16.0	1449
2009	Fuller	7.5		143	72	50	149	32.5	2.28	19.8	1706
2009	Overley	12		147	49	67	199	33.8	2.22	31.1	1858
2009	Fuller	None		139	70	50	140	26.7	2.56	14.9	1625
2009	Overley	7.5		137	74	46	101	22.0	2.02	14.7	1110
2009	Overley	None		124	47	62	129	27.1	2.01	28.7	1531
2009	Overley	3	1306	138	89	36	103	21.0	1.56	15.1	923
2009	Overley	12		134	65	51	91	19.4	2.23	13.4	1332
2009	Fuller	None		161	49	70	120	17.0	2.14	16.2	1216
2009	Fuller	3	945	125	68	46	102	28.9	2.01	21.2	1753
2009	Fuller	12		173	66	62	154	29.8	2.21	20.4	1496
2009	Fuller	7.5		120	52	57	130	26.0	2.2	22.7	1590
2009	Overley	12		148	81	45	119	25.4	2.28	13.7	1566
2009	Fuller	12		162	85	48	156	30.0	2.5	14.1	1122
2009	Overley	7.5		163	89	45	125	22.8	2.45	10.4	1508
2009	Overley	3	814	130	90	31	100	22.8	1.86	13.6	1087
2009	Fuller	7.5		122	73	40	141	30.9	2.32	18.2	1765
2009	Fuller	None		136	68	50	153	28.5	2.57	16.3	1344
2009	Overley	None		147	62	58	142	21.8	2.57	13.7	1227
2009	Fuller	3	689	156	83	47	117	35.7	2.65	16.2	1975

Table A6. Fractional canopy closure and NDVI data at Stillwater during the 2009-2010 growing season.

			Fractional canopy closure					NDVI				
Year (grain)	**Variety**	**Mowing Height (cm)**	**DOY 309**	**DOY 327**	**DOY 348**	**DOY 46**	**DOY 64**	**DOY 309**	**DOY 327**	**DOY 348**	**DOY 46**	**DOY 64**
2010	Fuller	None	0.79	0.88	0.81	0.58	0.70	0.71	0.80	0.77	0.59	0.65
2010	Fuller	3	0.78	0.70	0.23	0.15	0.37	0.72	0.73	0.37	0.40	0.49
2010	Fuller	7.5	0.89	0.88	0.58	0.47	0.62	0.78	0.81	0.58	0.55	0.66
2010	Fuller	12	0.87	0.87	0.71	0.62	0.73	0.73	0.80	0.71	0.61	0.69
2010	Overley	None	0.78	0.85	0.79	0.56	0.64	0.70	0.72	0.68	0.53	0.61
2010	Overley	3	0.81	0.58	0.09	0.07	0.18	0.69	0.63	0.27	0.31	0.33
2010	Overley	7.5	0.78	0.66	0.23	0.19	0.36	0.68	0.64	0.37	0.41	0.45
2010	Overley	12	0.75	0.80	0.55	0.41	0.54	0.64	0.67	0.53	0.48	0.51
2010	Overley	3	0.78	0.77	0.15	0.10	0.23	0.71	0.71	0.28	0.32	0.37
2010	Overley	7.5	0.82	0.83	0.41	0.37	0.57	0.69	0.74	0.44	0.45	0.54
2010	Overley	None	0.69	0.87	0.83	0.64	0.76	0.67	0.80	0.78	0.57	0.65
2010	Fuller	3	0.90	0.82	0.25	0.16	0.36	0.76	0.74	0.33	0.36	0.42
2010	Fuller	12	0.83	0.91	0.80	0.57	0.77	0.78	0.84	0.74	0.59	0.70
2010	Fuller	7.5	0.88	0.90	0.61	0.48	0.69	0.78	0.80	0.55	0.51	0.63
2010	Overley	12	0.76	0.86	0.65	0.46	0.68	0.70	0.77	0.61	0.51	0.61
2010	Fuller	None	0.86	0.92	0.88	0.66	0.82	0.75	0.81	0.77	0.59	0.67
2010	Overley	7.5	0.80	0.79	0.40	0.26	0.50	0.75	0.73	0.44	0.41	0.48
2010	Overley	None	0.76	0.87	0.84	0.64	0.78	0.71	0.77	0.75	0.55	0.61
2010	Overley	3	0.80	0.67	0.11	0.07	0.16	0.69	0.68	0.30	0.32	0.35
2010	Overley	12	0.78	0.82	0.56	0.38	0.56	0.71	0.72	0.54	0.45	0.54
2010	Fuller	None	0.86	0.91	0.85	0.63	0.72	0.74	0.79	0.76	0.53	0.61
2010	Fuller	3	0.80	0.65	0.18	0.16	0.28	0.69	0.64	0.33	0.34	0.40
2010	Fuller	12	0.82	0.87	0.65	0.40	0.58	0.73	0.74	0.62	0.47	0.56
2010	Fuller	7.5	0.87	0.78	0.40	0.26	0.46	0.76	0.74	0.49	0.43	0.53
2010	Overley	12	0.68	0.73	0.44	0.22	0.34	0.63	0.64	0.48	0.35	0.41
2010	Fuller	12	0.74	0.79	0.58	0.27	0.43	0.65	0.73	0.61	0.41	0.49
2010	Overley	7.5	0.55	0.55	0.23	0.12	0.23	0.58	0.57	0.38	0.32	0.37
2010	Overley	3	0.61	0.49	0.08	0.04	0.12	0.58	0.47	0.25	0.25	0.28
2010	Fuller	7.5	0.79	0.78	0.40	0.23	0.46	0.65	0.67	0.45	0.37	0.44
2010	Fuller	None	0.82	0.87	0.76	0.44	0.61	0.67	0.72	0.64	0.42	0.51
2010	Overley	None	0.49	0.50	0.30	0.14	0.25	0.53	0.54	0.47	0.34	0.35
2010	Fuller	3	0.70	0.46	0.11	0.07	0.20	0.60	0.48	0.27	0.27	0.32

Table A7. Yield component data at Stillwater during the 2009-2010 growing season.

Year (grain)	Variety	Mowing Height (cm)	Forage (kg ha^{-1})	Fertile spikes m^{-1}	Total Biomass (g m^{-1})	HI Seed weight (g m^{-1})	100 Seed weight (g)	Seeds head^{-1}	Above Canopy Insolation (um m^{-2})	Below Canopy Insolation (um m^{-2})	Insolation (%)	Yield (kg ha^{-1})
2010	Fuller	None		132	247	57.5	2.78	15.7	1660	44	97.3	3355
2010	Fuller	3	1523	104	149	40.4	3.11	12.5	1660	138	91.7	2221
2010	Fuller	7.5		110	197	34.8	2.43	13.0	1660	43	97.4	2922
2010	Fuller	12		129	204	35.7	2.44	11.3	1660	15	99.1	2642
2010	Overley	None		88	216	65.9	3.09	24.2	1660	50	97.0	4079
2010	Overley	3	2009	89	135	39.8	2.98	15.0	1660	319.4	80.8	2349
2010	Overley	7.5		115	213	66	3.09	18.6	1660	109.7	93.4	3705
2010	Overley	12		97	175	53.1	3.1	17.7	1660	75.7	95.4	3612
2010	Overley	3	1950	71	116	34.6	2.76	17.7	1700	467	72.5	1894
2010	Overley	7.5		100	210	57	3.13	18.2	1700	64	96.2	3355
2010	Overley	None		120	214	59.9	2.97	16.8	1700	32	98.1	4500
2010	Fuller	3	1753	102	134	27.9	2.8	9.8	1700	143	91.6	2057
2010	Fuller	12		128	234	50.7	2.39	16.6	1700	39	97.7	2805
2010	Fuller	7.5		137	207	33.6	2.28	10.8	1700	73	95.7	2560
2010	Overley	12		108	212	55.9	2.66	19.5	1700	88	94.8	3916
2010	Fuller	None		129	186	41.2	2.64	12.1	1700	18	98.9	2992
2010	Overley	7.5		82	212	73	3.32	26.8	1720	145	91.6	3296
2010	Overley	None		122	191	61.4	3.06	16.4	1720	86	95.0	4442
2010	Overley	3	1582	60	141	41.5	2.92	23.7	1720	485	71.8	1940
2010	Overley	12		125	203	62.5	2.95	16.9	1720	230	86.6	4032
2010	Fuller	None		135	190	49.9	2.64	14.0	1720	106	93.8	3588
2010	Fuller	3	2173	88	169	55	3.1	20.2	1720	207.5	87.9	2373
2010	Fuller	12		101	172	44.5	2.78	15.8	1720	108.7	93.7	3495
2010	Fuller	7.5		112	163	51.5	2.99	15.4	1720	154	91.0	2957
2010	Overley	12		77	202	59.1	3.19	24.1	1744	225	87.1	3881
2010	Fuller	12		100	198	67.6	3.3	20.5	1744	250	85.7	3904
2010	Overley	7.5		88	121	41.2	3.21	14.6	1744	370	78.8	3658
2010	Overley	3	1740	60	114	39.2	3.34	19.6	1744	698	60.0	1940
2010	Fuller	7.5		111	172	41.6	2.69	13.9	1744	291	83.3	3249
2010	Fuller	None		151	168	44.1	2.8	10.4	1744	170	90.3	4032
2010	Overley	None		77	110	40	3.37	15.4	1744	475	72.8	3284
2010	Fuller	3	1595	86	118	41.7	3.34	14.5	1744	384	78.0	2478

Table A8. Fractional canopy closure and NDVI data at Stillwater during the 2010-2011 growing season.

			Fractional canopy closure			NDVI		
Year (grain)	**Variety**	**Mowing Height (cm)**	**DOY 326**	**DOY 342**	**DOY 53**	**DOY 326**	**DOY 342**	**DOY 53**
2011	Fuller	None	0.88	0.92	0.81	0.86	0.85	0.76
2011	Fuller	3	0.89	0.43	0.59	0.85	0.51	0.64
2011	Fuller	7.5	0.89	0.90	0.82	0.86	0.76	0.73
2011	Fuller	12	0.89	0.93	0.80	0.85	0.83	0.74
2011	Overley	None	0.85	0.84	0.83	0.82	0.80	0.72
2011	Overley	3	0.87	0.23	0.57	0.82	0.31	0.56
2011	Overley	7.5	0.88	0.55	0.71	0.81	0.55	0.62
2011	Overley	12	0.85	0.77	0.82	0.83	0.75	0.71
2011	Overley	3	0.90	0.24	0.49	0.83	0.33	0.53
2011	Overley	7.5	0.87	0.55	0.69	0.83	0.56	0.65
2011	Overley	None	0.87	0.82	0.82	0.84	0.82	0.72
2011	Fuller	3	0.90	0.44	0.74	0.87	0.47	0.70
2011	Fuller	12	0.88	0.93	0.82	0.87	0.85	0.77
2011	Fuller	7.5	0.90	0.85	0.81	0.86	0.76	0.76
2011	Overley	12	0.86	0.81	0.85	0.83	0.71	0.71
2011	Fuller	None	0.89	0.92	0.80	0.86	0.85	0.76
2011	Overley	7.5	0.88	0.52	0.76	0.82	0.53	0.63
2011	Overley	None	0.88	0.83	0.81	0.81	0.78	0.71
2011	Overley	3	0.86	0.19	0.63	0.84	0.30	0.60
2011	Overley	12	0.85	0.80	0.83	0.82	0.76	0.73
2011	Fuller	None	0.85	0.88	0.83	0.86	0.86	0.79
2011	Fuller	3	0.87	0.41	0.72	0.85	0.49	0.72
2011	Fuller	12	0.90	0.88	0.85	0.86	0.85	0.81
2011	Fuller	7.5	0.87	0.83	0.82	0.86	0.79	0.79
2011	Overley	12	0.86	0.72	0.75	0.80	0.71	0.69
2011	Fuller	12	0.86	0.79	0.73	0.83	0.80	0.75
2011	Overley	7.5	0.80	0.54	0.64	0.80	0.54	0.62
2011	Overley	3	0.85	0.19	0.51	0.80	0.33	0.57
2011	Fuller	7.5	0.89	0.81	0.78	0.85	0.79	0.76
2011	Fuller	None	0.88	0.87	0.81	0.84	0.85	0.78
2011	Overley	None	0.86	0.80	0.80	0.80	0.79	0.74
2011	Fuller	3	0.88	0.51	0.70	0.86	0.51	0.67

Table A9. Yield component data at Stillwater during the 2010-2011 growing season.

Year (Grain)	Variety	Mowing Height (cm)	Forage (kg ha^{-1})	Fertile spikes m^{-1}	Total Biomass (g m^{-1})	HI Seed weight (g m^{-1})	100 Seed weight (g)	Seeds head^{-1}	Above Canopy Insolation (um m^{-2})	Below Canopy Insolation (um m^{-2})	Insolation (%)	Yield (kg ha^{-1})
2011	Fuller	None		44	61	8.5	2.98	6.5	1647	454	72.4	1279
2011	Fuller	3	1772	42	50	16.1	2.79	13.7	1647	1026	37.7	1341
2011	Fuller	7.5		63	87	20.9	2.78	11.9	1647	698	57.6	1366
2011	Fuller	12		36	60	12.2	2.85	11.9	1647	616	62.6	1105
2011	Overley	None		51	91	15.4	3.34	9.0	1647	548	66.7	956
2011	Overley	3	2399	41	33	10.9	3.04	8.7	1647	924	43.9	1279
2011	Overley	7.5		54	71	21.2	3.47	11.3	1647	1002	39.2	1528
2011	Overley	12		42	50	4.4	2.97	3.5	1647	715	56.6	1242
2011	Overley	3	1644	48	58	21.8	3.09	14.7	1673	1014	39.4	1354
2011	Overley	7.5		53	88	25.7	2.78	17.4	1673	590	64.7	1850
2011	Overley	None		60	116	28.7	3.52	13.6	1673	423	74.7	1975
2011	Fuller	3	2219	62	75	21.9	2.77	12.8	1673	634	62.1	1639
2011	Fuller	12		70	96	20.8	2.54	11.7	1673	519	69.0	1776
2011	Fuller	7.5		68	79	16.4	2.77	8.7	1673	593	64.6	1714
2011	Overley	12		62	129	28.1	2.82	16.1	1673	456	72.7	1565
2011	Fuller	None		57	104	20.5	2.82	12.8	1673	278	83.4	1795
2011	Overley	7.5		58	95	26	2.98	15.0	1738	668	61.6	1453
2011	Overley	None		51	99	23.9	3.19	14.7	1738	413	76.2	1739
2011	Overley	3	1904	42	58	20.9	3.17	15.7	1738	631	63.7	1354
2011	Overley	12		75	137	31.6	3.05	13.8	1738	439	74.7	1826
2011	Fuller	None		73	127	30.8	2.99	14.1	1738	353	79.7	1850
2011	Fuller	3	1963	62	71	22.8	2.88	12.8	1738	532	69.4	1863
2011	Fuller	12		95	131	35.5	2.72	13.7	1738	283	83.7	2211
2011	Fuller	7.5		64	131	36.2	3.06	18.5	1738	321	81.5	2011
2011	Overley	12		46	73	16.8	2.83	12.9	1712	706	58.8	1529
2011	Fuller	12		72	89	19.7	2.58	10.6	1712	739	56.8	1975
2011	Overley	7.5		42	55	12	2.98	9.6	1712	869	49.2	1397
2011	Overley	3	1510	39	39	13.3	3.01	11.3	1712	917	46.4	1325
2011	Fuller	7.5		61	85	18	2.74	10.8	1712	649	62.1	1855
2011	Fuller	None		68	90	20.4	2.71	11.1	1712	501	70.7	1445
2011	Overley	None		45	92	20.4	3.03	15.0	1712	526	69.3	1385
2011	Fuller	3	1260	42	55	16.2	2.67	14.4	1712	722	57.8	1385

Table A10. Fractional canopy closure and NDVI data at Lahoma during the 2009-2010 growing season.

			Fractional canopy closure					**NDVI**				
Year (grain)	**Variety**	**Mowing height (cm)**	**DOY 309**	**DOY 323**	**DOY 348**	**DOY 48**	**DOY 65**	**DOY 309**	**DOY 323**	**DOY 348**	**DOY 48**	**DOY 65**
2010	Fuller	None	0.89	0.95	0.81	0.46	0.60	0.79	0.87	0.84	0.45	0.63
2010	Fuller	3	0.85	0.87	0.58	0.30	0.50	0.80	0.79	0.54	0.38	0.54
2010	Fuller	7.5	0.95	0.95	0.85	0.46	0.65	0.83	0.87	0.74	0.45	0.68
2010	Fuller	12	0.88	0.96	0.87	0.52	0.69	0.82	0.86	0.82	0.46	0.65
2010	Overley	None	0.92	0.96	0.79	0.49	0.61	0.84	0.87	0.85	0.45	0.58
2010	Overley	3	0.82	0.81	0.37	0.09	0.14	0.82	0.75	0.41	0.24	0.26
2010	Overley	7.5	0.86	0.94	0.74	0.38	0.53	0.83	0.84	0.61	0.40	0.49
2010	Overley	12	0.91	0.95	0.79	0.47	0.60	0.84	0.86	0.73	0.43	0.57
2010	Overley	3	0.75	0.65	0.30	0.18	0.24	0.71	0.61	0.40	0.30	0.37
2010	Overley	7.5	0.83	0.87	0.51	0.34	0.48	0.69	0.75	0.60	0.39	0.54
2010	Overley	None	0.88	0.93	0.75	0.34	0.50	0.70	0.79	0.71	0.39	0.54
2010	Fuller	3	0.65	0.70	0.32	0.22	0.32	0.62	0.63	0.44	0.33	0.49
2010	Fuller	12	0.76	0.91	0.74	0.39	0.53	0.66	0.82	0.75	0.42	0.64
2010	Fuller	7.5	0.82	0.93	0.78	0.41	0.60	0.60	0.77	0.66	0.42	0.63
2010	Overley	12	0.88	0.96	0.85	0.45	0.60	0.71	0.82	0.73	0.47	0.60
2010	Fuller	None	0.68	0.94	0.84	0.46	0.65	0.60	0.81	0.80	0.47	0.68
2010	Overley	7.5	0.79	0.88	0.62	0.37	0.45	0.74	0.77	0.59	0.40	0.54
2010	Overley	None	0.67	0.83	0.50	0.32	0.42	0.66	0.74	0.63	0.39	0.52
2010	Overley	3	0.73	0.54	0.23	0.17	0.21	0.64	0.56	0.38	0.31	0.37
2010	Overley	12	0.58	0.81	0.64	0.34	0.45	0.68	0.78	0.69	0.42	0.54
2010	Fuller	None	0.51	0.77	0.68	0.33	0.50	0.61	0.76	0.72	0.42	0.61
2010	Fuller	3	0.50	0.64	0.40	0.23	0.37	0.57	0.60	0.45	0.36	0.50
2010	Fuller	12	0.50	0.77	0.61	0.30	0.49	0.51	0.64	0.61	0.38	0.56
2010	Fuller	7.5	0.49	0.74	0.51	0.33	0.46	0.45	0.65	0.63	0.41	0.62
2010	Overley	12	0.61	0.85	0.68	0.36	0.46	0.58	0.72	0.65	0.41	0.55
2010	Fuller	12	0.42	0.61	0.34	0.25	0.37	0.43	0.57	0.57	0.35	0.53
2010	Overley	7.5	0.39	0.52	0.33	0.22	0.28	0.45	0.54	0.51	0.36	0.50
2010	Overley	3	0.55	0.66	0.34	0.20	0.26	0.52	0.58	0.41	0.31	0.38
2010	Fuller	7.5	0.49	0.76	0.49	0.32	0.46	0.45	0.61	0.59	0.39	0.58
2010	Fuller	None	0.33	0.69	0.54	0.33	0.47	0.50	0.65	0.66	0.41	0.60
2010	Overley	None	0.47	0.69	0.45	0.28	0.39	0.52	0.70	0.66	0.40	0.56
2010	Fuller	3	0.27	0.48	0.31	0.23	0.36	0.40	0.54	0.45	0.36	0.54

Table A11. Yield component data at Lahoma during the 2009-2010 growing season.

Year (grain)	Variety	Mowing height (cm)	Forage (kg ha^{-1})	Fertile spikes m^{-1}	Total Biomass (g m^{-1})	HI Seed weight (g m^{-1})	100 Seed weight (g)	Seeds head^{-1}	Above Canopy Insolation (um m^{-2})	Below Canopy Insolation (um m^{-2})	Insolation (%)	Yield (kg ha^{-1})
2010	Fuller	None		126	162	28.6	2.53	9.0	1720	230	86.6	2373
2010	Fuller	3	2098	84	149	27.6	2.83	11.6	1720	300	82.6	1835
2010	Fuller	7.5		119	212	51.5	3.13	13.8	1720	380	77.9	2162
2010	Fuller	12		114	184	45.2	3.35	11.8	1720	218	87.3	2945
2010	Overley	None		98	176	47.6	3.48	14.0	1720	208	87.9	3495
2010	Overley	3	1731	45	138	31.7	2.9	24.3	1720	510	70.3	1484
2010	Overley	7.5		96	152	32.6	3.08	11.0	1720	470	72.7	2174
2010	Overley	12		98	172	37.5	3.08	12.4	1720	314	81.7	2595
2010	Overley	3	1554	74	102	27.6	2.97	12.6	1730	520	69.9	2081
2010	Overley	7.5		82	194	51.1	3.09	20.2	1730	287	83.4	2700
2010	Overley	None		86	176	40.6	3.3	14.3	1730	250	85.5	2969
2010	Fuller	3	951	71	144	27.1	3.07	12.4	1730	355	79.5	2431
2010	Fuller	12		99	139	29.2	2.8	10.5	1730	178	89.7	2852
2010	Fuller	7.5		118	172	32.7	2.88	9.6	1730	223	87.1	2069
2010	Overley	12		96	194	43.5	3.05	14.9	1730	240	86.1	2571
2010	Fuller	None		110	141	18	2.4	6.8	1730	167	90.3	2291
2010	Overley	7.5		75	150	40.4	3.21	16.8	1740	330	81.0	2747
2010	Overley	None		94	159	46.4	3.37	14.6	1740	322	81.5	2490
2010	Overley	3	1069	58	107	33.5	3.23	17.9	1740	447	74.3	2349
2010	Overley	12		84	177	46.9	3.27	17.1	1740	300	82.8	2840
2010	Fuller	None		95	182	34.7	2.78	13.1	1740	284	83.7	2583
2010	Fuller	3	892	84	116	22.4	2.87	9.3	1740	215	87.6	2478
2010	Fuller	12		101	164	36.4	2.89	12.5	1740	200	88.5	2139
2010	Fuller	7.5		100	129	30.8	2.75	11.2	1740	295	83.0	2174
2010	Overley	12		93	163	42.5	2.87	15.9	1755	210	88.0	2782
2010	Fuller	12		92	104	13.7	2.1	7.1	1755	315	82.1	2279
2010	Overley	7.5		71	106	23.4	2.87	11.5	1755	375	78.6	2560
2010	Overley	3	1187	68	126	34.5	3.04	16.7	1755	360	79.5	2443
2010	Fuller	7.5		89	127	24.2	2.78	9.8	1755	209	88.1	2712
2010	Fuller	None		91	162	34.1	2.67	14.0	1755	172	90.2	2525
2010	Overley	None		84	171	40.7	2.88	16.8	1755	283	83.9	2607
2010	Fuller	3	525	93	145	28.5	2.69	11.4	1755	218	87.6	2197

Table A12. Fractional canopy closure and NDVI data at Lahoma during the 2010-2011 growing season.

			Fractional canopy closure				NDVI			
Year (grain)	**Variety**	**Mowing height (cm)**	**DOY 312**	**DOY 326**	**DOY 343**	**DOY 53**	**DOY 312**	**DOY 326**	**DOY 343**	**DOY 53**
2011	Fuller	None	0.90	0.93	0.88	0.49	0.88	0.89	0.87	0.60
2011	Fuller	3	0.90	0.76	0.34	0.38	0.90	0.66	0.33	0.34
2011	Fuller	7.5	0.90	0.95	0.80	0.59	0.90	0.82	0.53	0.47
2011	Fuller	12	0.90	0.93	0.90	0.68	0.90	0.86	0.73	0.60
2011	Overley	None	0.91	0.94	0.88	0.46	0.91	0.86	0.77	0.53
2011	Overley	3	0.90	0.38	0.11	0.10	0.90	0.44	0.22	0.18
2011	Overley	7.5	0.90	0.74	0.24	0.19	0.89	0.69	0.35	0.32
2011	Overley	12	0.90	0.91	0.66	0.50	0.87	0.80	0.58	0.48
2011	Overley	3	0.91	0.36	0.15	0.12	0.90	0.45	0.25	0.19
2011	Overley	7.5	0.92	0.66	0.21	0.22	0.90	0.63	0.34	0.30
2011	Overley	None	0.92	0.93	0.86	0.44	0.90	0.86	0.79	0.52
2011	Fuller	3	0.93	0.65	0.22	0.20	0.90	0.61	0.31	0.30
2011	Fuller	12	0.93	0.96	0.82	0.60	0.91	0.84	0.71	0.57
2011	Fuller	7.5	0.91	0.92	0.61	0.49	0.90	0.80	0.52	0.43
2011	Overley	12	0.90	0.91	0.59	0.47	0.88	0.77	0.55	0.46
2011	Fuller	None	0.91	0.93	0.89	0.32	0.90	0.88	0.85	0.55
2011	Overley	7.5	0.92	0.74	0.27	0.28	0.89	0.66	0.35	0.33
2011	Overley	None	0.92	0.93	0.87	0.50	0.87	0.86	0.77	0.53
2011	Overley	3	0.91	0.31	0.10	0.05	0.89	0.38	0.22	0.19
2011	Overley	12	0.91	0.88	0.48	0.41	0.89	0.76	0.52	0.45
2011	Fuller	None	0.92	0.94	0.88	0.41	0.88	0.88	0.85	0.58
2011	Fuller	3	0.92	0.61	0.23	0.25	0.90	0.57	0.30	0.31
2011	Fuller	12	0.92	0.95	0.88	0.62	0.90	0.85	0.76	0.63
2011	Fuller	7.5	0.91	0.95	0.71	0.48	0.90	0.82	0.59	0.49
2011	Overley	12	0.92	0.90	0.71	0.63	0.87	0.79	0.63	0.60
2011	Fuller	12	0.93	0.95	0.89	0.69	0.91	0.87	0.81	0.72
2011	Overley	7.5	0.92	0.70	0.24	0.29	0.90	0.62	0.33	0.32
2011	Overley	3	0.92	0.37	0.13	0.19	0.88	0.43	0.24	0.27
2011	Fuller	7.5	0.92	0.92	0.55	0.42	0.89	0.80	0.60	0.55
2011	Fuller	None	0.92	0.93	0.89	0.43	0.89	0.88	0.86	0.64
2011	Overley	None	0.92	0.93	0.82	0.58	0.87	0.85	0.79	0.59
2011	Fuller	3	0.92	0.69	0.31	0.34	0.90	0.66	0.35	0.40

Table A13. Yield component data at Lahoma during the 2010-2011 growing season.

Year (grain)	Variety	Mowing height (cm)	Forage (kg ha^{-1})	Fertile spikes m^{-1}	Total Biomass (g m^{-1})	HI Seed weight (g m^{-1})	100 Seed weight (g)	Seeds head^{-1}	Above Canopy Insolation (um m^{-2})	Below Canopy Insolation (um m^{-2})	Insolation (%)	Shatter (%)	Yield (kg ha^{-1})
2011	Fuller	None		118	105	14.2	2.62	4.6	1722	193	88.8	1	2303
2011	Fuller	3	3062	80	132	24	2.36	12.7	1722	538	68.8	1	1578
2011	Fuller	7.5		113	163	25.1	2.44	9.1	1722	428	75.1	1	2478
2011	Fuller	12		131	182	39.5	2.8	10.8	1722	262	84.8	1	2782
2011	Overley	None		99	142	21.2	3.02	7.1	1722	200	88.4	4	1952
2011	Overley	3	2990	27	99	30.1	2.82	39.5	1722	987	42.7	2	853
2011	Overley	7.5		73	91	22	2.79	10.8	1722	420	75.6	3	1671
2011	Overley	12		95	111	18.7	2.48	7.9	1722	326	81.1	4	1812
2011	Overley	3	3049	30	85	22.7	2.9	26.1	1718	1088	36.7	2	865
2011	Overley	7.5		88	126	25.9	2.57	11.5	1718	542	68.5	3	1730
2011	Overley	None		76	136	14.2	2.81	6.6	1718	233	86.4	5	1788
2011	Fuller	3	2773	58	59	15.6	2.68	10.0	1718	879	48.8	1	1566
2011	Fuller	12		105	163	33.6	2.78	11.5	1718	332	80.7	1	3308
2011	Fuller	7.5		109	137	22.7	2.44	8.5	1718	448	73.9	1	2420
2011	Overley	12		86	138	23	2.85	9.4	1718	483	71.9	4	1917
2011	Fuller	None		82	109	18.7	2.8	8.1	1718	243	85.9	1	2431
2011	Overley	7.5		82	115	24.4	2.84	10.5	1724	742	57.0	3	1590
2011	Overley	None		101	155	18.6	2.54	7.3	1724	153	91.1	6	1987
2011	Overley	3	3187	35	44	14.1	3.02	13.3	1724	1378	20.1	2	736
2011	Overley	12		90	120	25.6	3.1	9.2	1724	529	69.3	5	2174
2011	Fuller	None		136	163	31.6	2.74	8.5	1724	114	93.4	2	3144
2011	Fuller	3	2833	75	91	31.2	2.94	14.1	1724	727	57.8	1	1847
2011	Fuller	12		127	155	36.2	2.86	10.0	1724	294	82.9	2	3600
2011	Fuller	7.5		87	116	33	3.01	12.6	1724	694	59.7	1	2653
2011	Overley	12		99	121	25.4	2.74	9.4	1732	358	79.3	2	2221
2011	Fuller	12		106	141	25.8	2.48	9.8	1732	256	85.2	1	3331
2011	Overley	7.5		80	109	24.6	2.67	11.5	1732	835	51.8	3	1847
2011	Overley	3	3691	60	69	24	3.14	12.7	1732	1336	22.9	2	1204
2011	Fuller	7.5		118	168	44.6	2.75	13.7	1732	443	74.4	1	2969
2011	Fuller	None		130	134	29.1	2.93	7.6	1732	98	94.3	2	3191
2011	Overley	None		108	137	23.9	3.22	6.9	1732	182	89.5	6	2127
2011	Fuller	3	2721	47	66	22.1	2.98	15.8	1732	1002	42.1	1	1870

VITA

John Dillon Butchee

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF SIMULATED GRAZING INTENSITY ON DUAL-PURPOSE WINTER WHEAT (*TRITICUM AESTIVUM* L.) GRAIN YIELD IN OKLAHOMA

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Date of Degree: December, 2011

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Title of Study: EFFECT OF SIMULATED GRAZING INTENSITY ON DUAL-PURPOSE WINTER WHEAT (*TRITICUM AESTIVUM* L.) GRAIN YIELD IN OKLAHOMA

Pages in Study: 55
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Major Field: Plant and Soil Sciences

Scope and Method of Study:

Dual-purpose winter wheat growth and grain yield are influenced by cattle stocking density and variety selection. The objectives of this study were to evaluate the quantitative effect of simulated grazing intensity on wheat canopy closure and grain yield of two varieties of wheat with different growth habits, Fuller (prostrate) and Overley (upright), and determine the potential to use NDVI as a means of monitoring crop canopy closure. Grazing intensity was simulated at Stillwater and Lahoma, OK by mowing wheat to heights of 3, 7.5, and 12 cm at approximately four-week intervals. Mowing was initiated in late October and terminated at first hollow stem in the spring. Canopy closure was obtained using digital photography, and NDVI was measured with a handheld sensor.

Findings and Conclusions:

Canopy closure and NDVI measured throughout the grazing season were positively correlated with mowing height. Regression analysis determined NDVI could be used as a substitute for canopy closure when determining the impact of grazing on wheat growth (R^2=0.93). Relative grain yield had an asymptotic response to canopy closure and NDVI measurements taken prior to winter dormancy and at grazing termination. The 3-cm mowing height reduced grain yield of Fuller by 26%, but reduced grain yield of Overley by 39%, as compared to the non-defoliated treatments. The results of this study indicate that there is a grain yield loss associated with grazing wheat, yield loss is greater at high grazing intensities, and grain yield of Fuller was not as negatively impacted by grazing as compared to Overley.

ADVISER'S APPROVAL: Dr. Jeff Edwards