# SELECTION RESPONSES IN GRAIN YIELD AND RELATED TRAITS AS INDUCED BY DUAL-PURPOSE AND GRAIN-ONLY MANAGEMENT SYSTEMS

By

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Bachelor of Science in Plant and Soil Sciences

Oklahoma State University

Stillwater, OK

2006

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2008

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# ACKNOWLEDGEMENTS

I would like to thank the Oklahoma State University Department of Plant and Soil Sciences for grating me an assistantship for my Master's degree. Firstly, I would like thank my major advisor Dr. Brett F. Carver for being a great source of guidance, inspiration and motivation to me throughout my study. I can never thank him enough for sharing his valuable knowledge, experience, and expertise in the field of plant breeding, and genetics. My sincere gratitude goes out to Dr. Carla Goad for her assistance in statistical analysis for this project. I would also like to thank my committee members Dr. Arthur Klatt and Dr. Patricia Duarte Rayas for their time and support. I would also like to thank the entire wheat breeding team and Plant and Soil Sciences family for their help, love and support: Wayne Whitmore, Jana Morris, Jared Johnson, Tarvis Collins, Dr. David Porter, Janet Rich, Jackei Nidiffer, Lisa Fultz, and Debbie Porter.

The most importantly, I would like to thank my family: Ram, Sushila, Amit, Sabin, and Rabin Thapa. They have been a great source of motivation, inspiration, support, and love to me, without which I would not have came this far. I would also like to thank my close friends for being there for me whenever I needed during my stay at Oklahoma State University: Sudhendu Raj Sharma, Billie McKean, Santanu Bikram Thapa, Dr. Garry Marley, and John Colby Johnson. Finally, I would like to thank god for giving me the strength, courage, and determination to complete this stage of my life successfully.

# TABLE OF CONTENTS

Chapter Page

III. METHODLOGY

IV. RESULTS AND DISCUSSIONS

# LIST OF TABLES

# LIST OF FIGURES

# CHAPTER I

# ABSTRACT

Winter wheat (*Triticum aestivum* L.) is widely used in the southern Great Plains as a winter forage resource to supplement income from a wheat monocrop system. Depending on production and prevailing market conditions, some producers may allow cattle (*Bos Taurus* L.) to graze wheat until the first-hollow-stem stage or to graze entirely. Thus, winter wheat offers dual benefits of grain and beef production in the form of three management systems: grain-only (GO, no grazing), forage only (full season grazing), or dual-purpose (DP, grazing and grain). Although traditionally, winter wheat cultivars are developed in GO production systems, they are often deployed in DP systems. The incidence and severity of soil-borne and insect transmitted diseases, insect herbivory, and abiotic stress are increased in DP system and thus can reduce grain yield depending on the year or cultivar. We hypothesized that a grazing system can be used as a selection tool to create breeding populations enriched with genes that confer grazing tolerance, persistence, and ultimately, improved adaptation. However, no clear evidence exists in wheat to refute or support this hypothesis. Thus, the main objective of this research was to determine selection responses in winter wheat induced by GO and DP management systems. Grain yield and associated traits for 24 sets of populations were measured in GO and DP systems, following natural selection in those systems for three consecutive generations ($F_2$ – $F_4$). Research was conducted in Marshall, Oklahoma using the $F_5$ bulk progeny from each population. Our analysis showed that grain yield in a DP system can be increased by early-generation selection in that system, without negative consequences to grain yield in a GO system.

# CHAPTER II

## INTRODUCTION

Winter wheat (*Triticum aestivum* L.) is widely used in the southern and central Great Plains as a winter forage resource to supplement income from a wheat monocrop system. Depending on production and prevailing market conditions some producers either allow cattle (*Bos taurus* L.) to graze wheat until the first-hollow-stem stage, defined as the growth stage when hollow stem can be observed between the crown and the developing spike (Redmon et al., 1996; Fieser et al., 2006), or to graze it entirely through reproductive development. Thus, winter wheat offers dual-purpose potential for grain and beef production. Traditionally, winter wheat cultivars have been developed in a grain-only (GO) management system, but they are often deployed in a dual-purpose (DP) management system.

An estimated 3.2 million hectares of wheat will be grazed in any given year in the Great Plains (Pinchak et al., 1996). One Oklahoma survey showed almost two-thirds of the 1995-1996 wheat crop was intended for the dual purpose of forage plus grain (Epplin et al., 1998), though less area will be dedicated to grazing as grain prices increase relative to beef prices. Choice of a DP production system introduces different management tactics and input requirements compared with a GO system. Dual-purpose wheat is planted earlier and seeded more densely (Epplin et al., 2000; Hossain et al, 2003), and it requires additional N fertilizer to compensate for the removal of wheat forage (Krenzer, 1991;

Zhang et al., 1998). When wheat is grown for dual-purpose, additional N is required to replace N removed as beef in the amount of 0.74 kg N per unit kg beef removed (Zhang et al., 1998).

Plant height is one of the best indicators of grazing response in grasses. It varies depending upon grazing intensity (Dỉaz et al., 2001), but plant height generally decreases in response to grazing (Noy-Meir et al., 1989; Landsberg et al., 1999). At the same time, in cereal species like triticale (x *Triticosecale* Witt) and wheat, there is a reduction in grain yield in response to forage removal by grazing (Garcỉa del Moral et al., 1995; Arzadủn et al., 2006). The grain yield reduction in a wheat dual-purpose system varied with cultivar from 30 to 70% in one year, with a mean of 49%, and from 4 to 35% in another year, averaging 22% (Khalil et al., 2002). Christiansen et al. (1989) found that when growth potential is such that removal of forage will prevent lodging, grazing could actually increase grain yield. Redmon et al. (1995) indicated that grazing will have minimal effect on grain yield if soil moisture is adequate throughout the growing season. In the same article, they reported that under adequate to excess soil fertility, the grazed system increased winter wheat grain yield due to reduced lodging.

Timely removal of cattle from wheat pasture is critical to maximum economics return from the DP management system, because beef gain and grains yield can be antagonistic if grazing termination occurs too late (Redmon et al., 1996). Cattle weight was shown to increase linearly with number of grazing days past FHS stage, whereas grain yield decreased by 10% when grazed for two weeks past FHS and an additional 10% for each of two subsequent weeks (Fieser et al., 2006). Both components of the dual-purpose enterprise are essential; thus optimal balance is best achieved by termination of grazing at the FHS stage (Fieser et al., 2006).

Various reports of grazing or clipping of small grains has shown different effects on grain yield depending on varying growing conditions, management, or cultivars. The Leaf Area Index (LAI) at anthesis showed significant loss because of clipping with a decrease in the number of leaves per plant and in the green area per leaf in triticale (Garcỉa del Moral, 1992). In the same experiment, they reported that there was an inverse relationship between the percent leaf loss at anthesis and final grain yield, implying that grain yield depend largely on the ability of the crop to produce new leaf tissue rapidly between defoliation and anthesis (Garcỉa del Moral, 1992). However, there is smaller leaf area in grazed population which does not allow speedy recovery from defoliation (Winter et al., 1990). Also delayed forage defoliation reduced tiller survival and caused fewer seeds per head but had a small effect on the average weight per seed (Dunphy et al., 1982). Grain yield was a function of total biomass at heading date in wheat (Winter and Thompson, 1987), implying that removal of forage late in the grazing season decreases grain yield (Swanson, 1995). The DP management system can add other potential risks which may reduce grain yield relative to a GO system. The incidence and severity of soil-borne and insect-transmitted diseases (Hammon et al., 1996; Hunger et al., 2002; Piccinni et al., 2001), insect herbivory (Royer et al., 1997), and abiotic stresses are increased in a DP system, and thus can reduce grain yield depending on the year or cultivar (Epplin and Peeper, 1998; Carver et al., 2001).

The unique stress factors which emerge when a grazing component is added to a winter wheat production system would imply that the appropriate field environment is needed to allow breeders to identify genotypes with exceptional grazing tolerance and persistence and thus minimum grain yield loss following grazing. Turning to other grass species, selection imposed by grazing cattle strongly acts upon the individual plant, which leads to the development of ecotypes over time (Bradshaw, 1972). Moreover, natural selection adds beneficial effects in adaptation to the particular complex of climatic and edaphic conditions of a particular location (Allard, 1988). Vaylay et al. (1999) showed population differentiation among grazed and ungrazed populations of tall fescue (*Festuca arundinacea* Schreb.) in their response to grazing, and primarily through an increase in tiller number in grazed survivors compared to ungrazed survivors. In another study by Brummer et al. (2000) with perennial cool-season grass species and legume cultivars, a prostrate canopy was formed among grazed survivors as an adaptation response to environmental stresses such as grazing. Formation of prostrate growth serves as a primary tolerance mechanism and reservoir of photosynthate in the perennial grass species, allowing tillers to recover from severe defoliation.

Consistent with findings in those grass species, prostrate genotypes of wild wheat (*Triticum dicoccoides*) showed greater tolerance to intensive grazing compared with erect genotypes (Noy-Meir et al., 2002). Grazing resistance was associated with leaf size and high surface leaf area (SLA) according to Westoboy (1999). They proposed a scheme explaining how specific leaf area and plant height plays a vital role in response to disturbance, i.e., to grazing. According to their model, plants with high SLA should be favored under heavy and non-selective grazing. Grain yield was dependent on the plant's potential to regenerate leaf area and also prevention of tiller senescence before anthesis (Dunphy et al., 1984). Several studies supported the importance of rapid regeneration of leaf area after defoliation to establish photosynthetic capacity to establish maximum grain yield (Dunphy et al., 1984; Winter and Thompson 1987). Grazed survivors of tall fescue produced more tillers compared with non-grazed survivors (Vaylay et al., 1999), a finding corroborated by Noy Meir (2002) in *T. dicoccoides*. This observation may be explained physiologically, as removal of the apex diminished the production of indole acetic acid, thus increasing the ratio of cytokinin to indole acetic acid, which induced the production of axillary buds (Murphy and Briske, 1992) and ultimately new tillers (Etter, 1951). Environmental variables like light intensity in the canopy, day length and competition among the plants may also increase tiller numbers.

We hypothesized that a grazing system can be used as a selection tool to create breeding populations enriched with genes that confer grazing tolerance, persistence, and ultimately, improved adaptation. However, no clear evidence exists in wheat to refute or support this hypothesis. Thus, this study is focused on the selection responses in grain yield and associated traits in winter wheat induced by GO and DP management systems.

# CHAPTER III

# METHODOLOGY

## Development of Experimental Materials

The experimental materials contained 24 sets of breeding populations derived from and representative of the winter wheat cultivar development program of Oklahoma State University (Table 1). Also included were three check cultivars, ‘2174’ (PI 602595; USDA-ARS, 2008), ‘Jagger’ (Sears et al., 1997), and ‘Custer’, which continue to occupy nearly 40% of the wheat acreage in Oklahoma (2007-2008 crop season; National Agricultural Statistics Service, 2008).

We report here only the most essential components of the development phase for the experimental materials. Grain-only and dual-purpose management systems were imposed at the Expanded Wheat Pasture Unit (EWPU) near Marshall, OK. This experiment station, located 56 km west of Stillwater, OK, is operated by Oklahoma State University through lease agreements with two farmer cooperators. Hence, management practices used at the station and incorporated into this study were precisely those which typify farmer-rancher practices in the southern Great Plains. General features of GO and DP management practices were described by Hossain et al. (2004).

Derivation of and selection within the breeding populations was described in an independent study that focused on the selection response in fall forage (MacKown and Carver, 2005).The $F_2$ seed of each population was divided into sublots and planted in each system for three consecutive years: 1998 ($F_2$), 1999 ($F_3$), and 2000 ($F_4$). Each generation was advanced following bulk breeding procedures, with no additional artificial selection beyond the environmental conditions inherent to, and natural selection associated with, each system. Seeds were harvested from the middle three rows of five-row plots, 3 m long by 1.2 m wide, and planted in the same system the following year. In addition to the selected populations (designated GO and DP according to the system in which they were selected), seed from each original $F_2$ population (designated Base) were planted in a seed-increase nursery at the Agronomy Research Station in Stillwater, OK. This single-generation seed increase balanced the need to produce sufficient seed for later field testing while limiting natural selection in a field environment to one year. Completion of the development and selection phase produced 24 triplicate sets of populations, with final plant generation of inbreeding as follows: Base, $F_2$; GO, $F_4$; and DP, $F_4$. Each component population will be referred to as selections in the treatment structure, and selections derived from the same population will be referred to as genetic backgrounds.

### Experimental Design and Data Collection

Using only the seed produced during the final selfing generation, the bulk progenies were evaluated for three subsequent years without further advancement in generation of inbreeding. Hence the GO- and DP-derived populations were repeatedly evaluated in the $F_5$ generation while the base populations were evaluated in the $F_3$ generation. Experiments were established on a fine, mixed, thermic Udertic Paleustoll soil (Kirkland silt loam) at the EWPU, Marshall, OK. Fertilizer N was applied as anhydrous ammonia, adjusting for residual mineral N, in amounts considered adequate for grain yield of 3000 kg $ha^{-1}$ and a dry forage yield of 3500 kg $ha^{-1}$. Soil pH was maintained above the minimum level of 5.5 throughout the selection and evaluation phases.

Two experiments were established each year at the EWPU to accommodate independent but proximate positioning of DP and GO systems in a 10-ha pasture. The plot area representing the GO system was protected from grazing by an electrical fence. The stocking rate in the DP system varied slightly within and between seasons depending on forage availability but was approximately two steers per hectare. Other management practices during the testing phase were similar to those used during the bulk selection stage, as described previously by MacKown and Carver (2005). Seeding occurred in the DP system on 10 Oct. 2000, 10 Sept. 2001, and 24 Sept. 2002 at a rate of 77 kg $ha^{-1}$; seeding occurred in the GO system on 11 Oct. 2000, 2 Oct. 2001, and 16 Oct. 2002 at a rate of 58 kg $ha^{-1}$. Respective dates of grazing initiation and termination in the DP system were 18 Dec. 2000 and 3 Mar. 2001; 15 Nov. 2001 and 12 Mar. 2002; 13 Nov. 2002 and 7 Mar. 2003. Grazing termination occurred at the time of FHS stage, determined in a given year by the appearance of hollow stem in non-grazed plots of an early-maturing cultivar planted on the same day as the DP experiment (Redmon et al., 1996).

For each management system (DP, GO) × year combination (2001-2003), the 24 triplicate sets of populations were arbitrarily divided in the field into two separate but contiguous nurseries of 12 sets each. This division allowed for smaller field experiments with smaller block size. In the first year, the base populations were not tested. The overall design structure was a split-split-plot in a completely randomized design, with management systems replicated across years. The field replicates (four in 2001, three in

2002 and 2003) within each system × year provided a subsample for system and the blocking factor for genetic background × selection combinations, which appeared within blocks in a split-plot arrangement (selections randomized within genetic backgrounds). The treatment structure was a 2 × 24 × 3 factorial, representing management systems, genetic backgrounds (pooled across nurseries), and selections, respectively. The three check cultivars were incorporated into the same design structure as the populations, but to maintain balance, each check cultivar was repeated among the three split-plots (two split-plots in 2001); hence differences among them were considered strictly environmental.

All five rows per plot were combine-harvested, and grain yield was measured as the weight of threshed, cleaned grain. Test weight was measured from a 0.96-L container according to standard procedures and expressed in units of kg $m^{-3}$. A random 200-kernel sample was drawn from each plot to measure 1000-kernel weight (TKW). Heading date was determined as the day of year in which 50% of the spikes in a plot had emerged completely from the boot. Wheat protein content was determined by near-infrared reflectance spectroscopy using a 15-g ground-wheat sample from each plot and expressed on a 120 g $kg^{-1}$ moisture basis. Yield components were determined by collecting 15 random spikes from the middle three rows per plot. Mean kernel weight and mean number of kernels per spike were determined among that sample, from which the number of spikes per meter squared was estimated as g $m^{-2}$ × (seed $spike^{-1}$ × g $seed^{-1}$). A visual score for growth habit was recorded on two dates generally at grazing initiation and grazing termination during the last two years of the study (2002, 2003). A 1-to-3 scale was used in the DP system only, in which an erect, semi-erect, and prostrate growth habit received scores of 1, 2, and 3, respectively. All attributes were measured in all replicates of each experiment.

## Statistical Analyses

Data for bulk populations and check cultivars were analyzed separately. The analysis for both sets of materials was pooled across years, systems, and nurseries by means of a mixed model. For the bulk populations, all effects were considered random except for selections (Base, GO, and DP) and systems (GO and DP). Though the Base populations were not tested in the first year, mixed model methodology accommodates the unequal sample sizes for treatment combinations. REML estimates of variance components were computed using the MIXED procedure of SAS (SAS Institute, 2002). Type 3 tests of fixed effects for system, selection, and their interaction were also conducted by the MIXED procedure. Main-effect tests for selections were interpreted only in the absence of significant system x selection interactions. In either case, the selection effect was orthogonally partitioned into two single-df contrasts representing i) DP versus GO means comparisons and ii) Base versus (DP+GO)/2 means comparisons. Least-squares estimates were obtained by the MIXED procedure. The first contrast represented the selection response (i.e., a significant difference indicated a significant selection response between bulk populations selected in GO vs. DP systems), while the second contrast indicated asymmetry of the selection response. Asymmetry could be caused by unidirectional changes in the GO and DP selections relative to the base population.

For the analysis of check cultivars, all effects were considered random except for cultivars and systems. Least-squares estimates of the system and system x cultivar means were computed by the MIXED procedure of SAS (SAS Institute, 2002).

The qualitative scores of 1, 2, and 3 for growth habit were analyzed using a chi-squared test for independence of selection (DP, GO, NS) vs. growth habit score (1, 2, and 3), pooled across years.

# CHAPTER IV

# RESULTS AND DISCUSSIONS

## Check Responses

The average system mean for grain yield for dual-purpose management system was 15.3% less compared to grain-only management system (Table 2). Within the GO system, Custer was significantly lower from 2174 and Jagger (Table 2). However, while comparing the average mean test weight and average mean thousand-kernel weight among systems, DP system had 1.3% and 3.7% higher test weight and thousand-kernel weight, respectively, compared to the GO system (Table 2). For test weight in each system, each of the varieties differed significantly. For thousand-kernel weight, in each system, Jagger was significantly different than 2174 and Custer (Table 2). For the DP system, Jagger showed 11.5% higher thousand-kernel weight than in GO system. Similarly, DP system showed 7.9% later heading date than GO system (Table 2). Jagger showed 11.5 % later heading date in DP system than in GO system (Table 2). However, there was 3.8% less wheat protein in DP system than in GO system (Table 2) and each of the varieties were significantly different in each system. This might be due to reduction of leaf area which reduces delivery of photosynthate and redistribution of accumulated N to the grain (MacKown and Rao, 1998).

## Bulk Responses

From the analysis of variance across years and systems, genetic effects associated with genetic backgrounds or genotypes were highly significant ($p<0.01$) for grain yield, test weight, thousand-kernel weight, heading date and wheat protein (Table 3). The three-way interaction of Genotype x Selection x System was significant for grain yield, but not for test weight, thousand-kernel weight, heading date, and wheat protein (Table 3). There was no difference in among the systems except for heading date (Table 4). However, there were significant differences in all related traits except for wheat protein (Table 4).

A correlation coefficient ($r^2$) of 0.08 and 0.03 in DP and GO system, respectively, indicated that there was no or minimal linear relationship existed between selection response and base population (Fig.1). The selection response was the difference of total yield in DP and GO selection environments. The base populations consisted of the typical parents with a phenotypic value of interest. The DP system showed a wide distribution suggesting a large range of values (Fig.1). In the DP system, with an increase in selection response there was no significant increase in grain yield in the base population (Fig.1), while the GO system showed an increase in grain yield in the base population with an increase in selection response (Fig.1). Although the same 24 genotypes from three different selection environments were used in both DP and GO system, they reacted differently in response to two systems.

Averaged over three years, the bulk populations selected from a DP selection environment had higher mean grain yields than the GO and base populations ( Table 5) in both the DP and GO systems. When comparing DP vs. GO management systems, grain yield was higher in the GO than in the DP management system (Table 5), which was due to the system effect of DP vs. GO system. Similarly, Ud-Din et al (1993) showed that forage removal by chipping reduced grain yield by about 30% in DP system compared to grain-only system. In the same study, they reported that forage removal could depress grain yield, but genetic potential to produce forage was not correlated with grain yield potential. Moreover, Arzadun et al (2003) stated that grain yield was reduced from low to high level of grazing pressure. Dunphy et al (1984) suggested that grain yield was dependent on plant's ability to regenerate leaf area after defoliation.

When genotypes were treated as qualitative factors, a non-significant genotype x system interaction was obtained (Table 3). This result was also supported by Khalil et al. (2002) who found a non-significant genotype x system interaction, and also showed that a management system had no significant effect on separation of cultivars. However, the significant genotype x system x selection interaction in Table 3 would imply that selection environment had significant effect on separation of genotypes or populations. Contrasts of GO vs. DP and Base vs. DP and GO means indicating selection response and asymmetry of the systems, respectively, were highly significant due to low yields from DP and Base respectively (Table 5).

An average grain yield difference among DP and GO management system across genotypes or as an estimate of genetic improvement could not be attributed to physical removal of reproductive tissues by grazing, expressed as reduced spike density. Grazing was terminated before the appearance of the first hollow stem above the crown (Redmon et al., 1996). Despite the differences among the management systems, DP system had 9.5 % more spike density compared with the GO system (Table 6). This result contradicted the study done by Christiansen et al (1989) where they reported grazing decreased spike density. Likewise, comparing among the selection environments, DP selection had 7.3% more spike density compared with GO selections (Table 6). While Kernel number per spike and seed weight were not significantly different among selection environments across the systems (Table 6). Similar results were reported by Christiansen et al. (1989) in wheat, i.e. kernel number per spike was not reduced or increased by grazing. However, in the same study they reported that seed weight was not affected the first year, but was affected in the second and third year due to grazing. Selection response for spike density was significant ($p<0.05$) but not for kernel number and seed weight as shown by the contrasts (Table 6). However, asymmetry contrasts were significant ($p<0.05$) for all yield components (Table 6).

Grain harvested from fields managed for grazing and grain production is often considered to have poor grain quality. However, our evaluation on 24 genotypes refuted this argument showing no significant difference ($p<0.05$) in test weight among genotypes from DP and GO system (Table 5). Khalil et al. (2002) also found no difference between system means averaged across years. Across systems, test weight averaged 737.7 kg m $^{-1}$ for the bulk populations. Genotype differences were observed for test weight but these differences varied depending on the selection environments (Table 3). Genetic improvement in test weight among three selection environments (S) was significant (Table 4). Also, asymmetry contrast was significant ($P\leq0.01$) indicating a difference in the base and DP and GO selection environments (Table 5).

The thousand-kernel weight for DP was1.77% lower compared with GO selection (Table 5). The significant selection response ($P<0.04$) was observed for the bulk populations (Table 5) indicating a difference among the two systems. The asymmetry contrast was also significant (*P*<0.01) for the bulk populations indicating a difference among the base and the mean of DP and GO selection environments, respectively.

Heading date for the DP management system was later than for the GO management system (Table 5). It might be due to time that plant takes to recover from defoliation. This was further supported by Edwards et al (2007) that a cultivar with later heading has later occurrence of first hollow stem in the same given environment. The late first hollow stem is a desirable characteristic for a DP system, as it allows later grazing in the spring. Within the GO management system (Table 5), heading date was longer for DP selections compared with GO selections. However, this refuted the report presented by van Santen et al (1999) in tall fescue where they mentioned that populations derived from pastures under grazing matured early. On the other hand, there was not significant difference between heading date among DP and GO selections within the DP management system (Table 5). The selection response was significant for GO but not for DP system (Table 5).

For wheat protein, no significant difference resulted between the two management systems (Table 4) or three selection environments (Table 5) for the bulk populations. For each system, grain protein averaged 129.69 g kg $^{-1}$. Our analyses for grain yield indicated higher grain yield for GO compared with DP management system (Table 5). Thus, we should have seen higher grain protein in genotypes from DP selection environment according to Campbell et al. (1981), who stated increases in protein content in spring wheat under moisture stress and reduced total grain yield. The two-way interaction of genotype and selection environment was highly significant (Table 3), as protein content of cereals is known to be influenced by genotype and environment. The variance component of the genetic background or genotypes was significant (Table 3) suggesting genetic improvement among the genotypes. The selection response and asymmetry contrast were not significant for the DP, GO, and base selection environments (Table 5).

The bulk populations from DP selection environment showed prostrate growth habit (Fig. 2) for both growth habit (GH) 1 and 2. The selection and rating were strongly related for GH1 and GH2 with the chi-square values of 175.5 ($p < 0.001$) and 105.5 ($p < 0.001$) respectively (data not shown). Positive relationships were found for prostrate growth habit for DP, erect for GO and semi-erect for base selection environments. Selections were significantly more prostrate (65.3 %) for DP selection, erect (47.2%) and semi-erect (48.6%) for GO selection and semi-erect (50%) for base selection for GH1. Growth habit patterns shown by GH1 were as expected. This result supported the findings of Landsberg et al, (1999) where they mentioned that prostrate growth habit was shown by plant communities in response to grazing. However, GH2 data were slightly different as the data was taken at the end of the grazing period. There were significantly more semi-erect (60%) for DP selection, erect (53.34%) for GO selection and semi-erect (65%) for base selection. The differences in the growth habit pattern might be due to genetic response of the genotypes for adaptation and change in the environment. Genetic variability allows any population to undergo changes required for better adaptation to new environments such as grazing.

# CHAPTER V

# CONCLUSION

Results of this study indicated that grain yield in dual-purpose system was lower compared with grain-only system due to the system effect of the DP system. However, among each system, grain yield was higher for dual-purpose selection environment compared to grain-only selection environment. Progress in test weight and wheat protein were observed in this genetic sample. Test weight and wheat protein were almost the same for both systems, indicating no compromise in quality due to grazing. Heading date was later for DP system than GO system. This might be the reason for later maturity in DP system allowing longer grazing period. However, there was no difference in heading date among the selection environment in each system. The genetic progress continued for the grain quality as the spike density was higher for the DP selection environment than GO selection environment in each of the system. Similarly, kernel number and kernel weight were not significantly different among selection environments in each of the system. Genotypes from DP selection environment showed more prostrate growth habit than GO and base selection environments. On the other hand, genotypes from GO selection environment showed more erect and semi-erect growth habit.

# CHAPTER VI

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Table 1. Genetic background of 24 winter wheat populations in which bulk selection was applied in the $F_2$, $F_3$, and $F_4$ generations in grain-only and dual-purpose management systems.

| Population | Genetic background |
|---|---|
| 1 | 2180//Crr*2/CtyA-/3/Ogallala |
| 2 | Tkw//Karl 92*2/CtyA-/3/Hickok |
| 3 | Platte//KS137-337/Wakefield |
| 4 | Plainsman V/OK79256 seln//FL302/3/Jagger |
| 5 | Custer/FL302//TAM 302 |
| 6 | KS92P0363-134/FL302//Ogallala |
| 7 | Jagger*2/FL302 |
| 8 | 2137/SW76-117C-4 |
| 9 | OK95G702/OK91P648 |
| 10 | OK95G703/2137 |
| 11 | OK95G703/OK92403 |
| 12 | OK95G704/OK91P648 |
| 13 | Oro Blanco/Custer |
| 14 | Betty/TAM 302 |
| 15 | OK9691E8/OK97G605 |
| 16 | Oro Blanco/KS85W663-11-6 |
| 17 | KS94WGRC32/OK93P735 |
| 18 | KS94WGRC33/TAM 302 |
| 19 | OK93P735/OK94P512 |
| 20 | OK91P648/2137 |
| 21 | OK93617/OK94519 |
| 22 | OK93P634/TAM 302 |
| 23 | N44/OK94P455 |
| 24 | 2174 |

Table 2. Least-squares means for three check cultivars evaluated in two management systems and 3 yr at the Expanded Wheat Pasture Unit, Marshall, OK.

|  | Grain yield |  | Test wt. |  | Thousand-kernel wt.. |  | Heading date |  | Wheat protein |  |
|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | GO | DP | GO | DP | GO | DP | GO | DP | GO | DP |
|  | kg ha$^{-1}$ |  | kg m$^{-3}$ |  | g |  | DOY |  | g kg$^{-1}$ |  |
| 2174 | 3530a | 3150a | 756a | 761a | 27.4a | 28.0a | 27a | 28a | 136a | 130a |
| Jagger | 3620a | 2750b | 723b | 741b | 23.3b | 26.6b* | 23b | 26b* | 133b | 127b |
| Custer | 3070b | 2760b | 743c | 751c | 28.8a | 28.3a | 24c | 25c | 126c | 124c |
| System mean | 3400 | 2880 | 741 | 751 | 26.5 | 27.6 | 24 | 26 | 132 | 127 |

* Significantly different between systems mean at 0.01 probability level.

System means within a column with the same letter are not significantly different (*P*> 0.05).

Table 3. Variance-component (VC) estimates and significance values for random effects from the ANOVA of $F_5$ selected progenies from 24 winter wheat populations or genetic backgrounds evaluated in two management systems for 3 yr at the Expanded Wheat Pasture Unit, Marshall, OK.

| | Grain yield | | Test wt. | | Thousand-kernel wt. | | Heading date | | Wheat protein | |
|---|---|---|---|---|---|---|---|---|---|---|
| Source of variation | VC | Test | VC | Test | VC | Test | VC | Test | VC | Test |
| | $(\text{kg ha}^{-1})^2$ | $P > Z$ | $(\text{kg m}^{-3})^2$ | $P > Z$ | $g^2$ | $P > Z$ | $d^2$ | $P > Z$ | $(\text{g kg}^{-1})^2$ | $P > Z$ |
| Year | 0 | - | 142 | 0.25 | 2.23 | 0.18 | 1.60 | 0.17 | 39.8 | 0.17 |
| Year × System | 111 219 | 0.09 | 111 | 0.16 | 0.32 | 0.18 | 0.12 | 0.19 | 5.0 | 0.18 |
| Genetic background (G) | 21 934 | 0.01 | 133 | <0.01 | 3.38 | <0.01 | 1.43 | <0.01 | 11.0 | <0.01 |
| G × System | 8 333 | 0.07 | NS | NS | 0.04 | 0.26 | 0.17 | 0.02 | 0.4 | 0.19 |
| G × Selection (S) | 751 | 0.36 | 15 | <0.01 | 0.39 | <0.01 | 0.16 | <0.01 | 0.5 | <0.01 |
| G × S x System | 5 694 | 0.02 | 3 | 0.10 | 0.02 | 0.30 | <0.01 | 0.43 | 0.0 | - |

*, ** Significant at $P \leq 0.05$ and 0.01, respectively; NS, not significant.

Table 4. Significance values for fixed effects from the ANOVA of $F_5$ selected progenies from 24 winter wheat populations or genetic backgrounds evaluated in two management systems for 3 yr at the Expanded Wheat Pasture Unit, Marshall, OK.

| Source of variation | df | Grain yield | Test wt. | Thousand kernel wt. | Heading date | Wheat protein |
|---|---|---|---|---|---|---|
| | | ------------------------------- | $P > F$ | ------------------------------------ | | |
| System | 1 | 0.46 | 0.46 | 0.17 | 0.01 | 0.17 |
| Selection | 2 | <0.01 | <0.01 | <0.01 | <0.01 | 0.77 |
| System × Selection | 2 | 0.01 | 0.23 | 0.90 | <0.01 | 0.49 |

* Significant at $P \leq 0.05$ and 0.01, respectively.

Table 5. Least-squares means and orthogonal contrasts for $F_5$ bulk progenies derived from either a GO or DP selection environment, compared with the base $F_3$ progeny with minimal selection, when evaluated in DP and GO management systems for 3 yr at the Expanded Wheat Pasture Unit, Marshall, OK.

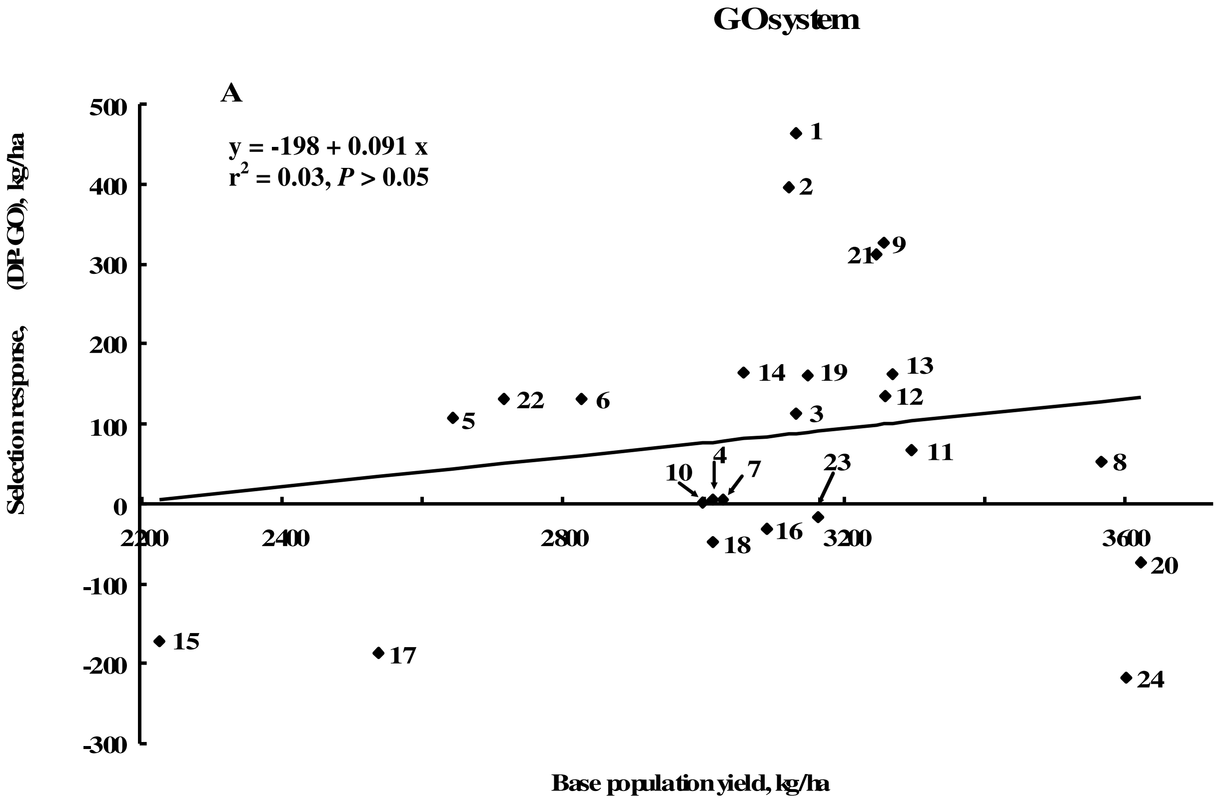
| | Grain yield | | Test wt. | Thousand-kernel wt. | Heading date | | Wheat protein |
|---|---|---|---|---|---|---|---|
| Environment of selection | GO | DP | Across systems | Across systems | GO | DP | Across systems |
| | ---------kg $ha^{-1}$------- | | kg $m^{-3}$ | g | --------DOY-------- | | g $kg^{-1}$ |
| Least-squares means | | | | | | | |
| GO | 3180 | 2870 | 742 | 28.3 | 114.8 | 117.0 | 129.6 |
| Base | 3080 | 2880 | 731 | 27.3 | 115.4 | 117.3 | 129.8 |
| DP | 3260 | 3090 | 740 | 27.8 | 115.3 | 116.9 | 129.7 |
| Contrasts | ---------------$P>F$--------------- | | | | | | |
| DP vs. GO | 0.01 | <0.01 | 0.15 | 0.04 | <0.01 | 0.50 | NS |
| Base vs. DP, GO mean | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | NS |

* Significant at $P \leq 0.05$ and 0.01, respectively; NS, not significant.

Table 6. Least-square means for yield components of $F_5$ bulk progenies derived from either a GO or DP selection environment, compared with the base $F_3$ progeny with minimal selection, when evaluated in DP and GO management systems for 3 yr at the Expanded Wheat Pasture Unitr, Marshall, OK.

|  | Spike density | Seed no. per spike | Seed wt. |
|---|---|---|---|
| Environment of selection | Across systems | Across systems | Across systems |
|  | spikes $m^{-2}$ | no. | mg |
| Least-squares means |  |  |  |
| GO | 343 | 29 | 30.9 |
| Base | 334 | 31 | 29.7 |
| DP | 370 | 29 | 30.4 |
| Contrasts | ----------------------*P*>*F*---------------------- |  |  |
| DP vs. GO | <0.01 | 0.12 | 0.05 |
| Base vs. DP, GO mean | <0.01 | <0.01 | <0.01 |

** Significant at $P \leq 0.01$ probability level.


GO system
A
y = -198 + 0.091 x
$r^2 = 0.03, P > 0.05$
Selection response, (DP-GO), kg/ha
500
400
300
200
100
0
-100
-200
-300
2200
2400
2800
3200
3600
Base population yield, kg/ha
1
2
21
9
14
19
13
12
22
6
5
3
11
8
10
4
7
23
16
18
20
15
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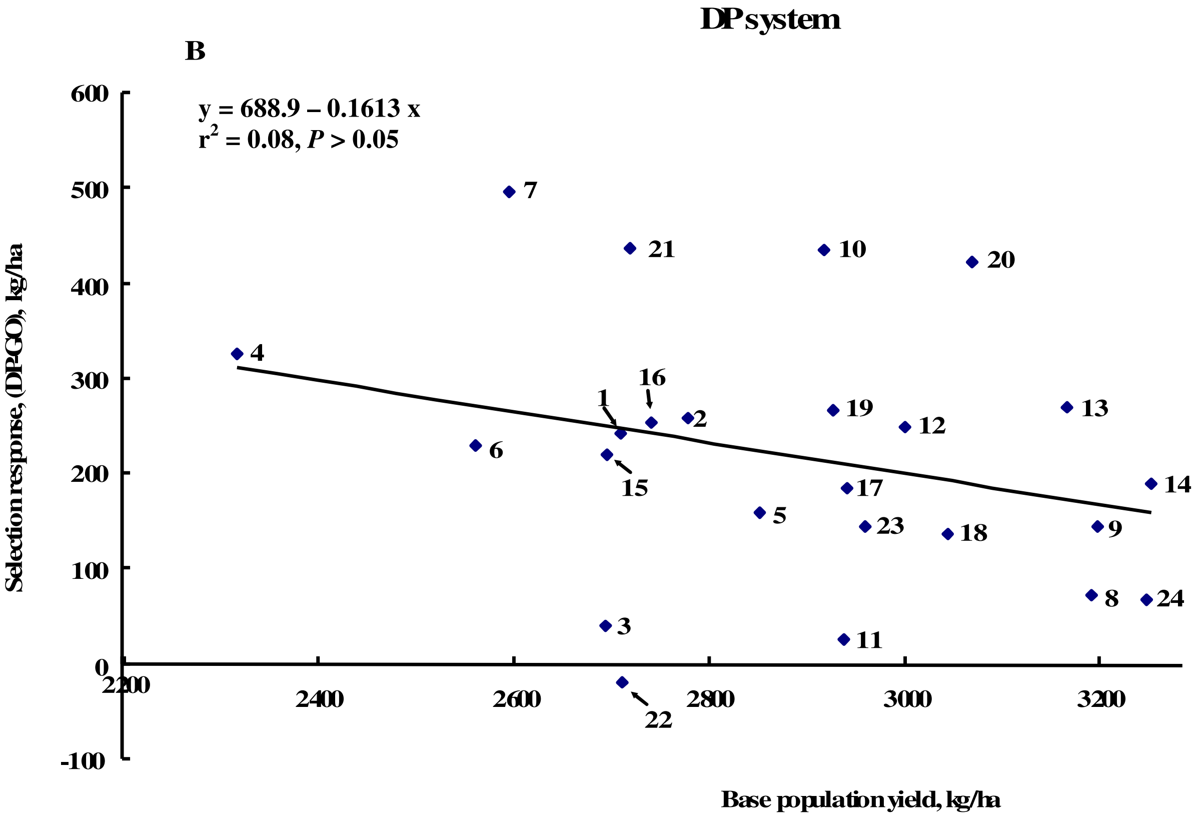
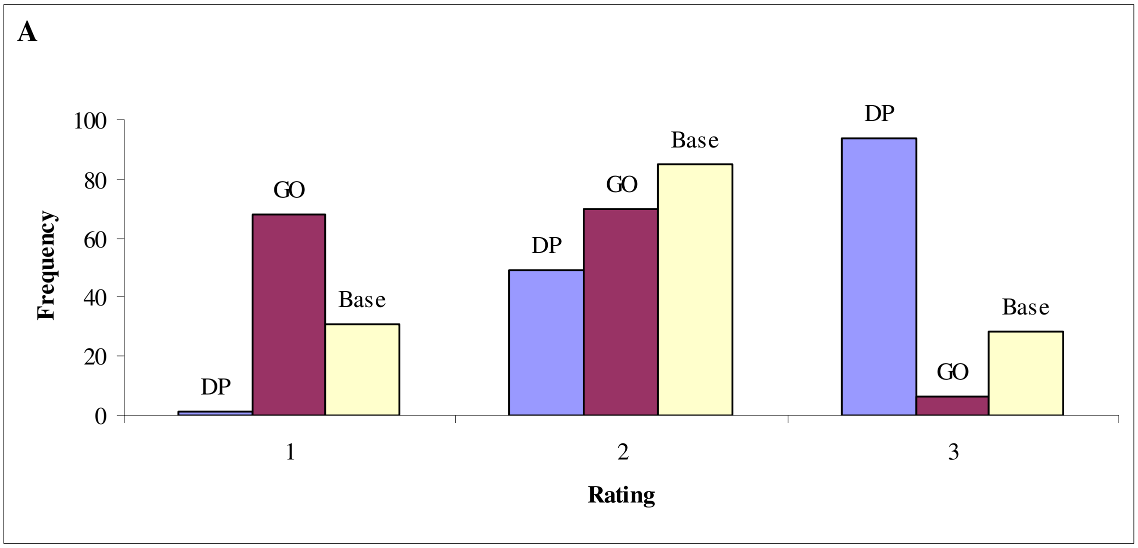


Figure 1. Relationships of the grain yield difference between DP and GO selections (selection response) versus mean yield of the corresponding base population in the GO (A) or DP (B) management system.



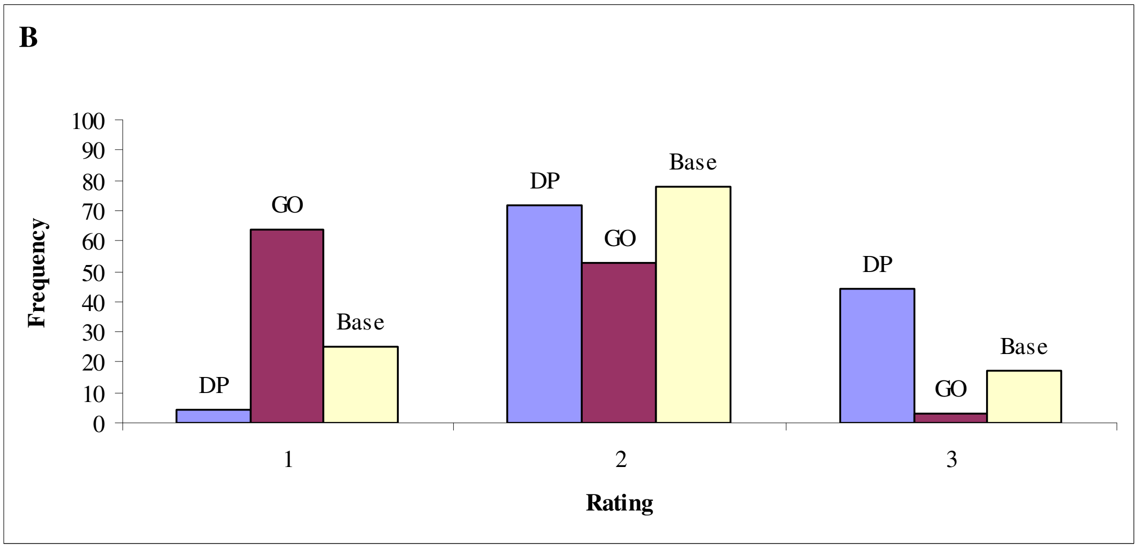


Figure 2. Growth habit frequency distributions of $F_5$ selected progenies and non-selected base progenies 24 winter wheat populations or genetic backgrounds ratings recorded in dual-purpose management system for 2 yr at the Expanded Wheat Pasture Unit, Marshall, OK at the beginning (A) and at the end (B) of the grazing period.

# VITA

Rima Thapa

Candidate for the Degree of

Master of Science

Thesis: SELECTION RESPONSES IN GRAIN YIELD AND RELATED TRAITS AS INDUCED BY DUAL-PURPOSE AND GRAIN-ONLY MANAGEMENT SYSTEMS

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Biographical:

Personal Data: Born and raised in Nepal. Parents are Ram and Sushila Thapa. Rima has three brothers; Amit, Sabin, and Rabin.

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Name: Rima Thapa Date of Degree: December, 2008

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: SELECTION RESPONSES IN GRAIN YIELD AND RELATED TRAITS AS INDUCED BY DUAL-PURPOSE AND GRAIN-ONLY MANAGEMENT SYSTEMS

Pages in Study: 35 Candidate for the Degree of Master of Science

Major Field: Plant and Soil Sciences

Scope and Method of Study: Grain yield and associated traits for 24 sets of populations were measured in grain-only and dual-purpose systems in the same field, following natural selection in those systems for the consecutive generations. Also included were three checks cultivars, 2174, Jagger, and Custer. A grazing system was used as a selection tool to create breeding populations enriched with genes that confer grazing tolerance, persistence, and ultimately, improved adaptation. Research was conducted in Marshall, Oklahoma using $F_5$ bulk progeny from each genetic background. The overall design structure was a split-split-plot in a completely randomized design, with management systems replicated across years. The treatment structure was a 2 x 24 x 3 factorial, representing management systems, genetic backgrounds, and selections, respectively. The primary traits analyzed in this study were grain yield, test weight, thousand-kernel weight, heading date, and wheat protein. The secondary response variables used were yield components like spike density, seed number and seed weight, and growth habit.

Findings and Conclusions: Selection responses were generally consistent between dual-purpose and grain-only systems. Dual-purpose selection had higher grain yield compared with grain-only selections without compromising test weight and wheat protein. In addition, spike density was higher for DP than for GO selections. Also seed number and seed weight were not significantly affected by the selection environment. As predicted DP selections showed a more prostrate growth habit during vegetative stages of development.

ADVISER'S APPROVAL: Dr. Brett F. Carver