IMPACT OF PLANTING DATE AND SEEDING RATE ON GRAIN AND FORAGE YIELDS OF WHEAT IN TEXAS

A Thesis

by

OLIVER JACOB SHAFFER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2007

Major Subject: Agronomy

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Approved by:

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ABSTRACT

Impact of Planting Date and Seeding Rate on Grain and Forage Yields of Wheat in Texas. (December 2007)

Oliver Jacob Shaffer, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Gaylon D. Morgan

Wheat serves three very important roles to producers in Texas and many states in the Great Plains. First, wheat is used as a cool season forage crop for livestock grazing. Second, wheat serves as a grain only crop. Third, wheat is used as both a forage and grain crop in the same season and is commonly referred to as a dual-use or dual-purpose crop. Previous research has demonstrated that planting date can significantly affect the success of these various production strategies. When wheat is planted early, more forage will be available for livestock; conversely, a delayed planting date should achieve a higher grain yield. The objective of this research was to determine the optimum seeding rate as planting date changes for wheat as a grain-only and dual-purpose crop in central Texas. Six different planting dates were evaluated starting with a target date of September 1st and having 14 d intervals between each planting date. Seeding rates were 34, 67, 101, and 135 kg ha^{-1} for Agri-Pro Cutter wheat variety. Results from the three year study showed that planting date had the greatest impact on forage and grain yields. Higher seeding rates maximized grain yields at the later planting dates, while lower seeding rates yielded higher for the earlier dates. Forage yields were maximized when planted prior to October 1st, while grain yields were maximized at the mid-October to early-November dates. This

research study demonstrated that producers could lower their seeding rates to between 34 and 67 kg ha^{-1} without sacrificing grain and season-long forage yields.

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I would especially like to thank Mr. Rex Herrington, the number one oat breeder in the state, for his advice, knowledge, counseling, but most of all his friendship. Without Rex I would not have finished this Master of Science degree and want to thank him for his loyalty to Texas A&M, the small grain industry, and passion for oats. His work ethic and research expertise inspired me throughout my time at Texas A&M.

DEDICATION

This thesis is dedicated to Mr. Rex Herrington for his outstanding contributions to the small grain industry in the great state of Texas. I do not think there is a more dedicated person to their job as Mr. Rex Herrington, as he has spent money from his own pocket to keep the program going when no funding was available. His 33 plus years of field research and experience make him top in his class. His name is associated with such varieties as TAMO 397, TAMO 405, and the next release TAMO 406. His passion for the small grain industry, particularly oats, sparked my interest in the breeding program, as well as field research. Although he is not a graduate of Texas A&M University he represents all the character traits of what a true Aggie should be. We can only hope there will be another Rex Herrington in the future.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Winter wheat (*Triticum aestivum* L.) is planted on over 2.43 million ha annually in Texas. During 2003 in Texas, 1.39 million ha of the 2.67 million ha average of winter wheat were harvested for grain. The 2.55 million ha of wheat planted in Texas in 2004 was second only behind Kansas in national rankings (Texas Agriculture Statistics Service, 2006). Wheat serves three very important purposes for Texas producers. First, wheat is a cool-season forage crop for grazing livestock. Second, wheat is as a grain crop. Third, wheat is used as both forage and grain during the growing season. Livestock graze the forage during fall and winter and grain is produced during spring after livestock are removed. Wheat can be used for these three purposes because it is adapted to a wide range of climates and soil types found throughout Texas and the Great Plains of the United States.

Wheat grown for grain only and the dual-purpose system are most common in Texas and are typically seeded between mid-August and early November (Winter and Musick, 1993). However, extreme planting dates can range from early August to early February. Wheat intended for forage only or a dual-purpose system is traditionally planted from mid-August to mid-October to maximize the number of grazing days. Increased number of grazing days in the fall increases profitability of cattle grazing and is critical to overall economic stability in dual-purpose wheat. (Personal communications, Todd Baughman, Extension Agronomist, Texas Cooperative Extension, Vernon, TX).

This thesis follows the style of the *Agronomy Journal.*

In contrast, wheat intended for grain only is generally planted mid-October or later. Studies have indicated that early-planted wheat (mid-August to mid-September) in Oklahoma produced less grain than wheat sown at later dates (mid-October) for grain production only (Epplin and Peeper, 1997). Grain yield increased as planting date was delayed from a very early planting date (23-28 August) to a recommended late planting date (10-19 September) in 1994 in Nebraska (Lyon et al. 2001). Additionally, these authors also observed a decrease in crown and root rot as planting date was delayed.

The planting date of winter wheat also affects fall forage, rooting depth, and soil water relations. Although planting in August increases the duration of wheat growth for forage and grazing of livestock, planting early can deplete available soil water prior to spring growth and reproductive development. Conversely, planting in November conserves soil water for spring vegetative growth and reproductive development. Winter and Musick (1993) observed that winter wheat planted in August for grazing, extracted water from a 1.8 m depth by December 7 of 1989 and 1990 in Bushland, Texas. However, wheat planted in early October for grain extracted soil water from depths of only 1.2 m and 0.6 m depth by December 7 in 1989 and 1990, respectively. If planting date was delayed until November, rooting depth before anthesis was 50% less and soil water extracted by the roots was 67% less than the early planted wheat (Winter and Musick, 1993). Based on these results, planting early shifted the period of major soil water extraction from spring to fall. This limited plant available water during the reproductive and seed development stages and reduced grain yields when compared to the optimal planting date (Winter and Musick, 1993).

Early planting increases the exposure of the wheat plant to abiotic and biotic stresses that can increase incidence of diseases and insects (Bowden, 1997; Lyon et al., 2001). Wheat streak mosaic virus, high plains virus, barley yellow dwarf virus, sharp eyespot, common root rot, crown rot, and take-all root rot are among wheat diseases associated with abiotic stress common in early planted wheat (Hossain et al., 2003). Similarly, an early planting date can increase the incidence and damage from aphids and Hessian fly. Feeding of wireworms and white grubs on seedling roots are another consequence of early planting that will reduce stands and plant vigor. Fall armyworm outbreaks are more common in early- than late-planted wheat (Patrick and Knutson, 2006).

Seeding rate is an equally important practice in the management of wheat productivity (Geleta et al., 2002). Studies relating seeding rate to agronomic performance of genotypes can be traced back to the 1920's. The optimum seeding rate is typically greater under high rainfall or irrigation, high yield potential, than under rain-fed conditions in arid regions and lower yield potential (Geleta et al., 2002). Under rain-fed conditions in Nebraska, an increase in seeding rate from 16 to 130 kg ha^{-1} resulted in a higher mean plant population, plant height, grain yield, and grain volume weight among wheat genotypes (Geleta et al., 2002). In contrast, seeding rates above 300 seeds m^{-2} (108 kg ha^{-1}) did not increase yield of wheat seeded during mid-September in the humid environment of Wisconsin (Wilhem, 1987).

The number of fertile tillers is dependent on seeding rate and environmental conditions during tiller development. Darwinkel et al. reported in 1977 that at high seeding rates, a major portion of grain producing heads comprised 240 main shoots m^{-2}.

At a lower seeding rate, 120 main seedlings m^{-2}, the majority of the ears came from tillers. Early seeding increases the potential for tiller development, which reduces the seeding rate necessary to maximize grain yield (Woodward, 1956). Conversely, a delayed seeding limited fall tiller development and grain yield yields of soft red winter wheat (SRWW) cultivars adapted to Wisconsin conditions (Dahlke et al., 1993). Delaying the seeding date in Wisconsin to later than 15 September exposed developing wheat to lower temperatures and required an increase of seeding rate from 390 to 520 seeds m^{-2} (163 to 217 kg ha^{-1}) to maximize yields (Dahlke et. al, 1993). For wheat seeded on September 3, a seeding rate of 260 seeds m^{-2} (108 kg ha^{-1}) was required to maximize grain yield of wheat in the Wisconsin study.

Wheat residue management affects the environment during seedling establishment and the relationships between seeding rate and grain yield. A typical asymptotic response of grain yield can occur as seeding rate increases from 34 to 202 kg ha^{-1} in seedbeds on which crop residue is maintained for hard red spring wheat (Lafond, 1994). Yet, a 3 yr study in a cool and temperate climate (Saskatchewan) revealed a greater grain yield response to increased seeding rate (22 to 124 kg ha^{-1}) of hard red spring wheat in a fallowed seedbed than where stubble was present (Wright et al., 1987).

Of the 2.43 million ha of hard red winter wheat planted in Texas each year, 36% is produced in the Texas Panhandle (Piccinni et al., 2001). During the 1994-95 season, 704,000 ha of wheat grown in the Texas panhandle were grazed by almost 900,000 head of cattle. A dual-purpose system enables a producer to manage risk under existing market conditions through an option of grazing cattle a little longer (March through May) for increased beef gains or removing cattle early (December through February) to allow the plant to produce grain (Lyon et al., 2001).

Stocker cattle are grazed on dual-purpose wheat when roots are established well enough to handle grazing animals. A good root system will prevent the entire plant from being dislodged from the field by the grazing livestock. In a dual-use wheat system, livestock grazing can start from early October to early November and will typically end in late February to mid March to avoid subsequent loss in grain production (Winter and Thompson, 1987). Currently, many producers still remove grazing livestock based on a specific calendar date; however, the jointing growth stage, also called first hollow stem, is a much better criterion for terminating spring grazing. Removing the livestock at or just prior to jointing minimizes grain yield losses from grazing and maximizes forage yields. Jointing date is affected by the environment and variety and varies from year to year depending on the number of growing degree days. Physical inspection of the most mature tillers is necessary to determine the date on which jointing begins (Hossain et al., 2003).

The economic optimum for planting date depends on comparative prices of wheat forage and grain. For example, Hossain et al. in 2003 found that a 20 day delay in planting date from 10 to 30 September reduced annual forage production 68%. In contrast, the delay increased expected grain yield 18% and seed test weight 0.5% (Hossain et al., 2003). Grain price will depend on test weight and production, and costs can differ among planting dates. A study in Lohoma, Oklahoma, indicated the economic optimum seeding date could range from 24 August to 29 September, depending on the relative prices of wheat forage and grain (Hossain et al., 2003). Additionally, grain yield can be reduced if wheat is grazed during early jointing stage. At fixed economic values, reduced grain yield will reduce income.

Regardless of the specific purpose of production, winter wheat grown in Texas is important to the Texas and U.S. economy. Price per unit of wheat was $3.06 bushel in 2003, $3.34 bushel in 2004 and $3.44 bushel in 2005. Price per unit is related to supply and demand as each year hectares harvested decreased, and priced increased. The Texas acreage harvested for grain rose to 1.42 million ha in 2004. Grain yields increased 9.7% from 1886 to 2088 kg ha^{-1} between 2003 and 2004 and decreased 25% from 2155 to 1617 kg ha^{-1} between 2005 and 2006. (Texas Agriculture Statistics Service, 2006). The wheat industry in Texas will continue to benefit the state in a positive manner, but research is needed to evaluate the optimum seeding date and rate for dual-purpose and grain only wheat to optimize net economic return and minimize input costs.

CHAPTER II

IMPACT OF PLANTING DATE AND SEEDING RATE ON GRAIN YIELDS OF WHEAT IN TEXAS

Introduction

Wheat has been referred to as the most important food grain produced in North America and the most important crop in many regions of the Great Plains (Epplin and Peeper, 1997). Due to this important role that wheat plays in agriculture and our society, there have been many studies conducted on improving cultivars, pest management, fertility management, and cultural practices, including seeding rates and planting dates. All of these studies are very important to the development and increased production efficiency of winter wheat in the United States. Both the planting date and seeding rate can significantly impact the profitability of wheat production in Texas. This study focuses on the effect of seeding rate and planting date on winter wheat yields in Central Texas, where no data is currently available. Although environmental factors are highly variable from season to season, this three year research project provides important information on the optimum range of planting dates and seeding rates for winter wheat in Central Texas.

Optimal growing conditions for winter wheat include temperatures between 10 and 24^{o} C, adequate soil moisture at planting and critical growth stages, and proper soil fertility. Wheat is very sensitive to high temperatures at planting and emergence and again during reproductive stages. Photosynthesis slows down and essentially ceases at 28^{o} to 29^{o} C (Cook and Veseth, 1991). Despite the sensitivity to heat, it is not uncommon for wheat to be planted in September in Texas, when air and soil temperatures commonly exceed 29^{o} C.

Planting dates of winter wheat affect rooting depth and soil water relations. Winter and Musick (1993) observed winter wheat planted in August for grazing extracted water from a 1.8 m depth by December 7 of 1989 and 1990 in Bushland, Texas. Wheat planted near the optimal planting date for grain harvest only, which was early October for this study, extracted soil water from a 1.2 m depth in 1989 and a 0.6 m depth in 1990 by December 7. Although planting in August increased the duration of wheat growth for forage and grazing of stocker cattle, planting early depleted available soil water storage prior to spring growth and reproductive development. Conversely, planting in November conserved soil water for spring growth and seed set and development. Rooting depth of the November planting date was 50% less than the earlier planting. Compared to the early dates, roots extracted 67% less soil water for the later planting date prior to anthesis (Winter and Musick, 1993). Based on these results, planting early can shift the period of major soil water extraction from spring to fall which can reduce grain yields compared with wheat planted at the optimal planting date.

Early planting increases the exposure of the wheat plant to abiotic and biotic stresses that can result in increased incidence of diseases and insects (Bowden, 1997; Lyon et al., 2001). Wheat streak mosaic virus, high plains virus, barley yellow dwarf virus, sharp eyespot, common root and crown rot, and take-all root rot are among wheat diseases associated with abiotic stress (Hossain et al., 2003). Similarly, an early planting date can increase damage from aphids and Hessian fly. Feeding of wireworms and white grubs on seedling roots are another consequence of early planting that will reduce stands and plant vigor. Fall armyworm is also a more prominent pest in early planted wheat (Patrick & Knutson, 2006).

Depending on the planting date, the seeding rate can be modified to optimize yields and decrease input costs. Past research, performed at Utah and the Netherlands, has shown that as planting date is delayed a higher seeding rate is necessary to maximized grain yields (Woodward, 1955; Darwinkel et al., 1977). The delay of planting date reduces growing degree days for tiller development and higher plant populations are required to compensate for less tiller development. Likewise, as planting date occurs earlier in the season the plants have more growing degree days to develop tillers and yields can be maximized with lower plant populations. In Central Texas, where fall and winter temperatures are typically mild, growing degree days can be sufficient for adequate tiller development even at planting dates in late November.

Due the wide range of planting dates used by producers across Texas, a three-year field study was conducted at McGregor, Texas to identify the optimum planting date and seeding rate on grain yield for winter wheat. Based on these findings, producers will have some guidelines on the optimum planting and seeding rate for grain yields in the Blacklands of Texas.

Materials and Methods

This research was initiated near McGregor, Texas at the Texas A&M University Agriculture Research and Extension Center (31° 25´ N lat; 97° 24´ W long; 276 m elevation above sea level). Soil type was a clay on a 0- to 2-percent slope. Soil permeability was very slow and water holding capacity was high. The soil has a capability subclass of 2E dryland. Taxonomic classification of the soil is a fine, montmorillonitic, thermic udic haplusterts (USDA-NRCS, 2006).

Agri-Pro Cutter® wheat was the variety selected based on previous performance in variety trials in the Blacklands area of Texas. A seven row small plot drill on 15 cm row spacing was used to plant. The plot size was 1.07 m wide by 3.35 m in length with approximately 0.30 m between plots. The crop seed was planted within the recommended depth range (2.5 to 3.75 cm). Grain was harvested using a Hege 125C small plot combine. Grain from the plots were placed in heavy duty 4.54 kg brown paper bags, weighed in grams, and converted to a yield basis at 14% moisture. Bushel weights were compiled by screening each sample through a standard wheat screen with 4.76 mm holes. Samples were run twice through a grain aspirator to further clean the sample of white caps and other foreign material. Samples were then funneled into an 81.7 cubic cm micro-test weighing device, which was tared on the scale, for measurement of bushel weight. Lodging was rated visually on a 0 to 10 scale with 0 being no lodging and 10 being the entire plot lodged. Spike density was measured by using a 0.92 m square made of 1.27 cm plastic pipe several days prior to harvest in 2005 and 2006. The plastic square was placed over the middle of the plot and heads were counted.

The main treatments for the research were 4 seeding rates and 6 planting dates (Table 1). Approximate emergence dates were recorded within 7 days of actual emergence (Table 2). The experimental design was a randomized complete block with 3 replications. The land was disked, harrowed, and fertilized in late-August. Fertilizer was applied by broadcast application in mid-August each year. The 2003 crop received 56 kg ha^{-1} of N, 24.5 kg ha^{-1} of P, and 46.6 kg ha^{-1} of K using a 13-13-13 fertilizer mix prior to planting. During 2004 to 2005, 106 kg ha^{-1} of N, 28.4 kg ha^{-1} of P, and 54 kg ha^{-1} of K were applied due to calibration errors in the field. In the 2005 season, application of pre-plant fertilizer (18-9-3) resulted in 56 kg ha^{-1} of N, 12.3 kg ha^{-1} of P, and 7.8 kg/ha of K. Top-dress application of 32-0-0 fertilizer provided 56 kg ha^{-1} of N prior to jointing (Feekes 6 stage) in late January or early February of each year. Weed control was conducted on an as-needed basis to manage broadleaf and grass species using Finesse® herbicide (chlorosulfuron and flucarbozone sodium). Foliar fungicides were applied on an as-needed basis to minimize yield losses from leaf rust (*Puccinia graminis*) and powdery mildew (*Ervsiphe gramninis*).

The target planting dates for all three years of the study started with September 1, with two weeks between each of the succeeding dates. Actual planting dates (Table 1) varied from the target dates due to weather and other unforeseen conflicts. Planting date 3 was not planted due to excessive soil moisture that during October, 2003. Grain was harvested at the earliest possible date after the wheat had reached less than 14% moisture (Table 3). The 2003/2004 season experienced above average rainfall for every month except November and December. In the 2004/2005 season, October precipitation was the 4th wettest month on record with just over 254 mm while rainfall was timely and adequate for the remainder of the season (Figure 1) (National Weather Service Forecast Office, 2007). The 2005/2006 season experienced drought from initial planting and during harvest. The plants received a total of 61 mm from September to December and below average precipitation in April and May.

Data were analyzed using the SPSS 12.0.1 for windows by using the general linear model running a univariate analysis. Means of main effects and interactions were compared using Fisher's Protected Least Significant Difference (LSD) with *P* values < 0.05 considered significant. Each year of data are presented separately due to significant year by environment interaction. Also, the inconsistencies in planting dates over years discouraged the authors from combining the data over years. With few exceptions, there were not significant interactions between seeding rates and planting dates in any year. Therefore, seeding rates were combined to determine the impact of planting date on grain yields.

Results and Discussion

Spike Density

In the 2004/2005 season, the number of tillers developing harvestable heads was not different among any of the seeding rates or planting dates (PD) (Figure 2). When all seeding rates were averaged, PD 5 produced more harvestable heads than planting dates 1, 2, and 3. Mean spike density of planting dates 1, 2, and 3 were similar. Planting date 6 produced 50% fewer heads than all other planting dates. This agrees with a Kansas state study which concluded that earlier planted wheat produced more tillers, thus resulting in more competition and decreased grain yield (Thiry et al). While later planted wheat produced less tillers resulting in lower grain yield, thus resulting in the need for a higher seeding rate as planting date is delayed.

In the 2005/2006 season, seeding rates of 34 and 101 kg ha^{-1} yielded fewer harvestable heads than rates of 67 and 135 kg ha^{-1} rate at PD 6 (Figure 3). Tiller densities at all other seeding rates were not different at any planting date. When seeding rates were averaged for each planting date, spike density did not differ among PD 1 through PD 5.

However, PD 6 head density was lower than PD 1, 2, 3, and 5, but not different than PD 4.

Planting date and seeding rate both play a critical role in the development of plant and ultimately how productive the crop will be during grazing and for grain harvest. Past research has shown that as planting date is delayed a higher seeding rate is necessary to maximized grain yields (Woodward, 1955; Darwinkel et al., 1977). This is due the fact that later planted wheat has fewer GDD for tiller development and higher plant populations are required to compensate for fewer tillers. Likewise, as planting date occurs earlier in the season the plants receive more GDD to develop tillers and do not require as high of a plant population.

Based on the 2004/2005 and 2005/2006 spike density data, a linear regression analysis was run to determine if spike density could predict grain yield (Figure 29). When combining both seasons, a significant positive correlation existed between tiller density and grain yield. Therefore, spike density can be used to estimate grain yield. This is consistent with previous research where spike density was used in an equation to help estimate production (Miller and Bean).

Grain Yields

The 2003/2004 season received above average precipitation compared to the 30 year average. Variation of grain yield among seeding rate was not significant ($P<0.05$) for the planting dates in 2004 (Figure 4). When all the seeding rates were combined for each planting date, grain only wheat yields ranged from 1600 to 2396 kg ha^{-1} among the six planting dates (Figure 4). Grain yields were similar between PD 4 and 5, which were greater than yields for PD 1 and 6. Generally, yields increased over planting dates from early September to early November, but declined for the late November date. However, increasing the seeding rate was not advantageous for any of the planting dates.

Grain yields for the 2004/2005 season ranged from 1381 kg ha^{-1} at the seeding rate of 67 kg ha^{-1} for PD 6 (14-December-04) to 4693 kg ha^{-1} at the seeding rate of 34 kg ha^{-1} for PD 4 (20-October-04). Yields were similar among seeding rates for PD 1, 2, 4, 5, and 6 (Figure 5). At PD 3, grain yield was greater ($P<0.05$) for a seeding rate of 135 kg ha^{-1} than the lowest seeding rate.

Averaging across all seeding rates, grain yields were comparable among PD 1, 3, 4, and 5 (Figure 5). The grain yields for PD 6 were 60% lower than all the other seeding rates. Yields from PD 2 were lower than PD 4 and higher than PD 6. The mean grain yield for 2006 was greatest among the three years of the study due to above average precipitation all season.

The 2005/2006 season was one of the driest on record with below average rainfall from August, 2005 through June, 2006 (Figure 1). Due to season-long drought stress, grain yields across all treatments were low. Very limited precipitation affected the overall stand establishment and resulted in non-uniform crop emergence and stands. The seeding rates, of 101 and 135 kg/ha produced greater ($P<0.05$) grain yields than the lowest seeding rate on PD 4. Similar trends of mean grain yield were observed among seeding rates on PD 1, 3, and 5, but rates were not significantly different ($P<0.05$) (Figure 6). For PD 2, mean grain yield at the seeding rate of 67 kg ha^{-1} was greater than at higher seeding rates contrasted with other PD.

Averaged over seeding rates, mean grain yields for the 2005/2006 season were similar among PD 2, 3, 4, and 5 (Figure 6). Mean grain yields for the first and last planting date were 30% and 24% below PD 4, respectively. Grain yield was lower for PD 1 than PD 2 and 3 even though emergence dates and spikes density was similar among the three dates (Table 2, Figure 3). Low soil moisture was a major yield limiting factor in 2005/2006, which could explain the yield difference between PD 1 and 2. Winter & Musick (1993) similarly reported that winter wheat planted early, August 23 for their study, increased rooting depth and soil water extraction during early compared to later planting dates. Early planting reduced grain yields due to water depletion during fall, which reduced extraction during anthesis compared to October and November planting dates.

Even when precipitation was above average during August, September, and October and in the spring, during the 2004/2005 season, grain yields were lower when wheat was planted in September and October compared to early- November. The planting dates did not have a large numerical impact on yield as long as wheat was planted after early September or before November 10th. Although moderate or high levels of pests were not observed in these plots, insect and disease incidence may have also contributed to the lower yields observed at the earlier planting dates.

The above average precipitation during August through October similarly diminished differences in grain yield among seeding rates. Grain yields were as high for the lowest (34 kg ha^{-1}) as for higher seeding rates during the 2003/2004 and 2004/2005 seasons. Dahlke et al.(1993) concluded that later planting dates required higher seeding rates, which contrasts with observations during the first two years of this study (Fig 4 and 5). During the 2004/2005 season, grain yield varied among seeding rates for PD 3 only, where the 135 kg ha^{-1} rate was significantly higher than the 34 kg ha^{-1} rate.

The yield response to seeding rate for the 2005/2006 season was more consistent with the conclusion of Dahlke et al. (1993) that later planting dates required higher seeding rates. Yet, yield differences among seeding rates was significant ($P<0.05$) on PD 4 only. The below average precipitation during January, February, April, May, and June of 2006 could have limited tillering and tiller survival of wheat per unit area. Above average precipitation in March could have enhanced growth and grain yield per tiller for the relatively high seeding rates. Variation of precipitation among years was a potential source of variation of yield responses to planting date among years. Compared to the 30 yr precipitation data for the area (859.09mm) the 2003/2004 and 2004/2005 seasons were above average (1255.70mm and 983.23mm, respectively). In contrast, precipitation for the 2005/2006 season was well below average (547.12mm) (National Weather Service, 2007). Grain yields declined from early to late November during 2003/2004 and 2004/2005 seasons, but were similar between the November dates in the 2005/2006 season. This is consistent with other research efforts, which have reported optimal planting dates for grain to be late October to early November in the Panhandle of Texas (Winter and Musick, 1992).

Bushel Weight

Similar to grain yield, bushel weights depend largely on environmental conditions at the time of grain-filling. The 2004 bushel weights were not taken for all replications and are not reported. Mean rainfall during the months of March, April, and June, which is essential for wheat growth and grain-filling, was near or below long-term averages during 2005. The bushel weights were similar among PD 1 through 4, but were significantly lower on PD 5 and 6 than the previous planting dates (Figure 7). The trend of declining bushel weights was similar to that of grain yield over PD 4 through 6 during 2005/2006.

The mean grain bushel weights for 2006 were much lower than in 2005 (Figure 8). Similar to mean grain yield, mean bushel weight of for PD 1 was significantly less than that of PD 2 and 3. In contrast, bushel weights were significantly lower for PD 4 and 5 than for PD 3 even though mean grain yields were similar among these three planting dates. Both tillering at low seeding rates and increased seeding rate contributed to comparable spike densities and grain yields for PD 4 and 5, but periodic stress during grain filling could have reduced seed size and bushel weights (Fig 3, 6, and 8). The lower bushel weights for PD 4 and 5 than PD 2 and 3 agree with findings from Darwinkel et al. (1977). Conversely, environmental constraints on tillering for PD 6 during 2005/2006 reduced spike density and grain yield compared to PD 3. The reduced spike density for PD 6 could have reduced interference among tillers during grain development and contributed to greater bushel weights than observed for PD 4 and 5 (Fig. 3, 6, and 8).

Based on the 2004/2005 and 2005/2006 bushel weight data, a linear regression analysis was run to determine if bushel weight could predict grain yield (Figure 31). When combining both seasons, a significant positive correlation existed between bushel weight and grain yield. Therefore, bushel weight can be used to estimate grain yield. This is consistent with previous research where bushel weight, spike density, and number of seeds per head were used in an equation to help estimate yield potential (Miller and Bean).

Lodging

Lodging was reported on a scale of 0 to 10 with 10 being the most severe (Figure 9). Lodging was not quantified in the 2003/2004. In 2004/2005, there were no differences among seeding rates for lodging. Ratings were averaged over seeding dates to compare planting dates. Lodging ratings were lowest for PD 6 and ratings for PD 6 were less than PD 1 and 2. The longer exposure of wheat to the abiotic and biotic stresses for early planting dates could have increased lodging values for PD 1 and 2 compared to PD 6. The earlier planted wheat was in the ground 40-60 days longer than the later planted wheat, which increases its exposure to stem weakening pests like Hessian fly and powdery mildew. Additionally, the early planted wheat remained in the field for a longer period of time after maturation and increased their propensity to lodge.

Lodging was much more severe for the 2005/2006 season compared to the 2004/2005 season, due to two wind storms prior to harvest. The 2005/2006 season also experienced below average rainfall for the months of September through February and April through June, which limited water during establishment and grain filling (Figure 1). Water stress limits turgor pressure and prevents normal development of wheat stems, which contributes to higher lodging (Cook and Vesseth, 1991). Yet, lodging rating in 2006 did not differ among seeding rates or planting dates (Fig. 10).

Conclusion

This study showed that wheat grain yields were optimized for planting dates near the end of October to early November in years with average to above average rainfall. In years with limited fall rainfall, as in 2005/2006, the planting date window widened to between mid-September and early November. Rainfall was shown to be the most limiting factor for yields, thus the amount of water transpired by the plants is directly proportional to grain yield (Cook and Vesseth, 1991). Additionally, earlier planted wheat was more prone to lodging for the 2004/2005 season, while the mid to late planting dates were more prone for the 2005/2006 season. Bushel weights were higher for earlier planted wheat for the 2004/2005 season and lower for 2005/2006 season for grain-only. For the three year study, with few exceptions, seeding rate was not significant for a particular planting date. Therefore, lower seeding rates can be used successfully to achieve grain yields.

CHAPTER III

IMPACT OF PLANTING DATE AND SEEDING RATE ON DUAL-PURPOSE FORAGE AND GRAIN YIELDS OF WHEAT IN TEXAS

Introduction

Wheat has been referred to as the most important food grain produced in North America and the most important crop in many regions of the Great Plains (Epplin and Peeper, 1997). Wheat not only serves as a grain crop, but as a dual-purpose crop (forage and grain) and is extremely important part of the cropping systems in the Southern Great Plains. It is estimated that over fifty percent of the wheat planted in Texas and the Southern Great Plains is grazed to some degree in the fall and winter months, and then harvested for grain (Morgan, personal communication, 2007). Winter wheat used in a dual-purpose system gives producers some options to take advantage of fluctuating livestock and grain prices. The main goal of a dual-use wheat system is to maximize cattle gain on fall and winter wheat pasture. Then, cattle are removed from the wheat prior to the jointing stage (Feekes 6) to minimize damage to the plant and allow the plant to develop grain for harvesting. Therefore, the producer's objective is to maximize profits from cattle gains without hindering grain yields.

Planting date for this dual-purpose system is typically about one month earlier than grain only wheat (Hossain et al., 2003). Early planting increases the duration of exposure to abiotic stress that the plant endures, which can increase incidences of diseases, insects, and other biotic stresses (Bowden, 1997; Lyon et al., 2001). Wheat streak mosaic virus, high plains virus, barley yellow dwarf virus, sharp eyespot, common root rot, crown rot, and take-all root rot are among wheat diseases associated with abiotic stress (Hossain et al., 2003). Feeding of wireworms and white grubs on seedling roots is another consequence of early planting that will reduce stands and plant vigor. Fall armyworm moths and Hessian flies are also more damaging to early planted wheat. Similarly, early planting date can increase damage due to piercing-sucking and toxin injection of aphids (Patrick and Knutson, 2006).

Although additional stress occurs for wheat planted in late-summer or early fall, these earlier planting dates do allow for the wheat plants to produce more fall and winter forage to be consumed by grazing animals. Planting dates after mid-October may not produce adequate forage to meet livestock management goals (Hossain et al., 2003). Therefore, planting from late-August to mid-September is currently the standard management practice for most dual-purpose systems in Texas. One study conducted in Lahoma, Oklahoma found the optimal planting date for a dual-purpose system to range from 24 August to 29 September (Hossain et al., 2003). Stocker cattle typically are put out to pasture from early November until the early joint stage in early-to mid-March. However, it should be noted that calendar date of jointing can vary considerably from year to year due to varietal and climatic differences (Dunphy et al., 1982).

It is estimated that at least 50% of the wheat acreage in the southern Great Plains is targeted for stocker cattle grazing as well as grain production (Carver et al., 1991). Winter wheat is preferred forage crop due to the high crude protein content and available standing biomass available for consumption by livestock. Crude protein and digestibility of winter wheat forage is comparable to that of alfalfa (Hossain et al., 2003). Average daily gain for stocker cattle grazing winter wheat pasture in Texas located in western Wilbarger County ranged from .85 to .89 kg d^{-1} (Pinchak et al., 1996). While average daily gain for stocker cattle grazing winter wheat pasture in South Carolina was 1.48 kg d^{-1} (Worrell et al., 1992). When non-consumptive loss is put into the equation, it is estimated that 1 kg of beef gain is expected to require 10 kg (dry matter) of standing wheat forage (Hossain et al., 2003).

Optimal growing conditions for winter wheat include temperatures between 10 and 24° C, adequate soil moisture at planting and at critical growth stages, and proper soil fertility. Wheat is very sensitive to high temperatures during germination, emergence, and seedling stages, especially under limited soil moisture. Photosynthesis slows down and essentially ceases at 28 to 29° C (Cook and Vesseth, 1991). Increasing soil temperature negatively affects coleoptile length and influences seeding depth, which plays a critical role in the stand establishment of wheat. Under hot, dry conditions that are common in September, seed is commonly planted deeper to reach adequate soil moisture. The deeper a seed is placed into the soil the longer it will take for that seed to emerge and the more energy it requires for emergence. Wheat development response to temperature is measured by accumulated heat units referred to as growing degree-days (GDD). The number of GDD is the average temperature on that day minus a base temperature of 0° C. Winter wheat seeds planted one inch deep require around 130 GDD for emergence and between 2,000-2,500 GDD from the time the seed starts to take up water until grain is ready for harvest (Cook and Vesseth, 1991).

Planting dates of winter wheat affects rooting depth and soil water relations. Winter and Musick (1993) observed winter wheat planted in August for grazing extracted water from a 1.8 m depth by December 7 of 1989 and 1990 in Bushland, Texas. Wheat planted near the optimal planting date for grain harvest only, which was early October for this study, extracted soil water from a 1.2 m depth in 1989 and a 0.6 m depth in 1990 by December 7th. Although planting in August increased the duration of wheat growth for forage and grazing of stocker cattle, planting early depleted available soil water storage prior to spring growth. Conversely, planting in November conserved soil water for spring growth. Rooting depth of the November planting date was 50% less than the earlier planting. Compared to the early dates, roots extracted 67% less soil water for the later planting date prior to anthesis (Winter and Musick, 1993). Therefore, planting early shifted the period of major soil water extraction from spring to fall, which reduced grain yields compared with wheat planted at the optimal planting date.

The rate of regrowth following clipping or grazing is crucial for the productivity of the grazing component of a dual-purpose system. Regrowth highly depends on the amount and timing of rainfall, GDD, radiation, and the availability of nutrients in the soil profile for the plant to uptake.

Due the wide range of environmental conditions that exist in the state of Texas, a 3-yr field study was conducted to evaluate planting date and seeding rate on the dual-use wheat system in the Blacklands of Texas. The study was implemented to provide guidelines for producers to optimize revenue from forage and grain in the dual-use wheat system.

Materials and Methods

This research was initiated near McGregor, Texas at the Texas A&M University Agriculture Research and Extension Center (31° 25´ N lat; 97° 24´ W long; 276 m elevation above sea level). Soil type was a clay with a 0- to 2-percent slope Permeability was very slow and water holding capacity was high. The soil capability subclass was 2E for dryland and none was irrigated. Taxonomic classification of the soil is a fine, montmorillonitic, thermic udic haplusterts (USDA-NRCS, 2006).

The main treatments for the research were 4 seeding rates and 6 planting dates for dual-purpose wheat (Table 1**)**. Approximate emergence dates were recorded within 7 days of actual emergence (Table 2). The experimental design was a randomized complete block with 3 replications. The land was disked, harrowed, and fertilized in late-August. Fertilizer was broadcast to achieve a minimum of 56 kg ha^{-1} of N, 24.5 kg ha^{-1} of P, and 46.6 kg ha^{-1} of K. The 2003/2004 crop received 56 kg ha^{-1} of N, 24.5 kg ha^{-1} of P, and 46.6 kg ha^{-1} of K from a 13-13-13 fertilizer mix. The 2004/2005 crop received 106 kg ha^{-1} of N, 28.4 kg ha^{-1} of P, and 54 kg ha^{-1} of K due to calibration errors in the field. The preplant application in 2005 provided 56 kg ha^{-1} of N, 12.3 kg ha^{-1} of P, and 7.8 kg ha^{-1} of K from a 18-9-3 fertilizer mix. Top dressing of 32-0-0 supplied 56 kg ha^{-1} of N prior to jointing (Feekes 6 stage) in late January or early February. Weed control was conducted on an as-needed basis to manage broadleaf and grass species using Finesse® herbicide (chlorosulfuron and flucarbozone sodium). The AgriPro Cutter® variety of wheat offered good resistance to leaf rust (*Puccinia graminis*) and did not need a fungicide application for the 2003/2004 season. However, two applications of Headline® fungicide (6 oz a^{-1}) were required in both 2005 and 2006 to minimize yield losses from leaf rust and powdery mildew (*Ervsiphe gramninis*).

The target planting dates for all three years of the study were scheduled at 2-week intervals starting on September 1. Actual dates are given in Table 1. Planting date 3 was not planted due to excessive soil moisture that occurred during the month of October,

2003. Grain was harvested at the earliest possible date after the wheat had reached less than 14% moisture (Table 3). The harvest month of June was fairly dry and the crop was harvested in a timely manner.

Agri-Pro Cutter® was the wheat variety grown in the dual-use research trial. Forage was harvested two times each year (Table 4)**.** Plots were harvested using an R-Tech Alfalfa-Omega flail harvester pulled by a L4310 Kubota tractor. Clipping height averaged around 5 cm. Total plot weight was recorded immediately following harvest and sub-sample weights were taken in the field to get a wet weight. Sub-samples were dried at 37.8^{o} C for minimum of 48 hours to remove all moisture. The percent dry matter from each sub-sample was determined and was used to determine total dry matter biomass for each plot. After the samples were dried and weights were recorded, selected samples were then sent to the Texas Cooperative Extension Soil, Water, and Forage Testing Laboratory at Texas A&M University. Analysis consisted of percent crude protein, acid detergent fiber percent, and total digestible nutrient percent (Table 5). Due to the financial expense of having samples analyzed two samples of the 101 kg ha^{-1} seeding rate from planting dates one, three, five were sent to the lab for analysis.

Grain was harvested using a Hege 125C small plot combine. Grain from the plots were placed in heavy duty 4.54 kg brown paper bags and weighed and converted to a kg ha^{-1} yield basis. Test weights were compiled by screening each sample through a standard wheat screen with 4.76 mm wholes. After the samples were screened they were run twice through a grain aspirator to further clean the samples of white caps and other foreign material. Once the samples were rated as clean, they were poured through a 10.2 cm funnel into a 179.6 gram micro-test weighing device which was tared out on the scale and the grain was then weighed to determine bushel weight. Lodging was rated visually on a 0 to 10 scale with 0 being no lodging and 10 being the entire plot lodged. Spike density was measured by using a 0.92 m square made of 1.27 cm plastic pvc pipe. The plastic square was randomly placed within the plot, and heads were counted that fell into the square area. Every plot was measured for spike density a few days prior to grain harvest.

Data were analyzed using the SPSS 12.0.1 for windows by using the general linear model running a univariate analysis. Means of main effects and interactions were compared using Fisher's Protected Least Significant Difference (LSD) with P values < 0.05 considered significant. There was significant year by environment interaction and the multi-year data was not combined. With few exceptions, there were not significant interaction between seeding rates and planting dates in any year. Therefore, seeding rates were combined to determine the impact of planting date on grain yields. Linear regression models were also run for yield by spike density interaction.

Results and Discussion

Precipitation

The 2003/2004 season received above average precipitation for every month excluding November and December. The 2004/2005 small grain season was a very good season due to adequate and timely rainfall. October of 2004 was recorded as the 4th wettest month on record with just over 254 mm of rain (Figure 1) (National Weather Service Forecast Office, 2007). The 2005/2006 season experienced drought from initial planting and during the months prior to harvest. The crop received a total of 61 mm from September to December. Grain yields for 2004/2005 were highest among the three years in this study. The 2005/2006 season was the lowest yielding of the 3 yr study highly due to the lack of soil moisture.

Forage Yields

For the first forage harvest on 12 December 2003, only PD 1, PD 2, and PD 4 had sufficient growth to harvest (Table 4). The third planting date was not planted due to field moisture conditions being too wet. Forage yield on the first harvest date for each planting date tended to be greater for the seeding rate of 67 kg ha^{-1} than for 34 kg ha^{-1}, but the difference between seeding rates was significant for PD 2 only (Figure 11). In addition, the mean yield among seeding rates for PD 1was greater than PD 2 and 4 (Figure 11)**.** For the first harvest date, as the planting dates were delayed, forage yields significantly decreased. This is consistent with previous research that stated if forage production is the sole objective planting early should meet these goals (Hossain et al. 2003).

Contradictory to the first clipping, forage yield for the lowest seeding rate (34 kg ha^{-1}) was greater than seeding rates of 101 and 135 kg ha^{-1} on PD 1 and 2 (Figure 12). There were no significant differences among the seeding rates of 67, 101 and 135 kg ha^{-1}. Seeding rate did not impact forage yields for PD 4, 5, or 6. Mean forage yield among seeding rates during the second harvest of PD 4 (19 February 2004), were greater than PD 1, 2, and 6, but similar to PD 5 (Figure 12). Similar to variation of grain yield, delaying planting until PD 6 reduced forage production compared to earlier planting dates.

The sum of forage yield over two harvests revealed variation among planting dates during 2003. Total forage yield was greatest for PD 1 and 2 and declined during each subsequent planting date (Figure 13). This is consistent with Lyon et al., 2001, where it was reported that forage yields were reduced for the first and second harvest as planting date was delayed. This can be tied to the fact that earlier planted wheat has more growing degree days (GDD) for leaf, tiller, and root development than the later planting dates. In contrast, total forage yield was similar among seeding rates for each planting date (Figure 13). Mean total forage yield for the first two planting dates was at least two times greater than for PD 4, 5, and 6. The yield for PD 4 was, in turn, higher than for both PD 5 and 6. Planting date 5 forage yield was lower than PD 1, 2, and 4, but greater than yield for PD 6.

The first harvest of the 2004/2005 occurred on 21 December 2004. Similar to the previous year, forage yields for the lowest seeding rate (34 kg ha^{-1}) were lower than a higher seeding rate for PD 2 (Figure 14). In addition, yield at first harvest was less for the lowest seeding rate than the three higher seeding rates on PD 1. Although yields were similar among seeding rates for PD 3, a trend of increasing yield was observed for increased seeding rate over PD 1, 2, and 3. Conversely, forage yield was greater for the lowest seeding rate than the highest seeding rate on PD 4 (Figure 14). Mean first harvest yield was similar between PD 1 and 2, and means for the first two dates were greater than PD 3 and 4 (Figure 14).

At the second harvest on 15 February 2005, mean forage yields were similar among seeding rates for PD 2, 3, 4 (Figure 15). For PD 1, forage yield was greater for the seeding rate of 67 kg ha^{-1} than the seeding rate of 135 kg ha^{-1}. For PD 5, the seeding rate of 101 kg ha^{-1} maximized yield at the second harvest and, in contrast to other planting dates, yield was lowest for the lowest seeding rate. The second-harvest forage yields for

PD 3 and 4 were similar and greater than the other planting dates (Figure 15). This agrees with previous research where it was found that later planting dates maximized forage yields when harvested during the boot stage (Lyon et al., 2001). Similar forage yields were observed for PD 1 and 2 and both yielded more forage than PD 5.

For the 2004/2005 season, the sum of forage yields over both harvests was lower for the seeding rate of 34 kg ha^{-1} than at higher seeding rates for PD 1 and PD 5 (Figure 16). For PD 5, forage yield over both harvests was greatest for the seeding rate of 101 kg ha^{-1}. Total forage yield was similar among seeding rates for the PD 2, 3, and 4. Similar to the trend for the first forage harvest, mean yield for the two harvests averaged over seeding dates for PD 1 and PD 2 were similar and greater than PD 3, 4, and 5 (Figure 16). In addition, yield for the two harvests decreased over PD 2 through 5. These results are consistent with the 2003/2004 results and previous reports that early-planted wheat produces more forage for livestock consumption than late-planted wheat (Lyon et al., 2001).

The first harvest in the 2005/2006 season occurred on 16 February 2006, due to extremely dry conditions and little fall forage growth. Planting date 3 was the only planting date for which forage yield differed among seeding rates. Forage yield for the seeding rate of 135 kg ha^{-1} was greater than that of 34 and 67 kg ha^{-1} (Figure 17). In addition, forage yield averaged over seeding dates was similar among the six planting dates. Similar emergence and forage yield over the multiple planting dates was the result of extremely dry soil conditions at planting and the lack of precipitation following planting to initiate germination. The dry conditions did not allow roots and seedlings to develop properly for adequate fall forage.

Harvest two for 2005/2006 occurred one month later than in previous seasons, 15 March 2006, due to the lack of forage present in mid-February. Similar to the first harvest, yields did not differ among the four seeding rates for any of the planting dates. Mean yield over seeding rates for PD 2 and 5 were similar and greater than mean yield of PD 3 (Figure 18). Extreme water stress over the six planting dates limited subsequent effects on yield of the second forage harvest.

For 2005/2006, the sum of yields for forage harvests one and two did not reveal consistent trends for seeding rate or planting date. For PD 3 and 6, total forage yields for the lowest seeding rate were less than the highest seeding rate (Fig. 19). For PD 6, yield over the two harvests was lower for the lowest seeding rate than the three higher seeding rates (Figure 19). When forage yield was averaged over seeding rates, mean yield over two harvests for PD 2 and 5 were similar and greater than that of PD 3.

Spike Density

Spike density was not quantified in the 2003/2004 season. For the 2004/2005 spike density data, PD 5 was the only date which resulted in a significant difference in spike density among the different seeding rates (Figure 20). When spike densities were averaged over seeding rates for each planting date, mean density was greatest for PD 5, followed by PD 4. Planting date 3 had the third highest density, but was not different than PD 2. Planting date 2 was not greater than PD 1, while PD 6 spike density was significantly lower than all planting dates except for PD 1. This agrees with a study completed at Kansas State University where they found that earlier planted wheat produced more tillers resulting in more competition and lower grain yield (Thiry et al.,).

The same study also found that later planted wheat produced less tillers confirming that as planting date is delayed a higher seeding rate is needed to maximize yield.

For 2005/2006, spike density was similar among seeding rates within each planting date (Figure 21). Similar to the previous year, mean spike density was lowest for the latest planting date. In contrast, spike density for PD 1 was greater than PD 6 only. Low rainfall and soil water content across planting dates may have limited mean spike densities for all planting dates. Densities in 2005/2006 were roughly one half of those observed in 2004/2005. Spike density for the dual-purpose wheat was lower than the grain-only wheat which is consistent with previous research (Worrell et al., 1992).

A linear regression analysis was run to determine if spike density could predict grain yield (Figure 30). It was shown to have a positive affect with grain yield. Therefore, spike density can be used to estimate grain yield. This is consistent with previous research where bushel weight, spike density, and number of seeds per head were used in an equation to help estimate yield potential (Miller and Bean).

Grain Yields

Except for planting date 1, mean grain yield was similar among seeding rates during the 2003/2004 season (Figure 22). For PD 1, grain yields were lowest for the lowest seeding rate. When averaged over seeding rates, mean grain yield was greatest for PD 5, a planting date that yielded no forage during the first harvest. Mean yield was similar among PD 1, 2, and 6 and between PD 4 and 6, but was less for PD 4 than PD 5. Although forage harvests reduced grain yield compared to wheat harvested for gain only, the trend of yields over planting dates was similar between wheat managed for dual-purposes and wheat grown for grain only during the 2003/2004 (Figure 4 and 22).

Although wheat forage was harvested twice during the year of plentiful precipitation, grain yields were comparable to that of wheat grown for grain only over the six planting dates during 2004/2005 (Figure 5 and 23). Grain yield of dual-purpose wheat was less for the highest seeding and maximized at the 67 kg seed ha^{-1} on PD 1, but similar among seeding rates on the later PD. When averaged over seeding rates within each planting date, mean grain yields were highest for PD 5 and lowest for PD 6 (Figure 23). In addition, mean grain yields were similar between PD 1 and 2 and between PD 3 and 4, but less for PD 2 than PD 3 and 4. Although delayed planting reduced forage yield over PD 1 through 6, grain yield of dual-purpose wheat was not reduced until the latest planting date. Low temperature and the reduced duration of fall growth, rather than low precipitation, were associated with the substantially lower grain yield for dual-purpose wheat planted on the latest date.

For the 2005/2006 season, dual-purpose grain yields for the lowest seeding rate were less than those of one or more of the higher seeding rates on PD 1, 3, 5, and 6 (Figure 24). Except for PD 1, grain yield was similar among the seeding rates ranging from 67 to 135 kg seed ha^{-1} for PD 2 through 6. On PD 1, the lowest seeding rate, 34 kg ha^{-1} was significantly lower than the 101 kg/ha rate at 1523 kg ha^{-1}. There was no difference between the three highest seeding rates (67, 101, and 135 kg ha^{-1}) or between the 34 kg ha^{-1} and 101 kg ha^{-1} rate; however, both the 67 and 135 kg ha^{-1} rate were significantly higher than the 34 kg ha^{-1} rate at PD 5. The 67, 101, and 135 kg ha^{-1} were all significantly higher than the 34 kg ha^{-1} rate at PD 6.

Averaged over seeding rates for each planting date, mean dual-purpose grain yield was similar among PD 2, 4, and 5 in the 2005/2006 season (Figure 24). Similar to yields of wheat harvested for grain only, mean dual-purpose grain yield was lower for the earliest and latest planting dates than PD 2, 3, 4, and 5 under limited rainfall during 2005/2006 (Fig. 6 and Fig. 24). In addition, mean dual-purpose grain yield for PD 3 was lower than PD 4 and 5, but greater than PD 1 and 6. Variation of emergence date was not associated with variation of dual-purpose grain yield among planting dates. Wheat seeded on PD 1, PD 2, and PD 3 all emerged around the same time (Table 2). Likewise, PD 4, 5, and PD 6 emerged around the same time. Similar to previous years, the decline of mean air temperature following PD 6 constrained seedling growth and spike density compared to PD 1, 2, 3, 4, and 5.

Bushel Weights

Grain bushel weight was not significantly different among planting dates 1, 2, 3, 4, or 5 for the 2004/2005 season (Figure 25). Similar to dual-purpose grain yield, bushel weight for PD 6 was less than all other planting dates. Grain bushel weight is largely correlated with growing conditions after anthesis (Darwinkel et al., 2002). Planting dates 1 through 5 experienced abundant rainfall and good growing conditions. Planting date 6, which was planted in mid-December, had lower tiller numbers than earlier planting dates. As reported by Darwinkel et. al. (1993), the grain-filling period for early planted wheat is long and results in high test weights, In contrast, the grain-filling period for late-planted wheat is shorter and results in low test weights.

Limited precipitation during 2005/2006 limited dual-purpose bushel weight for PD 1 through 5 compared to the previous year. Similar to Darwinkel et al. (1977), the reduction in test weight could have resulted from increased abiotic stress, high temperatures, compared to the earlier planted wheat. Although similar to the mean bushel weight for PD 6 during 2005, bushel weight for PD 6 was greater than all other planting dates for dual-purpose grain during the 2005/2006 season (Figure 26). Bushel weights for PD 2, 3, 4, and 5 were not different. Planting date 1 yield was lower than PD 2 and 6 but was not different when compared to PD 3, 4, or 5. The latest planting date near the end of November could have increased plant available water during grain maturation compared to earlier planted wheat. Additionally, April temperatures were above average while May temperatures were below average and PD 6 may have avoided some heat stress that earlier planting did not avoid.

Based on the 2004/2005 and 2005/2006 bushel weight data, a linear regression analysis was run to determine if bushel weight could predict grain yield (Figure 32). When combining both seasons, a significant positive correlation existed between bushel weight and grain yield. Therefore, bushel weight can be used to estimate grain yield. This is consistent with previous research where bushel weight, spike density, and number of seeds per head were used in an equation to help estimate yield potential (Miller and Bean).

Lodging

Lodging ratings were low and similar among the six planting dates for the 2004/2005 season (Figure 27). Lodging was much more severe for the 2005/2006 season compared to the 2004/2005 season, as there were two storms that produced very high winds. Lodging was similar and greatest on PD 1 and 5. Lodging ratings were reduced 50% and similar on PD 2, 4, and 6 compared to PD 1 and 5. Below average rainfall for the months of September through February and April through June during were not sufficient to balance evapotranspiration and could have contributed to high mean lodging ratings and variation among planting dates in 2005/2006. This long-term water stress and lack of turgor pressure weakened plants and led to higher lodging (Cooke and Veseth, 1991).

Conclusion

The 3 yr of data show similar yield trends over planting dates for yield of wheat harvested for grain only. Yields increased from PD 1 to PD 4 or 5 and then decreased at PD 6. This agrees with Winters & Musick (1993) that planting early results in deeper rooting and greater soil water extraction in the fall, but reduces grain yield as most of the soil water is used prior to the critical spring growth period. Later planted wheat does not use as much soil water since water use is delayed from fall to spring which lowers yield. The late-October to early-November planting dates yielded the highest due to the fact that soil water is used prior to the initiation of rapid spring growth, but sufficient stored soil water remains to supplement precipitation during anthesis and grain fill. The optimal date for a dual-purpose system ranged from September 5 to September 24 which agrees with findings by Hossain et al. 2003.

This study, when seeding rate was averaged over all planting dates, showed that there was no significant difference among the 67, 101, or 135 kg ha^{-1} rate. Thus, lowering the seeding rate is just one management strategy that can be used to help cut input cost.

Grain bushel weights were higher for the 2005 harvest, as rainfall was much higher during the growing season compared to the 2006 harvest. Higher rainfall results in more available water in the soil profile, which leads to more water moving from the roots to the stems and out through the leaves, resulting in higher yields (Cook and Veseth, 1991).

Lodging for dual-purpose wheat was lower than the grain-only wheat due the fact that forage harvests reduced disease incidence and damage to the plant. Also, forage harvests reduced the height of dual-purpose compared to the grain-only wheat.

Planting date was more important than the seeding rate decision for maximizing forage and grain yields in a dual-use system. Forage yield was maximized at the earlier planting dates and declined as planting date was delayed for the first harvest. This agrees with previous research where it was found that forage yields were maximized when planted before October 8^{th} (Hossain et al. 2003). Forage yield for the second harvest was maximized at the mid-planting dates. Seeding rates varied in results, but overall seeding rates above 67 kg ha^{-1} maximized forage yields. The earlier planted wheat at a mid to high seeding rate, maximized forage in a dual-use system.

With so many factors to consider when implementing a dual-use wheat system, weather forecasts needs to be considered to help determine if planting early and grazing of livestock for dual-purpose wheat are preferred late planted wheat harvested for grain only.

CHAPTER IV

CONCLUSIONS

Overall conclusions for this study resulted in little to no significant difference among the various seeding rates for forage or grain yield. Planting date was found to be the most important management decision that producers and researchers need to make to maximize production. Forage yields were maximized when planted prior to October at the 67 kg ha^{-1} rate, while grain yields for both the dual-purpose and grain-only wheat were maximized when planted from mid-October to early-November at the lower seeding rates.

Grain bushel weights were higher for the 2005 harvest, as rainfall was much higher during the growing season compared to the 2006 harvest. Higher rainfall resulted in more available water in the soil profile, which lead to more transpiration and resulted in higher yields (Cook and Veseth, 1991).

Lodging for dual-purpose wheat was lower than the grain-only wheat due the fact that forage harvests reduced disease symptoms and damage to the plant. Also, forage harvests reduced the height of dual-purpose compared to the grain-only wheat.

Spike density was related to planting date for both grain-only and dual-purpose wheat and was higher at PD 4 and PD 5 for the 2004/2005 season. The 2005/2006 season resulted in lower spike density as planting date was delayed. Spike density also showed to be a good predictor for grain yield for both the grain-only and dual-purpose plots (Figure 29 & 30).

For both the grain-only and dual-purpose wheat yields, it was determined that both bushel weight and spike density could be used to estimate wheat yield potential.

Spike density was also shown to some degree, to help in estimating bushel weight potential (Figure 33 & 34). These results are further evidence that plant growth is a complex system that works together to achieve an end product of grain. Each component of the system is affected in one way or another by another component.

The 3 yr of data show similar yield trends over planting dates for yield of wheat harvested for grain only. Yields increased from PD 1 to PD 4 or 5 and then decreased at PD 6. This agrees with Winters & Musick (1993) that planting early results in deeper rooting and greater soil water extraction in the fall, but reduces grain yield as most of the soil water is used prior to the critical spring growth period. Later planted wheat does not use as much soil water since water use is delayed from fall to spring which lowers yield. The late-October to early-November planting dates yielded the highest due to the fact that soil water is used prior to the initiation of rapid spring growth, but sufficient stored soil water remains to supplement precipitation during anthesis and grain fill.

Precipitation, in most cases, is the most limiting factor to plant growth and development in dryland crops. This was evident in this study as the 2005/2006 season did not yield as high as the previous two seasons and yields were not significantly different at any planting date. As weather prediction models continue to be developed and became more accurate producers and researchers alike will be able to make better decisions on when to plant.

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APPENDIX A

Table 1. Planting dates for 2003-2005 at McGregor, TX.

Variable	2003	2004	2005
Planting date 1	09 Sept.	08 Sept.	05 Sept.
Planting date 2	24 Sept.	21 Sept.	19 Sept.
Planting date 3	NA	11 Oct.	03 Oct.
Planting date 4	22 Oct.	20 Oct.	17 Oct.
Planting date 5	13 Nov.	10 Nov.	03 Nov.
Planting date 6	25 Nov.	14 Dec.	14 Nov.

Table 2. Approximate emergence date (within 7days) and soil temperatures at planting for planting dates during 2003 through 2005.

Planting Date	Emergence Date	Soil Temp °C
9/9/03	9/14/03	18
9/24/03	10/05/03	20
NP		
10/22/03	11/02/03	22
11/13/03	11/24/03	17
11/25/03	12/12/03	15
9/06/04	9/13/04	26.7
9/21/04	10/02/04	26.1
10/11/04	10/22/04	25
10/20/04	10/29/04	26.7
11/10/04	11/17/04	21.1
12/14/04	12/23/04	10
9/05/05	10/08/05	27.8
9/19/05	10/08/05	29.4
10/03/05	10/10/05	29.4
10/17/05	11/06/05	15.6
11/03/05	11/29/05	13.3
11/14/05	11/29/05	22.2

***NP refers to not planted**

Table 3. Grain harvest dates for all three seasons at McGregor, TX.

Harvest	2004	2005	2006
Grain & DP	28 May	6 June	5 June

Table 4. Dual-purpose forage harvest dates for all three seasons at McGregor, TX.

Harvest Date	2003-04 McGregor	2004-05 McGregor	2005-06 McGregor
HD 1	12 December	21 December	16 February
HD 2	19 February	15 February	15 March

Table 5. Forage Quality from 2nd cutting March 15, 2006.

Planting Date	Crop	%CP	ADF%	TDN%	DAP
1	Wheat	18.9	38.2	62.2	191
1	Wheat	17.9	39.8	60.1	191
3	Wheat	18	39.2	60.9	163
3	Wheat	17.7	44.7	53.4	163
5	Wheat	20.9	42.6	56.2	132
5	Wheat	20	41.7	57.5	132

*DAP = Days After Planting

APPENDIX B

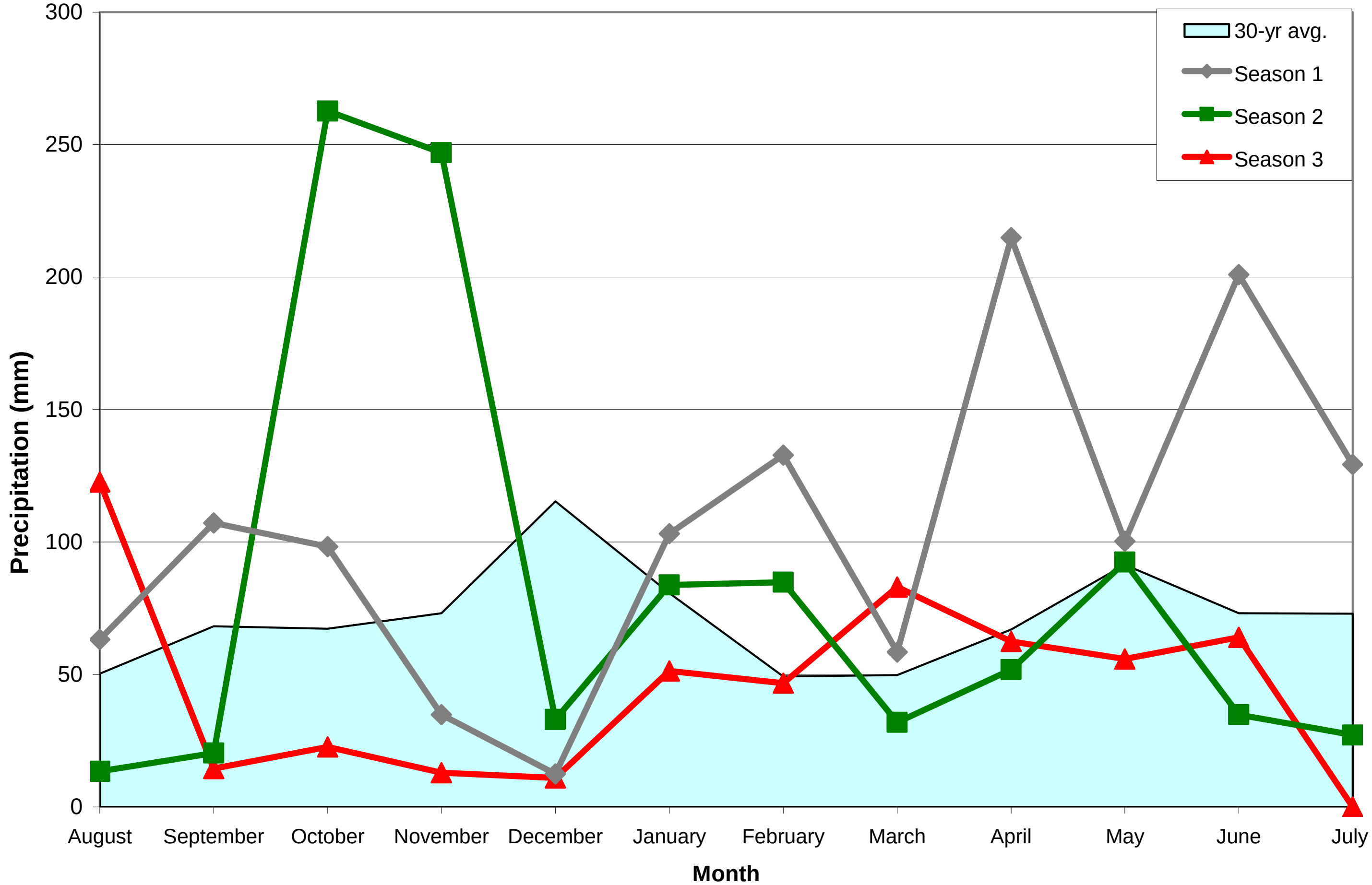

Fig. 1. Rainfall data for McLennan County. Season 1 starts at August 2003 and ends with July 2004. Season 2 starts at August 2004 and ends with July 2005. Season 3 starts with August 2005 and ends with July 2006. Points that fall in the shaded area are below the 30-yr average and points above the shaded area are above the 30-yr average.

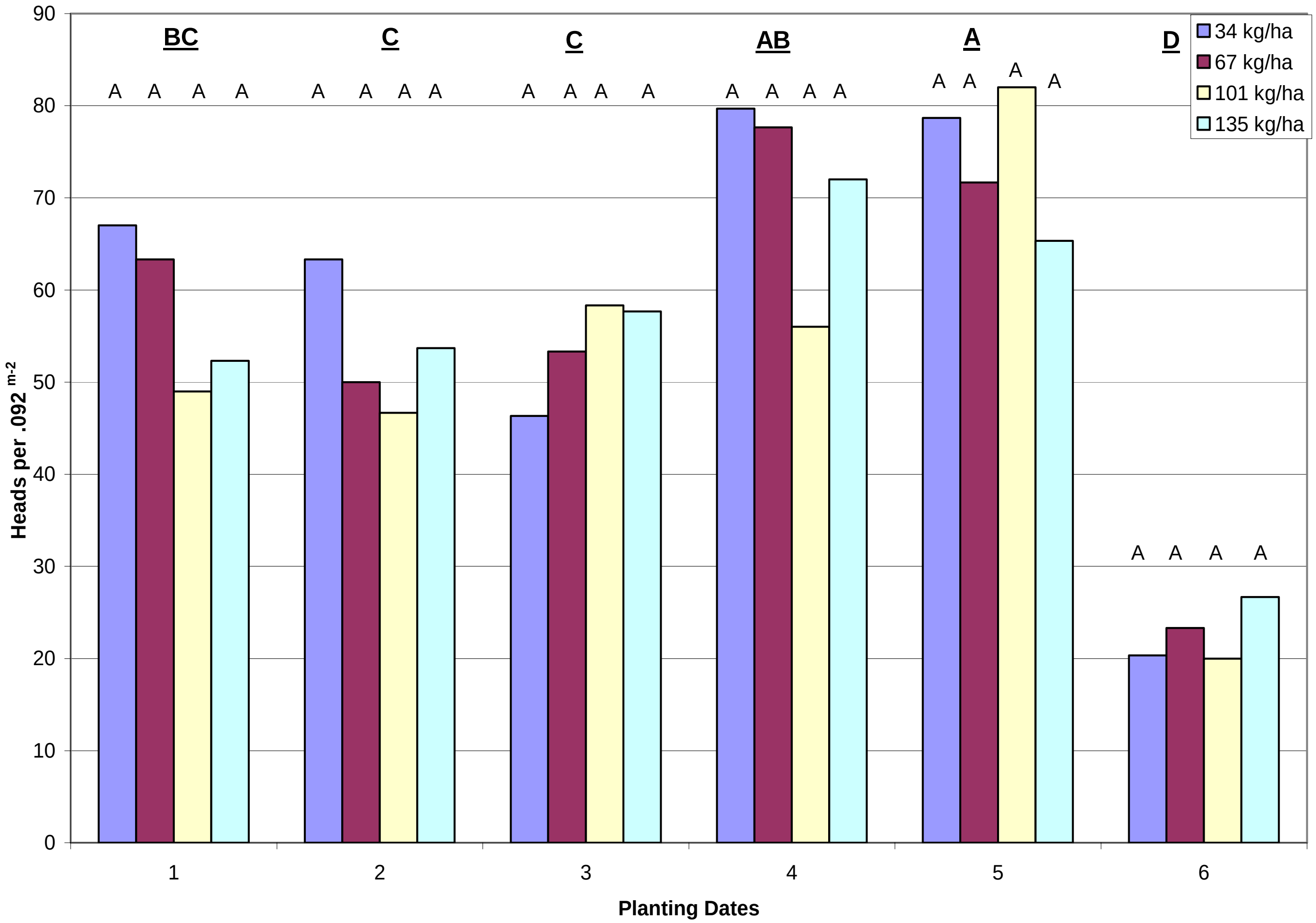

Fig. 2. Spike density for grain-only wheat for the six planting dates in the 2004/2005 season at McGregor, TX . Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Bold underlined letters represent the average of all seeding rates at that planting date. Planting 1= 09/08/04, Planting 2 = 09/21/04, Planting 3 = 10/11/04, Planting 4 = 10/20/04, Planting 5 =11/10/04, and Planting 6 = 12/14/04.

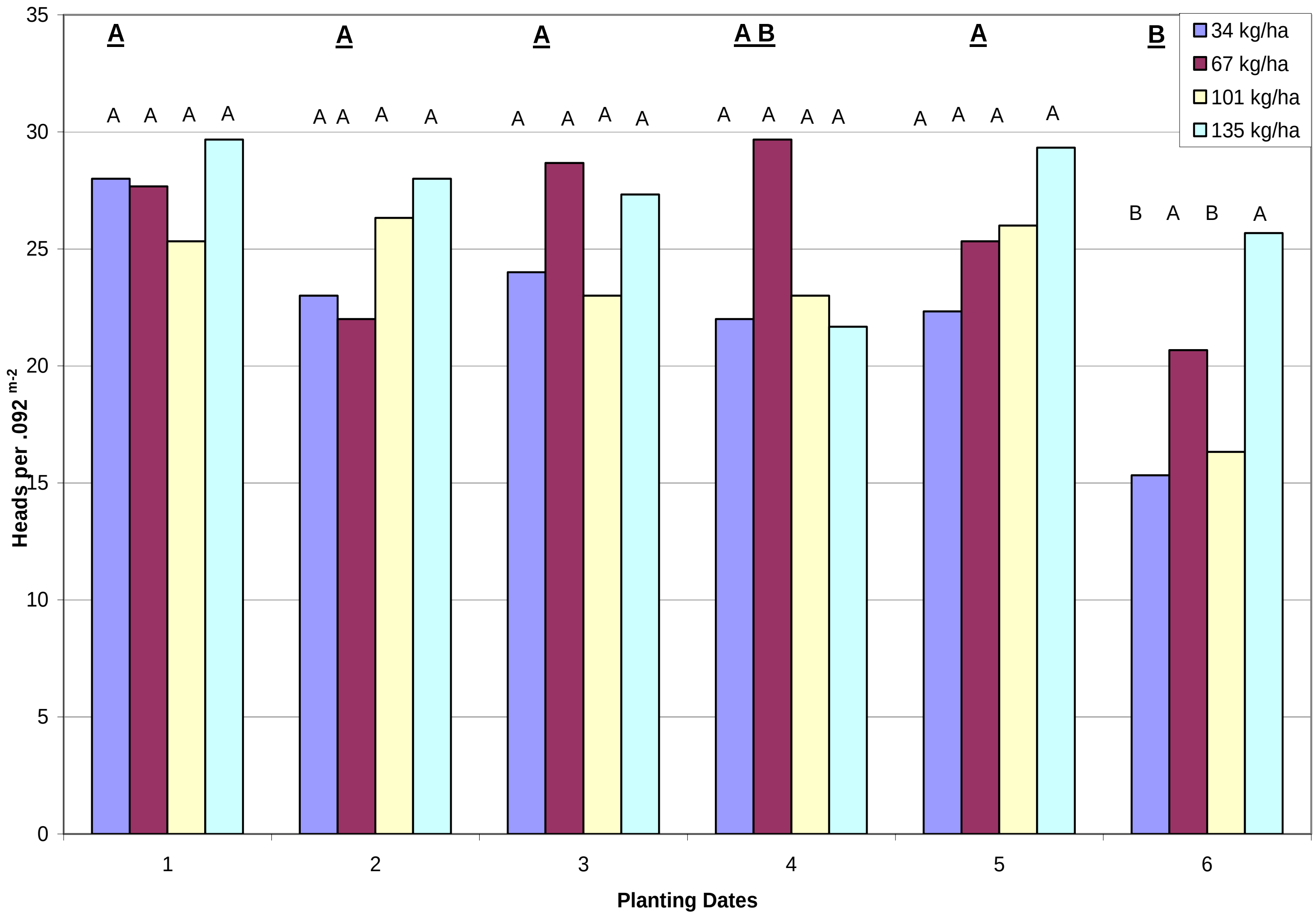

Fig.3. Spike density for grain-only wheat for the six planting dates in the 2005/2006 season at McGregor, TX . Bars with identical letters within a planting date are not significantly different according to Fisher's LSD ($P<0.05$). Bold underlined letters represent the average of all seeding rates at that planting date. Planting 1 = 09/05/05. Planting 2 = 09/19/05. Planting 3 = 10/03/05, Planting 4 = 10/17/05, Planting 5 = 11/03/05, and Planting 6 = 11/14/05.

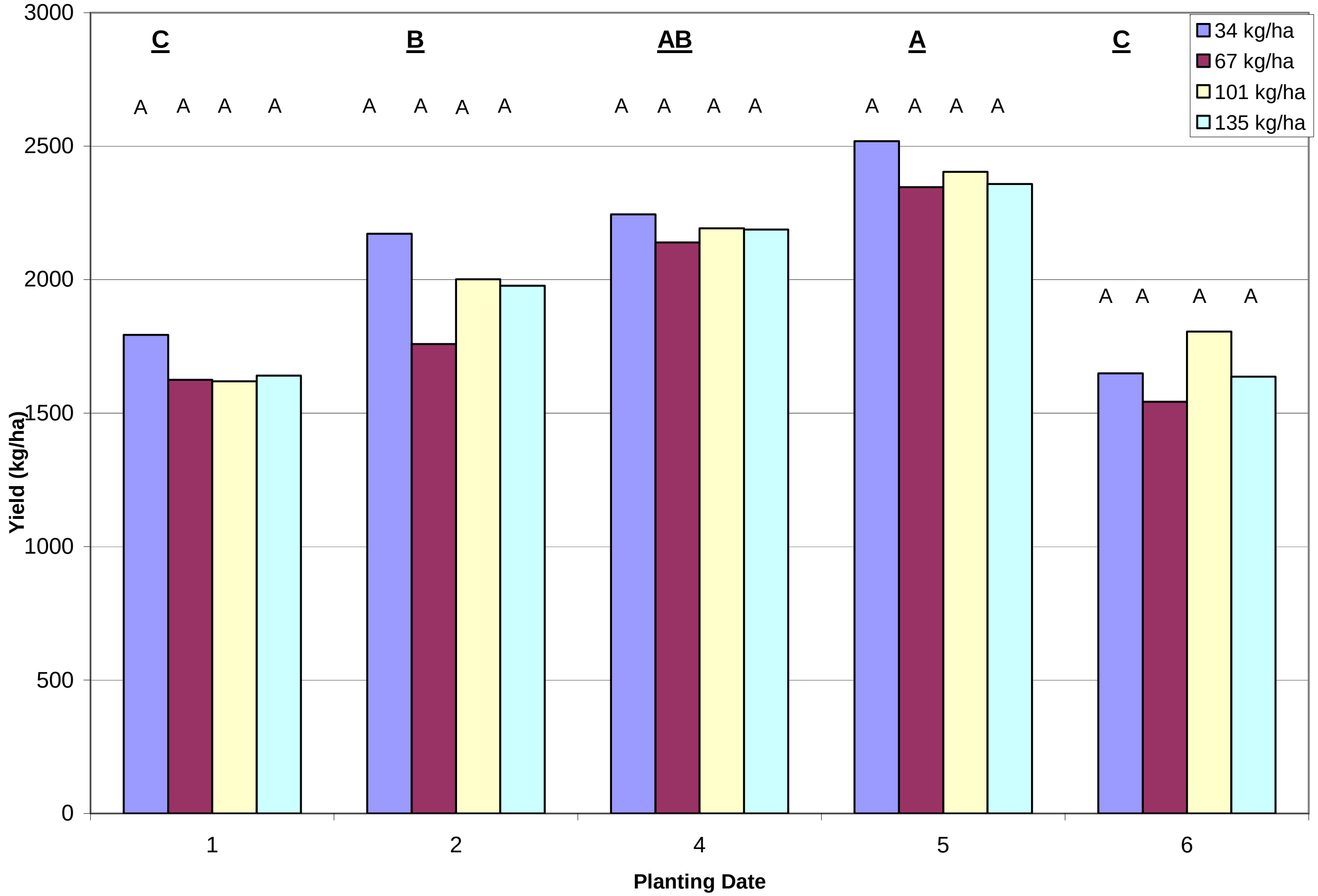

Fig. 4. The impact of seeding rate and planting date on grain yields for the grain-only crop at McGregor, TX in 2003/2004. Bold underlined letters represent planting date comparison. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Planting 1 = 09/09/03, Planting 2 = 09/24/03, Planting 3 = NA, Planting 4 = 10/22/03, Planting 5 = 11/13/03, and Planting 6 = 11/25/03.

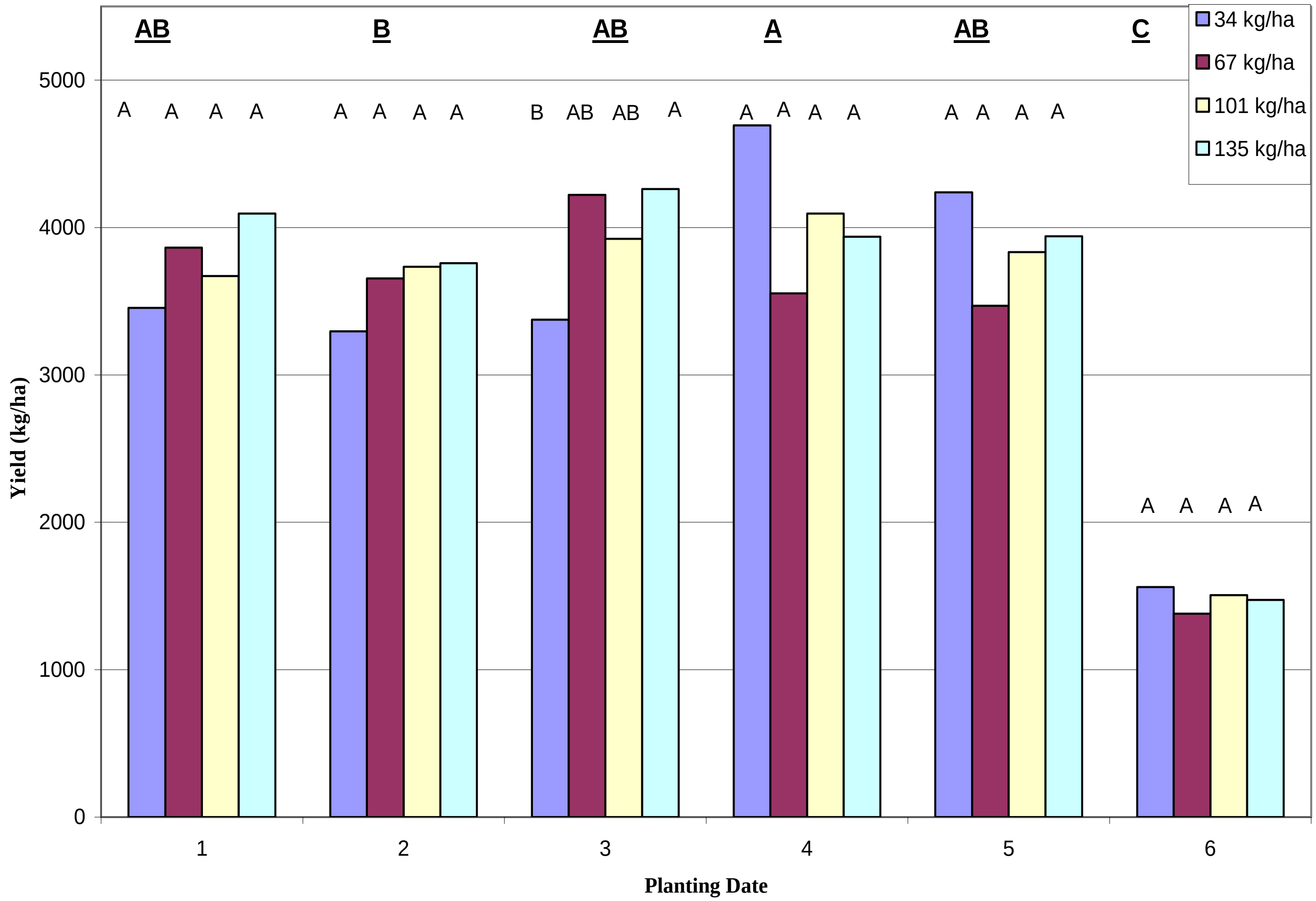

Fig. 5. The impact of seeding rate and planting date on grain yields for the grain-only crop at McGregor, TX in 2004/2005. Bold underlined letters represent the comparison among planting dates. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Planting 1= 09/08/04, Planting 2 = 09/21/04, Planting 3 = 10/11/04, Planting 4 = 10/20/04, Planting 5 =11/10/04, and Planting 6 = 12/14/04.

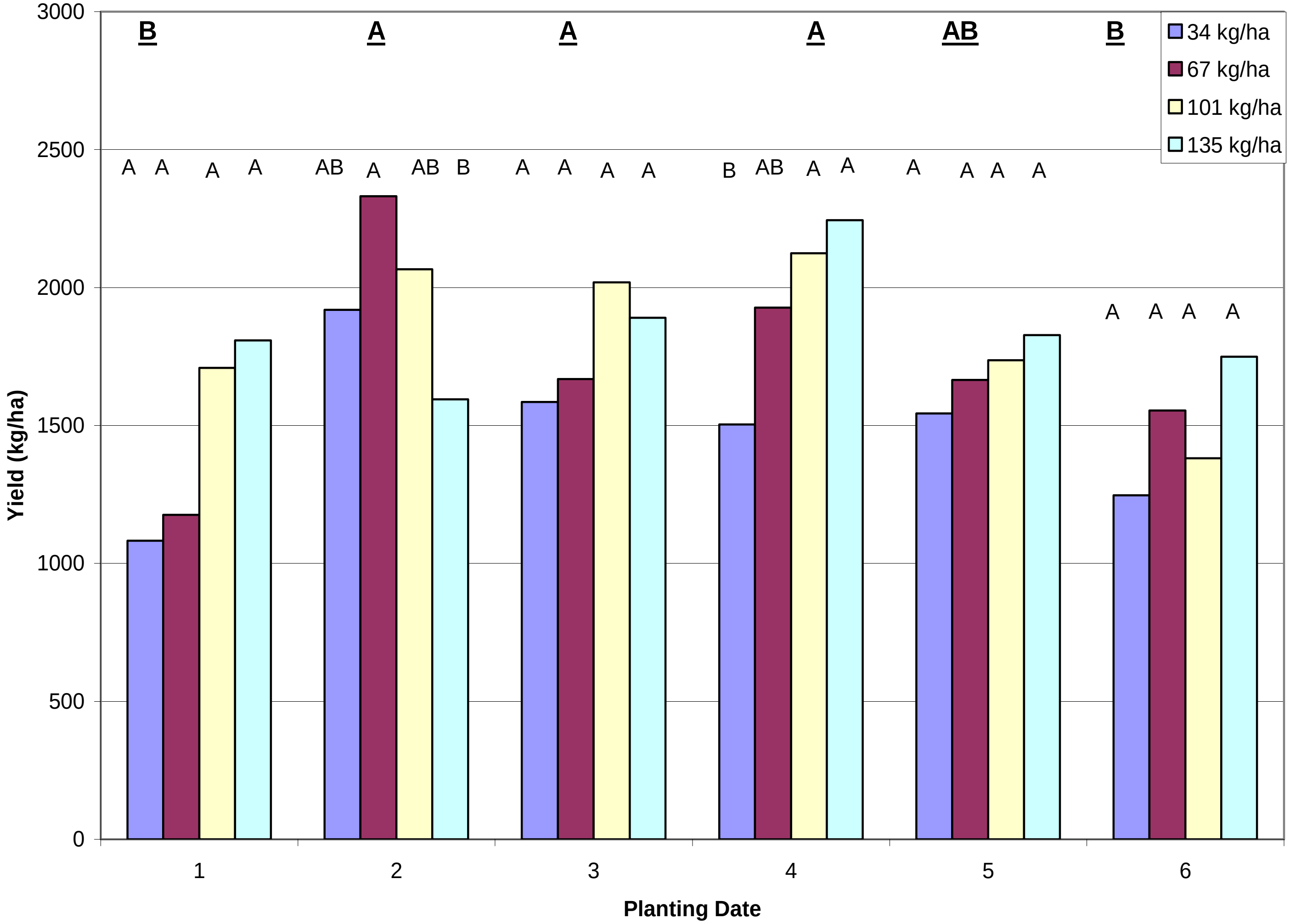

Fig. 6. The impact of seeding rate and planting date on grain yields for the grain-only crop at McGregor, TX in 2005/2006. Bold underlined letters represent the comparision among planting dates. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Planting 1 = 09/05/05, Planting 2 = 09/19/05, Planting 3 = 10/03/05, Planting 4 = 10/17/05, Planting 5 = 11/03/05, and Planting 6 = 11/14/05.

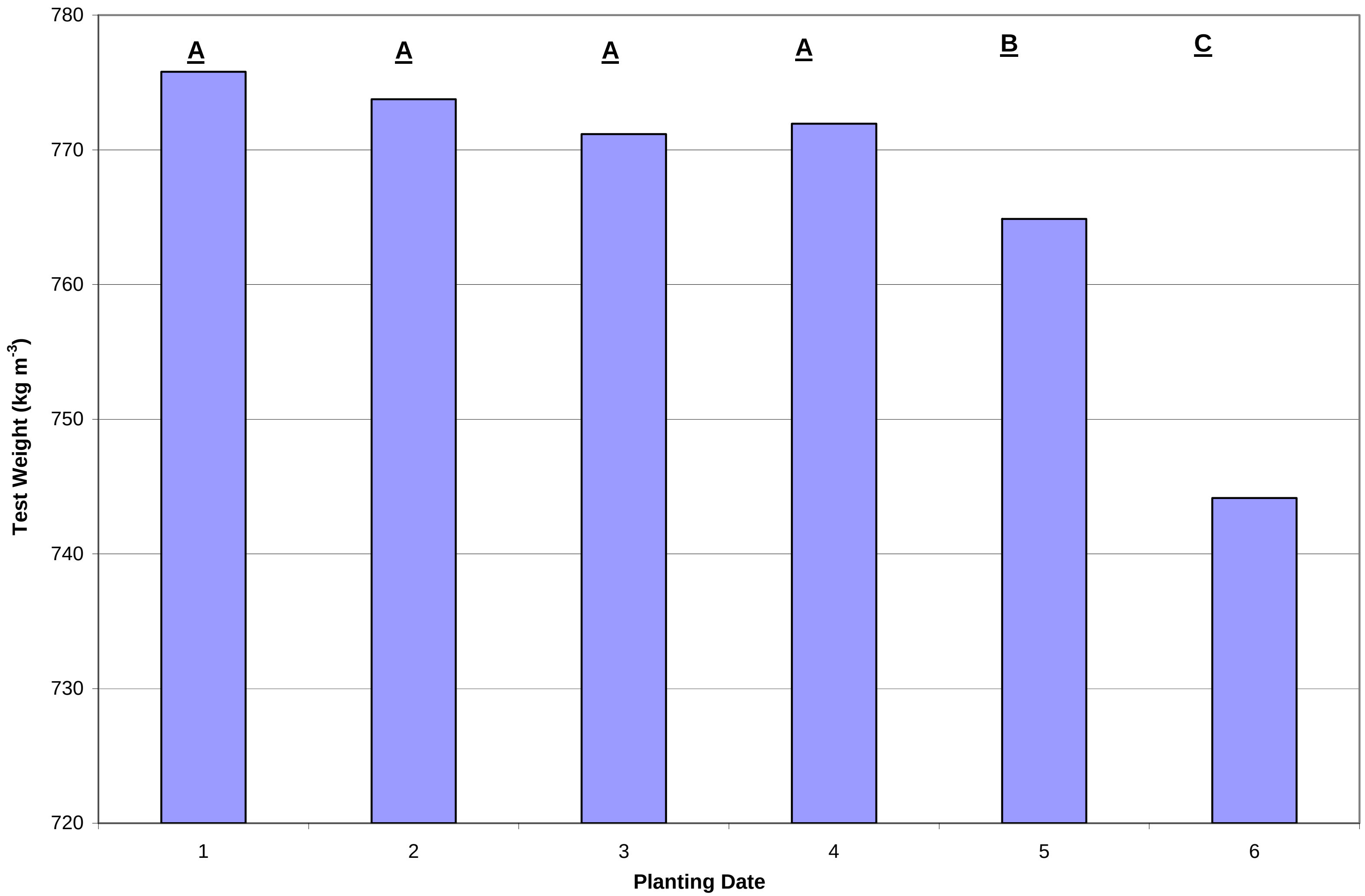

Fig. 7. McGregor 2005 bushel weights for grain-only wheat when seeding rates were averaged at each planting date. Bars with identical letters are not significantly different based on Fishers LSD (P<0.05). Planting 1= 09/08/04, Planting 2 = 09/21/04, Planting 3 = 10/11/04, Planting 4 = 10/20/04, Planting 5 =11/10/04, and Planting 6 = 12/14/04.

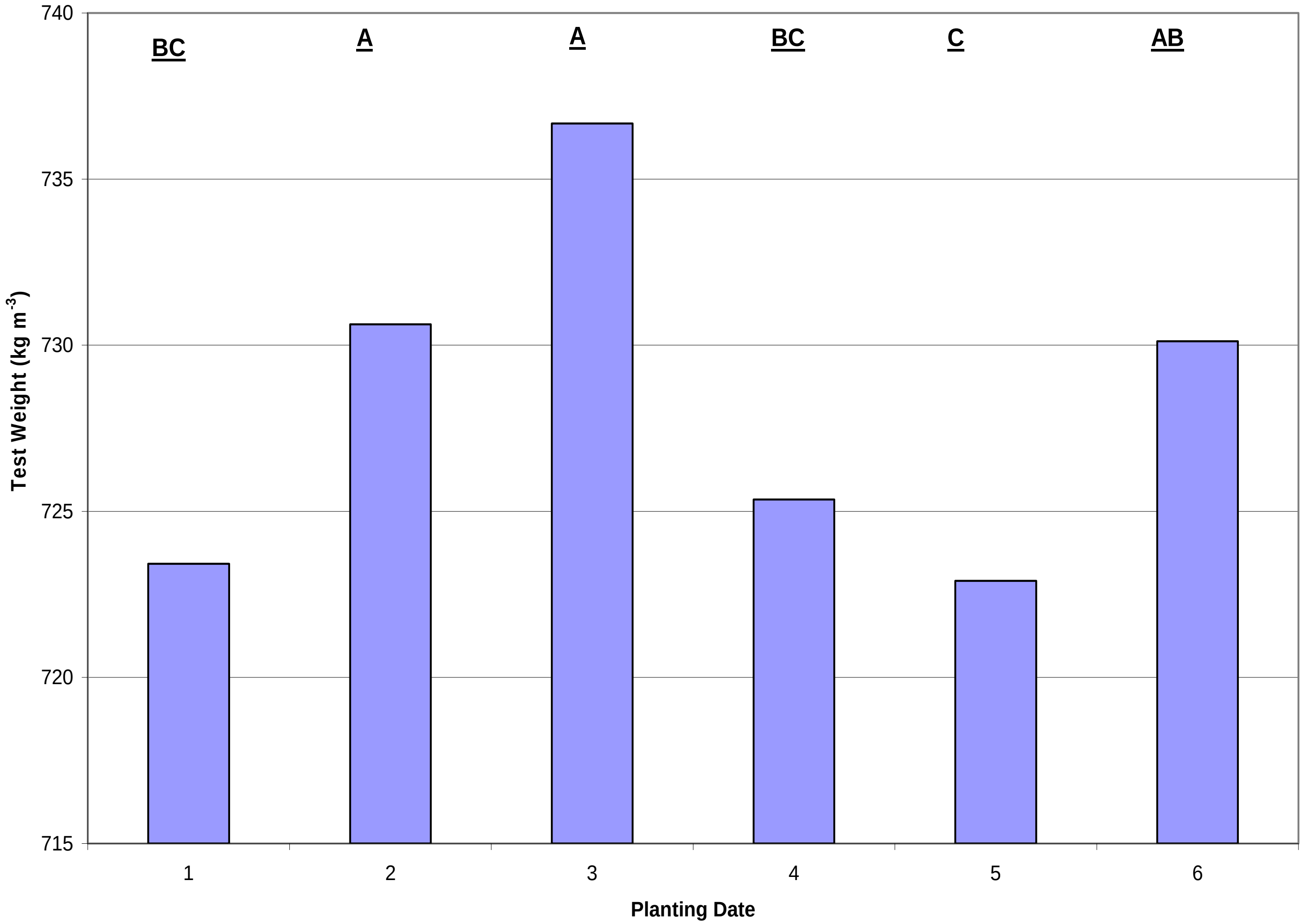

Fig. 8. McGregor 2006 bushel weight for grain-only wheat when averaged over seeding rates for each planting date. Bars with identical letters not significantly different according to Fisher's LSD (P<0.05). Planting 1 = 09/05/05, Planting 2 = 09/19/05, Planting 3 = 10/03/05, Planting 4 = 10/17/05, Planting 5 = 11/03/05, and Planting 6 = 11/14/05.

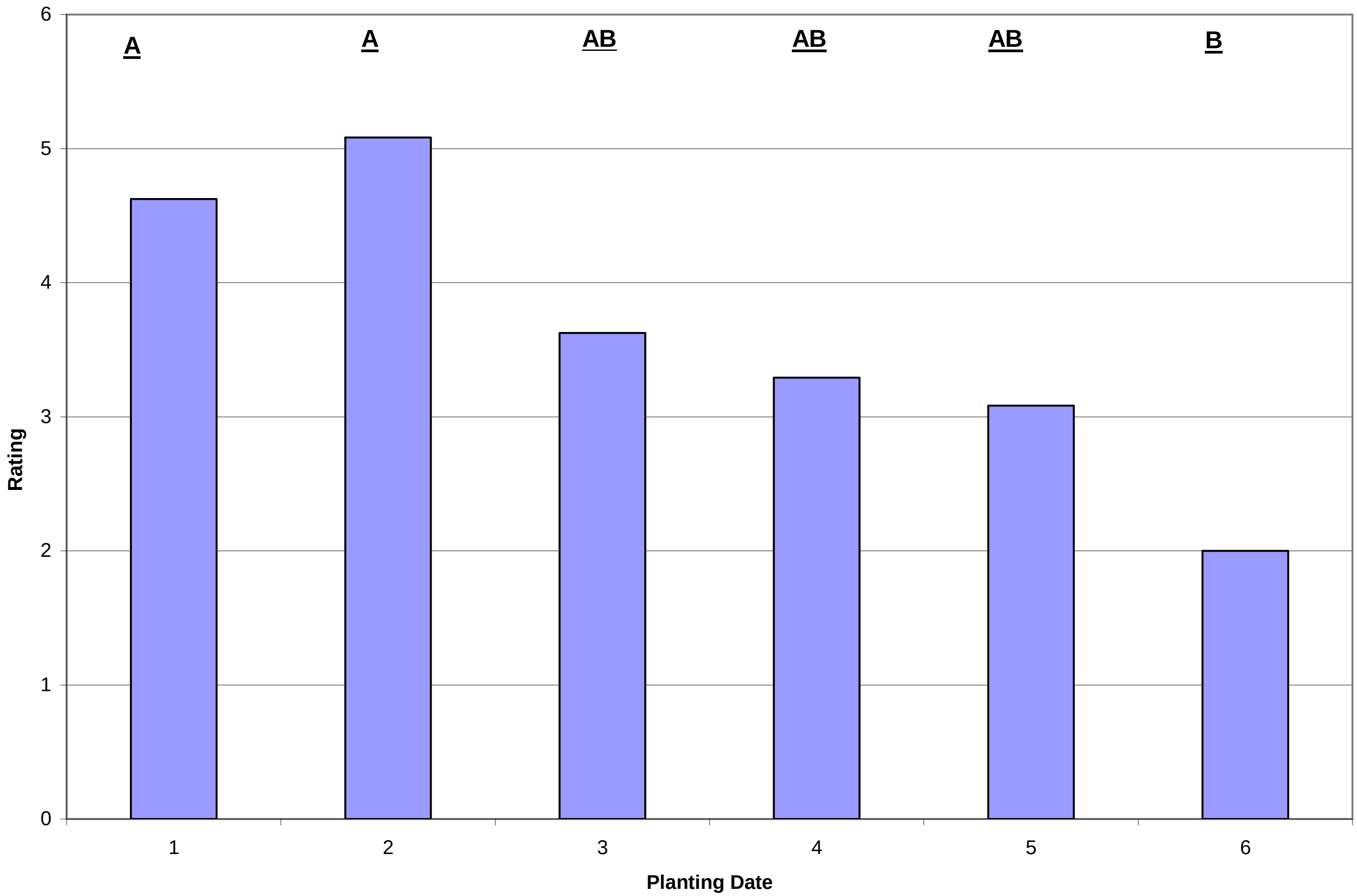

Fig. 9. McGregor 2005 lodging ratings for grain-only wheat when averaged over seeding rates at each planting date. Visual lodging rating for grain-only wheat (0 = no lodging, 10 = entire plot on ground). Bars with identical letters are not significantly different based on Fishers LSD (P<0.05). Planting 1= 09/08/04, Planting 2 = 09/21/04, Planting 3 = 10/11/04, Planting 4 = 10/20/04, Planting 5 =11/10/04, and Planting 6 = 12/14/04.

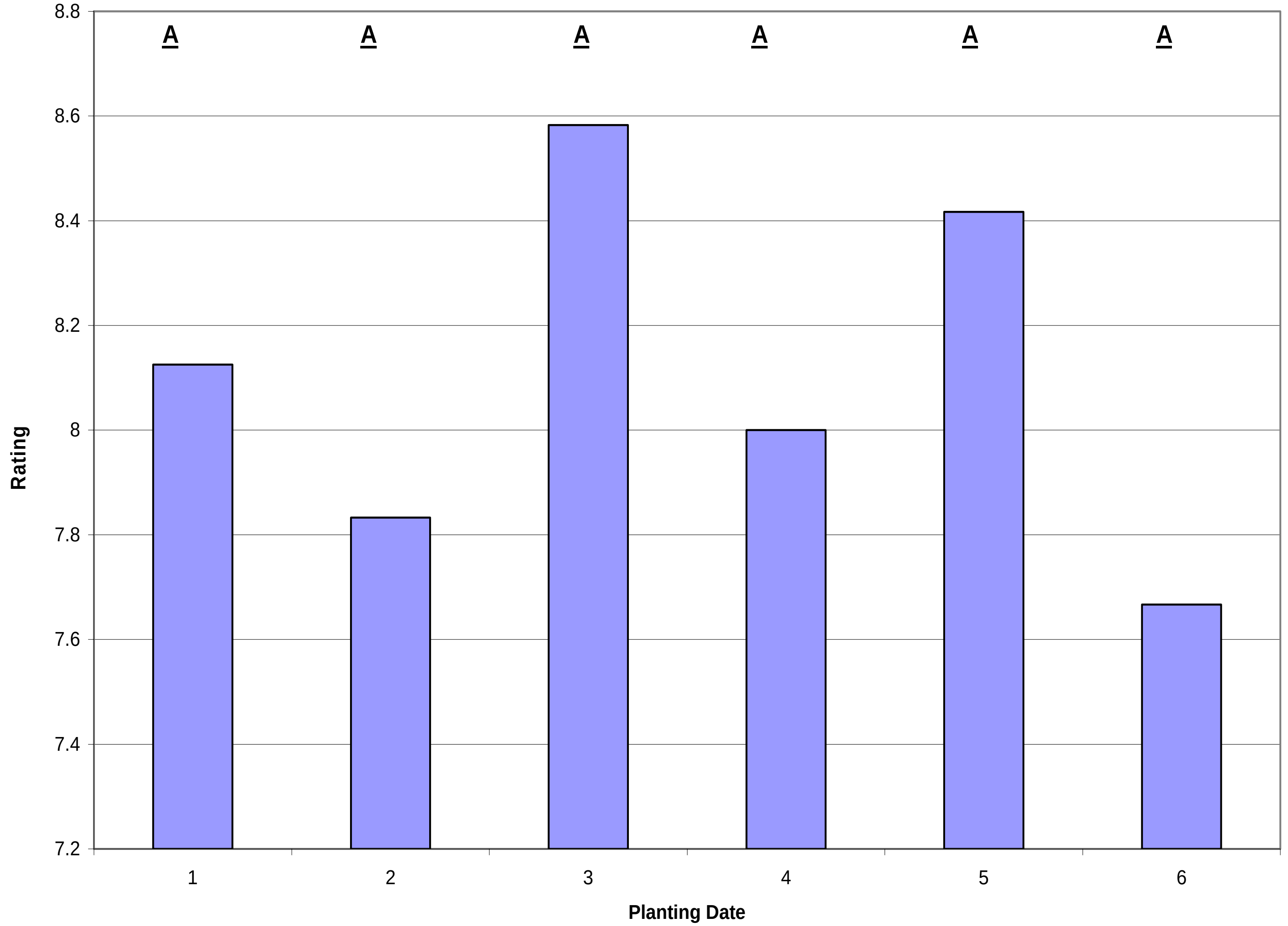

Fig. 10. McGregor 2006 lodging ratings for grain-only wheat when averaged over seeding rates for each planting date. Visual lodging rating for grain-only wheat (0 = no lodging, 10 = entire plot on ground). Bars with identical letters not significantly different according to Fisher's LSD ($p<0.05$). Planting 1 = 09/05/05, Planting 2 = 09/19/05, Planting 3 = 10/03/05, Planting 4 = 10/17/05, Planting 5 = 11/03/05, and Planting 6 = 11/14/05.

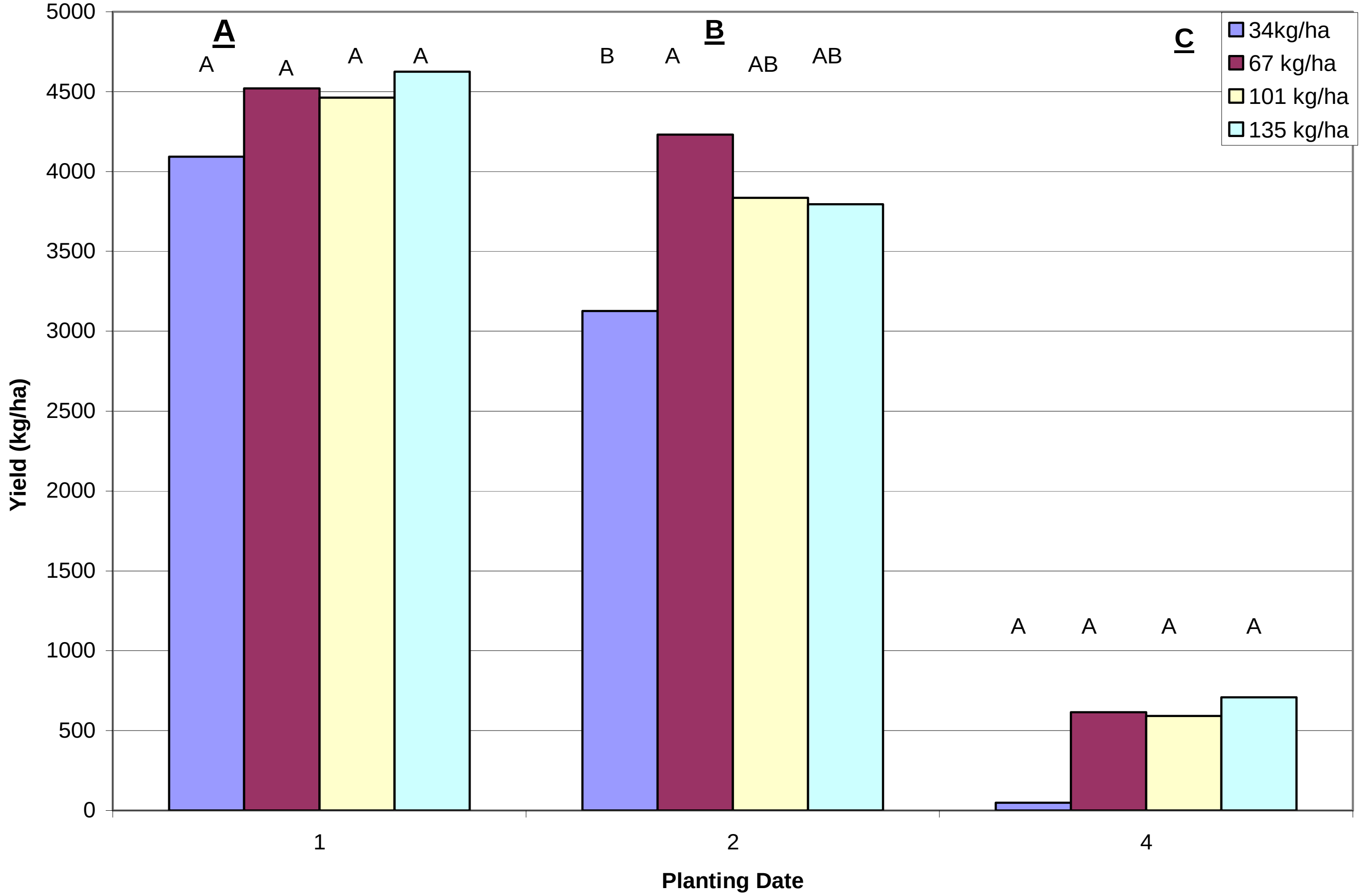

Fig. 11. McGregor dual-purpose first forage harvest for the 2003/2004 season (12 December 2003). Yields are mean for each seeding rate within a particular planting date. Bold underlined letters represent mean separation among planting dates. Bars with identical letters within within and among planting dates are not significantly different according to Fisher's LSD (P<0.05). Planting 1 = 09/09/03, Planting 2 = 09/24/03, Planting 3 = NA, and Planting 4 = 10/22/03.

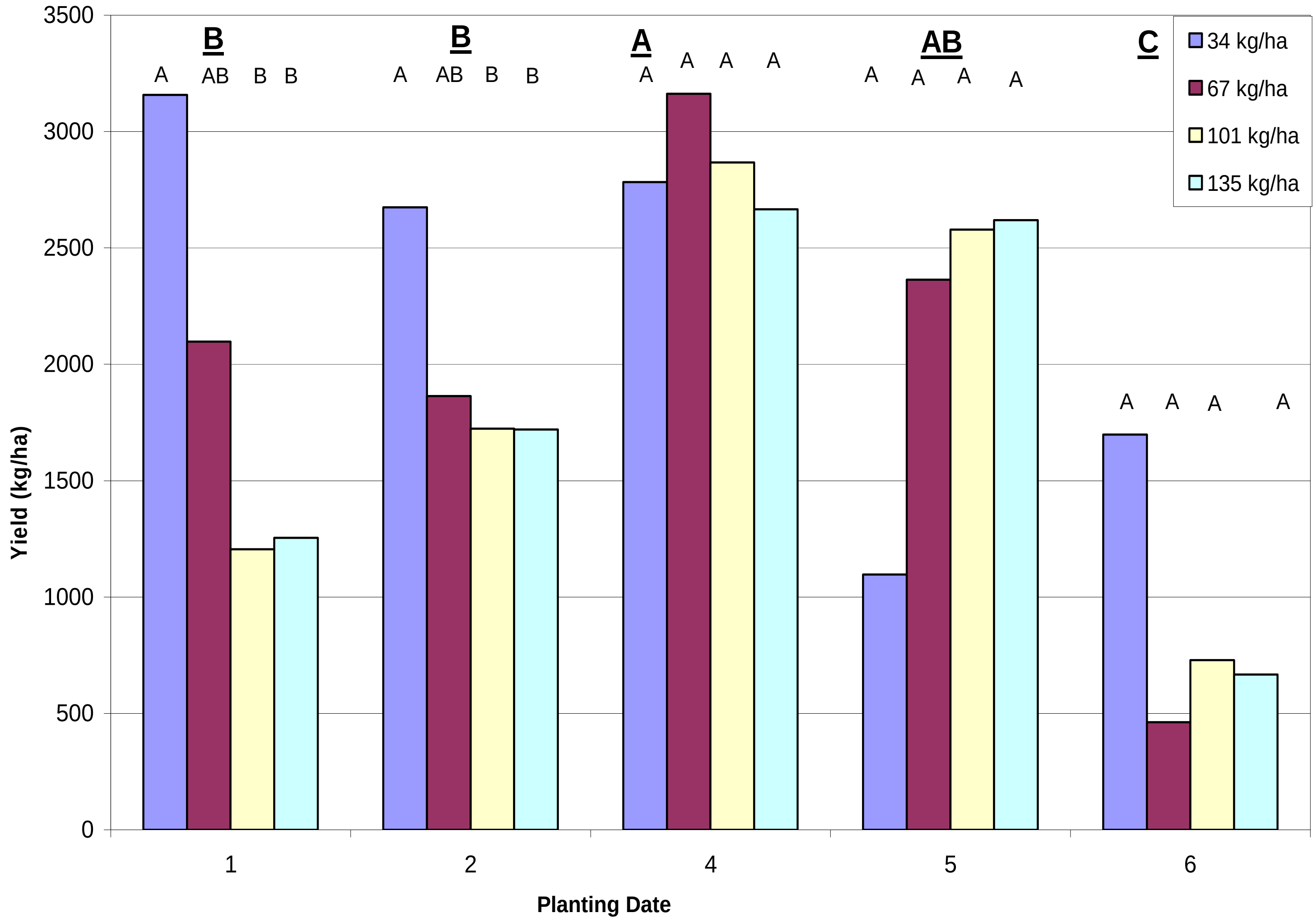

Fig. 12. Second forage harvest of dual-purpose wheat at McGregor for the 2003/2004 season (19 February 2004).Yields are means for seeding rates within a particular planting date. Bold underlined letters represent mean separation among planting dates. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05)). Planting 1 = 09/09/03, Planting 2 = 09/24/03, Planting 3 = NA, Planting 4 = 10/22/03, Planting 5 = 11/13/03, and Planting 6 = 11/25/03.

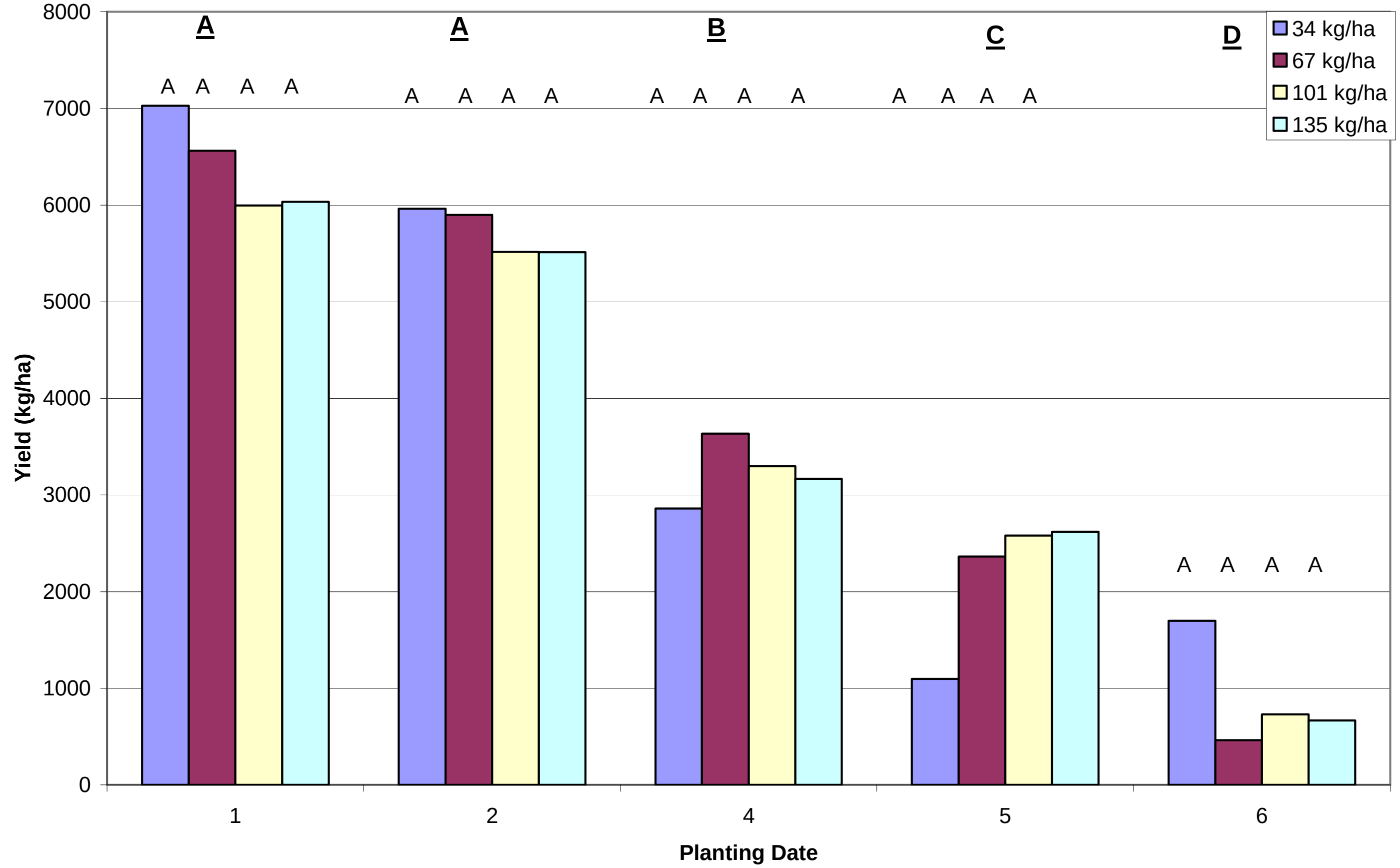

Fig. 13. McGregor total forage yields for dual-purpose wheat during 2003/2004 season. Yields are means for seeding rates within a particular planting date. Bold underlined letters represent mean separations among planting dates. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05)). Planting 1 = 09/09/03, Planting 2 = 09/24/03, Planting 3 = NA, Planting 4 = 10/22/03, Planting 5 = 11/13/03, and Planting 6 = 11/25/03.

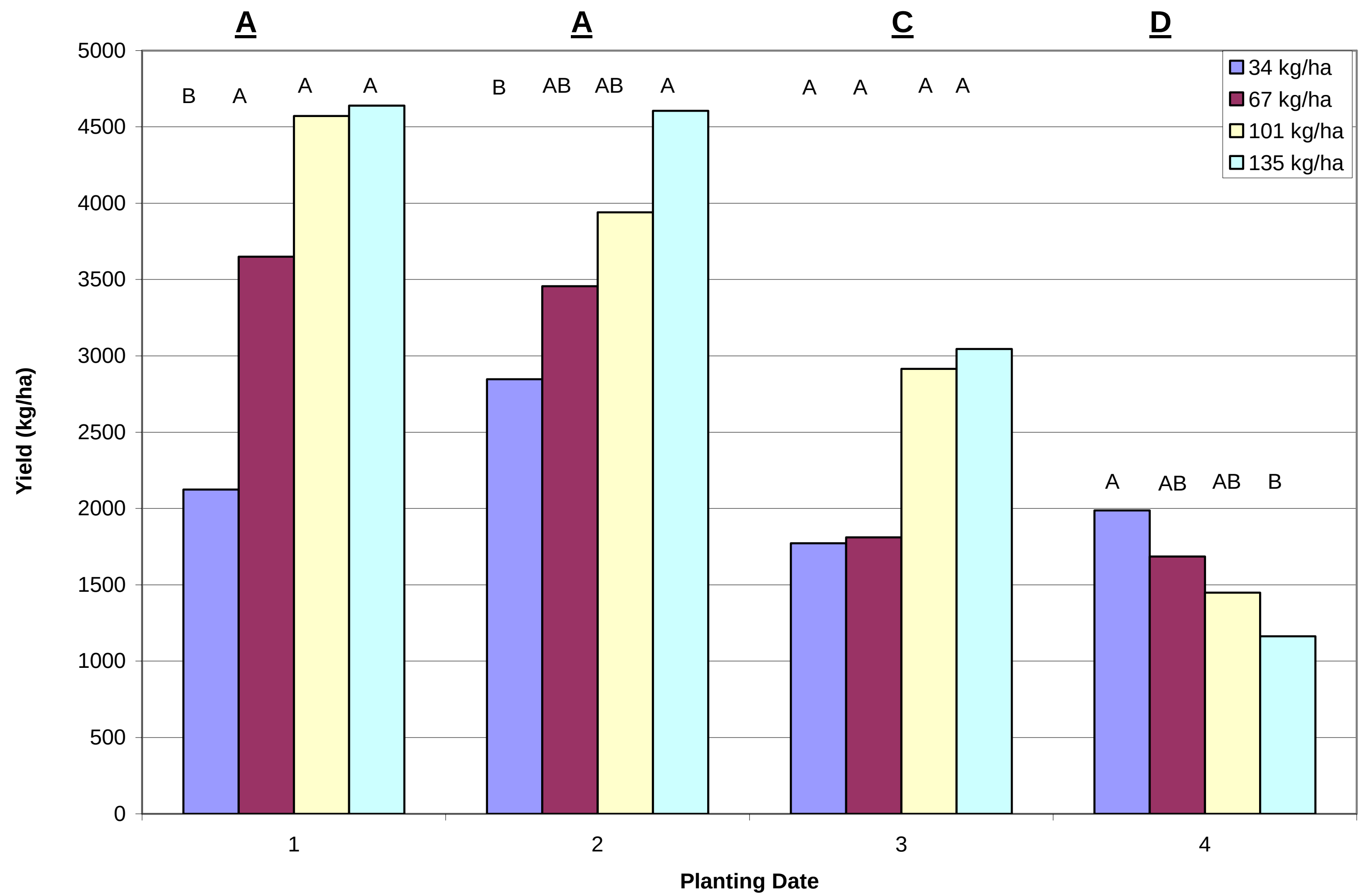

Fig. 14. McGregor dual-purpose first forage harvest for the 2004/2005 season (21 December 2004). Yields are means for seeding rates within a particular planting date. Bold underlined letters represent mean separations between planting dates. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Planting 1= 09/08/04, Planting 2 = 09/21/04, Planting 3 = 10/11/04, Planting 4 = 10/20/04, Planting 5 =11/10/04. and Planting 6 = 12/14/04.

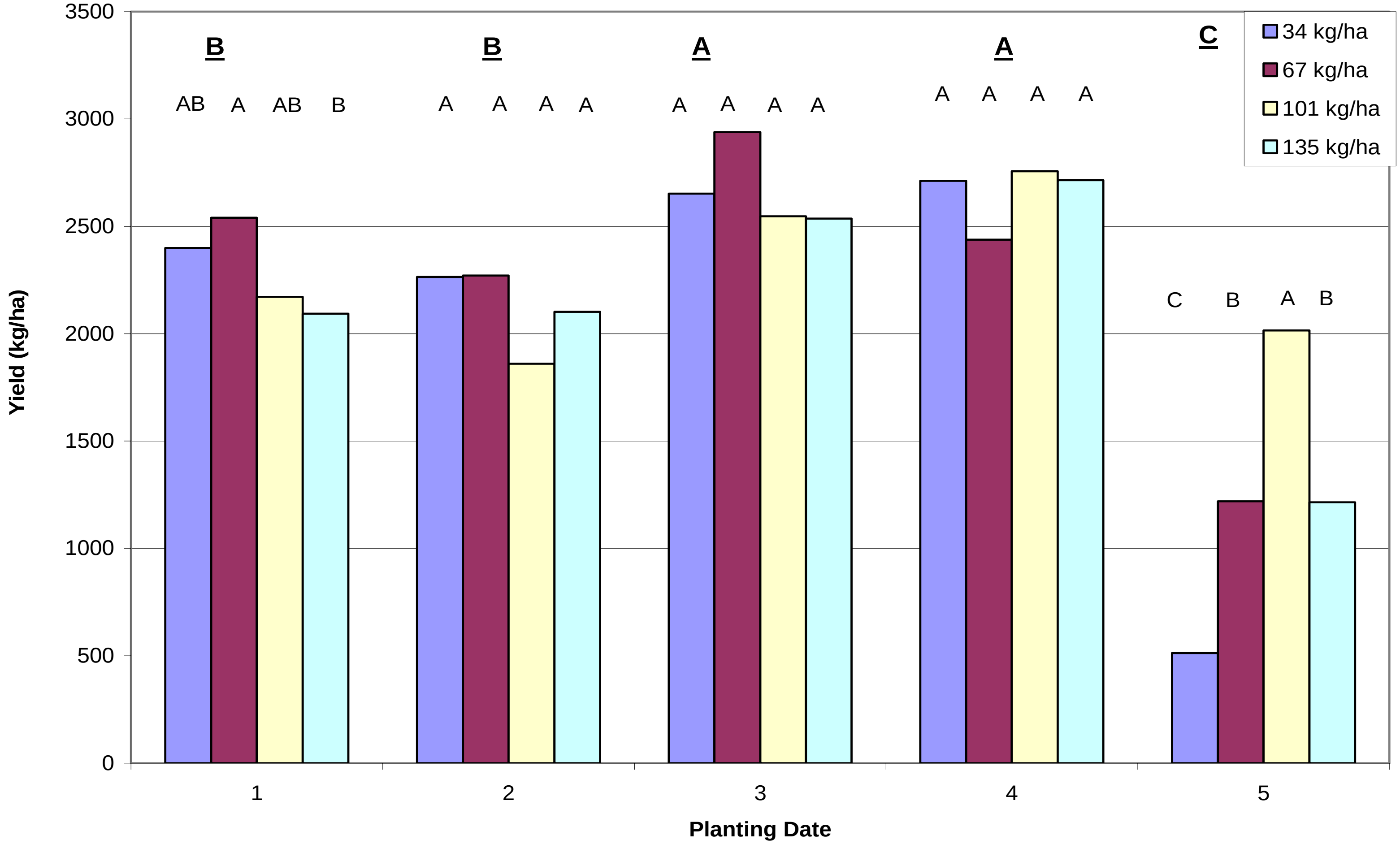

Fig. 15. McGregor dual-purpose second forage harvest for the 2004/2005 season (15 February 2005). Yields are means for seeding rates within a particular planting date. Bold underlined letters represent mean separations among planting dates. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Planting 1= 09/08/04, Planting 2 = 09/21/04, Planting 3 = 10/11/04, Planting 4 = 10/20/04, Planting 5 =11/10/04, and Planting 6 = 12/14/04.

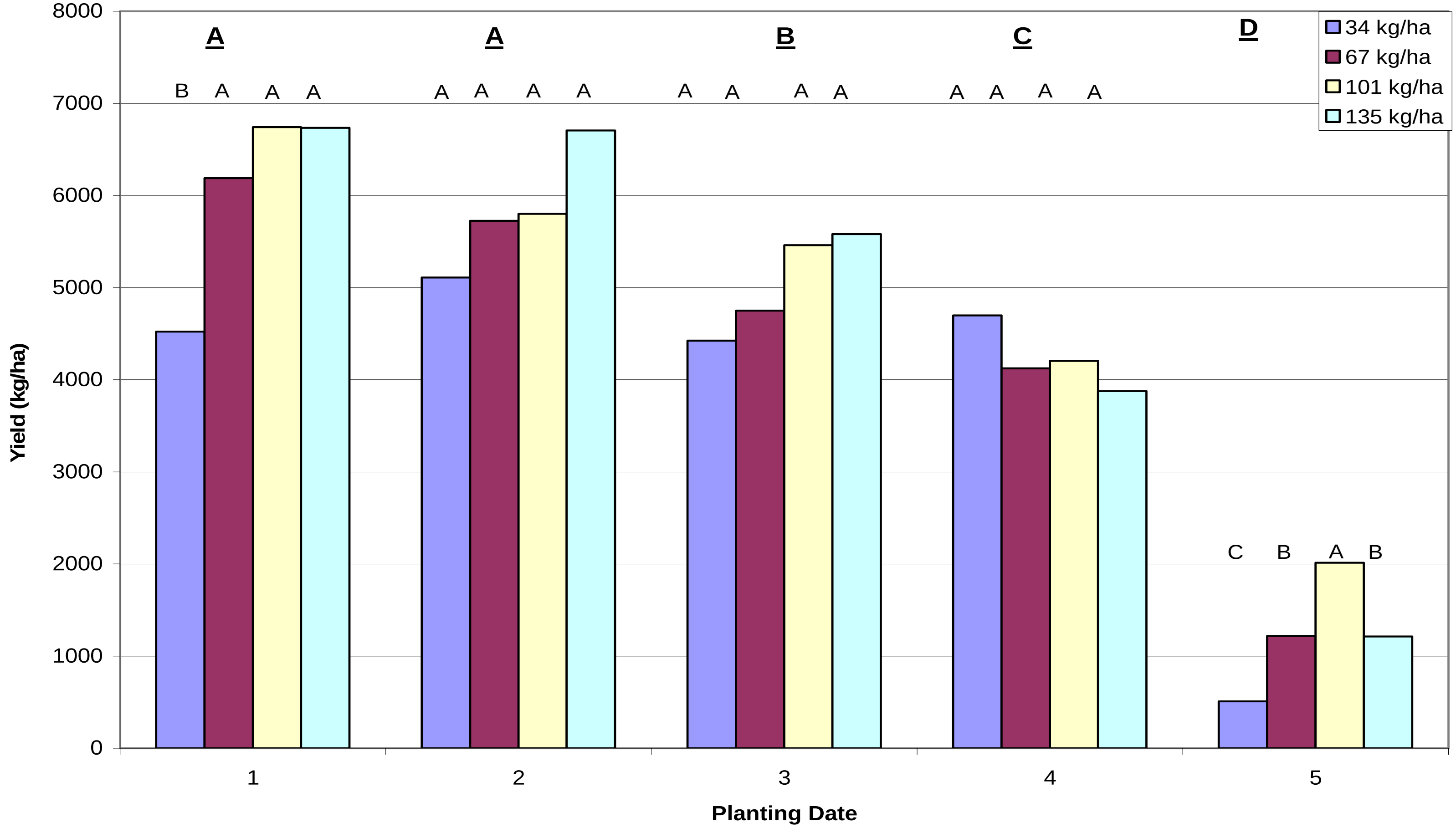

Fig. 16. McGregor forage yields summed over two harvest dates for the 2004/2005 season. Yields are means for earch seeding rate within a particular planting date. Bold underlined letters represent mean separations among planting dates. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Planting 1= 09/08/04, Planting 2 = 09/21/04, Planting 3 = 10/11/04, Planting 4 = 10/20/04, Planting 5 =11/10/04, and Planting 6 = 12/14/04.

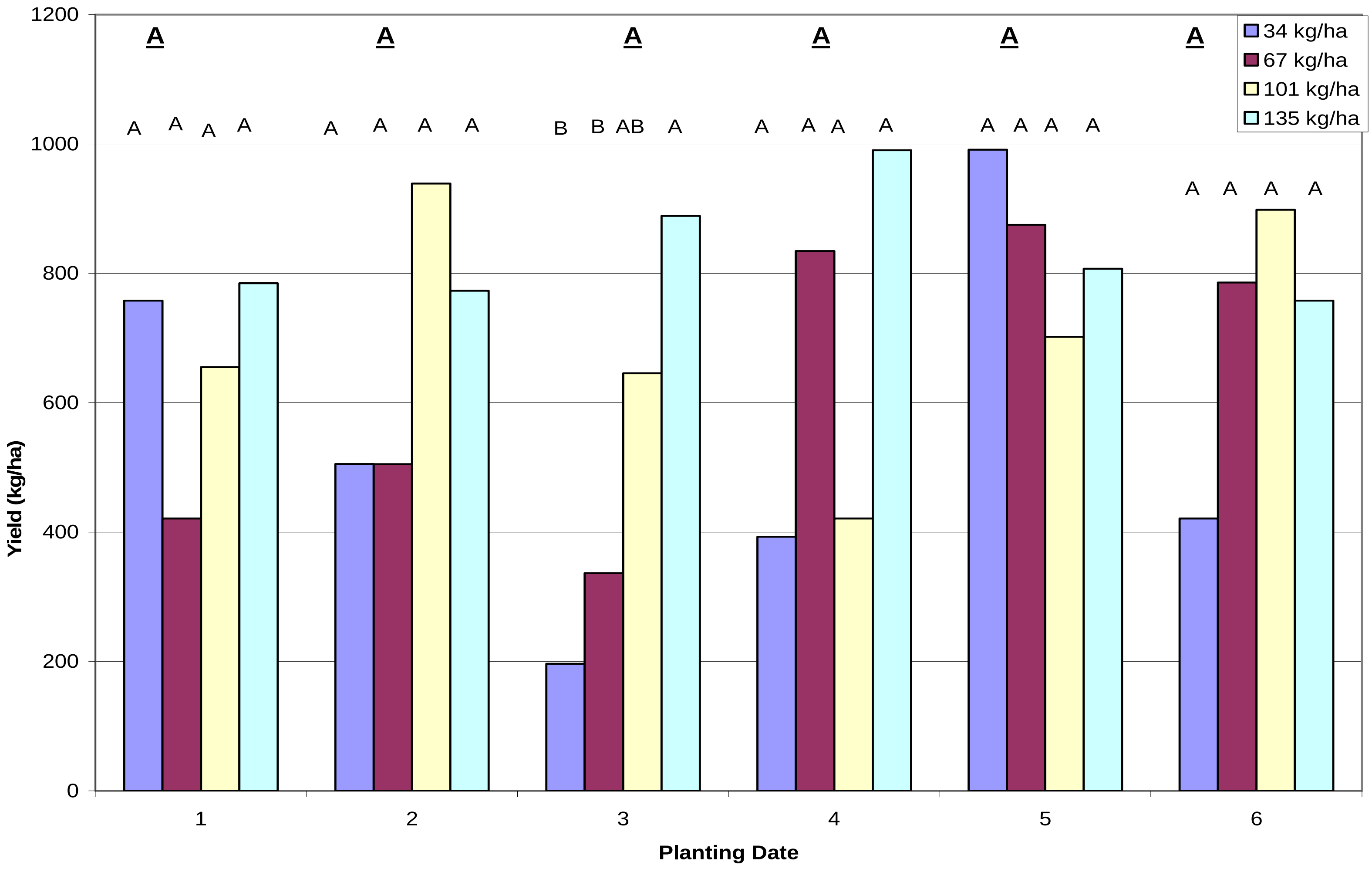

Fig. 17. McGregor dual-purpose first forage harvest for the 2005/2006 season (16 February 2006).Yields represent means for each seeding rate within a particular planting date. Bold underlined letters represent mean separations among planting dates. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P,0.05). Planting 1 = 09/05/05, Planting 2 = 09/19/05, Planting 3 = 10/03/05, Planting 4 = 10/17/05, Planting 5 = 11/03/05, and Planting 6 = 11/14/05.

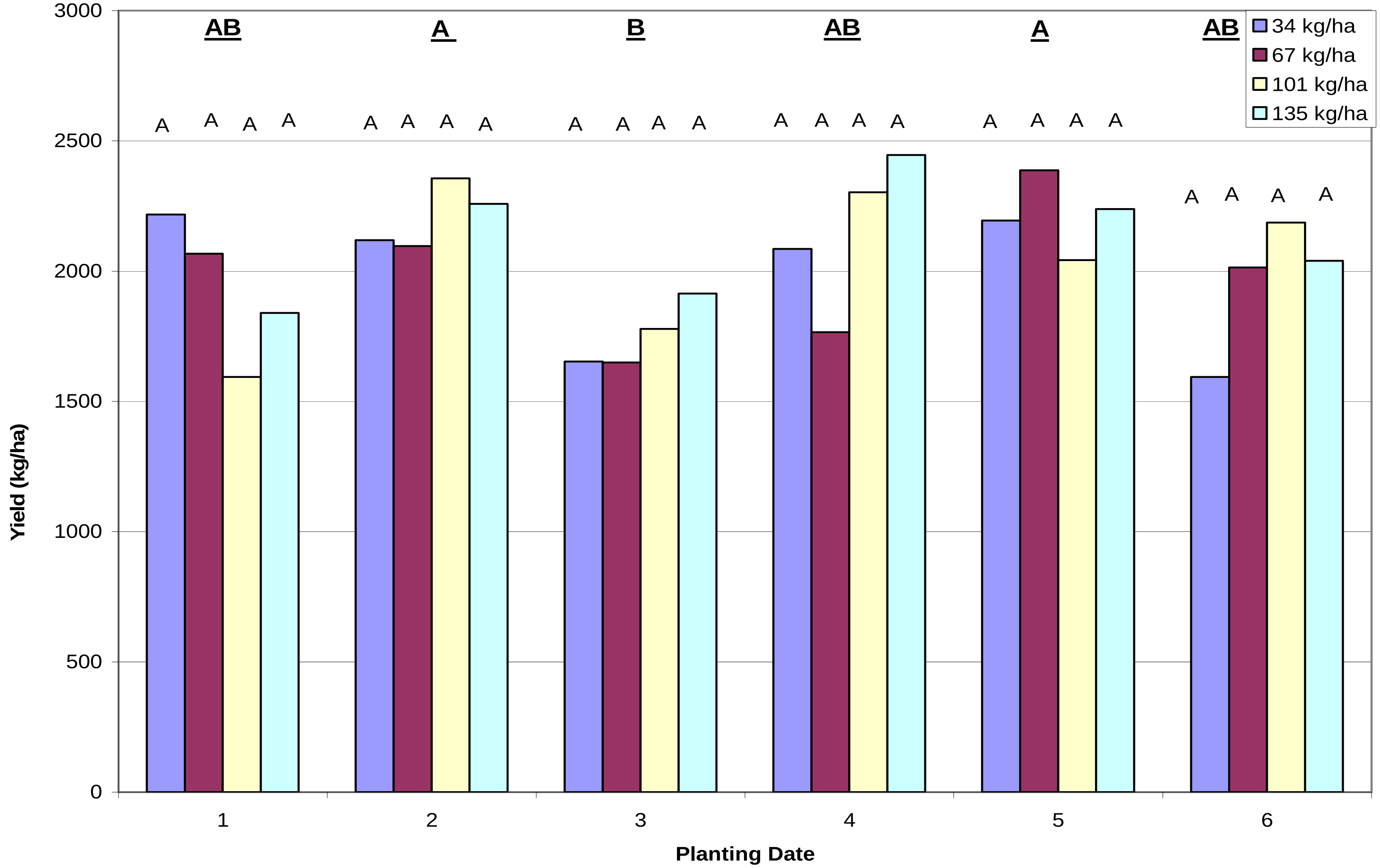

Fig. 18. McGregor dual-purpose second forage harvest for the 2005/2006 season (15 March 2006).Yields are means for each seeding rates within a particular planting date. Bold underlined letters represent mean separations among planting dates. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Planting 1 = 09/05/05, Planting 2 = 09/19/05 Planting, 3 = 10/03/05, Planting 4 = 10/17/05, Planting 5 = 11/03/05, and Planting 6 = 11/14/05.

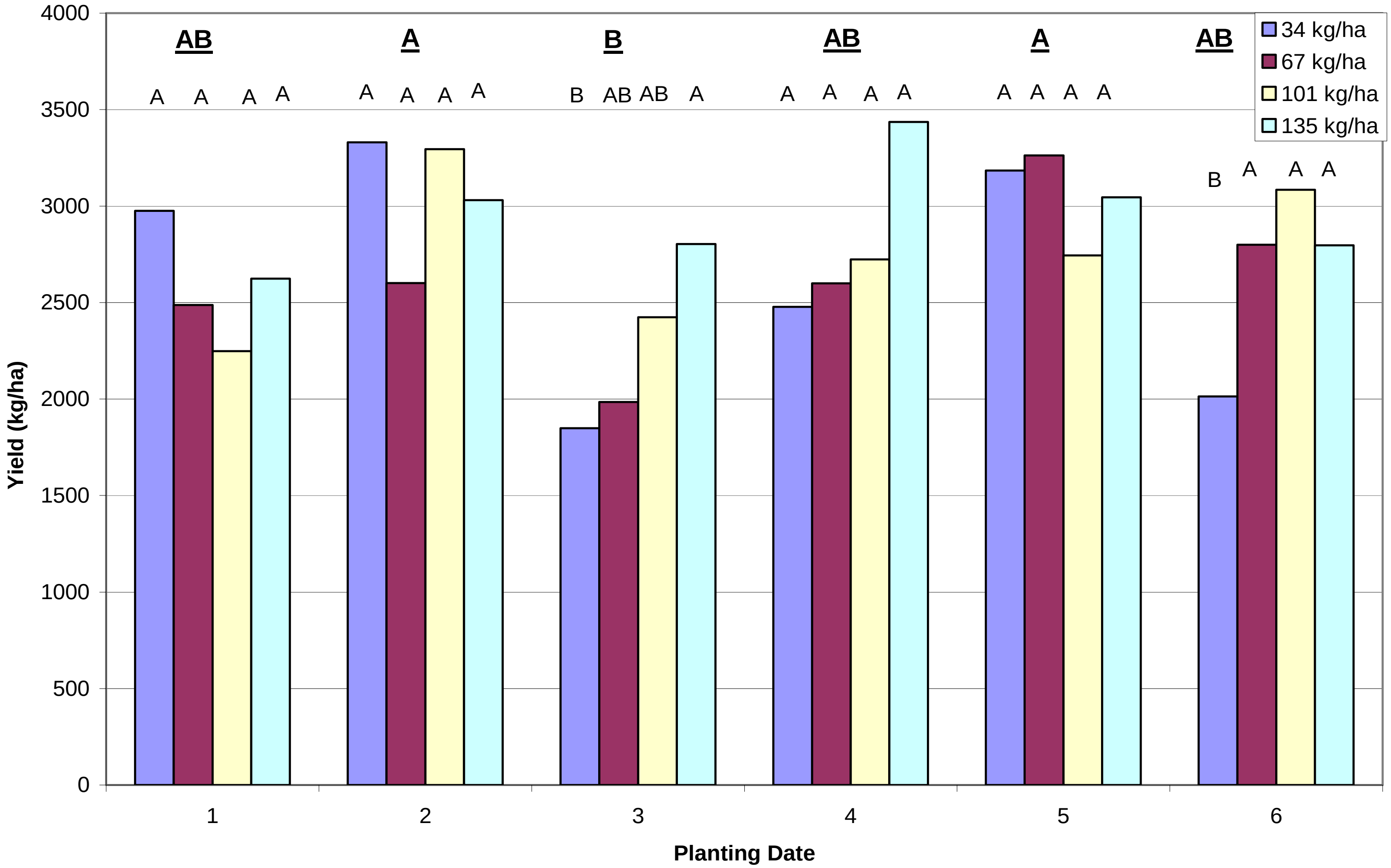

Fig. 19. McGregor season long forage yields for the 2005/2006 season.Yields are means for seeding rates within a particular planting date. Bold underlined letters represent mean separations among planting dates. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Planting 1 = 09/05/05, Planting 2 = 09/19/05, Planting 3 = 10/03/05, Planting 4 = 10/17/05, Planting 5 = 11/03/05, and Planting 6 = 11/14/05.

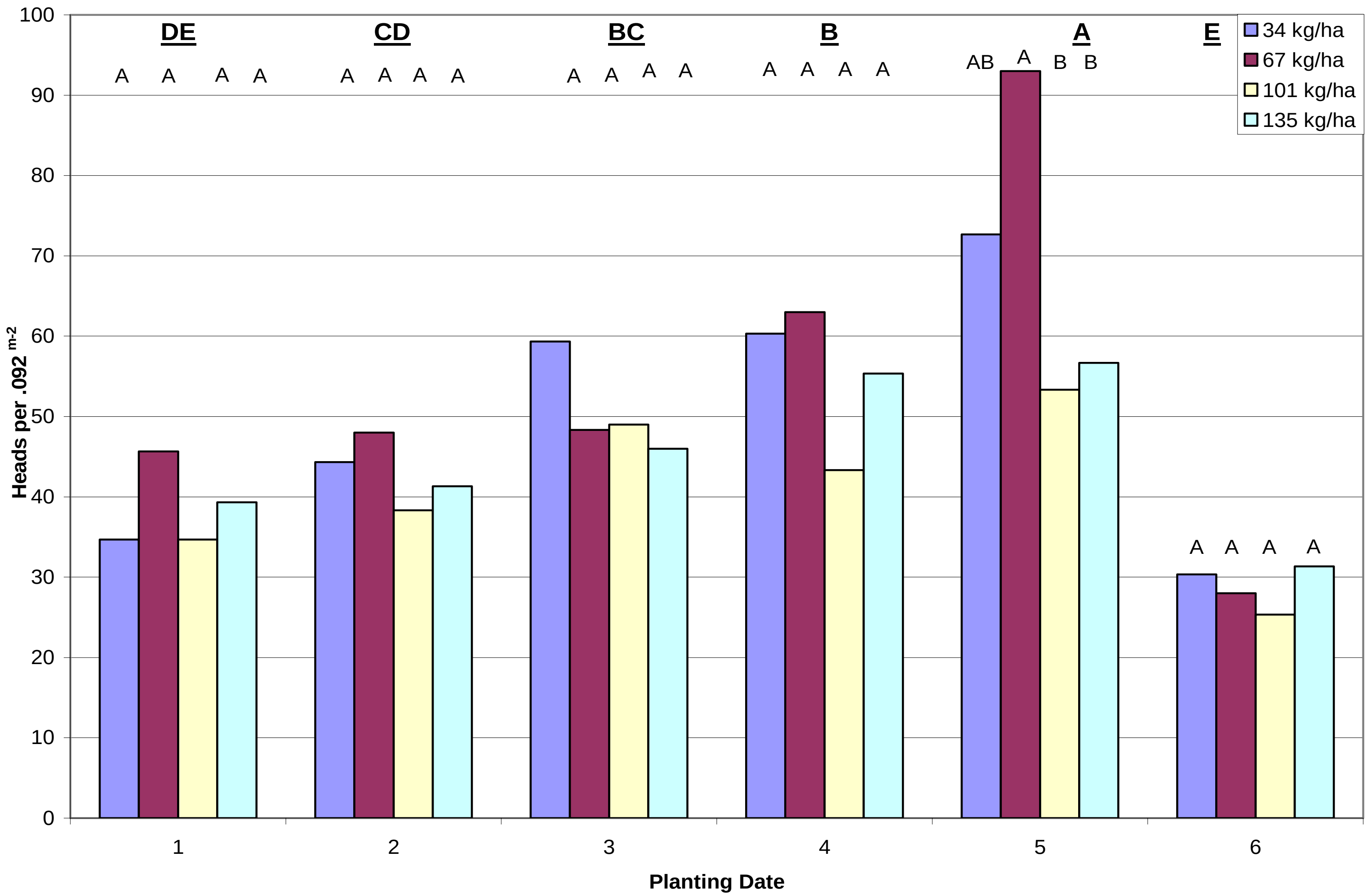

Fig. 20. McGregor spike density for dual-purpose wheat for the 2004/2005 season.Bars represent heads per square area for seeding rates within planting date. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Bold underlined letters represent the average of all seeding rates at that planting date. Planting 1= 09/08/04, Planting 2 = 09/21/04, Planting 3 = 10/11/04, Planting 4 = 10/20/04, Planting 5 =11/10/04, and Planting 6 = 12/14/04.

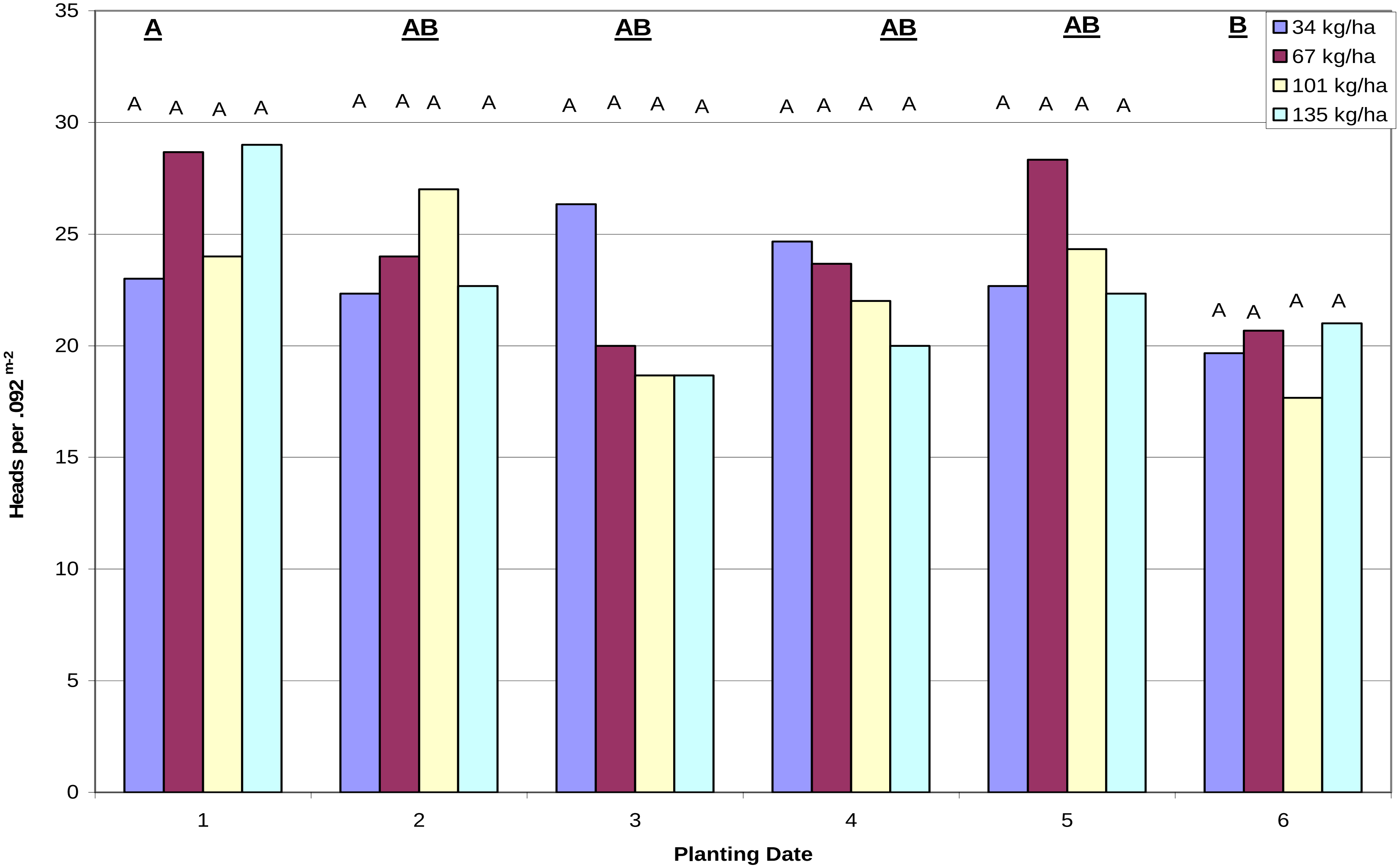

Fig. 21. McGregor spike density for dual-purpose wheat during the 2005/2006 season. Means are heads m^{-2} for each seeding date. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Bold underlined letters represent the mean separations among planting dates. Planting 1 = 09/05/05, Planting 2 = 09/1905, Planting 3 = 10/03/05, Planting 4 = 10/17/05, Planting 5 = 11/03/05, and Planting 6 = 11/14/05.

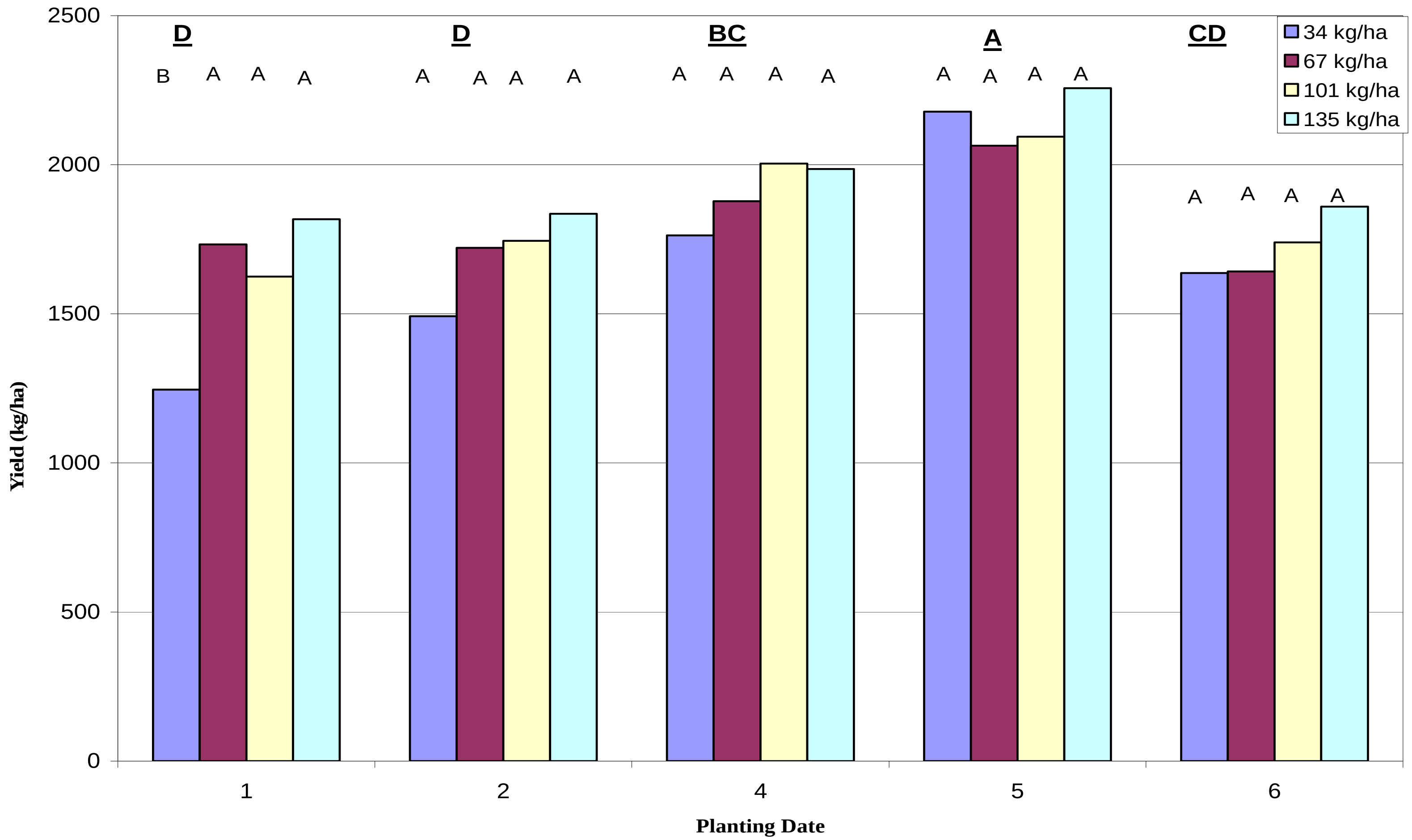

Fig. 22. The impact of seeding rate and planting date on mean grain yields for the dual-purpose crop at McGregor, TX in 2003/2004. Bold underlined letters represent mean separations among planting dates. Bars with identical letters within a planting date are not significantly different according to Fisher's LSD (P<0.05). Planting 1 = 09/09/03, Planting 2 = 09/24/03, Planting 3 = NA, Planting 4 = 10/22/03, Planting 5 = 11/13/03, and Planting 6 = 11/25/03.

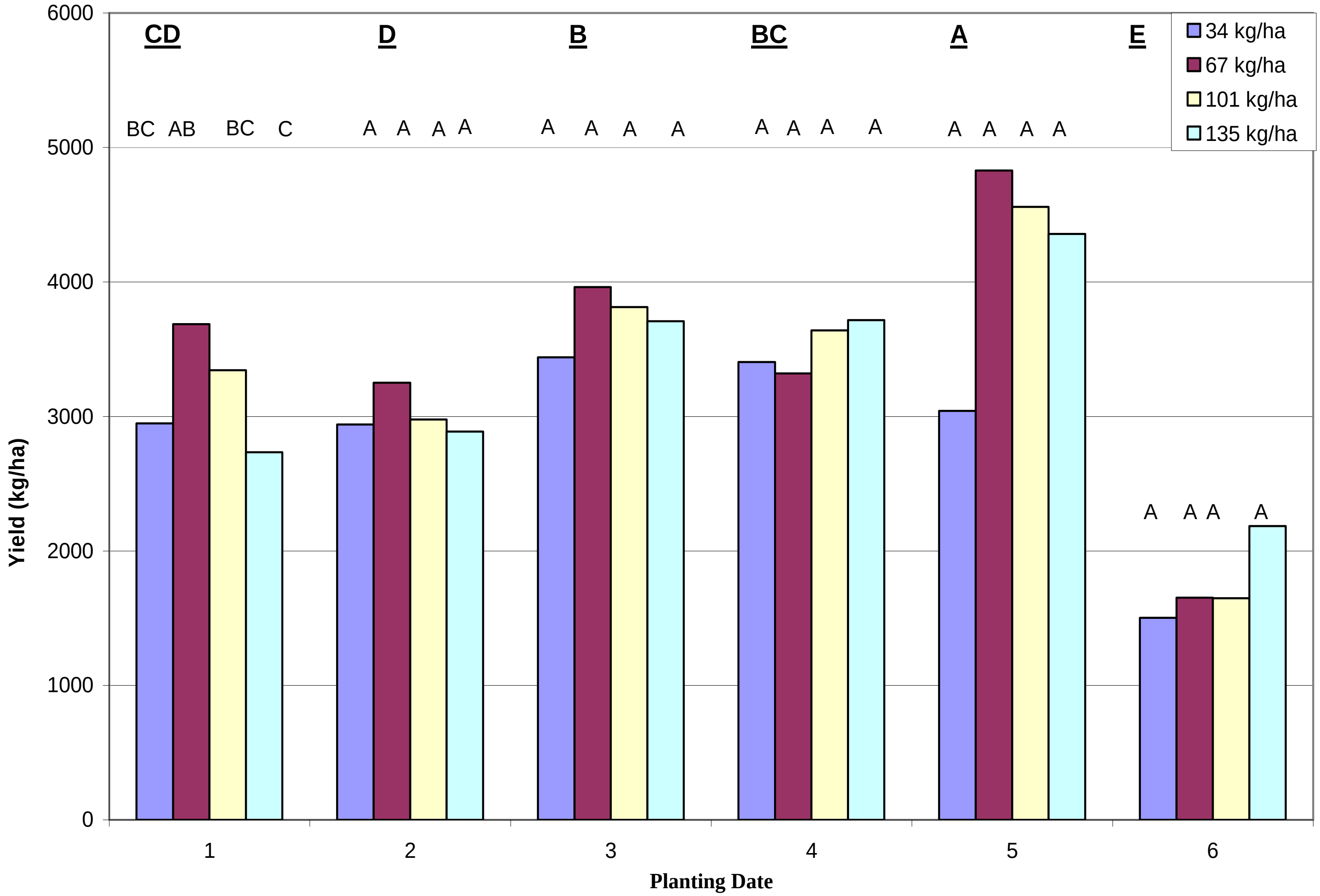

Fig. 23. The impact of seeding rate and planting date on grain yields for the dual-purpose crop at McGregor, TX in 2004/2005. Bold underlined letters represent mean separations among planting dates. Bars with identical letters represent mean grain yields for seeding dates within a planting date that were not significantly different according to Fisher's LSD (P<0.05). Planting 1= 09/08/04, Planting 2 = 09/21/04, Planting 3 = 10/11/04, Planting 4 = 10/20/04, Planting 5 =11/10/04, and Planting 6 = 12/14/04.

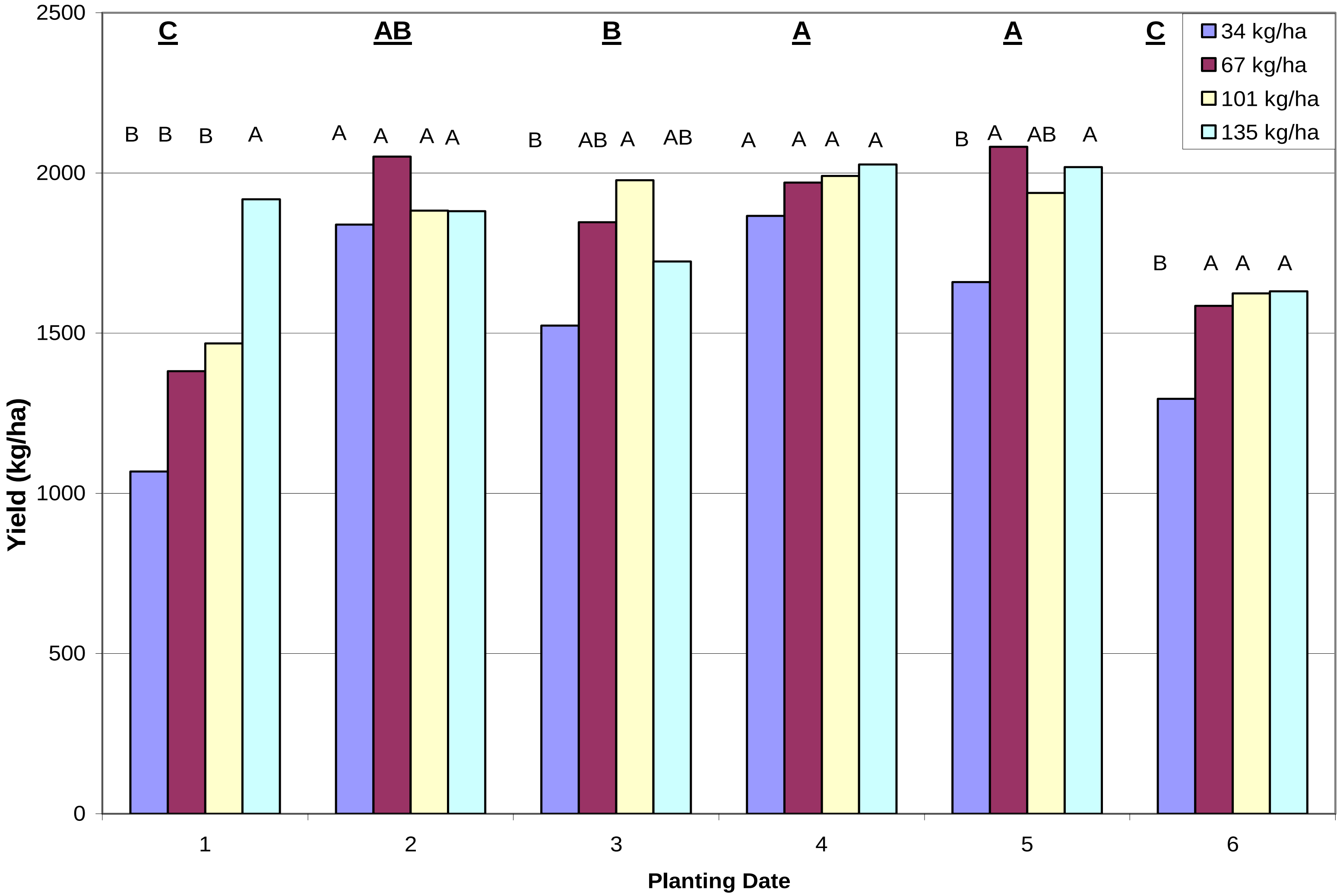

Fig. 24. The impact of seeding rate and planting date on grain yields for the dual-purpose crop at McGregor, TX in 2005/2006. Bold underlined letters represent mean separations among planting dates. Bars with identical letters within a planting date represent mean grain yields that were not significantly different according to Fisher's LSD (P<0.05). Planting 1 = 09/05/05, Planting 2 = 09/1905, Planting 3 = 10/03/05, Planting 4 = 10/17/05, Planting 5 = 11/03/05, and Planting 6 = 11/14/05.

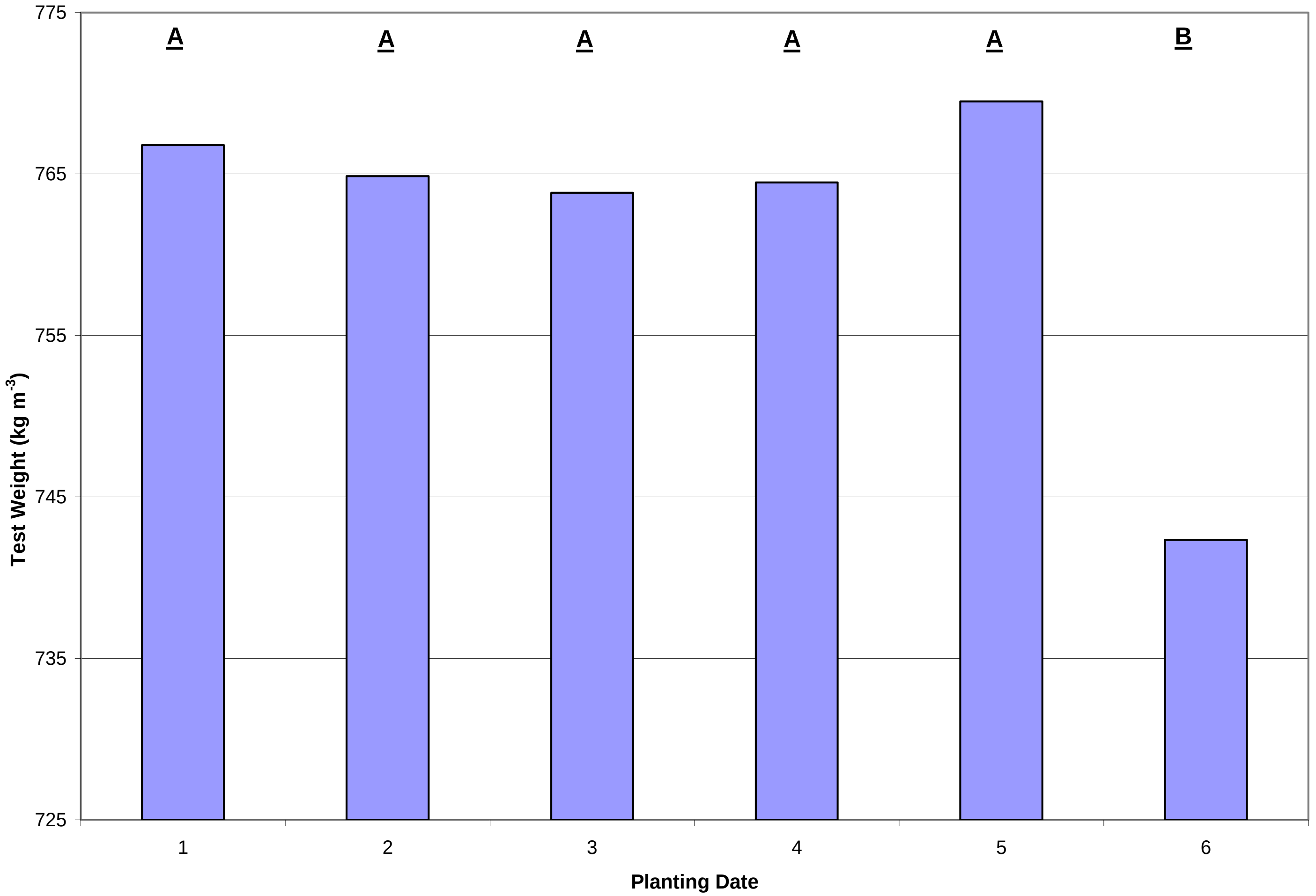

Fig. 25. McGregor 2004/2005 bushel weights for dual-purpose wheat when seeding rates were averaged at each planting date. Bars with identical letters are not significantly different based on Fishers LSD (P<0.05). Planting 1= 09/08/04, Planting 2 = 09/21/04, Planting 3 = 10/11/04, Planting 4 = 10/20/04, Planting 5 =11/10/04, and Planting 6 = 12/14/04.

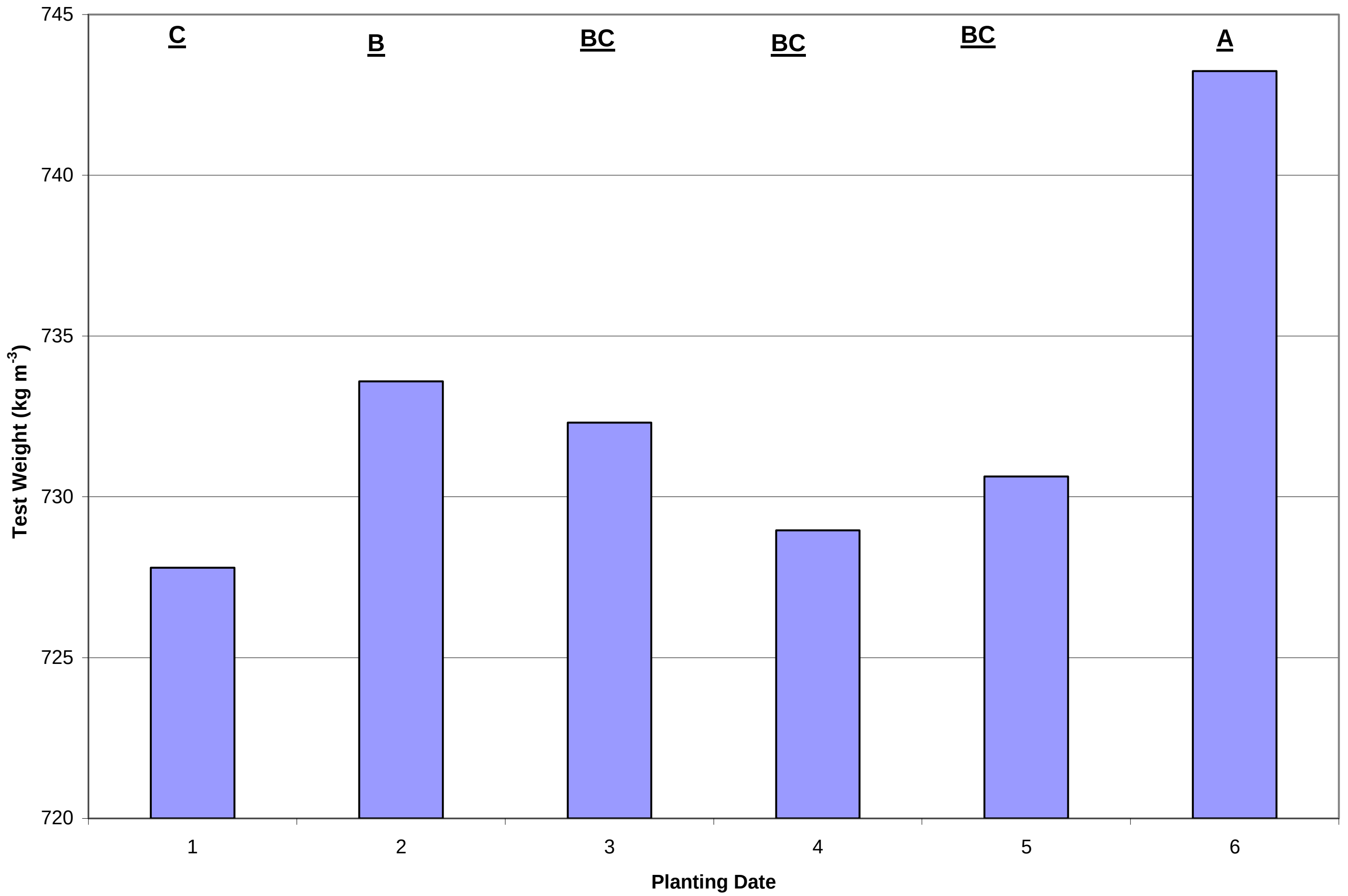

Fig. 26. McGregor 2005/2006 bushel weight for dual-purpose wheat when seeding rates were averaged at each. Bars with identical letters represent means that were not significantly different according to Fisher's LSD (P<0.05). Planting 1 = 09/05/05, Planting 2 = 09/19/05, Planting 3 = 10/03/05, Planting 4 = 10/17/05, Planting 5 = 11/03/05, and Planting 6 = 11/14/05.

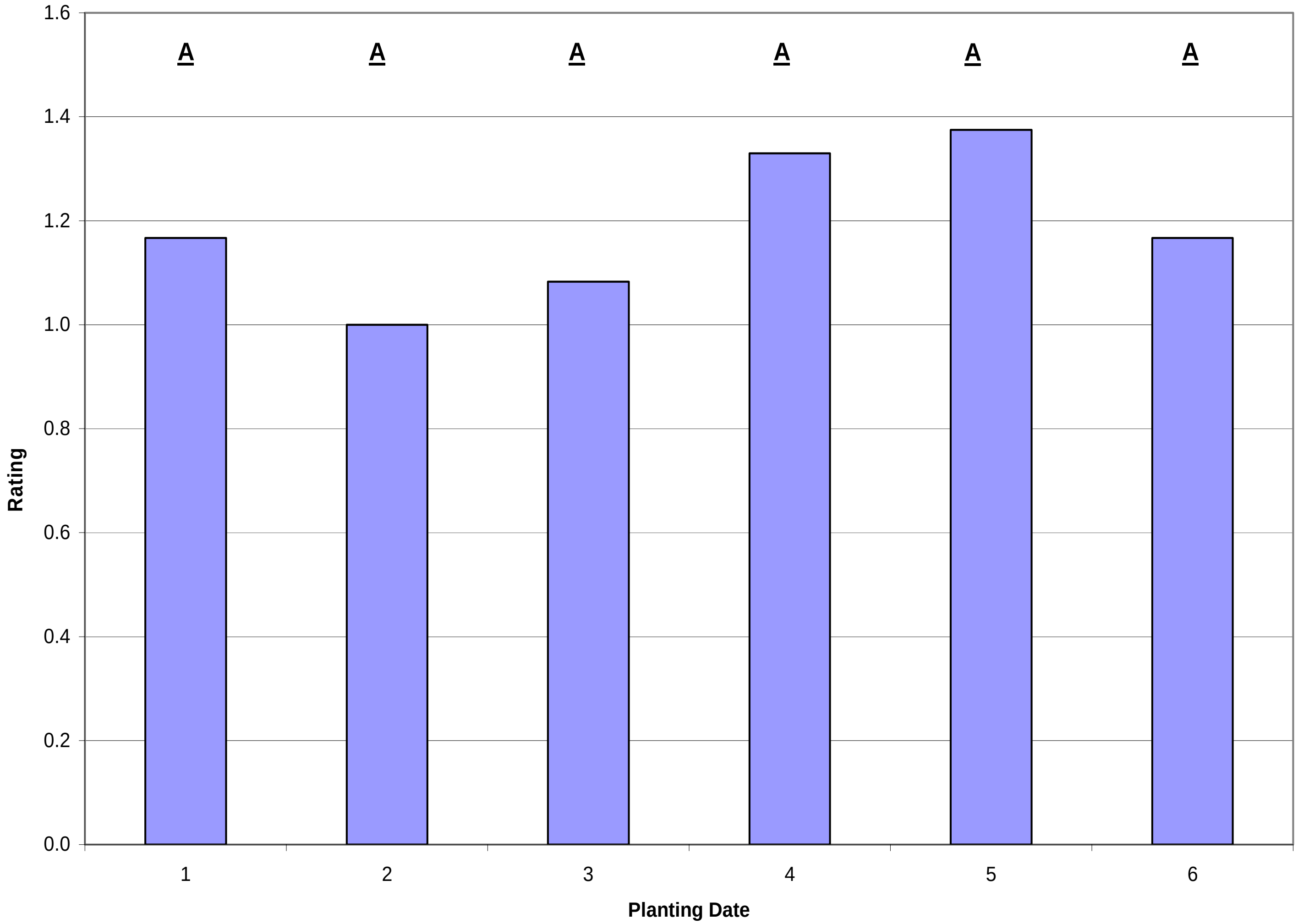

Fig. 27. McGregor 2004/2005 lodging ratings for dual-purpose wheat when seeding rates were averaged at each planting date. Visual lodging ratings for grain-only wheat were 0 = no lodging to 10 = entire plot on ground. Bars with identical letters are not significantly different based on Fishers LSD (P<0.05). Planting 1= 09/08/04, Planting 2 = 09/21/04, Planting 3 = 10/11/04, Planting 4 = 10/20/04, Planting 5 =11/10/04, and Planting 6 = 12/14/04.

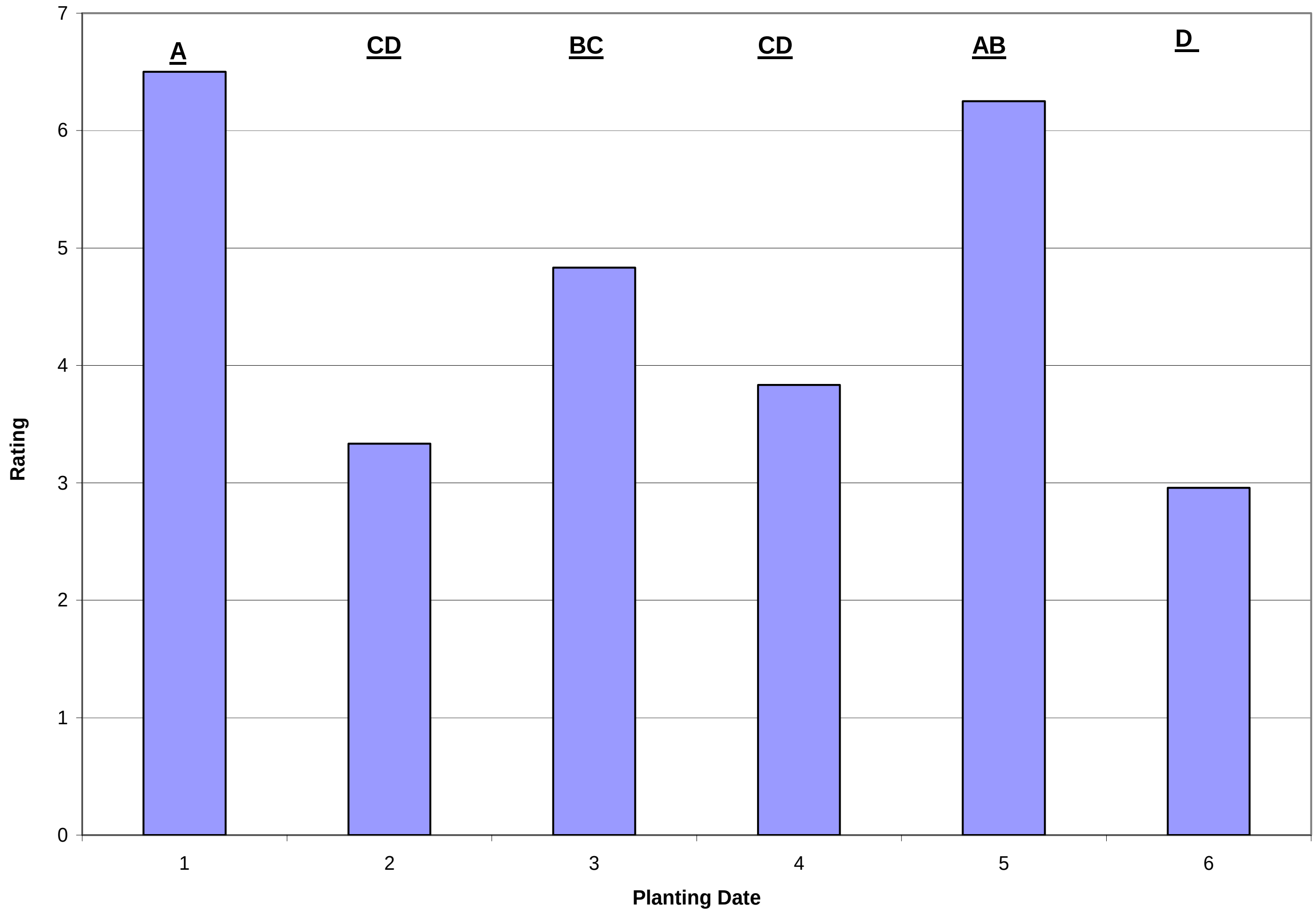

Fig. 28. McGregor 2005/2006 lodging ratings for dual-purpose wheat when seeding rates were averaged for each planting date. Visual lodging rating for grain-only wheat range from 0 = no lodging to 10 = entire plot on ground. Bars with identical letters not significantly different according to Fisher's LSD (P<0.05). Planting 1 = 09/05/05, Planting 2 = 09/19/05, Planting 3 = 10/03/05, Planting 4 = 10/17/05, Planting 5 = 11/03/05, and Planting 6 = 11/14/05.

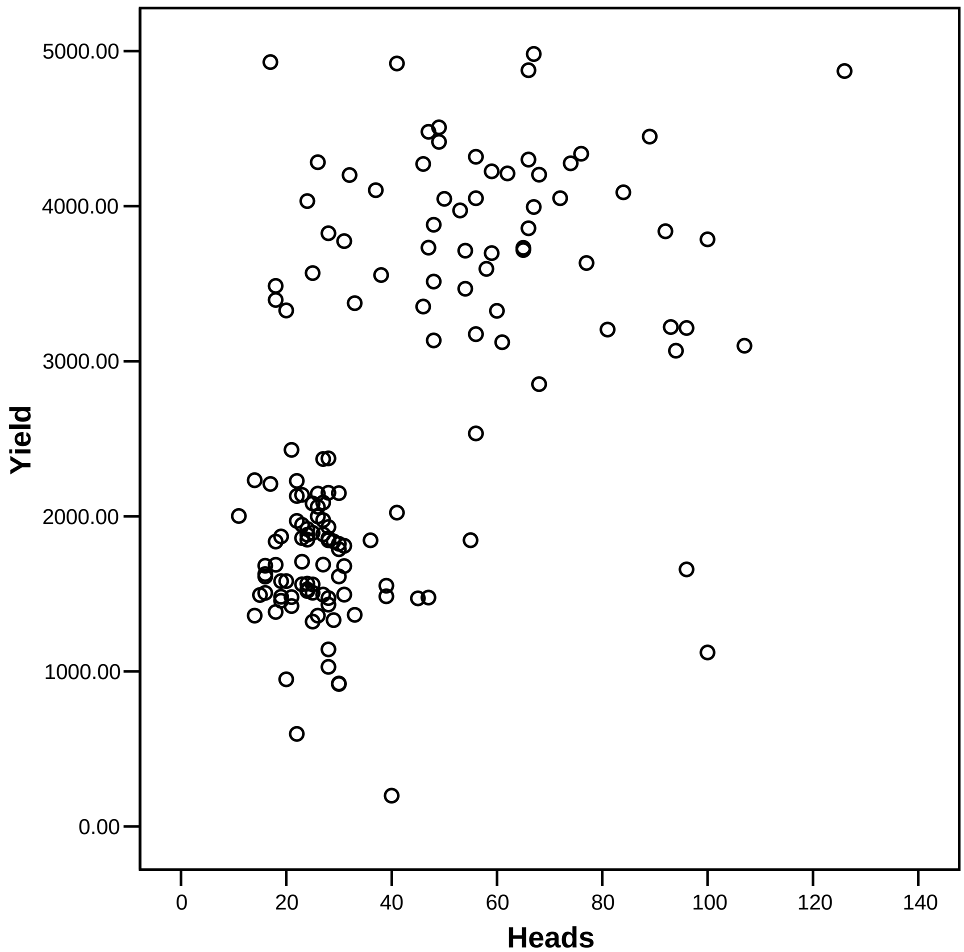

Fig. 29. Regression analysis for grain-only wheat yields where yield is the dependent variable and heads is the independent variable when the 2004/2005 and 2005/2006 seasons were combined. Yield = (1481.3 ± 162.7) + (27.6 ± 3.5) * HEADS ; R-squared = .310 ; P = .000

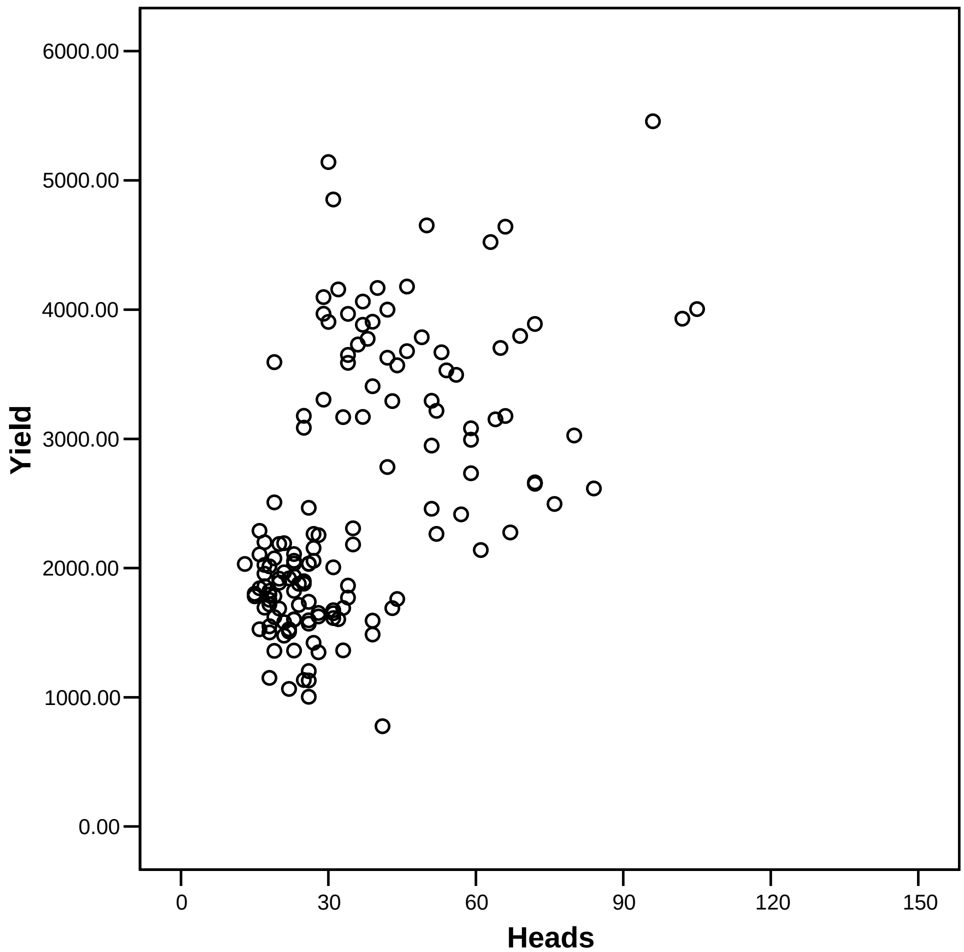

Fig 30. Regression analysis for dual-purpose wheat yields where yield is the dependent variable and heads is the independent variable when the 2004/2005 and 2005/2006 seasons were combined. Yield = (1450.1 ± 152.3) + (29.7 ± 3.8) * HEADS ; R-square = .303 ; P = .000.

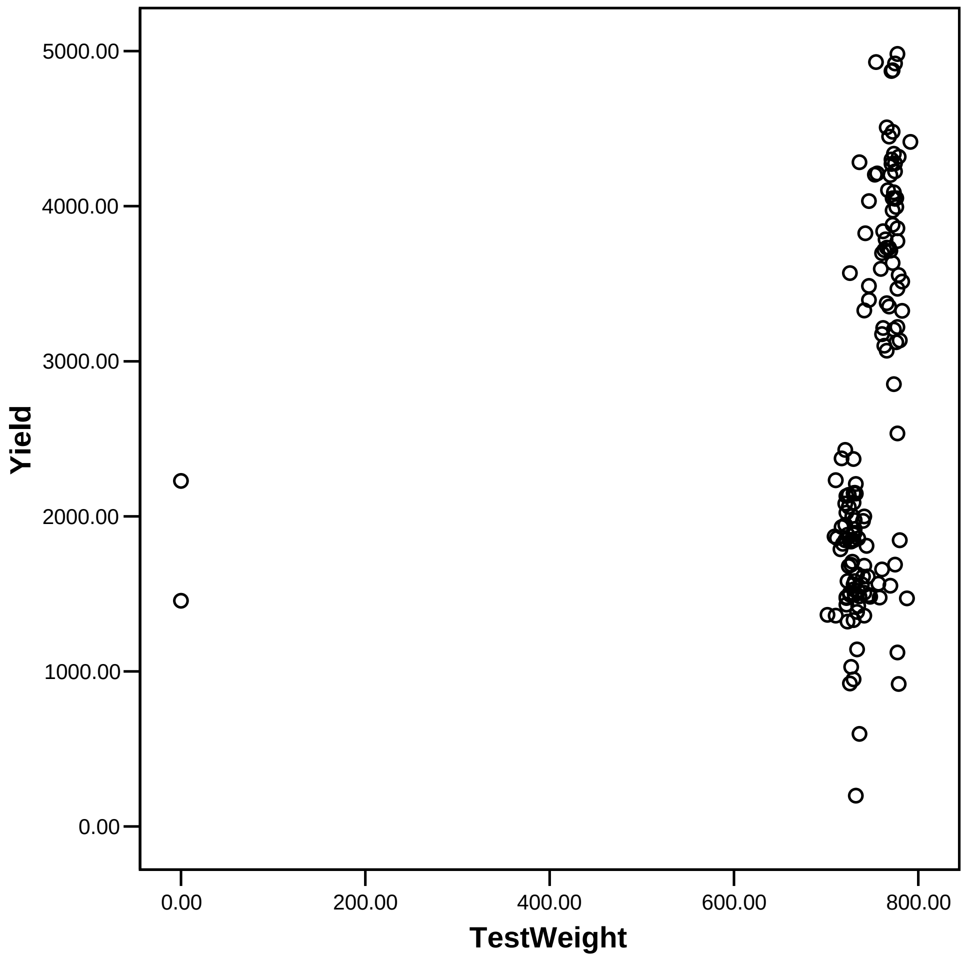

Fig 31. Regression analysis for grain-only wheat yields where yield is the dependent variable and test weight is the independent variable when the 2004/2005 and 2005/2006 seasons were combined. Yield = 350.3 ± 785.7) + (3.1 ± 1.1) * TEST WEIGHT ; R-square = .056 ; P=.005

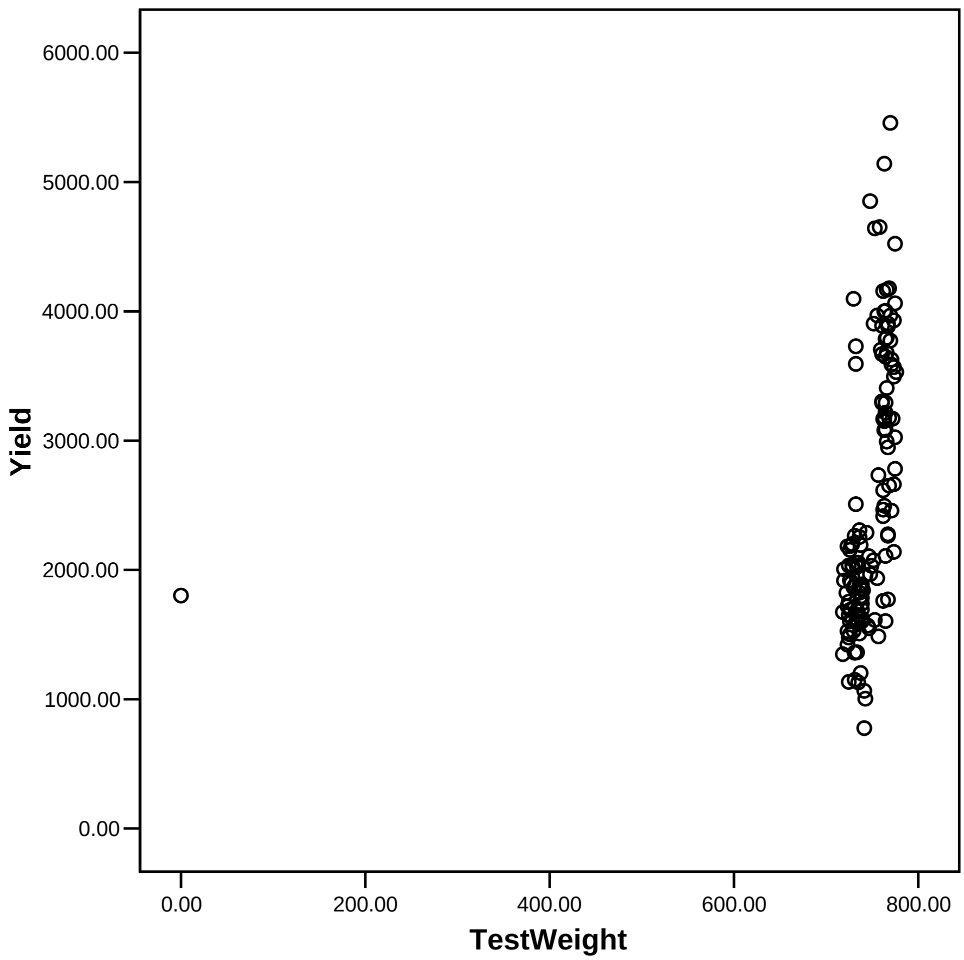

Fig. 32. Regression analysis for dual-purpose wheat yields where yield is the dependent variable and test weight is the independent variable when the 2004/2005 and 2005/2006 seasons were combined. Yield = -221.3 ± 956.8) + (3.7 ± 1.3) * TEST WEIGHT ; R-square = .055 ; P = .005

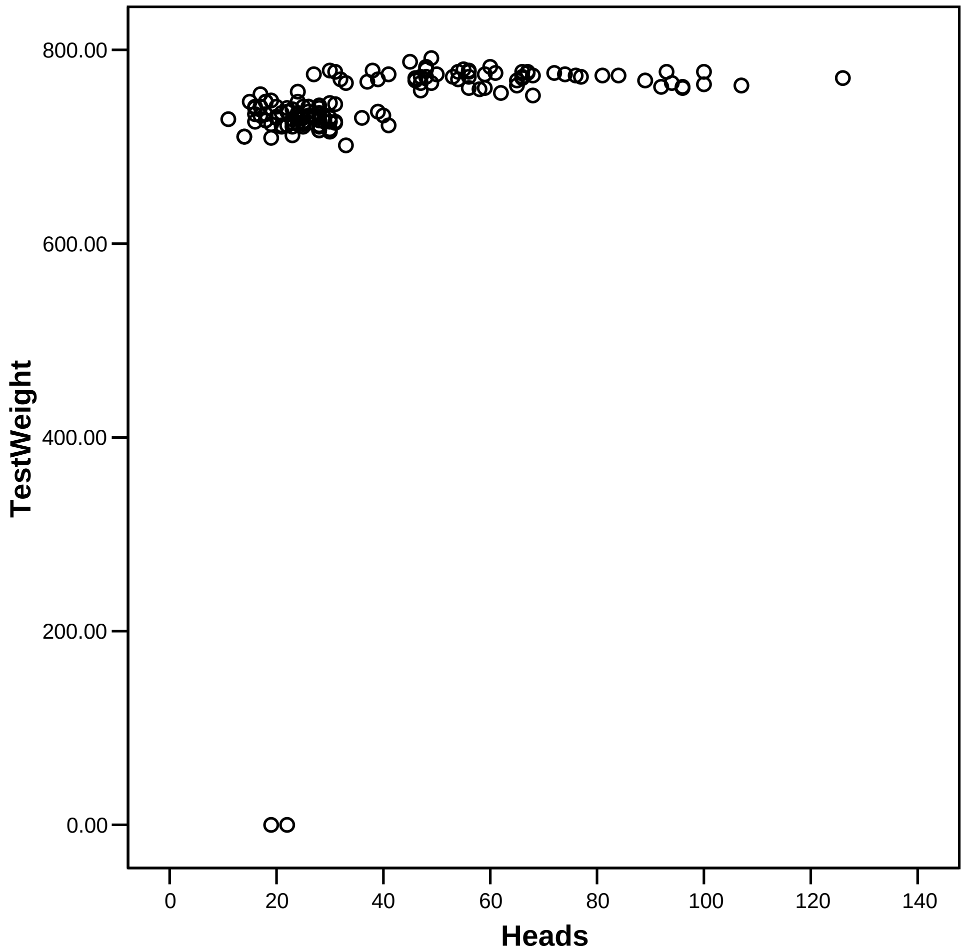

Fig. 33. Regression analysis for grain-only wheat where test weight is the dependent variable and heads is the independent variable when the 2004/2005 and 2005/2006 seasons were combined. Test Weight = (697.1 ± 14.4) + (1.0 ± .31) * HEADS ; R-square = .069 ; P = .002

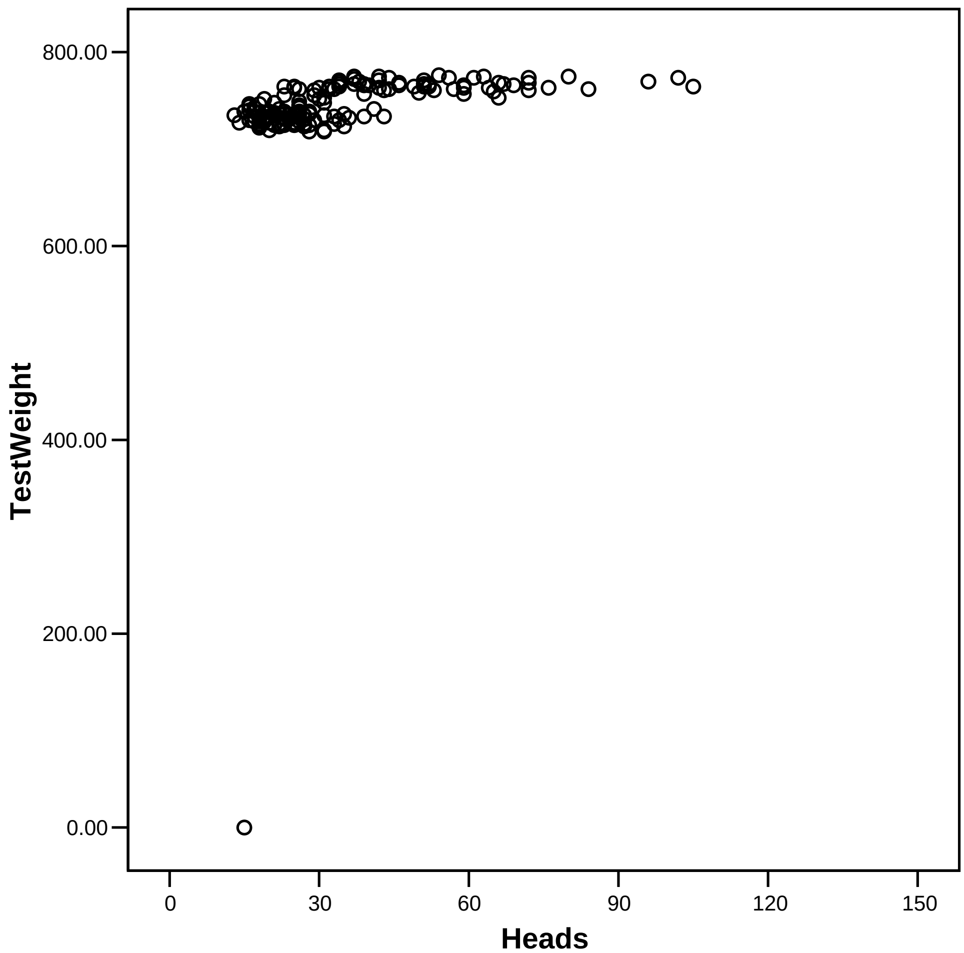

Fig. 34. Regression analysis for dual-purpose wheat where test weight is the dependent variable and heads is the independent variable when the 2004/2005 and 2005/2006 seasons were combined. Test Weight = (710.1 ± 11.1) + (.912 ± .28) * HEADS ; R-square = .071; P = .001

VITA

Oliver Jacob Shaffer received his Bachelor of Science degree in Agriculture Systems Management from Texas A&M University College Station in 2004. He entered the Soil & Crop Science department in May 2004, and received his Master of Science degree in Agronomy in December of 2007. His research was focused on determining the optimal planting date and seeding rate to maximize forage and grain yields. Jacob is currently employed with the United States Department of Agriculture Natural Resource Conservation Service as a Soil Conservationist.

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