EVALUATING THE INTERACTION BETWEEN HERBICIDE AND FERTILIZER APPLICATION TIMING TO IMPROVE ITALIAN RYEGRASS CONTROL, GRAIN QUALITY, AND YIELD IN OKLAHOMA WHEAT PRODUCTION

By

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Controlling Italian ryegrass (*Lolium multiflorum Lam.*) is a serious problem for Oklahoma winter wheat (*Triticum aestivum* L.) producers to face. Italian ryegrass, when not controlled, reduces wheat yield and overall grain quality due to higher than acceptable levels of inert material. The overarching objective of this experiment was to evaluate the interaction between N fertilizer application timing and post-emergence herbicide application timing for control of Italian ryegrass. This interaction will be evaluated based on grain yield, grain quality (protein concentration and dockage in harvested grain), N accumulation in winter wheat and Italian ryegrass, biomass growth, and control of Italian ryegrass. Italian ryegrass was controlled with Axial XL (Pinoxaden) four times, three in the fall during 2011 and once in the fall of 2012 and once in the fall 2012 and twice in the spring of 2013. Tissue samples collect during the 2011-2012 growing season showed an increase in wheat biomass weights when Italian ryegrass populations were controlled. Good growing conditions early in the 2011-2012 growing season allowed wheat biomass to develop and out compete the Italian ryegrass. The greatest Italian ryegrass densities were discovered in the 0 Kg N ha^{-1} N application rate, poor fertility reduced the competitiveness of wheat. Yields in the weedy plots were slightly lower than the weed free plots that received the same amount of N. Although not significant at all locations between each N rate, the overall grain yields where increase between 37 to 521 Kg ha^{-1} when Italian ryegrass was controlled in the fall. The results found in the study can be used to better manage herbicide and N inputs for maximum weed control, grain quality, yield, and economic return.

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CHAPTER I

INTRODUCTION & REVIEW OF LITERATURE

Weed control has been noted as one of the most difficult factors for Oklahoma producers to manage in winter wheat (*Triticum aestivum* L.). Italian ryegrass (*Lolium multiflorum Lam.*), a winter annual, can be very difficult to control due to similar life cycle to winter wheat and its ability to develop resistance to the limited herbicide options that are available. Italian ryegrass is very competitive for moisture, nutrients, light and space. When not controlled wheat yield and overall grain quality are reduced.

Winter wheat production in Oklahoma

Each year in Oklahoma producers plant approximately 2.3 million hectares of hard red winter wheat **(**USDA-NASS, 2011). Approximately one-half of this is managed as dual-purpose wheat (Barnes et al. 2001), and 10 to 20% of the winter wheat planted in the southern Great Plains is fully devoted to livestock grazing (Pinchak et al. 1996).

Oklahoma cropping systems include of many other commodities in addition to winter wheat. These include soybean (*Glycine max*), sorghum (*Sorghum b icolor* (L.), corn (*Zea Mays*), cotton (*Gossypium hirsutum* L.) and canola (*Brassica napus*). The combination of these crops is approximately 544,000 hectares (USDA-NASS 2011). Although there is a diversity of crops grown, most producers have traditionally continued the monoculture production of winter wheat. Weed problems continue to increase due to the lack of crop and herbicide chemistry rotations. Wheat harvest in Oklahoma typically begins in late-May or early-June, which is early enough to allow producers the chance to plant a second or double crop in the same season. Although rotating or double-cropping after wheat harvest is an option for many producers, available soil moisture and precipitation influences most of the crop production decisions in the state (Trusler et al. 2007).

Precipitation is typically the most limiting factor in Oklahoma cropping systems. Optimal utilization and conservation of limited resources such as moisture is vital to achieving optimal wheat yield. The average annual rainfall across the state since record keeping began in 1895 is approximately 33.93 inches (Anonymous 2013). The continuous monocropping of wheat over many years has led to the development of several problems for wheat production in Oklahoma. Wheat quality and yields are often lowered due to the uncontrolled influence of weed competition.

Impact of weeds on winter wheat grain quality

Many factors can influence wheat grain quality and yield, ultimately affecting market value of wheat. Dockage, test weight, and grain protein levels can all result in undesirable grain quality affect wheat values. The control of winter annual grasses in winter wheat production has been a serious problem facing producers for many years across the U.S. When not controlled, annual, grassy weeds reduce crop yield and overall grain quality due to high levels of inert material (dockage). Dockage is any material in a sample of grain that can be removed, such as undeveloped, shriveled, small pieces of grain kernels, and weed seeds. Whereas broken/shrunken kernels are materials that can pass through a 0.064 x 3/8 inch oblong-hole (USDA, GIHB 2004).

Dockage can be significantly reduced by controlling weeds. Foreign material is any material besides the grain that remains after the removal of dockage and broken/shrunken kernels (Anonymous 2013). In wheat a commonly found foreign material that reduces grain quality is Cereal Rye (*Secale cereal* L.). After the removal of inert material, wheat grain quality is then based on test weight and, most importantly, protein concentration, since this determines market price and the usage of the grain in the milling and baking industries (Bushuk 1977). The Hard Winter Wheat Quality Targets Committee (USDA/ARS 2006) set a recommended standard for grain quality in February 2006 for hard red winter wheat based on the end use of bread baking. This standard was set as a goal not only meant for producers to achieve but for all parties involved in the wheat grain production and marketing industries. Test weight and protein values were set at 60 lb/bu (67 kg ha^{-1}) or greater and 12% mb and above. The high protein levels (12-16% mb) of hard red winter wheat's makes it ideal for human, animal and livestock feed products (Hunter and Stanford 1973).

A study conducted in Oklahoma (Barnes et al. 2001) documented 11.4 to 19.3% dockage in wheat resulting from uncontrolled Italian ryegrass populations of 105 to 160 plants/m^2. This high population of Italian ryegrass reduced wheat yields from 4200 to 2700 Kg ha^{-1}, 36%. Libl and Worsham (1987) reported infestation levels of Italian ryegrass in North Carolina sufficient to cease the production of small grains in some areas, and producers were forced to adopt new farming practices for production to continue in those fields. Appleby et al. (1976) found that a density of 29 to 118 Italian ryegrass plants/m^2 resulted in a yield loss of 7 to 50% in wheat yield in the Pacific Northwest. Fast et al. (2009) determined a 16 to 20% yield reduction in wheat when Italian ryegrass populations ranged from 30 to 158 plants/m^2. The greatest loss in yield occured from 30 plants/m^2, after 30 plants marginal decreases in grain yield from increases in Italian ryegrass density decreased. Instead of approaching this situation with an herbicide management plan, many producers choose to graze the field out or harvest the forage for hay (Justice et al. 1994).

Weed control in winter wheat

Many grass weeds affect winter wheat production throughout the southern Great Plains. Some of the major grass weed species in Oklahoma are cheat (*Bromus secalinus* L.), cereal rye, Italian ryegrass, and jointed goat grass (*Aegilops cylindrica*). Of these weeds Italian ryegrass is the most problematic and difficult to control due to limited herbicide options. Several methods have been used to control or suppress Italian ryegrass populations in winter wheat; however, economic justification of weed control is often limited or not possible due to market prices and potential grain yields. A delay in planting date can reduce weed populations and increase early-season crop competiveness by allowing for weed seeds to germinate and become terminated by tillage (Buhler and Gunsolus 1996). Tillage of the soil prior to planting allows the wheat crop to establish a stand and outcompete Italian ryegrass for light, moisture, late germinating weed species will have to compete with a vigorous crop (Justice et al. 1994).

The most economical and efficient method of controlling Italian ryegrass in winter wheat is achieved through herbicide application. Chemical control allows for in-season elimination of Italian ryegrass when other methods are not optional. The ease and efficiency of weed control achieved through the application of herbicides has increased the use and popularity of chemical control. The repeated use or over-reliance on a single herbicide active ingredient or mode of action (MOA) selects for weeds that posse resistance traits. The best management plan to control these weeds is through crop rotation, which allows for a diverse use of weed control methods and herbicides with different modes of action (Peterson 1999). Crop rotation can be used as a cultural practice to control weed problems and prevent the future spread of resistant populations. The sequence of a crop rotation allows for alterations in planting date, harvest and herbicide use. Doucet et al. (1999) refers to crop rotation as a management practice that breaks up a monoculture creating unfavorable growing conditions for a specific weeds life cycle. Row spacing and planting rates are two cultural methods that have been used for years to minimize weed competition (Mertens 2002; Champion et al. 1998; Teasdale and Frank 1983). These methods of control increase the crop's competitiveness resulting in a suppression of weed density. Narrowing the row spacing from 30 to 10 cm in wheat reduced jointed goatgrass spikelet yield from 240 to 207 kg/ha (Kelley 1998). Roberts et al. (2001) discovered that doubling the seeding density of wheat in 10-cm row spacing increased yields 22% in the presence of cereal rye. An increase in winter wheat planting rates can boost crop competitiveness and production in the presence of weeds. This influence on yield is based on the species of weed and its density. In Chickasha, Oklahoma wheat yield increased from 1660 to 2190 kg/ha when the planting rate was increased from 67 to 134 kg/ha in the presence of a cheat seeding rate of 134 kg/ha (Koscelny et al. 1991).

Tank-mixing multiple herbicides can improve herbicide efficacy and broaden the spectrum of control. Barnes et al. (2001) achieved 89 to 93% control of Italian ryegrass when applying the preemergence tank mixture of chlorsulfuron plus metsulfuron, both belong to the Sulfonylurea chemical family. Herbicide application timing can increase product efficacy since smaller weeds are typically more easily controlled. For example, diclofop (from the Arloxyphenoxypropionate chemical family) applied at early post-emergence to 2-3 leaf Italian ryegrass plants resulted in 20% greater wheat grain yields (Griffin 1985).

Italian Ryegrass Management

Italian ryegrass was introduced into Oklahoma and many areas of the US for two main purposes. First, Italian ryegrass is a highly productive forage with high protein which made it popular with livestock producers. Secondly, it can be used as a cover crop to prevent soil erosion (Justice et al. 2000). The later-maturity of Italian ryegrass allows for an extended grazing period after wheat has matured and becomes less attractive to livestock. The combining of Italian ryegrass into wheat production systems has reduced the options for the end of product usage and somewhat limits the producer to only grazing out the crop. The cost associated with dockage or having the wheat seed cleaned to remove the Italian ryegrass seeds becomes hard to justify economically. Total forage production is reduced by incorporating both species together, due to competition for moisture, nutrients, light and space (Appleby et al. 1976; Liebl and Worsham 1987).

Since its introduction into the United States, Italian ryegrass has infested fields and become one of the most problematic weeds in winter wheat production.

Wheat production in Oklahoma and other areas of the United States has been negatively impacted by infestations of Italian ryegrass (Trusler et al. 2007). This cool-season, late-maturing annual grass has become a nuisance weed in winter wheat production because of its prolific seed production, long germination patterns, limited herbicide options, and ability to quickly develop resistance to commonly used herbicides. Italian ryegrass has many features that increase its weedy competitiveness against cereal crops. The small seed size enhances its distribution ability by mixing with other seeds and clinging to equipment. This causes a major problem spreading from field to field across production areas and even states. Italian ryegrass plants begin tillering after wheat and start to compete for plant-available N in the soil. One characteristic that makes Italian ryegrass such a nuisance is its ability to thrive in many different soil types with poor fertility (Barnes et al. 2003). This allows for Italian ryegrass to establish in areas less fit for crops and reduce overall crop production. Italian ryegrass plants have hairless waxy coated leaves that helps protect the plants from absorption of herbicides (Bryson and DeFelice 2010). At maturity the plant can reach up to 1.5 which can create problems at harvest by causing the wheat plant to lodge. The lodging results in a slower harvest with increased wear of equipment, which can decrease the efficiency of operations. The lack of controlling these infestations only leads to bigger problems in the future. Italian ryegrass plants can average around 5 to 38 spikelets per plant, which can produce 4 to 17 florets per spikelet (Bryson and DeFelice 2010). This high spiklet production provides the ability for each plant to produce hundreds of seeds making the early control of this species extremely important.

Italian Ryegrass Weed Control

ALS-inhibitors In-season control of Italian ryegrass in winter wheat can be achieved with the use of selective herbicides. This allows for weeds to be controlled with herbicides while not affecting crop production. The discovery of acetolactate synthase (ALS)-inhibiting herbicides provided many benefits for weed control in a variety of crops. It is understood that inhibition of the ALS enzyme, which biosynthesizes branched chain amino acids, affects several mechanisms that results in plant death. The starvation of isoleucine, leucine and valine amino acids is thought to be the main cause of death in susceptible plants (Umbarger 1978). Shaner and O'Connor (1991) indicated that accumulation of 2-ketobutyrate and the disruptions in photosynthate transport and protein synthesis also inflicts plant death. The broad-spectrum weed control, crop selectivity and safety, soil residual activity, wide application timings, and low mammalian toxicities made this MOA successful and popular (Mazur and Falco 1989). Because of the lower use rate of ALS-inhibiting herbicides at the time of commercialization, the products use was considerably higher than former herbicides.

The toxicity of ALS-inhibitors makes them extremely efficient in controlling of susceptible plants at low dose rates. Imazamox A imidazolinone herbicide, mesosulfuron a pyrimidinylsulfonylurea herbicide and pyroxsulam a pyridine, sulfonamide and triazolopyrimidine herbicide are all ALS-inhibitors that provide exceptional control of Italian ryegrass populations in wheat production (Ellis et al. 2010). Chlorsulfuron was commercialized in 1982 as the first ALS-inhibiting herbicide for controlling broadleaf weeds in cereals (Saari et al. 1994). By 1987, only five years after its introduction, a population of chlorsulfuron-resistant prickly lettuce (*Lactuca serriola L.*) was found in seven no-till wheat fields in/near Lewiston, Idaho (Mallory-Smith et al. 1990).

The widespread uses of ALS-inhibiting herbicides lead to herbicide resistant weeds. Mutations in the herbicide's targeted site enhanced the weeds ability of detoxification of ALS-inhibiting products (Cobb and Kirkwood 2000). The control received by using ALS-inhibiting herbicides led to a large dependence of the product that ultimately caused widespread resistance among a large number of weed species in many cropping systems (Tranel and Wright 2002). As a result of this widespread adoption and use, a total of 129 ALS-inhibiting resistant weed species exist in the world today with 43 present in the United States (Heap 2012).

ACC-ase inhibitors catalyses Herbicides that inhibit the acetyl-coenzyme A carboxylase (ACC-ase) were commercialized in the 1970s and provide selective control of grass weed species (Kuk and Burgos 2007). ACC-ase inhibitor herbicides cause an inhibition of fatty acids in plastids affecting the biosynthesis of lipids; specific cereal crops have the ability to quickly metabolize and detoxify these herbicides into a nonlethal form (Betts et al. 1992). The ability to control a grass weed in a grass crop (wheat) is extremely important to cereal production. The insensitive ACC-ase enzyme in broadleaf `plants presents a natural resistance to cyclohexanedione and propionate aryloxyphenoxy herbicides (Stoltenberg et al. 1989).

The first ACC-ase herbicide introduced for control of Italian ryegrass in winter wheat was Diclofop. Diclofop is an aryloxyphenoxypropionate herbicide that was released in the early 1980's, and has been used extensively to control Italian ryegrass throughout the southern Great Plains and many other areas of the United States (Trusler et al. 2007). However, the continuous monocropping of winter wheat and over-reliance on diclofop quickly selected for populations of herbicide-resistant Italian ryegrass. Diclofop-resistant Italian ryegrass was first documented in South Australia (Heap and Knight 1982). The first casein the U.S. was discovered in 1987 in Oregon (Heap 2012), and today populations of Italian ryegrass have been reported in 14 states. Diclofop-resistant Italian ryegrass populations have been confirmed in Arkansas with severe cases in the wheat producing areas neighboring the Louisiana and Missouri borders (Kuk et al. 2008).

Pinoxaden is a fairly new ACC-ase herbicide which can provide producers with excellent control of Italian ryegrass in wheat and barley production. Its ability to control grass weeds and not damage the crop is possibly due to inclusion of cloquintocet-mexyl, a safener included in the formulated product (Hofer et al. 2006). This safener allows the application of pinoxaden to control Italian ryegrass in wheat without injuring the crop. Herbicide safeners are compounds that increase crop tolerance through enhanced herbicide selectivity by quick detoxification of the product after adsorption (Cobb and Kirkwood 2000). Pinoxaden, sold commercially as Axial XL, is safe to incorporate into a rotational system, as it has little to no soil activity. Axial XL is labeled to control Italian ryegrass and wild oat at a single application rate of 60 g ai/ha^{-1}(Hofer et al. 2006). In Oklahoma, pinoxaden applications reduced Italian ryegrass seed contamination in winter wheat grain by 88 to 100% (Bushong and Peeper 2010). Proper application timing of pinoxaden is crucial to increase weed control and wheat yields. Early post applications of pinoxaden to small Italian ryegrass plants one leaf to one tiller in size increased grain yields from 2360 to 5320 kg ha^{-1} (Ellis et al. 2010). However the misuse and over-reliance of pinoxaden for Italian ryegrass control could soon lead to resistant Italian ryegrass populations in the future. Pinoxaden targets the same site of action as diclofop which could present the potential for cross-resistant Italian ryegrass populations to develop (Kuk et al. 2008).

Nitrogen fertilizer management in winter wheat

In addition to precipitation, N is a major factor that limits winter wheat production in the Great Plains (Major et al. 1988). To optimize grain yield, N fertilizer must be applied in the appropriate amount and at the correct stage of wheat growth (Major et al. 1988). This makes the timing, amount, source, and placement of N fertilizer essential to achieving optimal yields and high quality grain. Grain yield and protein concentration are or can be influenced by cultivar, moisture, growing conditions, and N fertilizer. Thus, it is critical to have enough plant available N in the soil to achieve optimal yield and grain quality (Fowler 2002).

The amount and source of N fertilizer required is based on yield goal, formulation and method of N application. The effectiveness with which N is used by wheat has become increasingly important because of increased cost associated with the supply and distribution of N fertilizer (Kanampiu and Raun 1997). Between 2007 and 2008, N fertilizer prices increased by 33% with phosphate and potassium nearly doubling in cost

(Huang 2009). The protection and availability of this resource is essential in achieving optimal crop productivity.

The amount of N required is based on the desired yield goal of a specific crop; however, phosphorus and potassium are based on soil test results. Current recommendations are to apply 2.24 kg ha^{-1} of N to produce 1 kg ha^{-1} of wheat grain (Zhang and Raun 2006). A wheat plant should have at least two tillers to successfully survive an Oklahoma winter until N fertilizer is applied in the spring. This growth is achieved by applying a minimum of 34 to 45 kg ha^{-1} of N preplant (Edwards et al. 2006). A wheat plant has high demands for N at the Feekes growth stage F3 (initiation of tillering at the onset of development of the third leaf). The N uptake remains high until reaching Feekes growth stage F11 (milky ripe). At this point the N uptake decreases (Girma et al. 2011).

Weed Interference

Proper fertilizer timing and placement can increase wheat competitiveness and reduce weed interference. Early weed control can lead to more efficient use of herbicides and N fertilizer. Proper timing fertilizer N will allow the crop to out-compete weeds and reduce herbicide inputs (Di Tomaso 1995). Applying N fertilizers while both weed size and population is small can increase the crops ability to outcompete weeds for resources. Mesbah and Miller (1999) found that placing a band of N in the soil close to the wheat seed (5 cm below and 2.5 cm to the side of the row) reduced jointed goatgrass biomass from 3.6 to 2.9 tons/ ha^{-1} compared with broadcast application. Banding the fertilizer and seed together decreases the overall area in the soil receiving fertilizer and reduces available N in the area between rows.

The application of additional N to a crop may not increase yields when weed control is not present. Di Tomaso (1995) discussed many different weed species that are superior to crops in resource uptake efficiency. Wheat yield will decrease in response to N applied to a field infested by a large population of Italian ryegrass. Appleby et al. (1976) conducted a study on the interference of Italian ryegrass on winter wheat yields; he evaluated three N fertilizer levels and four Italian ryegrass densities. The study indicated that when N levels are increased wheat yields remained the same or decreased due to the interference of high Italian ryegrass densities.

Carlson and Hill (1985) observed similar results when applying 0 to 134 kg/ha of N fertilizer in a wheat field with a wild oat (*Avena fatua*)density of 32 plants/m^2 which resulted in decreased wheat yield from 4530 to 2330kg/ha. The poor control of weed populations can result in the loss of N fertilizer and yield. When a large population of weeds takes over a field, weeds are able to out-compete the crop for light, water, space, and nutrients, thereby reducing grain yield and quality (Carlson and Hill 1985). However, additional N can increase crop yields by making the crop more competitive against weeds particularly when the weeds are at relatively low densities (Di Tomaso 1995). The level of competition for resources among weeds and the crop is heavily dependent on both the species of weeds and crop, time of season, growth stage, weed density, crop density, and soil fertility (Carlson and Hill 1985).

A weed's ability to out-compete a crop in resource uptake can be magnified by the addition of N fertilizer. Redroot pigweed (*Amaranthus retroflexus* L.) has been shown to have a higher N uptake when there are greater levels of N available (Teyker et al. 1991). When N increases from 110 to 220 mg N kg^{-1}, N accumulation is 2.5 times greater in pigweed than in maize (Teyker et al. 1991). This statement holds true for many different weed species and shows the importance of conserving plant available resources. A crop that receives little to no interference from weeds will benefit the most from plant available nutrients, in this case N.

The proper management of N fertilizer will not only increase yields but produce high quality grain. The information from this research can be used for improved management of N and herbicide application for maximum weed control, grain quality, yield, and economic return. Results from this research provide wheat producers with information regarding optimum application timing for grain yield and Italian ryegrass control and how these interact with the timing of N fertilizer application.

CHAPTER II

OBJECTIVES & HYPOTHESIS

Objectives

The overarching objective of this experiment was to evaluate the interaction between N fertilizer application timing and post-emergence herbicide application timing for control of Italian ryegrass. This interaction will be evaluated based on grain yield, grain quality (protein concentration and dockage in harvested grain), N accumulation in winter wheat and Italian ryegrass, biomass growth, and control of Italian ryegrass.

The specific objectives were to:

1. Determine impact of timing of N on Italian ryegrass control.
2. Determine the effect of herbicide timing on wheat grain quality, yield and weed control.
3. Evaluate the interaction between N and herbicide applications.

Hypothesis

Early herbicide application to Italian ryegrass in combination with split N rates will result increased wheat grain yield, grain quality, and improved Italian ryegrass control.

CHAPTER III

METHODOLOGY

Locations

The objective of this experiment was to investigate the effect of fall-applied N fertilizer rate and Italian ryegrass removal timing on grain yield and N uptake of winter wheat. This experiment was conducted during the 2011-2012 and 2012-2013 growing seasons at three locations; the Oklahoma State University Agronomy Research Station in Stillwater, the Cimarron Valley Research Station at Perkins and the Oklahoma State University Agronomy Research station near Lake Carl Blackwell. The soil series description for each site is listed in table 1.

Planting

Plots were 3 meters wide and 13.7 meters long. The first 9 meters of each plot (grain harvest plot) was used to collect grain yield and the remaining 4.7 meters was devoted to tissue sampling. This study was conducted to simulate a grain-only production system. Seeding density was 100 kg ha^{-1} at the Lake Carl Blackwell location and 84 kg ha^{-1} at the three remaining locations. ‘Duster’, an Oklahoma State University wheat variety, was the sole variety used in this study, because of its grain yielding potential and its disease resistance. These trials were placed in fields with natural populations of Italian ryegrass.

Treatment Combinations

This study was designed as a randomized complete block split plot arrangement treatment combination. The whole plot factor was fall-applied N fertilizer. Preplant N fertilizer was applied at four rates (0, 37, 74, and 112 kg of actual N ha^{-1}) at the Perkins and Stillwater locations (Table 1). Higher yield goals desired at the Lake Carl Blackwell location, so N application rates were increased to (0, 69, 138, and 207 kg of actual N ha^{-1}). The 28-0-0 UAN, urea ammonium nitrate formulation was chosen for its ability to be applied evenly across plots with minimal error. Treatments that received 37 and 74 kg of N in the fall received a top-dress N application of 74 and 37 kg, to bring the total N rate to 112 kg in the spring. The sub-plot factor was Herbicide application timing (5, 7, 9, and 18 weeks after planting) the first year and (6, 18, and 22 weeks after planting) the second year. Due to extreme weather conditions herbicide treatments 6, 12, 18, and 24 wap were dropped from the study in the 2012-2013 growth season (Table 2). Soil test results collected prior to planting indicated a 37 kg N ha^{-1} residual at Perkins in 2011-2012, 50 kg N ha^{-1} residual at Stillwater in 2011-2012, 3 kg N ha^{-1} residual at Perkins in 2012-2013 and 62 kg N ha^{-1} of residual at Lake Carl Blackwell in 2012-2013.

Herbicides Used

Italian ryegrass was terminated by applying Axial XL (Pinoxaden) at the various application timings. Weed-free and untreated controls plot were also established. Weed-free plots received a pre-emergence application of Zidua (Pyroxasulfone) and follow-up applications of Axial XL as needed. Plots were sprayed with a CO_2 propelled backpack sprayer, applying 60 a Ai ha^{-1} at 57 Liters per ha^{-1} solution of Axial XL with water as the carrier. 11003 Turbo Tee Jet nozzles were selected for product coverage and drift reduction.

Tissue Sampling

After each Italian ryegrass termination, plant biomass samples were collected from the destructive harvest area of each plot that was treated, as well as the weed-free plots to evaluate competition between species. Aboveground wheat and Italian ryegrass biomass was collected from two 19 by 28 cm areas, separated by species, and dried. Dry weights were recorded and representative samples from each species were analyzed for N concentration. Aboveground biomass samples were collected and analyzed for N content from all plots when the wheat was in the wheat boot growth stage, Feekes 10.

Harvest

Grain was collected at the end of each growing season using a Hege 140 plot combine. Grain protein was determined using the Perten Da7200, NIR spectrometer. Treatments were compared based on N content in the wheat and Italian ryegrass, Italian ryegrass control, grain yield, and grain protein content.

CHAPTER IV

FINDINGS

2011-2012 Growing Season Perkins

Biomass Growth

In 2011-2012, biomass samples were collected to evaluate Italian ryegrass competition across two of the four N split rates; 0 kg N ha^{-1} check, 37/74 kg N ha^{-1}, 74/37 kg N ha^{-1} and the 112 kg N ha^{-1} (Figure 1). A significant difference in plant growth was observed 7WAP, due to the amount of pre plant N applied. Italian ryegrass and wheat biomass growth throughout the season is compared in (Figure 2), at the 112 kg N ha^{-1} rate. Following the first herbicide application Italian ryegrass biomass ranged from 22 to 26 kg ha^{-1}, compared to 320 to 416 kg ha^{-1} of wheat biomass. As N rate increased the Italian ryegrass population increased. Uncontrolled Italian ryegrass populations continued to increase in biomass throughout the growing season; however, the heavily dense wheat stand reached upwards of 7707 kg ha^{-1}, suppressing overall Italian ryegrass biomass to 300+ kg ha^{-1} at the wheat boot stage, Feekes 10.

Nitrogen Concentration

Biomass samples were collected at the Feekes 10 growth stage, (boot stage) to evaluate the percent of N concentration in the wheat across herbicide treatments (Figure

3). In 2011-2012, the percent of N concentration in the wheat biomass at Perkins fluctuated across both herbicide and N treatments, however no significant difference was discovered in herbicide timing or in the interaction between herbicide and N applications (Table 6). The 112 kg N ha^{-1} rate, WF, produced the greatest N content recorded in wheat biomass at 1.87, while the 112 kg N ha^{-1} rate, UN had an N content of 1.4.

Grain Yield

In 2011-2012, the WF and 5WAP, 37/74 kg N ha^{-1} split rate, produced the greatest grain yields at 3169 and 3341 kg ha^{-1}, the UN check from the 37/74 kg N ha^{-1} rate yielded 2807 kg ha^{-1} (Figure 4). A significant difference was discovered in the 0 N fertilizer rate. The delay in herbicide application timing until spring, at the 0 N rate, resulted in the lowest grain yield of 1290 kg ha^{-1}. A significant differences was recorded when delaying Italian ryegrass control until the 18WAP, spring application timing resulting in yield losses of 66 to 431 kg ha^{-1} across N rates (Table 5). A significant difference was discovered in both main effects (Table 6).

Grain Protein

The 37/74 N split rate, WF, and 5 WAP produced the greatest grain protein content at 10.1% (Figure 5). Grain protein content were significantly reduced, when Italian ryegrass was uncontrolled. The lowest protein levels recorded from each of the four N rates were all the untreated checks (Table 5). No significant difference was discovered between the interaction of the herbicide timings and N applications (Table 6).

Dockage

In 2011-2012, the 0 kg N ha^{-1} rate, UN check had the greatest dockage 1.4, the 0 kg N ha^{-1} rate, WF only received 0.6 dockage (Figure 6). The delay in herbicide application timing after the fall and into the spring resulted in a significant increase in dockage across all N rates (Table 5). No significant difference was documented in N applications (Table 6).

2012-2013 Growing Season Perkins

Biomass Growth

In 2012-2013 at Perkins, Italian ryegrass growth and development started off slowly due to dry, hot weather in the fall, but moisture received during late winter and early spring quickly increase growth (Figure 7). Limited moisture early in the growing season reduced N uptake by both species, but moisture received in early spring increased plant growth and N uptake significantly. Italian Ryegrass biomass ranged from 36 kg ha^{-1} in late fall to 1840 kg ha-^{1},collected at the wheat boot stage Feekes 10 wheat samples collected at the same time periods yielded 292 kg ha-^{1} and 8419 kg ha-^{1} (Figure 8).

Nitrogen Concentration

In 2012-2013, at Perkins the highest levels of N concentration in wheat biomass resulted from the 37/74 kg N ha^{-1} split rate (Figure 9). The timing of the N rate applied significantly affected N content levels. However, the delay in herbicide application timing showed no significant effects on the percent levels of N concentration (Table 9).

Grain Yield

Grain yield from the 2012-2013 growing season at Perkins indicated decreased yield when herbicide timing was delayed (Figure 10). The 112 kg N ha^{-1} rate, UN and the 6WAP, produced grain yield of 3786 and 4206 kg ha^{-1}. The delay in herbicide application timing at the two N split rates resulted in little to no significant difference in yields (Table 8). A significant difference was discovered in N application rates (Table 9).

Grain Protein

In the 2012-2013 growing season at Perkins the 37/74 kg N ha^{-1} split rate produced the greatest protein levels, ranging from 15.25 to 16.73 (Figure 11). The 74 kg N ha^{-1} applied in February significantly increased wheat protein levels compared to the three remaining N rates. The delay in herbicide application timing had no significant effect on grain protein levels (Table 9).

Dockage

In 2012-2013 the dockage percent ranged from 1.76 to 3.73across the entire study, in the 0 kg N ha^{-1} rate, the WF and UN had recorded dockages of 1.9 and 2.98, with the lowest level being the 18WAP (Figure 12). No significant differences were discovered in herbicide application timing, N applications or the interaction between the two (Table 9).

2011-2012 Growing Season Stillwater

Biomass Growth

In the fall of 2011, Italian ryegrass biomass ranged between 4.5 and 5.6 Kg ha^{-1} across all four N rates, which is lower than expected (Figure 13). The wheat at the Stillwater location out-grew the Italian ryegrass early in the season naturally shading out the Italian ryegrass. The well-established wheat stand reduced Italian ryegrass competition for resource uptake, allowing the crop to express its full potential. The Italian ryegrass growth remained low throughout most of the growing season only accumulating up to 32 to 39.6 Kg ha^{-1} across all N rates at the 18WAP application timing in the spring. Italian ryegrass biomass weight of 270 Kg ha^{-1} and wheat biomass weight of 7603 Kg ha^{-1} were collected from the untreated, 112 kg N ha^{-1} rate plot at the wheat boot stage, Feekes 10 (figure 14). The weather conditions at Stillwater in the fall of 2011 where ideal for early season growth, stimulating wheat growth and production. Italian ryegrass growth was significantly reduced by the highly competitive, well-established wheat crop.

Nitrogen Concentration

In 2011-2012, the 37/74 kg N ha^{-1} split rate, WF, had the highest percent N concentration recorded at the Stillwater Location 1.98, the 37/74 kg N ha^{-1} split rate, UN, N concentration level was 1.66 (Figure 15). The only difference was the 0 N rate, UN, 1.33. No significant difference was discovered in herbicide timings or the interaction between N and herbicide timings (Table 12).

Grain Yield

In 2011-2012, the 9WAP, 37/74 kg N ha^{-1} split rate, resulted in the highest grain yield at 3699 Kg ha^{-1} , the 37/74 kg N ha^{-1} split rate, UN check yielded 3538 (Figure 16). No significant difference in grain yield was recorded with the delay in herbicide timing from treatment 7 through 24, which all received a total of 112 kg N ha^{-1}. However, grain yields were reduced by 8 to 9% in the 0 kg N ha^{-1} check, displaying a significant differences in N applications (Table 12).

Grain Protein

In 2011-2012, the 112 kg N ha^{-1} rate, 9WAP, had the greatest protein content level recorded across all treatments at 12%, the 112 kg N ha^{-1} rate, UN check displayed a protein level of 11.4 (Figure 17). The protein levels were significantly reduced in the 0 kg N ha^{-1} rate applied. No significant difference in protein content was discovered when the herbicide timings were delayed at this site year (Table 12).

Dockage

In 2011-2012, the 112 kg N ha^{-1} rate, WF and UN had recorded dockage levels of 0.09 and 0.68 (Figure 18). The highest and lowest levels of dockage recorded were from the 0 and 112 kg N ha^{-1} rates, WF. The interpretation of these values is difficult to analyze due to the variability in levels of dockage. No significant difference was discovered in dockage with the delay in herbicide timing or N application rates (Table 12).

2012-2013 Growing Season Lake Carl Blackwell

Biomass Growth

In 2012-2013, hot dry weather conditions delayed early fall growth of both wheat and Italian ryegrass species (Figure 19). An extremely low Italian ryegrass population was present during the fall and early spring. By mid spring adequate moisture and weather conditions encouraged Italian ryegrass growth and rapidly increased competitiveness for resources between the two species. An interaction was documented between herbicide timing and N fertilizer applied on Italian ryegrass growth (Table 15). At the 22WAP removal timing 4.7 kg ha^{-1} of Italian ryegrass and 486 Kg ha-1 of wheat biomass was collected from the 185 kg N ha^{-1} rate. A significant increase in both Italian ryegrass and wheat biomass was collected from the untreated, 185 kg N ha^{-1} rate plots at the wheat boot stage ranging from 1226 Kg ha^{-1} and 5000 Kg ha^{-1} (Figure 20).

Nitrogen Concentration

In 2012-2013, the percent of N concentration ranged from 2.21 to 3.34 across the study with 3.34 being observed in the 74/37 kg N ha^{-1} split rate, 22WAP (Figure 21). The 0 kg N ha^{-1} rate, UN, was the lowest N concentration level at 2.21. No variation in N concentration levels were documented in result of herbicide timing the only significant difference was discovered between the N application rates (Table 15).

Grain Yield

The highest grain yield recorded at the Lake Carl Blackwell location was Treatment 1 the 0 N rate, WF, at 3837 kg ha^{-1} , the 0 N rate, UN check yielded 3383 kg ha^{-1} (Figure 22). Late freezes reduced yield in the fertilized plots as grain was starting to mature, the 0 N check was farther behind in maturity protecting the plant from the weather. No significant differences on yield can be based on herbicide timings applied at this location due to inconsistence (Table 15).

Grain Protein

The highest protein level recorded was 17% which was recorded from treatment 21, the 74/37 kg N ha^{-1} split rate, 6 WAP herbicide timing, the 74/37 kg N ha^{-1} split rate, UN, displayed a grain protein content of 15% (Figure 23). The protein levels recorded displayed no significant difference due to the delay in herbicide application timing (Table 15). A significant difference was observed in wheat grain that received the 0 N fertilizer rate (Table 12).

Dockage

The highest and lowest levels of dockage 0.832 and 0.303 % were recorded from the UN check and the WF, at the 37/74 kg N ha^{-1} split rate and 74/37 kg N ha^{-1} split rates (Figure 24). No significant difference was recorded in dockage levels across either herbicide timings or N application rates during the 2012-2013 growing season at Lake Carl Blackwell (Table 15).

CHAPTER V

CONCLUSIONS

Environmental and weather conditions during the 2011-2012 and 2012-2013 growing seasons had the greatest influence on wheat and Italian ryegrass production. Optimal growing conditions in the fall, winter and spring of the 2011-2012 growing season boosted winter wheat growth, giving the crop the upper hand. The low Italian ryegrass density at both location in 2011-2012 had to compete against a well-established wheat crop. The poor soil fertility in the 0 Kg N ha^{-1} application rate reduced wheat N concentration and protein content. The largest levels of dockage recorded in the 2011-2012 growing season came from treatments that received 0 kg N ha^{-1}, however the N application rates had no significant effect on dockage at all site years. The 0 kg N ha^{-1} allowed the Italian ryegrass to compete with a less competitive wheat crop. The fall of 2012 presented extremely hot and dry weather conditions which induced early crop dormancy and delaying Italian ryegrass germination. The delay in crop growth and development reduced the amount of N use in the fall. The N applied prior to planting was not used by the wheat crop until adequate moisture was received in the spring. At this time post applications of N applied resulting in no significant differences in N application rates. The results from this study confirm that in the presents of low Italian ryegrass densities split N application rates are not need to significantly increase wheat yield.

Early herbicide application timings in the fall resulted in the highest of grain yields at all four locations. However no significant differences were documented in grain yield, N concentration and dockage at all site years, due to low Italian ryegrass densities and weather conditions. The delay in Italian ryegrass control until spring resulting in loss of grain yield and quality. Protein content levels where reduced in the 2011-2012 growing season at both locations when herbicide applications where delayed. During the 2012-2013 growing season herbicide application timing had no effect on grain protein, low Italian ryegrass competition and extreme weather conditions may have caused this response.

Differences in weather patterns, climates, soil types and Italian ryegrass densities all affected yield and more importantly grain quality. A threshold on detrimental Italian ryegrass populations was unidentified in yield loss and grain quality when Italian ryegrass populations were left uncontrolled. However (Barnes 2001) in Oklahoma determined a threshold of 105 to 160 Italian ryegrass plants/m^2 present will reduce grain yields by 36 %. With dockage levels and fertilizer prices being at an all-time high, Italian ryegrass control is becoming more crucial for wheat producers to maintain. Furthermore additional research needs to examine this interaction in more detail to define the timings that will cause the herbicide and N to increase the efficiency of each other.

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Tables and Figures

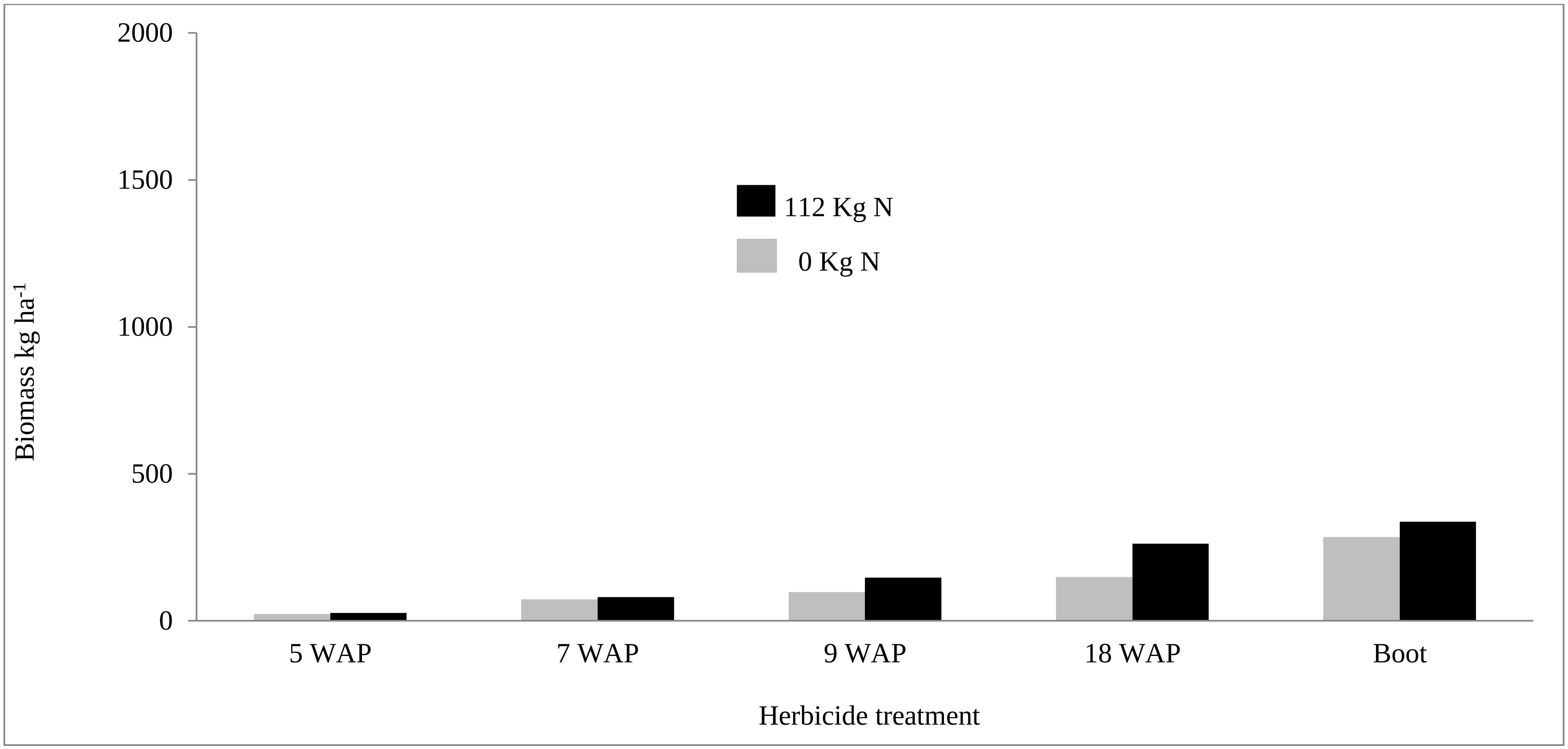


Figure 1. Herbicide and N fertilizer timing effects on Italian ryegrass growth, Perkins 2011-2012. WAP= Week after planting

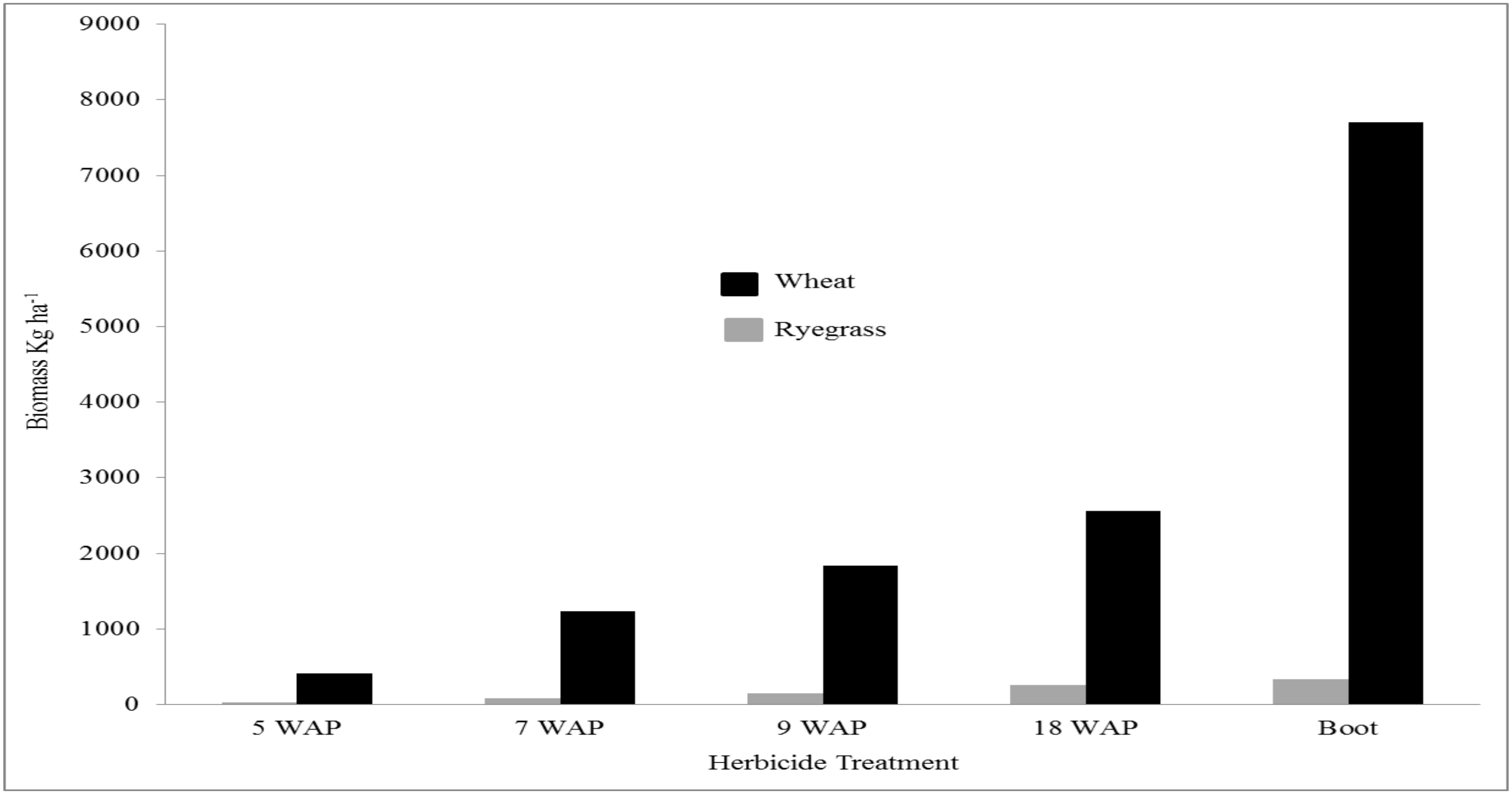


Figure 2. Italian ryegrass and Wheat Biomass at the 112 kg N ha^{-1} split rate, Perkins 2011-2012. WAP= Week after planting. ● = Extremely low Italian ryegrass population.

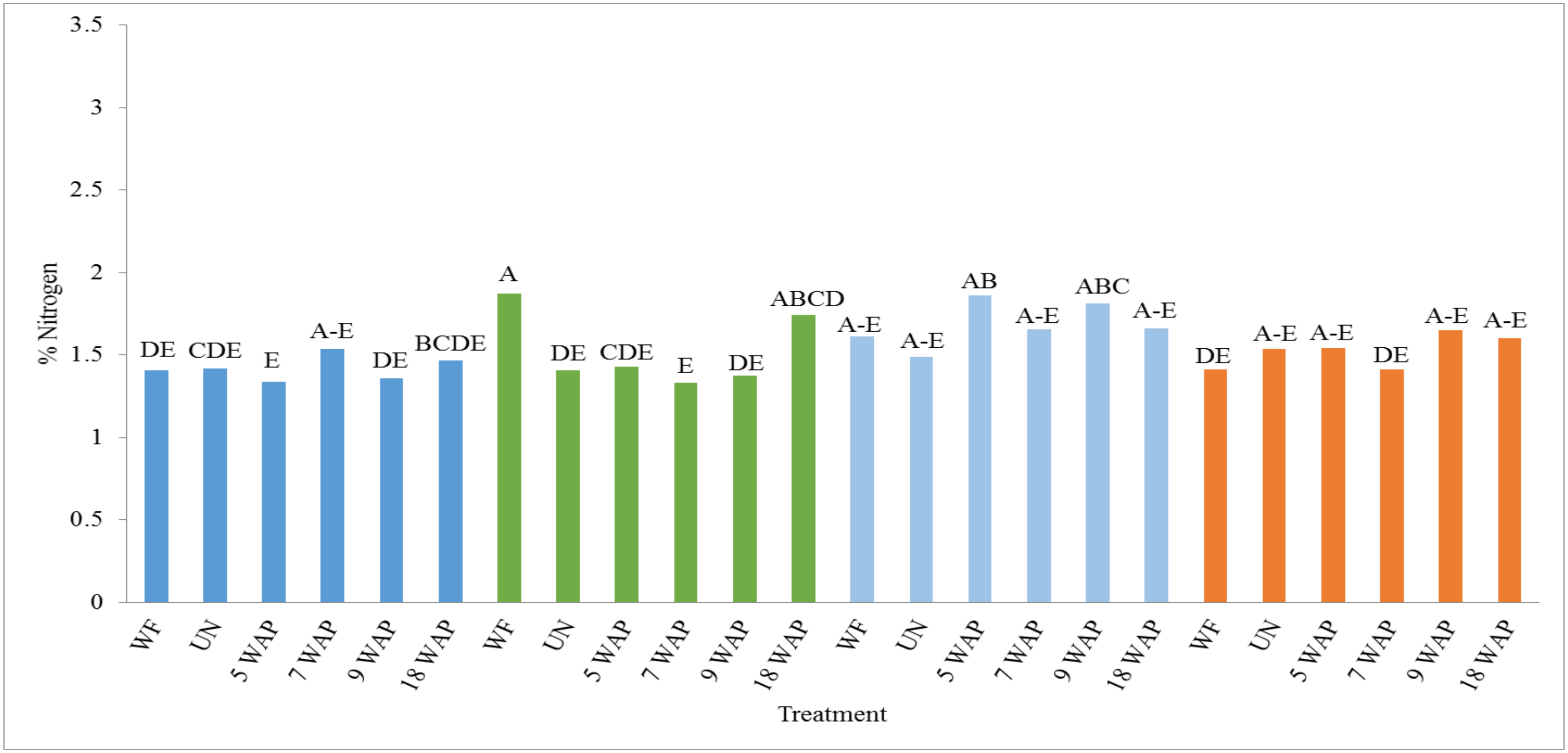


Figure 3. Herbicide and N fertilizer timing effects on N content in wheat at boot stage, Perkins 2011-2012. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).

= 0 N rate = 112 N rate = 37/74 N rate = 74/37 N rate

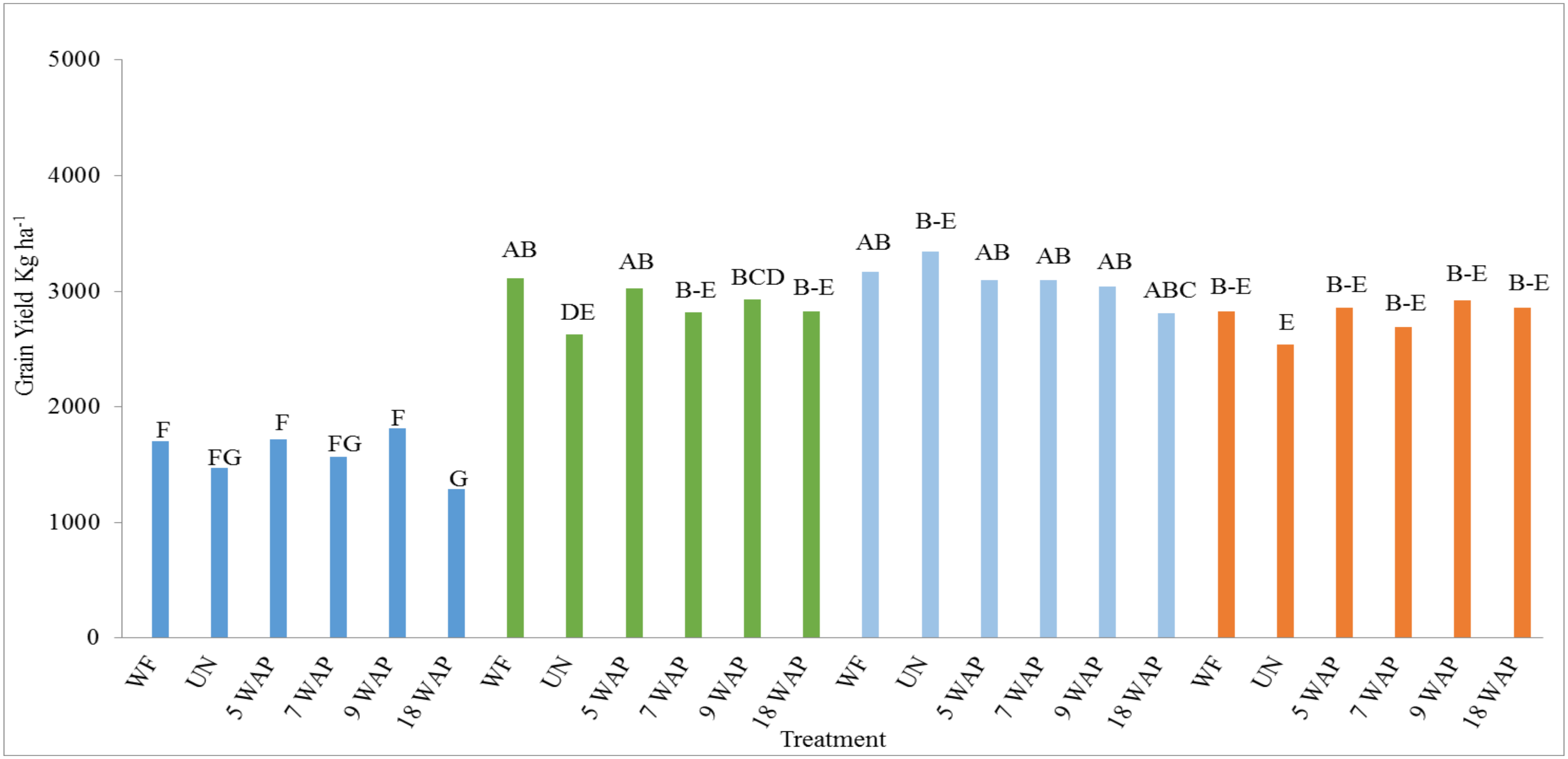
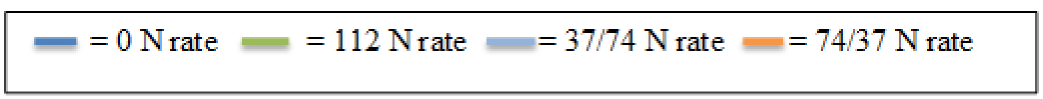


Figure 4. Herbicide and N fertilizer timing effects on Grain Yield in Kg ha^{-1}, Perkins 2011-2012. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).



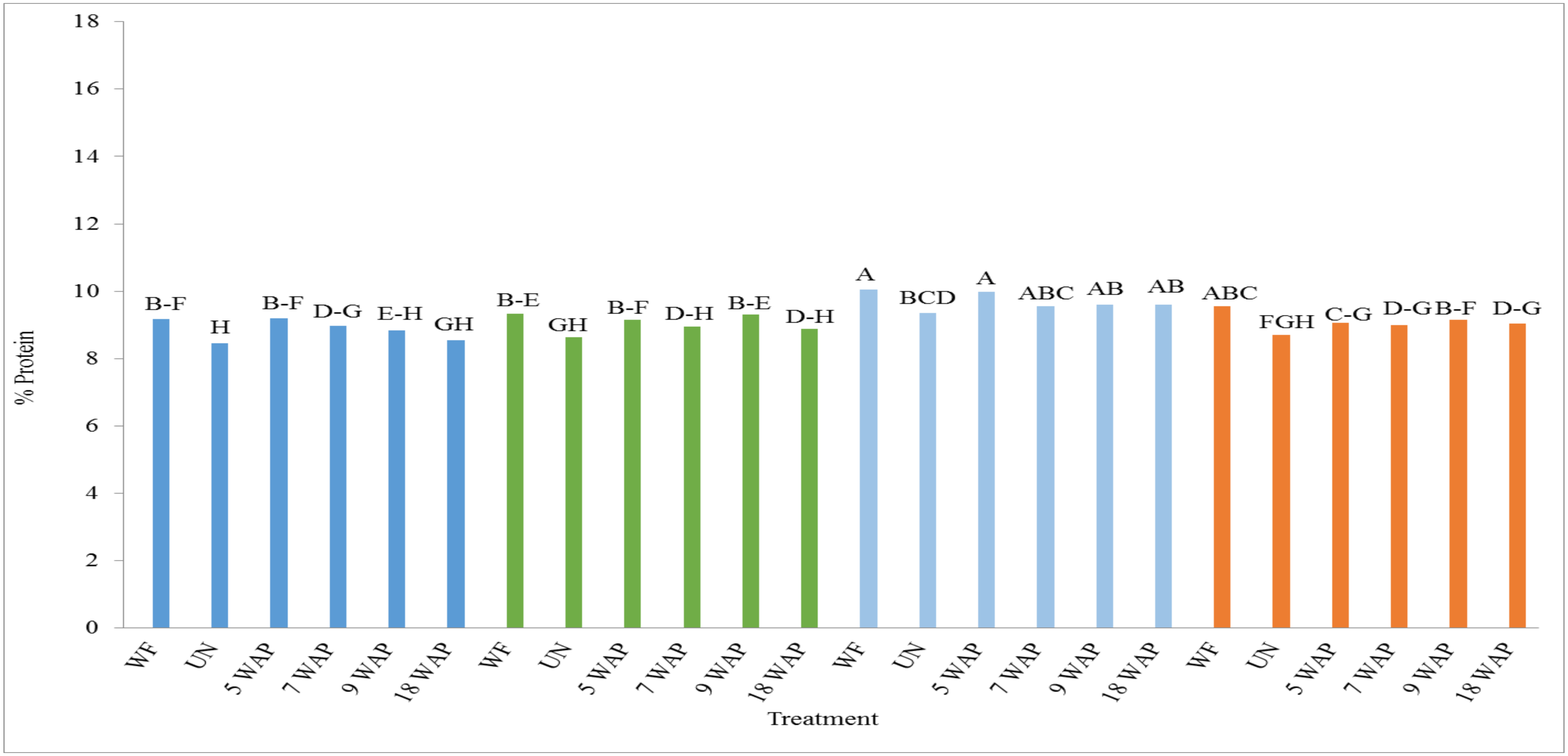
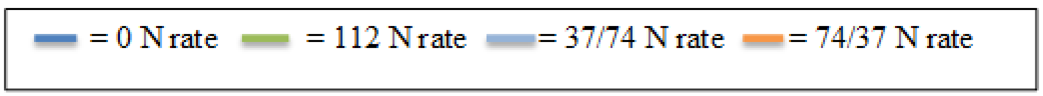


Figure 5. Herbicide and N fertilizer timing effects on Protein content levels, Perkins 2011-2012. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).



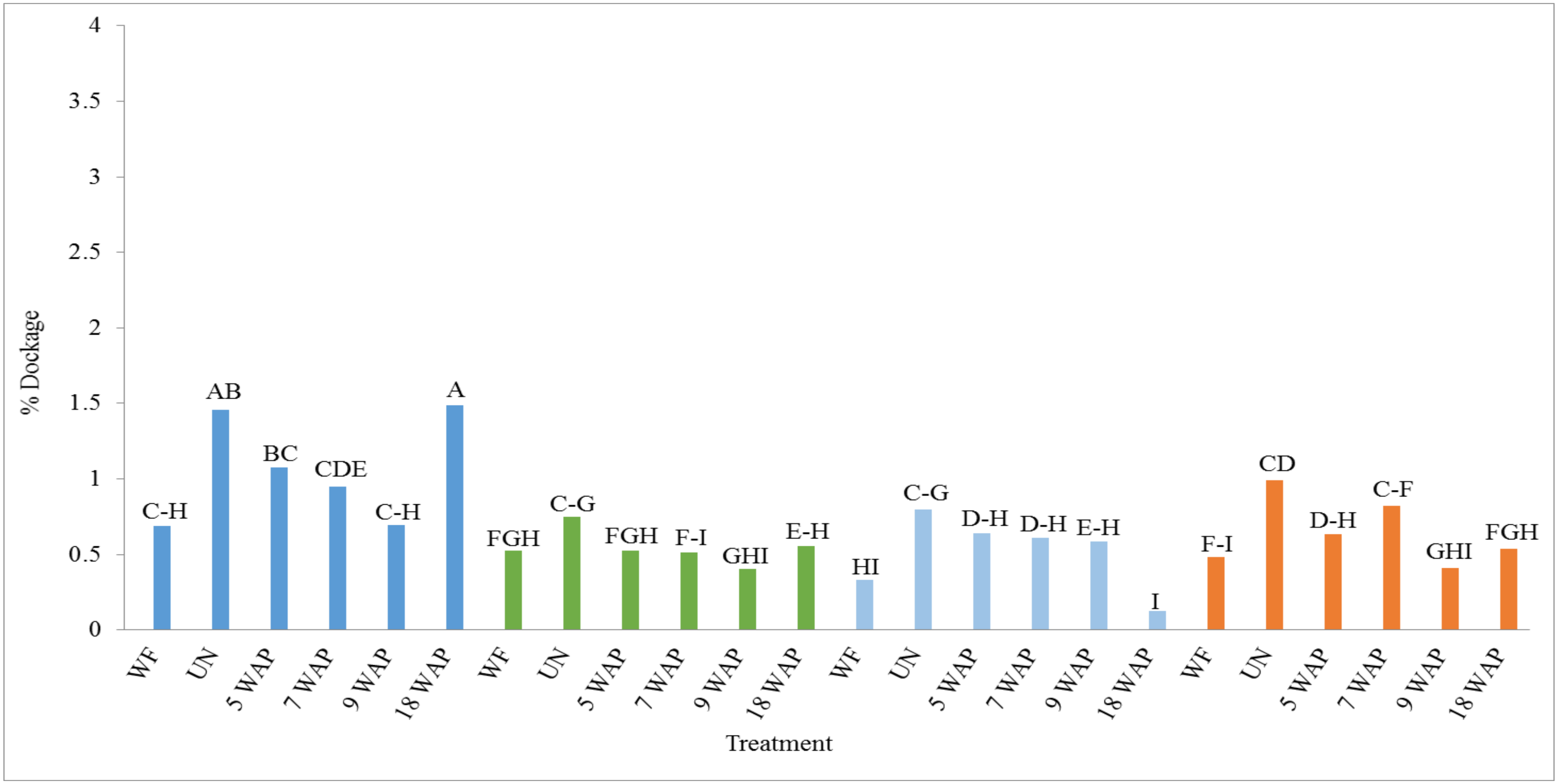


Figure 6. Herbicide and N fertilizer timing effects on Dockage levels, Perkins 2011-2012. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).

= 0 N rate = 112 N rate = 37/74 N rate = 74/37 N rate

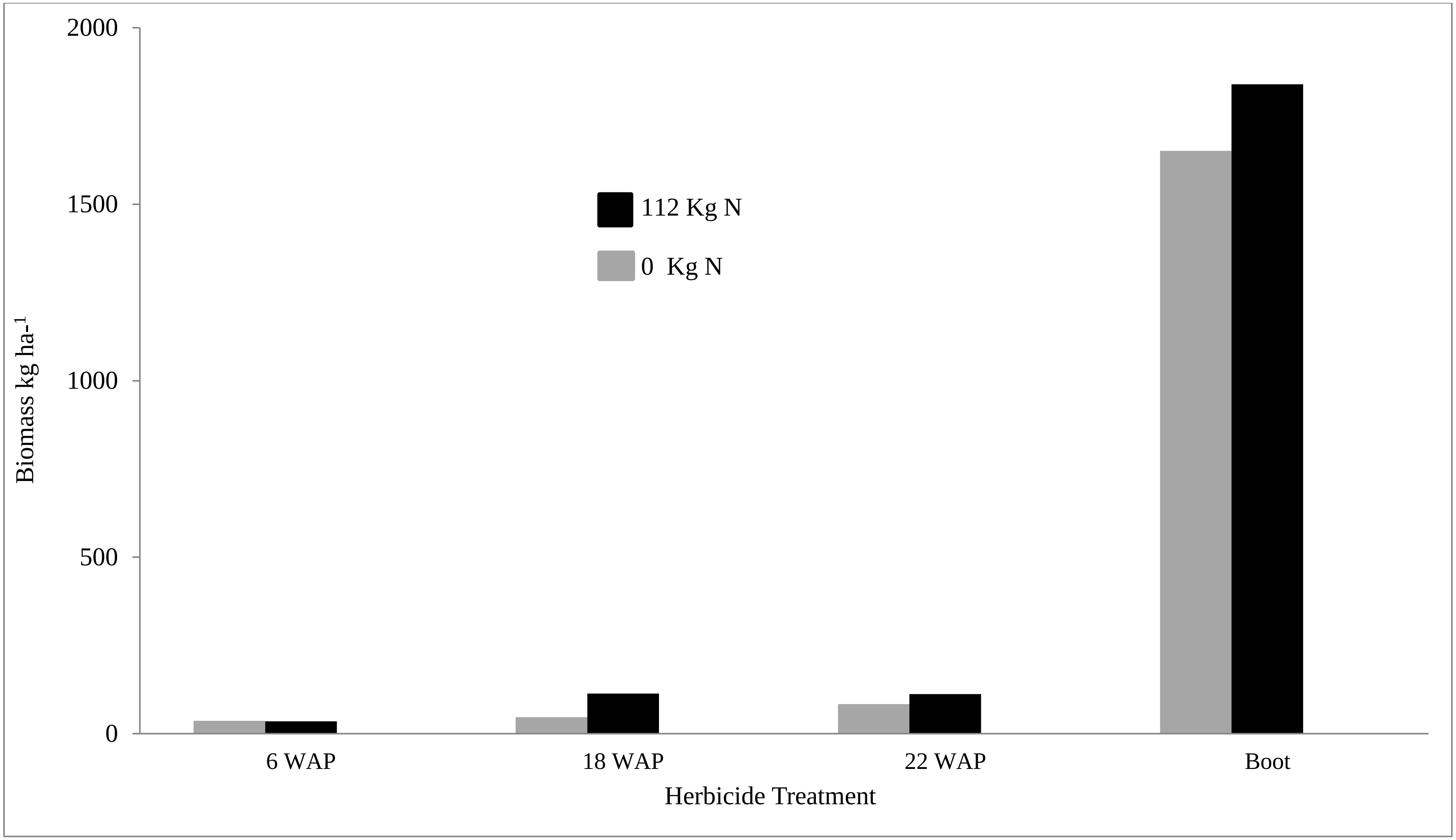


Figure 7. Herbicide and N fertilizer timing effects on Italian ryegrass growth, Perkins 2012-2013. WAP= Week after planting

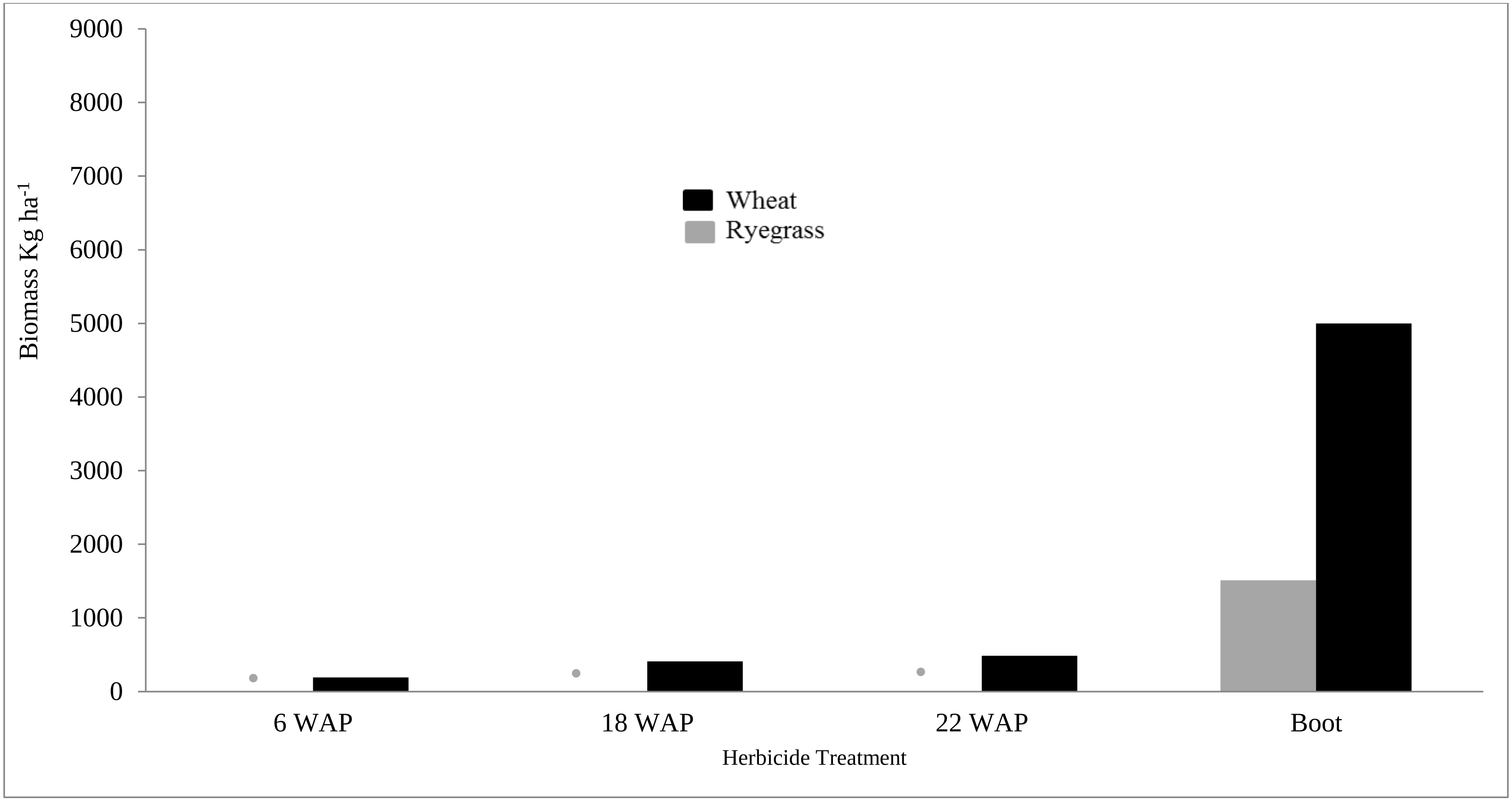


Figure 8. Italian ryegrass and Wheat Biomass at the 112 kg N ha^{-1} split rate, Perkins 2012-2013. WAP= Week after planting. ● = Extremely low Italian ryegrass population.

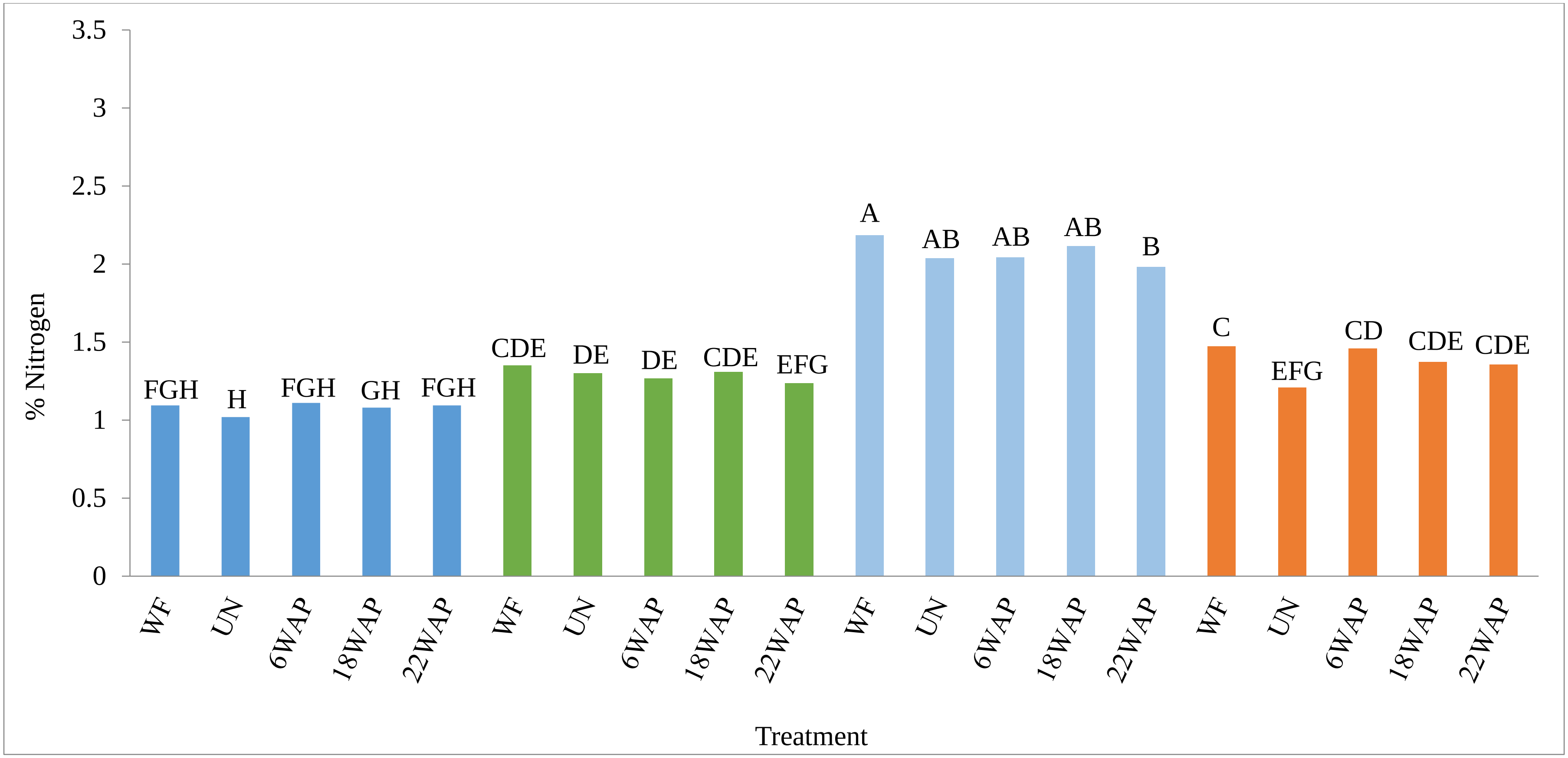
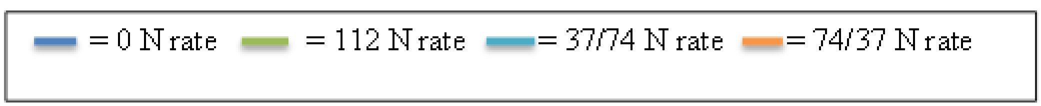


Figure 9. Herbicide and N fertilizer timing effects on N content in wheat at boot stage, Perkins 2012-2013. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).



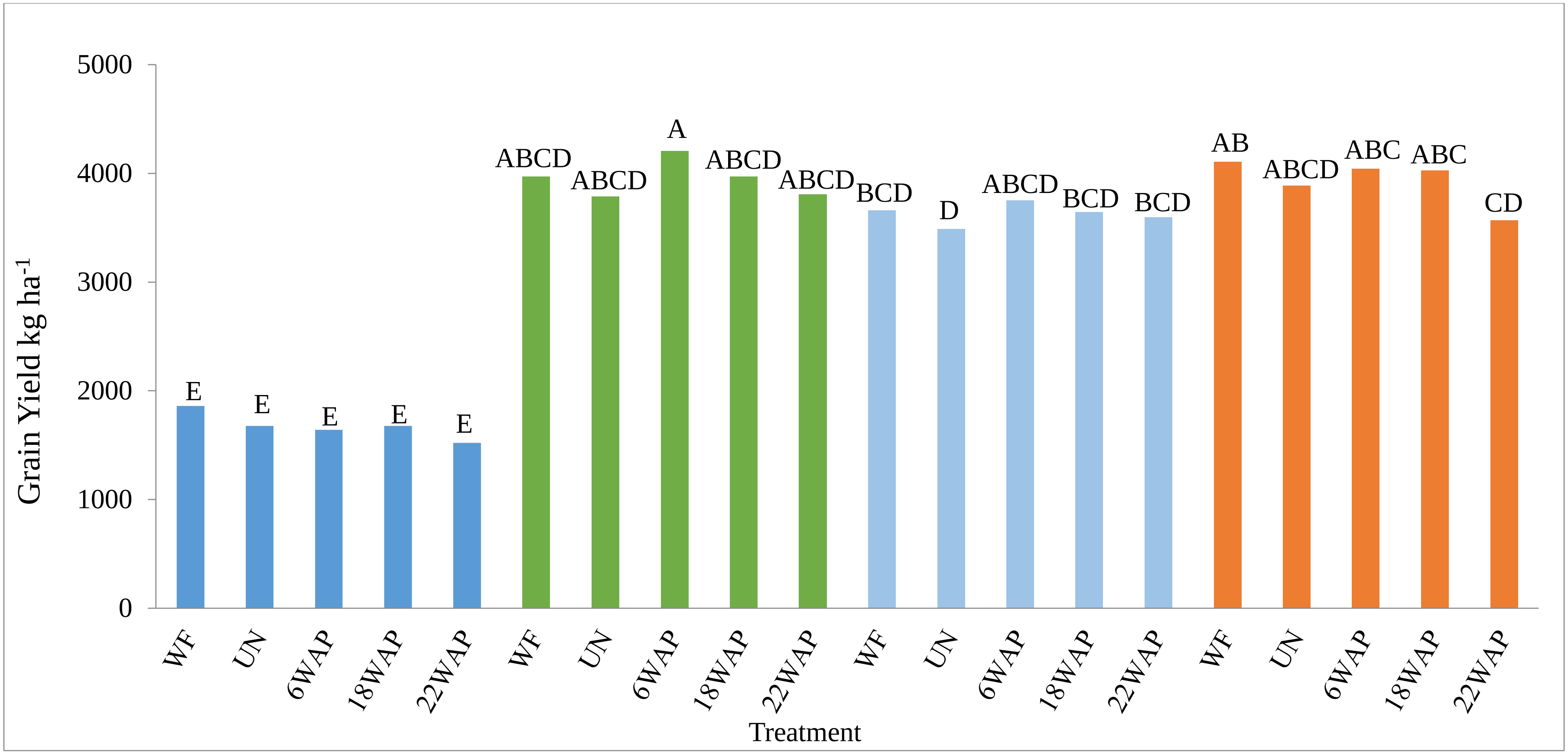


Figure 10. Herbicide and N fertilizer timing effects on Grain Yield in Kg ha^{-1}, Perkins 2012-2013. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).

= 0 N rate = 112 N rate = 37/74 N rate = 74/37 N rate

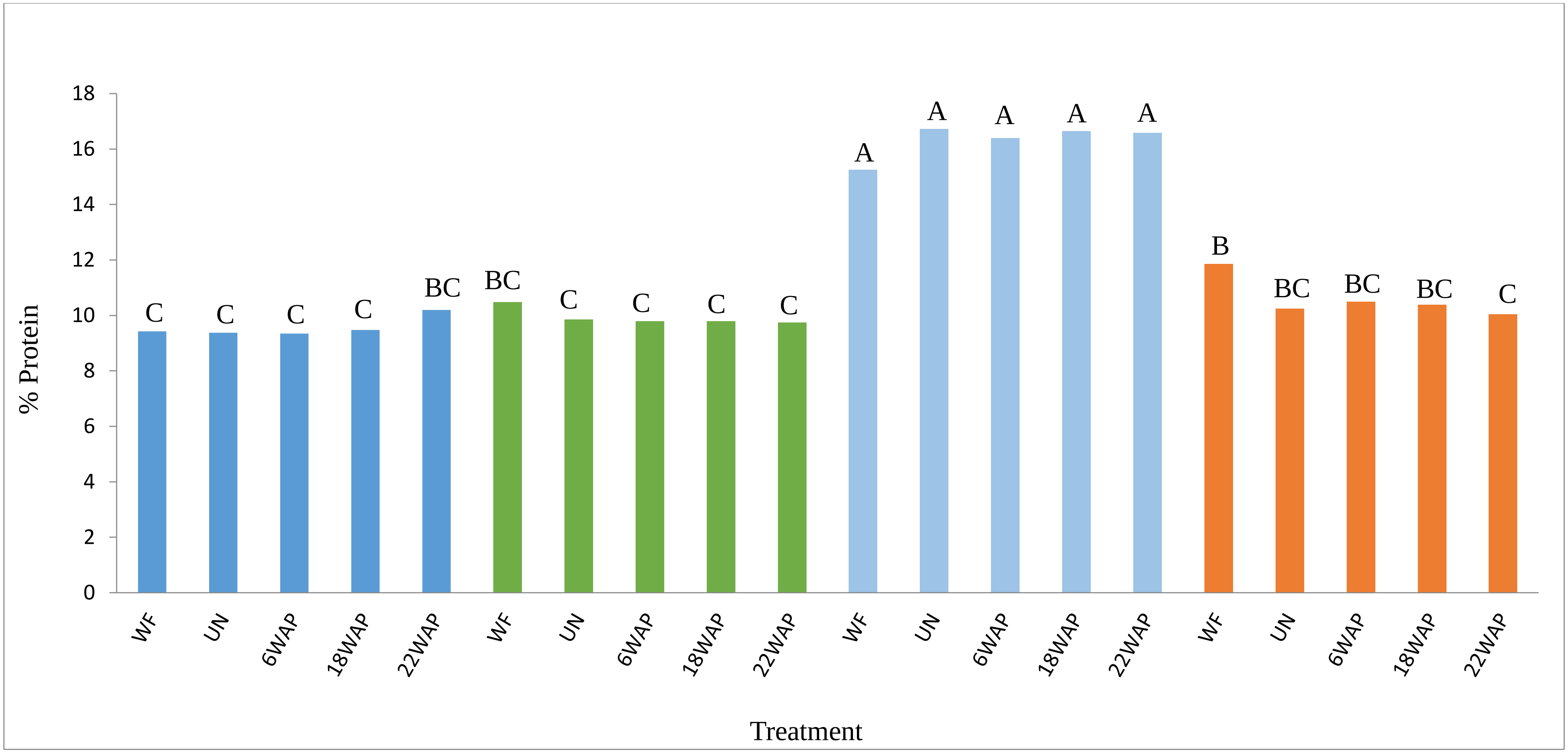
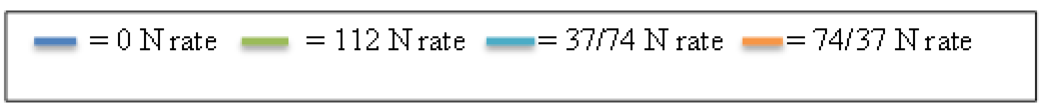


Figure 11. Herbicide and N fertilizer timing effects on Protein content levels, Perkins 2012-2013. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).



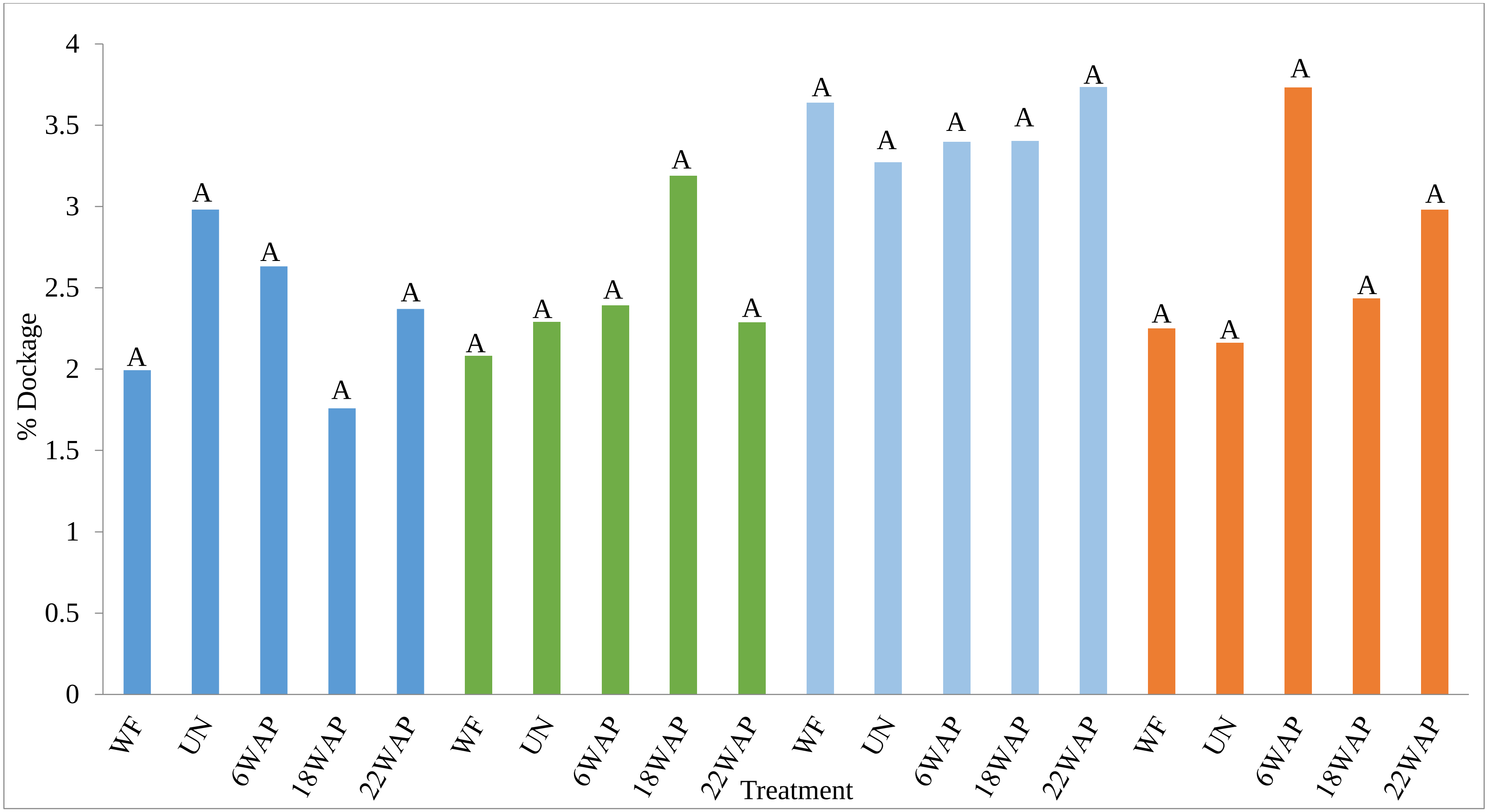


Figure 12. Herbicide and N fertilizer timing effects on Dockage levels, Perkins 2012-2013. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).

= 0 N rate = 112 N rate = 37/74 N rate = 74/37 N rate

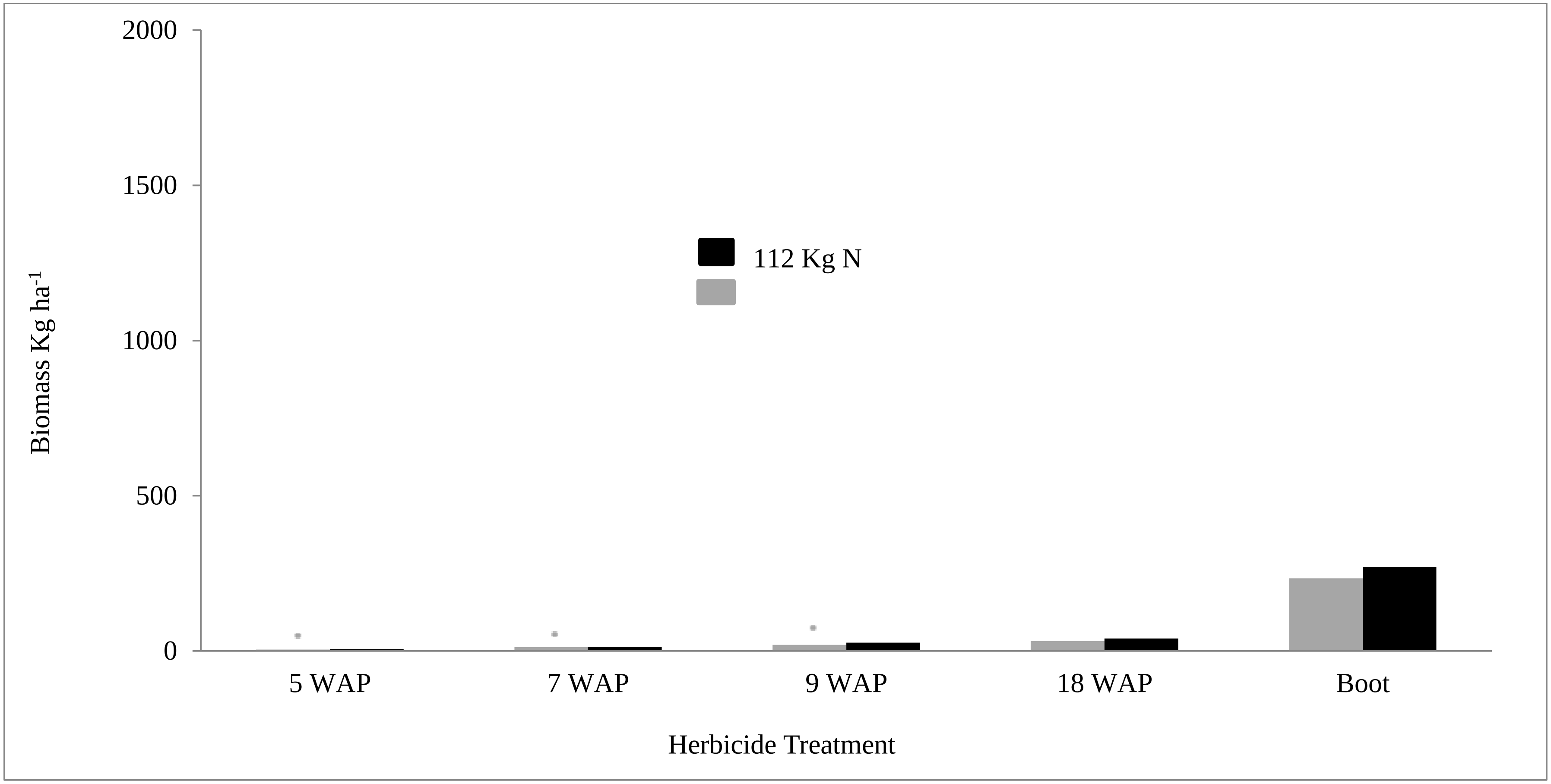


Figure 13. Herbicide and N fertilizer timing effects on Italian ryegrass growth, Stillwater 2011-2012. WAP= Week after planting • = Extremely low Italian ryegrass population.

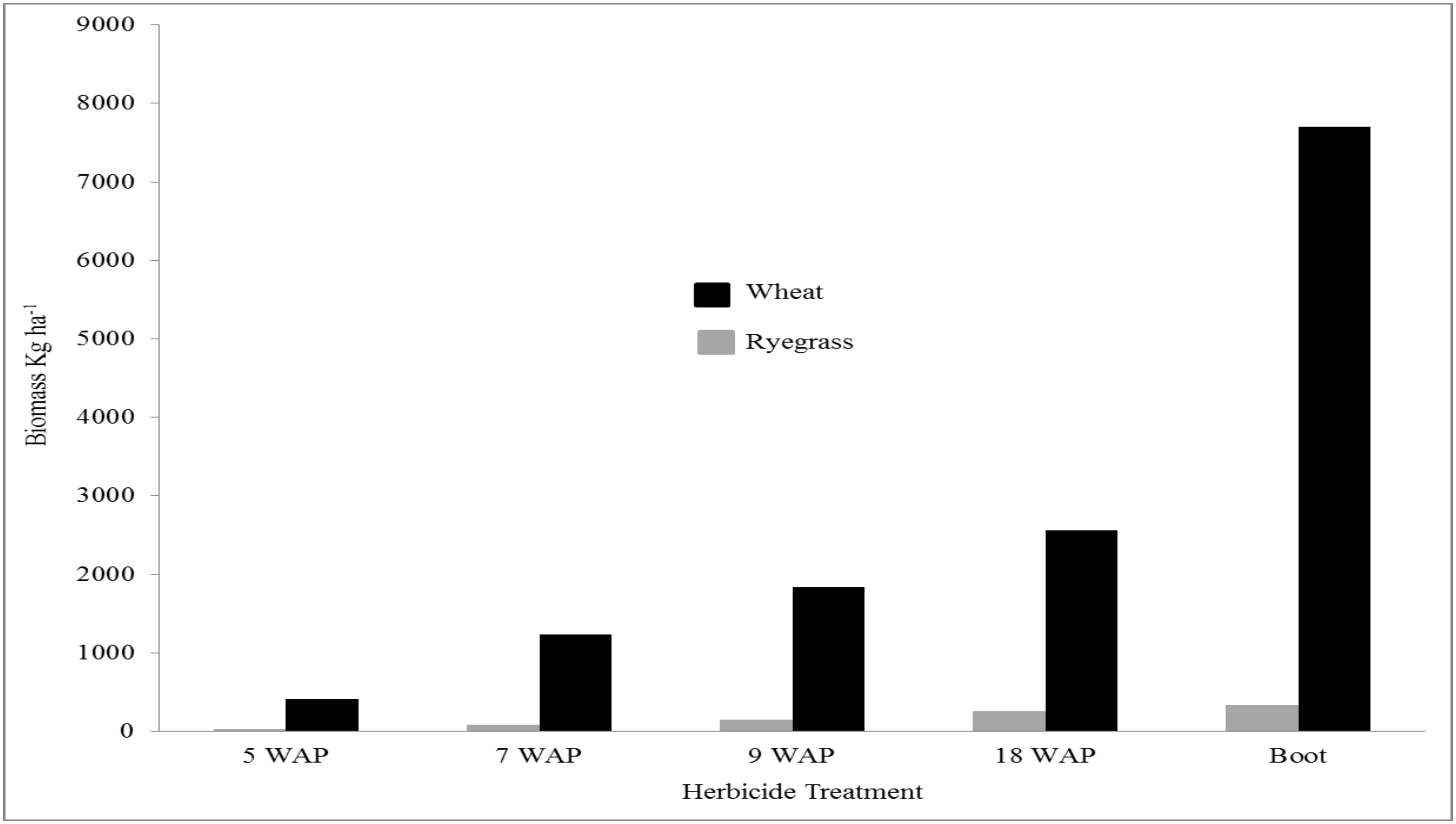


Figure 14. Italian ryegrass and Wheat Biomass at the 112 kg N ha^{-1} split rate, Stillwater 2011-2012. WAP= Week after planting.

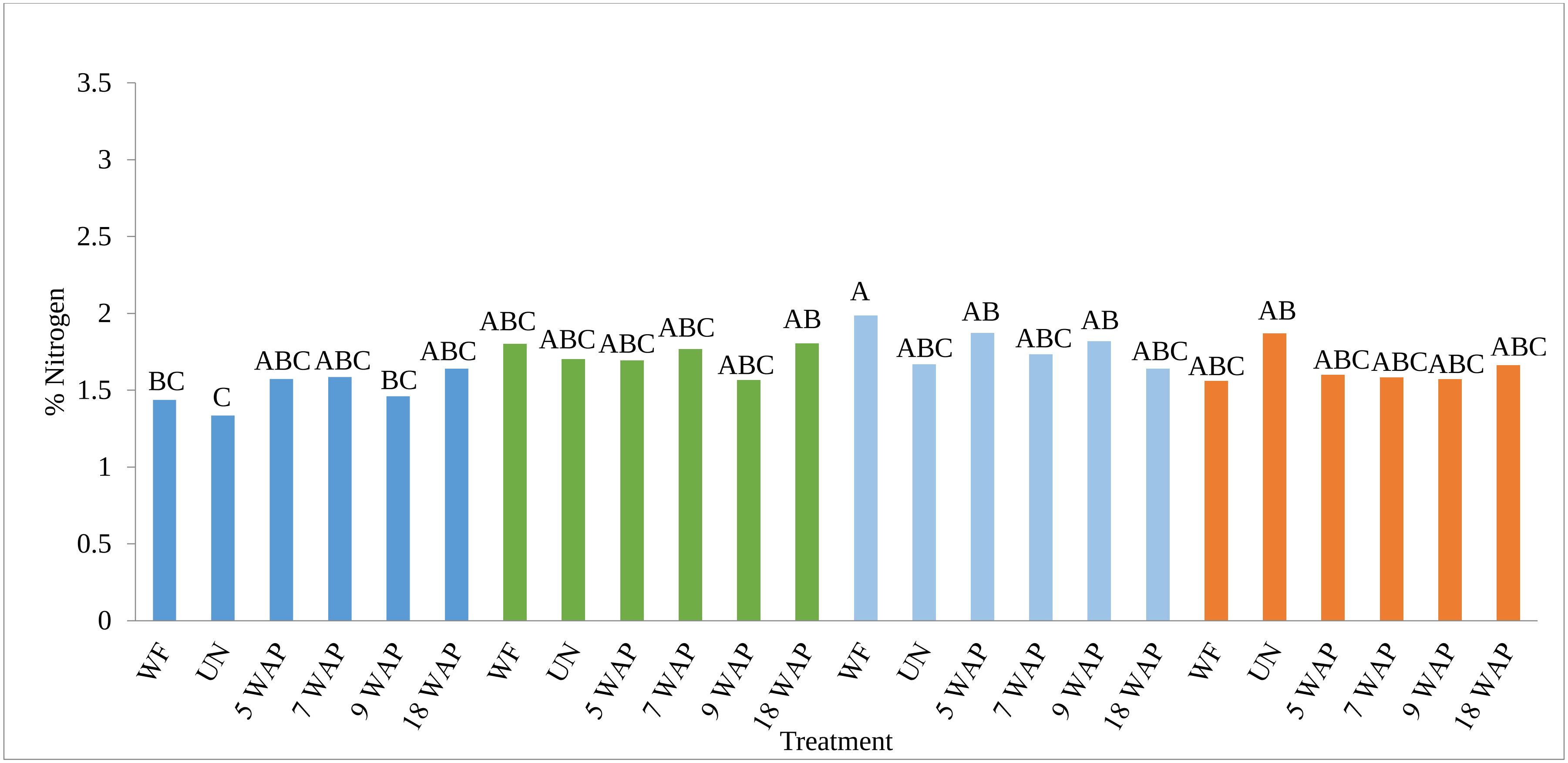
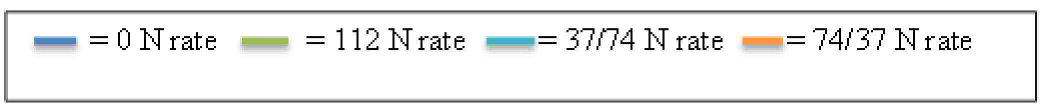


Figure 15. Herbicide and N fertilizer timing effects on N content in wheat at boot stage, Stillwater 2011-2012. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).



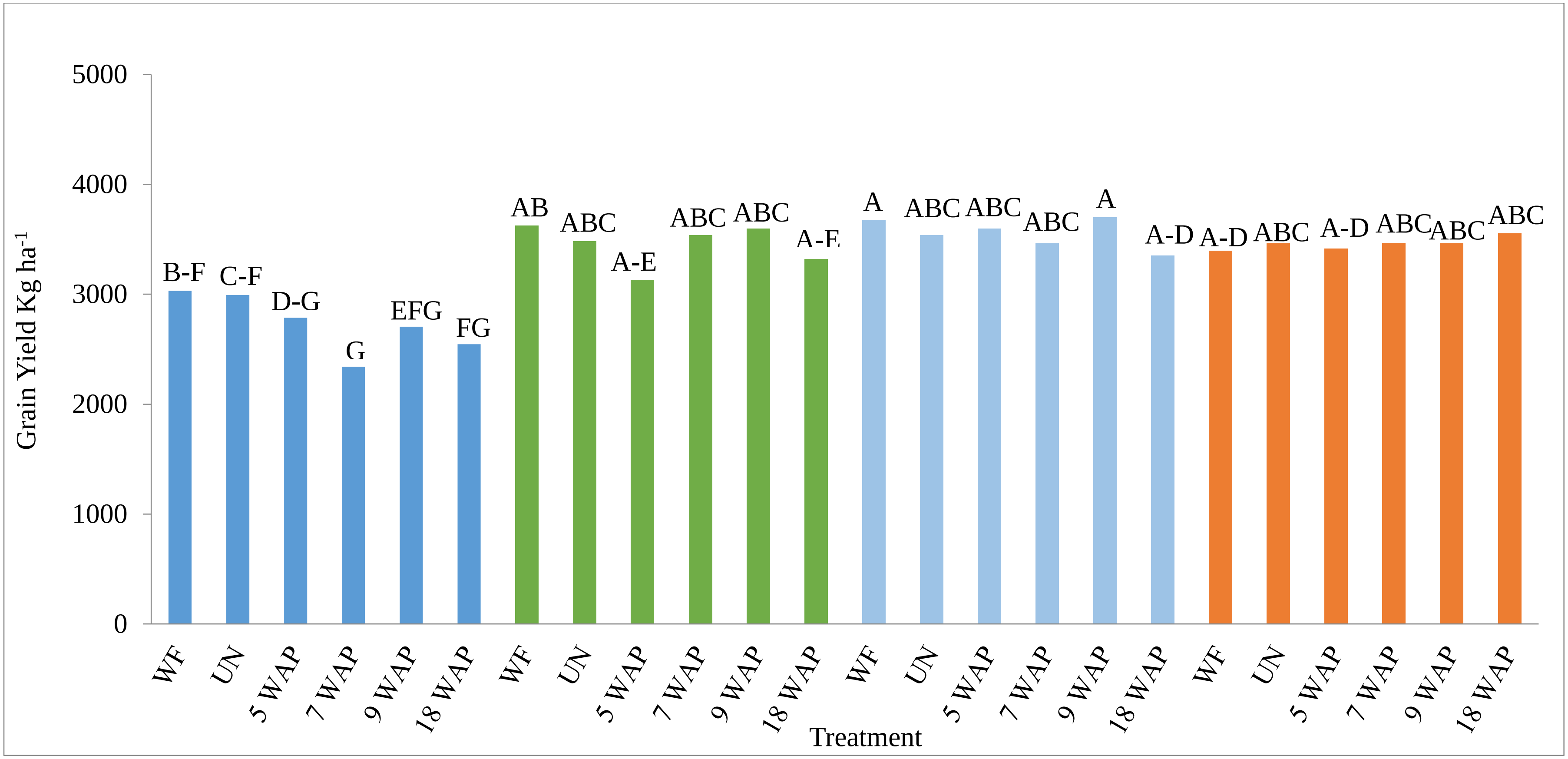


Figure 16. Herbicide and N fertilizer timing effects on Grain Yield in Kg ha^{-1}, Stillwater 2011-2012. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).

= 0 N rate = 112 N rate = 37/74 N rate = 74/37 N rate

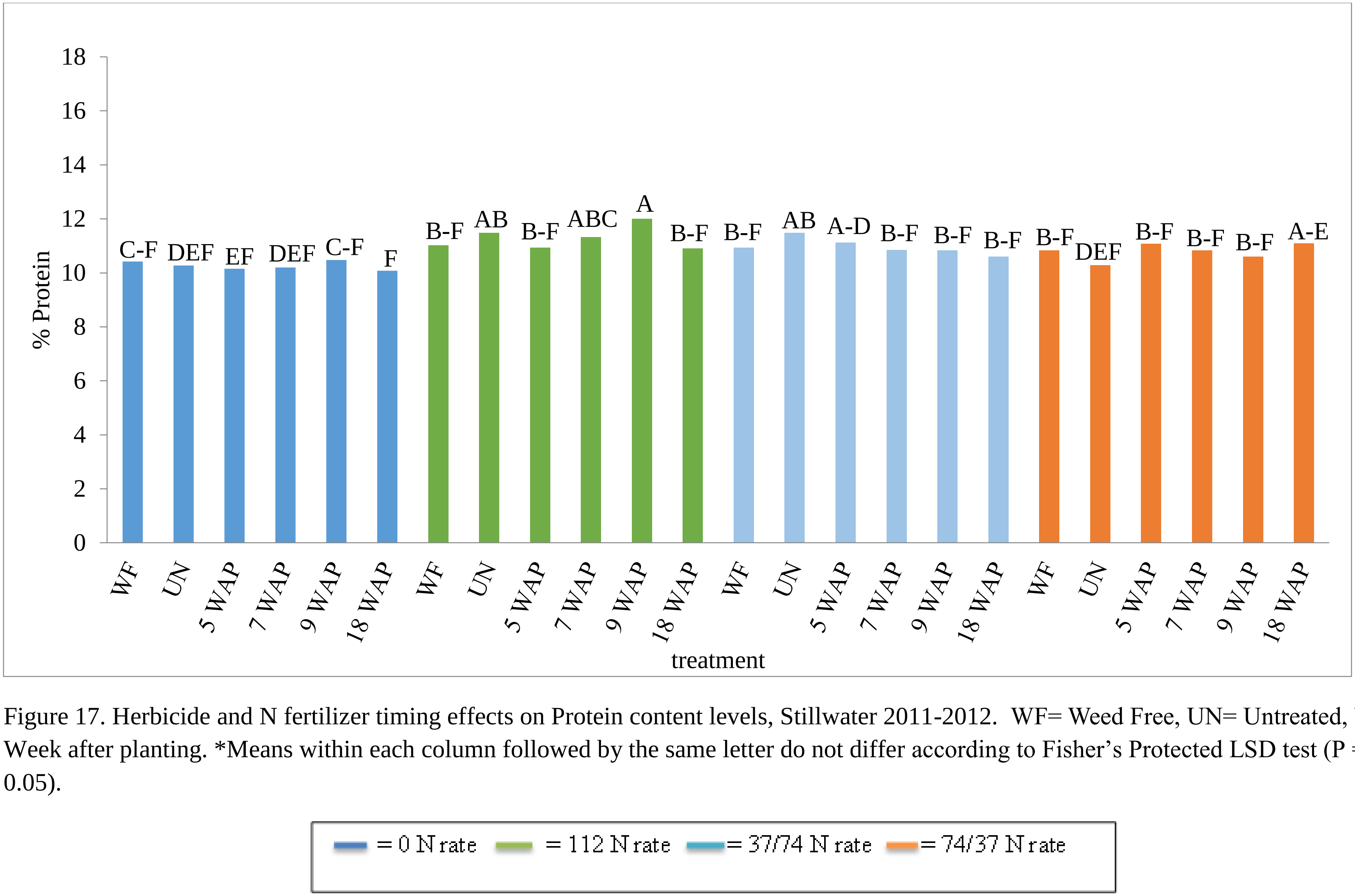


Figure 17. Herbicide and N fertilizer timing effects on Protein content levels, Stillwater 2011-2012. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).

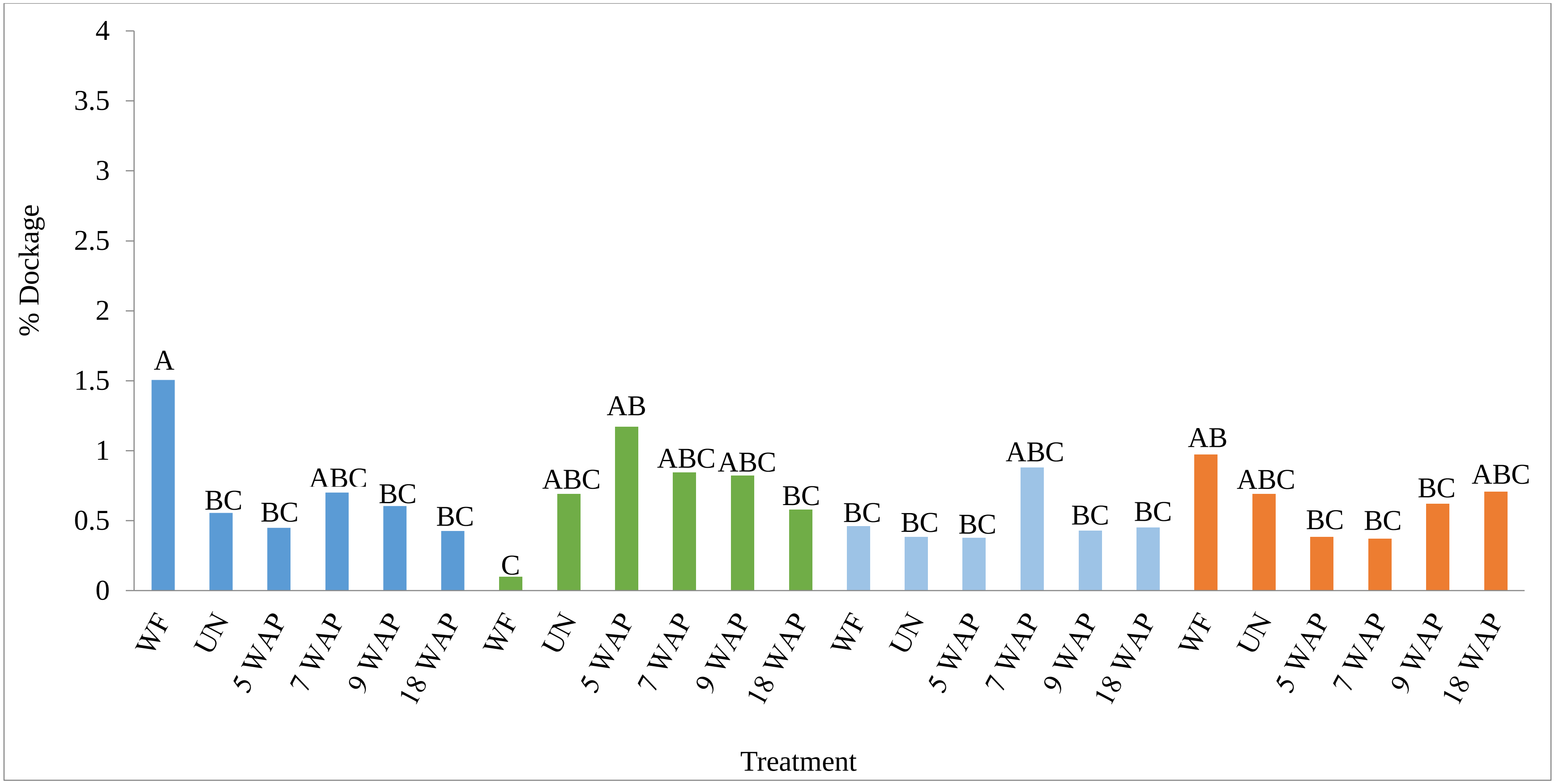


Figure 18. Herbicide t and N fertilizer timing effects on Dockage levels, Stillwater 2011-2012. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).

= 0 N rate = 112 N rate = 37/74 N rate = 74/37 N rate

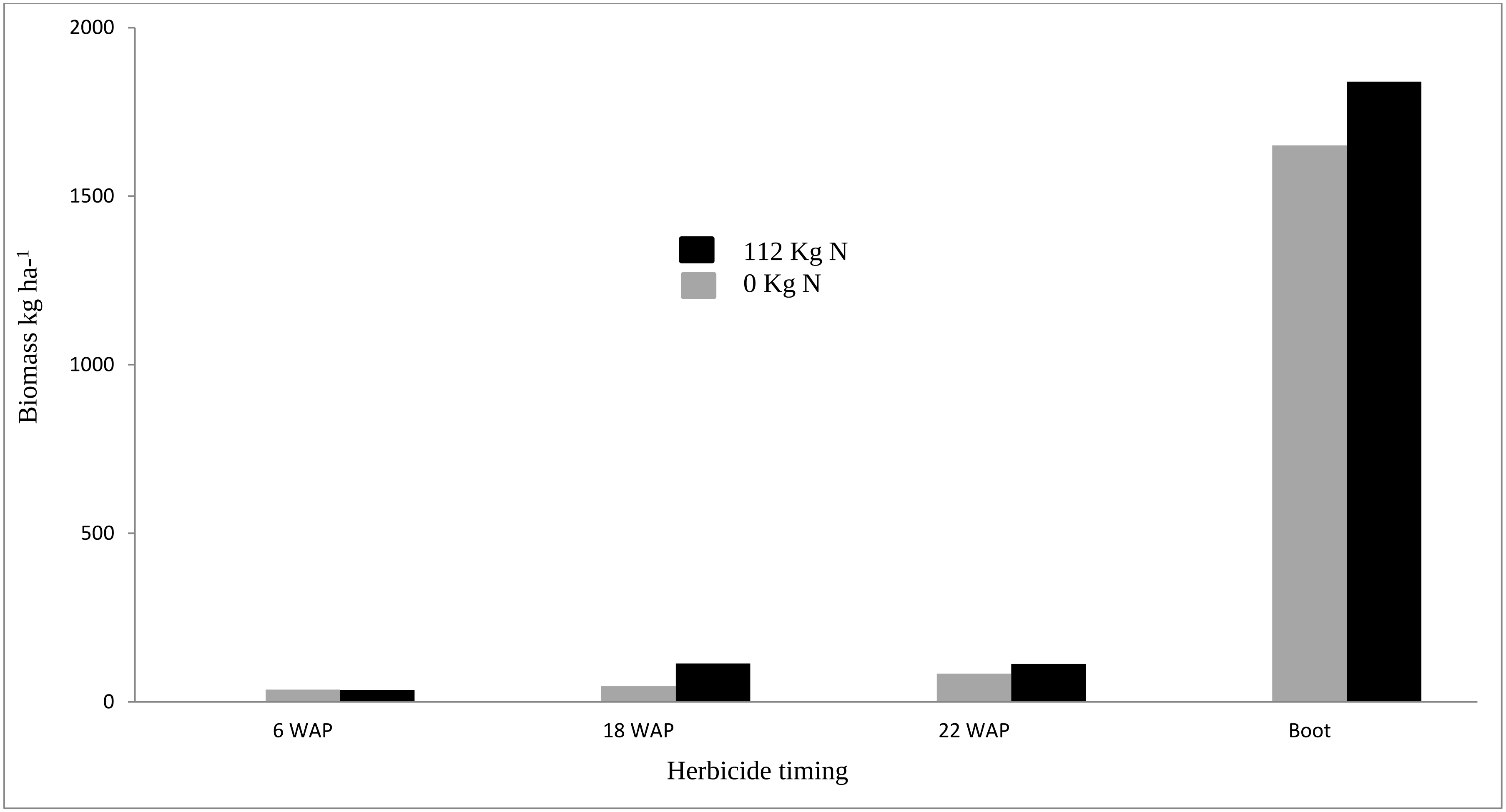


Figure 19. Herbicide and N fertilizer timing effects on Italian ryegrass growth, Lake Carl Blackwell 2012-2013. WAP= Week after planting.

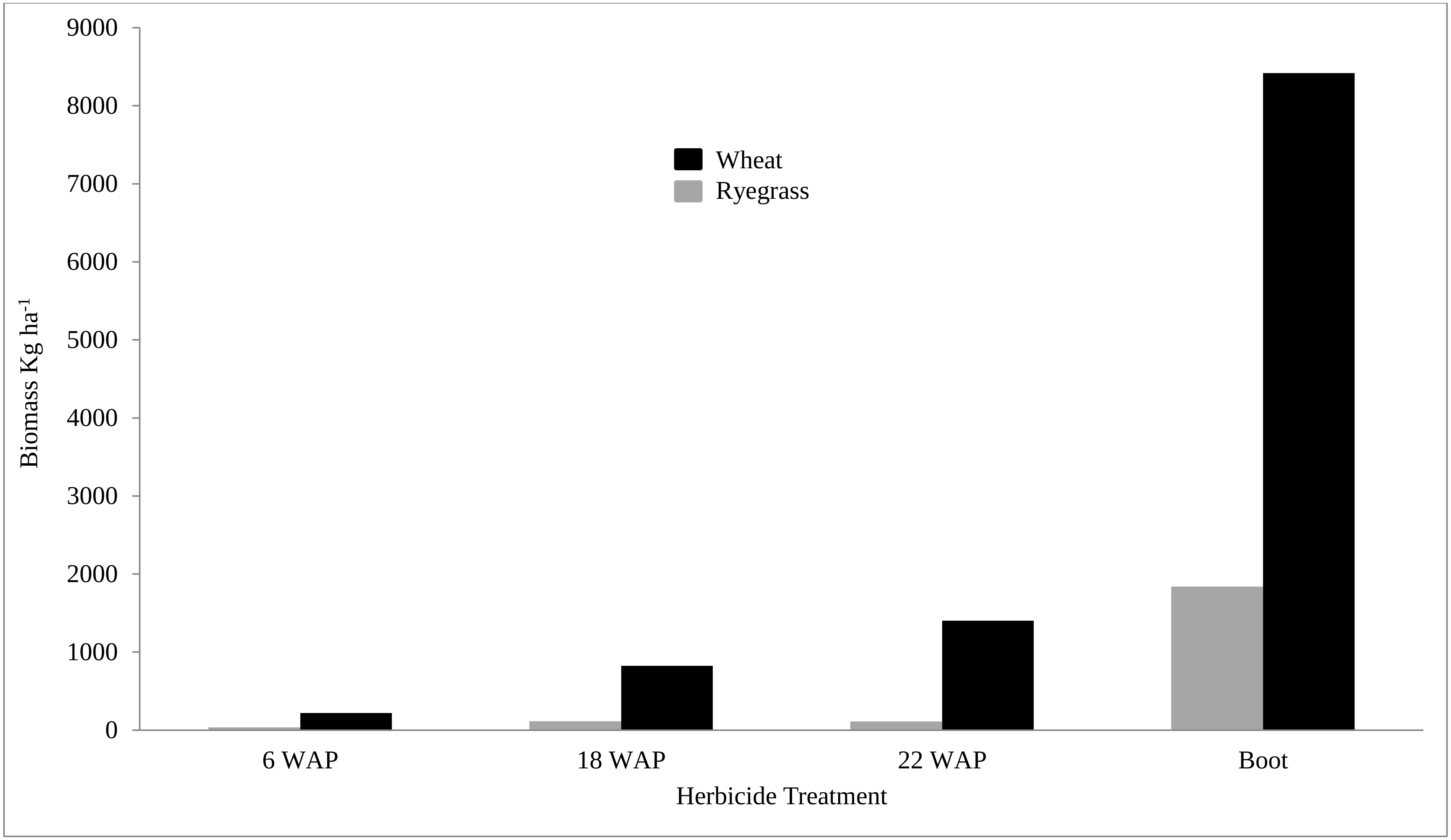


Figure 20. Italian ryegrass and Wheat Biomass at the 185 kg N ha^{-1} split rate, Lake Carl Blackwell 2012-2013. WAP= Week after planting. Early Italian ryegrass early growth was delayed at the 6 and 18 WAP due to hot dry weather conditions which delayed germination.

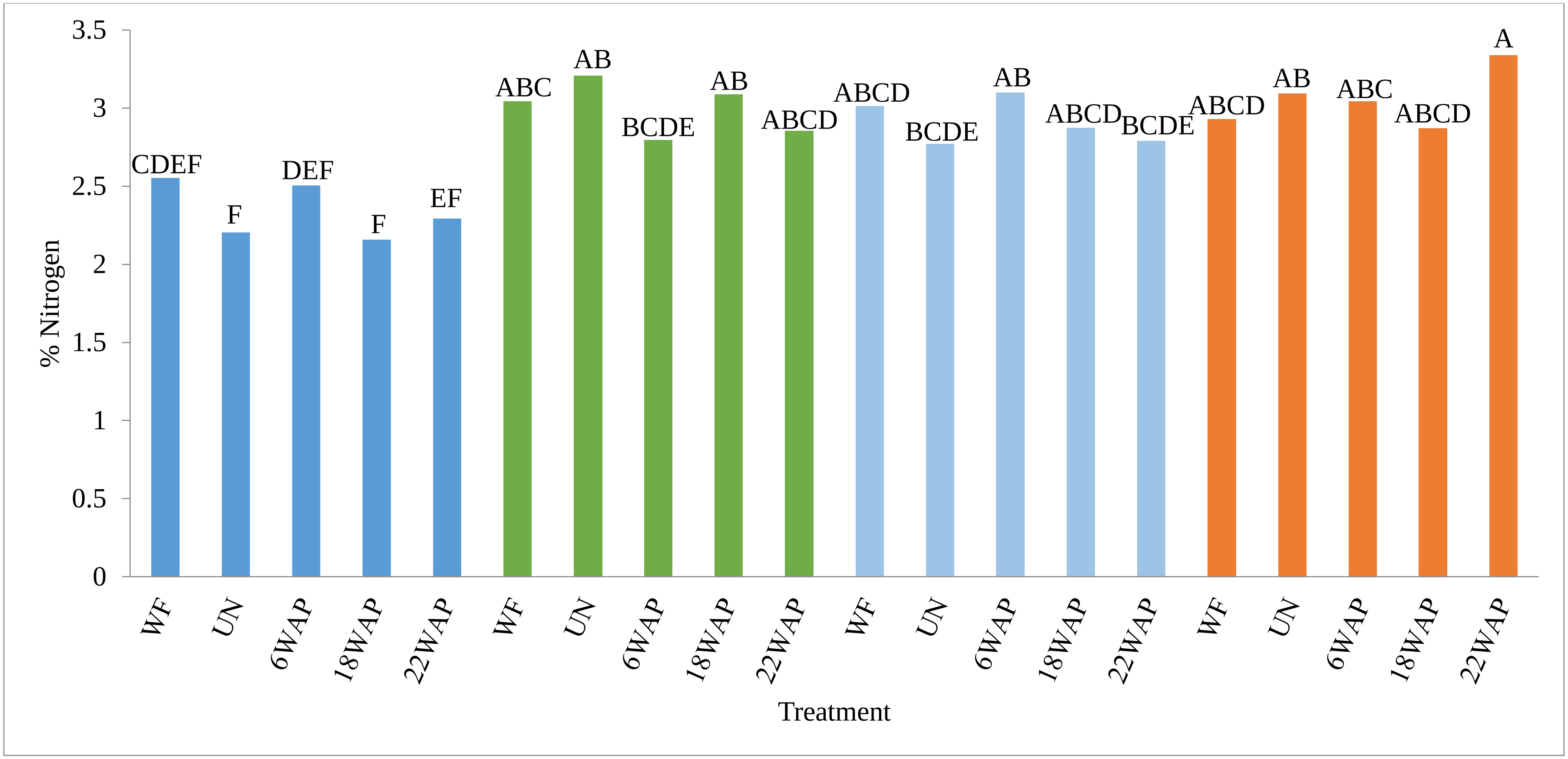
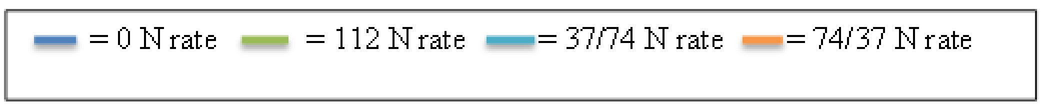


Figure 21. Herbicide and N fertilizer timing effects on N content in wheat at boot stage, Lake Carl Blackwell 2012-2013. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).



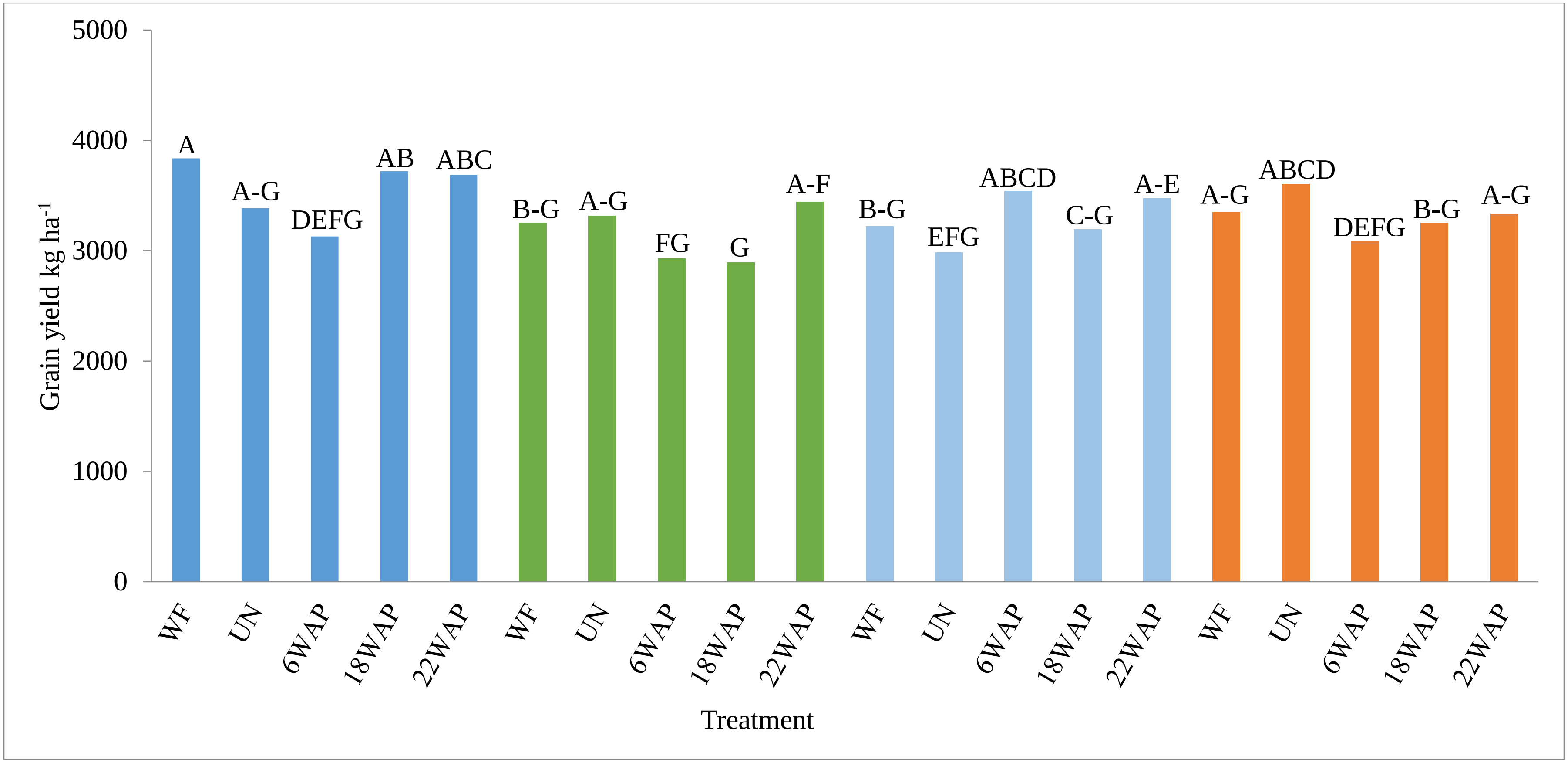


Figure 22. Herbicide and N fertilizer timing effects on Grain Yield in Kg ha^{-1}, Lake Carl Blackwell 2012-2013. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).

= 0 N rate = 112 N rate = 37/74 N rate = 74/37 N rate

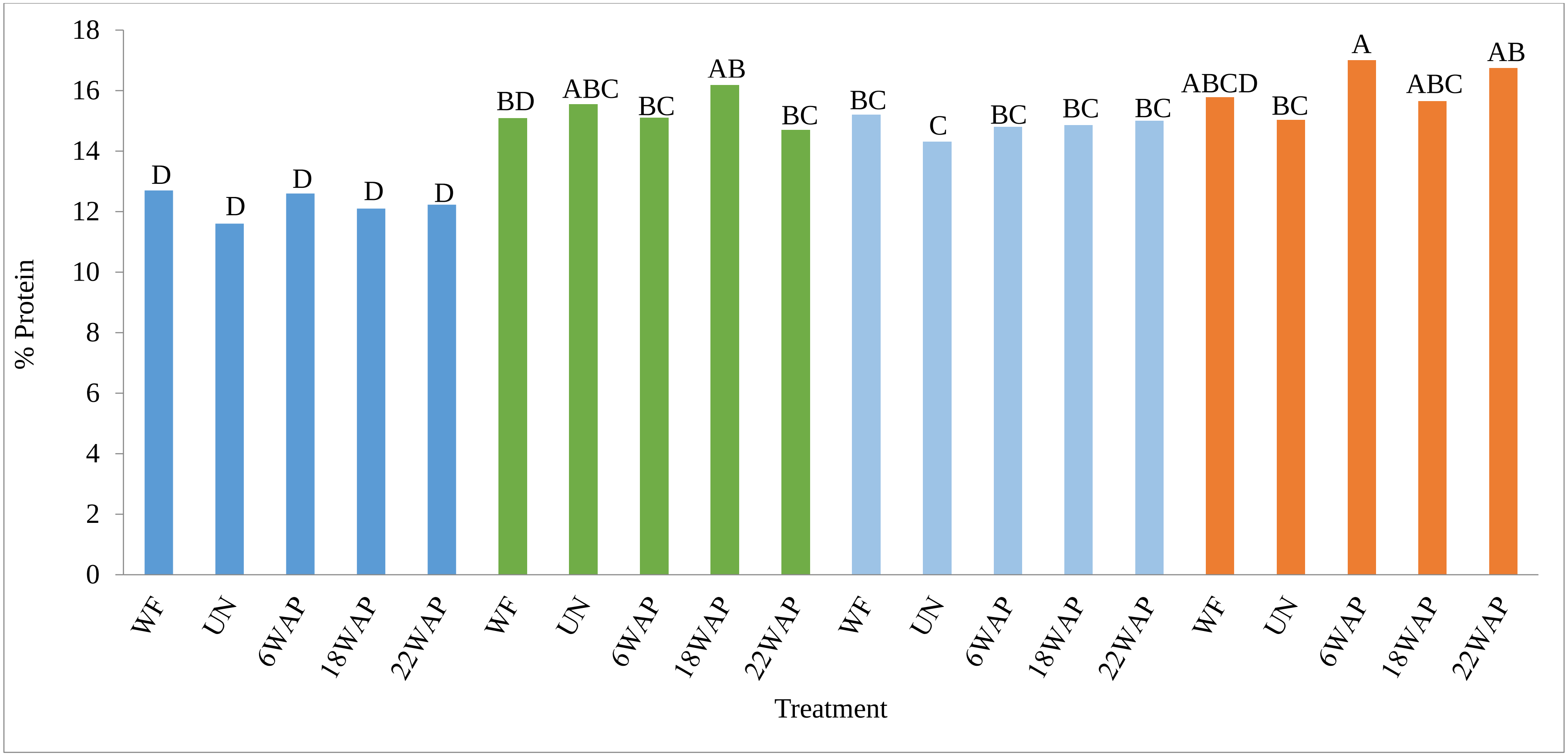
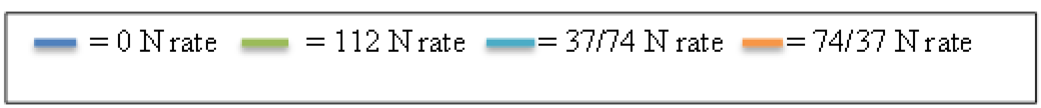


Figure 23. Herbicide and N fertilizer timing effects on Protein content levels, Lake Carl Blackwell 2012-2013. WF= Weed Free, UN= Untreated, WAP= Week after planting. *Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).



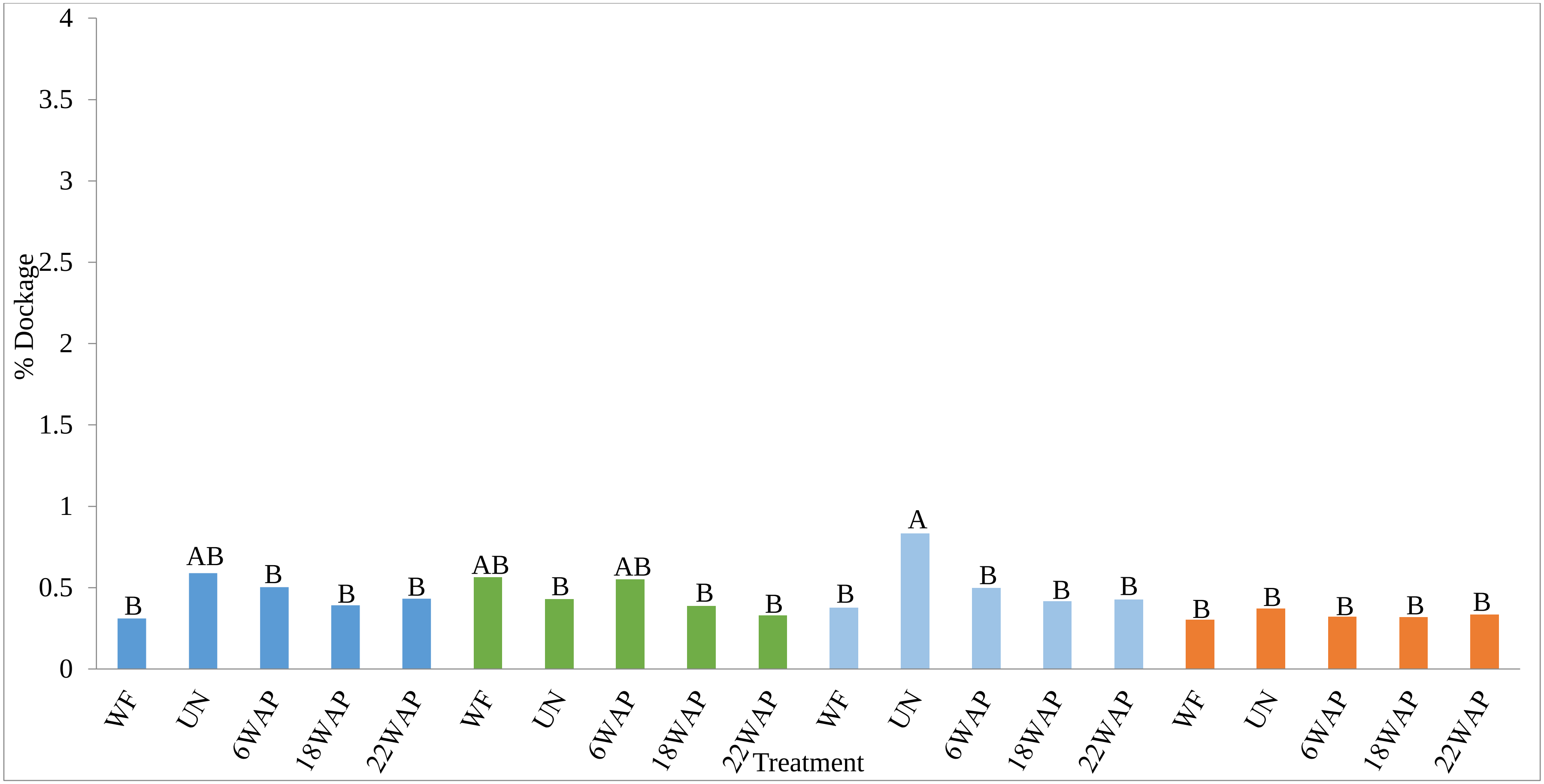


Figure 24. Herbicide and N fertilizer timing effects on Dockage levels, Lake Carl Blackwell 2012-2013.*Means within each column followed by the same letter do not differ according to Fisher's Protected LSD test (P = 0.05).

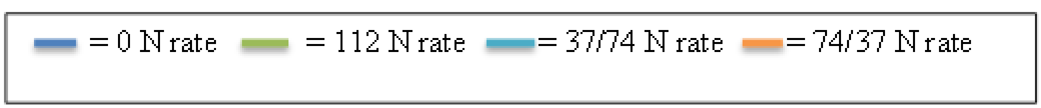


Table 1. Soil series descriptions for all locations are listed below, Perkins, Lake Carl Blackwell, Stillwater.

SOIL TYPES AND CHARACTERISTIC			
Characteristic	Perkins	Lake Carl Blackwell	Stillwater
Series	Teller	Pulaski	Norge
Texture	Sandy loam	Fine Sandy loam	Fine-silty,
Classification	Fine-loamy,	mixed, superactive,	mixed, active,
	mixed, active,	nonacid,	Thermic Udic
	Thermic Udic	Thermic Udic	Paleustolls
	Argiustolls	Ustifluvents	
pH	5.5	5.3	6.4
N	37	62	50
P	108	62	89
K	337	251	308

Table 2. The 2011-2012 Treatment descriptions, herbicide and fertilizer application timing, all treatments received a total of 112 kg ha^{-1} of N except for treatments 1-6, the unfertilized checks.

Pre-plant N kg ha^{-1}	Post-plant N kg ha^{-1}	Herbicide timing
0	0	WF
0	0	UN
0	0	5 WAP
0	0	7 WAP
0	0	9 WAP
37	74	WF
37	74	UN
37	74	5 WAP
37	74	7 WAP
37	74	9 WAP
74	37	WF
74	37	UN
74	37	5 WAP
74	37	7 WAP
74	37	9 WAP
112	0	WF
112	0	UN
112	0	5 WAP
112	0	7 WAP
112	0	9 WAP

WF= Weed Free, UN= Untreated, WAP= Week after planting

Table 3. The 2012-2013, Perkins, Treatment descriptions, herbicide and fertilizer application timing, all treatments received a total of 112 kg ha^{-1} of N except for treatments 1-5, the unfertilized checks.

Pre-plant N kg ha^{-1}	Post-plant N kg ha^{-1}	Herbicide timing
0	0	WF
0	0	UN
0	0	5 WAP
0	0	7 WAP
0	0	9 WAP
37	74	WF
37	74	UN
37	74	5 WAP
37	74	7 WAP
37	74	9 WAP
74	37	WF
74	37	UN
74	37	5 WAP
74	37	7 WAP
74	37	9 WAP
112	0	WF
112	0	UN
112	0	5 WAP
112	0	7 WAP
112	0	9 WAP

* One herbicide timing was dropped from all four N applications during the 2012-2013 season due to late ryegrass germination and environmental conditions. WF= Weed Free, UN= Untreated, WAP= Week after planting

Table 4. The 2012-2013, Lake Carl Blackwell, Treatment descriptions, herbicide and fertilizer application timing, all treatments received a total of 185 kg ha^{-1} of N except for treatments 1-5, the unfertilized checks.

Pre-plant N kg ha^{-1}	Post-plant N kg ha^{-1}	Herbicide timing
0	0	WF
0	0	UN
0	0	5 WAP
0	0	7 WAP
0	0	9 WAP
62	123	WF
62	123	UN
62	123	5 WAP
62	123	7 WAP
62	123	9 WAP
123	62	WF
123	62	UN
123	62	5 WAP
123	62	7 WAP
123	62	9 WAP
185	0	WF
185	0	UN
185	0	5 WAP
185	0	7 WAP
185	0	9 WAP

* One herbicide timing was dropped from all four N applications during the 2012-2013 season due to late ryegrass germination and environmental conditions. WF= Weed Free, UN= Untreated, WAP= Week after planting

Table 5. Grain yield, protein, dockage, test weight and moisture collected during harvest in 2012 at Perkins.

Fertilizer nitrogen		Herbicide	Wheat					
Preplant	Postplant	application	yield	Protein	Dockage	T. W.	Moisture	N at boot
(kg ha^{-1})		(timing)	(kg ha^{-1})					
…	…	WF	1701.9	9.175	0.689739	58.1	12.45	1.4075
…	…	UN	1470.8	8.45	1.454466	57.35	13.575	1.4175
…	…	5 WAP	1721.4	9.2	1.073835	58.425	12.8	1.3375
…	…	7 WAP	1570.3	8.975	0.950962	58.475	12.675	1.535
…	…	9 WAP	1811.7	8.825	0.695996	57.875	12.75	1.3575
…	…	18 WAP	1290.7	8.55	1.489334	56.125	13.5	1.4675
37	74	WF	3169.7	10.05	0.327926	59.65	12.35	1.6125
37	74	UN	2807.2	9.35	0.798143	59.425	12.5	1.49
37	74	5 WAP	3341.4	9.975	0.639773	60.35	12.425	1.86
37	74	7 WAP	3095.6	9.55	0.610767	59.225	12.45	1.655
37	74	9 WAP	3098.9	9.6	0.587599	59.675	12.45	1.8125
37	74	18 WAP	3040.4	9.6	0.122526	59.325	12.4	1.66
74	37	WF	2823.9	9.55	0.4798	59.475	12.475	1.4125
74	37	UN	2540.7	8.7	0.9879	58.775	12.625	1.535
74	37	5 WAP	2860.8	9.05	0.6319	59.575	12.625	1.545
74	37	7 WAP	2691.3	9	0.8237	58.85	12.6	1.4125
74	37	9 WAP	2924.6	9.15	0.4104	58.4	12.45	1.6525
74	37	18 WAP	2858	9.025	0.5375	59.425	12.7	1.6033
112	…	WF	3109.3	9.325	0.524238	59.725	12.45	1.8725
112	…	UN	2629.2	8.625	0.751337	56.4	12.75	1.4075
112	…	5 WAP	3024.3	9.15	0.523131	59.275	12.525	1.43
112	…	7 WAP	2820	8.95	0.510814	59.25	12.55	1.33
112	…	9 WAP	2925.5	9.3	0.400657	59.35	12.6	1.375
112	…	18 WAP	2828.9	8.875	0.554296	59.1	12.75	1.745

* T. W. = Test Weight, WF= Weed Free, UN= Untreated, WAP= Week after planting

Table 6. ANOVA table comparing main effect and interaction of herbicide timings and N applications on protein, dockage, yield, N concentration, wheat biomass and Italian ryegrass biomass at Perkins in 2011-2012.

Source	Protein	Dockage	Yield	N concentration	W bio	R Bio
Rep	NS	NS	NS	NS	NS	0.039
TMT	0.004	<.0001	0.01	NS	NS	<.0001
N	0.022	NS	<.0001	0.018	<.0001	0.031
H	0.001	0.048	0.005	NS	0.002	<.0001
N*H	NS	NS	NS	NS	NS	0.031
Residual	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Table 7. Application dates, environmental conditions, wheat growth stages and ryegrass removal heights at the timing of herbicide application at Perkins in 2011-2012.

Perkins 2011-2012						
Application Information	A	B	C	D	E	F
Application Date	9/30/2011	9/30/2011	11/2/2011	11/17/2011	12/1/2011	2/1/2012
Time of Day	2:00 PM	3:00 PM	10:15 AM	4:25 PM	3:00 PM	12:00PM
Application Timing	FALL N	PRE	5 WAP	7 WAP	9 WAP	18 WAP
Air Temperature (°C)	-	25.5	18	11	22	22
% Relative Humidity	-	38	74	39	40	38
Wind velocity (MPH)	-	5	7	7	7	2
Wind Direction	-	E	SE	SSW	W	S
Soil Temperature (°C)	-	24	15	50	10	8
Soil Moisture	-	Very dry	Adequate	Slightly dry	Adequate	Adequate
% Cloud Cover	-	0	95	0	10	10
Crop Stage at Application						
Crop: Wheat	A	B	C	D	E	F
Stage Majority	-	-	4 LF	4 T	5 T	8 T
Stage Minimum	-	-	4 LF	4T	4 T	6 T
Stage Maximum	-	-	5 LF	5 T	6 T	12 T
Height (cm) Mini. , Max.	-	-	15 , 20	15 , 22	12 , 20	15 , 25
Weed Stage at Application						
Weed: Italian ryegrass	A	B	C	D	E	F
Stage Majority	-	-	2 LF	4 LF	1 T	2 T
Stage Minimum	-	-	1 LF	2 LF	3 LF	3 LF
Stage Maximum	-	-	2 LF	1 T	2 T	5 T
Height (cm) Mini. , Max.	-	-	2 , 7	5 , 7	5 , 10	5 , 12

Table 8. Grain yield, protein, dockage, test weight and moisture collected during harvest in 2013 at Perkins.

Nitrogen Fertilizer		Herbicide	Wheat					
Preplant	Postplant	application	yield	Protein	Dockage	T. W.	Moisture	N at boot
(kg ha^{-1})		(timing)	(kg ha^{-1})					
…	…	WF	1859.82	9.425	1.993	58.275	12.425	1.095
…	…	UN	1677	9.375	2.981	57.525	12.6	1.02
…	…	6WAP	1641.5	9.35	2.632	56.9	12.675	1.11
…	…	18WAP	1676.1	9.475	1.759	56.65	12.6	1.08
…	…	22WAP	1520.8	10.2	2.37	57.533	12.467	1.09333
37	74	WF	3658.3	15.25	3.639	56.225	11.25	2.185
37	74	UN	3489.8	16.725	3.272	57.175	11.6	2.0375
37	74	6WAP	3748.9	16.4	3.397	55.133	11.467	2.04333
37	74	18WAP	3642.1	16.65	3.403	56.725	11.425	2.115
37	74	22WAP	3593.2	16.575	3.734	55.725	11.25	1.98
74	37	WF	4104.1	11.85	2.25	58.7	12.175	1.4725
74	37	UN	3883.8	10.25	2.163	58.25	12.225	1.2075
74	37	6WAP	4043.8	10.5	3.731	58.425	12.25	1.4575
74	37	18WAP	4028.2	10.375	2.434	58.475	12.325	1.3725
74	37	22WAP	3568.2	10.05	2.982	57.45	12.375	1.355
112	…	WF	3972.4	10.475	2.083	57.725	12.275	1.35
112	…	UN	3786	9.85	2.29	58.475	12.325	1.3
112	…	6WAP	4206.5	9.8	2.39	57.475	12.4	1.265
112	…	18WAP	3968.7	9.8	3.188	58.175	12.375	1.3075
112	…	22WAP	3805.6	9.75	2.287	58.325	12.5	1.235

* T. W. = Test Weight, WF= Weed Free, UN= Untreated, WAP= Week after planting

Table 9. ANOVA table comparing main effect and interaction of herbicide timings and N applications on protein, dockage, yield, N concentration, wheat biomass and Italian ryegrass biomass at Perkins in 2012-2013.

Source	Protein	Dockage	Yield	N concentration	W bio	R Bio
Rep	NS	NS	NS	NS	NS	NS
TMT	0.015	NS	NS	0.016	NS	<.0001
N	<.0001	NS	<.0001	<.0001	<.0001	NS
H	NS	NS	NS	NS	NS	<.0001
N*H	NS	NS	NS	NS	NS	NS
Residual	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Table 10. Application dates, environmental conditions, wheat growth stages and ryegrass removal heights at the timing of herbicide application at Perkins in 2012-2013.

Perkins 2012-2013					
Application Information	A	B	C	D	E
Application Date	10/11/12	11/14/12	11/28/12	2/19/2013	3/18/2013
Time of Day	2:00 PM	11:00 AM	9:45 AM	2:00 PM	2:30 PM
Application Timing	PRE	FALL N	6 WAP	18 WAP	22 WAP
Air Temperature (°C)	23	-	9	14	18
% Relative Humidity	70	-	48	20	32
Wind velocity (MPH)	9	-	5	5	9
Wind Direction	N	-	SSE	SE	N
Soil Temperature (°C)	18	-	6	12	18
Soil Moisture	Slight	-	Dry	Dry	Dry
% Cloud Cover	100	-	0	0	0
Crop Stage at Application					
Crop: Wheat	A	B	C	D	E
Stage Majority	-	-	2 T	6 T	11 T
Stage Minimum	-	-	3LF	4T	8 T
Stage Maximum	-	-	3 T	7 T	12 T
Height (cm) Mini. , Max.	-	-	6 , 9	8 , 12	15 , 25
Weed Stage at Application					
Weed: Italian ryegrass	A	B	C	D	E
Stage Majority	-	-	2 LF	4 LF	3 T
Stage Minimum	-	-	1 LF	2 LF	1 T
Stage Maximum	-	-	2 LF	1 T	5 T
Height (cm) Mini. , Max.	-	-	2 , 3	6 , 8	10 , 12

Table 11. Grain yield, protein, dockage, test weight and moisture collected during harvest in 2012 at Stillwater.

Fertilizer nitrogen		Ryegrass	Wheat					
Preplant	Postplant	removal	yield	Protein	Dockage	T. W.	Moisture	N at boot
(kg ha^{-1})		(timing)	(kg ha^{-1})	(%)			(%)	
…	…	WF	3032.2	10.425	1.506	59.925	11.05	1.4375
…	…	5 WAP	2785.7	10.15	0.4482	59.8	10.95	1.5725
…	…	7 WAP	2341	10.2	0.7007	59.525	10.875	1.585
…	…	9 WAP	2704.9	10.475	0.6042	59.85	10.975	1.46
…	…	18 WAP	2547	10.075	0.4269	59.575	11.15	1.64
…	…	UN	2993.8	10.275	0.5554	59.825	10.875	1.335
37	74	WF	3676.7	10.925	0.4615	59.9	10.75	1.9875
37	74	5 WAP	3598.6	11.125	0.3763	60.125	10.75	1.8725
37	74	7 WAP	3461.8	10.85	0.8789	60.15	10.875	1.7325
37	74	9 WAP	3699.5	10.825	0.4276	60.475	10.75	1.82
37	74	18 WAP	3351.9	10.6	0.451	60.625	10.8	1.64
37	74	UN	3538.5	11.475	0.3829	60.125	10.75	1.6675
74	37	WF	3393.7	10.825	0.9731	60.225	10.95	1.56
74	37	5 WAP	3412.7	11.075	0.3816	60.275	10.75	1.6
74	37	7 WAP	3465.8	10.825	0.3701	60.5	10.8	1.5825
74	37	9 WAP	3464.3	10.6	0.6197	60.4	10.8	1.5725
74	37	18 WAP	3554.7	11.1	0.7065	60.65	10.825	1.6625
74	37	UN	3460.6	10.275	0.6894	60.275	10.925	1.87
112	…	WF	3625.6	11.025	0.0963	60	10.75	1.8025
112	…	5 WAP	3129.1	10.925	1.1697	60.3	10.8	1.6925
112	…	7 WAP	3538.3	11.325	0.8445	60.125	10.75	1.7675
112	…	9 WAP	3597.3	12	0.8216	60.175	10.775	1.565
112	…	18 WAP	3320	10.9	0.5786	59.85	10.875	1.805
112	…	UN	3480.6	11.475	0.6884	59.975	10.825	1.7025

* T. W. = Test Weight, WF= Weed Free, UN= Untreated, WAP= Week after planting

Table 12. ANOVA table comparing main effect and interaction of herbicide timings and N applications on protein, dockage, yield, N concentration, wheat biomass and Italian ryegrass biomass at Stillwater in 2011-2012.

Source	Protein	Dockage	Yield	N concentration	W bio	R Bio
Rep	NS	NS	NS	NS	NS	NS
TMT	NS	NS	0.013	NS	NS	0.009
N	0.02	NS	0.015	0.024	0.027	NS
H	NS	NS	NS	NS	0.02	0.0002
N*H	NS	0.02	NS	NS	NS	NS
Residual	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Table 13. Application dates, environmental conditions, wheat growth stages and ryegrass removal heights at the timing of herbicide application at Stillwater in 2011-2012.

Stillwater 2011-2012						
Application Information	A	B	C	D	E	F
Application Date	9/30/2011	10/1/2011	11/2/2011	11/17/2011	12/1/2011	2/1/2012
Time of Day	6:00 PM	10:00 AM	8:30 AM	2:30 PM	3:40 PM	4:45 PM
Application Timing	FALL N	PRE	5 WAP	7 WAP	9 WAP	18 WAP
Air Temperature (°C)	-	22	16	12	17	18
% Relative Humidity	-	40	71	42	47	38
Wind velocity (MPH)	-	3	5	6	6	2
Wind Direction	-	E	SE	SW	NW	N
Soil Temperature (°C)	-	18	14	10.5	9	10
Soil Moisture	-	Dry	Adequate	Adequate	Adequate	Moist
% Cloud Cover	-	0	90	0	10	0
Crop Stage at Application						
Crop: Wheat	A	B	C	D	E	F
Stage Majority	-	-	4 LF	5 T	6 T	11 T
Stage Minimum	-	-	3 LF	4T	5 T	8 T
Stage Maximum	-	-	4 LF	6T	7 T	15 T
Height (cm) Mini. , Max.	-	-	12 , 20	20 , 27	22 , 30	25 , 45
Weed Stage at Application						
Weed: Italian ryegrass	A	B	C	D	E	F
Stage Majority	-	-	1 LF	2 LF	3 LF	2 T
Stage Minimum	-	-	1 LF	2 LF	2 LF	4 LF
Stage Maximum	-	-	2 LF	4 LF	4 LF	3 T
Height (cm) Mini. , Max.	-	-	2 , 5	7 , 10	7 , 12	5 , 10

Table 14. Grain yield, protein, dockage, test weight and moisture collected during harvest in 2013 at Lake Carl Blackwell.

Nitrogen Fertilizer		Herbicide	Wheat					
Preplant	Postplant	application	yield	Protein	Dockage	T. W.	Moisture	N at boot
(kg ha^{-1})		(timing)	(kg ha^{-1})					
…	…	WF	3837	12.7	0.3113	57	11.15	2.5525
…	…	UN	3383.8	11.6	0.5886	55.6	11.425	2.205
…	…	6WAP	3129.2	12.6	0.503	56.875	11.775	2.505
…	…	18WAP	3720.2	12.1	0.3913	57.7	11.3	2.1575
…	…	22WAP	3686.8	12.233	0.4316	58.033	11.2	2.2933
62	123	WF	3222.7	15.2	0.3759	55.05	10.925	3.0125
62	123	UN	2981.4	14.3	0.832	56.75	10.85	2.7725
62	123	6WAP	3540.1	14.8	0.4979	58.767	11.03	3.1
62	123	18WAP	3191.7	14.85	0.4153	57.6	10.975	2.875
62	123	22WAP	3474.8	15	0.4274	58.225	10.95	2.79
123	62	WF	3351.3	15.775	0.3026	59.4	11.075	2.93
123	62	UN	3605.4	15.025	0.3719	58.925	11.175	3.095
123	62	6WAP	3084.8	17	0.3199	57.425	11.125	3.0425
123	62	18WAP	3253.2	15.65	0.317	58.075	11	2.8725
123	62	22WAP	3336.1	16.75	0.3319	58.9	11.15	3.3375
185	…	WF	3250.5	15.075	0.5628	57.3	10.9	3.0433
185	…	UN	3317.3	15.55	0.4285	56.15	10.925	3.2075
185	…	6WAP	2929	15.1	0.5497	56.525	10.875	2.7975
185	…	18WAP	2892.3	16.175	0.3872	58.2	10.925	3.0875
185	…	22WAP	3441.9	14.7	0.3279	57.9	10.925	2.855

* T. W. = Test Weight, WF= Weed Free, UN= Untreated, WAP= Week after planting

Table 15. ANOVA table comparing main effect and interaction of herbicide timings and N applications on protein, dockage, yield, N concentration, wheat biomass and Italian ryegrass biomass at Lake Carl Blackwell in 2012-2013.

Source	Protein	Dockage	Yield	N concentration	W bio	R Bio
Rep	NS	NS	NS	NS	NS	NS
TMT	NS	NS	NS	NS	NS	0.022
N	0.001	NS	0.018	0.014	NS	NS
H	NS	NS	NS	NS	NS	0.0002
N*H	NS	NS	NS	NS	NS	NS
Residual	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Table 16. Application dates, environmental conditions, wheat growth stages and ryegrass removal heights at the timing of herbicide application at Lake Carl Blackwell in 2012-2013.

Lake Carl Blackwell 2012-2013					
Application Information	A	B	C	D	E
Application Date	10/19/12	11/14/12	11/28/12	2/20/2013	3/18/2013
Time of Day	8:10 AM	1:00 PM	1:30 PM	5:03 PM	4:30 PM
Application Timing	PRE	FALL N	6 WAP	18 WAP	22 WAP
Air Temperature (°C)	9	-	16	14	16
% Relative Humidity	33	-	38	35	29
Wind velocity (MPH)	3	-	4	5	8
Wind Direction	WNW	-	S	SE	N
Soil Temperature (°C)	13	-	11	11	17
Soil Moisture	Slight	-	Dry	Slight	Dry
% Cloud Cover	0	-	0	10	30
Crop Stage at Application					
Crop: Wheat	A	B	C	D	E
Stage Majority	-	-	1 T	3 T	8 T
Stage Minimum	-	-	3 LF	2 T	7 T
Stage Maximum	-	-	2 T	5 T	10 T
Height (cm) Mini. , Max.	-	-	2 , 3	7 , 9	12 , 20
Weed Stage at Application					
Weed: Italian ryegrass	A	B	C	D	E
Stage Majority	-	-	2 LF	1 T	3 T
Stage Minimum	-	-	1 LF	4 LF	1 T
Stage Maximum	-	-	4 LF	2 T	4 T
Height (cm) Mini. , Max.	-	-	1 , 3	5 , 7	8 , 10

APPENDICES

Table 17. Planting date, wheat variety, seeding rate, and harvest date at all locations, Stillwater, Perkins, Lake Carl Blackwell, 2011-2013.

Location	Crop Year	Planting Date	Variety	Seeding Rate kg ha^{-1}	Harvest Date
Stillwater	2011-2012	9/30/2011	Duster	84	5/ /2012
Perkins	2011-2012	9/29/2011	Duster	84	5/25/2012
Perkins	2012-2013	10/10/2012	Duster	84	6/21/2013
LCB	2012-2013	10/17/2012	Duster	100.8	6/24/2013

Table 18. Recorded rainfall for the 2011-2012 and 2012-2013 growing seasons at all locations

	Rain fall (cm)			
	2011-	2012	2012-	2013
Month	Perkins	Stillwater	Perkins	Lake Carl Blackwell
October	7.3	.	2.2	1.2
November	9.7	6.7	1.7	1.4
December	5.3	5.5	1.5	1.1
January	2.4	2.4	4.5	2.7
February	6.1	7.4	8.4	8.5
March	11.5	10.0	1.4	1.4
April	12.9	15.6	13.0	15.4
May	2.8	2.8	16.2	24.0
June	7.4	5.5	10.5	14.1
Total	65.4	55.9	59.3	69.6

* Source: Oklahoma Climatological Survey, Univ. of OK., http://www.mesonet.org

VITA

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