WEED MANAGEMENT AND NITROGEN LOSS IN GLYPHOSATE-RESISTANT CORN (ZEA MAYS)

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This is for my fiancée Whitney
And my parents, Donald and Virginia,
I love you all.

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Weed Control in Glyphosate-Resistant Corn

With the advent of herbicide-resistant crops, new options for weed control are available for cropping systems. When glyphosate-resistant corn was introduced in 1999, there was little research available for designing weed management programs utilizing glyphosate. Traditional programs often used a combination of a preemergence (PRE) herbicide followed by a postemergence (POST) herbicide as necessary. Glyphosate-resistant crops have contributed to an increase in POST applications, especially including glyphosate. Producers desire the simplicity of a single herbicide application (one-pass) with comparable efficacy of a sequential herbicide (two-pass) system. The objective of this field study was to determine the efficacy of various one-pass and two-pass herbicide programs in glyphosate-resistant corn.

Glyphosate-resistant technology offers broad-based weed control with flexibility in application timing. However, application timings have been shown to be very critical for efficacious weed control and crop yield (Bosnic and Swanton 1997; Hall 1992; Johnson et al. 2000). Previous research has shown that grass infestation in corn can be very competitive for nitrogen, especially when the timing of weed removal is delayed (Hellwig et al. 2002). Research is needed to determine the effects of weed removal timing for grasses and broadleaves and the effect on nitrogen accumulation in corn plants as well as the resultant grain yield. Thus, the objective of this field study was to determine the optimum weed removal timing using glyphosate, and to determine the influence of weeds on corn nitrogen content and grain yield.

Corn Production

Corn (*Zea mays*) has a long and varied history (Walden 1966, Weatherwax 1955). It is has been confirmed that wild ancestors of the modern corn plant were located in the Americas (Manglesdorf 1974). Still, the actual specific origin of corn is not fully known (Walden 1966). Cultivated corn can be documented as far back as 3,400 BC. The cultivation corn was the primary pursuit of the Native Americans of the Western Hemisphere. Corn was an ideal crop due to the ability of the plant to acclimate to many soil and climate conditions. Large Native American civilizations such as the Aztecs, Mayans, Incas and many of the tribes of North America based their agricultural systems upon the production of corn. Corn was grown primarily for food (Walden 1966), and the preparation of corn consisted of bread, hominy, tamales, and fermented liquors. Today, the original feral ancestor of corn is thought to be extinct (Walden 1966).

Western civilization was exposed to corn for the first time via Christopher Columbus. In 1492, during his initial landing in what it is now Cuba, Columbus wrote about the new grain plant he had seen. It is known that he brought samples back to Europe during his second trip to the New World (Weatherwax 1955). Upon arrival in Europe, its agricultural use spread quickly, including into parts of Africa and China.

Corn also played an important part in sustaining the initial settlements in North America by providing settlers with a crop that was high yielding when compared to other food staples of that time. Corn was also resilient and easy to cultivate. As settlers moved west, corn distribution began to spread throughout the Midwest into, what is now, the modern day states of Ohio, Indiana, Illinois, and Iowa and beyond (Weatherwax 1955).

Today, there is more corn produced in the United States than any other crop. In 2007, there were over 59, 300 kilotons harvested from approximately 35 million hectares. In Missouri alone, there was a total of 1,380,000 hectares of corn planted. In 2007, Missouri ranked 9th among states for total corn production (USDA 2008).

Weed Competition Factors

Weeds are considered undesirable or detrimental to other plants. Plants that are not part of the intended crop can vie for nutrients, water, light, and other factors integral to crop growth (Ross and Lembi 2009). Weed competition can cause reductions in crop yield and quality, serve as a habitat for insects and diseases, (Knake and Slife 1961; Tapia et al. 1997), as well as result in increased irrigation costs for the farmer due to moisture removal (Stahler 1948).

Competition between weeds and corn can occur for light, although this is not normally observed late in the season in tall crops such as corn (Olson and Sander 1998). However, competition does occur, especially early in the season. One study describes how the available light measured at the soil surface under a corn canopy can decrease by 60% with increasing giant foxtail (*Setaria faberi*) density (Knake and Slife 1961). Hall (1992) found that weed interference throughout the entire season can reduce leaf area of individual leaves. By restricting available light, weeds can induce higher numbers of senescing leaves than normal. The loss of available light on the lower leaves is detrimental to corn growth by affecting decreasing photosynthesis and increasing senesence.

Weeds also compete with corn for available moisture. Limiting available water creates water stress on the crop, thus reducing crop yield. The competitive ability of moisture use by weeds can create a water stress on surrounding plants (Radosevich 1997; Wiese and Vandiver 1970). Moisture stress at any stage of corn development can lead to reductions in crop growth and harvestable yield, although yield reductions are often increased when moisture stress is applied closer to the silking stage of development (Denmead and Shaw 1960).

Nutrient uptake by weeds versus corn is another major method of competition by weeds (Ross and Lembi 2009). For corn, nitrogen is the most limiting nutrient. Nitrogen is a mobile nutrient and thereby can move through the soil with the help of water. Most other nutrients in the soil are immobile and rely on root interception and diffusion for plant uptake. Nitrogen along with potassium and phosphorus, are all nutrients required by corn in large amounts. Macronutrients such as these are subject to deficiency more often because of this heavy requirement Troeh and Thompson (2005). In 2001, it was found that when weeds compete with corn, the total amounts of nitrogen, phosphorous, and potassium in corn biomass diminished with an increase in weed density (Hellwig et al. 2002). Gonzalez and Salas (1995) also determined that with 100 g/m^2 of additional weed dry weight, the uptake of nitrogen, phosphorus and potassium within the corn plant decreased by 14.6, 2.7 and 9.5 kg/ha, respectively.

Weeds grow in various areas relative to the crop those adjacent to the crop can impact nutrient availability (Ross and Lembi 2009). Weeds have the ability to take up nutrients as easily, if not better than the planted crop (Vengris et al. 1955). This luxury consumption by weeds is thought to negate any potential positive affects of increasing fertilizer amounts on the field to overcome this consumption (Radosevich 1997).

Radosevich also concluded that increasing the nutrient supply for a crop did replace the benefits gained by reducing the total weed density.

Hellwig et al. (2002) determined that weeds, especially grasses, had impacts on nitrogen uptake. The determination of the lost amount of plant nitrogen has been shown to be difficult to determine within the season due to the time and cost involved in collecting, processing and analyzing samples (Piekielek et al. 1995). However, *in vitro* leaf nitrogen content within the growing season has been shown to be an accurate tool for determining deficiencies (Bullock and Anderson 1998; Fox et al. 2001; Piekielek et al. 1995). Leaf nitrogen content can be measured with a Minolta® SPAD-502 (Single-Photon Avalance Diode, Minolta® Corporation) chlorophyll meter. The SPAD meter projects two beams of light through leaf tissue, one beam is in the red spectrum (600 to 700 nm) and one is in the infrared (400 to 500 nm) spectrum. The use of both wavelengths allows the meter to measure the ability of the plant to absorb light, while then assigning a relative value based on how rich and dark the tissue is (Minolta). As readings from the SPAD meter increase, they have been directly correlated to many physiological plant processes. In *Amaranthus* species, strong relationships exist between total chlorophyll content (R^2= .8921), transpiration rate (R^2=.9175), photosynthetic rate (R^2=.9491), and the stomatal conductance of CO_2 (R^2=.8759) (Kapotis et al. 2003). Bullock and Anderson (1998) determined that measurements using the SPAD chlorophyll meter were an efficient to determine leaf nitrogen concentration and grain yield, with a correlation coefficient of R=0.78 between yield and SPAD meter readings taken at the R4 corn stage. Scharf et al. (2006) found that using SPAD meter readings were accurate in predicting optimum nitrogen rate and the resultant yield response in corn across 66 locations in the Midwest.

Numerous other studies have shown that the correlation between nitrogen and SPAD meter readings are significant, and the SPAD meter was accurate in predicting leaf nitrogen content of corn (Bullock and Anderson 1998; Kantety et al. 1996; Scarf et al. 2006; Wood et al. 1992a and 1992b).

Measurement of plant chlorophyll with a SPAD meter is relative (Minolta; Schepers at al. 1998) and only strong correlations to leaf nitrogen can be made, however Reeves et al. (1993) suggested the use plant tissue testing in the form of stalk nitrates could be useful in determining a more accurate amount of plant deficiency. Fox et al. (2001) found that various nitrogen rates in corn could also be determined via testing for stalk nitrates (NO_3^-) during a time period from ¼ milk line (early R3) through approximately 3 weeks after black layer (R6). Even in more dry years, the study also determined that stalk nitrates could be accurate with an error up to 13.2%.

These data indicate that the SPAD meter can measure deficiencies within the season and stalk nitrates can be used to determine the nitrogen content post harvest; however few studies have been done to examine and measure the loss of nitrogen with various removal timings of weeds.

Critical Period for Weed Control

With weeds competing with corn for many growth factors, the duration of competition is important to determine the potential loss of grain yield. The critical period for weed control in corn is described as the length of time that corn must remain weed-free to prevent a significant reduction in grain yield. The critical period can vary somewhat, depending upon the density and species of the weed and the surrounding environmental factors (Hall 1992). Hall (1992) found that with a mixture of weed species at 267 plants m^{-2}, the critical period began just before the V-6 leaf stage of corn. However, with a weed density of 148 m^{-2}, the critical period was delayed until the V-9 leaf stage of corn. These studies concluded that the actual time of the critical period for weed control for corn is diverse and can vary from the 3- to 14-leaf stage. A study comparing barnyardgrass (*Echinochloa crus-galli*) emergence timing in relation to competition with corn concluded that when barnyardgrass emerged after the after the V-4 stage of corn, only a 6% yield reduction was observed; emergence at the 1- to 3 leaf stage resulted in as much as a 26 to 35% yield reduction (Bosnic and Swanton 1997). Another study measured the critical period for johnsongrass control in field corn. Ghosheh (1996) found that a weed free period from 3 to 6.5 weeks after corn emergence must be maintained in order to prevent yield losses of 5% or greater. Carey and Kells (1995) reported that late season germination of weeds was less detrimental to yield if the initial removal timing was at a weed height of 10 cm or less, and that delaying POST applications increased the possibility of yield loss due to early season weed competition.

The period of weed competition can be changed by altering the application timings of herbicides. In evaluating application timing on weed control, Johnson et al. (2000) found that mid-post (10 – 15 cm weeds) applications provided better control of weeds such as cocklebur (*Xanthium strumarium*) and shattercane (*Sorghum bicolor*) than did early-post (3 – 8 cm weeds) applications. However, the benefit of the increased efficacy was offset by the fact that mid-post applications allowed for early season weed interference, which resulted in a 23% yield reduction. Overall, the time at which in-season weed control in corn should begin is varied due to weed and environmental factors. However, providing that weed control is sufficient through the V-14 stage, yield will not be affected (Hall 1992).

Influence of Tillage on Weeds

Conservation tillage is considered to be any type of tillage in which the residue of the previous crop is maximized (Olson and Sander 1988). The phrase conservation tillage is broad and can be used to describe many different methods of crop production including ridge-tillage, strip-tillage and no-tillage. No-tillage is the act of crop production with minimal soil disturbance (Baker et al. 1996). In the mid-1970's, conventional tillage practices declined in favor of conservation-tillage and no-tillage practices (Hayes 1982). This change can be attributed to a greater adoption of POST herbicides, improved planting equipment, and the cost savings of reduced implement use (Olson and Sander 1988). Traditional methods of tillage relied predominantly upon the moldboard plow. Tillage via the moldboard plow contributes to weed control, among other factors (Olson and Sander 1988).

Weed emergence and growth is influenced by tillage and certain patterns have been documented. In reduced tillage systems, weed control has been shown to be an important concern (Buhler 1992). No-tillage seeding has been shown to reduce germination of some weeds due to the lack of physical disturbance of the soil, but any weeds that do emerge require control with herbicides instead of tillage (Baker et al. 1996). Thus, no-till can often lead to increased herbicide use (Buhler 1992; Baker et al. 1996). In addition, some studies indicate that certain weed species can increase in no-tillage conditions. In one study, no-tillage systems have also been shown to have a substantial increase in foxtail (*Setaria* spp.) emergence at 3 to 4 weeks after planting corn. Stahl (1997) found that foxtail grown under no-till practices had a more rapid growth rate and reached the target height for herbicide application 4-9 days earlier than foxtail grown under chisel plow and moldboard plow conditions. Additionally, tillage in another study was found impact redroot pigweed (*Amaranthus retroflexus*) growth. Densities of redroot pigweed were found to be higher under no-tillage and chisel plow systems, 307 and 245 plants m^{-2}, respectively, compared to conventional and ridge tillage systems (both under 25 plant m^{-2}) (Buhler 1992). Oryokot, Murphy and Swanton (1997) confirmed these results when they reported that no-till corn was infested with higher densities of pigweed than corn that had been chisel or moldboard plowed. Buhler (1992) also reported that green foxtail and redroot pigweed were more problematic in no-till fields compared to conventional and ridge tillage systems.

Conversely, Mulugeta and Stoltenberg (1997) found that under proper climatic conditions, soil disturbance increased common lambsquarters (*Chenopodium album)* emergence at a rate 6-fold higher compared to undisturbed soil. Giant foxtail and redroot pigweed germination also increased up to 6-fold with soil disturbance. Kegode et al. (1999) stated that under low input conditions, the production of green and yellow foxtail seed was higher in conventional and ridge tillage systems compared to no-tillage systems.

Glyphosate

The herbicide glyphosate [N-(phosphonomethyl)glycine] was discovered by John Franz in 1970 (Franz 1985). Glyphosate is very effective on grass and broadleaf weeds, and targets a key enzyme, 5-enolpyruvoylshikimate 3-phosphate synthase (EPSPS). The EPSPS reaction is a key step in the synthesis of the aromatic amino acids phenylalanine, tyrosine, and trypthophan (Cole 1985; Franz 1997; Sherman et al. 1996). By blocking the pathway between shikimate and chorismate, the above amino acids cannot be produced, terminating plant development. Phenylalanine is used in protein synthesis and contributes to the development of lignin, growth promoters and inhibitors, and anthocyanins. Tyrosine and tryptophan also contribute to protein synthesis within the plant. Tryptophan also is a precursor to the hormone indolacetic acid (IAA), which is required for cell expansion, the maintenance of apical dominance, as well as many other regulatory processes (Franz 1997). Glyphosate is translocated throughout the plant (Franz 1997), however when glyphosate is applied to the soil it is bound quickly, leading to inactivity (Franz 1997; Franz 1985; Sprankle et al. 1975a; Sprankle et al. 1975b). Of the 76 world's worst weeds compiled in 1997 (Holm et al.), glyphosate affects 74 (Franz 1985; Franz 1997).

Glyphosate-Resistant Corn

Glyphosate was initially labeled in 1971 for applications prior to crop establishment as well as many non-crop uses including orchards, right-of-ways, and industrial areas. Glyphosate resistance in corn was developed by screening bacteria for tolerance to the herbicide. The CP4 CPSPS bacterial strain had very high glyphosate degrading properties, and was incorporated into corn using *Agrobacterium tumefaciens*-mediated transformation (Dyer 1996; Padgette et al 1996). The insertion of the gene that encodes for glyphosate-resistant EPSP (5-enolpyruvoylshikimate 3-phosphate) synthase accounts for the expressed trait of increased glyphosate resistance level in plant tissue

(Kishore 1992).Glyphosate-resistant crops allow producers to apply glyphosate, after crop emergence, for post-emergent weed control. Glyphosate-resistant corn was first released and sold in the US in 1998, just two years after the release of glyphosate-resistant soybeans. The primary benefits of this technology were to provide a more flexible option for broad-spectrum weed control with minimal crop injury. In addition to applying less total herbicide, the reduction in cost was also found to be very advantageous (Burnside 1996).

In 2003, Missouri planted a total of 1,133,000 hectares of corn with 12% of that being glyphosate-resistant. While in 2002, the US had 7% of the total 31,990,000 hectares planted into glyphosate-resistant corn. (Bill Parker personal communication, Dec 7, 2004; Anonymous 2005). The weed control with glyphosate and glyphosate-resistant crops has been shown to be very effective (Tharp et al. 1999; Ferrell and Witt 2002). Ferrell and Witt (2002) found that two sequential POST applications of glyphosate in corn provided up to 92% control of ivyleaf morningglory (*Ipomoea* spp.) compared to the variable control (27 to 81%) provided by soil applied *s*-triazines. Control of common cocklebur (*Xanthium strumarium*) was found to be greater than 90% in all but one year's location with sequential glyphosate applications, while control of common cocklebur ranged from 27 to 93% with PRE herbicides. Nolte and Young (2002) found that glyphosate efficacy and economic return in glyphosate-resistant corn was just as good as any other type of weed management system for corn. Other studies have shown that two POST glyphosate applications on corn can provide better weed control than a single glyphosate application, especially if interfering weeds are controlled at heights < 15 cm (Johnson et al. 2000; Gower et al. 2002). Although Johnson et al. (2000) also reported that if weed control was >90%, input costs were higher for glyphosate resistant corn compared to non-transgenic varieties. The same study concluded that while the end result was similar, the use of glyphosate as a POST herbicide provided more flexibility for POST weed management options.

Summary

With the development and use of glyphosate-resistant crops and more POST oriented herbicide programs in corn, the adoption of a management program that entails single herbicide application timing may a viable method for weed control. However, the more commonly used two-pass herbicide system may provide better weed control options and yield results. The investigation of these types of systems for glyphosate-resistant corn is warranted. Arguably, shifting weed control trends to POST systems that permit early season weed competition may have unexpected implications on nitrogen management in corn.

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Chapter II

Weed Management in Glyphosate-resistant Corn (*Zea mays L.*)

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Abstract. The advent of glyphosate-resistant corn has changed traditional preemergence (PRE) followed by postemeregence (POST) herbicide programs to that ones that predominately utilize glyphosate POST. Programs using PRE, PRE plus POST, and POST combinations were compared for weed efficacy in glyphosate-resistant corn in both 2003 and 2004 at locations in central and northeast Missouri. Treatments included six, one-pass herbicide programs and nine, two-pass programs, with corn planted under a conventional tillage system. Sequential POST applications of glyphosate at 0.84 kg ae/ha or *s*-metolachlor PRE followed by glyphosate POST at 0.84 kg/ha were the only two-pass treatments which resulted in >90% weed control across all four-site years at evaluations 5 weeks after final herbicide applications. A treatment consisting of 0.07 kg ai/ha of mesotrione, 1.68 kg ai/ha atrazine, and 0.84 kg/ha of glyphosate applied on 7 to 10 cm weeds was the only one-pass system that resulted in >90% giant foxtail control for all four site-years. In site-years where species such as common ragweed and Pennsylvania smartweed were present, weed control from all the one-pass programs were comparable to the best two-pass programs on such weeds. All treatments that included atrazine resulted in weed control across a broader spectrum of species compared to treatments without atrazine.

For 3 of the 4 site-years, grain yield in plots receiving a single application of glyphosate application were 6-12% lower compared to plots receiving sequential herbicide applications. For all site-years and species, weed control failures occurred 29% more often using one-pass systems compared to two-pass programs utilizing PREs. As expected, yield reductions occurred more often in one-pass systems. Yields from one-pass herbicide programs can be comparable to two-pass programs, but they were inconsistent across site-years. Overall, two-pass systems which included the use of a PRE herbicide resulted in more consistent weed control across all species than one-pass POST treatments.

Nomenclature: atrazine, glyphosate, mesotrione, *s*-metolachlor, giant foxtail, *Setaria faberi* L. # [1]SETFA; Pennsylvania smartweed, *Polygonum pensylvanicum* L. # POLPY; common ragweed, *Ambrosia artemisiifolia* L. #AMBEL; *Zea mays* (L.) Merr. Dekalb (DKC 60-19).

Additional index words: herbicide-resistant, one-pass, two-pass, residual.

Abbreviations: PRE, preemergence; POST, postemergence.

Introduction

Modern approaches to weed management systems in corn include the use of herbicides on hybrids for which genes for resistance have been inserted. The most successful example has been glyphosate-resistant technology. In Missouri in 2007, applications of glyphosate on corn accounted for 35% of the hectares planted (W.B.

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[1] Letters following this symbol area wssa-approved computer code from the *Composite List of Weeds*, revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044

Parker, personal communication, March 3, 2008) and adoption of glyphosate systems in corn has increased steadily with the availability of more glyphosate-resistant hybrids (Anonymous 2007, Culpepper 2006).

Glyphosate-resistant corn is advantageous compared to non-resistant hybrids. Glyphosate is effective on numerous grass and broadleaf weeds, and rates can be adjusted to improve control of difficult species (Roundup Weathermax label). The efficacy of glyphosate can result in reduced usage of PRE herbicides. Environmentally, this reduction may be significant since two of the most commonly used PRE herbicides, atrazine and metolachlor, have both been detected in Missouri groundwater (Blanchard and Donald 1997; Donald et al. 1998). Economic returns of glyphosate-resistant corn systems are greater than or equal to any other type of weed management system, while efficacy of weed control is equivalent or better than conventional systems (Johnson et al. 2000; Nolte and Young 2002; Zuver et al. 2006).

Glyphosate-resistant technology can also have negative impacts. Repeated long-term use of glyphosate has selected for numerous resistant weed biotypes (Heap 2008). In addition, glyphosate lacks residual activity allowing additional weed emergence following applications; thus results in late season crop competition. The flexibility of glyphosate permits applications on larger weeds; delayed applications can allow early season competition and the potential for weed (Franz 1985; Frie et al. 2003; Lloyd et al. 2003). Hall et al. (1992) stated that corn in the V-14 stage is susceptible to competition from the emergence of weeds. Helwig et al. (2002) reported that corn competition with grasses greater than a height of 15 cm, reduced grain yield by as much as 12%. Carey and Kells (1995) reported that a second period of weed emergence following initial applications at 5 or 10 cm had no impact on grain yield. However, delaying the initial POST application until weed heights reached 15 cm resulted in grain losses up to 12%.

Weed control programs in glyphosate-resistant corn often include use of glyphosate with no other herbicides. In 2005 in the U.S, corn fields receiving glyphosate applications averaged 1.2 applications per season (Anonomous 2008). Properly timed sequential applications of glyphosate have been shown to be effective in season-long control of common waterhemp (*Amaranthus rudis*), giant foxtail (*Setaria faberi*), velvetleaf (*Abutilion theophrasti*), common cocklebur (*Xanthum strumarium*), and common lambsquarters (*Chenopodium album*) at levels >90% through the season (Hellwig et al. 2002; Bradley 1999; Young et al. 2002; Wax et al. 2002). Sequential applications are often not made; rather a single application is relied upon for total weed control, leading to increased weed pressure from continued emergence (Wait and Johnson 2002; Wax et al. 2002; Krausz and Young 2003).

Corn producers prefer the convenience of a one-pass (single application timing) weed management system. A single application would minimize application costs and allow producers to manage greater production areas. However, programs that utilize two separate herbicide applications (two-pass programs) have been shown to provide more consistent and effective control of giant foxtail, common waterhemp, and velvetleaf compared to a single application of glyphosate (Dalley et al. 2004; Gower et al. 2002; Gower et al. 2003; Johnson et al. 2002; Johnson et al. 2000; Schuster and Smeda 2007). Johnson et al. (2002) reported that two-pass programs under field conditions provided better control of giant foxtail, common cocklebur and common ragweed in 11 out of 12 years when compared to one-pass PRE or one-pass POST programs. Johnson (2002) also noted that a level of weed control >90% was more frequent across weed species for two-pass programs versus one-pass programs. Herbicides with residual activity increase the duration of weed control. Parker et al. (2006) found that the use of PRE herbicides minimized early season competition within corn compared to a strictly POST (non-residual) program. The delay of weed emergence enables the crop to be less stressed during the critical weed-free period, thereby increasing the feasibility of one-pass programs in glyphosate-resistant corn (Tharp and Kells 2002; Rhodes Jr. et al. 2000).

Little research exists documenting the efficacy of one-pass and two-pass herbicide programs in glyphosate-resistant corn production systems. Documentation of the efficacy of residual type herbicides and their effects in both one and two pass systems in glyphosate-resistant corn is also very limited. The objective of this study was to compare weed control efficacy in different weed management programs for glyphosate-resistant corn, utilizing one-pass and two-pass programs as well as the implications of residual herbicides in such programs.

Materials and Methods

Field experiments were conducted in 2003 and 2004 in central (Columbia) and northeastern (Novelty) Missouri. The Columbia location was at the Bradford Research and Extension Center. The soil was a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs) with a pH of 6.0 and an organic matter content of 2.9%. The second location was the Greenley Memorial Research Center in Novelty. The soil was a Putnam silt loam (fine, smectic, mesic Vertic Albaqualfs) with a pH of 6.6 and an organic matter content of 2.6%. Weather conditions during field trials were recorded for each site-year from April to September (Table 2.1).

Trials were established as a randomized complete block design with four replications. Plots were 3 by 14 m and in an experimental area previously planted in soybeans. Corn, Dekalb “DKC 60-19”, was planted at 69,500 seeds ha^{-1} in 76 cm rows at a depth of 4 cm. Planting dates for the Columbia location in 2003 and 2004 were May 22 and April 28, respectively. Planting dates at Novelty for 2003 and 2004 were May 17 and April 22, respectively. Herbicides were applied with a CO_2-pressurized backpack sprayer at a speed of 4.8 km hr^{-1}. The carrier volume was 187 L ha^{-1} at an operating pressure of 110 kPa utilizing XR8002[2] flat fan nozzle tips.

Herbicide treatments were catergorized into two groups, a single application of one or several herbicides (hereafter designated as one-pass) or two applications of one or several herbicides (hereafter designated as two-pass). There were a total of 16 herbicide treatments (Table 2.2), with six treatments consisting of one-pass herbicide programs and nine consisting of two-pass programs. An untreated check was also included. All treatments included the proper adjuvants as stated on the label.

For treatments with PRE applications, crop phytotoxicity and weed control were visually rated at the time of the POST application. Visual observations of weed control and crop injury were on a scale from 0 to 100%, where 0 indicate no crop injury or weed control and 100 indicates complete plant death. Evaluations of all treatments were made 2 and 5 weeks after the final POST application. Weed control evaluations were made on individual weed species within each site-year.

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[2] TeeJet Spraying Systems Co., Wheaton, IL 60188.

Five species were present for all site-years: giant foxtail (*Seteria faberi*) , common waterhemp (*Amaranthus rudis*) , velvetleaf (*Abutilion theophrasti*) , Pennsylvania smartweed (*Polygonum pensylvanicum*), and ivyleaf morningglory (*Ipomoea hederacea*).

Control was considered to be satisfactory above 90%. Grain yield was estimated from the 2 center rows of each plot over a distance of 10.5 m using a plot combine, and moisture was adjusted to 15.5%. Yields were taken at Columbia on October 6 and August 31, in 2003 and 2004, respectively. Yields at Novelty were taken on October 2 and September 3, in 2003 and 2004, respectively.

All data were subjected to analysis of variance and tested for homogeneity. However due to significant site by year interactions, the results were not pooled. Grain yields were then subjected to square root transformations to improve mean separation, however data separation were not improved; therefore the original weed control and yield data are presented (SAS 2000). Crop phytotoxicity, weed control and yield were separated by Fisher's Protected LSD with the level of significance of $\alpha = 0.05$.

Results and Discussion

Crop Phytotoxicity

Crop injury from PRE herbicides were evaluated at the timing of the POST application, as well as 2 and 5 weeks later (Tables 2.3 to 2.5). Crop phytotoxicity varied across site-years and treatments, with injury ranging from 0 to 13% across all treatments. Crop injury was greatest at 2 weeks after the last POST treatment (2 WAT) following the treatments of *s*-metolachlor followed by dicamba plus diflufenzopyr, and *s*-metolachlor followed by dicamba plus atrazine. Overall, most treatments resulted in less than 5% visual injury and declined for evaluations recorded 5 weeks after the last POST treatment (5 WAT).

Giant foxtail

Giant foxtail control varied between site-years, but results between treatments were consistent within most site-years. At the time that POST herbicides were applied, giant foxtail control was > 85% in 3 of 4 site-years for all treatments containing a PRE, except isoxaflutole. In 2003, control of giant foxtail using isoxaflutole was as much as 55% lower than other treatments, however reduced efficacy was observed in all PRE herbicide treatments. At 2 WAT, giant foxtail control for all two-pass programs was >90%, except where POST dicamba plus diflufenzopyr and mesotrione plus atrazine were used, as well as, one year (2003) that used isoxaflutole followed by foramsulfuron plus iodosulfuron plus dicamba plus diflufenzopyr (Table 2.7). Reduced giant foxtail control from POST dicamba plus atrazine was as low as 72% in certain 2 of 4 site years.

By 5 WAT, the effectiveness of the herbicide programs was clear. The loss of giant foxtail control in the dicamba plus atrazine treatment resulted in decreased control ranging from 49 to 75% (Table 2.8). This was consistent with reduced efficacy of other treatments in 2003 where PRE herbicides were applied. In 2004, PRE herbicides were overall more effective, with control ranging from 89 to 100%. However, certain programs such as isoxaflutole f/b foramsulfuron plus iodosulfuron plus dicamba plus diflufenzopyr and dimethanamid-P plus atrazine were not satisfactory in 3 of 4 and 4 of 4 site-years, respectively. At 5 WAT, only *s*-metolachlor plus atrazine f/b glyphosate, *s*-metolachlor f/b glyphosate, both timings of glyphosate followed by glyphosate, and the one-pass program of mesotrione plus atrazine plus glyphosate resulted in control for all four site-years. All others had at least one site-year of the treatment that provided unsatisfactory results.

One-pass programs were less consistent than two-pass programs at both 2 and 5 WAT. For all one-pass programs, control was <90% in 9 out of 24 site-years for each evaluation timing. Dimethanamid-P plus atrazine at early-POST provide the most inconsistent results ranging from 6 to 88% efficacy. In addition, final evaluations revealed that two pass programs that included a second application of glyphosate increased control of giant foxtail to >90% in every treatment. In treatments not receiving a second glyphosate application, giant foxtail control was lower at the 5 WAT evaluations compared to the 2 WAT evaluations. Two-pass programs produced better giant foxtail weed control, provided control with the PRE herbicide was >90%. In summary, at 5 WAT, the most efficient control from two-pass programs resulted with two sequential applications of glyphosate or from *s*-metolachlor PRE followed by glyphosate. The most effective one-pass program was mesotrione plus atrazine plus glyphosate at the mid-POST timing; providing ≥95% across all site-years, at all evaluation timings. The most efficient one-pass program that did not include a residual herbicide was glyphosate at late-POST, providing control from 88 to 96%.

Common waterhemp

Common waterhemp control was very definitive, with treatments either providing almost complete control (>95%) or poor control (<75%) (Table 2.9). Activity of PRE herbicides at the time of the POST application resulted in >90% control in 10 of 12 site-years when atrazine was a component. For PRE herbicides not using atrazine, control was

>90% in 10 of 20 site-years. The only PRE not utilizing atrazine or *s*-metolachlor was isoxaflutole, and control was >90% control in 3 of 4 site-years (Table 2.9).

Evaluations taken 2 WAT demonstrated that a single application of glyphosate resulted in <90% control in half the site-years. Similar results were found in the dimethanamid-P plus atrazine program, which was also a one-pass program. All other one- and two-pass programs provided ≥90% control of common waterhemp at 2 WAT (Table 2.10).

Evaluations of common waterhemp at 5 WAT were rated at 3 out of 4 site-years. At the Novelty location in 2003, assessments were not taken because competing weed species reduced population densities in the untreated check to minimal levels (Table 2.11). Other site-years resulted in control > 90% for all treatments, except for the single application of glyphosate, which resulted in reduced control of 81 to 89% control in 2 of 3 site years. Late season efficacy indicates POST herbicide treatments were more effective overall than early season PRE applications.

Velvetleaf

Velvetleaf control with PRE herbicides was highly variable (Table 2.12). The only PRE of the two-pass systems to provide satisfactory control was isoxaflutole, in 2 of 3 site-years evaluated. The one-pass programs using PRE herbicides provided excellent control, with the exception of the Novelty location in 2003 where conditions were drought stressed.

At 2 WAT, the one-pass program of acetochlor plus atrazine resulted in control < 90% in 2 of 3 site-years (Table 2.13). Compared to other programs, control with a single late-POST glyphosate treatment reduced by 7 to 11% in 2 of 3 site-years; however efficacy was very good, with control for all site-years >89%. With the exception of *s*-metolachlor followed by dicamba plus diflufenzopyr, all two pass programs provided >90% control of velvetleaf.

By 5 WAT, weed control with two-pass programs was consistent (Table 2.14). Compared to 2 WAT evaluations, weed control in one-pass programs were as much as 14% lower compared to 5 WAT. Reduced control can be partially attributed to large amounts of rainfall followed by a droughty period; which likely dissipated herbicides throughout the soil profile. This may explain the poor results with the one-pass treatment of acetochlor plus atrazine. Even still, differences between site-years can only be partially explained by environmental conditions. The only one-pass program to have >90% control across all site-years was mesotrione plus atrazine plus glyphosate; however a single application of glyphosate resulted in 88 to 99% control at the 5 WAT evaluation timing (Table 2.14). All other treatments provided ≥90% control at both 2 and 5 WAT.

Pennsylvania smartweed

Low populations of Pennsylvania smartweed early in the season precluded evaluation at the initial POST application. By 2 WAT, all but one treatment provided control >90% in 2 of 3 site-years (Table 2.15). The one-pass system of glyphosate was the only treatment that resulted in ≤85% control in the majority of site-years. Inconsistent weed control from treatments was restricted to Novelty in 2003, indicating that reduced control was possibly a product of the irregular environment.

At 5 WAT, control increased to >85% with the glyphosate alone treatment across all site-years (Table 2.16). Weed control likely increased after the 2 WAT evaluations because larger Pennsylvania smartweeds have a higher tolerance to glyphosate and often require increased rates (Monsanto Weathermax label). With the exception of a PRE application of acetochlor plus atrazine, all treatments resulted in satisfactory control.

Corn yield

Results from the grain yield data indicate that a number of herbicide programs, both one-pass and two-pass, can lead to optimum grain harvest (Table 2.17). However, one-pass programs with consistently higher grain yields across all four site-years contained herbicides with three different modes of action, with mesotrione and atrazine as two of the three components. For two-pass programs, multiple herbicides with different modes of action or sequential applications of glyphosate (early POST for the first application) were characteristic of high yielding treatments. It was evident that control of a broad spectrum of weeds with mixing different herbicides or using broad spectrum herbicides such as glyphosate was a key contributor to a successful program. Also, the presence of herbicides with long residual (e.g. atrazine) or high efficacy (glyphosate) improved the presence of high grain yields. Variation in weed control from single herbicide applications or exposure of corn to early season competition (sequential glyphosate applications with first timing at late POST) led to reduced grain yield for some site-years.

A total of eight programs were found to have the statistically highest yield for all four site-years (Table 2.17). Of the eight, the only high yielding treatment not utilizing a residual product was an early POST application of glyphosate followed by a late POST application. Only two of the eight treatments were one-pass programs, a PRE application of mesotrione plus *s*-metolachlor plus atrazine and the mid-POST application of nicosulfuron plus rimsulfuron plus mesotrione plus atrazine. The one-pass program of mesotrione plus atrazine plus glyphosate was effective in controlling all weed species across all site-years and had the highest grain yield in 3 of 4 site-years. Considering weed control in all species was never less than 90%, mesotrione plus atrazine plus glyphosate was an efficacious one-pass program for weed control in glyphosate-resistant corn. However, despite efficient weed control in all site-years, grain yield from this program was reduced at Columbia in 2003. This could be attributed to early season weed competition. The grain yields for all other one-pass treatments, including a single glyphosate application, were reduced in at least 2 of 4 site-years. This indicates that a number of factors, including environmental conditions and weed populations, can result in yield inconsistencies. This agrees with findings by Myers et al. (2005), who found that a total POST one-pass weed control program in corn could be feasible but numerous factors including weed density and herbicide timing are crucial.

Weed control was often a predictor of grain yield. In treatments such as dimethanamid-P plus atrazine at Columbia in 2003, giant foxtail control was as low as 6% and subsequent yield was reduced by as much as 38%. All other weeds were at controlled at levels greater than 90%, indicating giant foxtail competition compromised yield; however for the *s*-metolachlor followed by glyphosate where overall weed control was satisfactory yields were consistently among the highest for all site-years.

Across all treatments, weed control from two-pass programs resulted in less variability in weed control and higher yields; even for treatments with poor PRE activity. For example, s-metolachlor plus atrazine (low rates) followed by glyphosate, s-metolachlor plus atrazine (high rates) followed by glyphosate, and s-metolachlor followed by glyphosate all exhibited variable weed control activity initially. However, glyphosate POST improved control to >90% by 5 WAT. Two-pass programs involving a PRE herbicide also had consistently higher yields despite the variable efficacy of the PRE portion of the treatments. This was consistent with Johnson et al. (2002), who reported that control of giant foxtail, common waterhemp, and velvetleaf, were significantly higher with two-pass programs than one-pass programs over a 12 year period.

The increased efficacy by utilizing residual herbicides has been documented by Johnson et al. (2000), Gower (2002), and Johnson (2002). The use of a residual herbicide in a one-pass system increased weed control across species and grain yield, when compared to a single application of glyphosate without a residual herbicide. Under certain environmental conditions, one-pass systems result in satisfactory (>90%) weed control, however under environmental stresses, the risk for reduced efficacy increases dramatically using these types of programs. Programs that relied completely upon POST herbicides for weed control often allowed for early season competition that hindered plant vigor and has also been documented by others (Hall et al. 1992; Parker et al. 2006).

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Table 2.1. Average air temperature and total precipitation from April through September at Columbia and Novelty in 2003 and 2004.

	Temperature				Precipitation			
	Columbia		Novelty		Columbia[a]		Novelty	
Month	2003	2004	2003	2004	2003	2004	2003	2004
	C				mm			
April	13	14	12	13	208	65	160	78
May	17	19	16	19	137	119	93	120
June	20	21	20	21	166	44	82	84
July	25	23	25	23	92	112	83	67
August	26	21	25	20	120	130	75	206
September	18	20	17	19	241	24	158	25
Mean	20	20	19	19	---	---	---	---
Total	---	---	---	---	876	494	651	580

[a] Additional moisture (25 mm) was provided to the Columbia location by supplemental irrigation on July 8th, July 23rd, August 12th, and August 26th in 2003 and on June 29th in 2004.

Table 2.2 Application dates for each timing of study treatments and corresponding program and herbicide rates.

Herbicides[a]	Rate[b]	2003 Columbia	2003 Novelty	2004 Columbia	2004 Novelty	Timing[c]	Program
Untreated check	-	-	-	-	-	-	-
acetochlor + atrazine	1.2 + 0.6	5-23	5-17	4-28	4-27	PRE alone	One-pass
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	5-23	5-17	4-28	4-27	PRE alone	One-pass
s-metolachlor + atrazine f/b[d] glyphosate	0.42 + 0.53 f/b 0.84	5-23 f/b 6-25	5-17 f/b 6-20	4-28 f/b 6-1	4-27 f/b 6-10	PRE f/b Mid POST	Two-pass
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	5-23 f/b 6-25	5-17 f/b 6-20	4-28 f/b 6-1	4-27 f/b 6-10	PRE f/b Mid POST	Two-pass
s-metolachlor f/b glyphosate	1.0 f/b 0.84	5-23 f/b 6-24	5-17 f/b 6-17	4-28 f/b 5-28	4-27 f/b 6-1	PRE f/b Mid POST	Two-pass
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	5-23 f/b 6-24	5-17 f/b 6-17	4-28 f/b 5-28	4-27 f/b 6-1	PRE f/b Mid POST	Two-pass
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	5-23 f/b 6-20	5-17 f/b 6-11	4-28 f/b 5-28	4-27 f/b 6-1	PRE f/b 5 leaf corn[e]	Two-pass
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	5-23 f/b 6-17	5-17 f/b 6-11	4-28 f/b 5-23	4-27 f/b 5-24	PRE f/b Early POST	Two-pass
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	5-23 f/b 6-10	5-17 f/b 6-17	4-28 f/b 6-1	4-27 f/b 6-3	PRE f/b Mid POST	Two-pass
mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	6-17	6-17	5-28	6-1	Mid POST	One-pass
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	6-17	6-17	5-28	6-1	Mid POST	One-pass
dimethanamid-P + atrazine	0.5 + 0.98	6-16	6-11	5-23	5-24	Very Early POST	One-pass

glyphosate	0.84	6-22	6-19	6-1	6-3	Late POST	One-pass
glyphosate f/b glyphosate	0.84 f/b 0.84	6-22 f/b 6-30	6-19 f/b 6-30	6-1 f/b 6-10	6-3 f/b 6-10	Late POST f/b Early POST	Two-pass
glyphosate f/b glyphosate	0.84 f/b 0.84	6-17 f/b 7-2	6-17 f/b 7-5	5-28 f/b 6-24	6-1 f/b 6-15	Early POST f/b Late POST	Two-pass

[a] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.

[b] All herbicide rates are kg ai ha^{-1} except for glyphosate rates are given in kg ae ha^{-1}.

[c] PRE, preemergence; Very Early POST, very early postemergence (weeds 2.5 to 5 cm tall); Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid postemergence (weeds 7 to 10 cm tall); Late POST, late postemergence (weeds 10 to 15 cm tall).

[d] f/b, followed by.

[e] 5 leaf corn, application was made when corn reached physiological stage of V-5.

Table 2.3. Mean visual rating of crop injury in response to PRE herbicides. Evaluations were taken at the timing of at the time of first POST application for Columbia and Novelty, MO in 2003 and 2004.

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[a]	Rate[b]	Timing[c]	Program	% crop injury			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	3	2	0	0
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	5	1	0	0
s-metolachlor + atrazine f/b[e] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	3	1	0	0
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	2	1	0	0
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	2	1	0	0
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	1	2	0	0
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	2	2	0	0
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11+ 0.84	PRE Early POST	Two-pass	2	2	0	0
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid POST	Two-pass	4	6	0	0
LSD (0.05)[f]				**1.9**	**1.7**	-	-

[a] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.

[b] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.

[c] PRE, preemergence; Very Early POST, very early postemergence (weeds 2.5 to 5 cm tall); Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid postemergence (weeds 7 to 10 cm tall); Late POST, late postemergence (weeds 10 to 15 cm tall).

[d] Crop injury was rated on a scale from 0-100 where 0 is no injury and 100 is total plant death.

[e] f/b, followed by

[f] Fisher's Protected LSD at p=0.05.

Table 2.4. Mean visual rating of crop injury at 2 WAT for Columbia and Novelty, MO in 2003 and 2004.[a]

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[b]	Rate[c]	Timing[d]	Program	% crop injury			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	0	0	0	0
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	0	0	0	0
s-metolachlor + atrazine f/b[f] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	0	2	0	0
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	0	1	0	0
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	0	4	0	0
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	5	2	2	8
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	4	1	4	13
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	0	2	3	2
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	4	5	5	2

mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	Mid-POST	One-pass	0	2	0	0
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	Mid-POST	One-pass	0	6	0	0
dimethanamid-P + atrazine	0.5 + 0.98	Very Early POST	One-pass	0	4	0	0
glyphosate	0.84	Late POST	One-pass	0	2	0	0
glyphosate f/b glyphosate	0.84 f/b 0.84	Late POST Early POST	Two-pass	0	5	0	0
glyphosate f/b glyphosate	0.84 f/b 0.84	Early POST Late POST	Two-pass	0	5	0	0
LSD (0.05)[g]				**0.9**	**2.5**	**2.2**	**1.9**

[a] WAT, Weeks after treatment.

[b] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.

[c] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.

[d] Very Early POST (2.5. to 5 cm weeds) PRE, preemergence; Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid-postemergence (weeds 7 to 10 cm tall); Late POST, Late postemergence (20 to 30 cm weeds).

[e] Crop injury was rated on a scale from 0-100 where 0 is no injury and 100 is total plant death.

[f] f/b, followed by.

[g] LSD represents the Least Significant Difference between treatments at p=0.05.

Table 2.5. Mean visual rating of crop injury at 5 WAT for Columbia and Novelty, MO in 2003 and 2004.[a]

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[b]	Rate[c]	Timing[d]	Program	% crop injury			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	0	0	0	0
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	0	0	0	0
s-metolachlor + atrazine f/b[f] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	0	0	0	0
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	0	0	0	0
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	0	0	0	0
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	0	5	0	0
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	0	4	0	0
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	0	3	0	0
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	0	1	0	0

mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	Mid-POST	One-pass	0	0	0	0
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	Mid-POST	One-pass	0	0	0	0
dimethanamid-P + atrazine	0.5 + 0.98	Early POST	One-pass	0	4	0	0
glyphosate	0.84	Late POST	One-pass	0	0	0	0
glyphosate f/b glyphosate	0.84 f/b 0.84	Late POST Early POST	Two-pass	0	0	0	0
glyphosate f/b glyphosate	0.84 f/b 0.84	Early POST Late POST	Two-pass	0	0	0	0
LSD (0.05)[g]				**-**	**1.4**	**-**	**-**

[a] WAT, Weeks after treatment.

[b] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.

[c] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.

[d] Very Early POST (2.5. to 5 cm weeds) PRE, preemergence; Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid-postemergence (weeds 7 to 10 cm tall); Late POST, Late postemergence (20 to 30 cm weeds).

[e] Crop injury was rated on a scale from 0-100 where 0 is no injury and 100 is total plant death.

[f] f/b, followed by.

[g] LSD represents the Least Significant Difference between treatments at p=0.05.

Table 2.6. Mean visual rating for giant foxtail at the timing of at the time of first POST application for Columbia and Novelty, MO in 2003 and 2004.

Treatment[a]	Rate[b]	Timing[c]	Program	2003 Columbia	2003 Novelty	2004 Columbia	2004 Novelty
				% control[d]			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	98	80	100	100
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	97	85	100	100
s-metolachlor + atrazine f/b[e] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	91	74	98	100
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	92	87	100	100
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	95	80	100	100
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	91	65	100	100
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	85	73	100	100
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	95	79	100	95
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	45	38	98	99
LSD (0.05)[f]				**15.3**	**17.9**	**2.1**	**0.03**

[a] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.

[b] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.

[c] PRE, preemergence; Very Early POST, very early postemergence (weeds 2.5 to 5 cm tall); Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid postemergence (weeds 7 to 10 cm tall); Late POST, late postemergence (weeds 10 to 15 cm tall).

[d] Weed control was rated on a scale from 0-100 where 0 is no control and 100 is total absence of living weeds.

[e] f/b, followed by

[f] Fisher's Protected LSD at p=0.05.

Table 2.7. Mean visual rating for giant foxtail control 2 WAT at Columbia and Novelty, MO in 2003 and 2004.[a]

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[b]	Rate[c]	Timing[d]	Program	% control[e]			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	92	58	100	100
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	92	68	100	100
s-metolachlor + atrazine f/b[f] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	96	99	91	98
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	98	100	93	99
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	94	98	96	100
s-metolachlor f/b dicamba + diflufenzopyr	1.0 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	100	65	98	99
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	85	72	99	96
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	94	77	99	97
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	71	82	90	99

mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	Mid-POST	One-pass	95	99	95	98
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	Mid-POST	One-pass	85	59	87	88
dimethanamid-P + atrazine	0.5 + 0.98	Early POST	One-pass	15	60	63	77
glyphosate	0.84	Late POST	One-pass	81	95	88	98
glyphosate f/b glyphosate	0.84 f/b 0.84	Late POST Early POST	Two-pass	95	99	100	100
glyphosate f/b glyphosate	0.84 f/b 0.84	Early POST Late POST	Two-pass	98	100	100	100
LSD (0.05)[g]				**8.1**	**14.5**	**12.4**	**4.8**

[a] WAT, Weeks after treatment.

[b] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.

[c] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.

[d] Very Early POST (2.5. to 5 cm weeds) PRE, preemergence; Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid-postemergence (weeds 7 to 10 cm tall); Late POST, Late postemergence (20 to 30 cm weeds).

[e] Weed control was rated on a scale from 0-100 where 0 is no control and 100 is total absence of living weeds.

[f] f/b, followed by.

[g] LSD represents the Least Significant Difference between treatments at p=0.05.

Table 2.8. Mean visual rating for giant foxtail control 5 WAT at Columbia and Novelty, MO in 2003 and 2004.[a]

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[b]	Rate[c]	Timing[d]	Program	% control[e]			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	91	60	98	100
Mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	92	58	99	100
s-metolachlor + atrazine f/b[f] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	96	90	91	100
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	95	94	95	100
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	94	95	99	100
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	80	70	98	96
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	75	49	98	99
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early-POST	Two-pass	92	56	98	100
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	70	71	89	98

mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	Mid-POST	One-pass	97	98	96	99
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	Mid-POST	One-pass	93	68	87	95
dimethanamid-P + atrazine	0.5 + 0.98	Early POST	One-pass	6	36	77	88
glyphosate	0.84	Late POST	One-pass	88	89	92	96
glyphosate f/b glyphosate	0.84 f/b 0.84	Late POST Early POST	Two-pass	97	95	99	100
glyphosate f/b glyphosate	0.84 f/b 0.84	Early POST Late POST	Two-pass	98	97	100	100
LSD (0.05)[g]				**8.5**	**16.0**	**5.1**	**4.4**

[a] WAT, Weeks after treatment.

[b] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.

[c] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.

[d] Very Early POST (2.5. to 5 cm weeds) PRE, preemergence; Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid-postemergence (weeds 7 to 10 cm tall); Late POST, Late postemergence (20 to 30 cm weeds).

[e] Weed control was rated on a scale from 0-100 where 0 is no control and 100 is total absence of living weeds.

[f] f/b, followed by.

[g] LSD represents the Least Significant Difference between treatments at p=0.05.

Table 2.9. Mean visual rating for common waterhemp control at the timing of the POST application at Columbia and Novelty, MO in 2003 and 2004.

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[a]	Rate[b]	Timing[c]	Program	% control[d]			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	100	100	100	100
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	100	100	99	100
s-metolachlor + atrazine f/b[e] glyphosate	0.42 + 0.53 0.84	PRE Mid-POST	Two-pass	100	76	100	100
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	100	83	99	100
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	33	78	75	100
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	83	56	100	100
s-metolachlor f/b dicamba + atrazine	1.0 0.21 + 0.34	PRE 5 leaf corn	Two-pass	68	68	100	100
s-metolachlor f/b mesotrione + atrazine	1.0 0.11 + 0.84	PRE Early POST	Two-pass	51	47	100	91
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	96	33	98	100
LSD (0.05)[f]				**15.3**	**17.9**	**18.0**	**3.6**

[a] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.

[b] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.

[c] PRE, preemergence; Very Early POST, very early postemergence (weeds 2.5 to 5 cm tall); Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid postemergence (weeds 7 to 10 cm tall); Late POST, late postemergence (weeds 10 to 15 cm tall).

[d] Weed control was rated on a scale from 0-100 where 0 is no control and 100 is total absence of living weeds.

[e] f/b, followed by

[f] Fisher's Protected LSD at p=0.05.

Table 2.10. Mean visual rating for common waterhemp control 2 WAT at Columbia and Novelty, MO in 2003 and 2004.[a]

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[b]	Rate[c]	Timing[d]	Program	% control[e]			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	100	91	96	100
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	99	100	96	100
s-metolachlor + atrazine f/b[f] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	93	100	82	95
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	93	99	95	100
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	93	99	98	99
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	96	94	91	94
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	98	99	98	100
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	100	100	98	100
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	91	97	93	98

mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	Mid-POST	One-pass	100	100	99	100
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	Mid-POST	One-pass	97	96	92	99
dimethanamid-P + atrazine	0.5 + 0.98	Early POST	One-pass	96	68	92	71
glyphosate	0.84	Late POST	One-pass	70	89	91	92
glyphosate f/b glyphosate	0.84 f/b 0.84	Late POST Early POST	Two-pass	95	99	99	98
glyphosate f/b glyphosate	0.84 f/b 0.84	Early POST Late POST	Two-pass	98	98	100	99
LSD (0.05)[g]				**8.1**	**10.4**	**9.2**	**7.9**

[a] WAT, Weeks after treatment.

[b] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.

[c] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.

[d] Very Early POST (2.5. to 5 cm weeds) PRE, preemergence; Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid-postemergence (weeds 7 to 10 cm tall); Late POST, Late postemergence (20 to 30 cm weeds).

[e] Weed control was rated on a scale from 0-100 where 0 is no control and 100 is total absence of living weeds.

[f] f/b, followed by.

[g] LSD represents the Least Significant Difference between treatments at p=0.05.

Table 2.11. Mean visual rating for common waterhemp control 5 WAT at Columbia and Novelty, MO in 2003 and 2004.[a]

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[b]	Rate[c]	Timing[d]	Program	% control[e]			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	98	-	96	99
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	100	-	96	99
s-metolachlor + atrazine f/b[f] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	93	-	82	96
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	94	-	95	98
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	95	-	97	93
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	97	-	90	96
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	100	-	97	100
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	100	-	97	98
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	85	-	92	94

mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	Mid-POST	One-pass	100	-	98	100
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	Mid-POST	One-pass	100	-	90	98
dimethanamid-P + atrazine	0.5 + 0.98	Early POST	One-pass	93	-	92	94
glyphosate	0.84	Late POST	One-pass	81	-	89	96
glyphosate f/b glyphosate	0.84 f/b 0.84	Late POST Early POST	Two-pass	97	-	99	100
glyphosate f/b glyphosate	0.84 f/b 0.84	Early POST Late POST	Two-pass	97	-	100	100
LSD (0.05)[g]				**6.9**	**-**	**9.4**	**6.0**

[a] WAT, Weeks after treatment.
[b] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.
[c] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.
[d] Very Early POST (2.5. to 5 cm weeds) PRE, preemergence; Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid-postemergence (weeds 7 to 10 cm tall); Late POST, Late postemergence (20 to 30 cm weeds).
[e] Weed control was rated on a scale from 0-100 where 0 is no control and 100 is total absence of living weeds.
[f] f/b, followed by.
[g] LSD represents the Least Significant Difference between treatments at p=0.05.

Table 2.12. Mean visual rating for velvetleaf control at the timing of the POST application at Columbia and Novelty, MO in 2003 and 2004.

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[a]	Rate[b]	Timing[c]	Program	% control[d]			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	99	42	-	98
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	100	100	-	100
s-metolachlor + atrazine f/b[e] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	66	34	-	88
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	81	59	-	96
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	76	14	-	34
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	65	16	-	18
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	79	46	-	10
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	60	45	-	21
Isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid POST	Two-pass	98	62	-	100
LSD (0.05)[f]				**21.5**	**1.7**	**-**	**22.6**

[a] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.

[b] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.

[c] PRE, preemergence; Very Early POST, very early postemergence (weeds 2.5 to 5 cm tall); Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid postemergence (weeds 7 to 10 cm tall); Late POST, late postemergence (weeds 10 to 15 cm tall).

[d] Weed control was rated on a scale from 0-100 where 0 is no control and 100 is total absence of living weeds.

[e] f/b, followed by

[f] Fisher's Protected LSD at p=0.05.

Table 2.13. Mean visual rating for velvetleaf control 2 WAT at Columbia and Novelty, MO in 2003 and 2004.[a]

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[b]	Rate[c]	Timing[d]	Program	% control[e]			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	96	9	-	81
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	98	97	-	93
s-metolachlor + atrazine f/b[f] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	100	91	-	99
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	100	98	-	98
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	98	95	-	100
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	100	81	-	87
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	99	97	-	100
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	99	99	-	94
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	96	93	-	100

mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	Mid-POST	One-pass	100	100	-	100
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	Mid-POST	One-pass	98	98	-	100
dimethanamid-P + atrazine	0.5 + 0.98	Early POST	One-pass	100	100	-	64
glyphosate	0.84	Late POST	One-pass	89	93	-	94
glyphosate f/b glyphosate	0.84 f/b 0.84	Late POST Early POST	Two-pass	99	99	-	100
glyphosate f/b glyphosate	0.84 f/b 0.84	Early POST Late POST	Two-pass	92	100	-	100
LSD (0.05)[g]				**6.0**	**6.2**	**-**	**10.2**

[a] WAT, Weeks after treatment.
[b] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.
[c] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.
[d] Very Early POST (2.5. to 5 cm weeds) PRE, preemergence; Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid-postemergence (weeds 7 to 10 cm tall); Late POST, Late postemergence (20 to 30 cm weeds).
[e] Weed control was rated on a scale from 0-100 where 0 is no control and 100 is total absence of living weeds.
[f] f/b, followed by.
[g] LSD represents the Least Significant Difference between treatments at p=0.05.

Table 2.14. Mean visual rating for velvetleaf control 5 WAT at Columbia and Novelty, MO in 2003 and 2004.[a]

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[b]	Rate[c]	Timing[d]	Program	% control[e]			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	91	10	-	97
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	96	89	-	91
s-metolachlor + atrazine f/b[f] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	93	88	-	100
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	95	91	-	100
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	91	91	-	99
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	87	94	-	98
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	100	95	-	100
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	99	92	-	100
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	90	94	-	99

mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	Mid-POST	One-pass	99	99	-	100
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	Mid-POST	One-pass	98	86	-	96
dimethanamid-P + atrazine	0.5 + 0.98	Early POST	One-pass	100	86	-	79
glyphosate	0.84	Late POST	One-pass	88	92	-	99
glyphosate f/b glyphosate	0.84 f/b 0.84	Late POST Early POST	Two-pass	97	95	-	100
glyphosate f/b glyphosate	0.84 f/b 0.84	Early POST Late POST	Two-pass	97	98	-	100
LSD (0.05)[g]				**9.6**	**9.8**	**-**	**5.7**

[a] WAT, Weeks after treatment.
[b] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.
[c] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.
[d] Very Early POST (2.5. to 5 cm weeds) PRE, preemergence; Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid-postemergence (weeds 7 to 10 cm tall); Late POST, Late postemergence (20 to 30 cm weeds).
[e] Weed control was rated on a scale from 0-100 where 0 is no control and 100 is total absence of living weeds.
[f] f/b, followed by.
[g] LSD represents the Least Significant Difference between treatments at p=0.05.

Table 2.15. Mean visual rating for Pennsylvania smartweed control 2 WAT at Columbia and Novelty, MO in 2003 and 2004.[a]

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[b]	Rate[c]	Timing[d]	Program	% control[e]			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	100	83	100	-
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	100	100	100	-
s-metolachlor + atrazine f/b[f] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	100	93	100	-
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	100	100	100	-
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	94	69	100	-
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	100	96	100	-
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	100	100	100	-
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	100	100	100	-
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	93	92	100	-

mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	Mid-POST	One-pass	100	100	100	-
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	Mid-POST	One-pass	100	100	100	-
dimethanamid-P + atrazine	0.5 + 0.98	Early POST	One-pass	100	97	100	-
glyphosate	0.84	Late POST	One-pass	85	70	94	-
glyphosate f/b glyphosate	0.84 f/b 0.84	Late POST Early POST	Two-pass	96	75	96	-
glyphosate f/b glyphosate	0.84 f/b 0.84	Early POST Late POST	Two-pass	91	77	100	-
LSD (0.05)[g]				**6.2**	**18.4**	**4.3**	**-**

[a] WAT, Weeks after treatment.
[b] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.
[c] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.
[d] Very Early POST (2.5. to 5 cm weeds) PRE, preemergence; Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid-postemergence (weeds 7 to 10 cm tall); Late POST, Late postemergence (20 to 30 cm weeds).
[e] Weed control was rated on a scale from 0-100 where 0 is no control and 100 is total absence of living weeds.
[f] f/b, followed by.
[g] LSD represents the Least Significant Difference between treatments at p=0.05.

Table 2.16. Mean visual rating for Pennsylvania smartweed control 5 WAT at Columbia and Novelty, MO in 2003 and 2004.[a]

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[b]	Rate[c]	Timing[d]	Program	% control[e]			
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	100	85	100	-
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	100	100	100	-
s-metolachlor + atrazine f/b[f] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	100	96	96	-
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	99	100	100	-
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	95	92	100	-
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	100	98	99	-
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	100	100	100	-
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	100	100	100	-
isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	93	100	100	-

mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	Mid-POST	One-pass	100	100	100	-
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	Mid-POST	One-pass	100	96	100	-
dimethanamid-P + atrazine	0.5 + 0.98	Early POST	One-pass	100	100	100	-
glyphosate	0.84	Late POST	One-pass	92	88	100	-
glyphosate f/b glyphosate	0.84 f/b 0.84	Late POST Early POST	Two-pass	100	94	100	-
glyphosate f/b glyphosate	0.84 f/b 0.84	Early POST Late POST	Two-pass	100	97	100	-
LSD (0.05)[g]				**4.2**	**9.7**	**2.8**	-

[a] WAT, Weeks after treatment.
[b] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha.
[c] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha.
[d] Very Early POST (2.5. to 5 cm weeds) PRE, preemergence; Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid-postemergence (weeds 7 to 10 cm tall); Late POST, Late postemergence (20 to 30 cm weeds).
[e] Weed control was rated on a scale from 0-100 where 0 is no control and 100 is total absence of living weeds.
[f] f/b, followed by.
[g] LSD represents the Least Significant Difference between treatments at p=0.05.

Table 2.17. Grain yield harvested from Columbia and Novelty, MO in 2003 and 2004.[a]

				2003		2004	
				Columbia	Novelty	Columbia	Novelty
Treatment[b]	Rate[c]	Timing[d]	Program	kg/ha			
untreated				1,155	3,400	5,594	8,828
acetochlor + atrazine	1.2 + 0.6	PRE alone	One-pass	3,675	7,797	13,833	14,822
mesotrione + *s*-metolachlor + atrazine	0.09 + 0.97 + 0.36	PRE alone	One-pass	3,594	8,167	15,363	14,868
s-metolachlor + atrazine f/b[e] glyphosate	0.42 + 0.53 f/b 0.84	PRE Mid-POST	Two-pass	3,775	7,914	14,879	15,014
s-metolachlor + atrazine f/b glyphosate	0.84 + 1.1 f/b 0.84	PRE Mid-POST	Two-pass	3,778	7,904	15,239	14,596
s-metolachlor f/b glyphosate	1.0 f/b 0.84	PRE Mid-POST	Two-pass	3,927	8,167	15,296	14,705
s-metolachlor f/b dicamba + diflufenzopyr	1.00 f/b 0.10 + 0.04	PRE Mid-POST	Two-pass	3,642	8,064	15,573	14,069
s-metolachlor f/b dicamba + atrazine	1.0 f/b 0.21 + 0.34	PRE 5 leaf corn	Two-pass	3,433	7,852	14,141	13,985
s-metolachlor f/b mesotrione + atrazine	1.0 f/b 0.11 + 0.84	PRE Early POST	Two-pass	4,152	7,951	15,782	14,801

isoxaflutole f/b foramsulfuron + iodosulfuron + dicamba + diflufenzopyr	0.05 f/b 0.02 + 0.001+ 0.05 + 0.02	PRE Mid-POST	Two-pass	3,613	7,791	14,483	14,413
mesotrione + atrazine + glyphosate	0.07 + 1.7 + 0.84	Mid-POST	One-pass	3,143	8,212	16,096	14,893
nicosulfuron + rimsulfuron + mesotrione + atrazine	0.02 + 0.01+ 0.05+ 0.84	Mid-POST	One-pass	3,661	8,075	15,585	14,460
dimethanamid-P + atrazine	0.5 + 0.98	Early POST	One-pass	2,566	7,762	15,043	14,645
glyphosate	0.84	Late POST	One-pass	3,284	8,233	14,085	12,920
glyphosate f/b glyphosate	0.84 f/b 0.84	Late POST Early POST	Two-pass	3,726	8,067	13,943	13,258
glyphosate f/b glyphosate	0.84 f/b 0.84	Early POST Late POST	Two-pass	3,672	8,020	15,862	13,849
LSD (0.05)[f]				**748**	**401**	**1,950**	**1,245**

[a] Grain yield was harvested on 9-6 and 9-2 at Columbia and Novelty respectfully, in 2003. Grain yield for 2004 was harvested on 8-31 and 9-3 for Columbia and Novelty, respectfully. Moisture of the grain was taken and adjusted to 15.5%.

[b] Ammonium sulfate was added to all glyphosate treatments at 2.8 kg/ha

[c] Glyphosate rates are given in kg ae/ha; all other herbicide rates are kg ai/ha

[d] Very Early POST (2.5. to 5 cm weeds) PRE, preemergence; Early POST, early postemergence (weeds 5 to 10 cm tall); Mid-POST, mid-postemergence (weeds 7 to 10 cm tall); Late POST, Late postemergence (20 to 30 cm weeds).

[e] f/b, followed by.

[f] LSD represents the Least Significant Difference between treatments at p=0.05

Chapter III

Delayed Weed Removal Increases Nitrogen Stress in Corn (*Zea mays L.*)

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Abstract. Nitrogen is an important nutrient in corn production to optimize grain yield. Introduction of glyphosate-resistant corn has led to greater reliance on post-emergence (POST) weed management, allowing for possible early season weed competition. The objective in this research was to measure the effect of delaying glyphosate applications on corn nitrogen levels and grain yield. Studies were established at two locations over two years in Missouri with preplant herbicide treatments to favor grass, broadleaf, or mixed weed populations, followed by different herbicide timing of glyphosate applications. Overall mixed weed populations achieved a higher total biomass than either grasses or broadleaves alone. However, delaying initial herbicide applications from 5 to 10 cm to 10 to 15 cm tall weeds did not significantly increase the overall biomass. The biomass, as well as, grain yield from sequential glyphosate applications were equivalent in yield and independent of timing. Grass weeds attained biomass more quickly and were more detrimental to yield than broadleaf weeds. Early season (V-5 through V-9) chlorophyll meter readings documented nitrogen deficiency between treatments; however readings taken later in the season (R-1 through R-5) better patterned the decrease in plant nitrogen over time. Corn leaf chlorophyll meter readings depended upon the length of weed competition and weed species, however readings taken at tasseling correlated strongly to the resultant grain yield ($R^2 \geq .84$). Higher year-end stalk nitrate accumulations were reflective of higher grain yield. Early season weed competition in corn populations did reduce the nitrogen available for grain production.

Nomenclature:, SPAD-502 chlorophyll meter; glyphosate ; *Zea mays* (L.) Merr. Dekalb (DKC 60-19).

Additional index words: chlorophyll meter, competition.

Abbreviations: POST, postemergence.

Introduction

Weed control practices in corn are shifting to increased use of postemergence (POST) herbicides. This is partially the result of declining availability of new chemistries with residual activity (Anonymous 2008). Glyphosate-resistant corn was produced on more than 35% of the corn area in Missouri in 2008. This is expected to increase to 60% of the corn area by 2010. In addition, introduction of herbicide-resistant transgenic hybrids has encouraged use of POST herbicides such as glyphosate and glufosinate (Bill Parker personal communication, 2008).

The effectiveness of glyphosate allows for greater flexibility in the application timing for weeds (Johnson et al. 2000), which has implications for crop development. Delayed POST application can lead to weed competition early in the growth cycle of corn. Alternatively, the lack of residual activity of glyphosate leads to the presence of weeds later in the season (Gower et. al. 2003; Harbur and Owen 2006; Johnson et al. 2000). Many studies have shown that the emergence and density of weeds are critical factors in determining the level of competition. (Cordes et al. 2004; Massinga et al. 2001; Myers et al. 2005; Vangessel et al. 1995)

Exclusive use of glyphosate for weed management can result in early season weed competition. One factor competed for are nutrients such as nitrogen which is critical for optimum corn yields (Aldrich and Kremer 1997; Hellwig et al. 2002). Research has shown that nitrogen uptake in corn occurs primarily after V-4 (Mengel 1995), allowing early season weeds to compete for available nitrogen. Reduced availability of nitrogen reduces grain yield (Beckett et al. 1988; Cordes et al. 2004; Gonzalez and Salas 1995; Hellwig et al. 2002; Ross and Lembi 2009). Myers et al. (2005) documented that a single glyphosate application on V-2 corn reduced yields on average 25%. Carey and Kells (1995) found that weeds 10 cm in height or less did not impact corn; however, delaying POST applications until weed heights were 15 cm reduced grain yields up to 11%.

Among weeds, grasses have been shown to significantly reduce available soil nitrogen (Hellwig et al. 2002; Johnson et al. 2002). Hellwig et al. (2002) found when grass weeds reach heights greater than 15cm, grain yield is significantly. However, quantifying in-season nitrogen loss is difficult because nitrogen measurement techniques are often destructive to plant tissues (Fox et al. 2001). Traditional methods to quantitatively estimate nitrogen levels involve leaf tissue and stalk analysis, both destructive methods (Binford et al. 1992, Fox et al. 2001, and Blackmer and Mallarino 1994). Binford et al. (1992) found that from 30 site-year evaluations, correlations between stalk nitrates and nitrogen rates ranged from R=0.56 to 0.94. Varvel et al. (1997) determined that the use of a chlorophyll meter in conjunction with stalk nitrate estimates reduced misdiagnosis of nitrogen deficiency. A rapid non-destructive technique for measuring nitrogen availability in the crop could identify the onset of competition for nitrogen.

The SPAD-502[3] (single photon avalanche diode) chlorophyll meter is a non-destructive measuring tool, and provides a way to estimate corn leaf nitrogen. Chlorophyll has absorbance in the 400 to 500 nm (blue) region and 600 to 700 nm (red) wavelength region. The SPAD chlorophyll meter uses two light-emitting diodes in conjunction with a silicon photodiode to measure absorbance of light through the blue and red wavelength. A relative numerical calculation is produced based upon variations in measured light absorption (Minolta USA, 2003). Numerous researchers have found

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[3] Minolta USA, 101 Williams Drive, Ramsey, NJ 07446

that the use of the Minolta SPAD chlorophyll meter for measurement of leaf nitrogen provides accurate evaluations of nitrogen deficiencies within the season, as well as resultant grain yield (Bullock and Anderson 1998, Fox et al. 2001, Ma and Dwyer 1997, Piekielek et al. 1995, Scharf et al. 2006, Shukla et al. 2004, and Vetsch and Randall 2004). Bullock and Anderson (1998) determined that measurements using the SPAD chlorophyll meter were an efficient method to determine leaf nitrogen concentration and grain yield, with a correlation coefficient of R=0.78 between yield and SPAD meter readings at the R4 corn stage. However, measurements at the V7 stage had a lower correlation (R=0.22). Readings taken by Fox et al. (2001) indicated that measurement at the initial milk stage (R5) had a correlation coefficient of R= 0.75 to relative yield. Vetsch and Randall (2004) reported that numerical deficiencies observed from the SPAD meter could be used to indicate timing for additional in-season nitrogen applications. The study also indicated that the correlation of relative leaf chlorophyll content to grain yield was stronger at the R1 and R3 growth stages compared to the V10 growth stage.

Currently, there is little research comparing chlorophyll meter readings and stalk nitrates for predicting weed competition in corn. Therefore, the objective of this study was to determine the affects of broadleaf and grass weeds alone, as well as mixed weed populations on leaf nitrogen content, stalk nitrate accumulation, and resultant grain yield.

Materials and Methods

Field studies were conducted in 2003 and 2004 in central (Columbia) and northeast (Novelty) Missouri. Columbia studies were carried out at the Bradford

Research and Extension Center on a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs) with a pH of 6.0 and an organic matter content of 2.9%. Studies at Novelty were carried out on a Putnam silt loam (fine, smectic, mesic Vertic Albaqualfs) with a pH of 6.6 and an organic matter content of 2.6%. Plots were located on land in a corn-soybean rotation with soybeans grown the year prior to corn establishment. The study area was tilled and ammonium nitrate (NH_4NO_3) was applied at 168 kg/ha of actual nitrogen. Weather conditions were recorded for the duration of the field trials and are listed in Table 3.1.

All trials were established as a randomized complete block design with four replications. Plot size was 3 by 14 m and Dekalb "DKC 60-19" was planted at 69,500 seeds/ha in 76 cm rows and at a depth of 4 cm. Planting dates for the Columbia location in 2003 and 2004 were May 22 and April 28, respectively. The Novelty planting dates for 2003 and 2004 were May 17 and April 22, respectively. Planting was delayed in 2003 due to excessive soil moisture. To ensure adequate grass competition for the study, 3.8 L of barnyardgrass (*Echinochloa crus-galli* ECHCH) and 3.8 L of large crabgrass (*Digitaria sanguinalis* DIGSA) seed were scattered over the 0.3 ha trial area prior to corn planting each site-year.

Studies consisted of 16 treatments. Six treatments represented different approaches to POST weed management with glyphosate. Two treatments included single POST applications of 0.84 kg ae/ha glyphosate on 5 to 10 cm weeds and also 10 to 15 cm weeds. Two other treatments included an initial glyphosate application on 5 to 10 cm weeds, followed by a second application (0.84 kg ae/ha) on 5 to 10 cm or 10 to 15 cm weeds. Two additional treatments included an initial application of glyphosate (0.84

kg/ha) on 10 to 15 cm weeds, followed by sequential applications of glyphosate (0.84 kg/ha) on 5 to 10 cm or 10 to 15 cm weeds.

Four additional treatments allowed for competition of grasses only. Broadleaf weeds were removed with an early POST application of 2, 4-D at 0.3 kg ai/ha followed by hand weeding as necessary. Grass weeds were allowed to compete until weed heights reached an average of 13, 19, 25 and 32 cm, then were removed with glyphosate at 0.84 kg/ha. Total grass plant populations in each plot ranged from 40 per square meter to over 1000 per square meter and the predominant species were giant foxtail (*Setaria faberi* SETFA), barnyardgrass, and large crabgrass.

Four treatments focused on the competition of broadleaf weeds only. To suppress grasses, *s*-metolachlor (1.07 kg ai/ha) was applied PRE; later emerging grasses were removed by hand. Although *s*-metolachlor suppressed some types of broadleaf populations, mean broadleaf plant densities ranged from 20 per square meter to 100 per square meter. The resulting broadleaf weed population was allowed to compete until designated sizes, then removed with glyphosate at 0.84 kg/ha. Removal of broadleaf weeds occurred at an average height of 5 to10 cm, 10 to15 cm, 15 to 20 cm, and 20 to 25 cm. Predominant species included: common waterhemp (*Amaranthus rudis* AMATA), morningglories (*Ipomea spp.* IPOSS), giant ragweed (*Ambrosia trifida* AMBTR), common ragweed (*Ambrosia artemisiifolia* AMBEL), and velvetleaf (*Abutilon theophrasti* ABUTH).

Two control treatments were included: weed-free and untreated. The weed-free control received a PRE application of acetochlor at 1.2 kg ai/ha plus atrazine[4] at 0.6 kg

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[4] Degree Xtra, Monsanto Co., 800 N. Lindbergh Blvd., St. Louis, MO 63167.

ai/ha. To maintain season-long weed control, sequential POST applications of glyphosate at 0.84 kg/ha were made; hand weeding was utilized to remove weeds escaping treatment.

Treatments were applied with a CO_2-pressurized backpack sprayer. The sprayer was calibrated to deliver a carrier volume of 187 L ha^{-1} at a speed of 4.8 km/hr with an operating pressure of 110 kPa while utilizing XR8002[5] flat fan nozzle tips. A pre-plant application of ammonium nitrate fertilizer was made at 134 kg ha^{-1}.

To evaluate weed pressure, total weed biomass was evaluated from each plot. Prior to weed removal from each treatment, all of the above ground weed biomass was harvested for each plot from a random 0.37 m^2 area. The weed tissue was oven dried at 50 C for 4 days and the dry weight recorded. In the case of multiple harvests, data were combined for the entire treatment.

Chlorophyll meter readings and stalk nitrate evaluations were recorded for five treatments: 25 cm grass, 32 cm grass, 20 to 25 cm broadleaves, untreated check, and weed-free check. The SPAD-“model 502” chlorophyll meter’s self-calibration was performed periodically during use. All data were recorded from corn plants within the center two rows of each plot. For each selected plot, 25 corn plants from the center two rows were selected at random. For the selected plants, a single adaxial sample was taken midway between the leaf tip and the leaf collar and 30% of the distance from midrib to the leaf edge. Readings were taken on the most fully developed leaf. Readings were taken initially at the V6 stage and every 10 days thereafter until plant senescence. Initial leaf chlorophyll meter readings were recorded on the top leaf with a full collar from 39 to 54 days after planting (DAP) and results were included in the appendix (Appendix 3.1, 3.2,

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[5] TeeJet Spraying Systems Co., Wheaton, IL 60188

3.3, 3.4). When plants were mature enough for the ear leaf to be discerned, at approximately V12 (Ritchie et. al 2008), SPAD meter readings were only recorded from the ear leaf. Timing and respective growth stages of ear and top-leaf chlorophyll meter readings are located in Table 3.4.

Grain was harvested on Sept. 6 and 2 at Columbia and Novelty respectfully, in 2003. Grain yield for 2004 was estimated on Aug. 31 and Sept. 3 for Columbia and Novelty, respectfully. Grain yield from plots was estimated by harvesting 10.5 m of the two center rows of each plot; moisture was adjusted to 15.5%. Immediately following grain harvest, stalk tissue was harvested for nitrate analysis. Collection of the stalk tissue was accomplished by cutting a 20 cm section beginning 15 cm above the ground. A total of 10 subsample stalks were harvested at random from each plot for a total of 40 per treatment. Leaf sheath residue around the stalk was removed to prevent contamination of the sample. Samples were oven dried at 50 C for 4 days, combined across subsamples, then ground for each plot using a tissue grinder with a #10 screen (2.0 mm). Ground tissue was then submitted to the University of Missouri Soil Testing Laboratory, where a flow injection analyzer was used for nitrate analysis (Manjula Nathan, Personal Communication, 2008).

Plant biomass data as well as grain yield were subjected to analysis of variance using SAS (2006)and tested for homogeneity of variances. The interaction between years and location for both broadleaf and grass biomass were significant. Therefore, data are presented separately. No interactions were observed across site-years for grain yield; therefore data were pooled. All means were separated by Fisher’s Protected LSD with a significance level of $\alpha = 0.05$ (Table 3.6). A logarithmic transformation on stalk nitrate values did not improve data distribution; therefore means were separated on untransformed data. Chlorophyll meter readings were plotted against time and standard deviations were applied to data points. In order to regress across yield, similar representative sample dates of chlorophyll meter readings around tasseling (VT) were chosen for each site-year and then regressed against yield.

Results and Discussion

Weed Biomass

Mean weed biomass was greatest at the Columbia location in 2004, least at the Novelty location in 2003, and intermediate at the other two locations (Table 3.2 and 3.2) Grasses dominated weed biomass at Columbia in both years, while broadleaves dominated weed biomass at Novelty in 2004. Biomass of both grasses and broadleaves was low and approximately equal at Novelty in 2003.

The accumulation of grass biomass depended upon the initial application timing of glyphosate. In treatments containing grass alone, biomass increased by a factor of nearly 7 between the 13 and 32 cm removal timings (Table 3.2). Indifferences among smaller grasses (< 19cm) could be based on species differences and varying growth characteristics of seedling grasses. The removal of the 32 cm grass was 21 to 178% higher than that of the 25 cm grass, indicating that larger grasses accumulate biomass more quickly. Grass biomass from mixed weed populations were similar when regrowth applications were delayed, indicating minimal late-season weed germination. Delaying an initial glyphosate application in mixed weed populations resulted in increased grass biomass only at Novelty in 2003.

Broadleaf biomass steadily progressed as weed removal was delayed (Table 3.3). Biomass increased by a factor of nearly 4 between the 5-10 and 20-25 cm removal timings in treatments containing broadleaves alone. Broadleaf biomass differences were more common when the plant height was > 10 cm, indicating rapid late growth. Delaying applications from 5-10 to 10-15 cm on mixed weed populations only resulted in increased biomass in only 2 of 4 site-years. Due to natural variations in weed populations, in addition to growth habits of individual weed species, delaying weed removal of 5 to 10 cm mixed weeds until 10 to 15 cm did not conclusive increase biomass across site-years.

Results from both grass and broadleaf biomass indicate rapid growth occurs in larger weeds. This larger growth also represents rapid uptake of available soil N. Johnson (2002) estimated that shattercane (*Sorghum bicolor*) at populations around 200 plants/m^2 competing until 31 cm in height could remove up to 20 kg N ha^{-1}. Six week old weed populations often have tissue nitrogen concentrations between 2 and 5% (Blackshaw et al. 2003). Based on an average grass biomass of 352 g in 1.0 m^2 at the 32 cm removal height, and assuming a grass tissue N concentration of 3% at this height, we estimate that 105 kg N ha^{-1} was already taken up by the grass at this point. A similar calculation for broadleaf weeds gives an average N uptake of 25 kg N ha^{-1} at the 20-25 cm removal timing. These estimates suggest that weeds, especially grasses, can take up large amounts of N and deplete N available for crop uptake if allowed to grow too long prior to controlling them.

Chlorophyll Meter Readings

Variation of chlorophyll meter readings was dependant upon site-years. Site-year variation was in the timing for initial measurements were due to differences in planting dates and moisture accumulation for each year (Table 3.1). Chlorophyll meter readings for the weedy check were consistently lower than that of the treated plots and the weed-free check (Figures 3.1, 3.2, 3.3, and 3.4). All readings decreased as the season progressed, indicating plant senescence. Chlorophyll meter measurements were highest between 50 and 80 days after planting for each site-year, and quickly declined as plants reached maturity. For all site-years, initial readings through 100 days were lower in the weedy check as compared to all other treatments.

At Columbia in 2003 (Figure 3.1), only SPAD meter readings for the 20 to 25 cm broadleaf treatments were consistently lower than the weed-free check throughout much of the growing season. Up to 100 days after planting in 2004 (Figure 3.3), chlorophyll readings for the 25 and 32 cm grass-removal treatments were up to 12% lower than that of the weed-free treatment; measurements for the 20 to 25 cm broadleaves were similar to the weed-free treatment. At the Novelty location, chlorophyll meter readings for the weedy check were consistently lower compared to all other treatments. In 2003, no differences among weed competition treatments were detected compared to the weed-free check (Figure 3.2). In 2004 (Figure 3.4), all weed removal treatments were different than the weed-free check at times after 100 DAP, but not before. Overall, estimates of corn leaf nitrogen from the grass and broadleaf treatments were lower in 3 of 4 site-years, with the Columbia location having more noticeable early season effects, and the 2004 Novelty location indicating later season effects.

Stalk Nitrate

Corn stalk nitrate levels varied between years and locations (Table 3.5). At two site years, stalk nitrate levels were very low; from 2 to 316 and 3 to 165 parts per million (ppm) at Columbia in 2003 and Novelty in 2004, respectively. The weedy check was significantly lower at both Novelty site-years. Nitrate levels were highest at Novelty in 2003, with a concentration of 357 ppm for the weedy check, while the other four treatments ranged from 1,958 to 3,102 ppm. The increased competition was found by the weedy check having 34% increase in nitrate concentration than those of the 20-25 cm broadleaves and the 32 cm grass was 44% lower than the 25 cm grass. However in 2004, the weed-free treatment had the highest amount but a distinction between all other treatments could not be made, indicating equal usage of nitrogen from weed populations.

Stalk nitrates for both years at Columbia were similar across all treatments due to less than optimal weather conditions (Table 3.1); however nitrate levels for the grass competition treatments were closer in value to the weedy check than the weed-free treatment. At Columbia in 2004, stalk nitrate levels were less than 206 ppm for the weed-free check, as well as the 25 and 32 cm grass removal timings. However, the weed-free and 20 to 25 cm broadleaf removal timing nitrate levels were 1,171 and 1,160 ppm, respectively.

Blackmer and Mallarino (1994) have suggested that nitrate levels below 250 ppm indicate a deficiency and between 250 and 700 ppm are adequate. Concentrations greater than 2,000 ppm are considered excessive. Using these estimates, nitrate levels for corn in the weedy check were deficient or barely adequate for all four site-years, indicative of weed competition. The chlorophyll levels for the weedy check were also consistently lower than the other treatments at all four site-years. For three out of four site-years, nitrate levels were 316 ppm or less for the 25 and 32 cm grass removal timings. Nitrate levels for corn in two of the site-years for the 20 to 25 cm broadleaf removal timing were <10 ppm, but >1,160 ppm for corn in the other two site-years.

Overall, results from the measurement of stalk nitrates indicate that in years where the weather is normal, stalk nitrates levels were at expected levels, with the weedy check having lower amounts than treatments with the competition removed, and those had lower amounts than that of the weed-free check.

Grain Yield

Grain yield was reflective of the effects of weed competition and limited availability of nitrogen (Table 3.6). Grain yield was consistent among treatments within site-years, but varied between site-years. Yield levels in the Novelty 2003 experiment were around 8 Mg ha^{-1}, which is typical for corn production in this region, while yield levels at both 2004 locations exceeded 15 Mg ha^{-1} for multiple treatments. Ideal rainfall amounts and distribution coupled with cool night temperatures created ideal conditions for corn growth in 2004, thus creating greater yields than 2003.

Despite site-year variation, noticeable trends were found yield data. Yield from the weedy check was consistently lower than that of all other treatments in all 4 site-years, with a yield reduction of 36 to 98% compared to the weed-free check. Weed competition from mixed populations initially removed at 5-10 cm had similar grain yields across all treatments with regrowth applications, as well as the treatment that lacked a regrowth application. Similar results were also detected in treatments where weeds were initially removed at the 10-15 cm height; no yield differences were found between any regrowth treatments. However compared to a single application at 5-10 cm, a decrease in yield was found where a single application of glyphosate was applied at 10-15 cm. The data could be explained by early season competition found by others such as Carey and Kells (1995) who documented that yield losses increased if mixed weed populations were allowed to compete beyond 10 cm in height.

Differences in grain yield between treatments with only grass or broadleaf competition were more variable than the grain yield differences with mixed weed populations. In 2004, when grain yields were overall much higher than 2003, the influence of delaying grass and broadleaf weed removal was noticeable, although only significant at Columbia. Considering the combined yield across site-years, grain yield was 5.5% lower for the 13 versus 32 cm removal timing for grasses. For broadleaf weeds only, the 20-25 cm broadleaf plots yielded 8% less than the 5-10 cm plot and 9% less than the 10-15 cm plot, but yield was similar to the 15-20 cm removal timing. Overall, grass competition was more detrimental to yield than broadleaf competition. When yield data was pooled, similar trends were found to that of each site-year, where yield reduction was most impacted by grasses, followed by mixed weeds, followed by broadleaves.

As evidenced by Cordes et al. (2004), the increase in weed biomass (Table 3.2 and 3.3) found at the later stages of growth most likely resulted in a higher nitrogen uptake from the weeds, thus the greater impact on yield. For broadleaf versus grass weeds at similar removal heights, broadleaf competition was not as detrimental to grain yield as grass competition. Hellwig et al. (2002) demonstrated that delays in grass removal resulted in reduced grain yield of corn. This is especially when high grass populations are present, where weed removal should be made prior to grass species reaching 19 cm. To minimize nitrogen loss from broadleaf weeds, removal should be made at heights of 15 to 20 cm or less. These data agree with the findings of Cordes et. al. (2004), Hellwig et al. (2002), Johnson et al. (2001) and Myers et al. (2005) and suggest that proper timing, as well as weed densities, contribute to efficient weed control and maximized yields.

Discussion of Relationships between Collected Data

A linear regression analysis was performed on chlorophyll meter readings for the corn growth stage closest to V-T (tassel) against grain yield to determine if the SPAD meter was a predictor for yield (Figures 3.5, 3.6, 3.7, and 3.8). For all 4 site-years, SPAD meter readings were significantly ($P < 0.05$) correlated to grain yield, with a correlation coefficient ranging from 0.838 to 0.947. This was despite the fact that grain yield for Columbia and Novelty were up to 84 and 48% lower for 2003 compared to 2004, respectively. Scharf et al. (2006) found that chlorophyll measurements taken between V-10 and R-1 were a reasonably good predictor of grain yield in response to different levels of nitrogen application. In this research, chlorophyll meter readings taken around the time of tasseling predict grain yield following differential levels of weed competition for nitrogen. These findings agree with Waskom et al. (1996) who found that chlorophyll meter readings taken at tasselling were predictive of grain yield in 7 of 8 site-years.

The Columbia location had a very wet spring in 2003 (over 50 cm of rain from April through June) followed by a dry summer (9 cm of rain in July and August) (Table 3.1). Due to the wet spring, planting was late, and yields at this location were very low—no treatment mean yield exceed 3.6 Mg ha^{-1} (Table 3.6). Although many corn fields in the region had similar yields due to the July-August drought, the 12 cm of irrigation applied during these months should have supported higher yield levels. Post-harvest stalk nitrate samples suggest that all treatments in 2003 at Columbia location were severely N-deficient (Table 3.5), which may have been the primary yield-limiting factor. Chlorophyll meter measurements confirm that this was the most N-deficient location—it was the only location at which the ear-leaf chlorophyll meter value never exceeded 60 (Figures 3.1 to 3.4). The excess April to June precipitation, coupled with the somewhat poorly drained soil at this location, could conceivably have triggered enough denitrification to explain this severe N deficiency. When denitrification was not occurring, only the 25 cm and 32 cm grass treatments had excessively high biomass which could contribute to their reduced chlorophyll meter values, as well as stalk nitrate values (Table 3.2).

In 2003 at Novelty, much of the high stalk nitrate values can be contributed to reduced grass biomass (Table 3.2). Additional factors such as a reduced (no month between May through August totaled more than 100mm) but consistent rainfall, could allow for an increase in stalk nitrate accumulation (Table 3.1). These data support the chlorophyll meter readings, that when patterned across the season show similar measurements for all grass and broadleaf treatments as well as the weed-free check. The similar nitrogen data provide explanation as to why the yield for the selected treatments from that specific year is statistically the same.

At Columbia in 2004, grain yields were much higher than 2003, with all treatments yielding greater than 13.0 Mg ha^{-1}, with the exception of the weedy check. Chlorophyll meter readings taken on the weed-free check and 20-25 cm broadleaf treatments were higher than the 25 cm grass and 32 cm grass through 100 days after planting, These data are supported by the weed biomass as it indicates heavy pressure from grass populations at Columbia in 2004, as well as the grain yield from the site-year showing the 20-25 cm broadleaf and weed-free check having significantly higher yields than the 25 cm grass and the 32 cm grass or the weedy check.

The Novelty 2004 site-year also had exceptionally high grain yields as well as most local fields in the surrounding area due to mild temperatures in July and August as well as early August rainfall relieving the short drought in July (Table 3.1). Chlorophyll meter readings showed a slight reduction in the grass and broadleaf treatments compared to the weed-free. This difference became slightly greater as the season progressed, however variation in the measurements increased too (Figure 3.4). Weed biomass was high for both the selected grass and broadleaf treatments. Along with minimal stalk nitrate accumulation, these data signify that the treatments simply used all available nitrogen and weather conditions allowed for maximum uptake by the crop in an ideal year.

Despite unique site-year variation, these data indicate that stalk nitrate testing and chlorophyll meter readings can be used to pattern nitrogen loss from weed competition. Other research has noted the efficiency of chlorophyll meter readings determining nitrogen rates and yield (Scharf et al. 2006; Waskom et al. 1996; Wood et al. 1992), however this research suggests that these data suggest that chlorophyll meter readings as late as tasseling can be an excellent predictor of reduced grain yield from weed competition even under environmental stress. This study confirms the results of Helwig et al. (2002) and Johnson et al. (2002) in that grass weeds can significantly reduce in-season nitrogen availability and decrease grain yield, however these data also suggests that larger broadleaf weeds and mixed populations can create similar results.

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Table 3.1. Average monthly air temperature and total precipitation from April through September at Columbia and Novelty in 2003 and 2004.

	Temperature				Precipitation			
	Columbia		Novelty		Columbia†		Novelty	
Month	2003	2004	2003	2004	2003	2004	2003	2004
	C				mm			
April	13	14	12	13	208	65	160	78
May	17	19	16	19	137	119	93	120
June	20	21	20	21	166	44	82	84
July	25	23	25	23	48	112	83	67
August	26	21	25	20	76	130	75	206
September	18	20	17	19	241	24	158	25
Mean	20	20	19	19	---	---	---	---
Total	---	---	---	---	876	494	651	580

† Additional moisture (3 cm) was provided to the Columbia location by supplemental irrigation on July 8th, July 23rd, August 12th, and August 26th in 2003 and on June 29th in 2004. These data are incorporated into precipitation totals.

Table 3.2. Mean grass biomass (dry) collected prior to application at Columbia and Novelty, MO in 2003 and 2004. Biomass adjusted from a 0.37 m^2 area to 1.0 m^2 and combined across multiple applications if applicable.

Treatment†	1st application timing‡	Regrowth application timing‡	Type of weed competition	2003 Columbia	2003 Novelty	2004 Columbia	2004 Novelty
				g/m^2			
Weedy Check	None	None	Mixed	N/A	N/A	N/A	N/A
Weed-free	N/A	N/A	Weed-free	N/A	N/A	N/A	N/A
glyphosate	5-10	5-10	Mixed	55.9	18.7	98.7	23.5
glyphosate	5-10	10-15	Mixed	78.5	23.3	74.9	14.6
glyphosate	5-10	N/A	Mixed	36.2	55.7	64.5	20.2
glyphosate	10-15	5-10	Mixed	46.9	63.4	71.3	5.5
glyphosate	10-15	10-15	Mixed	99.1	47.3	77.8	6.6
glyphosate	10-15	N/A	Mixed	92.6	74.4	81.2	21.8
glyphosate	13	N/A	Grass	27.2	25.5	152.8	14.2
glyphosate	19	N/A	Grass	84.8	24.7	572.0	48.7
glyphosate	25	N/A	Grass	156.7	59.8	546.7	128.9
glyphosate	32	N/A	Grass	435.0	124.9	660.5	187.2
LSD (α=0.05)§				**161.3**	**31.9**	**71.8**	**30.6**

† All treatments were removed with glyphosate at 0.84 kg ae/ha, with the exception of the weed-free check which received an PRE application of acetochlor at 1.2 kg ai/ha plus atrazine at 0.6 kg ai/ha in addition to multiple POST applications of glyphosate at 0.84 kg ae/ha. N/A represents treatments that were not applicable.

‡ Application timing refers to average height of weeds in cm.

§ Fisher's Protected Least Significant D at p=0.05.

Table 3.3. Mean broadleaf biomass (dry) collected prior to application at Columbia and Novelty, MO in 2003 and 2004. Biomass adjusted from a 0.37 m^2 area to 1.0 m^2 and combined across multiple applications if applicable.

Treatment†	1st application timing ‡	Regrowth application timing‡	Type of weed competition	2003		2004	
				Columbia	Novelty	Columbia	Novelty
				g/m^2			
Weedy Check	None	None	Mixed	N/A	N/A	N/A	N/A
Weed-free	N/A	N/A	Weed-free	N/A	N/A	N/A	N/A
glyphosate	5-10	5-10	Mixed	6.7	40.4	70.9	102.1
glyphosate	5-10	10-15	Mixed	16.7	32.0	84.0	127.5
glyphosate	5-10	N/A	Mixed	12.3	33.3	85.8	79.9
glyphosate	10-15	5-10	Mixed	31.5	55.5	138.5	145.1
glyphosate	10-15	10-15	Mixed	22.0	79.6	128.6	147.9
glyphosate	10-15	N/A	Mixed	20.5	48.7	139.3	175.3
glyphosate	5-10	N/A	Broadleaves	17.7	12.6	32.8	44.5
glyphosate	10-15	N/A	Broadleaves	40.9	25.2	24.2	74.4
glyphosate	15-20	N/A	Broadleaves	127.3	53.0	60.8	183.7
glyphosate	20-25	N/A	Broadleaves	70.4	94.7	76.0	177.5
LSD (α=0.05)§				**35**	**33.3**	**50.5**	**95.5**

† All treatments were removed with glyphosate at 0.84 kg ae/ha, with the exception of the weed-free check which received an PRE application acetochlor of at 1.2 kg ai/ha plus atrazine at 0.6 kg ai/ha in addition to multiple POST applications of glyphosate at 0.84 kg ae/ha. N/A represents treatments that were not applicable.

‡ Application timing refers to average height of weeds in cm.

§ Fisher's Protected Least Significant Difference

Table 3.4. Date of leaf sampling, the corresponding vegetative stage and the number of days after planting for corn leaf chlorophyll measurements recorded using the SPAD-502 meter.

	Timing of chlorophyll meter readings							
Growth Stage	Columbia 2003		Novelty 2003		Columbia 2004		Novelty 2004	
	DAP†	DATE	DAP†	DATE	DAP†	DATE	DAP†	DATE
V-5			39	6-26				
V-6	40	7-1						
V-7			46	7-2			48	6-7
V-8					54	6-21		
V-9	54	7-15	54	7-10				
V-10							60	6-29
V-11			58	7-14	63	6-30		
V-12								
V-13	60	7-21 ‡						
V-T			69	7-25 ‡	70	7-7 ‡	70	7-8‡
R-1	70	7-31						
R-2	78	8-8	80	8-5	85	7-22	84	7-22
R-3					95 & 110§	8-1 & 8-6§	91	7-29
R-4	88	8-18	94	8-19				
R-5	98	8-28	104	8-29	110 & 121§	8-16 & 8-27§	98, 110, & 119§	8-5, 8-17, & 8-26§
R-6								

† Days after planting.
‡ Indicates selected sample timings that were regressed against grain yield.
§ Chlorophyll meter readings taken at multiple dates while crop was in same growth stage.

Table 3.5. Nitrate (NO_3) levels, in parts per million (ppm) in corn stalks from Columbia and Novelty, MO in 2003 and 2004. Data were collected from 40 combined plants within the two center rows of each treatment.

			Parts per million			
			2003		2004	
Treatment†	Application timing‡	Weed Species	Columbia	Novelty	Columbia	Novelty
Weedy check	None	Weedy	211	357	73	3
Weed-free	N/A	Weed-free	86	2,968	1,171	165
Late removal	25	Grass	31	3,102	63	15
Late removal	32	Grass	316	2,149	206	8
Late removal	20-25	Broadleaves	2	1,958	1,160	7
Fishers Protected LSD (α=0.05)			**NS§**	**453**	**NS§**	**134**

† All weeds were removed with glyphosate at 0.84 kg ae/ha, including the weed-free check which received a PRE application of acetochlor at 1.2 kg ai/ha plus atrazine at 0.6 kg ai/ha in addition to multiple POST applications of glyphosate.
‡ Application timing refers to average height of weeds in cm. N/A represents not applicable.
§ Not significant.

Table 3.6. Mean grain yield harvested from the center two rows from Columbia and Novelty, MO in 2003 and 2004.

			kg/ ha^{-1}				
1st application timing†	Regrowth application timing†	Type of weed competition	2003		2004		Pooled yield ‡
			Columbia	Novelty	Columbia	Novelty	
None	None	Mixed	53	5209	7336	7591	4944 **F**
N/A	N/A	Weed-free	3062	8124	14,783	14,189	10,040 **BCDE**
5-10	5-10	Mixed	3080	8122	14,664	14,361	10,057 **BCDE**
5-10	10-15	Mixed	3338	8233	14,998	14,428	10,249 **BCDE**
5-10	N/A	Mixed	2887	7945	15,504	13,946	9574 **E**
10-15	5-10	Mixed	2765	8288	15,308	14,065	10,106 **ABCDE**
10-15	10-15	Mixed	2395	7739	15,349	14,617	10,025 **BCDE**
10-15	N/A	Mixed	3543	7756	15,771	15,002	10,518 **ABC**
13	N/A	Grass	2731	7970	15,268	14,616	10,146 **ABCDE**
19	N/A	Grass	2626	8318	13,617	14,510	9768 **DE**
25	N/A	Grass	2956	8000	13,011	14,286	9563 **E**
32	N/A	Grass	3281	7750	13,059	14,260	9588 **E**
5-10	N/A	Broadleaves	3332	8054	16,289	15,213	10,722 **AB**
10-15	N/A	Broadleaves	3327	8222	16,111	15,376	10,759 **A**
15-20	N/A	Broadleaves	3085	7823	15,541	14,943	10,348 **ABCD**
20-25	N/A	Broadleaves	2798	7753	14,988	14,031	9892 **CD**
LSD (α=0.05)§			**828**	**1555**	**1063**	**1308**	**701**

† Application timing refers to average weed height in cm. N/A represents not applicable.

‡ Data were pooled from Columbia 2003, Columbia 2004, Novelty 2003 and Novelty 2004. Treatments having the same letter are not statistically different.

§ Fisher's Protected Least Significant Difference=0.05.

Figure 3.1. Estimated leaf chlorophyll level of corn in different stages of corn plant development using a SPAD-502 Chlorophyll Meter. Data points represent the mean of readings from the ear leaf of 100 plants at Columbia in 2003. Vertical bars represent standard deviation of sampled data.

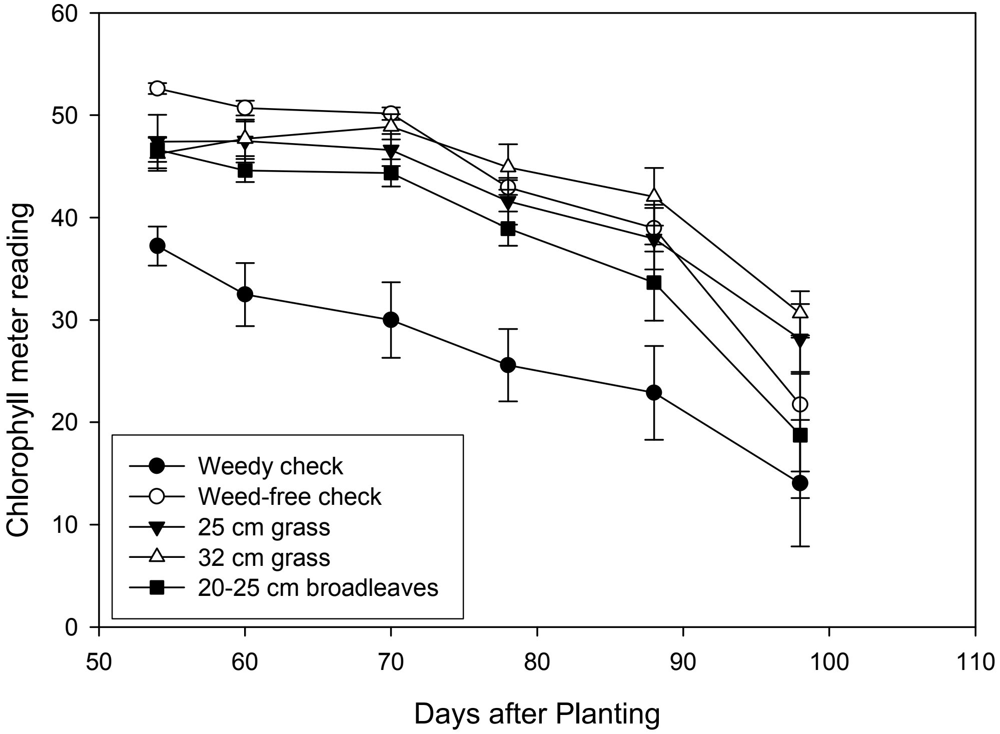


Figure 3.2. Estimated leaf chlorophyll level of corn in different stages of corn plant development using a SPAD-502 Chlorophyll Meter. Data points represent the mean of readings from the ear leaf of 100 plants at Novelty in 2003. Vertical bars represent standard deviation of sampled data.

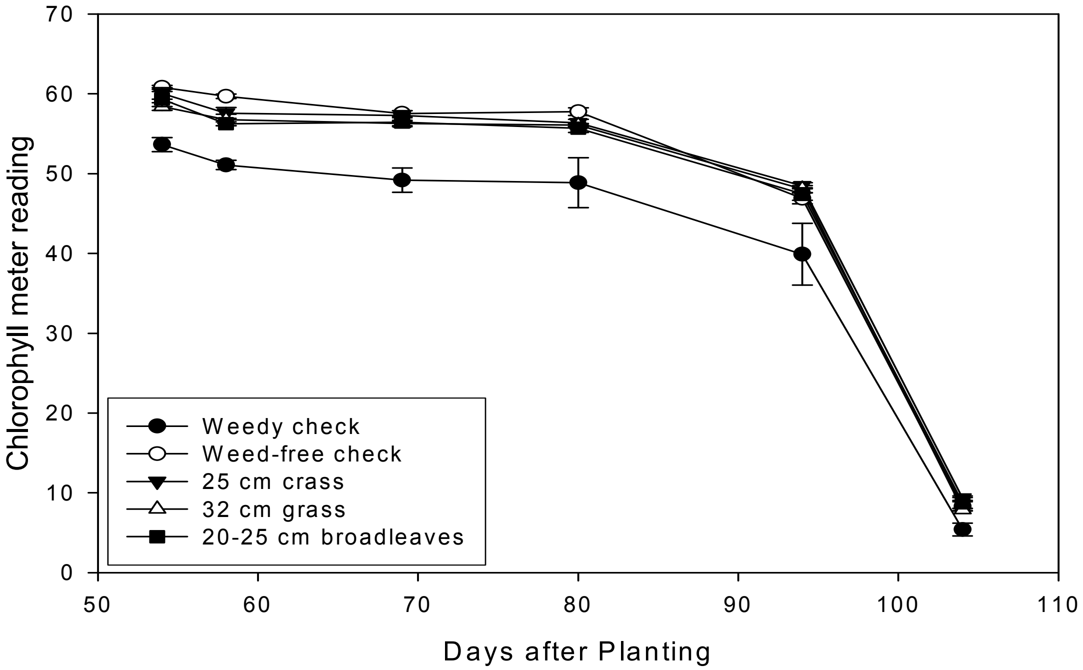


Figure 3.3. Estimated leaf chlorophyll level of corn in different stages of corn plant development using a SPAD-502 Chlorophyll Meter. Data points represent the mean of readings from the ear leaf of 100 plants at Columbia in 2004. Vertical bars represent standard deviation of sampled data.

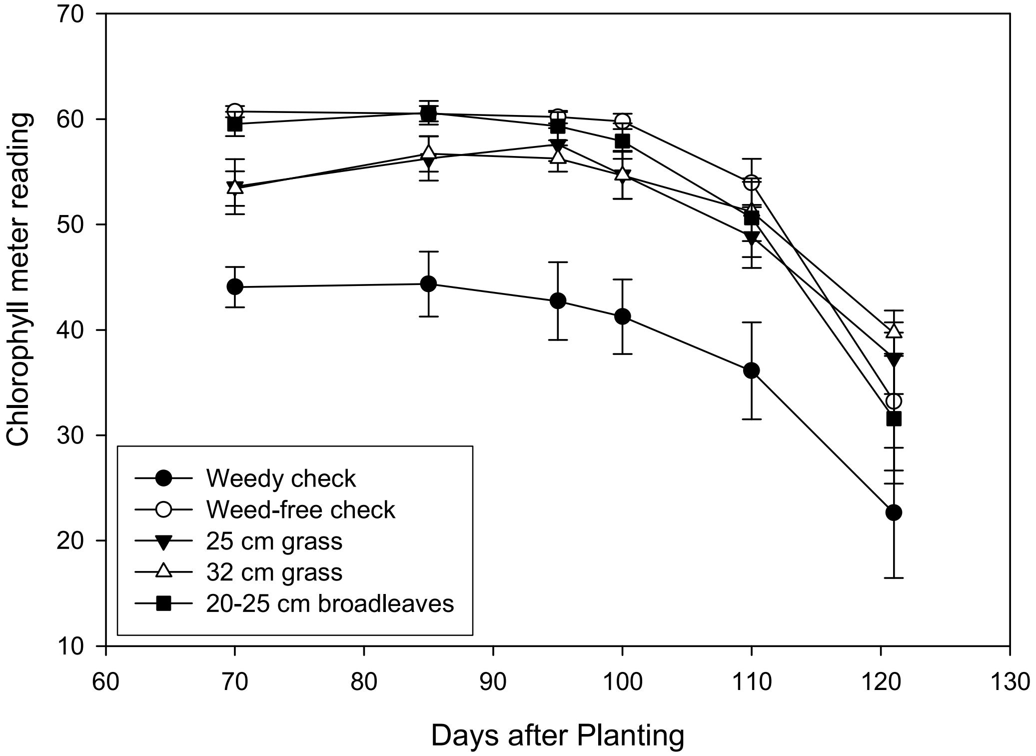


Figure 3.4. Estimated leaf chlorophyll level of corn in different stages of corn plant development using a SPAD-502 Chlorophyll Meter. Data points represent the mean of readings from the ear leaf of 100 plants at Novelty in 2004. Vertical bars represent standard deviation of sampled data.

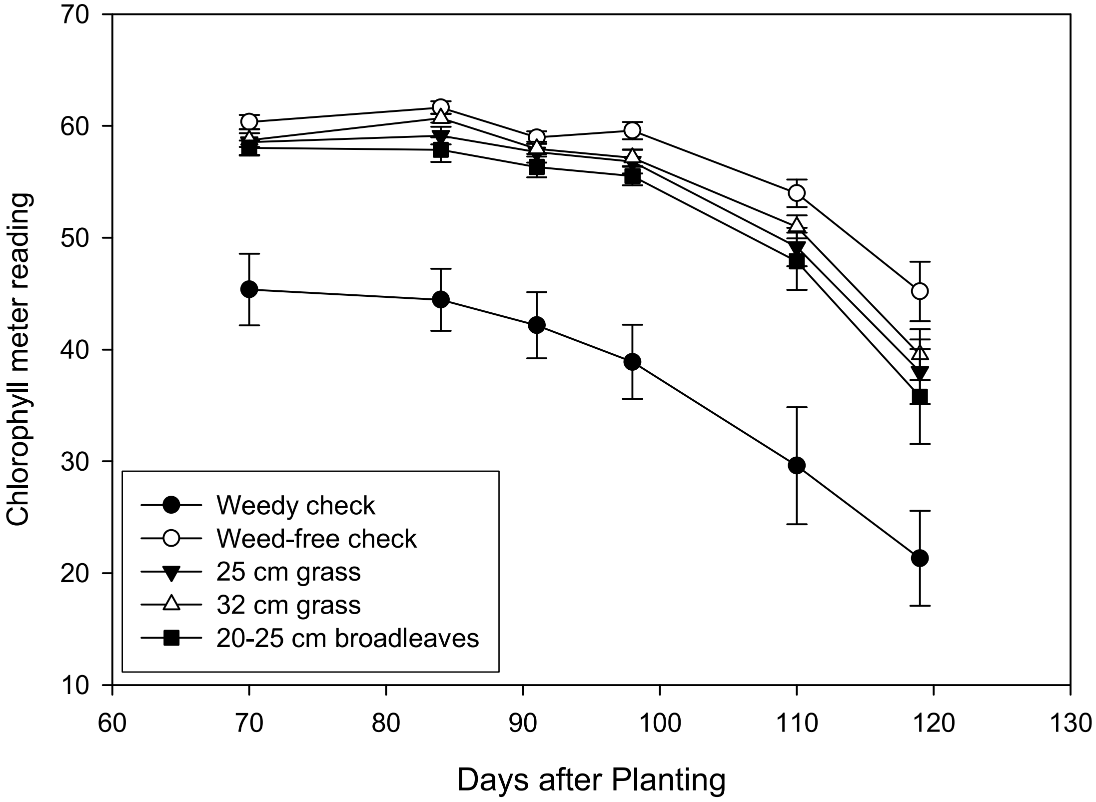


Figure 3.5. Chlorophyll meter readings for July 21, 2003 at the V-13 growth stage at Columbia regressed linearly against grain yield in kg/ha**.** Data points represent the mean readings from the ear leaf of 100 plants against their respective plot yields.

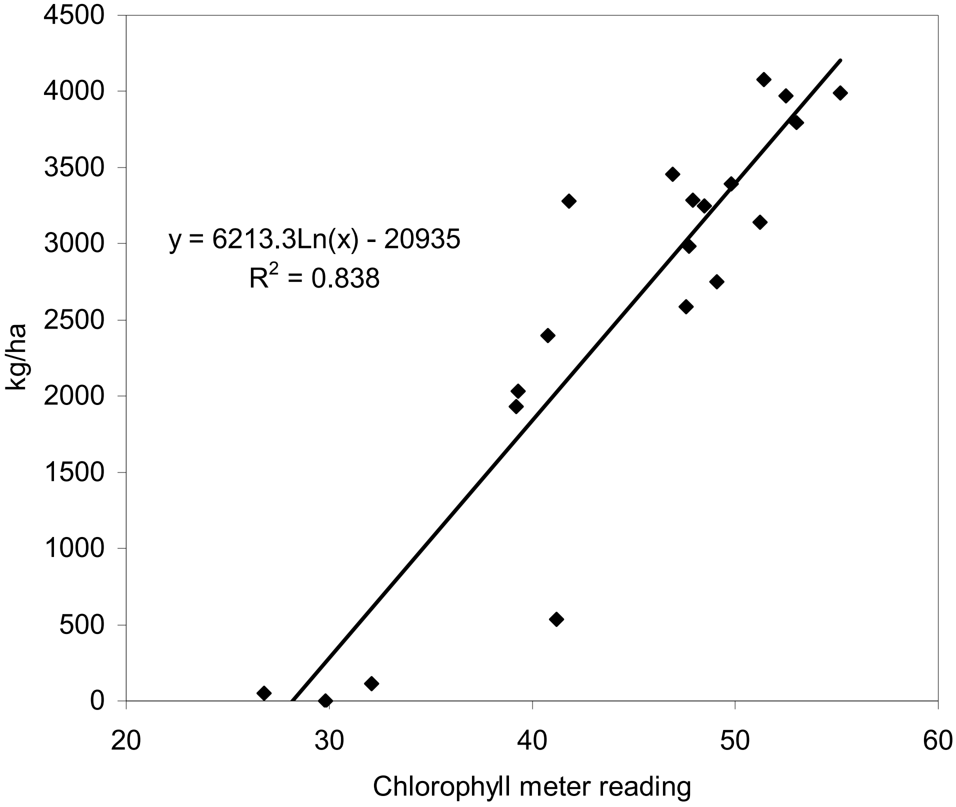


Figure 3.6. Chlorophyll meter readings for July 10, 2003 at the V-T growth stage at Novelty regressed linearly against grain yield in kg/ha. Data points represent the mean readings from the ear leaf of 100 plants against their respective plot yields.

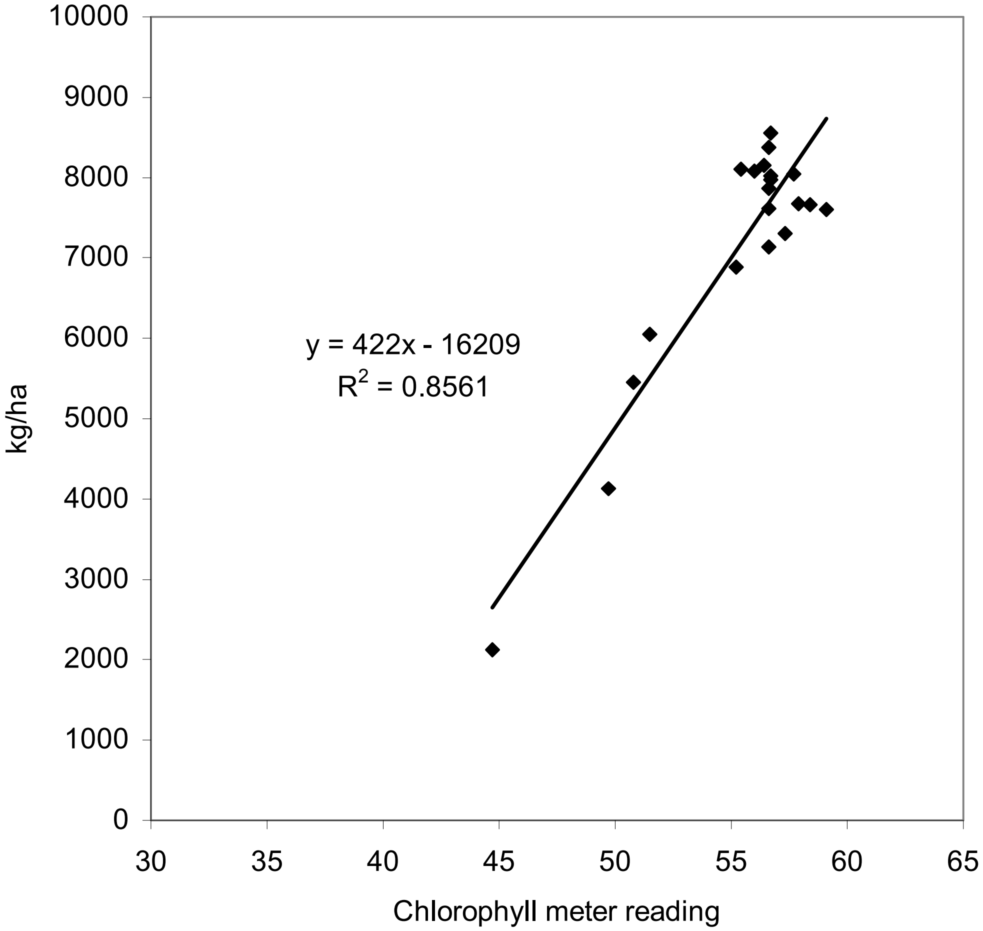


Figure 3.7. Chlorophyll meter readings for July 7, 2004 at the V-T growth stage at Columbia regressed linearly against grain yield in kg/ha. Data points represent the mean readings from the ear leaf of 100 plants against their respective plot yields.

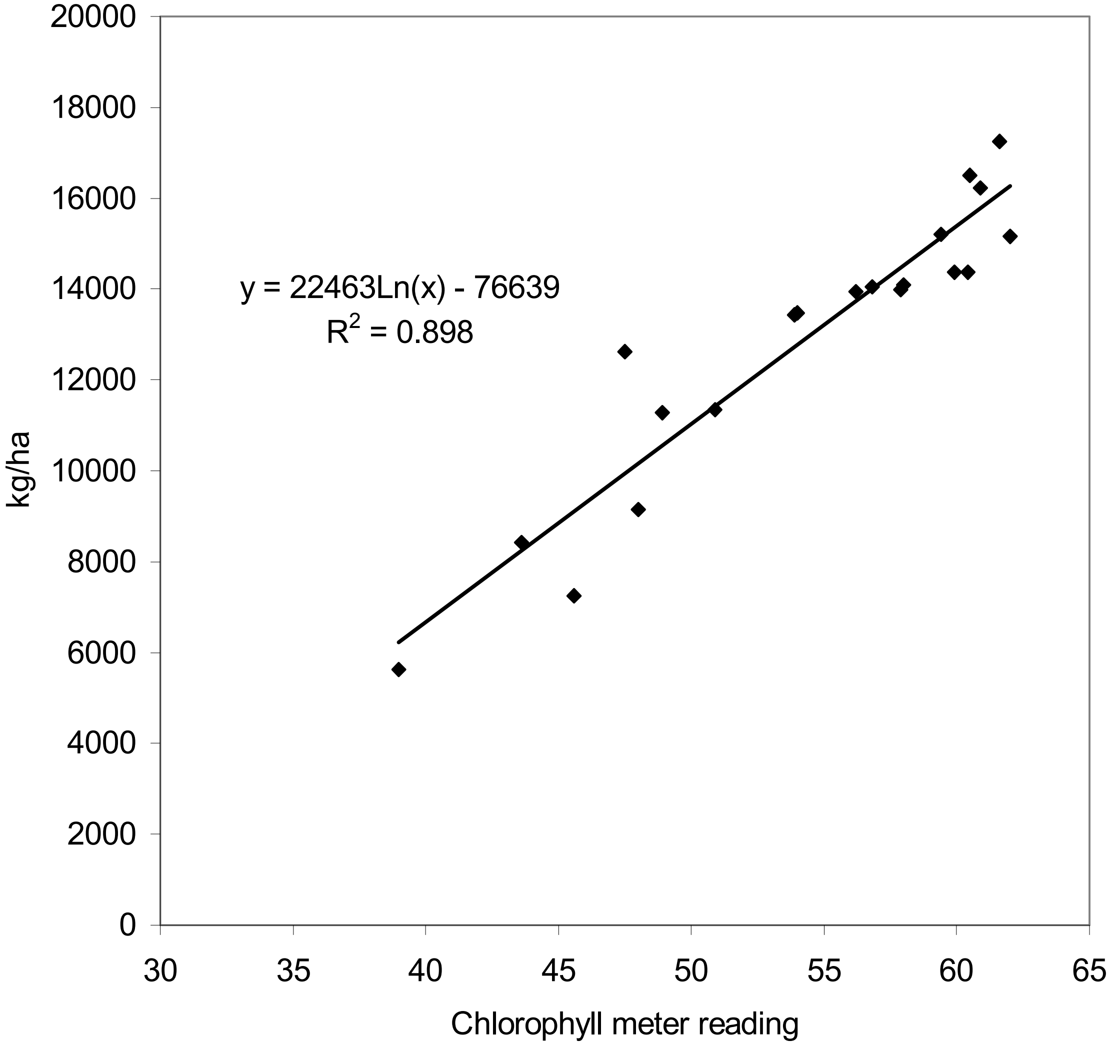
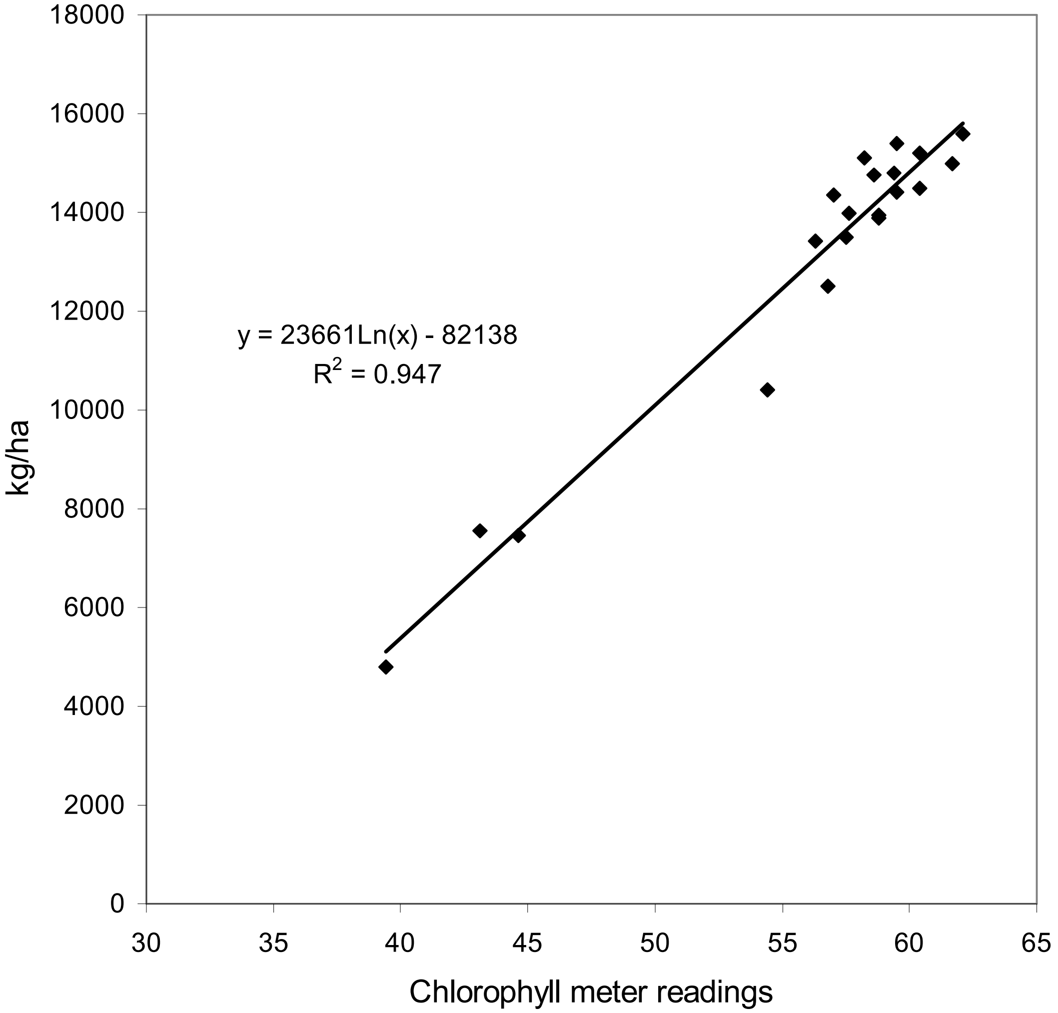
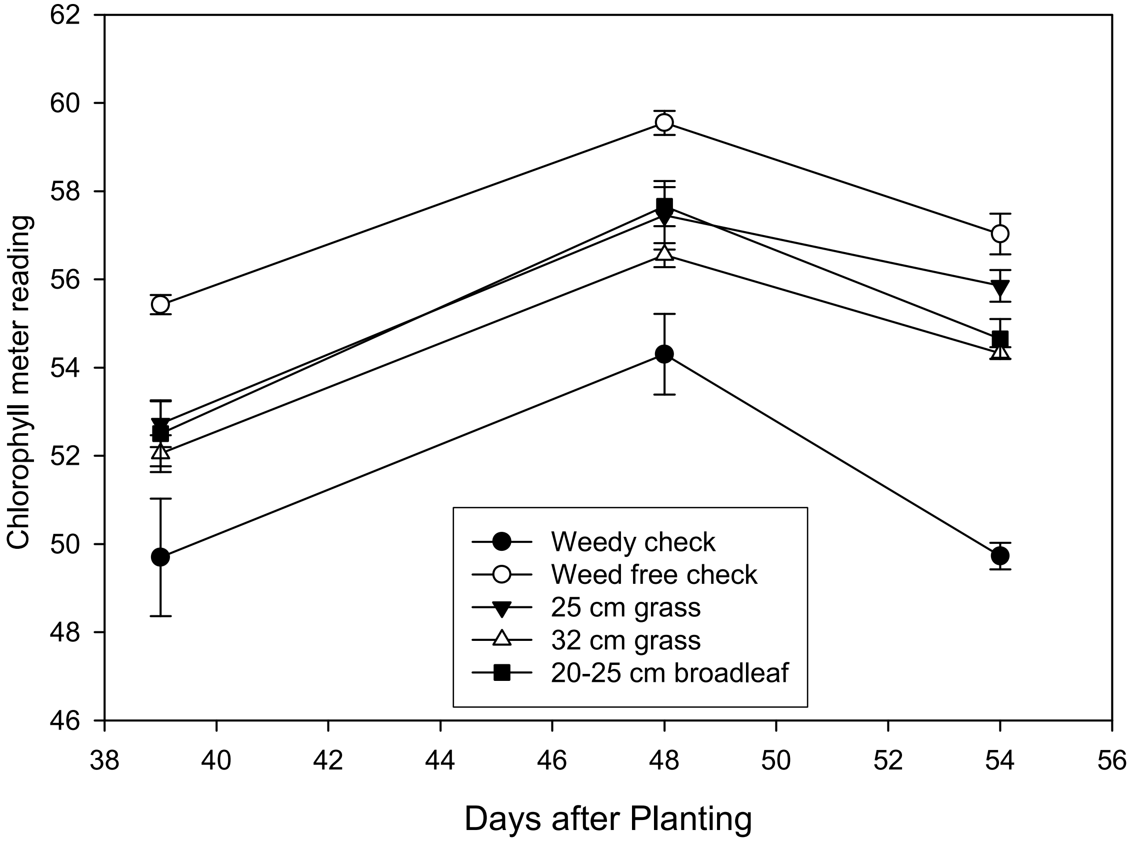


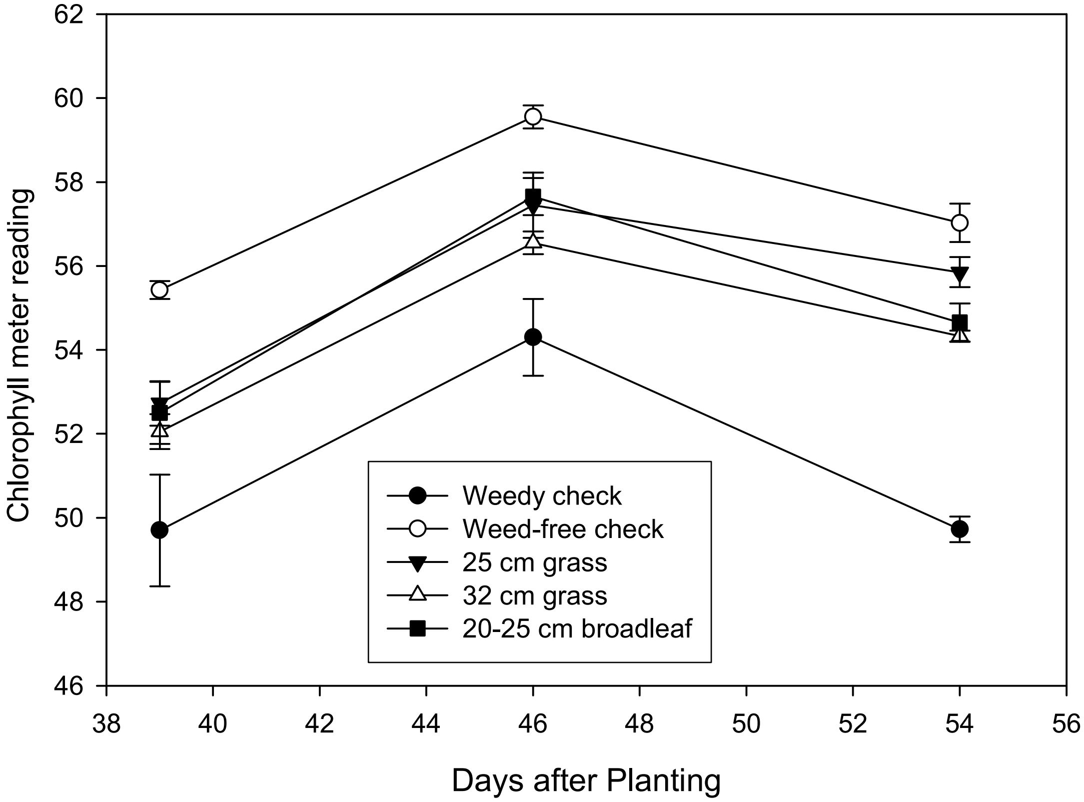
Figure 3.8. Chlorophyll meter readings for July 8, 2004 at the V-T growth stage at Novelty regressed linearly against grain yield in kg/ha. Data points represent the mean readings from the ear leaf of 100 plants against their respective plot yields.



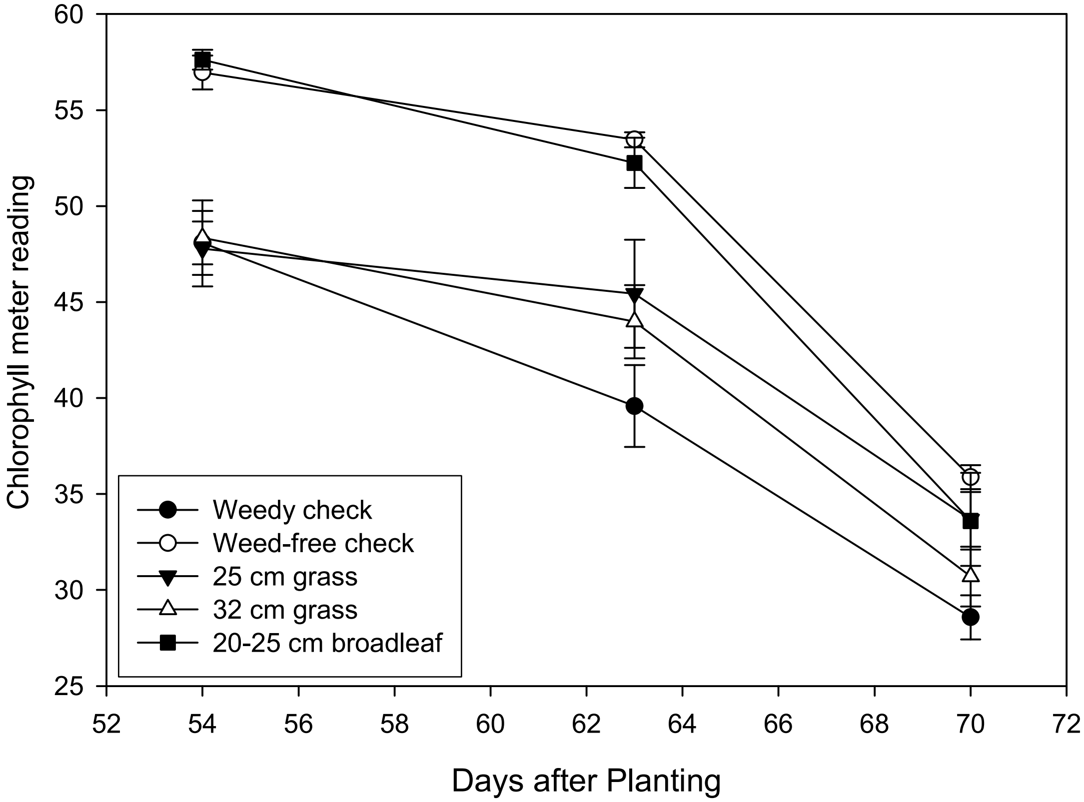
Appendix 3.1. Estimated chlorophyll level for corn at different stages of plant development. Data points represent the mean of readings from the top leaf of 100 plants at Columbia in 2003. Vertical bars represent standard deviation of sampled data.



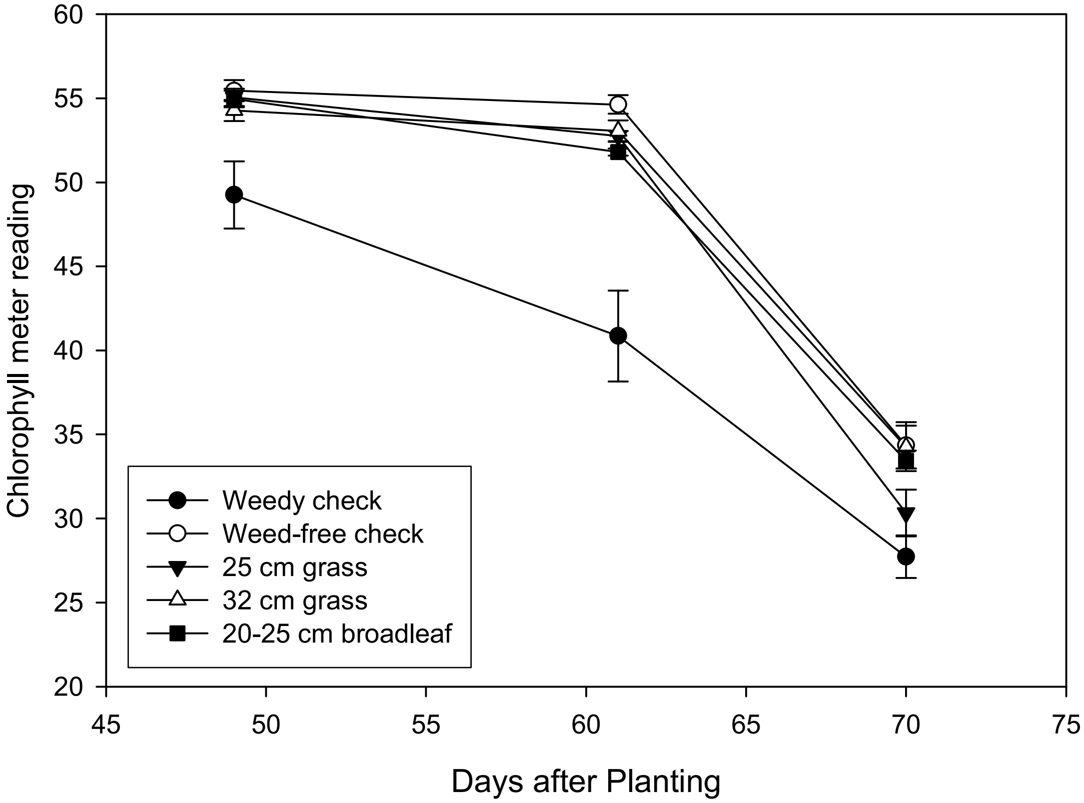
Appendix 3.2. Estimated chlorophyll level for corn at different stages of plant development. Data points represent the mean of readings from the top leaf of 100 plants at Novelty in 2003. Vertical bars represent standard deviation of sampled data.



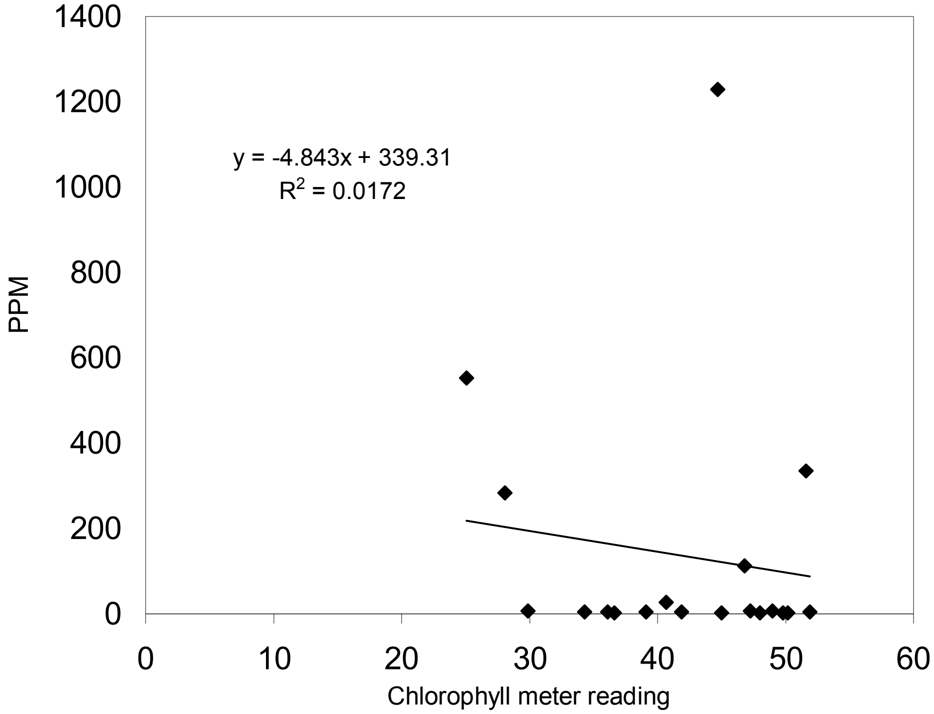
Appendix 3.3. Estimated chlorophyll level for corn at different stages of plant development. Data points represent the mean of readings from the top leaf of 100 plants at Columbia in 2004. Vertical bars represent standard deviation of sampled data.



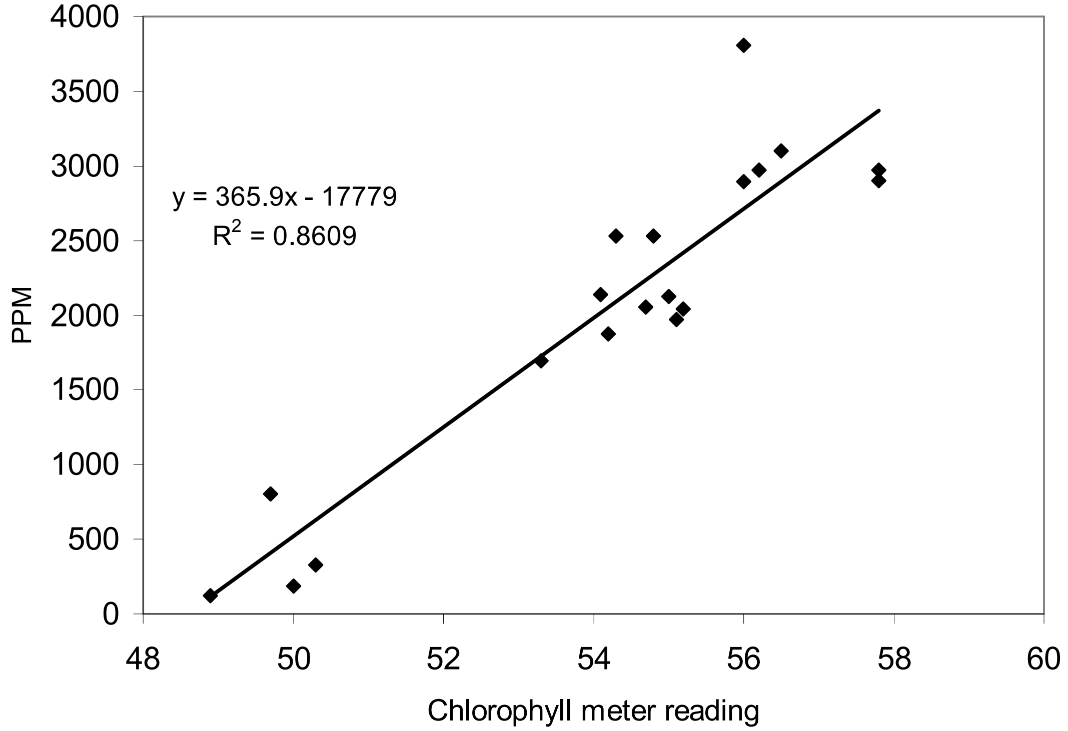
Appendix 3.4. Estimated chlorophyll level for corn at different stages of plant development. Data points represent the mean of readings from the top leaf of 100 plants at Novelty in 2004. Vertical bars represent standard deviation of sampled data.



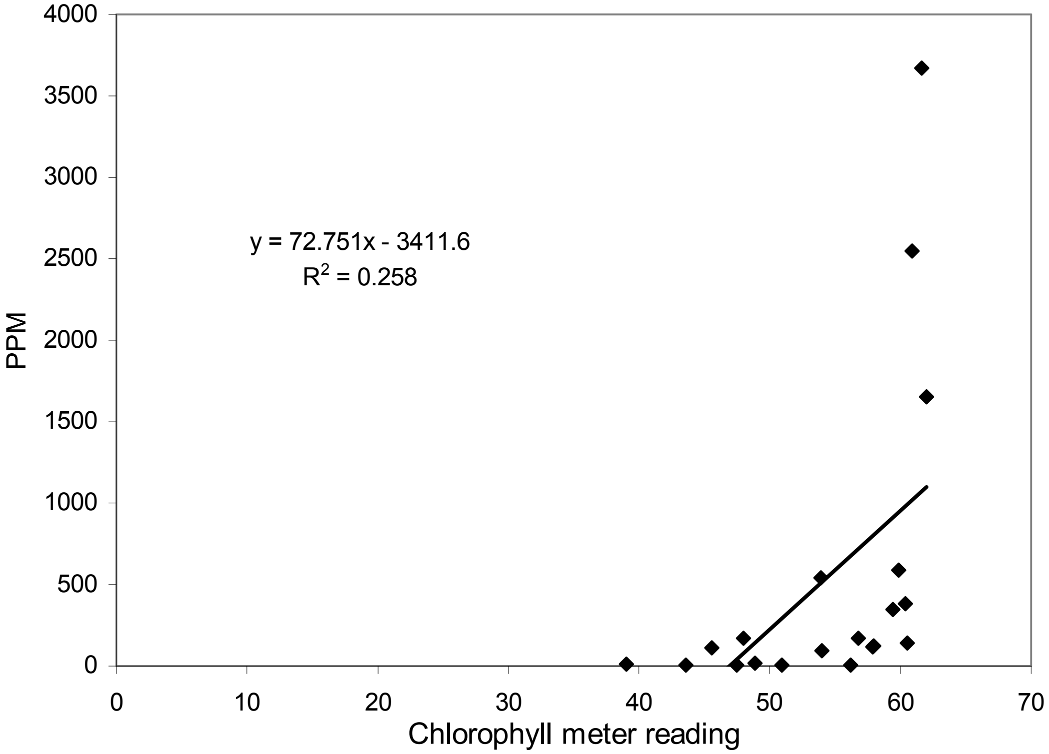
Appendix 3.5. Chlorophyll meter readings for July 21, 2003 at the V-13 growth stage at Columbia regressed linearly against year-end stalk nitrate (NO_3) values in parts per million (ppm). Data points represent the mean readings from the ear leaf of 100 plants against the respective mean values of 10 stalks.



Appendix 3.6. Chlorophyll meter readings for July 10, 2003 at the V-T growth stage at Novelty regressed linearly against year-end stalk nitrate (NO_3) values in parts per million (ppm). Data points represent the mean readings from the ear leaf of 100 plants against the respective mean values of 10 stalks.



Appendix 3.7. Chlorophyll meter readings for July 7, 2004 at the V-T growth stage at Columbia regressed linearly against year-end stalk nitrate (NO_3) values in parts per million (ppm)**.** Data points represent the mean readings from the ear leaf of 100 plants against the respective mean values of 10 stalks.



Appendix 3.8. Chlorophyll meter readings for July 8, 2004 at the V-T growth stage at Novelty regressed linearly against year-end stalk nitrate (NO_3) values in parts per million (ppm)**.** Data points represent the mean readings from the ear leaf of 100 plants against the respective mean values of 10 stalks.