

INFLUENCE OF NITROGEN ON WEED GROWTH AND COMPETITION WITH GRAIN  
SORGHUM

by

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## Abstract

Nitrogen (N) fertilizer intended for the crop may benefit highly competitive weeds to the detriment of the crop. A field experiment was conducted in 2009 to determine the influence of increasing N fertilizer rates and increasing Palmer amaranth densities on weed biomass and grain sorghum biomass and yield. Three rates were 0, 67, and 134 kg N ha<sup>-1</sup> and natural populations of Palmer amaranth were thinned to densities of 0, 0.5, 1, 2, 4, and 8 plants m<sup>-1</sup> of row. Palmer amaranth biomass increased as weed density and N rates increased. Weed-free grain sorghum yields were similar across all three N rates, and parameter estimates of yield across Palmer amaranth densities were not different between N rates. Based on the parameter estimates from the rectangular hyperbola model, initial slope (*I*) as density approached zero was 16%. Maximum expected yield loss (*A*) at high Palmer amaranth densities was 68%. Palmer amaranth showed a high response to N and the higher N rate increased the ability of the weed to reduce grain sorghum yield. A greenhouse experiment was conducted to determine the influence of six N rates on growth of six selected plant species, including grain sorghum, soybean, yellow foxtail, velvetleaf, Palmer amaranth and shattercane. Covariance analysis was performed with N rate as a covariate. Biomass of all species increased as N rate increased in both runs of the study. Soybean responded the least to N rate of all species in regards to biomass, height and leaf area production. In the first run, the biomass of three grass species (grain sorghum, yellow foxtail, shattercane) had similar estimates of slope and intercept of biomass across N rates. In the second run, the biomass slopes of grain sorghum and shattercane differed from soybean and were the only slopes that differed between species. Palmer amaranth had the highest rate of response as N increased but slopes of height were similar for Palmer amaranth, grain sorghum and shattercane. Soybean leaf area slopes were different from grain sorghum, yellow foxtail, and velvetleaf, but

all other slopes were not different among species. Addition of N to grain sorghum increased weed growth and resulted in more yield loss as a result of weed density. The greenhouse study demonstrated that grain sorghum and Palmer amaranth increased in response similarly to the addition of N. Alternative N fertilizer management could play a role in minimizing Palmer amaranth impacts in grain sorghum production.

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## Chapter 1 - Literature Review

Numerous factors such as genetics, row spacing, plant population, soil fertility, soil type, soil moisture, air temperature, weeds, disease and pests can influence crop yield. Interactions of these variables are complex and ways they will affect the yield of the crop can be difficult to understand. The following will review important research related to the influence of nitrogen (N) on Palmer amaranth (*Amaranthus palmeri* S. Wats.) interference with grain sorghum (*Sorghum bicolor* (L.) Moench) as well as the way N influences growth characteristics of grain sorghum, soybean (*Glycine max* L. Merr.), yellow foxtail (*Setaria pumila* (Poir.) Roem. & Schult.), velvetleaf (*Abutilon theophrasti* Medik.), shattercane (*Sorghum bicolor* (L.) Moench), and Palmer amaranth. This review will cover season-long weed competition with crops, the critical period of weed-control, crop planting date, weed density, time of weed emergence, proximity of weeds to the crop, Palmer amaranth, N, and how phosphorus (P) and potassium (K) affect weeds.

Weeds that are left uncontrolled all season have been shown to result in extreme yield losses. For example, corn (*Zea mays* L.) yield was reduced up to 74% when common waterhemp (*Amaranthus rudis* Sauer) was left uncontrolled all season (Steckel and Sprague, 2004a). When allowed to grow season-long shattercane caused 43 and 85% yield loss in corn in two separate years (Hans and Johnson, 2002). At a density of 0.5 plants m<sup>-2</sup>, giant ragweed (*Ambrosia trifida* L.) did not affect corn yields when removed by the V8 stage but season-long interference resulted in up to 19% yield loss (Johnson et al., 2007).

The critical period of weed-control is the maximum amount of time that weeds can be tolerated without affecting crop yield (Zimdahl, 2004). The critical period of weed-control

depends on the weed species present and the crop, along with environmental conditions (Hall et al., 1992). In cotton (*Gossypium hirsutum* L.), biomass was decreased by over 50% eight weeks after emergence with Palmer amaranth interference at a density of 10 plants m<sup>-1</sup> of row (Morgan et al., 2001). By delaying weed control for 3, 4 and 5 weeks after planting grain sorghum, yield loss increased with time by 4, 12 and 18%, respectively (Burnside and Wicks, 1969). Grass weed interference caused a 3.6% yield reduction for each week left uncontrolled in grain sorghum (Smith et al., 1990). No yield was lost when common waterhemp was controlled for only the first two weeks after soybean unifoliolate leaf expansion, although yield was reduced when weed control was delayed for four weeks and ten weeks caused 43% yield reduction (Hager et al., 2002). Often assumed is the idea that weeds cause yield loss very early in the growing season. Weed control techniques are much more effective when at an early growth stage, but studies have shown that early control may not be necessary to prevent yield loss. Left uncontrolled, giant foxtail (*Setaria faberi* Hermm.) caused biomass reductions in soybeans, starting at 15 and 25 days after emergence (Harrison et al., 1985). Broadleaf signalgrass (*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster) caused no yield loss in the first 28 days with corn (Alford et al., 2005). Soybeans were affected little by the presence of jimsonweed (*Datura stramonium* L.) in the first twelve weeks after planting (Henry and Bauman, 1991). Shattercane did not cause soybean yield loss when removed two weeks after emergence one year and six weeks after emergence the next year (Fellows and Roeth, 1992).

Other than time, weed growth stage or height can be used to describe the critical period of weed control. Yield loss started when shattercane grew to heights of 31 cm and greater (Hans and Johnson, 2002). In soybeans, common waterhemp should be controlled before the V4 to V5

growth stage to mitigate weed seed production and yield loss (Steckel and Sprague, 2004b).

Yield loss started when shattercane grew above the soybean canopy (Fellows and Roeth, 1992).

Planting date can shorten the length of time that weeds have to compete. Comparing three planting dates (early-May, mid-May, early-June) soybean yield loss increased from weed interference as planting date became later (Klingaman and Oliver, 1994b). The planting date of cotton, however, did not affect the competition with entireleaf morningglory (*Ipomoea hederacea* (L.) Jacq.) and sicklepod (*Senna obtusifolia* (L.) H.S. Irwin & Barneby) (Klingaman and Oliver, 1994a).

Density of weeds is an important factor in crop competition but large variations occur between the competitive ability of crop-weed combinations. Significant yield losses in corn occurred only with high densities of broadleaf signalgrass (Alford et al., 2005). Yield of cotton steadily decreased as density of Palmer amaranth increased (Morgan et al., 2001). For each increase of one kg of weed biomass per plot, cotton lint yield was reduced 5.2 to 9.3% (Rowland et al., 1999). Potato (*Solanum tuberosum* L.) tuber yield was reduced 22 to 33% from one redroot pigweed (*Amaranthus retroflexus* L.) plant m<sup>-1</sup> of row and four plants m<sup>-1</sup> of row reduced yield by 40% (Vangessel and Renner, 1990). At the highest density of 8 plants m<sup>-1</sup> of row, Palmer amaranth, common waterhemp and redroot pigweed caused a 79, 56 and 38% yield decrease in soybeans, respectively (Bensch et al., 2003). Palmer amaranth densities of 0.33, 2 and 10 plants m<sup>-1</sup> of row in soybeans caused 17, 48 and 68% yield loss (Klingaman and Oliver, 1994b). Smooth pigweed (*Amaranthus hybridus* L.) reduced corn yield by up to 39%, but once yield loss reached this level, higher density did not affect yield (Coffman and Frank 1991). Similar phenomena have been reported in other species (Stoller et al. 1997), which can be described by a rectangular hyperbola function with crop yield loss as a function of weed density.

At low densities, increasing weed density causes sudden increase in yield loss, but as density increases the rate of yield loss decreases up to a maximum weed density after which no more yield can be lost. This indicates when higher densities are present, density may no longer be as important to yield as other factors (Steckel and Sprague 2004a).

Weeds have the greatest impact when they emerge prior to or at the same time as the crop (Hall et al. 1992; Knezevic et al. 1994). In fact, corn yield loss was affected more by Palmer amaranth emergence timing than from density (Massinga et al., 2001). Palmer amaranth that emerged with corn reduced yield by 91% at a weed density of eight plants  $m^{-1}$  of row (Massinga et al., 2001). Weeds that emerged later caused only 35% yield loss at the same density (Massinga et al., 2001) Maximum corn yield loss occurred when common waterhemp emerged before V6 corn (Steckel and Sprague, 2004a).

Proximity of the weed to the crop has been shown to be an important factor in crop-weed competition. Weeds grown in the row with corn caused a yield loss of 24%, whereas weeds growing between the rows caused a 37% yield reduction. More yield loss was caused by weeds growing between the rows than with the row, since weeds between the rows had a longer period of capturing resources prior to canopy closure, whereas weeds in the row were out competed by the corn early in the season (Donald and Johnson, 2003). An individual common cocklebur (*Xanthium strumarium* L.) plant 1.5 m from the soybean row caused 16% yield loss during a full season (Henry and Bauman, 1989). When jimsonweed was grown in the soybean row, size of the jimsonweed plants were reduced 80 to 93% (Henry and Bauman, 1991).

Palmer amaranth was first recorded in the drier portions of the southwest states of California, Arizona, New Mexico and Texas and have since made an expansion north and east (Sauer, 1957). Palmer amaranth is an annual broadleaf weed that can grow over 2 m tall (Horak

and Loughin, 2000) easily covering up many crops. A dioecious species, female plants can produce hundreds of thousands of seeds that can remain dormant for years (Keeley et al., 1987). Viable seeds can be produced at nine to 12 weeks after weed emergence, indicating that in places such as California, two generations could be produced per year (Keeley et al., 1987). High seed production allows for this species to quickly spread. In cotton with minimum tillage, Palmer amaranth population doubled in one year when no herbicides were applied (Keeling et al., 1991). Palmer amaranth uses C<sub>4</sub> photosynthesis (Ehleringer, 1983) which makes the species very competitive in hot and dry conditions. Roots of Palmer amaranth expand quickly and take up a large area (Wiese, 1968) which allows the roots to come in contact with more water and nutrients. Palmer amaranth produces more leaf area, primary branches, plant volume, dry matter and had the highest relative growth rate compared to tumble pigweed (*Amaranthus albus* L.), common waterhemp and redroot pigweed (Horak and Loughin, 2000).

For Palmer amaranth densities of 1 to 10 plants 9.1 m<sup>-1</sup> of row, cotton yields decreased from 13 to 54% (Morgan et al., 2001). In Oklahoma, cotton lint yield was reduced 5.9 to 11.5% for each increase of 1 Palmer amaranth row<sup>-1</sup> (Rowland et al., 1999). Soybean yield losses of 17 to 68% were reported when Palmer amaranth densities ranged from 0.33 to 10 plants m<sup>-1</sup> of row (Klingaman and Oliver, 1994b).

Harvesting cotton infested with Palmer amaranth forced slower speeds and also caused stoppages to unplug thick stems from the stripper head (Smith et al., 2000). Increased Palmer amaranth density was associated with higher grain moisture content in grain sorghum as well as more seed lost through the combine (Moore et al., 2004). Incorporated residues of Palmer amaranth exhibited allelopathic effects on cabbage (*Brassica oleracea* L.), carrot (*Daucus carota* L.) (Menges, 1987), onion (*Allium cepa* L.), and grain sorghum (Menges, 1988).

Compared to tumble pigweed, common waterhemp and redroot pigweed, Palmer amaranth was most difficult to control (Mayo et al., 1995). Alone, preemergent herbicides did not sufficiently control Palmer amaranth in Texas, although effective control was achieved when either pendimethalin or trifluralin were also used (Keeling et al., 1991). At least two applications of glyphosate to Palmer amaranth in soybeans were needed for adequate control and to prevent yield loss (Jha et al., 2008a). Consistent control of Palmer amaranth was found with imazethapyr (Mayo et al., 1995). In a study comparing acifluofen, chlorimuron and imazaquin, the high rate of imazaquin was the only one that adequately controlled Palmer amaranth in soybeans (Gossett and Toler, 1999).

Cross-pollination and high seed production contribute to the ability of Palmer amaranth to spread resistance very quickly. Glyphosate-resistant Palmer amaranth have been found in several states including Georgia (Culpepper et al., 2006), Arkansas (Norsworthy et al., 2008) and Tennessee (Steckel et al., 2008). Palmer amaranth showed cross-resistance to the sulfonylurea herbicides thifensulfuron and chlorimuron (Sprague et al., 1997). In Kansas, Palmer amaranth withstood eight times the labeled use rate of imazethapyr and thifensulfuron (Horak and Peterson, 1995), indicating ALS-resistant biotypes. In cotton growing areas of South Carolina, five to six times the rate of trifluralin was needed to control Palmer amaranth which was identified as a resistant biotype (Gossett et al., 1992).

Originating in the southwest (Sauer, 1957), Palmer amaranth has an advantage in hot dry situations. In a comparison of nine *Amaranthus* species, Powell amaranth (*Amaranthus powellii*) and Palmer amaranth germinated more rapidly across all temperature regimes (Steckel et al., 2004). Palmer amaranth responded negatively while soybean increased response to lower root and air temperatures. Palmer amaranth responded more to higher temperatures, indicating why

weed pressure may increase even after soybean canopy closure. (Wright et al., 1999) At the highest temperature treatments, Palmer amaranth produced more biomass and root volume than common waterhemp and redroot pigweed, although Palmer amaranth had the lowest root volume at the lowest temperature (Guo and Al-Khatib, 2003).

Palmer amaranth can compete with crops in low light environments by increasing leaf area 28 and 42% in 87% shade (Jha et al., 2008b). Only 10% Palmer amaranth emerged after soybean canopy closure (Jha and Norsworthy, 2009). Reaching heights greater than corn and holding greater leaf area above the layers of corn maximum leaf area allows Palmer amaranth much light interception (Massinga et al., 2003).

Ever increasing costs of N along with high value crops have stressed the importance of maximizing each unit of N applied to fields. Through recent research, valuable information has been gained in the areas of N rates, sources, application methods and decreasing N loss. Though only a few studies have observed how weeds change the effects of N with the crop (Zimdahl, 2004). Typical research uses recommended N rates and focuses on another aspect of weed-crop competition. Many researchers assume that competition remains constant as N fertilizer rate increased (Cathcart and Swanton, 2003), but at high N levels, weeds that respond more to N fertilizer could be more competitive (Barker et al., 2006). This interaction is highly dependent on the weed species and crop with which it is growing along with the amount of soil N.

Of all nutrients, N is used in the highest amounts by plants, but it is the one most often limiting to crop growth and development. An essential nutrient, N is required by many processes in the plant. Some of the most important of which are chlorophyll production, proteins, and enzyme reactions (Brady and Weil, 2003). The main source of N for crop production comes from applications of inorganic fertilizer, but other significant sources are soil organic matter,

organic fertilizer such as manure, N fixation through leguminous plants and rainfall (Brady and Weil, 2003). Nitrogen is mobile in plants and soil. Plants take up N as ammonium and nitrate, although nitrate is more available to the plants. (Brady and Weil, 2003)

Nitrogen is an important factor in weed-crop competition but studies vary on which one benefits more from N fertilization. Many times the crop is more competitive with increased N. Corn was more responsive than giant ragweed in early season growth indicating the N fertilization should not be altered to decrease the effects of giant ragweed in corn (Johnson et al., 2007). Nitrogen increased early-season corn growth, which was detrimental to the weeds, extending the critical period of weed control (Evans et al., 2003). Increased N was needed to increase cotton yields to offset that which was taken by weeds (Robinson, 1976). Weeds may benefit more from increased N, as with Carlson and Hill (1986), in which wild oat (*Avena fatua* L.) panicles increased while wheat (*Triticum aestivum* L.) yields decreased with the addition of N. In some situations N may not be important in weed-crop competition. Additional N did not change the relationship of cotton infested with grassy weeds that were expected to be highly responsive (Buchanan and McLaughlin, 1975).

Timing of N application, method of N application and source of N may be important factors in the ability of the crops and weeds to compete. When studying multiple timings of N applications in winter wheat infested by downy brome (*Bromus tectorum* L.) Ball et al., (1996) and Anderson (1991) found split applications, or timings other than in fallow increased downy brome productivity while the wheat benefited little. Compared to later timings, applications of N during fallow caused the lowest response of downy brome, and all applications during the growing season increased biomass and culms of downy brome. Comparing PRE N to POST N applications, leaf area of velvetleaf and giant foxtail were 64 and 41% lower respectively with



POST N compared to PRE N, although common waterhemp was not affected (Harbur and Owen, 2004). Placement of fertilizer may be a way of decreasing weed pressure. (Kirkland and Beckie, 1998) found that emergence and growth of weeds increased where N was broadcast-applied and wheat yielded 12% higher where N was side-banded at planting. (Blackshaw et al., 2002) found that point-injected N, compared to broadcast N increased wheat yields not by reducing N uptake by weeds but by increasing N uptake by wheat. Form of N could potentially reduce the impact of certain species. Redroot pigweed increased growth when N was supplied in the nitrate form but growth was restricted when N was in the ammonium form (Teyker et al., 1991). When fertilized with organic sources yield of sweet corn was unaffected by weeds, compared to ammonium nitrate treatments which had 20 to 35% yield losses to weed competition (Davis and Liebman, 2001).

Phosphorus and potassium are two nutrients that are often applied with N and that have been shown to influence the competitive nature of crops and weeds. Banding P increased lettuce (*Lactuca sativa*) yields even when common lambsquarters (*Chenopodium album* L.) was allowed to interfere for long durations (Santos et al., 2004b) and influence of common lambsquarters was decreased (Santos et al., 2004c). When N is not limiting, field horsetail (*Equisetum arvense* L.) requires high soil K for maximum growth (Andersson and Lundegårdh, 1999). Although spiny amaranth (*Amaranthus spinosus* L.) was more competitive at all P levels, lettuce became more competitive as P level increased (Shrefler et al., 1994). With increasing rates of soil P, the P tissue content of smooth pigweed increased but biomass did not. In mixtures of smooth pigweed and lettuce, the competitive ability of lettuce was increased in high P soils (Santos et al., 2004a). Out of ten weeds studied, ones that were most responsive to P, redroot pigweed, jimsonweed, and Florida beggarweed (*Desmodium tortuosum* (Sw.) DC.) were also most responsive to K

(Hoveland et al., 1976). When testing 22 weeds, Blackshaw et al. (2004) found 17 responded to P in shoot biomass more than wheat and 19 responded more than canola (*Brassica napus* L.).

Competition can be described as “when each of two or more organisms seeks the measure they want of any particular factor or things and when the immediate supply of the factor or things is below the combined demand of the organisms” (Zimdahl, 2004). In plants, much of this interspecific competition occurs in the soil between neighboring roots for water and numerous essential mineral nutrients. This competition in the soil can affect the competition that takes place aboveground for light and vice versa. Growth rate of a species may often be limited by the resource in least abundance. Competition will occur if a neighboring plant reduced the rate of this resource, causing that resource to be the most limiting factor. Three processes allow uptake of resources to the plant. Diffusion occurs when the uptake of nutrients is higher than mass flow, causing a concentration gradient around the roots. Root interception is the expansion of roots through the soil coming in contact with minerals. Mass flow requires dissolved nutrients and water movement across the root surface. Nutrient uptake is driven mainly by mass flow and diffusion, with very little by root interception. Mass flow accounts for a large portion of nitrate brought to the root surfaces. Diffusion though, is believed to be the main way neighboring roots compete, by causing nutrient depletion zones where roots overlap (Casper and Jackson 1997). Root architecture is important to the uptake of nutrients. Competition for nutrients increase with higher root density, but too high of a density in a locale may be less beneficial to the plant. Besides root density in a single area, ability to move into patches of higher nutrient concentrations and where fewer neighboring roots exist give plants a competitive advantage (Casper and Jackson 1997).

An improved understanding of the role of N in crop-weed interactions could help develop strategies to increase the ability of the crop to compete for N. Information of the relationship between grain sorghum and Palmer amaranth in different rates of N fertilizer with several densities of Palmer amaranth can aid weed control and N fertilizer decisions. The first objective of this study was to determine the influence of increasing Palmer amaranth densities and N rates on grain sorghum yield, biomass, N concentration and Palmer amaranth biomass. The second objective of this study was to determine the effects of N on dry weight, height and leaf area of certain weed and crop species.

## Literature Cited

- Alford L. J., R. M. Hayes, R. G. Neil Jr, L. E. Steckel, and T. C. Mueller. 2005. Broadleaf signalgrass (*Brachiaria platyphylla*) interference in corn. *Weed Science* 53:97-100.
- Anderson R. L. 1991. Timing of nitrogen application affects downy brome (*Bromus tectorum*) growth in winter wheat. *Weed Technology* 5:582-585.
- Andersson T. N. and B. Lundegårdh. 1999. Field horsetail (*Equisetum arvense*): Effects of potassium under different light and nitrogen conditions. *Weed Science* 47:47-54.
- Ball D. A., D. J. Wysocki, and T. G. Chastain. 1996. Nitrogen application timing effects on downy brome (*Bromus tectorum*) and winter wheat (*Triticum aestivum*) growth and yield. *Weed Technology* 10:305-310.
- Barker D. C., S. Z. Knezevic, A. R. Martin, D. T. Walters, and J. L. Lindquist. 2006. Effect of nitrogen addition on the comparative productivity of corn and velvetleaf (*Abutilon theophrasti*). *Weed Science* 54:354-363.
- Bensch C. N., M. J. Horak, and D. Peterson. 2003. Interference of redroot pigweed (*Amaranthus retroflexus*), Palmer amaranth (*A. palmeri*), and common waterhemp (*A. rudis*) in soybean. *Weed Science* 51:37-43.
- Blackshaw R. E., R. N. Brandt, H. H. Janzen, and E. Toby. 2004. Weed species response to phosphorus fertilization. *Weed Science* 52:406-412.
- Blackshaw R. E., G. Semach, and H. H. Janzen. 2002. Fertilizer application method affects nitrogen uptake in weeds and wheat. *Weed Science* 50:634-641.
- Brady N. C. and R. R. Weil. 2003. Elements of the nature and properties of soils. 2<sup>nd</sup> ed.: Prentice Hall. Pp. 624.

- Buchanan G. A. and R. D. McLaughlin. 1975. Influence of nitrogen on weed competition in cotton. *Weed Science* 23:324-328.
- Burnside O. C. and G. A. Wicks. 1969. Influence of weed competition on sorghum growth. *Weed Science* 17:332-334.
- Carlson H. L. and J. E. Hill. 1986. Wild oat (*Avena fatua*) competition with spring wheat: Effects of nitrogen fertilization. *Weed Science* 34:29-33.
- Casper, B. and Jackson, R. B. 1997. Plant competition underground. *Annual Review of Ecology and Systemics* 28:545-570.
- Cathcart R. J. and C. J. Swanton. 2003. Nitrogen management will influence threshold values of green foxtail (*Setaria viridis*) in corn. *Weed Science* 51:975-986.
- Coffman C. B. and J. R. Frank. 1991. Weed-crop responses to weed management systems in conservation tillage corn (*Zea mays*). *Weed Technol.* 5:pp. 76-81.
- Culpepper A. S., T. L. Grey, W. K. Vencill, J. M. Kichler, T. M. Webster, S. M. Brown, A. C. York, J. W. Davis, and W. W. Hanna. 2006. Glyphosate-resistant palmer amaranth (*Amaranthus palmeri*) confirmed in Georgia. *Weed Science* 54:620-626.
- Davis A. S. and M. Liebman. 2001. Nitrogen source influences wild mustard growth and competitive effect on sweet corn. *Weed Science* 49:558-566.
- Donald W. W. and W. G. Johnson. 2003. Interference effects of weed-infested bands in or between crop rows on field corn (*Zea mays*) yield. *Weed Technology* 17:755-763.
- Ehleringer J. 1983. Ecophysiology of *Amaranthus palmeri*, a Sonoran desert summer annual. *Oecologia* 57:107-112.

- Evans, S. P., S. Z. Knezevic, J. L. Lindquist, C. A. Shapiro, and E. E. Blankenship. 2003. Nitrogen application influences the critical period for weed control in corn. *Weed Science* 51:408-417.
- Fellows G. M. and F. W. Roeth. 1992. Shattercane (*Sorghum bicolor*) interference in soybean (*Glycine max*). *Weed Science* 40:68-73.
- Gossett B. J., E. C. Murdock, and J. E. Toler. 1992. Resistance of palmer amaranth (*Amaranthus palmeri*) to the dinitroaniline herbicides. *Weed Technology* 6:587-591.
- Gossett B. J. and J. E. Toler. 1999. Differential control of palmer amaranth (*Amaranthus palmeri*) and smooth pigweed (*Amaranthus hybridus*) by postemergence herbicides in soybean (*Glycine max*). *Weed Technology* 13:165-168.
- Guo P. and K. Al-Khatib. 2003. Temperature effects on germination and growth of redroot pigweed (*Amaranthus retroflexus*), Palmer amaranth (*A. palmeri*), and common waterhemp (*A. rudis*). *Weed Science* 51:869-875.
- Hager G. A., L. M. Wax, E. W. Stoller, and G. A. Bollero. 2002. Common waterhemp (*Amaranthus rudis*) interference in soybean. *Weed Science* 50:607-610.
- Hall M. R., C. J. Swanton, and G. W. Anderson. 1992. The critical period of weed control in grain corn (*Zea mays*). *Weed Sci.* 40:pp. 441-447.
- Hans S. R. and W. G. Johnson. 2002. Influence of shattercane [*Sorghum bicolor* (L.) Moench.] interference on corn (*Zea mays*) yield and nitrogen accumulation. *Weed Technology* 16:787-791.
- Harbur M. M. and M. D. K. Owen. 2004. Response of three annual weeds to corn population density and nitrogen fertilization timing. *Weed Science* 52:845-853.

- Harrison S. K., C. S. Williams, and L. M. Wax. 1985. Interference and control of giant foxtail (*Setaria faberi*) in soybeans (*Glycine max*). *Weed Science* 33:203-208.
- Henry W. T. and T. T. Bauman. 1991. Interference between soybean (*Glycine max*) and jimsonweed (*Datura stramonium*) in Indiana. *Weed Technology* 5:759-764.
- Henry W. T. and T. T. Bauman. 1989. Interference between soybeans (*Glycine max*) and common cocklebur (*Xanthium strumarium*) under Indiana field conditions. *Weed Science* 37:753-760.
- Horak M. J. and T. M. Loughin. 2000. Growth analysis of four *Amaranthus* species. *Weed Science* 48:347-355.
- Horak M. J. and D. E. Peterson. 1995. Biotypes of palmer amaranth (*Amaranthus palmeri*) and common waterhemp (*Amaranthus rudis*) are resistant to imazethapyr and thifensulfuron. *Weed Technology* 9:192-195.
- Hoveland C. S., G. A. Buchanan, and M. C. Harris. 1976. Response of weeds to soil phosphorus and potassium. *Weed Science* 24:194-201.
- Jha P., K. N. Jason, M. B. Riley, D. G. Bielenberg, and B. William Jr. 2008a. Acclimation of Palmer amaranth (*Amaranthus palmeri*) to shading. *Weed Science* 56:729-734.
- Jha P., K. N. Jason, B. William Jr, and M. B. Riley. 2008b. Influence of glyphosate timing and row width on Palmer amaranth (*Amaranthus palmeri*) and pusley (*Richardia spp.*) demographics in glyphosate-resistant soybean. *Weed Science* 56:408-415.
- Jha P. and J. K. Norsworthy. 2009. Soybean canopy and tillage effects on emergence of Palmer amaranth (*Amaranthus palmeri*) from a natural seed bank. *Weed Science* 57:644-651.

- Johnson W. G., E. J. Ott, K. D. Gibson, R. L. Nielsen, and T. T. Bauman. 2007. Influence of nitrogen application timing on low density giant ragweed (*Ambrosia trifida*) interference in corn. *Weed Technology* 21:763-767.
- Keeley P. E., C. H. Carter, and R. J. Thullen. 1987. Influence of planting date on growth of Palmer amaranth (*Amaranthus palmeri*). *Weed Science* 35:199-204.
- Keeling J. W., K. T. Siders, and J. R. Abernathy. 1991. Palmer amaranth (*Amaranthus palmeri*) control in a conservation tillage system for cotton (*Gossypium hirsutum*). *Weed Technology* 5:137-141.
- Kirkland K. J. and H. J. Beckie. 1998. Contribution of nitrogen fertilizer placement to weed management in spring wheat (*Triticum aestivum*). *Weed Technology* 12:507-514.
- Klingaman T. E. and L. R. Oliver. 1994a. Influence of cotton (*Gossypium hirsutum*) and soybean (*Glycine max*) planting date on weed interference. *Weed Science* 42:61-65.
- Klingaman T. E. and L. R. Oliver. 1994b. Palmer amaranth (*Amaranthus palmeri*) interference in soybeans (*Glycine max*). *Weed Science* 42:523-527.
- Knezevic S. Z., S. F. Weise, and C. J. Swanton. 1994. Interference of redroot pigweed (*Amaranthus retroflexus*) in corn (*Zea mays*). *Weed Sci.* 42:pp. 568-573.
- Massinga R. A., R. S. Currie, M. J. Horak, and B. John Jr. 2001. Interference of Palmer amaranth in corn. *Weed Science* 49:202-208.
- Massinga R. A., R. S. Currie, and T. P. Trooien. 2003. Water use and light interception under Palmer amaranth (*Amaranthus palmeri*) and corn competition. *Weed Science* 51:523-531.
- Mayo C. M., M. J. Horak, D. E. Peterson, and J. E. Boyer. 1995. Differential control of four amaranthus species by six postemergence herbicides in soybean (*Glycine max*). *Weed Technology* 9:141-147.



- Menges R. M. 1987. Allelopathic effects of Palmer amaranth (*Amaranthus palmeri*) and other plant residues in soil. *Weed Science* 35:339-347.
- Menges R. M. 1988. Allelopathic effects of Palmer amaranth (*Amaranthus palmeri*) on seedling growth. *Weed Science* 36:325-328.
- Moore J. W., S. M. Don, and R. B. Westerman. 2004. Palmer amaranth (*Amaranthus palmeri*) effects on the harvest and yield of grain sorghum (*Sorghum bicolor*). *Weed Technology* 18:23-29.
- Morgan G. D., P. A. Baumann, and J. M. Chandler. 2001. Competitive impact of Palmer amaranth (*Amaranthus palmeri*) on cotton (*Gossypium hirsutum*) development and yield. *Weed Technology* 15:408-412.
- Norsworthy J. K., G. M. Griffith, R. C. Scott, K. L. Smith, and L. R. Oliver. 2008. Confirmation and control of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in Arkansas. *Weed Technology* 22:108-113.
- Robinson E. L. 1976. Yield and height of cotton as affected by weed density and nitrogen level. *Weed Science* 24:40-42.
- Rowland M. W., S. M. Don, and L. M. Verhalen. 1999. Full-season Palmer amaranth (*Amaranthus palmeri*) interference with cotton (*Gossypium hirsutum*). *Weed Science* 47:305-309.
- Santos B. M., J. A. Dusky, W. M. Stall, T. A. Bewick, and D. G. Shilling. 2004a. Mechanisms of interference of smooth pigweed (*Amaranthus hybridus*) and common purslane (*Portulaca oleracea*) on lettuce as influenced by phosphorus fertility. *Weed Science* 52:78-82.

- Santos B. M., J. A. Dusky, W. M. Stall, and J. P. Gilreath. 2004b. Effects of phosphorus fertilization on common lambsquarters (*Chenopodium album*) duration of interference in lettuce (*Lactuca sativa*). *Weed Technology* 18:152-156.
- Santos B. M., J. A. Dusky, W. M. Stall, and J. P. Gilreath. 2004c. Effects of phosphorus fertilization on the area of influence of common lambsquarters (*Chenopodium album*) in lettuce. *Weed Technology* 18:1013-1017.
- Sauer J. 1957. Recent migration and evolution of the dioecious amaranths. *Evolution* 11:11-31.
- Shrefler J. W., D. G. Shilling, J. A. Dusky, and B. J. Brecke. 1994. Influence of phosphorus fertility on intra- and interspecific interference between lettuce (*Lactuca sativa*) and spiny amaranth (*Amaranthus spinosus*). *Weed Science* 42:574-578.
- Smith B. S., S. M. Don, J. D. Green, W. M. Wanyahaya, and D. L. Weeks. 1990. Interference of three annual grasses with grain sorghum (*Sorghum bicolor*). *Weed Technology* 4:245-249.
- Smith D. T., R. V. Baker, and G. L. Steele. 2000. Palmer amaranth (*Amaranthus palmeri*) impacts on yield, harvesting, and ginning in dryland cotton (*Gossypium hirsutum*). *Weed Technology* 14:122-126.
- Sprague C. L., E. W. Stoller, L. M. Wax, and M. J. Horak. 1997. Palmer amaranth (*Amaranthus palmeri*) and common waterhemp (*Amaranthus rudis*) resistance to selected ALS-inhibiting herbicides. *Weed Science* 45:192-197.
- Steckel L. E., C. L. Main, A. T. Ellis, and T. C. Mueller. 2008. Palmer amaranth (*Amaranthus palmeri*) in Tennessee has low level glyphosate resistance. *Weed Technology* 22:119-123.
- Steckel L. E. and C. L. Sprague. 2004a. Common waterhemp (*Amaranthus rudis*) interference in corn. *Weed Science* 52:359-364.

- Steckel L. E. and C. L. Sprague. 2004b. Late-season common waterhemp (*Amaranthus rudis*) interference in narrow- and wide-row soybean. *Weed Technology* 18:947-952.
- Steckel L. E., C. L. Sprague, E. W. Stoller, and L. M. Wax. 2004. Temperature effects on germination of nine *Amaranthus* species. *Weed Science* 52:217-221.
- Stoller, E. W., S. K. Harrison, L. M. Wax, E. E. Regnier, and E. D. Nafziger. 1997. Weed interference in soybeans (*Glycine max*). Pages 155-181 in C. L. Foy, ed. *Reviews of Weed Science*. Champaign, IL: Weed Science Society of America.
- Teyker R., H. Hoelzer, and R. Liebl. 1991. Maize and pigweed response to nitrogen supply and form. *Plant and Soil* 135:287-292.
- Vangessel M. J. and K. A. Renner. 1990. Redroot pigweed (*Amaranthus retroflexus*) and barnyardgrass (*Echinochloa crus-galli*) interference in potatoes (*Solanum tuberosum*). *Weed Science* 38:338-343.
- Wiese A. F. 1968. Rate of weed root elongation. *Weed Science* 16:11-13.
- Wright S. R., H. D. Coble, R. C. David Jr, and R. T. W. Jr. 1999. Comparative responses of soybean (*Glycine max*), sicklepod (*Senna obtusifolia*), and Palmer amaranth (*Amaranthus palmeri*) to root zone and aerial temperatures. *Weed Science* 47:167-174.
- Zimdahl R. L. 2004. *Weed-crop competition: a review*. 2<sup>nd</sup> ed.: Blackwell Pub. Professional. Pp. 220.

## Chapter 2 - Influence of Nitrogen on Palmer Amaranth in Grain Sorghum

### Abstract

Palmer amaranth (*Amaranthus palmeri* S. Wats.) is a problematic weed in numerous cropping systems in Kansas. One reason may be that Palmer amaranth responds to increasing nitrogen (N) levels, thus making it more competitive with crops. A field experiment was conducted in 2009 to determine the influence of increasing N fertilizer rates and increasing Palmer amaranth densities on Palmer amaranth and grain sorghum (*Sorghum bicolor* L.) vegetative biomass and yield. Three N rates were 0, 67, and 134 kg N ha<sup>-1</sup> and natural populations of Palmer amaranth were thinned to densities of 0, 0.5, 1, 2, 4, and 8 plants m<sup>-1</sup> row. Aboveground portions of vegetative grain sorghum and Palmer amaranth plants in one meter of row were harvested for biomass on September 15 and 25, respectively. Center two rows of plots were combine-harvested for grain sorghum yield. Weed-free grain sorghum yields and vegetative biomass were similar across all three N rates. Parameter estimates of *I* and *A* were not different between N rates for yield or biomass. Based on the parameter estimates from the rectangular hyperbola model, initial yield loss (*I*) as density approached zero was 16%. Maximum expected yield loss (*A*) at infinite Palmer amaranth densities was 68%. Comparing grain N concentrations by N rate indicated only a difference between the 0 kg N ha<sup>-1</sup> rate and the 67 and 134 kg N ha<sup>-1</sup> rates. Highest grain N concentration occurred in the weed-free 134 kg N ha<sup>-1</sup> rate conditions. Palmer amaranth biomass increased as weed density and N rates increased.

### Introduction

Grain sorghum is an integral part of cropping systems in Kansas. In 2009, over 1 million hectares of grain sorghum were harvested with average yields of 5,205 kg ha<sup>-1</sup> (83 bu acre<sup>-1</sup>) in

Kansas (NASS, 2011). Of all the summer crops grown in Kansas, grain sorghum is one of the most drought tolerant (Tucker, 2009). Grain sorghum is typically grown on dryland fields where drought stress is expected or where yields for corn (*Zea mays* L.) and soybeans (*Glycine max* L. Merr.) are not adequate. If Great Plains groundwater sources continue to be depleted, hectares of grain sorghum have potential to increase in currently irrigated areas (Weber, 2010). Besides lack of water, nutrient deficiencies are another major factor that reduce crop yield.

Nitrogen is essential to maximize grain sorghum yields in Kansas, but it is the nutrient most often lacking in optimum grain sorghum production (Whitney, 1998). In 1960, 2.7 million tons of N were applied in the United States and by 2008, this number had grown to 12.5 million tons (ERS, 2010). The main source of N for grain sorghum comes from applications of inorganic fertilizer, but other significant sources are soil organic matter, organic fertilizer such as manure, and N fixation if the field was previously cropped in a legume. Nitrogen is needed for many important processes within the plant including chlorophyll production, proteins, and enzyme reactions. Plants use two forms of N, nitrate-N and ammonium-N (Graaf et al., 1998). The ammonium form cannot be leached since it is held tightly to clay particles, but nitrification soon turns ammonium into the leachable form of nitrate, which is not held to the clay particles. Management of N is a complex task. Not enough N reduces yield but if applied in excess it may be lost causing environmental problems; neither of which are economical. Potential N loss mechanisms include leaching of nitrate, denitrification of nitrate, and volatilization of urea-based substances. Immobilization, although only temporary, is another type of loss. Weeds also take away valuable N from the crop. Grain sorghum is slow growing and little N is taken up in the first 20 days after emergence (Vanderlip, 1993). N uptake increases rapidly after 20 days and slows as the plant nears maturity. Rate of uptake is highest between 25 and 55 days after

emergence. At 55 days, about 60% of total N is taken up. Most of the remaining uptake will occur between 55 and 90 days after emergence (Vanderlip, 1993).

Competition can be described as the interaction between plants and the environment. During growth, plants modify the environment around them and the modified environment in turn influences the growth of the nearby plants (Zimdahl, 2004). Many factors determine the intensity of competition between plant species such as row spacing, water availability, soil and nutrient availability (Evans et al., 2003). There are a few studies that have inspected how N rate affects competition between plants (Zimdahl, 2004). Most researchers assumed that competition remained constant as N fertilizer rate increased (Cathcart and Swanton, 2003). At high N levels, weeds that respond more to N fertilizer could be more competitive (Barker et al., 2006). Knowledge of specific species response to N could be used to develop fertilizer management strategies to improve competitiveness of the crop (Blackshaw et al., 2003). Crop yield losses are caused primarily by competition for light between crop-weed systems (King and Purcell, 1997; Munger et al., 1987). Although aboveground growth is determined by nutrient supply in the soil (Casper and Jackson, 1997), during times of limited N supply, plants will put more energy into root growth to seek N (Bonifas and Lindquist, 2006). In high N soils however, plants will partition more growth to stems and leaves and less to roots. Studies have shown that the effects of soil fertility are specific to the crop and weed species that are interacting (Harbur and Owen, 2004). Carlson and Hill (1986) found that with increased N fertilization, wheat (*Triticum aestivum* L.) had yield loss to wild oat (*Avena fatua* L.), but Anderson et al. (1998) found that with increased N fertilization, wheat yield increased in the presence of green foxtail (*Setaria viridis* (L.) Beauv.). In corn, Teyker et al. (1991) found that redroot pigweed (*Amaranthus retroflexus* L.) had greater N uptake when N was increased in the soil than corn uptake.

Although, Nieto and Staniforth (1961) found that yield loss in corn from foxtail spp. was greater at low N levels. The way in which N affects crop-weed competition is important to understand since N management could be used in an integrated weed management (IWM) program (Barker et al., 2006). Nutrient management is not typically included in IWM programs, although fertilization may be as important as other strategies (Gunsolus and Buhler, 1999).

The presence of Palmer amaranth has increased throughout the southern Great Plains (Sauer, 1957). Grown alone, in a noncompetitive environment, Palmer amaranth grew the largest and had the highest relative growth rate compared to three other *Amaranthus* species (Horak and Loughin, 2000). Palmer amaranth is an annual broadleaf weed that can grow 3 to 4 m tall. A dioecious species, female plants can produce hundreds of thousands of seeds that can remain dormant for years (Keeley et al., 1987). High seed production allows it to quickly spread. Incorporated residues of Palmer amaranth exhibited allelopathic effects on cabbage, carrot, onion, and grain sorghum (Menges, 1987; 1988).

Palmer amaranth has been reported to cause extensive yield loss in other row crops. As densities of Palmer amaranth increased from 0.5 to 8 plants  $\text{m}^{-1}$  of row, corn yield was reduced from 11 to 91%, when both emerged together (Massinga et al., 2001). For Palmer amaranth densities of 1 to 10 plants in  $9.1 \text{ m}^{-1}$  of row, cotton yields decreased from 13 to 54% (Morgan et al., 2001). In Oklahoma, cotton lint yield was reduced 5.9 to 11.5% for each increase of 1 Palmer amaranth row $^{-1}$  (Rowland et al., 1999). Soybean yield losses of 17 to 68% were reported when Palmer amaranth densities ranged from 0.33 to 10 plants  $\text{m}^{-1}$  of row (Klingaman and Oliver, 1994).

An improved understanding of the relationship between grain sorghum and Palmer amaranth in different rates of N fertilizer with several densities of Palmer amaranth can aid weed

control and N fertilizer decisions. Without weed interference, grain sorghum yields and vegetative biomass are expected to increase as rates of N fertilizer increase. In plots competing with Palmer amaranth, we hypothesize the grain sorghum will be less responsive to N fertilizer when compared to weed-free plots. Biomass of Palmer amaranth is expected to increase as N rate increases and with a higher Palmer amaranth density. With greater densities of Palmer amaranth, grain sorghum yields are expected to decrease. Concentrations of N are expected to increase with higher N rates, but concentrations will increase less when weeds are present. The objective of this study was to determine the influence of increasing Palmer amaranth densities and N rates on grain sorghum yield, biomass, grain N concentration and Palmer amaranth biomass.

## **Materials and Methods**

A field study was conducted in 2009 to assess the N competition outcomes between Palmer amaranth and grain sorghum. The experiment was conducted on a Wymore silty clay loam at the Kansas State University Ashland Bottoms Research Farm near Manhattan, KS (39°07'N 96°38'S). The field experiment was a split-block design with four replications, where N rate was assigned to the whole plot and Palmer amaranth density as a sub-plot. Nitrogen rates for the whole plots were 0, 67 and 134 kg N ha<sup>-1</sup>. Palmer amaranth densities in the sub-plots were 0, 0.5, 1, 2, 4 and 8 plants m<sup>-1</sup> row. Each treatment was replicated four times. The experimental area was tilled using a field cultivator prior to planting to remove any existing plants. One-inch diameter soil cores were sampled from depths of 60.96 cm for nitrate and 15.24 cm for all others for lab analysis prior to fertilization (Table 2.1). Urea (46%) as the source of N was broadcast 12 hours prior to an incorporating rainfall, on the appropriate whole plots using a



manual drop seeder after cultivation and prior to planting. The grain sorghum hybrid Pioneer 84G62 was planted on May 28 at rate of 136 000 seeds ha<sup>-1</sup>. Each plot was four rows wide at 76 cm spacing and 9 m in length. Palmer amaranth emerged about the same time as the crop and was not controlled. The plots were row cultivated three weeks after planting leaving only Palmer amaranth plants that were closest to the row. Hand weeding was done to the desired densities. Weeding continued throughout the season to maintain the initial densities and to remove other weeds. One meter of row of physiological mature above-ground grain sorghum plants were harvested on September 15. Leaves and stems (vegetative biomass) were separated out from the reproductive parts. Above-ground Palmer amaranth plants were also taken from one meter of row on September 25. Plant samples of Palmer amaranth plants and grain sorghum vegetative biomass were placed in a forced-air dryer at 63° C until at a constant weight and were weighed. Grain was threshed from the grain sorghum reproductive samples that were from the 1 m<sup>-1</sup> of row, and finely ground. Ground grain samples were submitted to the Kansas State University Soil Testing Laboratory and tested for N using the Sulfuric Acid/Hydrogen Peroxide digest procedure. Prior to harvest many Palmer amaranth plants were removed to reduce interference with the combine. The center two rows of grain sorghum were harvested on November 7. Yield was recorded using a yield monitor on board the combine then corrected to 13% moisture.

Grain sorghum yield, aboveground Palmer amaranth and grain sorghum vegetative biomass, and N concentration in sorghum grain were analyzed using PROC GLM (SAS Version 9.1.3 SAS Institute Inc. SAS Campus Drive, Cary, NC 27513) with N rate and Palmer amaranth density as fixed effects and replication as random effect.

The relationship for the Palmer amaranth biomass as a function of N rate was determined using Equation 1:

$$B = \left( \frac{Cd}{1 + \left( \frac{Cd}{E} \right)} \right) \quad [1]$$

where B is Palmer amaranth biomass ( $\text{g m}^{-1}$  row), d is the Palmer amaranth density ( $\text{plants m}^{-1}$  row), and C and E are model parameters estimated from the data. Parameter C is biomass as Palmer amaranth density approaches zero, and parameter E is asymptotic maximum biomass produced as Palmer amaranth density approaches infinity.

The relationship of grain sorghum yield or vegetative biomass in response to increasing Palmer amaranth density was analyzed by fitting the following model to each data set separately by N rate:

$$Y = Y_{wf} \left[ 1 - \left\{ \frac{Id}{100 \left( 1 + \frac{Id}{A} \right)} \right\} \right] \quad [2]$$

where Y is observed grain sorghum yield ( $\text{kg ha}^{-1}$ ) or vegetative biomass ( $\text{g m}^{-1}$  of row),  $Y_{wf}$ , I, and A are model parameters estimated from the data, and d is Palmer amaranth density ( $\text{plants m}^{-1}$  row). Parameter  $Y_{wf}$  is estimated weed-free yield (or biomass), I is the percent yield loss (or biomass) as density approaches zero, and A is asymptotic maximum percent yield loss (or vegetative biomass) as the weed density approaches infinity.

Parameter estimates were determined using nonlinear regression techniques in SigmaPlot (SigmaPlot V.10 Systat Software, Inc. 1735 Technology Drive, Suite 430, San Jose, CA 95110) such that a rectangular hyperbola function was fit to biomass data and to yield data in response to increasing weed density across different N rates (Cousens, 1985). These estimates were

compared among N rates for grain sorghum yield loss and grain sorghum vegetative biomass using the method proposed by Chism et al. (1992) and used by Deines et al. (2004). These comparisons were accomplished by using binary variables for each N rate to calculate differences between parameter estimates. When the upper and lower confidence intervals for the difference in parameter estimates did not contain zero, then a significant difference was realized (Chism et al. 1992).

## **Results and Discussion**

### ***Grain sorghum yield response to N rates***

Observed grain sorghum yields in weed-free plots ranged from 8046 kg ha<sup>-1</sup> in plots where no N was added to 8751 kg ha<sup>-1</sup> in the 134 kg N ha<sup>-1</sup> plots and to 8771 kg ha<sup>-1</sup> with 67 kg N ha<sup>-1</sup> added (Figure 2.1). No differences in observed or predicted weed-free grain sorghum yields were detected among the N rates (Table 2.2). The lack of response of grain sorghum to N may have occurred from a sufficient amount of N already in the soil, with a level of 8.8 NO<sub>3</sub><sup>-</sup> mg kg<sup>-1</sup> (Table 2.1). Lack of observed yield response to N could also be attributed to lower than average temperatures and higher than average precipitation during the summer, resulting in a less stressful growing environment (Table 2.3). In 2009, temperatures between May and October were around 2 C less than the 30-year normal. Typically, July is the warmest month followed by August but in 2009, June was the warmest and was similar to the normal. The 30-yr average temperature in July was 26.6 C but in 2009 was 23.1 C. The average temperature in August is 25.6 C but in 2009 was 22.9 C. Precipitation received between May and October was slightly less than normal. Compared to the 30-year average, very little rainfall came in May. However, above average precipitation occurred in the warmest months of June, July and August (Table

2.3). The higher than average moisture during the summer may have increased decomposition of soil organic matter, which would have added significant amounts of N. With an organic matter level of 2.1% (Table 2.1) this would have provided ~47 kg N ha<sup>-1</sup> for the crop year in a typical year (Leikam et al., 2003), but significantly more with conditions such as these.

### ***Grain sorghum yield response to N and Palmer amaranth***

Knezevic et al. (1997) observed that weed-free grain sorghum yields in Kansas varied from 6,813 to 9,144 kg ha<sup>-1</sup> depending on year and location. In the presence of Palmer amaranth, yields of grain sorghum ranged from a low of 4,053 kg ha<sup>-1</sup> with high N rate and high weed density (134 kg N ha<sup>-1</sup> and 8 weeds m<sup>-1</sup> of row) to a high of 8,626 kg ha<sup>-1</sup> with 0 kg N ha<sup>-1</sup> and 0.5 weeds m<sup>-1</sup> of row (Figure 2.1). When grown with redroot pigweed at densities of 0.5 to 12 plants m<sup>-1</sup> of row, they found grain sorghum yield losses increased from 3 to 46% (Knezevic et al., 1997).

Values of parameter estimate *I* (yield loss as weed density approaches 0) were not different among N rates and was a pooled estimate of 16% (Table 2.2). Parameter estimate *A* was not different among N rates and the pooled estimate was 68% (Table 2.2). Knezevic et al., (1997) evaluated redroot pigweed in grain sorghum in Kansas, both planted on the same day, and parameter estimate *I* was predicted to be 2.6 to 13.9% across years and locations. Predicted maximum yield loss (*A*) ranged from 4.3 to 61.9% (Knezevic et al., 1997). The yield loss values of *I* and *A* were larger with Palmer amaranth in our study compared to the estimates that Knezevic et al., (1997) found with redroot pigweed in grain sorghum, indicating redroot pigweed may be less competitive than Palmer amaranth.

Across all N rates, yield loss increased as weed density increased. To further understand this yield loss, green vegetative biomass of grain sorghum and Palmer amaranth plants at physiological maturity were determined prior to crop harvest.

### ***Grain sorghum biomass***

Grain sorghum vegetative (leaf and stem) biomass was harvested at physiological maturity on September 15, 2009. Observed grain sorghum vegetative biomass in weed-free plots ranged from 632 g ha<sup>-1</sup> in plots where no N was added to 675 g ha<sup>-1</sup> in the 134 kg N ha<sup>-1</sup> plots and to 702 g ha<sup>-1</sup> with 67 kg N ha<sup>-1</sup> added (Figure 2.2). Estimated weed-free grain sorghum vegetative biomass was not different among the N rates (Table 2.4).

In the presence of Palmer amaranth, vegetative biomass of grain sorghum ranged from a low of 476 g ha<sup>-1</sup> with 67 and 134 kg N ha<sup>-1</sup> and 8 weeds m<sup>-1</sup> of row to a high of 644 g ha<sup>-1</sup> with 0 kg N ha<sup>-1</sup> and 0.5 weeds m<sup>-1</sup> of row (Figure 2.2). Compared to grain sorghum yield loss, percentage of biomass loss was much less, possibly indicating increased competition later in the growing season during the grain-fill period. Values of *I* were not different among all N rates and was a pooled estimate of 15%. Maximum grain sorghum biomass (*A*) as density approached infinity was not different between N rates and the pooled estimate was 32% (Table 2.4).

### ***Nitrogen concentration in grain***

Grain sorghum N concentration in the grain among four Palmer amaranth densities (0, 0.5, 1, and 8 plants m<sup>-1</sup> of row) was not a significant effect indicating that Palmer amaranth uptake of N may not have been enough to cause a shortage for the grain sorghum even with a density as high as 8 plants m<sup>-1</sup> of row. Nitrogen rate was a significant factor. Over all four densities tested, the N concentration at the 0 kg N ha<sup>-1</sup> rate was 1.16%. The 67 and 134 kg N ha<sup>-1</sup> N concentration were 1.26 and 1.32%, respectively. Comparing N concentrations by N rate at a

significance level of 0.05, with the LSD value at 0.09, indicated no difference between the 67 and 134 kg N ha<sup>-1</sup> rates, although the 0 kg N ha<sup>-1</sup> rate was different than the 67 and 134 kg N ha<sup>-1</sup> rates. Increasing the N fertilizer rate increased the N concentration of the grain.

### ***Palmer amaranth biomass***

Palmer amaranth biomass was harvested at physiological maturity on September 25, 2009. Biomass of Palmer amaranth ranged from a low of 100 g m<sup>-1</sup> of row with 0 kg N ha<sup>-1</sup> and 1 Palmer amaranth m<sup>-1</sup> of row to a high of 774 g m<sup>-1</sup> of row with 134 kg N ha<sup>-1</sup> and 8 plants m<sup>-1</sup> of row. Palmer amaranth produced more biomass across low densities with 134 kg N ha<sup>-1</sup> compared to the lower N rates (Figure 2.3). Equation 1 was fit to the data by N rate and weed density. Parameter estimates of *C* at 0 kg N ha<sup>-1</sup> were 138 g m<sup>-1</sup> of row. Parameter estimates of *C* at 67 kg N ha<sup>-1</sup> were 354 g m of row<sup>-1</sup>. Parameter estimates of *C* at 134 kg N ha<sup>-1</sup> were 532 g m of row<sup>-1</sup>. At *C*, 0 kg N ha<sup>-1</sup> estimates were different from the 67 and 134 kg N ha<sup>-1</sup>, which were not different from each other. Palmer amaranth parameter estimates at *E* were not different among N rates (Table 2.5).

## **Conclusions**

To conclude, previous hypothesis statements along with the outcome from the experiment will be reviewed. Without weed interference, grain sorghum yields and biomass were expected to increase as rates of N fertilizer increase, but in this experiment grain sorghum yield and vegetative biomass did not respond to N. In treatments competing with Palmer amaranth, grain sorghum was expected to be less responsive to N fertilizer when compared to weed-free treatments, and since grain sorghum had no response to N, yields were decreased with Palmer amaranth. Biomass of Palmer amaranth was expected to increase as N rate increased and as density of Palmer amaranth increased and it did. With greater densities of Palmer amaranth,

grain sorghum yields were expected to decrease, which was also true. Concentrations of N were expected to increase with higher N rates, but concentrations were thought to have increased less when weeds were present. Nitrogen concentration in the grain sorghum grain did positively respond to N rate but N concentration was not affected by Palmer amaranth density.

Although N did not impact grain sorghum yield, Palmer amaranth density did have a negative impact on yield. From the parameter estimates, yield loss can be estimated at any Palmer amaranth density. With only 0.25 Palmer amaranth plants  $\text{m}^{-1}$  of row, grain sorghum yield loss was estimated to be 4%. At a density of 0.5, 0.75, and 1 plant  $\text{m}^{-1}$  of row, estimated yield loss was 7, 10, and 13% respectively. At a density of 2, 4, and 6 plant  $\text{m}^{-1}$  of row, estimated yield loss was 22, 33, and 40% respectively. This highlights that very low densities of Palmer amaranth have a significant impact on potential grain sorghum yields.

Palmer amaranth responded to applied N by increasing biomass, whereas grain sorghum, when grown alone, showed no response through grain yield or biomass. Palmer amaranth responded very well to the higher N rates at lower densities, and increased biomass as density increased. Of the three variables measured in grain sorghum, only N concentration showed no differences between Palmer amaranth densities. This could indicate that the Palmer amaranth was not directly depleting N sources to the point that N was a limiting factor for grain sorghum yield. If grain sorghum could take up plenty of soil N, other factors, such as water or sunlight must have been a direct cause of yield loss.

These results improve the understanding of the interactions between Palmer amaranth, grain sorghum and N, when the summer is cooler and wetter than normal. Results from this experiment have provided information on the role that nutrient management plays in crop-weed

competition outcomes. Further research is needed in different environmental conditions to better understand the influential factors of competition.

### **Literature Cited**

- Anderson R. L., L. T. Don, A. L. Black, and E. E. Schweizer. 1998. Weed community and species response to crop rotation, tillage, and N fertility. *Weed Technology* 12:531-536.
- Barker D. C., S. Z. Knezevic, A. R. Martin, D. T. Walters, and J. L. Lindquist. 2006. Effect of nitrogen addition on the comparative productivity of corn and velvetleaf (*abutilon theophrasti*). *Weed Science* 54:354-363.
- Blackshaw R. E., R. N. Brandt, H. H. Janzen, T. Entz, C. A. Grant, and D. A. Derksen. 2003. Differential response of weed species to added nitrogen. *Weed Science* 51:532-539.
- Bonifas K. D. and J. L. Lindquist. 2006. Predicting biomass partitioning to root versus shoot in corn and velvetleaf (*Abutilon theophrasti*). *Weed Science* 54:133-137.
- Carlson H. L. and J. E. Hill. 1986. Wild oat (*Avena fatua*) competition with spring wheat: Effects of nitrogen fertilization. *Weed Science* 34:29-33.
- Casper, B. and R. B. Jackson. 1997. Plant competition underground. *Annual Review of Ecology and Systemics*. 28:545-570.
- Cathcart R. J. and C. J. Swanton. 2003. Nitrogen management will influence threshold values of green foxtail (*Setaria viridis*) in corn. *Weed Science* 51:975-986.
- Chism W. J., J. B. Birch, and S. W. Bingham. 1992. Nonlinear regressions for analyzing growth stage and quinclorac interactions. *Weed Technology* 6:898-903.
- Cousens R. 1985. A simple model relating yield loss to weed density. *Annals of Applied Biology* 107:239-252.



- Deines S. R., J. A. Dille, E. L. Blinka, D. L. Regehr, and S. A. Staggenborg. 2004. Common sunflower (*Helianthus annuus*) and shattercane (*Sorghum bicolor*) interference in corn. *Weed Science* 52:976-983.
- ERS. 2010. U.S. Consumption of Nitrogen, Phosphate, and Potash, 1960-2009. Volume 2011. Available at <<http://www.ers.usda.gov/Data/FertilizerUse/>>.
- Evans, S. P., S. Z. Knezevic, J. L. Lindquist, C. A. Shapiro, and E. E. Blankenship. 2003. Nitrogen application influences the critical period for weed control in corn. *Weed Science* 51:408-417.
- Graaf, M. C. C. D., R. Bobbink, J. G. M. Roelofs, and P. J. M. Verbeek. 1998. Differential effects of ammonium and nitrate on three heathland species. *Plant Ecol.* 135:pp. 185-196.
- Gunsolus, J. L. and D. D. Buhler. 1999. A risk management perspective on integrated weed management. *Journal of Crop Production* 2:167-187.
- Harbur, M. M. and M. D. K. Owen. 2004. Light and growth rate effects on crop and weed responses to nitrogen. *Weed Science* 52:578-583.
- Horak, M. J. and T. M. Loughin. 2000. Growth analysis of four *Amaranthus* species. *Weed Science* 48:347-355.
- Keeley P. E., C. H. Carter, and R. J. Thullen. 1987. Influence of planting date on growth of palmer amaranth (*Amaranthus palmeri*). *Weed Science* 35:199-204.
- King, C. A. and L. C. Purcell. 1997. Interference between hemp sesbania (*sesbania exaltata*) and soybean (*glycine max*) in response to irrigation and N. *Weed Science* 45:91-97.
- Klingaman, T. E. and L. R. Oliver. 1994. Palmer amaranth (*amaranthus palmeri*) interference in soybeans (*glycine max*). *Weed Science* 42:523-527.
- Knezevic S. Z., M. J. Horak, and R. L. Vanderlip. 1997. Relative time of redroot pigweed

- (*Amaranthus retroflexus* L.) emergence is critical in pigweed-sorghum [*Sorghum bicolor* (L.) moench] competition. *Weed Sci.* 45:502-508.
- Leikam D. F., R. E. Lamond, and D. B. Mengel. 2003. Soil test interpretations and fertilizer recommendations. Manhattan, KS: Kansas State University MF-2586.
- Massinga, R. A., R. S. Currie, M. J. Horak, and B. John Jr. 2001. Interference of Palmer amaranth in corn. *Weed Science* 49:202-208.
- Menges, R. M. 1987. Allelopathic effects of Palmer amaranth (*Amaranthus palmeri*) and other plant residues in soil. *Weed Science* 35:339-347.
- Menges, R. M. 1988. Allelopathic effects of Palmer amaranth (*Amaranthus palmeri*) on seedling growth. *Weed Science* 36:325-328.
- Morgan, G. D., P. A. Baumann, and J. M. Chandler. 2001. Competitive impact of palmer amaranth (*Amaranthus palmeri*) on cotton (*Gossypium hirsutum*) development and yield. *Weed Technology* 15:408-412.
- Munger, P. H., J. M. Chandler, J. T. Cothren, and F. M. Hons. 1987. Soybean (*Glycine max*)-velvetleaf (*Abutilon theophrasti*) interspecific competition. *Weed Science* 35:647-653.
- [NASS]. United States Department of Agriculture National Agricultural Statistics Service. 2011. Kansas Crop Production Down from 2009. <http://www.nass.usda.gov/>. (2011)
- Nieto, H. J. and D. W. Staniforth. 1961. Corn-foxtail competition under various production conditions. *Agron. J.* 53:1-5.
- Rowland, M. W., S. M. Don, and L. M. Verhalen. 1999. Full-season Palmer amaranth (*Amaranthus palmeri*) interference with cotton (*Gossypium hirsutum*). *Weed Science* 47:305-309.
- Sauer J. 1957. Recent migration and evolution of the dioecious amaranths. *Evolution* 11:11-31.

- Teyker, R., H. Hoelzer, and R. Liebl. 1991. Maize and pigweed response to nitrogen supply and form. *Plant and Soil* 135:287-292.
- Tucker, A. N. 2009. Managing nitrogen in grain sorghum to maximize N use efficiency and yield while minimizing producer risk. MS Thesis, Department of Agronomy, Manhattan: Kansas State University. 152 p.
- Vanderlip, R. L. 1993. How a sorghum plant develops. Cooperative Extension Service. Contribution no. 1203, Kansas Agricultural Experiment Station, Manhattan, Kansas. .
- Weber, H. S. 2010. Use of Nitrogen Management Products and Practices to Enhance Yield and Nitrogen Uptake in no-Till and Grain Sorghum. MS thesis, Department of Agronomy Manhattan: Kansas State University. 136 p.
- Whitney, D. 1998. Fertilizer Requirements, Grain Sorghum Production Handbook. Available at <http://www.ksre.ksu.edu/library/crps12/c687.pdf>. Accessed 1/16, 2011.
- Zimdahl R. L. 2004. *Weed-Crop Competition: A Review*. : Blackwell Pub. Professional.

## **Figures and Tables**

**Table 2.1 Pre-treatment soil analyses in 2009 near Manhattan, KS.**

Soil Type	pH	NO <sub>3</sub> -N	Mehlich-3 P	K	OM
		----- mg kg <sup>-1</sup> -----			%
Wymore Silty Clay Loam	6.5	8.8	11.7	235	2.1

**Table 2.2 Mean observed weed-free grain sorghum yield and parameter estimates ( $\pm$ SE) based on Equation 2 in Manhattan, KS in 2009.**

N rate	Observed weed-free yield	<i>Parameter estimates</i> *		
		$Y_{wf}$	$I$	$A$
kg ha <sup>-1</sup>	-----kg ha <sup>-1</sup> -----		-----%-----	
0	8046 (677)	8404 (329)	6 (5)	58 (51)
67	8771 (109)	8585 (436)	20 (10)	66 (18)
134	8751 (248)	8846 (548)	23 (11)	83 (24)
Pooled**		8591 (289)	16 (6)	68 (16)

\*  $Y_{wf}$  is weed-free yield,  $I$  is percent yield loss caused by Palmer amaranth as density approaches zero, and  $A$  is asymptotic yield loss at high Palmer amaranth densities.

\*\* Yield is pooled from a lack of difference among N rates.

**Table 2.3 Monthly mean air temperatures and total precipitation for May-October 2009 and 30-year normal (1971-2000) at Manhattan, KS.**

Month	Temperature (C)		Precipitation (mm)	
	2009	Normal	2009	Normal
May	18	18.3	11.7	129.0
June	23.7	23.7	207.0	132.8
July	23.1	26.6	128.3	104.1
August	22.9	25.6	135.1	83.1
September	18.4	20.4	46.0	93.2
October	9.5	13.9	59.4	70.4
Total			587.5	612.6

**Table 2.4 Mean observed weed-free grain sorghum vegetative biomass and parameter estimates ( $\pm$ SE) based on Equation 2 in 2009.**

N rate	Observed weed-free biomass	<i>Parameter estimates*</i>		
		<i>Y<sub>wf</sub></i>	<i>I</i>	<i>A</i>
kg ha <sup>-1</sup>	-----g m <sup>-1</sup> of row-----		-----%-----	
0	632 (10)	643 (25)	6 (5)	18 (7)
67	702 (24)	703 (36)	18 (13)	43 (12)
134	675 (25)	665 (24)	13 (8)	36 (10)
Pooled**		671 (17)	15 (7)	32 (5)

\**B<sub>wf</sub>* is weed-free biomass, *I* is percent biomass loss caused by Palmer amaranth as density approaches zero, and *A* is asymptotic biomass loss at high Palmer amaranth densities.

\*\* Vegetative biomass is pooled from a lack of difference among N rates.



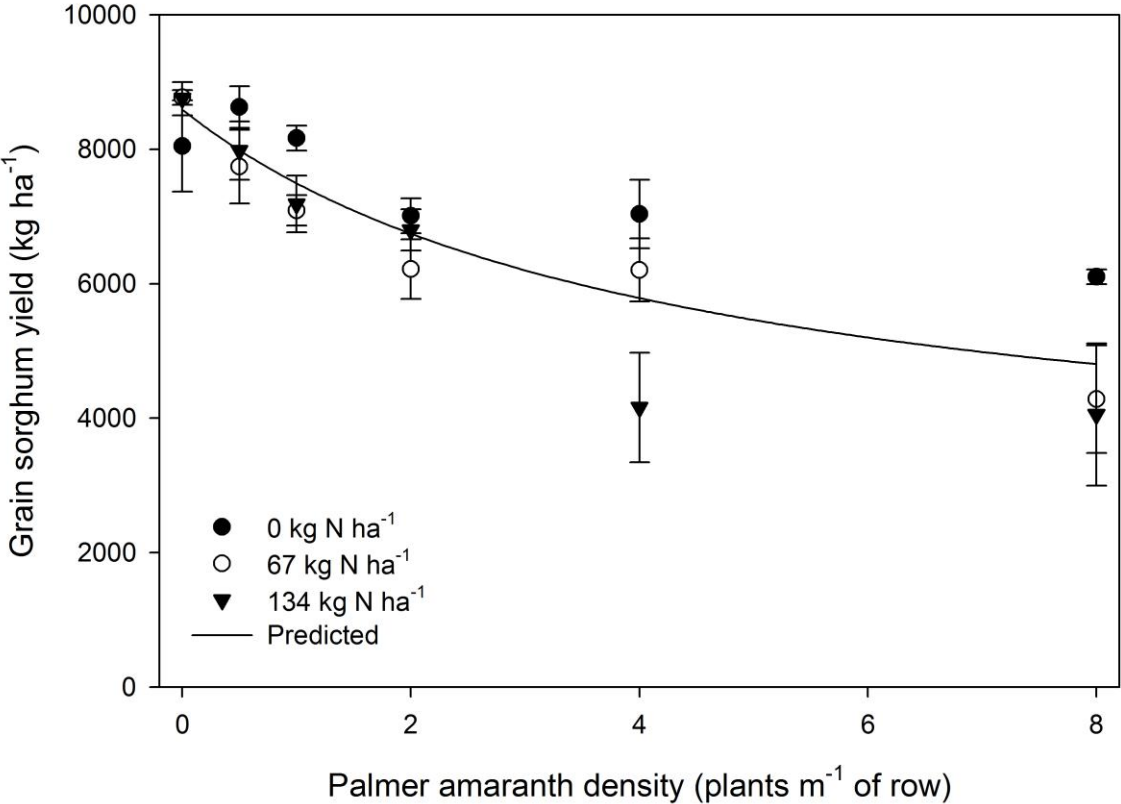
**Table 2.5 Palmer amaranth biomass parameter estimates ( $\pm$ SE) from equation 1.**

<i>Parameter estimates<sup>a</sup></i>		
N rate	<i>C</i>	<i>E</i>
kg ha <sup>-1</sup>	-----g m <sup>-1</sup> of row-----	
0	138 (46)	869 (335)
67	354 (108)	591 (91)
134	532 (167)	841 (129)
0 and 67 <sup>b</sup>	*	NS
67 and 134	NS	NS
0 and 134	*	NS

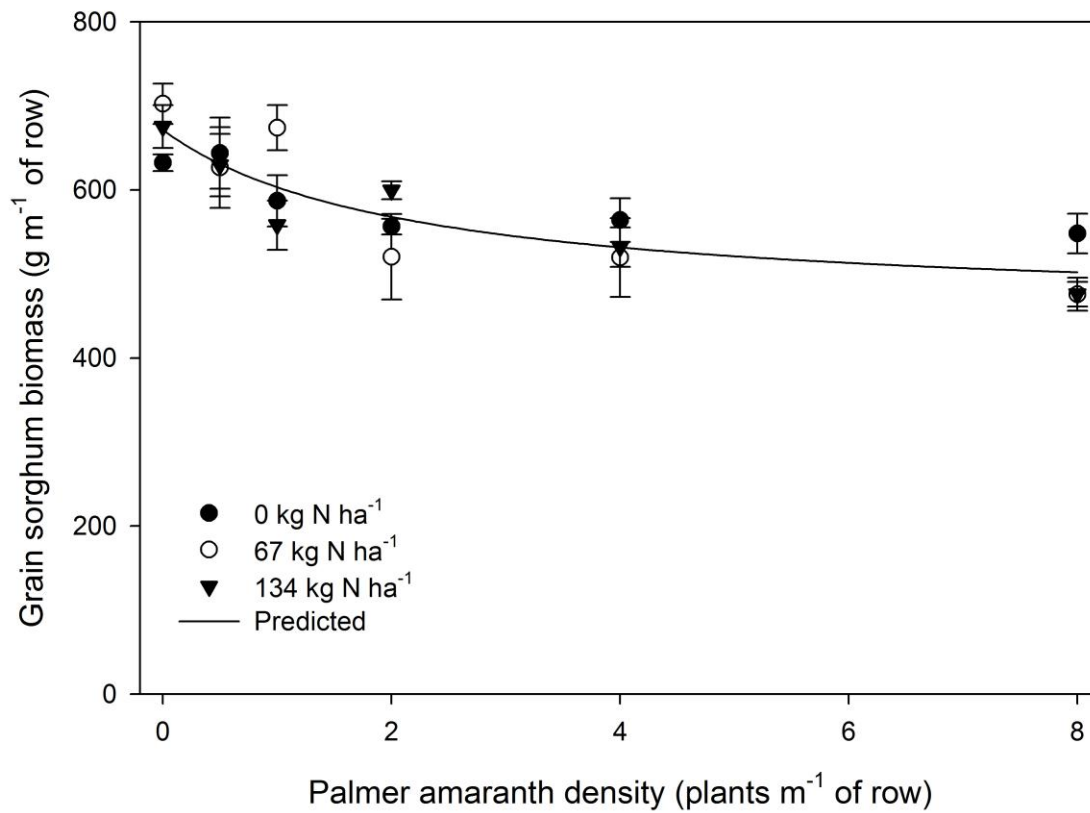
<sup>a</sup> *C* is percent biomass as density of Palmer amaranth approaches zero, and *E* is asymptotic biomass at high Palmer amaranth densities.

<sup>b</sup> Comparisons of significance ( $\alpha=0.05$ ) between N rates. NS indicates no difference and \* indicates significant difference.

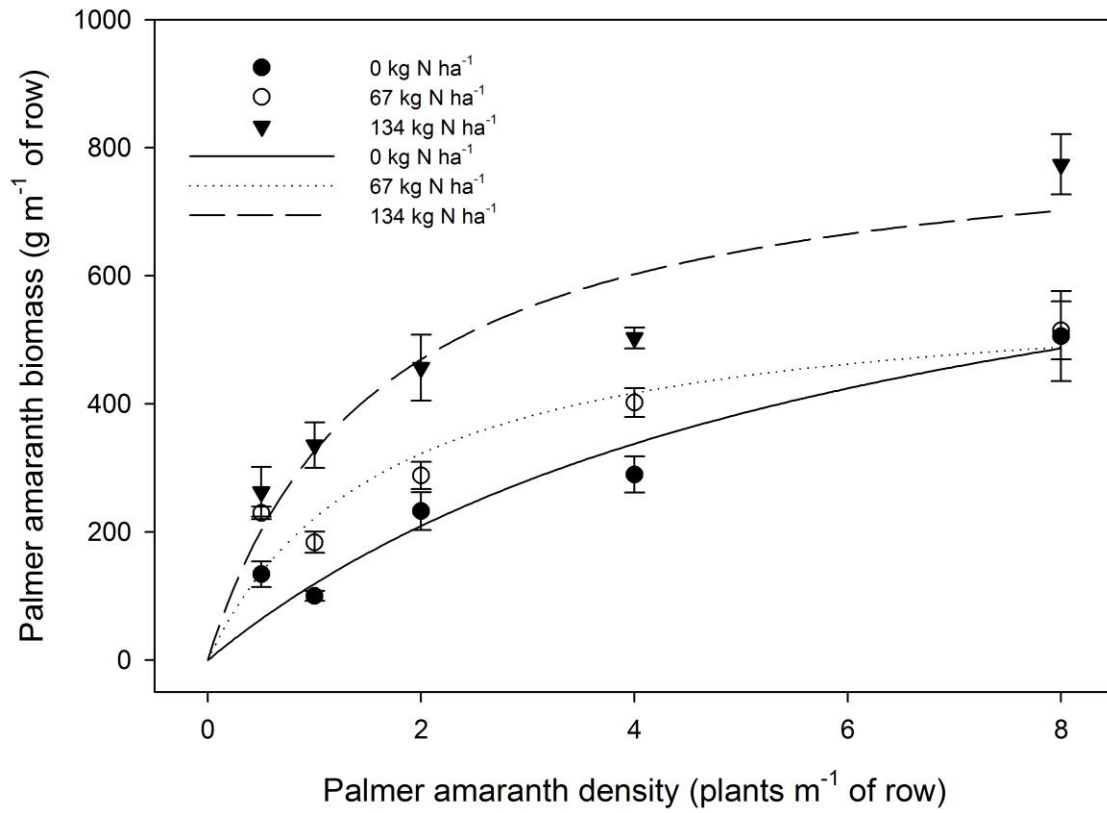
**Figure 2.1** Observed and predicted grain sorghum yield as a function of increasing Palmer amaranth densities and N rates at Manhattan, KS in 2009. Symbols are the means of four replications, and the line is the result of fitting Equation 2 to the data. Refer to table 2.2 for parameter estimates.



**Figure 2.2** Observed and predicted grain sorghum aboveground vegetative biomass as a function of increasing Palmer amaranth densities and N rates on September 15 in Manhattan, KS in 2009. Symbols represent means and standard errors of four replications and the line represents a fit of Equation 2 to the data. Refer to Table 2.4 for parameter estimates.



**Figure 2.3** Observed and predicted Palmer amaranth biomass at physiological maturity as a function of increasing Palmer amaranth densities and N rates on September 25 at Manhattan, KS in 2009. Symbols represent the mean and standard error of four replications and lines represent the fit of Equation 1 to the data. Refer to Table 2.5 for parameter estimates.



# Chapter 3 - Nitrogen Rate Effects on Crop and Weed Species Growth

## Abstract

Nitrogen (N) fertilization could be used in an integrated weed management (IWM) program to decrease the competitive ability of weeds or to increase that of a crop. Understanding how certain species react to N is critical in this kind of strategy. A greenhouse experiment was conducted to determine the influence of six N rates on growth of six selected plant species. Grain sorghum (*Sorghum bicolor* (L.) Moench), soybean (*Glycine max* L. Merr.), yellow foxtail (*Setaria pumila* (Poir.) Roem. & Schult.), velvetleaf (*Abutilon theophrasti* Medik.), Palmer amaranth (*Amaranthus palmeri* S. Wats.), and shattercane (*Sorghum bicolor* (L.) Moench) were grown separately in response to six rates of N including 0, 56, 112, 168, 224, and 280 mg kg<sup>-1</sup> and the experiment was repeated. Aboveground biomass was determined six weeks after emergence. Plant height and leaf area were also determined during the second run of the study. Covariance analysis was performed with applied N as a covariate. Biomass of all species increased as N rate increased in both runs, however, the magnitude of the biomass increase and the shape of the estimated response curves varied among plant species. Soybeans responded the least to N rate of all species in the three variables tested. In the first run, the biomass of three grass species (grain sorghum, yellow foxtail, shattercane) had similar estimates of slope and intercept of biomass across N rates. In the second run, the biomass slopes of grain sorghum and shattercane differed from soybean and were the only slopes that differed between species. Soybean leaf area slopes were different from grain sorghum, yellow foxtail, and velvetleaf, but all other slopes were similar among species. Height of Palmer amaranth had the

highest intercept, or rate of response as N increased to a maximum, but slopes of height were similar for Palmer amaranth, grain sorghum and shattercane.

## Introduction

Applications of N fertilizer are aimed at increasing crop productivity but more attention is being focused on understanding how weed species respond differently to N and the effect on crop-weed interactions in the field. In the presence of highly responsive weeds to soil N, N could be used in an IWM program as a management tool through modifying rates, forms of N applied, or methods of application (Blackshaw and Brandt, 2008).

Interactions of crops and weeds with N are complex and can widely vary depending on the species. Crop and weed species with high relative growth rates in high N soils have greater decreases in relative growth rate in low N soils (Harbur and Owen, 2004a). The way in which N influences the emergence of weeds is dependent on weed species (Sweeney et al., 2008). Of 23 species tested, 15 weed species exhibited greater shoot biomass response to N than wheat (*Triticum aestivum* L.) and 10 species showed similar responses to canola (*Brassica napus* L.) (Blackshaw et al., 2003). In low N soils, plants grown from smaller seeds were less competitive, but where N levels were high plants from small seeds and large seeds were similar in competitive abilities (Tungate et al., 2006).

Nitrogen fertilizer is an important economic input and is vitally important to maximize yields in non-leguminous crops. Nitrogen is needed for many important processes within the plant including chlorophyll production, proteins, and enzyme reactions (Brady and Weil, 2003). Nitrogen not only benefits crops but weeds can take up large amounts of N, which decreases availability to the crop. Weed growth is also highly dependent upon soil N (Blackshaw et al.,

2003) as well as the weed species present (Blackshaw and Brandt, 2008). Management of N to give an advantage to the crop may be a way to lessen the impacts of weeds on the crop.

Although, a single approach model of N management will not be sufficient enough to account for all the weed species. Information of the effects of N on specific weed species in a region is important in a weed and fertilizer management program. Strategies using N fertilizer that could improve crop competitiveness include timing of applications, placement, row spacing, improving N use efficiency through cultivar selection, and source of N. Effectiveness of these strategies though, depends on how weeds will respond, which is dependent on the species present.

Two crops that are grown on many acres in Kansas were used in the experiment. In 2009, 1.01 million hectares of grain sorghum and 1.36 million hectares of soybeans were harvested in Kansas (NASS, 2011). The four weed species in the experiment are commonly found growing among field crops in parts of Kansas. Two grass and two broadleaf species were chosen for the experiment. Since they are often found in fields that are fertilized, a large positive response to N is expected. Little information has been published about Palmer amaranth response to N. Effects of N have been studied in another *Amaranthus* species, redroot pigweed (*A. retroflexus* L.) (Blackshaw and Brandt 2008; Blackshaw et al. 2003). When competing with wheat, N uptake and shoot biomass of redroot pigweed increased as N rate increased (Blackshaw and Brandt 2008). Corn (*Zea mays* L.) dry weight increased 1.6 times at the high N rate compared to the zero rate, whereas redroot pigweed increased by 4.4 times (Teyker et al. 1991) Palmer amaranth, which has more biomass and higher relative growth rate than redroot pigweed (Horak and Loughin, 2000), may respond even more to N. Others have reported the effects of N on velvetleaf (Harbur and Owen, 2004b). Including velvetleaf in this study would allow comparisons to be made. With limited N supply velvetleaf partitions more biomass to roots than

shoots compared to corn, but at higher N levels velvetleaf partitions more biomass to shoots compared to corn. This could make corn a better competitor for light at low N levels and velvetleaf better at higher N rates (Bonifas et al., 2005). Velvetleaf responded more than corn in height, leaf area index and biomass production with all N application rates. Velvetleaf may be more competitive at high N levels. In the presence of velvetleaf at a similar growth stage as corn, yield loss in corn increased with increasing N levels (Barker et al., 2006). Additional N fertilization increased the ability of corn to compete with weeds early in the season (Evans et al., 2003). Shattercane is a troublesome weed in grain sorghum but is not well understood how it reacts to N and if it would be different than sorghum. At a high density, while competing with corn, shattercane accumulated 38 kg ha<sup>-1</sup> of N when allowed to reach 46 cm in height (Hans and Johnson 2002). When comparing among five *Setaria* spp., Schreiber and Orwick (1978) found yellow foxtail produced the most leaf area at all N levels. Root biomass of yellow foxtail was also highest at the low N levels. O'Donovan et al. (1997) found that green foxtail (*Setaria viridis* (L.) Beauv.) and field pennycress (*Thlaspi arvense* L.) appeared most often in areas with low soil N, but decreased in number where soil N levels were higher, indicating that foxtail species in general may respond little to N.

With increasing N, the broadleaves were expected to respond more with increased dry weight, height and leaf area than the grasses. Since soybean is a legume, it as expected to respond the least. The objective of this research was to determine the effects of N on dry weight, height and leaf area of certain weed species in comparison to crops.

## **Materials and Methods**

A greenhouse experiment was conducted to determine the influence of N on growth of selected crop and weed species. The split-block design contained six plant species as the sub-



plot, including grain sorghum, soybean, yellow foxtail, velvetleaf, Palmer amaranth and shattercane were grown at six rates of N as the whole plots including 0, 56, 112, 168, 224, and 280 mg kg<sup>-1</sup>, with each tray containing pots at the same N level. The experiment was conducted twice with each of the treatments being replicated five times.

Each treatment was established in separate pots, which measured 15.25 cm in diameter across the top and 14.5 cm tall. The containers had holes for drainage and filter paper was placed on the bottom to prevent soil loss. Soil mixed with sand was steamed and allowed to dry before being placed into the pots. Pots were placed in metal trays that were filled with water; this allowed for similar uptake of water for each pot in a tray. Urea-ammonium nitrate was mixed with water and a syringe was used to deliver rates of N fertilizer to the surface of the soil. The pots with equivalent amounts of N were placed in the same trays to avoid transfer of fertilizer through the water from high N concentrations to low N concentrations and vice versa. Seeds of each species were planted shallow into moist soil and water was continually added to the trays as sub-irrigation throughout the experiment. Within three to four days after emergence, the plants were evenly thinned to six plants per container. Conditions of the greenhouse were 33/25 C day/night temperature and 14/10 day/night photoperiod.

The first run was established on October 15, 2010 and biomass was the only response variable measured. Six weeks after emergence in the first run, the aboveground biomass was cut and placed in paper bags. Palmer amaranth and velvetleaf were not tested in the first run because of a low survival rate. Samples were dried and subsequently weighed for dry biomass.

The second run was established on January 10, 2011. Plant height was recorded four and six weeks after emergence by measuring extended leaf height of each of the six plants and calculating the average per pot. Aboveground biomass was determined six weeks after

emergence by removing plants at the soil surface, separating leaves from stems, and leaf area was determined using a LI-COR 3100 area meter (LI-COR Biosciences, 4647 Superior Street Lincoln, NE 68504-0425). Stems and leaves were combined and placed in paper bags that were dried to a constant weight and dry biomass was determined.

Data were analyzed based on percentage of response (transformed), since species were very different in their response to increasing N. Aboveground biomass produced by each plant species was transformed by the percent increase in aboveground biomass from the 0 N dose to the highest N dose at which maximum biomass occurred to permit valid statistical comparisons among species that varied considerably in their biomass production (as done by Blackshaw et al., 2003). The transformed data was calculated using the following equation:

$$B_{ij} = ((\max_i - \text{var}_{ij}) / (\max_i)) * 100$$

Where  $\max_i$  is average maximum biomass, leaf area, or height for a given species ( $i$ ),  $\text{var}_{ij}$  is individual plant biomass, leaf area, or height for a given species ( $i$ ) at a given N rate, and  $B_{ij}$  is transformed biomass, leaf area, or height as a percent of maximum biomass, leaf area, or height, respectively.

Transformed aboveground biomass variables give a measure of the responsiveness of each species to increasing N doses relative to its own maximum biomass production. This modification was also done with leaf area and plant height to measure responsiveness. Plant species and N rate were included as main effects and their interaction in the statistical analyses done with PROC GLM (SAS Version 9.1.3 SAS Institute Inc. SAS Campus Drive, Cary, NC 27513). Analysis of covariance was performed for each variable using a linear and quadratic term of applied N as a covariate. These analyses were performed in an attempt to quantify the

response of each species to increasing N doses. Within each variable, the parameter estimates of each species' slope and intercept were compared to find differences among species.

## **Results and Discussion**

Aboveground biomass (transformed) was different between the two runs; thus each run was analyzed separately. In run one, only four plant species were included in the analysis (grain sorghum, soybean, yellow foxtail, and shattercane) while six plant species were included in run two. Analysis of covariance indicated that the relationship between N rate and aboveground biomass could be modeled using a quadratic equation. All plant species increased biomass as N rate increased in both runs. However, the magnitude of the biomass increase and the shape of the response curves varied among plant species. A significant interaction between N rate and plant species was detected in the first run, but not in the second run of the greenhouse experiment. These results indicated that in the first run, at least one of the plants responded differently to increasing N rate, but in the second run, all plants responded the same to increasing N rate. In the second run, the main effect of plant species was significant, whereas the main effect of N rate was not significant, such that each plant species influenced the differences in the biomass response but N rate had very little influence in the differences among the transformed biomass responses.

The intercept represents the greatest percent increase in biomass, leaf area, or height from the 0 N rate to the highest N rate. The slope represents the degree to which biomass, leaf area, or height of the species responds at each addition of N. High N response by the species was indicated in the graphs by a large negative slope and a large y-intercept, whereas low response to increasing N was shown by a small negative slope and a small y-intercept. In response to N, soybean had the lowest percent biomass increase (smallest negative slope and y-intercept) of all

the species in both runs (Figure 3.1; Figure 3.2). In the first run, the three grass species (grain sorghum, yellow foxtail, shattercane) were similar in slope and intercept across all of the rates, with soybeans differing from all three species (Figure 3.1). Velvetleaf and Palmer amaranth were included in the second run of the experiment. The biomass in the second run, like the first run, of yellow foxtail and shattercane were not different in their slope from grain sorghum but in comparison with Palmer amaranth, it too was not different from grain sorghum (Figure 3.2). Grain sorghum, Palmer amaranth, yellow foxtail, and shattercane have a steep slope and higher degree of response to increasing N rate compared to soybean. Unlike the first run, biomass of soybean was similar to yellow foxtail, and also to Palmer amaranth and velvetleaf in degree of response in the second run. This group that is similar to soybean biomass had the lowest degree of response to N. The slope of yellow foxtail and Palmer amaranth were not different from any other species. In the second run, grain sorghum had similar intercepts to yellow foxtail, shattercane, and Palmer amaranth for biomass. This group had a greater intercept, representing greater percent biomass with maximum N than soybeans and velvetleaf, which had similar intercepts.

Leaf area per pot was only measured in the second run. Analysis of covariance indicated that the relationship between N rate and leaf area (transformed) could be modeled using a quadratic equation. Leaf area increased as N rate increased for all species, although the shape of the response curves and the scale of leaf area increase were different for all species (Figure 3.3). Plant species as a main effect was the only part of the model that was significant. The main effect N rate did not significantly influence the model as did the interaction between plant species and N rate. This indicates that each plant responds similarly to N rate and that the plant species is the most important factor in production of leaf area. The leaf area of yellow foxtail,

Palmer amaranth, shattercane, and velvetleaf were not different in their slope from grain sorghum (Figure 3.3). Grain sorghum, yellow foxtail, and velvetleaf have a steep slope and higher degree of response to increasing N rate compared to soybean. Leaf area of soybeans was similar to Palmer amaranth and shattercane in degree of response. This group that is similar to soybean leaf area had the lowest degree of response to N. The slope of shattercane and Palmer amaranth were not different from any other species. Grain sorghum had similar intercepts to velvetleaf, shattercane, and Palmer amaranth for leaf area. This group had a greater intercept, representing greater percent leaf area with maximum N than soybeans, which had a different intercept than the other five species. The greatest intercepts were in the group of yellow foxtail, which was only similar to velvetleaf.

Plant heights were also measured in the second run. Analysis of covariance indicated that the relationship between N rate and plant height (transformed) could be modeled using a quadratic equation. As expected, plant heights increased as N rate increased for all species, but variation occurred between the shape of the response curves and magnitude of the plant heights (Figure 3.4). The plant species by N rate interaction was significant for plant heights. These results suggest that each plant responds differently to N rate, which can also be seen visually by comparing the slopes of the curves of the plant species in response to N rate. Plant species was the only significant effect. In this experiment, species of plant was more of a contributing factor to variations in height than N rate. The height of soybean, Palmer amaranth, and shattercane were not different in their slope from grain sorghum (Figure 3.4). Palmer amaranth had a steep slope and higher degree of response to increasing N rate compared to soybean, yellow foxtail, and velvetleaf. Height of soybean was similar to grain sorghum, yellow foxtail, velvetleaf, and shattercane in degree of response. Yellow foxtail height had the lowest degree of response to N

and was similar to soybean, velvetleaf, and shattercane. The slope of shattercane was not different from any other species. Grain sorghum had similar intercepts to velvetleaf and shattercane for height. The intercept of soybeans were similar to yellow foxtail and velvetleaf for height. Palmer amaranth was different from the other species and had the greatest intercept, representing greater percent height with maximum N than the other five species.

Soybean was expected to exhibit low response to N rate, since soybeans can use biological N<sub>2</sub> fixation if soil N is lacking, in which they did by responding the least in every response variable (Figures 3.5 to 3.8). Although velvetleaf is a broadleaf that utilizes the C<sub>3</sub> photosynthetic pathway and yellow foxtail, a C<sub>4</sub> grass, they were not significantly different in their degree of response to N or percent response with maximum N for biomass, leaf area, and height. Shattercane and grain sorghum are related and both were not significantly different in their degree of response to N or percent response with maximum N for biomass, leaf area, and height. Compared to others, Palmer amaranth responded to N in height more so than it did in leaf area or biomass (Figure 3.8). This may be an important advantage for Palmer amaranth if it can use its height to stay above the canopy and continue to capture sunlight, allowing it to be competitive later in the season. Besides the high response in height to N by Palmer amaranth, grain sorghum and Palmer amaranth were comparable in response to N with leaf area and biomass (Figures 3.5 to 3.8). Variables in this study were measured in the relatively short time of 6 weeks after emergence, so longer studies are needed to understand how these responses to N would change.

## Literature Cited

- Barker D. C., S. Z. Knezevic, A. R. Martin, D. T. Walters, and J. L. Lindquist. 2006. Effect of nitrogen addition on the comparative productivity of corn and velvetleaf (*Abutilon theophrasti*). *Weed Science* 54:354-363.
- Blackshaw R. E. and R. N. Brandt. 2008. Nitrogen fertilizer rate effects on weed competitiveness is species dependent. *Weed Science* 56:743-747.
- Blackshaw R. E., R. N. Brandt, H. H. Janzen, E. Toby, C. A. Grant, and D. A. Derksen. 2003. Differential response of weed species to added nitrogen. *Weed Science* 51:532-539.
- Bonifas K. D., D. T. Walters, K. G. Cassman, and J. L. Lindquist. 2005. Nitrogen supply affects root:shoot ratio in corn and velvetleaf (*Abutilon theophrasti*). *Weed Science* 53:670-675.
- Brady N. C. and R. R. Weil. 2003. Elements of the nature and properties of soils. 2<sup>nd</sup> ed.: Prentice Hall. Pp. 624.
- Evans S. P., S. Z. Knezevic, J. L. Lindquist, C. A. Shapiro, and E. E. Blankenship. 2003. Nitrogen application influences the critical period for weed control in corn. *Weed Science* 51:408-417.
- Hans S. R. and W. G. Johnson. 2002. Influence of shattercane [*Sorghum bicolor* (L.) Moench.] interference on corn (*Zea mays* L.) yield and nitrogen accumulation. *Weed Technology* 16:787-791.
- Harbur M. M. and M. D. K. Owen. 2004a. Light and growth rate effects on crop and weed responses to nitrogen. *Weed Science* 52:578-583.
- Harbur M. M. and M. D. K. Owen. 2004b. Response of three annual weeds to corn population density and nitrogen fertilization timing. *Weed Science* 52:845-853.

- Horak M. J. and T. M. Loughin. 2000. Growth analysis of four *Amaranthus* species. *Weed Science* 48:347-355.
- [NASS]. United States Department of Agriculture National Agricultural Statistics Service. 2011. Kansas Crop Production Down from 2009. <http://www.nass.usda.gov/>. (2011)
- O'Donovan J. T., D. W. McAndrew, and A. G. Thomas. 1997. Tillage and nitrogen influence weed population dynamics in barley (*Hordeum vulgare*). *Weed Technology* 11:502-509.
- Schreiber M. M. and P. L. Orwick. 1978. Influence of nitrogen fertility on growth of foxtail (*Setaria*) taxa. *Weed Science* 26:547-550.
- Sweeney A. E., K. A. Renner, C. Laboski, and A. Davis. 2008. Effect of fertilizer nitrogen on weed emergence and growth. *Weed Science* 56:714-721.
- Teyker R., H. Hoelzer, and R. Liebl. 1991. Maize and pigweed response to nitrogen supply and form. *Plant and Soil* 135:287-292.
- Tungate K. D., M. G. Burton, D. J. Susko, M. S. Shannon, and T. W. Rufty. 2006. Altered weed reproduction and maternal effects under low-nitrogen fertility. *Weed Science* 54:847-853.

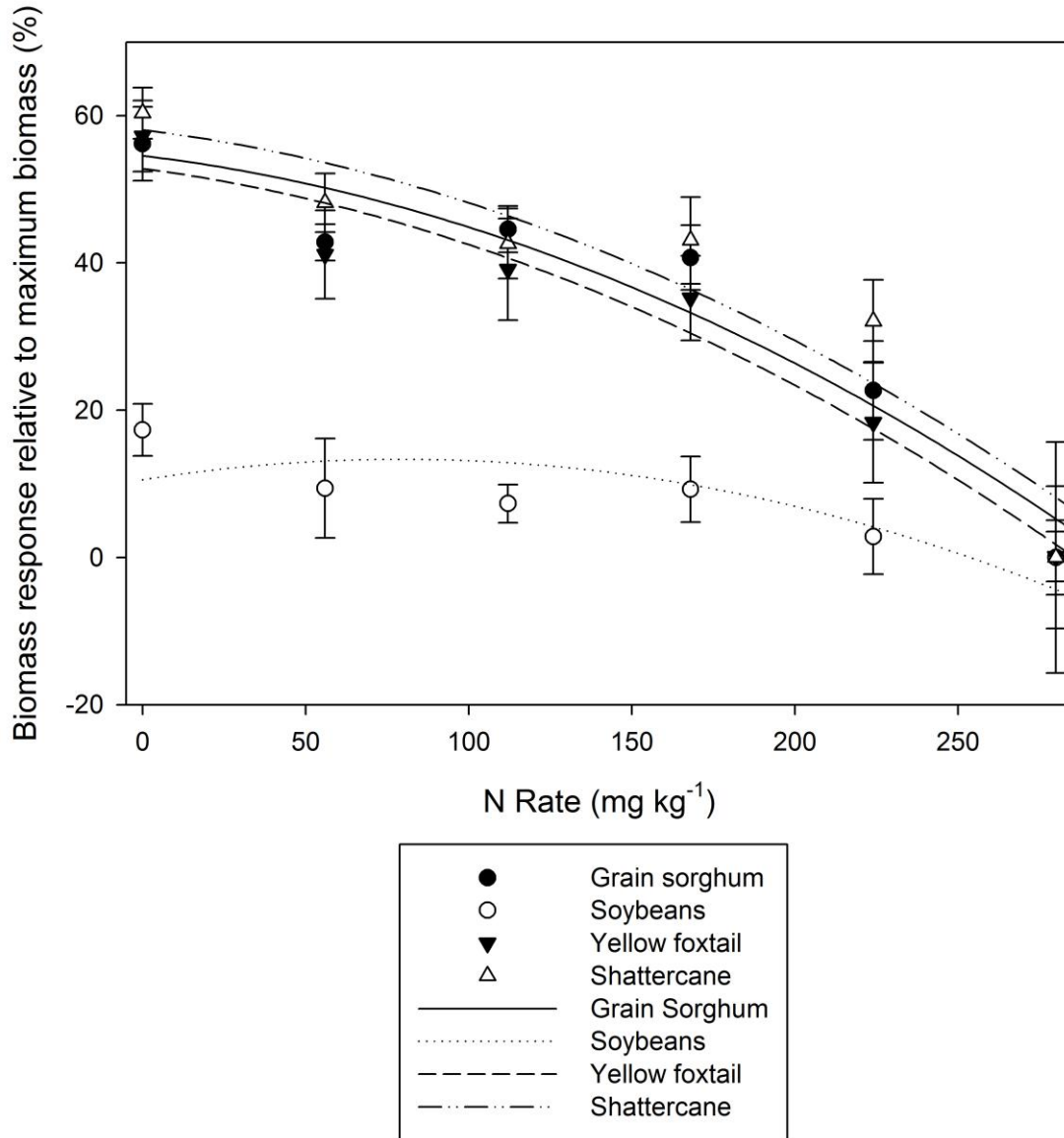


## **Figures and Tables**

**Table 3.1 Pre-treatment soil analyses in greenhouse.**

Run	pH	Mehlich P	K	Ca	Mg	Na	NH <sub>4</sub> -N	NO <sub>3</sub> -N	Fe	Zn	OM
-----mg kg <sup>-1</sup> -----											
1	8.1	39.6	262	3079	114	25	17.8	16.1	3.0	0.7	1.5
2	7.9	41.6	266	3129	117	24	13.4	16.8	3.4	0.8	1.6

**Figure 3.1 Biomass response (%) relative to maximum biomass observed as a function of increasing N rates of Run 1.**



**Figure 3.2 Biomass response (%) relative to maximum biomass observed as a function of increasing N rates of Run 2.**

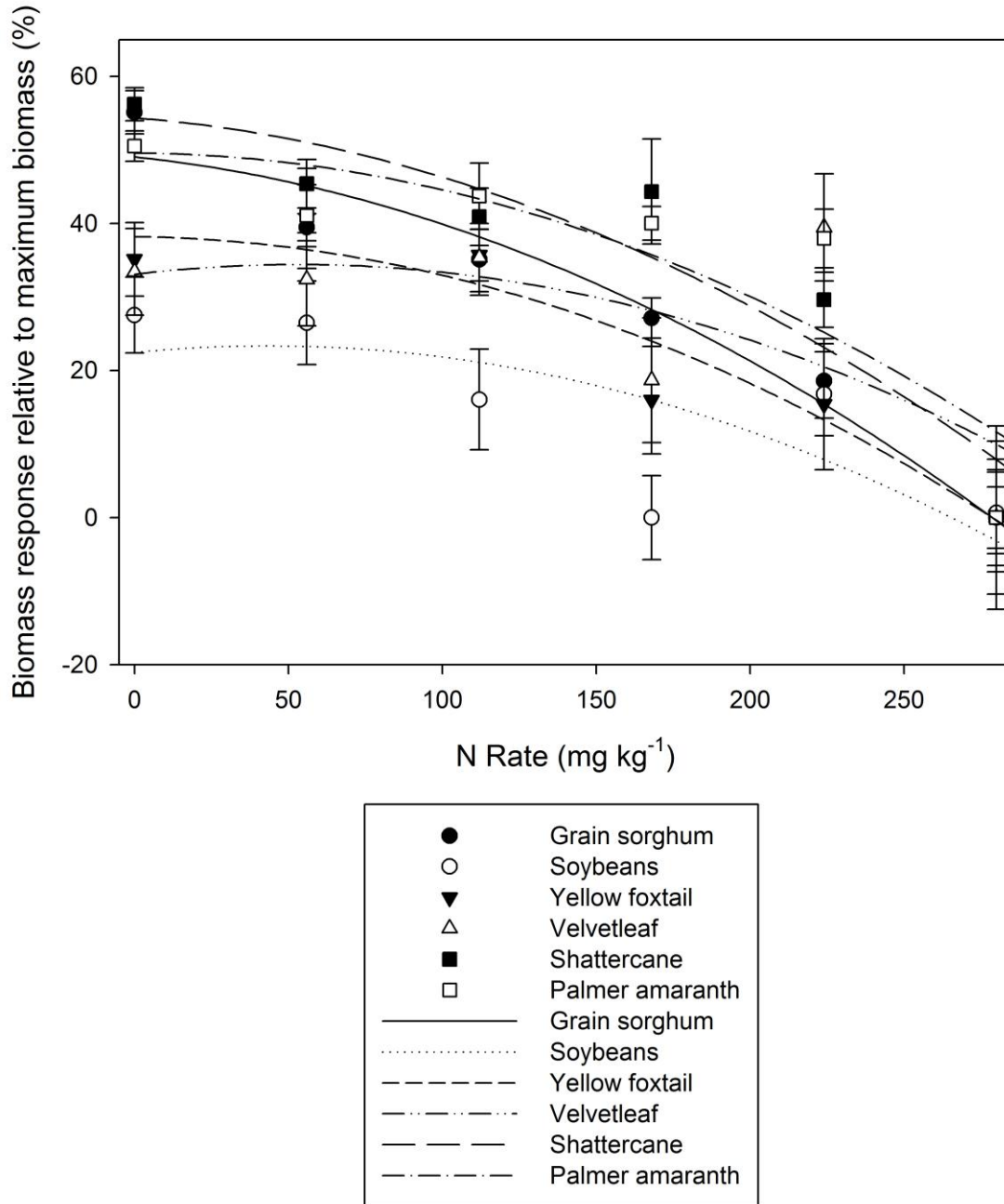
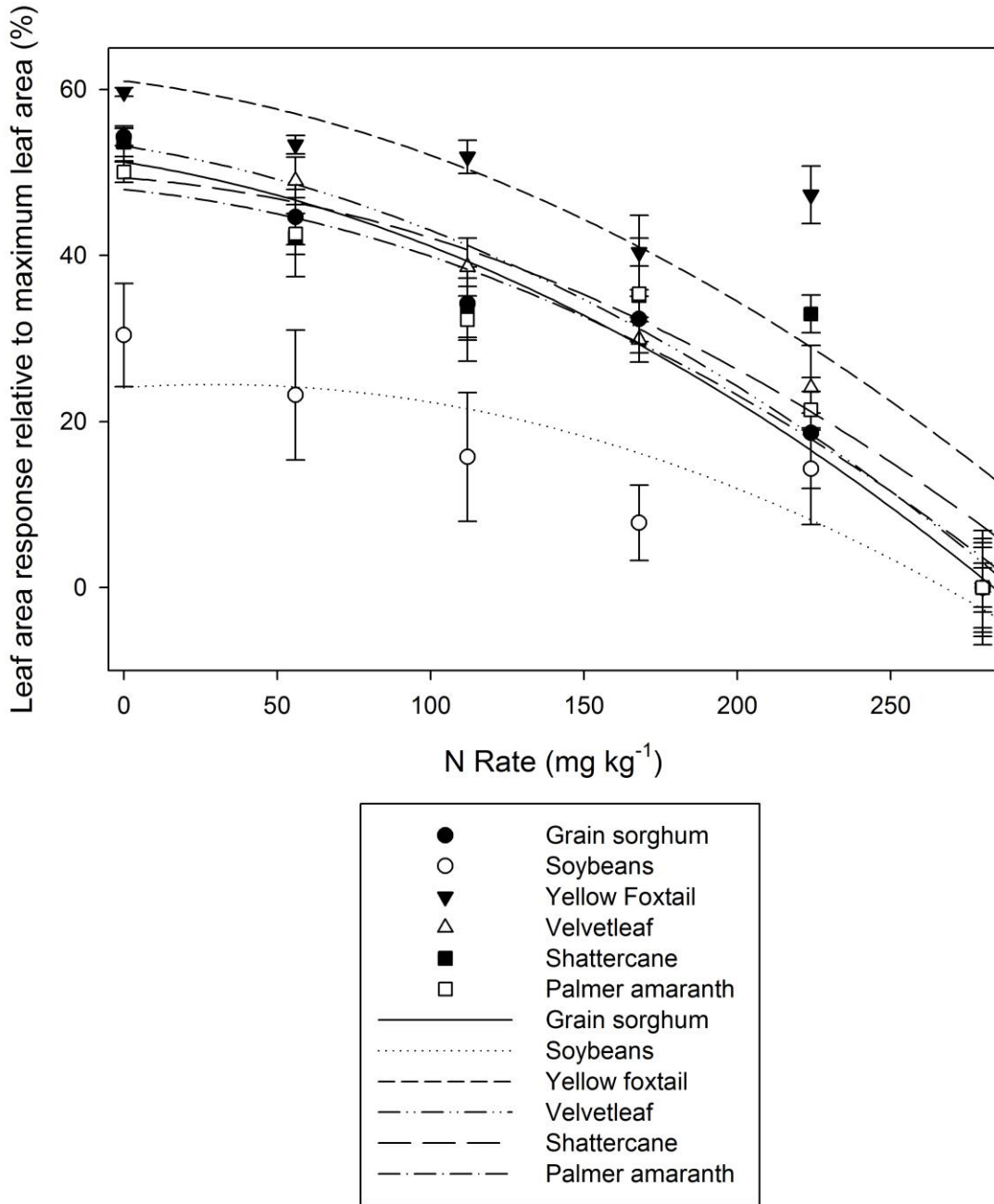
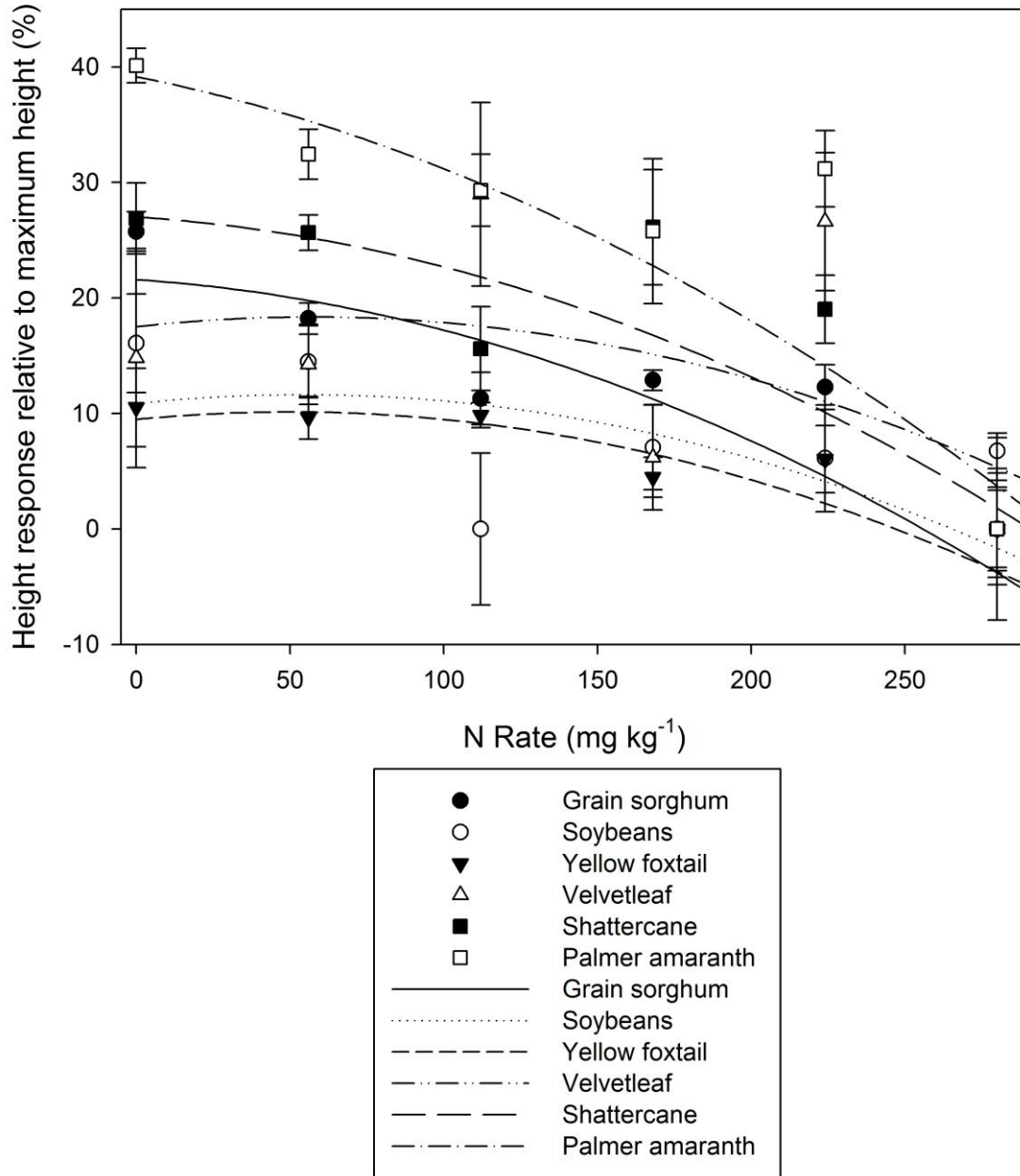


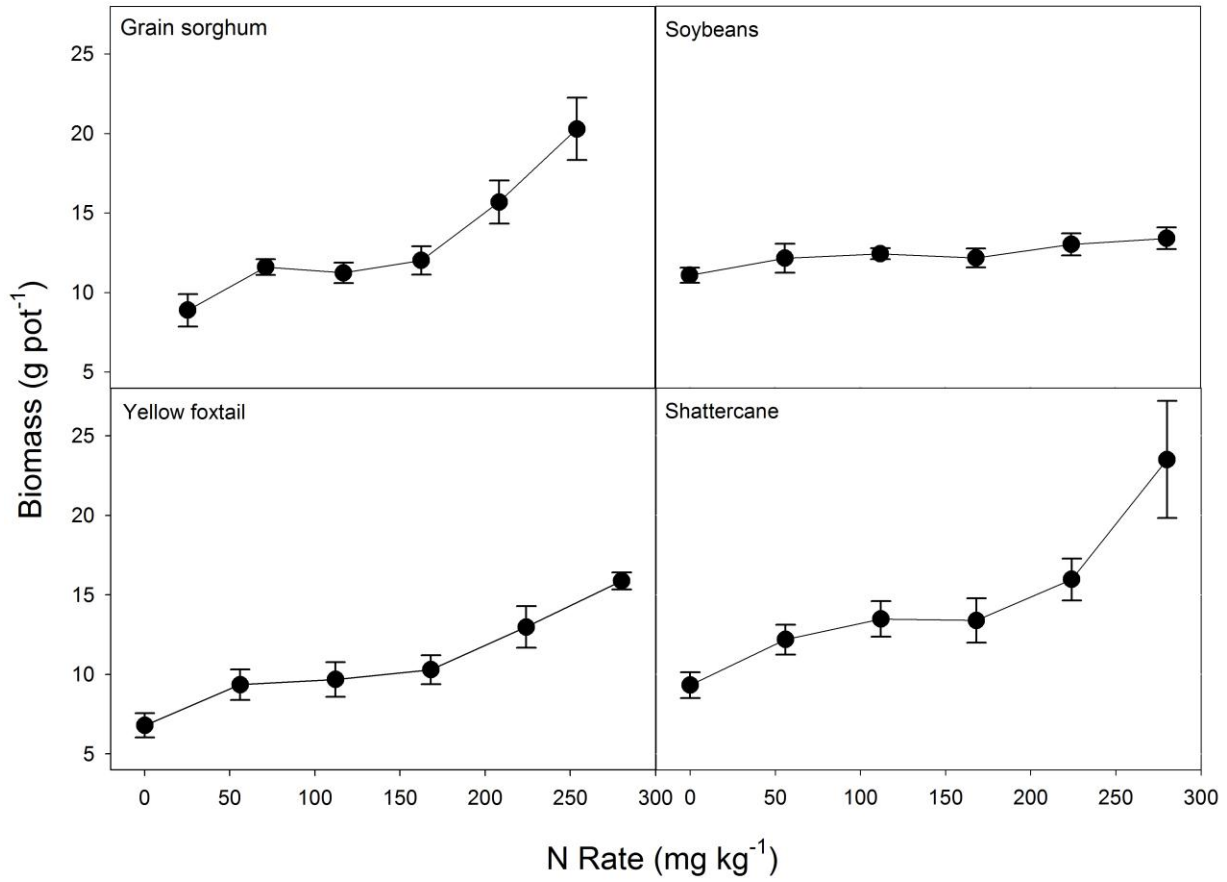
Figure 3.3 Leaf area response (%) relative to maximum leaf area observed as a function of increasing N rates of Run 2.



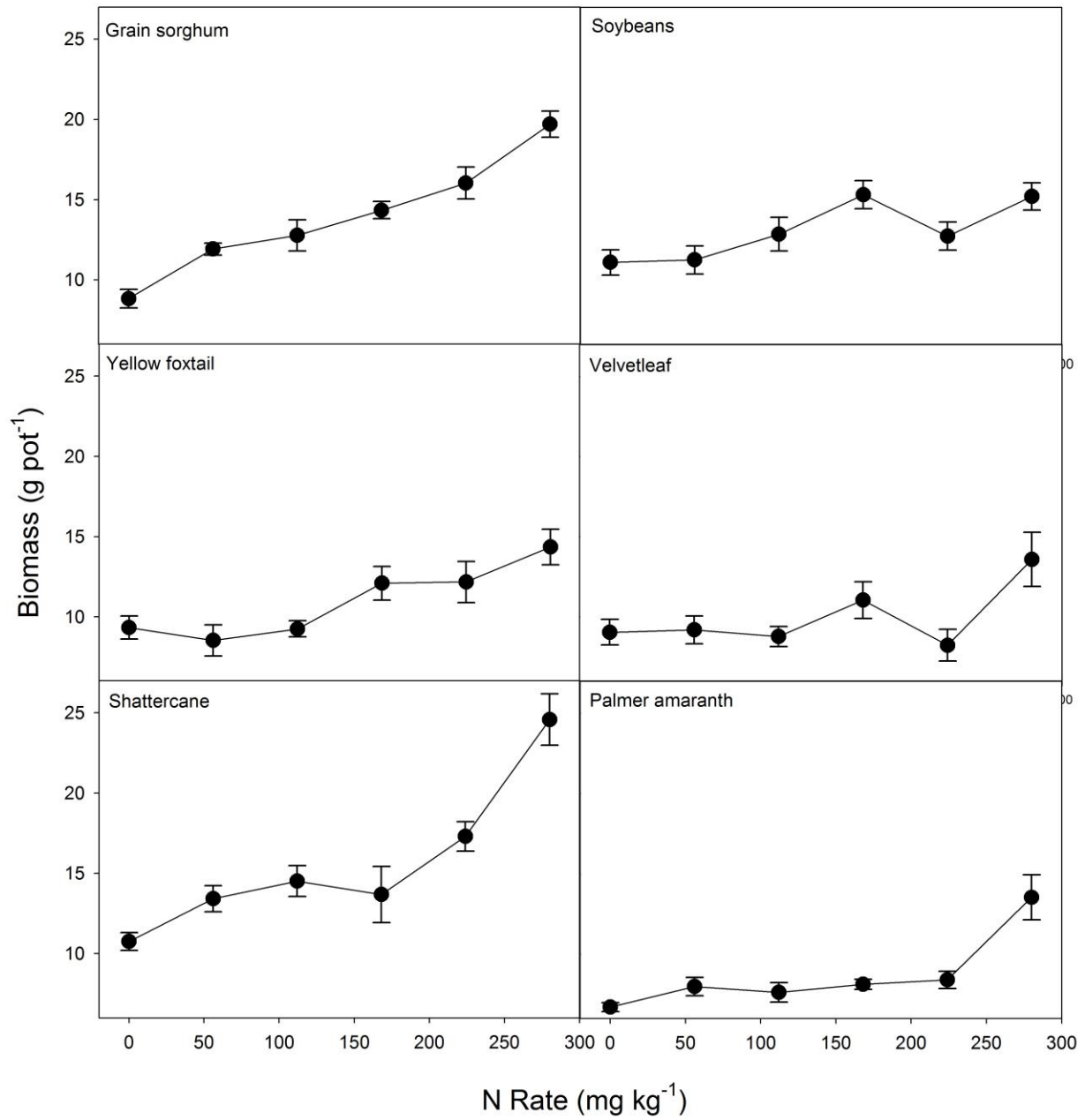
**Figure 3.4 Height response (%) relative to maximum height observed as a function of increasing N rates of Run 2.**



**Figure 3.5 Observed aboveground biomass ( $\text{g pot}^{-1}$ ) as a function of N rate for each of six weed species after 6 weeks of growth of run 1.**

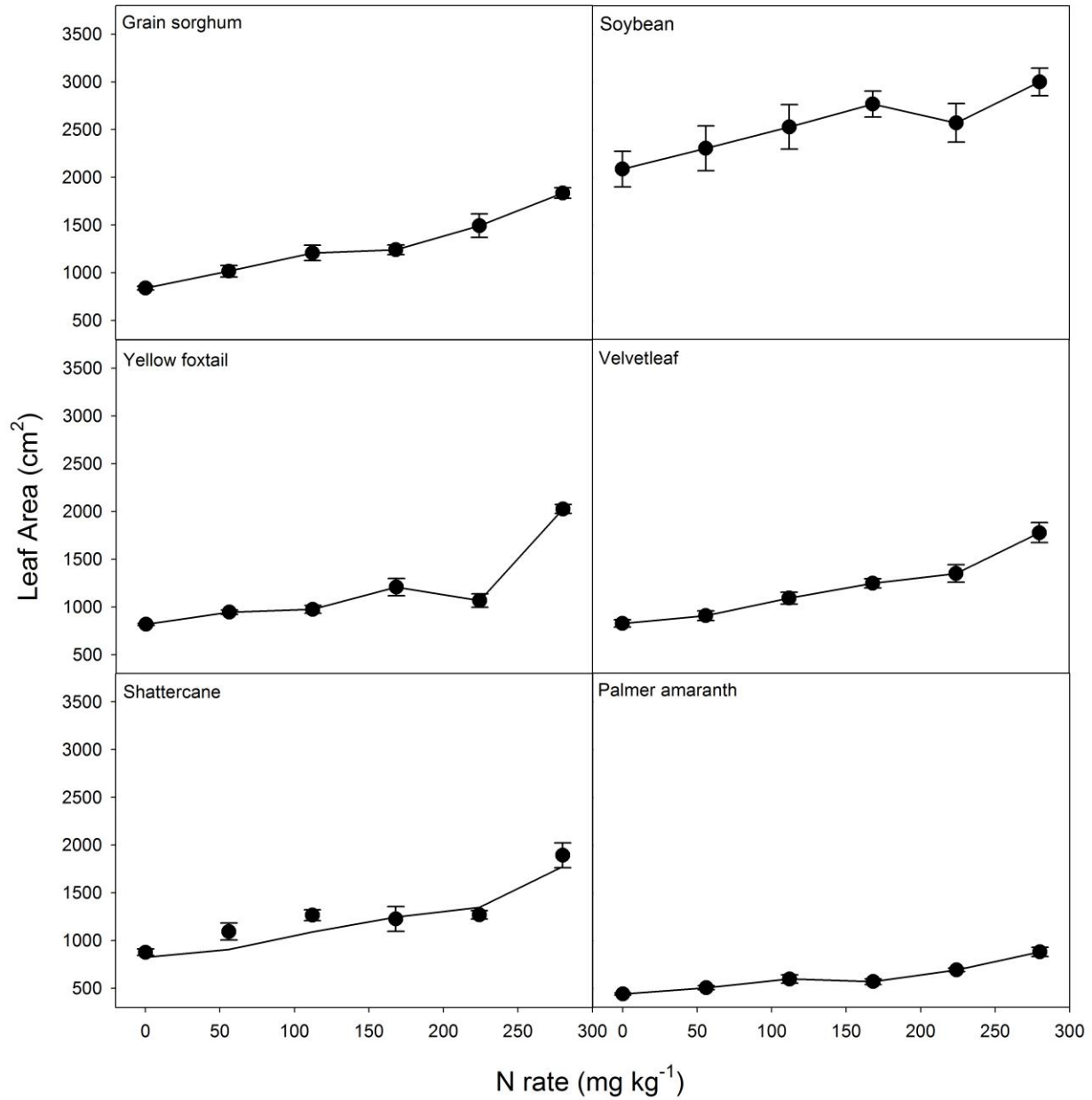


**Figure 3.6 Observed aboveground biomass ( $\text{g pot}^{-1}$ ) as a function of N rate for each of six weed species after 6 weeks of growth of run 2.**





**Figure 3.7 Observed leaf area ( $\text{cm}^2 \text{ pot}^{-1}$ ) as a function of N rate for each of six weed species after 6 weeks of growth of run 2.**



**Figure 3.8** Observed height (cm averaged pot<sup>-1</sup>) as a function of N rate for each of six weed species after 6 weeks of growth of run 2.

