

EFFECT OF ROW SPACING AND SEEDING RATE ON
GRAIN SORGHUM TOLERANCE OF WEEDS

by

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Abstract

Weed control in grain sorghum has always presented a challenge to producers in the semi-arid Great Plains. Cultural control tactics such as narrowing of row spacings and increasing seeding rates can be effective control methods. The objective of this research was to determine the row spacing and seeding rates that maximizes yield while suppressing weeds. Grain sorghum row spacings of 25, 51, and 76-cm and seeding rates of 75,000, 100,000, 125,000, and 150,000 seeds ha⁻¹ were evaluated in Kansas at Beloit and Manhattan in 2013 and Beloit, Manhattan, and Hays in 2014. Grain sorghum growth and yield response were measured in response to natural weed communities. After evaluation, Beloit was considered a low weed pressure site while Manhattan and Hays were considered to be moderate and high weed pressure sites, respectively. Grain sorghum biomass was different while weed biomass was consistent across row spacings. Yield loss equations and profit functions were derived to determine the amount of grain yield and \$ ha⁻¹ loss from each of the three locations. Yield and profit lost was greatest amongst weedy observations. Results indicated that grain sorghum grown on wide row spacings and seeding rates of 125,000 seeds ha⁻¹ out yielded all other treatments under a low weed pressure site (Beloit) and narrow row spacings out yielded wider spacings in moderate and high weed pressure sites (Manhattan and Hays). These results imply that a Kansas grain sorghum producer should evaluate potential weed pressure before determining a final row spacing and seeding rate.

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Chapter 1 - Literature Review

Grain Sorghum Production in the Semi-Arid Great Plains

Grain sorghum [*Sorghum bicolor* (L.) Moench] was first grown in the United States in New York in 1853 (Bennett et al. 1990). Grain sorghum has ranked fourth in terms of production among U.S. cereal crops in recent years with 2.6 million hectares being harvested in 2014 (NASS, 2015). Grain sorghum tolerates drought better than corn (*Zea mays* L.) and therefore, is better adapted to the semi-arid climate of central and southern Great Plains (Stahlman and Wicks 2000). Most grain sorghum in the U.S. is grown in areas with limited rainfall and often as a rotational or replacement crop (NGSP 2010). Inadequate weed management, however, can greatly reduce yields and net returns. This presents an opportunity to look deeper into the effects of cultural control options on weed suppression, yield, and the economics of using fewer herbicides. The goal of this literature review is to understand weed competition, weed control, and the economics of weed control in grain sorghum.

Weed Competition in Grain Sorghum

Weed control in grain sorghum has always presented a challenge to producers in the semi-arid Great Plains. Weeds compete with grain sorghum for light, nutrients, and soil water, resulting in reduced yields, lower grain quality, and increased production costs. Bridges (1992) listed more than 40 common or troublesome weeds of grain sorghum production areas in the United States. Eleven weeds were listed as either common, troublesome, or both common and troublesome. The weeds listed as common for the state of Kansas included common cocklebur (*Xanthium strumarium* L.), common purslane (*Portulaca oleracea* L.), pigweed species (*Amaranthus* spp.), velvetleaf (*Abutilon theophrasti* Medik.), Venice mallow (*Hibiscus trionum* L.), field bindweed (*Convolvulus arvensis* L.), foxtail species (*Setaria* spp.), large crabgrass

(*Digitaria sanguinalis* L.) and shattercane (*Sorghum bicolor* (L.) Moench *ssp. arundinaceum* (Desv.) de Wet & Harlan). The weeds listed as troublesome for Kansas included velvetleaf, common milkweed (*Asclepias syriaca* L.), field bindweed, hemp dogbane (*Apocynum cannabinum* L.), large crabgrass and shattercane. The weeds listed as both common and troublesome for the state of Kanas included velvetleaf, field bindweed, large crabgrass, and shattercane.

Many weed species like Palmer amaranth (*Amaranthus palmeri* S. Wats.) use as much or more water and nutrients than grain sorghum. Shipley and Wiese (1969) found that an unidentified pigweed species used 1.5 to 2.2 times more nitrogen and 2.7 times more potassium per kilogram of dry matter produced than grain sorghum used. The study also found that as pigweed species density increased, weed dry matter production increased and grain sorghum yield decreased. Crop-weed competition for moisture has received the most attention, perhaps because it frequently is the most limited resource in semi-arid environments. Water consumption by weeds reduces the amount of soil water available to support crop growth, thereby contributing to crop water stress and directly influencing the duration of critical weed-free period for crops. The amount of water needed to produce a kilogram of dry matter is a measure of water use efficiency (WUE) (Stahlman and Wicks 2000). Water use efficiencies of most C4 plants are considerably greater than those of C3 plants (Stahlman and Wicks 2000). Grain sorghum and several important weeds of grain sorghum like Palmer amaranth are C4 plants. Plants that produce the most dry matter with the least amount of water are the most efficient; weed species having high WUE typically are highly competitive with crops (Stahlman and Wicks 2000). Grain sorghum yield reductions of up to 85% have been reported in the presence of severe weed competition (Okafor and Zitta 1991). Weed control is optimized when differences in the

biological characteristics of grain sorghum and competing weeds are exploited (Stahlman and Wicks 2000).

Many weeds can interfere with grain sorghum establishment and harvest but if weeds are controlled within the first four weeks after crop emergence, yield loss from later emerging weeds is minimal (Moore et al. 2004). Burnside and Wicks (1967) reported no loss in grain sorghum yields when weeds were removed three weeks after planting (WAP), if control was maintained thereafter. The same study showed that sorghum yields decreased progressively when weeds were not removed for 4, 5, 6, or 8 WAP. These data suggest that weeds should be controlled within three WAP. Stahlman and Wicks (2000) noted that the critical period for weed control in grain sorghum is the first four WAP, when the crop is young and growing.

Research indicates that the percent of grain sorghum yield lost from weed competition exceeds that of most other grain crops. Losses typically range from 30 to 50%, but can be much greater under extreme densities and drought conditions. Stahlman and Wicks (2000) reviewed and compiled the results of grain sorghum yield reductions due to weed interference from 27 different sources spanning from 1954 to 1998. Grain sorghum yield reductions were reported as low as 4 to 18% (Burnside and Wicks 1969) and as high as 26 to 100% (Vencill and Banks 1994). Many of the weeds listed above contributed to these documented yields losses, but 12 out of these 27 sources reported that a “mixed population” of weed species caused these yield losses. With many weeds being problematic in grain sorghum, it is very crucial that the weed control program selected for use be extremely effective.

Weed control in grain sorghum

Producers utilize tillage, pre-emerge herbicides, and cultural control tactics to maintain weed control in grain sorghum production. Conservation tillage eliminates most mechanical

weed control practices. Therefore, the majority of weed control in grain sorghum is relying on chemical and cultural tactics. Within conventional as well as conservation tillage systems, herbicide applications have been the basis for weed management during the last 60 years. In 1992, herbicides were applied to 96% of the US grain sorghum hectares (Morrison et al. 1994). Gianessi and Marcelli (1998) credit the overall increase in herbicide use since the 1960s for reducing grain sorghum losses from weed interference by more than half. In western Kansas, herbicides are estimated to have replaced, on average, about 1.75 tillage operations devoted to grain sorghum production (Williams et al. 1987). Herbicides are always an option, but often will not provide season-long weed control. Fewer herbicides are registered for grain sorghum than for other major row crops. Most herbicides used in grain sorghum were developed first for use in corn. Chemical companies contend that the worldwide market is not large enough to justify screening and developing herbicides specifically for grain sorghum (Stahlman and Wicks 2000). The use of selective pre-emerge (PRE) or pre-plant incorporated (PPI) herbicides can be effective in controlling weeds in grain sorghum (Fromme et al. 2012). Atrazine applied PPI or PRE controls several small seeded annual grass and broadleaf weed species in sorghum. Atrazine is one of the most widely used herbicides in grain sorghum being applied on 81% of the U.S. grain sorghum hectares in 2011 (NASS 2015), but potential carryover to sensitive crops like soybeans (*Glycine max* L. Merr) as well as triazine-resistant weed species are major concerns. As a result, there is renewed interest in developing integrated weed management (IWM) systems that balances the use of many different types of control practices. IWM can be thought of as the “use of many little hammers” (Liebman and Gallandt 1997) that, on their own, are not stand-alone weed control measures but, if applied in a systematic way, will control or suppress weeds (Swanton et. al. 2008).

Several cultural methods can help minimize weed impact on grain sorghum, such as crop rotation, hybrid selection, and narrowing of crop row spacing and increasing seeding rate. Crop rotation involves alternating crops over a series of growing seasons. Rotation of crops aids in crop production by breaking weed cycles that may be detrimental to long-term management of a particular field. One of these cycles may be where one weed species or weed population has an advantage under a monoculture system. Rotating to another crop may increase weed diversity and prevent one particular weed community from becoming unmanageable. Regardless of tillage, crop rotation is an effective practice to use for weed control. Because of fewer selective POST herbicides in grain sorghum, it may not be possible or economical to control certain weeds in a particular crop. For example, annual grass weeds can be controlled in soybean since a selective POST herbicide may be used, when compared to grain sorghum. When crops are rotated, new herbicides and practices may control problem weeds (Locke et al. 2002).

Hybrid selection can also play an important role in suppression of weeds and optimization of grain sorghum yield. Early season vigor, height, and tillering ability would be favorable traits that allow for a grain sorghum plant to be more competitive with a weedy species. Martin and Vanderlip (1997) found that the most consistent yields across five planting dates were achieved with early-maturing hybrids, and yield variation increased as hybrid maturity increased. This study also noted that hybrids should be selected on the basis of long-term performance in an area, not maturity. Although grain yield potential increases as hybrid maturity increases, one or several factors typically prevent full-season hybrids from expressing that potential. Grain sorghum is planted in the central Great Plains because it can withstand adverse conditions of extreme heat and moisture stress better than other summer row crops, especially corn and soybeans. These adverse conditions place full-season grain sorghum at a

disadvantage and often result in inadequate length of growing season or moisture from reproduction through physiological grain maturity. As hybrid maturity decreases, a shorter growing season or less water are necessary to produce the crop, particularly for vegetative growth, and the danger of damage from cool conditions in fall decreases.

Narrowing of crop row spacing and increasing seeding rates can provide some weed suppression and could be relied on more heavily. Row spacings in modern grain sorghum production vary from 25 to 102 cm, with 76-cm row spacing being the most common (Stahlman and Wicks 2000). Bishnoi et al. (1990) found that grain sorghum produced significantly higher yields in 45-cm rows than 60- and 90-cm row spacings and that narrow row spacings resulted in fewer weeds than wide row spacings. Marin and Weiner (2014) reported that weeds would have a tough time competing against crops such as corn, cereal grains, and soybean if farmers were to alter their row spacings. They found that narrower row spacings suppressed weed growth and increased crop yields in fields prone to heavy densities of weeds. The amount of weed biomass was reduced by up to 72% while grain yields increased by more than 45% in heavily weed-infested fields. Research conducted at Kansas State University indicated that the growth of emerged weeds was reduced in the 25-cm spaced rows by 24% compared to 51-cm spaced rows and by 45% when compared to the 76-cm spaced rows (Staggenborg et al. 1999). Under heavy broadleaf weed pressure, the 25-cm rows produced 8660 kg ha⁻¹ and this was 404 kg ha⁻¹ more than the 51-cm rows and 2085 kg ha⁻¹ more than the 76-cm rows (Staggenborg et al. 1999). Limon-Ortega et al. (1998) found that grain sorghum was equally competitive in 38- and 76-cm row spacings when weed pressure was low, but as weed pressure increased, grain sorghum was more competitive in 38-cm row spacings. Under weed-free conditions, grain sorghum yield was enhanced in narrow rows (Limon-Ortega et al. 1998). Planting in narrow rows is an option for

many crops and as a soil conservation measure, can provide protection against soil erosion from raindrop impact. Planting sorghum in rows spaced 76 to 107 cm worsens the problem and allows weeds to compete with grain sorghum, because the crop canopy forms slowly and provides little shading of weeds between rows until mid-season; by then, most weeds are well established (Stahlman and Wicks 2000). Faster canopy closure also may reduce weed germination, growth and establishment by shading (Locke et al. 2002). Smith et al. (1990) found that canopy closes quicker over the inter rows with higher grain sorghum populations before grass species (and later emerging broadleaves) became established. Optimum grain sorghum seeding rates vary depending on available moisture (Stahlman and Wicks 2000). Staggenborg et al. (1999) concluded that producers should not alter seeding rates when converting to narrow rows because of grain sorghum's ability to adjust head number and seed number per plant. Conley et al. (2005) reported that even though grain sorghum yield was lower at densities of 75,000 seeds ha⁻¹, the sorghum plants were able to compensate by developing >1 additional head per plant. Hickman et al. (1992) stated that populations of 200,000 to 250,000 plants ha⁻¹ are recommended for irrigated sorghum, and populations of 75,000 to 100,000 plants ha⁻¹ are more appropriate for dryland conditions. Conley et al. (2005) reported that grain yield was lowest at 75,000 seeds ha⁻¹ when compared to all other plant densities in 2002 and when compared to 150,000, 225,000, and 300,000 seeds ha⁻¹ in 2003. These data show that yield differences due to populations can be quite variable on a year to year basis. High-population grain sorghum is more prone to stress under limited soil moisture conditions (Stahlman and Wicks 2000). Moisture-stressed plants may lose leaves, and have restricted growth, delayed panicle emergence, shrunken kernels, and higher incidence of lodging. However, high sorghum populations reduced competitiveness of weeds (Stahlman and Wicks 2000). Burnside (1977) reported that weed growth was greater in

low-population (120,000 plants ha⁻¹) grain sorghum with no postemergence herbicide treatment than for either low- or high populations (207,000 plants ha⁻¹) sprayed POST with atrazine and crop oil concentrate. Grain sorghum produces similar yields over a wide range of seeding rates because of its ability to adjust tillering and head size. However, late-emerging tillers often delay grain harvest, and low seeding rates are less competitive with weeds (Stahlman and Wicks 2000). Marin and Weiner (2014) reported that the idea is to increase crop-weed competition and utilize the crop's head start, so that it gains a large competitive advantage over the neighboring weeds. These are a few of the reasons seeding rates usually are increased and row spacing is narrowed. The critical point is at which grain sorghum seeding rates are too low or row spacings are too wide to compensate for yield and maintain weed suppression. Studies have been conducted and confirm that both yield and weed suppression can be obtained through the use of narrow-row spacings and higher seeding rates. Establishing a seeding rate and spacing that optimizes both grain yield and weed suppression is important for the producers growing grain sorghum. Methods can be developed for outcompeting weeds if more is learned about how the weeds and grain sorghum interact.

Light Interception and Canopy Closure

When moisture and nutrients are not limited, light becomes the major factor affecting plant growth. Weed density and morphology affect distribution of light in the canopy and absorption of photosynthetic active radiation (PAR) by the crop. Weed competition has been shown to reduce crop leaf area index and chlorophyll content (Tollenaar et al. 1994). Grain sorghum and other C₄ plants do not tolerate shading well because of the way they fix carbon. Corn is also a C₄ plant and Ottman and Welch (1989) reported that reduced row spacings increased the total interception of PAR by the corn canopy and redistributed the radiation

towards the top of the canopy. Tharp and Kells (2009) reported that photosynthetic efficiency, corn growth, and ultimately grain yield are influenced by the distribution and interception of PAR within a corn canopy. Early-season interception of PAR by corn canopies increased as row spacing decreased, but differences were not apparent later in the season. Interception of PAR was similar throughout the growing season when corn populations exceeded 72,900 plants ha⁻¹. Corn yields were not affected by row spacing, but they were increased with corn populations of 72,900 plants ha⁻¹ or higher. Reduced row spacings and increased corn populations are thought to increase weed control by increasing the competitiveness of a crop with weeds and by reducing light transmittance to the soil surface (Tharp and Kells 2009). Teasdale (1995) showed that reduced row spacing and increased population in corn decreased weed growth in the absence of herbicides and shortened the time to canopy closure by 1 week. As grain sorghum approaches anthesis and maturity, light quantity becomes increasingly important in determining final yield (Stahlman and Wicks 2000). Graham et al. (1988) found that grain sorghum leaf area and light absorption decreased as weed density increased which had a large impact on yield. During the past five to six decades, the influence of row spacing on grain sorghum canopy architecture, light interception, and grain yields has been of interest (Staggenborg et al. 1999). Light interception advantages of narrow-row sorghum systems offer weed control advantages over wider rows since early canopy closure reduces the number of weeds that emerge during the growing season. Yield increases from narrowing the row spacing have been attributed to better light interception and more efficient water use (Staggenborg et al. 1999). Burnside et al. (1964) reported that moisture use efficiency by sorghum is increased in narrow rows, as water loss, soil temperature, and light intensity are less under 51- than under 101-cm row spacings. Northam et al. (1996) found that narrowing crop row spacing from 76 to 18 cm reduced light penetration to the soil

surface by 15%, which limited weed growth and competitiveness. Weed competition is enhanced in grain sorghum because of sorghum's open canopy structure and slow establishment (Everaarts 1993). Burnside et al. (1964) found that grain sorghum in 25-, 51-, and 76-cm row spacings shaded the ground 49-55, 54-63, and 59-91 days after planting, respectively. These findings offer an opportunity to evaluate the differences in light intercepted amongst different seeding rates and spacings and their effects on weed suppression and grain sorghum yield.

Postemergence Weed Control in Grain Sorghum

Weed control in grain sorghum is a challenge because of the limited number of herbicides available to growers, rotational crop restrictions following a number of herbicides registered for use in grain sorghum, and because of the increased presence of herbicide resistant weeds. For example, the increase in triazine resistant kochia has been associated with the widespread use of atrazine in corn, sorghum, fallow, right-of-ways, around feedlots, or on industrial sites (Haack 1987). Kochia (*Kochia scoparia* L. Schrad.) resistance to the triazine herbicides was confirmed first in 1976 where high rates of triazine herbicides were used for nonselective residual weed control (Bandeem et al. 1982). Additionally resistance to ALS-inhibitor herbicides has been documented in Palmer amaranth, common waterhemp (*Amaranthus rudis* Sauer.), kochia, common cocklebur, shattercane, and common sunflower (*Helianthus annuus* L.) (Heap 2015). Rotating herbicides with different modes of action is recommended to reduce the risk of resistance evolution (Citation??). However, there are fewer options to rotate herbicide modes of action in grain sorghum than in corn or soybean (Thompson et al. 2015). Bromoxynil is a POST herbicide that is used for weed control in many crops and controls a broad spectrum of annual broadleaf weeds. It does not effectively control grass species and only controls pigweed species when applications are timely. Pyrasulfotole is a new herbicidal active ingredient belonging to

the HPPD inhibitor mode of action and the pyrazoles family class of herbicides (Schmitt et al. 2008). It has been suggested that pyrasulfotole be included in mixtures with bromoxynil to improve control of broadleaf weeds (Schmitt et al. 2008). Thompson et al. (2009) reported that all treatments which contained pyrasulfotole plus bromoxynil combinations controlled redroot pigweed (*A. retroflexus* L.), Palmer amaranth, common lambsquarters (*Chenopodium album* L.) velvetleaf, common sunflower (*Helianthus annuus* L.), and ivyleaf morningglory (*Ipomoea hederacea* Jacq.) within the range of weed sizes treated, while Brandon and Bean (2012) reported that this combination controlled pigweed species by 85% one week after application, but control was reduced to 61% by the end of the season. Pyrasulfotole plus bromoxynil has an excellent crop rotation profile, making it an attractive herbicide to use in grain sorghum (Fromme et al. 2012). A prepackaged mixture of pyrasulfotole and bromoxynil (1:5.64 ratio) and herbicide safener mefenpyr-diethyl (Huskie™; Bayer Crop Science, 2 T. W. Alexander Drive, Research Triangle Park, North Carolina 27709) has been registered for broadleaf control in wheat (*Triticum aestivum* L.) barley (*Hordeum vulgare* L.), triticale (*Triticale hexaploide* Lart.), and grain sorghum crops. The herbicide label recommends tank mixing the premix with atrazine at 0.28 to 1.12 kg ha⁻¹ to improve and expand weed control. Past research has reported excellent control of some key broadleaf weeds with the use of Huskie in cereal crops (Paulsgrove et al. 2006; Reddy et al. 2012; Thorsness et al. 2007). Fromme et al. (2012) reported at least 94% control of Palmer amaranth in grain sorghum with Huskie in combinations with other herbicides in Texas. Reddy et al. (2013) reported that the mixture of Huskie at 244 g ai ha⁻¹ plus atrazine at 560 g ha⁻¹ applied early- to mid-POST or late-POST controlled pigweeds (Palmer amaranth, tumble pigweed (*Amaranthus albus* L.), and redroot pigweed) more than 93% and more than 90%, respectively.

Economics of Weed Control in Grain Sorghum

The economics of a weed control program needs to be considered when producing grain sorghum. The best weed control and maximum grain yields are obtained by using IWM strategies that combine mechanical, chemical, and cultural methods (Stahlman and Wicks 2000). Weed control in grain sorghum can be achieved with an IWM system, but is that system economical to the production and profit of a grain sorghum crop? With lower than previous year's crop prices in 2015 and little reduction in input prices, the economics of crop production are more important than ever. Through the manipulation of row spacing and seeding rates, a reduction in inputs via herbicide costs is possible. Smith et al. (1990) suggested that narrow row spacing may be an alternative grain sorghum production system with lower inputs from herbicides. New herbicides like Huskie have been produced to aid in weed control and new grain sorghum varieties have been developed to optimize yield. The economics of weed control in a grain sorghum production systems need to be evaluated based on the current production costs and prices.

The overall goal and objective of this research was to evaluate the influence of grain sorghum row spacing and seeding rates on crop and weed biomass production, light interception, and grain yields and resulting economics to determine the combination that optimizes grain sorghum yield while suppressing weeds.

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Chapter 2 - Effect of Row Spacing and Seeding Rate on Grain

Sorghum Tolerance of Weeds

Abstract

Weed control in grain sorghum (*Sorghum bicolor* L. Moench) has always presented a challenge to producers in the semi-arid Great Plains. Cultural control tactics such as narrowing of row spacings and increasing seeding rates can provide some level of weed control. The objective of this research was to determine the row spacing and seeding rates that optimizes yield while suppressing weeds. Grain sorghum row spacings of 25, 51, and 76 cm and seeding rates of 75, 100, 125, and 150 thousand seeds ha⁻¹ were evaluated in Kansas near Beloit and Manhattan in 2013 and Beloit, Manhattan, and Hays in 2014. Grain sorghum growth and yield response were studied in response to natural weed communities. After evaluation Beloit was considered a low weed pressure site while Manhattan and Hays were considered to be moderate and high weed pressure sites, respectively. Grain sorghum biomass was greater with narrow rows as compared to wider rows while weed biomass was consistent across row spacings. Yield loss equations and profit functions were derived to determine the amount of grain yield and \$ ha⁻¹ lost at each of the three locations in 2014. Yield and profit lost was greatest amongst weedy treatments. Results indicated that grain sorghum grown under a treatment combination of wide row spacings (76 cm) and a seeding rate of 125,000 seeds ha⁻¹ out yielded all other treatments under a low weed pressure site (Beloit) and grain sorghum grown in narrow row spacings (25 cm) out yielded the two wider spacings (51 and 76 cm) in moderate and high weed pressure sites (Manhattan and Hays). These results imply that a Kansas grain sorghum producer should evaluate potential weed pressure before determining a final row spacing and seeding rate.

Introduction

Grain sorghum is an important cash crop of the semi-arid Great Plains. Grain sorghum is a key ingredient in many livestock feeds and has more protein content than corn (*Zea mays* L.) Grain sorghum tolerates drought better than corn and, therefore, is better adapted to the semi-arid climate of central and southern Great Plains (Stahlman and Wicks 2000). Most grain sorghum in the U.S. is grown in areas with limited rainfall and often as a rotational or replacement crop (NGSP 2010). Grain sorghum has ranked fourth in terms of production among U.S. cereal crops in recent years with 2.6 million hectares being harvested in 2014. Kansas was the top producing state with 1.1 million hectares harvested (NASS 2015).

Weed control in grain sorghum has always presented a challenge to producers. Weeds compete with grain sorghum for light, nutrients, and soil water, resulting in reduced yields, lower grain quality, and increased production costs. Yield losses to weeds generally range from 30 to 50% (Stahlman and Wicks 2000). Producers utilize tillage, pre-emerge (PRE) herbicides, and cultural tactics to control weeds in grain sorghum production. The switch from conventional tillage to conservation tillage eliminates most mechanical methods of weed control. The use of PRE herbicides can be effective in the control of weeds in grain sorghum. Several selective herbicides may be used pre-plant or pre-plant incorporated (PPI) in sorghum (Fromme et al. 2012). Atrazine is one of the most widely used herbicides in grain sorghum (NASS 2015) and controls a number of different weed species (Anonymous 2009), but potential carryover to sensitive crops like soybeans (*Glycine max* L. Merr) as well as weeds that are triazine-resistant are major concerns. Repeated use of atrazine in corn and grain sorghum has resulted in the selection of triazine-resistant weed biotypes such as Palmer amaranth (*Amaranthus palmeri* S. Wats.), common waterhemp (*Amaranthus rudis* Sauer.), redroot pigweed (*Amaranthus*

retroflexus L.), and kochia (*Kochia scoparia* L. Schrad.) reported in Kansas (Heap 2015). This is important because all of these weeds are listed as common or troublesome in grain sorghum production (Bridges 1992).

There is an enhanced need for the understanding and influence of cultural control tactics. Altering row spacing and seeding rates have been considered as practical weed control methods in the past (Stahlman and Wicks 2000). Row spacing in modern grain sorghum production varies from 25 to 102 cm, with 76-cm row spacing being the most common (Stahlman and Wicks 2000). Bishnoi et al. (1990) found that grain sorghum in Alabama produced significantly higher yields when grown in 45-cm rows than wider row spacings and that narrow row spacings resulted in 25 to 54% fewer weeds than wider row spacings. Marin and Weiner (2014) reported that weeds would have a tough time competing against crops such as corn, cereal grains, and soybeans if farmers were to narrow their row spacings. The study showed that narrower row spacings in general suppressed weed biomass and increased crop yields in fields prone to heavy amounts of weed biomass. The weed suppression was attributed to increased crop-weed competition and the utilization of the crop's head start (assuming the field was weed-free prior to planting) giving it a large competitive advantage over neighboring weeds. The study found that corn grown at high densities in a grid pattern reduced weeds up to 72% while grain yields increased by more than 45% in heavily weed-infested fields compared to low densities in standard sowing patterns (Marin and Weiner 2014).

Though optimal seeding rates for grain sorghum production differ among geographic regions, past research has indicated that grain yield generally increases as seeding rate increases (Staggenborg et al. 1999). Conley et al. (2005) reported that grain sorghum yield was lowest at 75,000 seeds ha⁻¹ when compared 150,000, 225,000, and 300,000 seeds ha⁻¹.

The combination of narrower row spacing and higher seeding rates have also been attributed to overall higher grain sorghum yields. Past research has indicated that weed suppression may be seen with altering row spacing and seeding rates. Staggenborg et al. (1999) reported that the growth of weeds was reduced by 24 to 45% with an increase in row spacing. Burnside (1977) reported that weed growth was less at a high population (207,000 plants ha⁻¹) than at a lower population (120,000 plants ha⁻¹). The objective of this research was to evaluate the influence of grain sorghum row spacing and seeding rates on crop and weed biomass production, light interception, grain yields, and resulting economics to determine the combination that optimizes grain sorghum yield while suppressing weeds.

Materials and Methods

Field experiments were conducted near Beloit and Manhattan, KS in 2013 and 2014 with an additional experimental location at Hays, KS in 2014. The Beloit location in 2013 was in a grain sorghum producer's field (39.395821 N, -98.085628 W) approximately 6.4 km southeast of Beloit, KS while in 2014, it was 21 km further southeast from the previous year (39.290320 N, -97.967708 W). The Manhattan location was 8 km southwest of Manhattan at the Kansas State University Agronomy Department Ashland Bottoms Research Farm (39.07228 N 96.38061 W) with adjacent sites in the same field used in different years. The Hays location was at the Kansas State University Agricultural Research Center-Hays (38.51063 N 99.19217 W).

Each field site had 135 kg ha⁻¹ N fertilizer as urea (Beloit and Hays) or UAN (Manhattan) applied approximately one month prior to crop planting. Previous crops at experiment locations near Beloit and Hays were winter wheat (*Triticum aestivum* L.), while at the location near Manhattan it was soybean. A burndown application of glyphosate at 1260 g ae ha⁻¹, 2, 4-D at 350 g ae ha⁻¹, and ammonium sulfate at 2% w/v was applied on June 14, 2013 and May 29, 2014

at Beloit and on May 27, 2014 in Hays. At Manhattan, the field was disked and field cultivated on June 16, 2013 and June 8, 2014 prior to planting.

Grain sorghum hybrid Mycogen 697 was sown in 2013 near Manhattan, while DKS 49-45 was sown in the other four site-years. Four seeding rates of 75,000, 100,000, 125,000, and 150,000 seeds ha⁻¹ and three row spacings of 25-, 51-, and 76-cm and each of the combinations were studied. Equipment available at each location determined how these row spacing and seeding rates were established. At Beloit, the 25- and 51-cm spacing plots were drilled with a 15.24 m John Deere 1890 Air Seeder. The 76-cm plots were planted with a 12-row John Deere 1760 Conservation planter. Grain sorghum was planted on June 18, 2013 and May 29, 2014 at Beloit. At Manhattan, the 25- and 51-cm spacing plots were drilled with a Tye grass drill. The 76-cm spacing plots were planted with a White Model 6700 6-row planter. Grain sorghum was planted near Manhattan on June 18, 2013 and June 18, 2014. At Hays, the grain sorghum was planted on June 3, 2014 with a Great Plains double disc drill. Row units were closed off in order to achieve the different row spacings. A single seeding rate of 175,000 seeds ha⁻¹ was drilled into each of the 25 and 51-cm experimental units near Manhattan and all three row spacings near Hays. Hand-thinning was delayed until all sorghum had emerged, and took place on July 12, 2014 and June 30, 2014 at the locations near Manhattan and Hays, respectively. The grain sorghum on average was at growth stage 2 (GS2) (Vanderlip 1979) or the five leaf stage, at this time.

Naturally-occurring weed communities were used in the study and observations were made of weedy crop yields. In 2014, two additional observation quadrats were nested within each treatment at each location to document yields from a weed-free and an herbicide-treated quadrat within each sub-plot. Weed-free sub-plots (1-m²) were established 2 to 5 weeks after

grain sorghum emergence at each location and maintained throughout the growing season by hand weeding. The herbicide application consisted of the premix pyrasulfotole and bromoxynil (Huskie™) at a rate of 252 g ha⁻¹ plus atrazine at 560 g ha⁻¹, NIS at 0.25% v/v, and ammonium sulfate at 2% w/v. Herbicide application was made 5 weeks after planting (WAP) at the location near Beloit on July 7, 2014 , 4 WAP on July 18, 2014 at the location near Manhattan , and 6 WAP on July 15, 2014 at Hays. The herbicide was applied across the back 2 m of each replicate at each location.

At each location, the overall experimental design was a split plot arrangement of all treatments with whole plots being row spacing to accommodate planting equipment and subplots being seeding rates. There were four replications of each treatment. Each seeding rate subplot was 15.2 m by 30.5 m at the Beloit locations or 6.1 m by 9.1 m at the Manhattan and Hays locations.

Light interception.

Light interception readings were taken with a line quantum sensor and a LI-COR LI-1400 dataLOGGER (LI-COR Inc. 4647 Superior Street P.O. Box 4425 Lincoln, Nebraska 68504-0425). Light interception readings were taken 10-cm above the sorghum canopy and below the canopy at ground level across the rows of different row spacings. In order to get effective data, light interception readings were taken on bright sunny days and when the sun was near its highest point between 10 a.m. and 2 p.m. These readings were taken to help determine the amount of solar radiation absorbed by the weeds and grain sorghum throughout the growing season up to the point when the grain sorghum was done growing vegetatively.

Readings were taken at growth stage 6 (GS6) (Vanderlip 1979) on August 21, 2013 and August 14, 2013 at Beloit and Manhattan, respectively. In 2014, readings were taken 2 to 3

times during the growing season. Readings were taken in both weedy and weed-free portions of each plot. These readings were taken at growth stage 4 (GS4) (Vanderlip 1979), 6 to 7 weeks after planting on July 16, 2014, August 1, 2014, and July 15, 2014 at Beloit, Manhattan and Hays, respectively. The second set of light interception readings were taken at growth stage 5 (GS5) (Vanderlip 1979) (boot stage, or when all leaves are fully extended providing maximum light interception (Vanderlip 1979)) 8 to 10 weeks after planting on July 31, 2014, September 3, 2014, and August 3, 2014 at Beloit, Manhattan, and Hays, respectively. The third set of light interception readings were taken at GS6 on August 24, 2014 in Beloit.

Plant sampling and grain yield.

Grain sorghum plant height, tillers per plant, and plants ha⁻¹ were recorded once grain sorghum reached GS6 at all locations in 2013 and 2014. Above-ground biomass samples of weeds and grain sorghum were collected from a 1-m² quadrat placed approximately 0.5 m into and 0.5 m from the edge of the next plot, parallel with crop rows just before plants had reached physiological maturity on September 26, 2013 and September 8, 2014 near Beloit, September 5, 2013 and October 17, 2014 near Manhattan, and on September 26, 2014 at Hays. The number of individuals for each weed species, and weed biomass samples were collected and recorded. The biomass samples were dried at 66 C for seven days and then allowed to air dry until samples did not dry down further. Only grain sorghum biomass samples were collected for Beloit in 2013 due to low natural infestations of weeds.

Weedy grain sorghum was machine harvested on November 4, 2013, and November 7, 2014 with a John Deere 9770 combine with a 7.62 meter draper header at the Beloit locations. All grain sorghum was hand harvested on October 24, 2013, and November 24, 2014 at the Manhattan location. Weedy grain sorghum plots were machine harvested on November 21, 2014

at Hays. All herbicide-treated and weed-free observation plots were hand harvested. The hand harvested samples were allowed to air dry for several weeks and were then hand threshed with a gas-powered thresher. The number of heads m^{-2} was recorded from the samples at threshing time. Grain samples from each plot were collected and used to determine moisture and test weight. Grain sorghum yields were adjusted to 14% moisture. All machine-harvested samples were cleaned and free of weed seed when sub-samples were used to determine moisture and test weight values.

Economic Analysis.

The economic analysis involved substituting values and parameter estimates for the yield loss functions into the profit function. Several simplifying assumptions were involved in the economic analysis to emphasize the impact of row spacing and seeding rates on weed tolerance and gross profit. In the decision to control/tolerate weeds, it was assumed that all other crop production inputs would remain constant and were not included in the profit calculations. Herbicide used (Huskie™) was assumed to have >90% efficacy on broadleaf weeds and no control on annual grass weeds. The gross profit in \$ ha^{-1} amongst seeding rates, row spacings, and the use of a POST herbicide were considered. Weed-free yield was considered the maximum achievable yield and, therefore, was used to determine the maximum achievable gross profit amongst treatments and observations. Expressing yield loss as a percentage of weed-free yields has proven to be useful for making broad predictions about the response of crops to weeds (Green et al. 1987; Rowland et al. 1999; Wood et al. 1999).

Yield loss weedy function.

Yield loss from weedy environment compared to a weed-free observation was calculated using the equation:

$$YL = \{(Y_{WF} - Y_W)/Y_{WF}\} * 100$$

[1]

where YL is the yield loss (%) due to competition by natural weed infestation, Y_{WF} is the yield attained from the weed-free observation (kg ha⁻¹), and Y_W is the weedy yield (kg ha⁻¹) (J.A. Dille, personal communication; Dieleman et al. 1996).

Yield loss with POST herbicide function.

Yield loss from an untreated weedy environment compared to the use of a POST herbicide application was calculated using the equation:

$$YL_H = \{(Y_H - Y_W)/Y_H\} * 100$$

[2]

where YL_H is the yield loss (%) due to competition by natural weed infestations compared to the use of a POST herbicide-treated weedy environment, Y_H is the yield attained from the herbicide-treated observation (kg ha⁻¹), and Y_W is the weedy yield (kg ha⁻¹) (J.A. Dille, personal communication).

Yield loss prevented function.

Yield loss from the hand-weeded weed-free observation compared to a POST herbicide-treated weedy environment was calculated to determine if yield loss was prevented by the POST herbicide application using the equation:

$$YL_{WF-H} = \{(Y_{WF} - Y_H)/Y_{WF}\} * 100$$

[3]

where Y_{WF-H} is the yield loss prevented (%) by POST herbicide application, Y_{WF} is the yield attained from the weed-free observation (kg ha^{-1}), and Y_H is the yield attained from the herbicide-treated observation (kg ha^{-1}) (J.A. Dille, personal communication).

Expected profits were derived from the following equations proposed by Moffit (1988) and Pannell (1990) and described by Dieleman et al. (1996).

Weed-free profit function:

$$\Pi_{WF} = P_Y * Y_{WF} - P_S * S - F \quad [4]$$

where Π_{WF} is profit of the weed-free observation ($\$ \text{ha}^{-1}$), P_Y is the price ($\$ \text{kg}^{-1}$) of weed-free grain sorghum yield Y_{WF} (kg ha^{-1}), P_S is per unit price ($\$0.25$ per 1000 seeds) of seed planted S , and F is cost ($\$ \text{ha}^{-1}$) of additional weed control components included such as application cost and surfactants (J.A. Dille, personal communication). This equation does not include herbicide costs, or any other costs associated with maintaining a weed-free environment through conventional methods.

Herbicide-treated profit function:

$$\Pi_H = P_Y * Y_H - P_H * H - P_S * S - F \quad [5]$$

where Π_H is profit of the POST herbicide-treated observation ($\$ \text{ha}^{-1}$), P_Y is the price of yield of herbicide-treated observation Y_H (kg ha^{-1}), P_H is the per unit price ($\$ \text{ha}^{-1}$) of herbicide applied H (g ha^{-1}), P_S is per unit price of seed planted S , and F is cost of additional weed control components such as application cost and surfactants (J.A. Dille, personal communication).

Profit function for no weed control:

$$\Pi_w = P_Y * Y_w - P_S * S - F$$

[6]

where Π_w is the profit of the weedy yield ($\$ \text{ ha}^{-1}$), P_Y is the price of Y_w , P_S is per unit price of seed planted S , and F is cost of additional weed control components such as application cost and surfactants (J.A. Dille, personal communication).

These equations only included seeding rates prices (P_S) when yields among treatments were significantly different. A price of $\$0.20 \text{ kg}^{-1}$ was used as an average value for the price of grain sorghum. An average grain sorghum seeding rate of $113,000 \text{ seeds ha}^{-1}$ and an average seed price of $\$27.80 \text{ ha}^{-1}$ was used when no significant differences were seen among seeding rates.

Statistical Analyses.

All data were analyzed using PROC GLIMMIX procedure in SAS (SAS 9.3 SAS® Institute Inc.) to evaluate differences among treatment main effects and to test for interactions. The Mixed Model procedure provides Type III F values but does not provide mean square values for each element within the analysis or the error terms. The degrees of freedom method used was Satterthwaite. The means were separated using the least square means method. All effects except replication were considered fixed. No interactions were significant so results were analyzed according to main effects of treatments. Because of differences in weed populations and densities among locations and years, data were not combined and were presented separately by years and locations. A Tukey parameter was used to determine if main effects and interactions were considered significant when $P \leq 0.05$.

Results and Discussion

Precipitation can be erratic throughout Kansas in any given year. Annual precipitation throughout the state can range from <500 mm to >1000 mm (NOAA 2014). Precipitation patterns and growing conditions were quite normal in 2013. The field near Beloit received 690 mm of precipitation, 330 mm of which fell during the 2013 growing season, and in 2014 this location received 508 mm, 410 mm of which fell during the growing season. Beloit receives 660 mm of annual precipitation on average. The field near Manhattan received 742 mm annual precipitation, and 453 mm of which fell during the 2013 growing season, and in 2014 this location received 606 mm, 223 mm of which fell during the growing season. On average, Manhattan receives 860 mm of annual precipitation. The location at Hays received 571 mm annual precipitation and 507 mm of which fell during the 2014 growing season. On average, Hays receives 560 mm of annual precipitation (NOAA 2014). Growing season was considered to be from planting to harvesting of grain sorghum at a given location.

Weed infestation levels.

Weed species, densities, and biomass varied across sites and years, so that there was a range of low (Beloit), moderate (Manhattan) to high infestation (Hays) levels. Weed species and densities were recorded at GS6 in 2013 (Table 2.1). Weed species and densities were recorded at GS3 and GS6 in 2014. Weed species present at Beloit in 2013 included Palmer amaranth (*Amaranthus palmeri* S. Wats.), velvetleaf (*Abutilon theophrasti* Medik.), and yellow foxtail (*Setaria pumila* Poir.). The most numerous weed was Palmer amaranth at an average density 0.25 plants m⁻². Velvetleaf was only present in 8 of 48 plots, while yellow foxtail was only present in 1 of the 48 plots. Weed species present at Beloit in 2014 included carpetweed (*Mollugo verticillata* L.) at 36 plants m⁻² and common purslane (*Portulaca oleracea* L.) with 6

plants m⁻². No research studies have been reported to look at the impact of these weeds on grain sorghum yield loss. A few of the plots contained large crabgrass (*Digitaria sanguinalis L.*) (7 plots) and Russian thistle (*Salsola tragus L.*) (2 plots). No differences in weed biomass were seen amongst the row spacings or seeding rates. Combined weed biomass averaged 43 g m⁻² across all plots (Table 2.1). Weed biomass was very low for Beloit in 2013 and 2014 and, therefore, was considered a low weed pressure site.

Weed species present at Manhattan in 2013 included Palmer amaranth, ivyleaf morningglory (*Ipomoea hederacea Jacq.*), velvetleaf, and large crabgrass. The most numerous weed was Palmer amaranth and produced 294 g m⁻² averaged across all plots (Table 2.1). Moore et al. (2004) reported that the most costly effect caused by the presence of Palmer amaranth was through interference and grain yield loss. There was a limited occurrence of ivyleaf morningglory (11 of 48 plots), velvetleaf (8 of 48), and large crabgrass (3 of 48). Weed densities were very high (>10 plants m⁻²) on average for Manhattan in 2013. Weed biomass was not different across any of the grain sorghum row spacings or seeding rate treatments (Table 2.1). Weed species present at Manhattan in 2014 included Palmer amaranth with 10 plants m⁻², and large crabgrass with 6 plants m⁻². Many other weed species were present but in few plots. Combined weed biomass averaged 261 g m⁻² across all plots (Table 2.1). Weed densities were moderately high for Manhattan both years and it was considered a moderate weed pressure site.

Weed species present at Hays in 2014 included Palmer amaranth with 26 plants m⁻², puncturevine (*Tribulus terrestris L.*) with 8 plants m⁻², and carpetweed with 7 plants m⁻². The Palmer amaranth infestation was a high density and appeared to impact grain sorghum yield. Moore et al. (2004) reported that for each increase of 1 Palmer amaranth plant per 15 m of grain sorghum row decreased grain sorghum yield by 92 to 190 kg ha⁻¹. All weed species were

competitive with grain sorghum during the growing season with a combined weed biomass averaged 449 g m⁻² across all plots (Table 2.1). No significant differences in weed biomass were seen amongst grain sorghum row spacings and seeding rates (Table 2.1). Weed densities were very high (>25 plants m⁻²) for Hays and considered a high weed pressure site.

Grain Sorghum Production.

Grain sorghum yields from both fields near Beloit were very good both years. Average yields for Mitchell county (Beloit) were 3450 and 5130 kg ha⁻¹ in 2013 and 2014, respectively (NASS 2015). Yields in response to grain sorghum seeding rates were only significant among weedy treatments across both years. Grain sorghum planted at a seeding rate of 125,000 seeds ha⁻¹ yielded 8510 kg ha⁻¹ and out yielded 75,000 seeds ha⁻¹ by 10% in 2013 and 19% in 2014 (Table 2.2). This is consistent with what Conley et al. (2005) reported such that grain yield was lowest at 75,000 seeds ha⁻¹ when compared plant densities of 150, 225, and 300 thousand seeds ha⁻¹. In 2013, grain sorghum grown in weed-infested 76-cm rows yielded 8520 kg ha⁻¹ and out yielded narrower rows by 8%. In 2014, grain sorghum grown in weed-infested wide rows yielded 5310 kg ha⁻¹ and out yield 25-cm rows by 16% (Table 2.3). In 2014, grain sorghum yields from weedy plots were some of the lowest observed, while highest yields were from weed free observation plots. Yields from herbicide-treated plots were variable depending on the amount of natural weed pressure (Table 2.3). Weed pressure was low in Beloit, therefore, yield levels from herbicide-treated observations were similar and sometimes above those of weed-free observations. These results could be attributed to the amount of surface disturbance (hoeing) needed to maintain the weed-free plot throughout the growing season.

Grain sorghum yields at Manhattan were highly variable with no differences amongst row spacing and seeding rate treatments in 2013. Grain sorghum yields were 6290 kg ha⁻¹

averaged across all plots in 2013. Weedy, herbicide-treated, and weed-free observations in 2014 indicated that grain sorghum grown in narrow rows (25-cm) yielded 7120 kg ha⁻¹ and out yielded 51- and 76-cm rows by 30 and 69%, respectively (Table 2.3). Herbicide treatments were not as effective at Manhattan due to the presence of high level of annual grass weeds (10 plants m⁻²). The grass weeds were not controlled with the POST herbicide of pyrasulfotole and bromoxynil and weeds continued to compete with the grain sorghum throughout the growing season. Data suggests that grain sorghum grown on narrow rows (25-cm) were able to tolerate grass weed competition through increased grain sorghum biomass (Table 2.1) better than wider rows, and therefore yielded better than wide rows (Table 2.3). No studies have been conducted that evaluate the effect of row spacing on grain yield across weed free, herbicide-treated, and weedy environments.

Grain sorghum yields at Hays were very poor in 2014. Grain sorghum planted in narrow row spacings (25-cm) out yielded wider row spacings (51- and 76-cm) for weedy, herbicide-treated, and weed-free plots. Poor grain yields in the weedy treatment were likely caused by high weed density and biomass (Table 2.1).

Potential yield losses in grain sorghum.

Yield losses in grain sorghum between weed free, herbicide-treated and weedy observations were evaluated in 2014. Weed-free plots were considered the maximum achievable yield for each row spacing and seeding rate treatment. When comparing weed-free to weedy grain sorghum yields, significant yield losses occurred at each location in 2014 (Table 2.4). Both row spacing and seeding rate influenced yield loss (YL). As grain sorghum row spacing widened from 25 to 76 cm, YL decreased from 56 to 40 to 36% at Beloit in 2014, but not as expected. At Manhattan as row spacings were widened from 25 to 76 cm, YL fluctuated from 40

to 32 to 58% but greater YL with wider rows as expected. At Hays, yield losses were very high, increasing from 86 to 92% as grain sorghum rows widened (Table 2.4).

Effect of grain sorghum seeding rate on YL was highly variable and not consistent across locations. As grain sorghum seeding rates increased from 75,000 to 150,000 seeds ha⁻¹, YL decreased from 52 to 34% at Beloit as expected. (Table 2.5). Grain sorghum seeding rates did not affect yield losses in Manhattan or Hays. These data suggest that under moderate to heavy weed pressure (Manhattan and Hays) yield loss can be substantial with wide-row spacings and low seeding rates. At the low weed pressure site (Beloit) yield loss was greater in narrow rows and low seeding rates.

When comparing herbicide-treated to weedy observations, differences were inconsistent and highly variable for YL prevented with an herbicide application (YL_H) amongst locations. Both grain sorghum row spacing and seeding rate had significant main effects on YL_H at Beloit. As row spacing widened from 25 to 76 cm, YL_H decreased from 53 to 36% (Table 2.4). Effect of grain sorghum seeding rate was only significant at the Beloit location for YL_H. As seeding rate increased from 75,000 to 150,000 seeds ha⁻¹ YL_H decreased from 51 to 37% (Table 2.5). These data were similar to that of YL, suggesting there was a benefit to the application of a POST herbicide at Beloit. Manhattan and Hays showed no significant responses when comparing herbicide-treated to weedy observations. Differences among locations could be attributed to different weed species and densities present at each location. The large crabgrass infestation in Manhattan (2014) likely contributed to yield loss in herbicide-treated observations because the products applied were not effective on annual grass weeds.

When comparing weed-free observations to herbicide-treated observations, differences were inconsistent and highly variable for YL_{WF-H} due to early season weed interference. These

two observations were compared to evaluate the potential yield loss due to early season weed interference. Differences could've been attributed to varying levels of weed competition, the timing of herbicide application relative to the time of hand hoeing and removal of weeds, and the soil disturbance caused by hand hoeing. Only grain sorghum row spacing had an effect on YL_{WF-H} . No differences were seen amongst observations at Beloit. At Manhattan, as row spacing was narrowed from 76 to 25 cm YL_{WF-H} decreased from 51 to 13 to 0.5%. Grain sorghum row spacings in Hays responded with 51, 45, and 63% yield reductions as row spacing widened from 25 to 76 cm (Table 2.4). YL_{WF-H} was not influenced by grain sorghum seeding rate at any of the locations. These data suggest that when considering a POST herbicide application, greater yield loss can be seen in grain sorghum grown on wider rows versus narrow rows in moderate to heavy weed pressure environments.

Grain sorghum and weed biomass.

Grain sorghum biomass increased as row spacings were narrowed from 76 to 25 cm (Table 2.1). No differences in biomass were seen amongst seeding rates. These data suggest that greater sorghum biomass contributed to greater weed tolerance and higher grain yields.

Weeds studied in this experiment emerged with or soon after crop emergence. Weed biomass values were different among locations but were not different among row spacing and seeding rates treatments (Table 2.1). These data suggest that narrow row spacings and high seeding rates do not suppress weeds, but the grain sorghum can actually tolerate weeds better than when grown in narrow rows and at high seeding rates. Past research has indicated that yield increases from narrow row spacings are attributed to more efficient uses of soil nutrients, water and solar radiation and better weed control (Stahlman and Wicks 2000). There was no mention made of increased sorghum biomass being attributed to greater grain yields in narrow rows.

Light interception and canopy closure.

Light interception values were inconsistent and highly variable across both years and all locations. Light interception values were taken from both weedy and weed-free observations in 2014. No significant differences of light interception were seen in the weed-free observations among row spacing and seeding rate treatments. The first set of readings were taken at 42 to 49 days after planting (DAP) and only grain sorghum at Manhattan had differences in light interception among row spacing and seeding rate treatments. As grain sorghum row spacing widened from 25 to 76 cm, light intercepted fluctuated from 56 to 40 to 42% (Table 2.6). The second set of readings was taken at 56 to 70 DAP, and only showed significant differences in the weedy observations and as grain sorghum row spacing widened from 25 to 76 cm, light intercepted fluctuated from 53 to 66 to 49% (Table 2.6). These data suggest that narrow rows intercepted more light than wide rows early in the growing season. The late readings taken at 70-84 DAP showed no significant differences among row spacings at any location, suggesting that late in the season (GS6) grain sorghum planted on all row spacings had reached canopy closure (Table 2.6). Values taken in 2013 were recorded late in the growing season (GS6) and were rarely different from each other. As grain sorghum row spacing was widened from 25 to 76 cm, percentage of light intercepted fluctuated from 93 to 97 to 95% in Beloit in 2013. No differences were seen in Manhattan 2013, suggesting that by (GS6) all row spacings canopies were closed and near similar values (Table 2.6). These data suggest that the canopies amongst row spacings closed up rather similar to each other by the end of the growing season. The canopy was nearly closed by weeds by GS3 so no difference among light interception values were found at the Hays locations (Table 2.6).

Economic analysis.

Gross profit across grain sorghum seeding rates was evaluated in the weedy environments both years in Beloit. Even when considering additional seed cost with higher seeding rates, grain sorghum planted at 125,000 seeds ha⁻¹ had more gross profit than any of the other seeding rates studied (Table 2.2). Gross profit across row spacings were evaluated in the weed-free, herbicide-treated, and weedy observations at all locations in 2014 (Table 2.3). Grain sorghum grown in narrow rows grossed the most profit in all weed free and herbicide-treated observations at all sites, and weedy observations at Manhattan and Hays sites with the exception being the wider rows at the Beloit site grossed more profit than narrower rows in the weedy observation. Grain sorghum weed-free observations grossed the most profit at all locations. Grain sorghum gross profit from herbicide-treated observations varied and depended on the location (Table 2.3). The herbicide application was assumed at no efficacy on grass weeds. When considering herbicide dosage, and application costs (\$54.61 ha⁻¹), herbicide observations grossed more profit than weedy observations at all locations and row spacings with one exception. Grain sorghum grown on wide rows (76-cm) grossed less profit in the herbicide observation compared to the weedy observation in Manhattan. This result could be attributed to the presence of grass weeds at the location and by better weed tolerance of the narrower row spacings (25-, and 51-cm). Grain sorghum grown in weedy environments grossed the least amount of profit amongst the three observations. This indicates that grain yield and profit were affected by weed interference no matter the density, species, or biomass of weeds present.

Conclusions and Recommendations

Grain sorghum response to seeding rate was variable and dependent upon weed environment. Grain sorghum grown in a low weed pressure site (Beloit) indicated that 125,000

seeds ha⁻¹ out yielded 75,000 seeds ha⁻¹ but was not different from 100,000, or 150,000 seeds ha⁻¹. The differences in yield and gross profit among seeding rates suggested that it is economical to raise seeding rates to optimal levels when including seed costs in a low weed pressure site. However, the seeding rates utilized in this study were within recommended seeding rates to be used across these locations in KS (Staggenborg et. al 1999) so that minimal differences were observed in yields with grain sorghum sown at different seeding rates in weedy situations. Conley et al. (2005) reported that grain sorghum is somewhat flexible to seeding rate or stand density. Yield responses to row spacings were fairly consistent but also depended on the environment in which evaluated. The study also reported that grain sorghum grain yield response to row spacings was variable and dependent upon weed pressure. Grain sorghum grown in a low weed pressure site (Beloit) showed a yield advantage to 76-cm row spacings and a seeding rate of 125,000 seeds ha⁻¹ among the four seeding rates evaluated in this experiment. Grain sorghum grown in a moderate to high weed pressure situation yielded better with narrow row spacings. These yield responses may not be due to weed suppression but more likely by the grain sorghum's ability to tolerate weed pressure. Past research has indicated that narrower rows should suppress weeds, such as up to 72% reduction in weed biomass in narrow-row corn (Marin and Weiner (2014). Weed biomass levels were did not differ among treatments suggesting that grain sorghum grown in narrow row spacings and at high seeding rates may tolerate weed pressure more so than suppress it. These results could be attributed to the fact that grain sorghum in narrow rows produced more sorghum biomass with the same amount of weed biomass as other row spacing treatments, therefore possibly tolerating weeds better than wider row spacings. The data from this experiment would suggest that grain sorghum can be produced across a wide range of row spacings and seeding rates. To determine the optimal row spacing

and seeding rate, the weed pressure and biomass of the environment in question should be considered. Low weed pressure situations would warrant wide row spacings and an average or common seeding rate for the area. A high weed pressure situation would warrant narrow row spacings and an average or common seeding rate for the area. Post-emergence herbicides like pyrasulfotole plus bromoxynil can be effective and economical if application timing is precise and no annual grass weeds are present. When annual grass weeds are present a chloroacetamide herbicide may be used as a PRE to achieve grass weed control. Grain sorghum grown in weed-free situations are the best choice for achieving optimal yield and highest profits but may not always be economical due to added costs associated with a weed-free environment. An IWM (integrated weed management) system should be highly prioritized to achieve maximum weed control/suppression in order to achieve high yields. Future research could look at a wider range of seeding rates and establishing a consistent density and species of weeds across all experimental units. Also, an understanding of the critical weed free period is needed to help adjust weed suppression practices to maximize effectiveness and minimize cost. With the potential release of Inzen (ALS-resistant) grain sorghum hybrids on the horizon, an understanding of grass weed interference and yield loss due to those weeds is crucial to understanding the benefit this product can have on grain sorghum production.

Tables

Table 2.1 Grain sorghum and weed biomass (g m^{-2}) collected at GS6, in response to row spacing averaged across seeding rates at Beloit, Manhattan, and Hays, KS in 2013 and 2014.

Plant Type	Row Spacing	Beloit				Manhattan				Hays	
		2013		2014		2013		2014		2014	
	cm	g m^{-2}									
Sorghum	25	2220	a	1360	a	1260	a	1240	a	840	a
	51	1410	c	950	b	640	b	900	b	240	b
	76	1800	b	1060	b	810	b	920	b	430	b
Weeds	25	-		33	a	330	a	300	a	480	a
	51	-		26	a	260	a	150	a	440	a
	76	-		38	a	290	a	170	a	430	a

Means followed by different letters within plant type are statistically different at the 0.05 probability level within each site and site-year.

– indicates no data were collected for the site-year.

Table 2.2 Grain sorghum weedy yields (kg ha^{-1}) and corresponding gross profits ($\text{\$ ha}^{-1}$) (Eq. 6) determined at a grain price (P_Y) of $\text{\$0.20 kg}^{-1}$ and including seed costs ($\text{\$0.25}$ per 1000 seeds) for four seeding rates averaged across three row spacings in a low weed pressure situation near Beloit, KS in 2013 and 2014.

Year	Seeding Rate	Weedy Yield	Π_w
	$1000 \text{ seeds ha}^{-1}$	kg ha^{-1}	$\text{\$ ha}^{-1}$
2013	75	7640 b	1510
	100	8130 ab	1600
	125	8510 a	1670
	150	8050 ab	1570
2014	75	4270 b	840
	100	4670 ab	910
	125	5270 a	1020
	150	5020 ab	970

Mean yield values in a given year followed by same letters are not different at 0.05 level.

Table 2.3 Grain sorghum yield from weed-free, herbicide-treated, and weedy plots (kg ha^{-1}) and corresponding gross profits ($\text{\$ ha}^{-1}$) with a P_Y of $\text{\$0.20 kg}^{-1}$ for three different row spacings averaged across four seeding rates at three locations in Kansas in 2014.

Assumptions about herbicide efficacy are described in the text.

Location	Row Spacing	2014				2013			
		W-F yield	Π_{WF}	H yield	Π_H	W yield	Π_w	W yield	Π_w
	cm	kg ha^{-1}	$\text{\$ ha}^{-1}$						
Beloit	25	10490 a	2098	10120 a	1970	4470 b	894	7850 b	1570
	51	7950 b	1590	8700 ab	1690	4650 ab	930	7870 b	1570
	76	8330 b	1666	8350 b	1620	5310 a	1062	8520 a	1700
Manhattan	25	8260 a	1652	7700 a	1490	5400 a	1080	6820 a	1360
	51	6380 b	1276	5760 b	1100	4370 ab	874	6110 a	1220
	76	6150 b	1230	3340 c	610	3160 b	632	5930 a	1190
Hays	25	6920 a	1384	3340 a	610	930 a	186	-	-
	51	5440 b	1088	2860 ab	520	350 b	70	-	-
	76	5820 ab	1164	2030 b	350	550 b	110	-	-

Mean yield values for each location observation, and year followed by same letters are not different at the 0.05 level.

Table 2.4 Grain sorghum yield loss (%) based on Equations 1, 2, 3 for each row spacing averaged across seeding rates for each location based on 2014 data.

Location	Row Spacing	YL	YL _H	YL _{WF-H}
	cm	—————%—————		
Beloit	25	56 a	53 a	1 a
	51	40 b	46 ab	-1 a
	76	36 b	36 b	-12 a
Manhattan	25	39 ab	34 a	0.5 b
	51	32 b	24 a	13 b
	76	58 a	-16 a	51 a
Hays	25	86 b	70 a	51 ab
	51	92 a	87 a	45 b
	76	92 ab	64 a	63 a

Means within each location followed by different letters are statistically different at the 0.05 probability level. YL is the yield loss (%) due to natural weed infestation competition (Eq. 1). YL_H is the yield loss (%) due to natural weed infestation competition compared to the use of a POST herbicide-treated observation (Eq. 2). Y_{WF-H} is the yield loss prevented by POST herbicide-treated application as compared to the weed-free observation (Eq. 3).

Table 2.5 Yield losses (%) for each seeding rate averaged across row spacings in the field study near Beloit, KS in 2014.

Seeding Rate	YL	YL _H
seeds ha ⁻¹	%	
75,000	52 a	51 a
100,000	46 a	50 ab
125,000	43 ab	42 ab
150,000	34 b	37 b

Means followed by different letters are statistically different at the 0.05 probability level for each yield loss column. YL is the yield loss (%) due to natural weed infestation competition (Eq. 1), and YL_H is the yield loss (%) due to natural weed infestation competition compared to the use of a POST herbicide-treated weedy observation (Eq. 2).

Table 2.6 Light interception by grain sorghum and weeds (% of incoming radiation) early (42 to 49 days after planting (DAP)), mid (56 to 70 DAP), and late (70 to 84 DAP) in the weedy observation plots for three row spacings averaged across seeding rates at Beloit, Manhattan and Hays, KS in 2014.

Row Spacing cm	Beloit		Manhattan		Hays	
	Early	Mid	Early	Late	Early	Late
	% Intercepted					
25	65 a	53 ab	56 a	89 a	81 a	93 a
51	63 a	66 a	40 b	79 a	78 a	91 a
76	59 a	49 b	42 ab	88 a	80 a	87 a

Means followed by different letters are statistically different at the 0.05 probability level within each location and timing

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Appendix A -

Table A.1 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), sorghum height (cm) at the timing of light interception readings, light interception values both above and below the canopy, and sorghum density (# m⁻²) and number of tillers at the time of biomass harvest (# m⁻²) for Beloit in 2013.

Light Interception								
August 24th								
Plot	Rep	Row Spacing	Seeding Rate	Sorghum Height	Above	Below	Sorghum Density	Tillers
#	#	cm	1000 seeds ha ⁻¹	cm			# m ⁻²	# m ⁻²
108	1	25	75	124	1475	244.8	16	2
107	1	25	100	125	1501	205.4	15	8
106	1	25	125	118	1500	65.4	11	10
105	1	25	150	111	1500	245.8	10	6
102	1	51	75	125	1515	155.4	12	4
103	1	51	100	133	1518	25.6	14	5
101	1	51	125	112	1508	33.6	13	2
104	1	51	150	122	1508	47.6	20	0
110	1	76	75	123	1480	56.5	15	6
111	1	76	100	130	1465	185.6	17	3
112	1	76	125	127	1480	115.4	20	3
109	1	76	150	135	1479	38.6	18	1
201	2	25	75	110	1450	57	6	13
202	2	25	100	122	1508	68	11	4
203	2	25	125	113	1470	258	7	11
204	2	25	150	124	1450	44	16	3
208	2	51	75	123	1400	130	13	0

207	2	51	100	115	1415	7	16	15
205	2	51	125	142	1455	42	14	8
206	2	51	150	130	1460	18	10	3
211	2	76	75	127	1415	52	12	12
212	2	76	100	130	1400	60	17	7
210	2	76	125	123	1430	25	14	9
209	2	76	150	124	1420	115	21	5
307	3	25	75	120	1220	38.6	14	6
305	3	25	100	123	1205	17.6	9	6
306	3	25	125	125	1250	42.6	15	6
308	3	25	150	127	1225	46.8	16	7
303	3	51	75	134	1250	7.8	16	5
304	3	51	100	145	1230	26.4	14	2
302	3	51	125	127	1325	18.8	11	4
301	3	51	150	135	1330	14.8	11	6
311	3	76	75	136	1255	29.8	12	15
309	3	76	100	136	1215	150.4	14	5
310	3	76	125	130	1220	52.4	14	6
312	3	76	150	140	1185	36.4	16	2
401	4	25	75	119	1158	22	23	0
402	4	25	100	188	1110	26.8	23	4
404	4	25	125	110	1120	5	15	1
403	4	25	150	109	1135	225	12	2
406	4	51	75	101	1130	35	13	6
405	4	51	100	115	1135	8.8	15	9
408	4	51	125	127	1100	56.8	14	5
407	4	51	150	125	1030	38	23	2
409	4	76	75	137	1125	22	13	7
411	4	76	100	123	1000	27.6	17	5
412	4	76	125	127	1280	63	18	4
410	4	76	150	139	1065	27	21	4

Table A.2 Plot number, replication, row spacing (cm), seeding rate (1000 seeds ha⁻¹), light interception values both above (Weedy A) and below (Weedy B) the canopy as detected by line quantum sensor, and sorghum density (# m⁻²) determined at time of biomass harvest for Manhattan in 2013.

Light Interception						
September 3rd						
Plot	Rep	Row Spacing	Seeding Rate	Weedy A	Weedy B	Sorghum Density
#	#	cm	1000 seeds ha ⁻¹			# m ⁻²
112	1	25	75	1021	342	10
109	1	25	100	1150	285	14
110	1	25	125	1128	619	11
111	1	25	150	1075	516	17
108	1	51	75	1051	504	10
107	1	51	100	1062	412	12
105	1	51	125	986	828	17
106	1	51	150	1081	382	15
103	1	76	75	995	877	19
104	1	76	100	976	752	17
102	1	76	125	950	563	17
101	1	76	150	696	386	20
207	2	25	75	1268	393	18
206	2	25	100	1270	676	14
208	2	25	125	1209	221	13
205	2	25	150	1176	1063	17
203	2	51	75	1162	1146	18
201	2	51	100	1216	544	13
204	2	51	125	1172	1158	15

202	2	51	150	1230	275	18
211	2	76	75	1353	187	8
210	2	76	100	1249	742	17
209	2	76	125	1236	329	12
212	2	76	150	1336	303	11
306	3	25	75	1035	525	17
305	3	25	100	758	606	17
308	3	25	125	1185	430	18
307	3	25	150	1100	656	18
303	3	51	75	873	730	15
302	3	51	100	783	658	19
304	3	51	125	839	691	13
301	3	51	150	1252	875	21
312	3	76	75	716	122	14
309	3	76	100	1005	385	14
311	3	76	125	693	363	18
310	3	76	150	1125	396	20
401	4	25	75	1022	825	20
403	4	25	100	1015	875	20
404	4	25	125	825	730	24
402	4	25	150	1132	818	25
409	4	51	75	861	411	13
410	4	51	100	900	512	15
412	4	51	125	1580	1120	17
411	4	51	150	1200	495	22
408	4	76	75	820	471	15
406	4	76	100	825	396	18
407	4	76	125	705	385	22
405	4	76	150	755	505	24

Table A. 3 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), sorghum biomass wet and dry (g m⁻²), yield (kg ha⁻¹) at 14% grain moisture for Beloit in 2013.

Plot #	Rep #	Row Spacing (cm)	Seeding Rate (1000 seeds ha ⁻¹)	Sorghum Biomass		Adjusted Yield
				Wet (g m ⁻²)	Dry (g m ⁻²)	Weedy (kg ha ⁻¹)
108	1	25	75	6006	2119	5264
107	1	25	100	7637	2594	7465
106	1	25	125	7313	2580	8017
105	1	25	150	5680	1957	5988
102	1	51	75	5056	1779	7355
103	1	51	100	7208	2741	6610
101	1	51	125	4646	1600	8546
104	1	51	150	5125	1723	7617
110	1	76	75	7171	2662	7000
111	1	76	100	5668	2001	8041
112	1	76	125	6540	2468	8521
109	1	76	150	5765	2184	7215
201	2	25	75	7537	2788	7629
202	2	25	100	5269	1858	8192
203	2	25	125	7442	2723	8137
204	2	25	150	5358	1764	8192
208	2	51	75	5403	1846	7509
207	2	51	100	7142	2561	8903
205	2	51	125	6183	2173	8454
206	2	51	150	4858	2500	7950
211	2	76	75	7931	2920	8406
212	2	76	100	7784	2692	8781
210	2	76	125	7230	2618	7707

209	2	76	150	7081	2570	8362
307	3	25	75	6609	2871	6266
305	3	25	100	5507	2146	8864
306	3	25	125	5028	1984	8782
308	3	25	150	6982	3057	8459
303	3	51	75	5206	2210	7870
304	3	51	100	5189	2317	7280
302	3	51	125	3793	1692	6795
301	3	51	150	4321	1582	7272
311	3	76	75	8462	3796	8517
309	3	76	100	6285	2819	8736
310	3	76	125	6084	2753	8770
312	3	76	150	5616	2482	9361
401	4	25	75	4259	1824	8895
402	4	25	100	4586	2072	8296
404	4	25	125	4208	1908	8714
403	4	25	150	4673	2038	8462
406	4	51	75	6141	2698	7831
405	4	51	100	5616	2404	7651
408	4	51	125	5055	2114	10196
407	4	51	150	5072	2139	8086
409	4	76	75	5972	2791	9077
411	4	76	100	6785	2935	8740
412	4	76	125	5962	2746	9513
410	4	76	150	6841	3227	9591

Table A. 4 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), grain sorghum and weeds wet and dry weights (g m⁻²), head count at harvest time (# m⁻²) and grain yield (kg ha⁻¹) for Manhattan in 2013.

Plot	Rep	Row Spacing	Seeding Rate	Weed Biomass		Sorghum Biomass		Heads	Adjusted Yield
				Wet	Dry	Wet	Dry	Weedy	Weedy
#	#	cm	1000seeds ha ⁻¹	g m ⁻²				# m ⁻²	kg ha ⁻¹
112	1	25	75	1752	405	2593	571	10	1626
109	1	25	100	1567	354	2175	441	14	2620
110	1	25	125	4392	1000	1798	393	11	3721
111	1	25	150	3864	922	2393	563	17	3670
108	1	51	75	3472	767	2262	488	10	1936
107	1	51	100	2456	518	2587	565	12	2264
105	1	51	125	971	263	3376	955	17	4792
106	1	51	150	2256	523	4526	115	15	2856
103	1	76	75	938	273	3114	886	19	8127
104	1	76	100	820	162	4864	1273	17	7204
102	1	76	125	585	135	6504	1953	17	7023
101	1	76	150	931	248	4636	1113	20	6156
207	2	25	75	2934	603	876	186	18	6893
206	2	25	100	2881	658	1833	378	14	2481
208	2	25	125	2229	464	1991	407	13	2185
205	2	25	150	332	68	5347	1377	17	11132
203	2	51	75	2027	442	2169	537	18	5168
201	2	51	100	2064	485	2528	607	13	2643
204	2	51	125	523	103	3924	982	15	6586
202	2	51	150	2695	583	2294	460	18	2877
211	2	76	75	3855	733	2266	450	8	222

210	2	76	100	3217	720	2993	615	17	1366
209	2	76	125	3202	641	1334	272	12	1236
212	2	76	150	3762	766	915	181	11	165
306	3	25	75	1018	336	3229	1518	17	6181
305	3	25	100	13	12	5165	2462	17	10185
308	3	25	125	668	220	3836	1726	18	5141
307	3	25	150	232	89	4127	1921	18	9878
303	3	51	75	67	28	3916	1893	15	6796
302	3	51	100	4	8	3898	1837	19	7553
304	3	51	125	129	38	4606	2212	13	7436
301	3	51	150	157	50	4447	2025	21	6833
312	3	76	75	1682	458	2914	963	14	1186
309	3	76	100	1155	326	3369	1469	14	2202
311	3	76	125	2471	851	3151	1148	18	4339
310	3	76	150	740	238	3813	1394	20	4938
401	4	25	75	26	16	4464	2543	20	10571
403	4	25	100	260	72	3530	1838	20	10935
404	4	25	125	0	0	4035	1978	24	12074
402	4	25	150	45	139	4534	2334	25	7599
409	4	51	75	2984	855	1461	526	13	2380
410	4	51	100	2588	721	1897	647	15	1572
412	4	51	125	2184	599	1951	788	17	1282
411	4	51	150	1383	385	2046	834	22	2475
408	4	76	75	2587	685	1184	433	15	2600
406	4	76	100	1380	400	4648	2318	18	5406
407	4	76	125	1218	355	4414	2191	22	5152
405	4	76	150	109	38	5847	3057	24	6299

Table A. 5 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), sorghum density (# 0.5 m⁻²) and weed density (# 0.5 m⁻²) and sorghum height (cm) recorded on July 16, 2014 for Beloit in 2014.

Plot	Rep	Row Spacing	Seeding Rate	Sorghum	Sorghum Height	Weed Densities	
						Common Purslane	Carpetweed
#	#	cm	1000 seeds ha ⁻¹	# 0.5 m ⁻²	cm	# 0.5 m ⁻²	# 0.5 m ⁻²
109	1	25	75	1	74	2	6
110	1	25	100	2	75	0	16
111	1	25	125	2	83	0	3
112	1	25	150	3	75	5	1
103	1	51	75	3	87	6	28
101	1	51	100	4	85	0	17
102	1	51	125	3	83	5	8
104	1	51	150	1	86	4	11
107	1	76	75	2	72	5	24
106	1	76	100	3	75	4	6
105	1	76	125	1	64	0	7
108	1	76	150	1	70	2	12
203	2	25	75	3	80	0	11
204	2	25	100	1	81	6	16
202	2	25	125	4	72	0	7
201	2	25	150	4	76	0	12
211	2	51	75	3	80	1	23
210	2	51	100	3	70	1	11
209	2	51	125	4	75	8	23
212	2	51	150	3	80	5	3
205	2	76	75	1	83	3	1

206	2	76	100	2	77	2	6
208	2	76	125	4	75	3	5
207	2	76	150	3	65	1	14
310	3	25	75	2	72	3	15
311	3	25	100	4	90	1	2
309	3	25	125	1	74	2	2
312	3	25	150	4	76	0	11
303	3	51	75	1	72	3	29
304	3	51	100	2	80	4	0
302	3	51	125	2	81	2	2
301	3	51	150	2	71	5	0
308	3	76	75	2	72	9	2
307	3	76	100	4	74	1	11
306	3	76	125	4	88	2	9
305	3	76	150	2	71	2	9
401	4	25	75	4	88	6	0
404	4	25	100	3	76	3	2
402	4	25	125	2	73	1	1
403	4	25	150	3	74	10	10
409	4	51	75	6	76	2	8
411	4	51	100	7	85	1	5
412	4	51	125	3	74	3	14
410	4	51	150	3	82	1	0
408	4	76	75	2	73	9	3
407	4	76	100	2	72	5	6
405	4	76	125	2	67	3	3
406	4	76	150	2	74	2	8

Table A. 6 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), sorghum density (# 0.5 m⁻²), sorghum height (cm) and weed densities (# 0.5 m⁻²) recorded on August 1, 2014 for Manhattan in 2014.

Plot	Rep	Row Spacing	Seeding Rate	Sorghum Density	Sorghum Height	Weed Densities		
						Carpetweed	Large Crabgrass	Palmer Amaranth
#	#	cm	1000seeds ha ⁻¹	# 0.5 m ⁻²	cm	# 0.5 m ⁻²		
112	1	25	75	2	70	0	2	1
109	1	25	100	3	77	0	2	2
110	1	25	125	7	80	1	3	0
111	1	25	150	2	60	0	3	1
108	1	51	75	5	75	3	0	0
107	1	51	100	1	90	0	1	1
105	1	51	125	6	82	0	0	1
106	1	51	150	3	77	1	0	2
103	1	76	75	2	45	1	4	1
104	1	76	100	2	72	1	2	7
102	1	76	125	4	50	1	8	2
101	1	76	150	1	45	0	4	2
207	2	25	75	2	70	0	1	0
206	2	25	100	3	79	0	2	0
208	2	25	125	1	77	0	1	1
205	2	25	150	5	62	0	3	0
203	2	51	75	4	77	1	0	0
201	2	51	100	1	86	0	3	1
204	2	51	125	2	85	0	1	0
202	2	51	150	2	64	1	1	0
211	2	76	75	2	50	0	5	0
210	2	76	100	4	70	2	4	1

209	2	76	125	3	54	1	3	11
212	2	76	150	5	55	0	3	0
306	3	25	75	3	66	2	2	0
305	3	25	100	3	67	0	0	0
308	3	25	125	2	60	1	2	0
307	3	25	150	1	55	0	6	2
303	3	51	75	1	84	3	1	0
302	3	51	100	3	80	0	0	0
304	3	51	125	1	79	0	0	0
301	3	51	150	3	70	1	0	0
312	3	76	75	4	50	2	10	1
309	3	76	100	3	60	0	4	3
311	3	76	125	4	57	1	2	5
310	3	76	150	3	55	0	1	2
401	4	25	75	7	79	0	1	0
403	4	25	100	1	73	0	0	0
404	4	25	125	1	60	0	2	2
402	4	25	150	3	65	0	5	4
409	4	51	75	4	90	0	0	0
410	4	51	100	1	79	1	0	1
412	4	51	125	1	74	0	0	0
411	4	51	150	1	60	0	2	1
408	4	76	75	1	47	2	7	7
406	4	76	100	2	60	0	7	1
407	4	76	125	3	56	0	5	2
405	4	76	150	2	45	2	7	1

Table A. 7 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), weed and sorghum densities (# 0.5 m⁻²) recorded on July 8, 2014 for Hays in 2014.

Plot	Rep	Row Spacing	Seeding Rate	Palmer Amaranth	Weed Density July 8 th		
					Puncturevine	Carpetweed	Sorghum
#	#	cm	1000 seeds ha ⁻¹		# 0.5 m ⁻²		
102	1	25	75	12	0	3	3
103	1	25	75	20	3	2	3
106	1	25	125	1	2	4	2
105	1	25	150	11	4	4	0
104	1	51	75	3	13	0	1
101	1	51	100	25	6	3	5
109	1	51	150	9	5	0	5
110	1	51	150	3	2	2	8
107	1	76	75	6	1	13	2
108	1	76	75	19	4	1	2
111	1	76	125	22	3	3	3
112	1	76	150	10	0	9	3
209	2	25	75	24	4	4	2
201	2	25	100	11	1	8	5
206	2	25	100	9	3	4	3
207	2	25	150	3	1	5	2
211	2	51	75	20	10	4	2
202	2	51	100	12	5	7	0
203	2	51	125	40	3	12	0
205	2	51	125	23	9	5	5
204	2	76	75	14	2	2	2
212	2	76	100	11	1	4	3
208	2	76	150	5	4	1	2

210	2	76	150	8	0	4	1
308	3	25	75	19	4	1	3
301	3	25	100	12	5	2	1
302	3	25	150	5	1	4	4
304	3	25	150	6	6	0	4
309	3	51	75	6	4	4	7
312	3	51	100	31	4	5	1
306	3	51	125	27	7	4	2
311	3	51	150	20	0	9	6
303	3	76	75	14	2	3	1
305	3	76	75	1	1	3	4
307	3	76	125	24	4	3	8
310	3	76	125	4	3	0	11
409	4	25	100	16	3	3	2
410	4	25	100	2	0	2	4
406	4	25	125	14	3	3	6
411	4	25	125	6	5	0	1
405	4	51	100	25	7	0	0
403	4	51	125	7	5	5	3
404	4	51	125	20	6	3	4
407	4	51	150	18	2	8	2
408	4	76	100	4	1	5	2
412	4	76	100	4	1	2	3
402	4	76	125	3	1	1	3
401	4	76	150	17	1	6	5

Table A. 8 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), light interception values for both non weedy above (Non A) and below (Non B) and weedy above (Weedy A) and below (Weedy B) the sorghum canopy recorded on July 16, 2014 for Beloit in 2014.

Light Interception July 16th							
Plot	Rep	Row Spacing	Seeding Rate	Non A	Non B	Weedy A	Weedy B
#	#	cm	1000seeds ha ⁻¹				
109	1	25	75	2.669	1.292	2.657	1.041
110	1	25	100	2.304	0.9599	2.391	1.236
111	1	25	125	2.351	0.5699	2.381	0.7909
112	1	25	150	1.984	0.8154	2.062	0.729
103	1	51	75	3.203	1.638	3.055	0.8081
101	1	51	100	2.321	1.089	2.789	1.239
102	1	51	125	2.174	0.8766	2.599	0.6389
104	1	51	150	2.251	0.7439	2.372	0.4331
107	1	76	75	2.066	1.031	2.035	1.043
106	1	76	100	2.731	0.6369	2.64	0.93
105	1	76	125	2.816	1.359	2.868	1.397
108	1	76	150	3.109	1.919	3.852	2.692
203	2	25	75	2.647	1.02	2.642	1.252
204	2	25	100	2.325	1.211	2.293	0.7367
202	2	25	125	2.197	0.9122	2.045	0.2897
201	2	25	150	2.076	0.7665	2.086	0.6711
211	2	51	75	2.962	1.519	2.943	0.6985
210	2	51	100	2.235	1.048	2.773	1.254
209	2	51	125	2.149	1.349	2.415	1.14
212	2	51	150	2.351	1.084	2.426	0.6454

205	2	76	75	2.009	0.9583	2.063	0.6308
206	2	76	100	2.763	1.212	2.695	0.7894
208	2	76	125	3.101	1.327	3.033	1.358
207	2	76	150	4.544	1.879	4.828	1.836
310	3	25	75	2.596	1.5	2.484	1.126
311	3	25	100	2.302	1.019	2.364	0.6032
309	3	25	125	2.137	0.7547	2.051	0.8451
312	3	25	150	2.025	1.143	2.085	0.8736
303	3	51	75	2.908	1.776	2.838	1.693
304	3	51	100	2.209	1.105	2.721	0.6721
302	3	51	125	2.164	1.099	2.402	1.412
301	3	51	150	2.438	1.174	2.484	0.9078
308	3	76	75	2.003	0.668	2.068	0.6445
307	3	76	100	2.663	1.48	2.632	0.9119
306	3	76	125	3.434	1.666	3.477	2.026
305	3	76	150	5.106	3.012	5.173	2.395
401	4	25	75	2.459	0.843	2.443	0.742
404	4	25	100	2.254	1.594	2.288	0.5099
402	4	25	125	2.047	1.183	2.068	0.7246
403	4	25	150	2.073	1.288	2.017	1.006
409	4	51	75	2.152	0.9845	2.805	0.7378
411	4	51	100	2.196	0.7695	2.648	0.5936
412	4	51	125	1.98	0.7762	2.254	0.571
410	4	51	150	2.462	1.002	2.611	1.025
408	4	76	75	1.944	0.5812	1.904	0.4041
407	4	76	100	2.715	1.469	2.791	1.221
405	4	76	125	3.661	1.945	3.747	2.202
406	4	76	150	5.135	1.836	4.862	1.972

Table A. 9 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), light interception values for both weedy above (Weedy A) and below (Weedy B) and non-weedy above (Non A) and below (Non B) the sorghum canopy recorded on July 31, 2014 for Beloit in 2014.

Light Interception July 31st							
Plot	Rep	Row Spacing	Seeding Rate	Weedy A	Weedy B	Non A	Non B
#	#	cm	1000seeds ha ⁻¹				
109	1	25	75	5.96	2.025	6.069	3.031
110	1	25	100	6.084	0.5176	6.247	2.637
111	1	25	125	6.148	2.014	6.145	0.916
112	1	25	150	5.915	2.744	6.094	2.999
103	1	51	75	6.145	0.8462	6.165	3.688
101	1	51	100	6.213	1.762	6.056	2.66
102	1	51	125	6.239	3.22	6.23	3.538
104	1	51	150	6.001	2.738	6.142	1.305
107	1	76	75	6.182	3.664	6.149	3.101
106	1	76	100	6.193	2.567	6.737	1.898
105	1	76	125	6.023	4.301	5.944	2.586
108	1	76	150	6.167	4.852	6.187	4.256

203	2	25	75	5.806	4.008	5.901	3.635
204	2	25	100	5.91	4.059	6.001	2.933
202	2	25	125	6.134	0.2432	6.002	3.04
201	2	25	150	6.019	2.637	5.994	3.527
211	2	51	75	6.156	1.098	6.083	1.761
210	2	51	100	5.871	1.074	6.137	1.611
209	2	51	125	6.147	4.376	6.332	4.134
212	2	51	150	5.997	1.717	6.069	2.484
205	2	76	75	6.12	3.515	6.207	2.727
206	2	76	100	5.968	1.931	6.177	1.375
208	2	76	125	6.026	2.249	5.782	2.835
207	2	76	150	6.319	3.616	6.107	2.232
310	3	25	75	5.91	3.618	6.048	3.579
311	3	25	100	5.962	2.637	6.039	1.959
309	3	25	125	6.175	1.843	6.126	1.432
312	3	25	150	5.657	3.654	5.535	1.81
303	3	51	75	6.182	1.311	6.047	2.567
304	3	51	100	6.133	3.606	6.129	2.512
302	3	51	125	6.242	3.367	6.207	4.542
301	3	51	150	5.861	2.088	6.087	2.497
308	3	76	75	5.943	3.056	6.098	1.611

307	3	76	100	6.062	2.101	6.075	3.575
306	3	76	125	6.185	4.632	6.202	2.845
305	3	76	150	6.025	3.048	5.956	3.107
401	4	25	75	6.127	3.156	6.152	3.017
404	4	25	100	6.042	2.532	6.175	4.028
402	4	25	125	5.564	2.05	6.145	4.416
403	4	25	150	5.867	4.042	5.622	2.368
409	4	51	75	6.135	0.5832	6.232	1.424
411	4	51	100	6.171	2.897	6.231	3.31
412	4	51	125	5.808	2.868	6.007	1.952
410	4	51	150	6.002	1.762	6.129	2.895
408	4	76	75	6.044	3.138	6.144	1.368
407	4	76	100	6.077	3.206	6.072	3.635
405	4	76	125	6.284	2.474	6.168	3.408
406	4	76	150	6.218	2.021	6.087	1.412

Table A. 10 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), light interception values for both non weedy above (Non A) and below (Non B) and weedy above (Weedy A) and below (Weedy B) the sorghum canopy recorded on August 24, 2014 for Beloit in 2014.

Light Interception August 24 th							
Plot	Rep	Row Spacing	Seeding Rate	Non A	Non B	Weedy A	Weedy B
#	#	cm	1000seeds ha ⁻¹				
109	1	25	75	1.334	0.2933	1.261	0.1631
110	1	25	100	5.254	0.8656	5.59	2.541
111	1	25	125	5.544	0.5636	5.482	0.2634
112	1	25	150	1.33	0.239	1.427	0.2875
103	1	51	75	4.681	0.8435	4.163	0.6553
101	1	51	100	4.247	0.4601	4.357	0.4852
102	1	51	125	4.534	0.3533	4.679	0.5495
104	1	51	150	5.151	0.5257	5.258	0.8923
107	1	76	75	5.692	0.6916	5.383	1.675
106	1	76	100	5.724	0.5819	5.425	0.4693
105	1	76	125	4.978	0.9389	5.768	2.383
108	1	76	150	5.732	1.762	1.588	0.3934
203	2	25	75	1.237	0.2085	1.189	0.2377
204	2	25	100	1.702	0.4267	5.081	1.376
202	2	25	125	5.442	0.7536	6.089	0.6783
201	2	25	150	5.849	0.5173	5.587	0.7441
211	2	51	75	4.239	0.4106	4.053	2.637
210	2	51	100	4.545	0.6545	4.417	0.9531
209	2	51	125	4.771	1.785	4.935	0.3815
212	2	51	150	5.831	0.6116	5.518	0.5029

205	2	76	75	5.356	0.6712	5.146	0.8735
206	2	76	100	5.472	0.9275	5.657	0.9811
208	2	76	125	5.848	1.022	5.703	0.8703
207	2	76	150	1.344	0.3003	1.39	0.3712
310	3	25	75	1.375	0.2808	1.454	0.2696
311	3	25	100	1.67	0.3177	1.608	0.3224
309	3	25	125	1.65	0.249	1.248	0.3226
312	3	25	150	5.782	1.494	5.286	0.8231
303	3	51	75	4.082	2.386	4.308	0.6651
304	3	51	100	4.536	0.5233	4.681	2.015
302	3	51	125	4.916	0.7851	4.705	0.6989
301	3	51	150	1.549	0.1968	1.354	0.221
308	3	76	75	5.269	0.7709	5.361	1.268
307	3	76	100	5.791	0.8707	5.617	0.8747
306	3	76	125	5.843	1.027	5.885	1.831
305	3	76	150	2.579	0.5361	5.324	1.204
401	4	25	75	1.834	0.2097	1.649	0.3858
404	4	25	100	1.683	0.6415	5.693	0.8472
402	4	25	125	5.572	1.142	5.779	0.5229
403	4	25	150	5.686	2.486	5.401	1.139
409	4	51	75	4.334	0.628	4.575	0.6341
411	4	51	100	4.525	1.502	4.844	0.3921
412	4	51	125	4.937	1.19	4.657	0.3326
410	4	51	150	1.285	0.1756	1.126	0.1205
408	4	76	75	5.238	1.688	5.517	1.388
407	4	76	100	5.611	1.097	2.574	0.2233
405	4	76	125	5.795	2.019	5.779	2.077
406	4	76	150	5.652	1.221	1.385	0.2561

Table A. 11 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), light interception values for both weedy above (Weedy A) and below (Weedy B) and non-weedy above (Non A) and below (Non B) the sorghum canopy recorded on August 1, 2014 for Manhattan in 2014.

Light Interception August 1st							
Plot	Rep	Row Spacing	Seeding Rate	Weedy A	Weedy B	Non A	Non B
#	#	cm	1000seeds ha ⁻¹				
112	1	25	75	5.548	3.009	5.611	4.484
109	1	25	100	5.577	2.583	5.624	4.575
110	1	25	125	5.412	2.664	5.637	2.162
111	1	25	150	5.585	2.614	5.535	3.688
108	1	51	75	5.539	0.8662	5.443	0.639
107	1	51	100	5.186	0.9023	5.744	1.697
105	1	51	125	5.522	2.161	5.325	0.535
106	1	51	150	5.815	3.098	5.619	2.921
103	1	76	75	5.867	4.356	5.999	3.748
104	1	76	100	5.941	1.309	5.879	3.813
102	1	76	125	5.903	2.895	5.962	3.215
101	1	76	150	6.244	2.866	5.493	5.344
207	2	25	75	5.841	4.469	5.302	0.7925
206	2	25	100	5.434	4.295	5.369	4.576
208	2	25	125	5.964	4.764	5.43	4.357
205	2	25	150	5.934	3.938	5.735	2.743
203	2	51	75	5.388	1.838	5.128	1.314
201	2	51	100	5.271	3.953	5.567	1.485
204	2	51	125	5.624	2.206	5.368	0.789
202	2	51	150	5.685	3.352	5.241	2.965

211	2	76	75	5.927	5.272	5.597	4.066
210	2	76	100	5.991	2.882	6.105	3.904
209	2	76	125	5.99	2.591	5.799	3.334
212	2	76	150	6.322	3.317	6.052	2.045
306	3	25	75	5.322	3.078	5.585	3.666
305	3	25	100	5.852	2.647	5.199	4.351
308	3	25	125	5.445	2.883	5.453	4.229
307	3	25	150	5.619	2.116	5.776	3.831
303	3	51	75	5.378	2.897	5.757	2.996
302	3	51	100	5.252	4.142	5.527	2.079
304	3	51	125	5.206	0.789	5.368	2.068
301	3	51	150	5.588	5.103	5.447	3.704
312	3	76	75	5.732	3.755	5.963	4.845
309	3	76	100	6.103	2.788	5.859	4.236
311	3	76	125	5.729	4.258	5.896	4.025
310	3	76	150	6.056	3.362	5.913	4.166
401	4	25	75	5.234	3.494	5.258	2.35
403	4	25	100	5.386	3.635	5.273	4.398
404	4	25	125	5.754	3.48	5.474	2.573
402	4	25	150	5.626	1.425	5.824	5.146
409	4	51	75	5.274	2.897	5.587	2.727
410	4	51	100	5.569	2.185	5.315	0.8495
412	4	51	125	5.556	1.109	5.52	1.564
411	4	51	150	5.729	4.128	5.447	2.067
408	4	76	75	5.936	4.295	5.944	4.431
406	4	76	100	5.934	2.621	6.033	5.686
407	4	76	125	6.311	3.732	6.004	4.078
405	4	76	150	5.946	4.465	5.682	4.327

Table A. 12 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), light interception values for both non-weedy above (Non A) and below (Non B) and weedy above (Weedy A) and below (Weedy B) the sorghum canopy recorded on September 3, 2014 for Manhattan in 2014.

Light Interception September 3rd							
Plot	Rep	Row Spacing	Seeding Rate	Non A	Non B	Weedy A	Weedy B
#	#	cm	1000seeds ha ⁻¹				
112	1	25	75	5.132	0.4919	5.12	0.8253
109	1	25	100	5.049	1.398	5.089	0.2576
110	1	25	125	5.569	1.779	5.492	1.272
111	1	25	150	5.419	2.612	5.659	0.4359
108	1	51	75	4.748	0.1606	4.85	0.1902
107	1	51	100	4.883	1.591	4.844	0.1389
105	1	51	125	4.858	0.2544	4.903	0.3853
106	1	51	150	5.18	0.7738	5.247	0.1695
103	1	76	75	5.746	4.545	5.469	1.159
104	1	76	100	5.795	2.233	5.664	0.1986
102	1	76	125	5.493	1.566	5.492	0.1644
101	1	76	150	5.294	5.204	5.409	2.3
207	2	25	75	4.974	0.9589	5.007	1.21
206	2	25	100	5.175	0.5503	5.17	0.5077
208	2	25	125	5.493	2.061	5.518	2.338
205	2	25	150	5.507	0.6832	5.534	1.304
203	2	51	75	4.774	0.1746	4.704	0.1859
201	2	51	100	5.112	0.5113	5.101	0.4191
204	2	51	125	4.942	0.2013	4.959	0.4203
202	2	51	150	5.171	0.5658	5.304	0.1709

211	2	76	75	5.545	2.174	5.659	2.056
210	2	76	100	5.536	3.7	5.658	0.247
209	2	76	125	5.556	2.116	5.564	0.1815
212	2	76	150	5.479	0.258	5.681	0.6287
306	3	25	75	5.046	0.7237	5.283	0.3329
305	3	25	100	5.227	1.676	5.049	1.777
308	3	25	125	5.415	5.166	5.65	1.943
307	3	25	150	5.521	2.648	5.637	0.6268
303	3	51	75	4.84	0.6113	5.035	0.3601
302	3	51	100	4.818	0.7776	4.984	0.1389
304	3	51	125	4.778	0.1812	5.149	0.1003
301	3	51	150	4.962	0.7066	5.271	0.1959
312	3	76	75	5.511	2.541	5.647	0.7713
309	3	76	100	5.62	4.269	5.526	0.5539
311	3	76	125	5.604	4.62	5.503	0.5381
310	3	76	150	5.498	0.6321	5.598	3.466
401	4	25	75	4.828	0.6832	4.979	0.1653
403	4	25	100	4.968	0.4794	5.093	0.445
404	4	25	125	5.52	1.266	5.518	2.338
402	4	25	150	5.541	3.346	5.615	1.396
409	4	51	75	4.915	0.3333	4.98	0.3442
410	4	51	100	4.681	0.1426	5.123	0.206
412	4	51	125	5.164	0.6889	5.013	0.324
411	4	51	150	5.149	0.7177	5.145	1.923
408	4	76	75	5.743	3.12	5.547	0.4558
406	4	76	100	5.428	2.731	5.464	0.7026
407	4	76	125	5.495	3.455	5.561	0.686
405	4	76	150	5.544	5.289	5.544	0.5757

Table A. 13 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), light interception values for both weedy above (Weedy A) and below (Weedy B) and non-weedy above (Non A) and below (Non B) the sorghum canopy recorded on July 15, 2014 for Hays in 2014.

Light Interception July 15th							
Plot	Rep	Row Spacing	Seeding Rate	Weedy A	Weedy B	Non A	Non B
#	#	cm	1000seeds ha ⁻¹				
102	1	25	75	1.683	0.2354	1.426	0.8927
103	1	25	75	1.491	0.1328	1.413	0.8447
106	1	25	125	3.329	1.097	4.476	2.763
105	1	25	150	5.154	1.737	3.762	0.8521
104	1	51	75	2.246	0.433	2.21	1.306
101	1	51	100	2.461	0.1399	2.834	0.8542
109	1	51	150	2.051	0.375	1.885	0.6545
110	1	51	150	1.937	0.5032	1.857	0.9635
107	1	76	75	2.361	0.5436	2.164	1.183
108	1	76	75	2.353	0.4224	2.235	1.032
111	1	76	125	3.124	0.9982	3.677	3.265
112	1	76	150	2.973	1.336	2.753	1.391
209	2	25	75	1.484	0.06692	1.324	0.6707
201	2	25	100	1.477	0.2208	1.429	0.5402
206	2	25	100	1.595	0.1833	1.692	0.042
207	2	25	150	3.078	1.467	3.761	2.649
211	2	51	75	2.366	0.1058	2.228	0.732
202	2	51	100	2.681	0.174	2.521	0.6256
203	2	51	125	2.914	0.2312	2.492	2.274
205	2	51	125	3.365	0.1754	2.447	1.279

204	2	76	75	2.316	0.3099	2.321	0.9228
212	2	76	100	2.888	1.357	2.743	1.499
208	2	76	150	2.712	0.7109	2.639	1.621
210	2	76	150	2.538	0.5608	2.692	1.447
308	3	25	75	1.513	0.08551	1.282	0.7776
301	3	25	100	1.591	0.3136	1.803	0.8539
302	3	25	150	2.766	0.7662	2.444	1.491
304	3	25	150	2.427	0.6917	2.4447	1.177
309	3	51	75	2.371	0.2123	2.277	0.637
312	3	51	100	2.872	0.121	2.969	0.824
306	3	51	125	3.765	0.2944	4.027	1.74
311	3	51	150	1.958	0.2064	1.791	0.6686
303	3	76	75	2.246	0.1953	2.118	1.28
305	3	76	75	3.102	0.9557	2.917	1.128
307	3	76	125	4.094	0.8002	5.362	1.928
310	3	76	125	3.114	1.312	3.454	2.129
409	4	25	100	1.869	0.3428	2.055	1.189
410	4	25	100	3.341	1.183	3.213	0.8372
406	4	25	125	4.565	1.146	3.674	1.773
411	4	25	125	4.942	1.497	4.119	1.137
405	4	51	100	2.915	0.142	2.663	0.9982
403	4	51	125	3.603	0.3996	6.912	2.441
404	4	51	125	3.525	0.609	6.581	3.192
407	4	51	150	1.71	0.3271	1.552	0.032
408	4	76	100	3.006	1.508	2.954	1.291
412	4	76	100	3.061	0.613	2.927	2.283
402	4	76	125	3.168	1.348	3.108	1.499
401	4	76	150	2.387	0.5116	2.234	0.7687

Table A. 14 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), interception values for both non-weedy above (Non A) and non-weedy below (Non B) and weedy above (Weedy A) and below (Weedy B) the sorghum canopy recorded on August 19, 2014 for Hays in 2014.

Light Interception August 19th							
Plot	Rep	Row Spacing	Seeding Rate	Non A	Non B	Weedy A	Weedy B
#	#	cm	1000seeds ha ⁻¹				
102	1	25	75	4.131	1.187	3.464	0.3838
103	1	25	75	3.868	0.4423	4.181	0.2277
106	1	25	125	4.727	1.259	4.998	0.2861
105	1	25	150	5.024	0.3006	4.61	0.5707
104	1	51	75	6.367	1.697	6.58	0.843
101	1	51	100	6.449	1.152	5.576	0.594
109	1	51	150	6.458	1.144	6.544	0.2249
110	1	51	150	5.959	0.914	6.477	0.382
107	1	76	75	5.896	0.6536	5.787	0.4424
108	1	76	75	6.548	1.752	6.586	0.7116
111	1	76	125	2.663	0.6633	2.499	0.1685
112	1	76	150	2.566	0.3668	2.515	0.1565
209	2	25	75	3.866	0.8756	3.998	0.3536
201	2	25	100	2.223	0.09436	2.367	0.08774
206	2	25	100	3.001	0.9002	2.175	0.3032
207	2	25	150	5.786	0.4497	6.178	0.4115
211	2	51	75	6.867	0.4337	6.341	0.3077
202	2	51	100	5.106	0.9662	5.187	0.5862
203	2	51	125	3.471	1.402	3.484	0.296
205	2	51	125	3.178	0.9724	3.821	0.2791

204	2	76	75	6.434	0.3696	6.525	0.5816
212	2	76	100	2.581	0.3479	2.616	0.2323
208	2	76	150	2.852	0.3468	2.478	0.2477
210	2	76	150	2.524	0.2702	2.361	0.1445
308	3	25	75	2.699	0.7983	2.909	0.3141
301	3	25	100	4.311	0.2235	3.506	0.2544
302	3	25	150	5.371	0.7112	6.439	0.4623
304	3	25	150	6.167	0.6207	6.507	0.4802
309	3	51	75	6.548	0.103	6.572	0.3815
312	3	51	100	4.794	0.8391	5.669	0.3326
306	3	51	125	3.899	0.3568	4.702	3.693
311	3	51	150	5.923	1.208	6.252	0.4675
303	3	76	75	6.1	0.3637	6.793	0.6421
305	3	76	75	2.355	0.1521	2.652	0.1512
307	3	76	125	2.285	0.2802	2.421	0.2135
310	3	76	125	2.082	0.4614	2.236	0.1165
409	4	25	100	5.203	1.099	4.514	0.1694
410	4	25	100	3.901	0.1192	3.318	0.1288
406	4	25	125	5.206	1.833	5.334	0.4551
411	4	25	125	4.794	0.6336	5.656	0.6879
405	4	51	100	5.727	2.676	4.713	0.3783
403	4	51	125	5.164	0.3565	5.486	0.4115
404	4	51	125	4.995	0.2953	2.998	0.3985
407	4	51	150	4.305	0.6174	4.997	0.1445
408	4	76	100	2.412	0.3309	2.502	0.2927
412	4	76	100	2.264	1.075	2.354	0.2197
402	4	76	125	2.192	0.2962	2.365	0.4704
401	4	76	150	2.469	0.7259	2.674	0.1844

Table A. 15 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), sorghum density and tillers (# m⁻²) and both the sorghum and weeds wet and dry biomass (g m⁻²) for Beloit in 2014.

Plot	Rep	Row Spacing	Seeding Rate	Sorghum		Weeds		Sorghum	
				Density	Tillers	Wet	Dry	Wet	Dry
#	#	cm	1000seeds ha ⁻¹	# m ⁻²	# m ⁻²	g m ⁻²			
109	1	25	75	13	5	132	39	3831	1453
110	1	25	100	11	2	124	56	3072	1174
111	1	25	125	14	8	35	15	3908	1755
112	1	25	150	20	3	41	20	4957	2165
103	1	51	75	12	5	165	53	2976	1365
101	1	51	100	15	8	163	46	4902	2120
102	1	51	125	19	2	112	49	3390	1152
104	1	51	150	13	0	62	22	3656	1453
107	1	76	75	12	4	219	71	3246	1238
106	1	76	100	14	8	158	57	5140	1922
105	1	76	125	14	6	142	45	4650	1887
108	1	76	150	13	0	137	51	2437	869
203	2	25	75	10	9	68	13	3907	1587
204	2	25	100	11	5	84	44	3361	1460
202	2	25	125	13	6	49	14	3574	1624
201	2	25	150	16	7	30	13	5088	2175
211	2	51	75	15	2	160	52	3026	1221
210	2	51	100	16	8	75	26	5089	1997
209	2	51	125	16	2	182	73	3415	1364
212	2	51	150	14	2	38	18	3962	1520
205	2	76	75	9	7	47	15	3634	1362
206	2	76	100	15	3	140	43	3854	1589

208	2	76	125	16	4	374	135	4406	1821
207	2	76	150	16	4	403	114	2754	951
310	3	25	75	17	3	63	19	4669	1874
311	3	25	100	13	5	117	46	3546	1498
309	3	25	125	13	2	22	8	4643	1754
312	3	25	150	18	3	63	26	4965	2205
303	3	51	75	6	15	164	48	4442	1646
304	3	51	100	11	6	464	108	2814	1059
302	3	51	125	22	2	150	55	3535	1297
301	3	51	150	9	10	16	7	4317	1703
308	3	76	75	17	5	0	0	3191	1043
307	3	76	100	11	5	173	66	3668	1343
306	3	76	125	14	0	414	124	2974	1099
305	3	76	150	14	0	59	27	4089	1610
401	4	25	75	15	6	48	16	4081	1648
404	4	25	100	18	4	161	47	2836	1226
402	4	25	125	11	4	16	5	4246	1350
403	4	25	150	9	2	89	36	3436	1262
409	4	51	75	11	6	106	30	3439	1369
411	4	51	100	22	3	220	82	4258	1752
412	4	51	125	15	0	33	7	2683	1020
410	4	51	150	13	12	46	13	4752	1892
408	4	76	75	21	3	25	12	2734	874
407	4	76	100	15	5	60	26	3857	1460
405	4	76	125	12	1	546	183	3490	1373
406	4	76	150	13	8	31	14	5066	2191

Table A. 16 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), sorghum density (# m⁻²) and both the sorghum and weeds wet and dry biomass weights (g m⁻²) for Manhattan in 2014.

Plot	Rep	Row Spacing	Seeding Rate	Sorghum Density	Weeds		Sorghum	
					Wet	Dry	Wet	Dry
#	#	cm	1000seeds ha ⁻¹	# m ⁻²	g m ⁻²			
112	1	25	75	17	104	84	4052	1831
109	1	25	100	15	138	117	3263	1514
110	1	25	125	13	1430	277	4018	1659
111	1	25	150	19	963	402	2086	821
108	1	51	75	16	581	230	5033	2434
107	1	51	100	24	70	24	5918	2614
105	1	51	125	25	0	0	4840	2100
106	1	51	150	13	958	241	2734	1221
103	1	76	75	10	1299	493	1643	656
104	1	76	100	10	1368	448	1691	620
102	1	76	125	27	497	168	2941	1077
101	1	76	150	50	1220	415	1126	371
207	2	25	75	25	477	172	3334	1258
206	2	25	100	19	130	88	5157	2453
208	2	25	125	17	719	226	2735	1149
205	2	25	150	14	1386	526	2044	793
203	2	51	75	15	60	37	4550	2106
201	2	51	100	18	18	10	5173	2246
204	2	51	125	24	0	0	4162	1812
202	2	51	150	14	80	65	3313	1554
211	2	76	75	23	717	326	1769	694
210	2	76	100	13	1921	848	1277	418

209	2	76	125	14	989	323	2004	646
212	2	76	150	14	1709	600	2804	1104
306	3	25	75	14	146	114	3832	1693
305	3	25	100	14	228	162	3218	1435
308	3	25	125	12	488	444	2013	884
307	3	25	150	17	1271	448	1913	661
303	3	51	75	14	223	88	4712	2102
302	3	51	100	13	62	33	3714	1593
304	3	51	125	26	0	0	4629	1901
301	3	51	150	12	100	84	2627	1269
312	3	76	75	18	736	312	1782	573
309	3	76	100	17	11197	344	3061	1228
311	3	76	125	20	2026	689	2693	1015
310	3	76	150	25	484	155	3497	1452
401	4	25	75	19	115	88	3566	1640
403	4	25	100	20	85	68	5195	2477
404	4	25	125	12	488	155	2813	1133
402	4	25	150	10	1547	636	1184	403
409	4	51	75	18	0	0	5731	2535
410	4	51	100	15	13	6	4479	1933
412	4	51	125	21	0	0	4559	1990
411	4	51	150	14	269	200	2047	811
408	4	76	75	7	1228	482	501	88
406	4	76	100	17	1480	735	2262	808
407	4	76	125	10	1425	427	1577	528
405	4	76	150	13	1489	759	1559	746

Table A. 17 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), and both the sorghum and weeds wet and dry biomass weights (g m⁻²) for Hays in 2014.

Plot	Rep	Row Spacing	Seeding Rate	Weeds		Sorghum	
				Wet	Dry	Wet	Dry
#	#	cm	1000seeds ha ⁻¹	g m ⁻²			
102	1	25	75	1665	640	467	218
103	1	25	75	1564	775	1737	842
106	1	25	125	404	192	4019	1756
105	1	25	150	1016	441	1597	700
104	1	51	75	817	391	1556	604
101	1	51	100	2830	1033	269	124
109	1	51	150	830	423	1963	887
110	1	51	150	1931	822	1423	599
107	1	76	75	1895	727	525	223
108	1	76	75	1883	730	1493	596
111	1	76	125	657	236	2266	991
112	1	76	150	274	147	2683	1165
209	2	25	75	1700	777	1249	600
201	2	25	100	2686	1108	577	256
206	2	25	100	2682	1031	537	249
207	2	25	150	1783	679	758	320
211	2	51	75	2145	826	478	203
202	2	51	100	1561	650	987	437
203	2	51	125	2044	874	986	432
205	2	51	125	2946	1059	374	178
204	2	76	75	2531	938	56	25
212	2	76	100	1554	675	1977	951
208	2	76	150	103	60	4298	1954

210	2	76	150	743	394	2688	1287
308	3	25	75	1808	777	501	243
301	3	25	100	2573	1085	196	98
302	3	25	150	2134	852	511	219
304	3	25	150	690	335	3293	1405
309	3	51	75	2079	826	594	277
312	3	51	100	2378	959	723	351
306	3	51	125	2797	1060	42	26
311	3	51	150	3299	1303	490	249
303	3	76	75	2052	782	213	80
305	3	76	75	1702	461	3097	1342
307	3	76	125	130	120	2739	1190
310	3	76	125	1287	485	1422	634
409	4	25	100	2467	1054	174	88
410	4	25	100	956	360	2841	1139
406	4	25	125	1140	403	3123	1208
411	4	25	125	2167	811	1997	823
405	4	51	100	2379	949	430	215
403	4	51	125	2574	1017	1365	569
404	4	51	125	2845	1136	588	228
407	4	51	150	1759	748	1646	756
408	4	76	100	463	270	2270	984
412	4	76	100	580	281	2488	928
402	4	76	125	742	279	3606	1662
401	4	76	150	97	62	3443	1634

Table A. 18 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), and the number of heads collected (# m⁻²) during harvest for both the weed-free and herbicide observations for Beloit in 2014.

Sorghum Heads					
Plot	Rep	Row Spacing	Seeding Rate	Weed-free	Herbicide
#	#	cm	1000seeds ha ⁻¹	# m ⁻²	
109	1	25	75	13	20
110	1	25	100	21	18
111	1	25	125	18	19
112	1	25	150	21	22
103	1	51	75	29	23
101	1	51	100	18	20
102	1	51	125	22	27
104	1	51	150	21	28
107	1	76	75	18	12
106	1	76	100	17	18
105	1	76	125	16	21
108	1	76	150	24	17
203	2	25	75	15	19
204	2	25	100	17	17
202	2	25	125	17	24
201	2	25	150	23	17
211	2	51	75	13	24
210	2	51	100	17	16
209	2	51	125	12	16
212	2	51	150	18	12
205	2	76	75	14	27
206	2	76	100	13	17

208	2	76	125	18	16
207	2	76	150	23	26
310	3	25	75	21	25
311	3	25	100	16	23
309	3	25	125	21	17
312	3	25	150	15	20
303	3	51	75	13	16
304	3	51	100	15	19
302	3	51	125	17	25
301	3	51	150	16	15
308	3	76	75	23	16
307	3	76	100	11	18
306	3	76	125	18	16
305	3	76	150	16	22
401	4	25	75	21	17
404	4	25	100	14	23
402	4	25	125	19	17
403	4	25	150	10	13
409	4	51	75	18	29
411	4	51	100	45	46
412	4	51	125	25	30
410	4	51	150	18	18
408	4	76	75	34	32
407	4	76	100	13	16
405	4	76	125	20	25
406	4	76	150	10	17

Table A. 19 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), and the number of heads collected (# m⁻²) during harvest for weedy, weed-free, and herbicide observations for Manhattan in 2014.

Sorghum Heads						
Plot	Rep	Row Spacing	Seeding Rate	Weedy	Weed-free	Herbicide
#	#	cm	1000seeds ha ⁻¹		# m ⁻²	
112	1	25	75	22	17	37
109	1	25	100	20	9	17
110	1	25	125	11	20	23
111	1	25	150	19	20	18
108	1	51	75	23	25	23
107	1	51	100	18	21	27
105	1	51	125	17	35	29
106	1	51	150	17	17	19
103	1	76	75	11	18	10
104	1	76	100	16	22	6
102	1	76	125	22	23	19
101	1	76	150	12	8	5
207	2	25	75	21	21	17
206	2	25	100	13	18	7
208	2	25	125	12	18	16
205	2	25	150	21	32	28
203	2	51	75	22	20	26
201	2	51	100	25	23	21
204	2	51	125	20	17	25
202	2	51	150	25	21	23
211	2	76	75	16	24	15
210	2	76	100	13	8	20

209	2	76	125	16	18	20
212	2	76	150	22	16	21
306	3	25	75	27	12	25
305	3	25	100	12	13	11
308	3	25	125	19	12	17
307	3	25	150	27	14	22
303	3	51	75	16	15	12
302	3	51	100	29	17	33
304	3	51	125	17	25	47
301	3	51	150	15	17	19
312	3	76	75	12	16	14
309	3	76	100	23	16	17
311	3	76	125	17	22	17
310	3	76	150	14	6	29
401	4	25	75	16	17	30
403	4	25	100	20	21	19
404	4	25	125	12	16	16
402	4	25	150	13	21	19
409	4	51	75	16	16	20
410	4	51	100	21	27	14
412	4	51	125	15	21	29
411	4	51	150	10	20	15
408	4	76	75	8	17	9
406	4	76	100	20	9	24
407	4	76	125	13	13	17
405	4	76	150	11	11	16

Table A. 20 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), and the number of heads collected (# m⁻²) during harvest for both the weed-free, and herbicide observations for Hays in 2014.

Sorghum Heads					
Plot	Rep	Row Spacing	Seeding Rate	Weed-free	Herbicide
#	#	cm	1000seeds ha ⁻¹	# m ⁻²	
102	1	25	75	29	14
103	1	25	75	18	10
106	1	25	125	15	17
105	1	25	150	14	17
104	1	51	75	14	14
101	1	51	100	21	18
109	1	51	150	23	15
110	1	51	150	26	21
107	1	76	75	20	21
108	1	76	75	18	12
111	1	76	125	18	9
112	1	76	150	21	19
209	2	25	75	14	12
201	2	25	100	35	18
206	2	25	100	22	12
207	2	25	150	18	12
211	2	51	75	19	10
202	2	51	100	19	9
203	2	51	125	15	18
205	2	51	125	29	15
204	2	76	75	24	14
212	2	76	100	23	13

208	2	76	150	9	9
210	2	76	150	20	12
308	3	25	75	31	25
301	3	25	100	26	23
302	3	25	150	25	14
304	3	25	150	17	13
309	3	51	75	44	27
312	3	51	100	17	9
306	3	51	125	22	15
311	3	51	150	26	15
303	3	76	75	32	30
305	3	76	75	20	13
307	3	76	125	23	10
310	3	76	125	19	19
409	4	25	100	34	14
410	4	25	100	26	23
406	4	25	125	20	18
411	4	25	125	20	11
405	4	51	100	20	33
403	4	51	125	26	13
404	4	51	125	28	18
407	4	51	150	16	12
408	4	76	100	10	12
412	4	76	100	13	10
402	4	76	125	18	23
401	4	76	150	27	10

Table A. 21 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), grain sorghum yields (kg ha⁻¹) for the weedy, weed-free, and herbicide observations adjusted to 14% for Beloit in 2014.

Plot	Rep	Row Spacing	Seeding Rate	Adjusted Yields		
				Weedy	Weed-free	Herbicide
#	#	cm	1000seeds ha ⁻¹		kg ha ⁻¹	
109	1	25	75	6049	6403	8463
110	1	25	100	4435	6076	8550
111	1	25	125	5636	6132	8100
112	1	25	150	5633	6605	6284
103	1	51	75	3815	5342	5867
101	1	51	100	6268	7309	5682
102	1	51	125	3616	4895	5757
104	1	51	150	4785	5729	5303
107	1	76	75	3842	5991	4459
106	1	76	100	4940	6040	5630
105	1	76	125	5852	6662	5450
108	1	76	150	3182	5942	3527
203	2	25	75	6275	6355	6691
204	2	25	100	4525	5283	6078
202	2	25	125	6294	6627	7928
201	2	25	150	5923	6847	6199
211	2	51	75	5611	5060	6494
210	2	51	100	6031	6805	7014
209	2	51	125	4293	4829	5149
212	2	51	150	5860	6435	5657
205	2	76	75	3797	4966	4559
206	2	76	100	5751	4884	5352

208	2	76	125	5617	5084	5369
207	2	76	150	4169	4148	4900
310	3	25	75	5889	6795	6861
311	3	25	100	3495	3893	4802
309	3	25	125	4564	8737	6344
312	3	25	150	5662	5724	7806
303	3	51	75	3721	7327	7582
304	3	51	100	3838	6339	7284
302	3	51	125	4712	5507	4937
301	3	51	150	4351	7806	6447
308	3	76	75	3258	3725	4962
307	3	76	100	4528	4173	5624
306	3	76	125	4396	6218	6247
305	3	76	150	4238	5648	6397
401	4	25	75	3963	7079	5670
404	4	25	100	4844	4726	5760
402	4	25	125	4758	8194	7864
403	4	25	150	5133	5834	6163
409	4	51	75	6138	6328	7339
411	4	51	100	4239	4963	5013
412	4	51	125	4685	3754	4920
410	4	51	150	4946	7551	6720
408	4	76	75	4299	3927	2076
407	4	76	100	3832	5725	5018
405	4	76	125	4351	5342	5239
406	4	76	150	4746	6595	7553

Table A. 22 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), grain sorghum yields (kg ha⁻¹) for the weedy, weed-free, and herbicide observations adjusted to 14% for Manhattan in 2014.

Plot	Rep	Row Spacing	Seeding Rate	Adjusted Yield		
				Weedy	Weed-free	Herbicide
#	#	cm	1000seed ha ⁻¹		kg ha ⁻¹	
112	1	25	75	3997	9287	13222
109	1	25	100	1762	4462	5441
110	1	25	125	4281	10318	6107
111	1	25	150	8577	8364	5459
108	1	51	75	11604	9312	8240
107	1	51	100	9546	9803	10748
105	1	51	125	8685	8842	6827
106	1	51	150	5603	6764	6205
103	1	76	75	512	3514	1075
104	1	76	100	309	4015	1184
102	1	76	125	2484	6748	1006
101	1	76	150	1336	3020	1197
207	2	25	75	5593	10983	7011
206	2	25	100	1007	11198	1266
208	2	25	125	7890	10966	7172
205	2	25	150	4852	12847	7709
203	2	51	75	9369	10347	9412
201	2	51	100	8889	7231	9702
204	2	51	125	8390	6253	6435
202	2	51	150	4733	11566	9653
211	2	76	75	98	5174	572
210	2	76	100	474	1622	3418

209	2	76	125	654	5883	2365
212	2	76	150	2435	4153	3425
306	3	25	75	7915	6725	10762
305	3	25	100	993	5752	2573
308	3	25	125	4899	7256	4764
307	3	25	150	2835	6568	6144
303	3	51	75	10323	8836	7921
302	3	51	100	8033	8756	10532
304	3	51	125	4723	7621	8351
301	3	51	150	3162	6812	725
312	3	76	75	408	5852	787
309	3	76	100	1275	3881	2193
311	3	76	125	1040	6003	4544
310	3	76	150	1859	2138	2625
401	4	25	75	2488	8145	7539
403	4	25	100	5706	8720	1107
404	4	25	125	8484	7139	6810
402	4	25	150	2113	6148	4255
409	4	51	75	9817	10095	10007
410	4	51	100	7775	7334	9165
412	4	51	125	7702	8558	10075
411	4	51	150	1889	6303	4346
408	4	76	75	953	4581	481
406	4	76	100	1288	2189	2988
407	4	76	125	1397	3093	952
405	4	76	150	887	4787	1591

Table A. 23 Plot number, replication, row spacing (cm) seeding rate (1000 seeds ha⁻¹), grain sorghum yields (kg ha⁻¹) for the weed-free, herbicide, and weedy observations adjusted to 14% for Hays in 2014.

Plot	Rep	Row Spacing	Seeding Rate	Adjusted Yield		
				Weed-free	Herbicide	Weedy
#	#	cm	1000seeds ha ⁻¹	kg ha ⁻¹		
102	1	25	75	10158	1715	40
103	1	25	75	8635	1780	17
106	1	25	125	9270	5979	224
105	1	25	150	8683	3274	35
104	1	51	75	4440	1451	3
101	1	51	100	10294	3158	11
109	1	51	150	7629	2832	32
110	1	51	150	9908	6141	42
107	1	76	75	9741	9146	26
108	1	76	75	10098	5783	27
111	1	76	125	5891	4176	73
112	1	76	150	7578	6265	175
209	2	25	75	8236	3325	30
201	2	25	100	7983	3260	33
206	2	25	100	9199	2676	34
207	2	25	150	8102	4902	31
211	2	51	75	6024	2310	6
202	2	51	100	4760	1724	30
203	2	51	125	2106	1381	6
205	2	51	125	10676	2688	7
204	2	76	75	10257	5299	10
212	2	76	100	10277	4349	107

208	2	76	150	4604	3320	236
210	2	76	150	7345	4437	119
308	3	25	75	10486	1607	29
301	3	25	100	10090	7147	24
302	3	25	150	11467	3127	42
304	3	25	150	7583	5806	176
309	3	51	75	6469	3399	3
312	3	51	100	2948	1525	8
306	3	51	125	6965	3297	3
311	3	51	150	7238	4065	30
303	3	76	75	11907	2756	6
305	3	76	75	11725	4238	80
307	3	76	125	6033	695	93
310	3	76	125	6798	6645	84
409	4	25	100	9735	2517	24
410	4	25	100	7187	5041	147
406	4	25	125	9922	2033	64
411	4	25	125	7856	2770	58
405	4	51	100	3552	1426	4
403	4	51	125	7728	3617	1
404	4	51	125	6271	2140	3
407	4	51	150	8448	2138	47
408	4	76	100	5075	3300	54
412	4	76	100	4320	3527	75
402	4	76	125	10254	7824	172
401	4	76	150	11167	944	147
