

**INTEGRATED PEST MANAGEMENT STRATEGIES FOR A TERRESTRIAL
ISOPOD, *ARMADILLIDIUM VULGARE*, IN NO-TILL SOYBEAN PRODUCTION**

By

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Abstract

No-till management of soybean benefits producers by lowering input costs and retaining soil moisture, but may also provide optimal conditions for increasing populations of soil-inhabiting pests. For Kansas soybean, damaging populations of soil-inhabiting isopods (Malacostraca: Isopoda) have been observed in fields under no-tillage management. To control damage to soybean stands from feeding isopods, current management strategies need to be evaluated. The objectives of my research were to evaluate the effects of chemical and cultural control combinations (seed treatment and planting date, planting date and seed size, seed treatment and natural crop residue removal, and seeding rate and seed treatment) on soybean stand densities exposed to natural isopod populations, and to evaluate the effects of burning crop residue on isopod populations and emergence rates in soybean under no-tillage management. Field studies were conducted in consecutive years (2009 and 2010) in two separate soybean fields within each year. All fields were under no-till management and had a history of damaging isopod populations. In the second chapter, we demonstrated that seed treatment with an insecticide is not a reliable strategy. Doubling normal seeding rates can potentially reduce the number of trips a grower makes across a field (single, high-density versus multiple, low-density plantings). In doing so, growers may save time and money (e.g., fuel). A high seeding rate (563,380/ha), along with a low rate (50 g a.i. / 100 kg seed) of neonicotinoid seed treatment, appears to improve soybean stands ($P < 0.05$). No other combinations of control methods appeared to affect stand density. In the third chapter, we show burning to be an effective strategy to directly influence isopod populations but its overall effect on soybean stands needs further investigation.

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Dedication

I dedicate this thesis to my Father and my Mother, my brother Anas, and my siblings, Yasmine, Susan, and Hala who are more like best friends than family. I also dedicate it to our family angels Haya and Najm Aldeen Sebaiee. I cannot thank my family enough for their constant support, encouragement and for always believing in my choices and standing by me through thick and thin.

Chapter 1: Integrated pest management strategies for terrestrial isopod, *Armadillidium vulgare*, in no-till soybean production

Introduction

The benefits of reduced tillage, or ‘no-till’, cropping systems include the conservation of soil moisture, soil structure, and reduced input costs for producers; however, there may be potential costs or risks associated with pest management in reduced tillage. The undisturbed no-till environment may be optimal for increasing populations of soil-inhabiting pests (Stinner and House 1990). Specifically, soil-borne secondary pests (i.e., those not considered key perennial pests) may be more problematic in no-till cropping systems. Damaging populations of isopods (Malacostraca: Isopoda) have recently been observed in Kansas soybean fields under no-tillage management. Isopods are soil-dwelling organisms that generally feed on dead plant tissue, but have been observed consuming tender seedling tissues (Saska 2008) of many plants, such as soybean (Tulli et al. 2009). Perhaps, no-till management is increasing isopod populations to the extent of inducing intra-specific competition among isopods which may result in consumption of soybean seedlings and reduction of soybean stand densities. In the summer, when climatic conditions are stressing, *A.vulgare* populations remain below the surface of leaf layers to avoid desiccation with no food supply (Brody and Lawlor 1984). Thus, the competition among the populations for the limited resources of food is increased, and exposure to climatic fluctuations is increased with higher mortality. As a response, the growth rate is decreased significantly (Hassall and Dangerfield 1990) and the size of offspring becomes larger to increase the chance

of survival (Brody and Lawlor 1984). Conversely, in the spring when the climatic conditions are cool, the populations of *A.vulgare* are active and can move over 20 m per night so they can get the high quality food which limits competition among populations, and significantly increases the fecundity and growth rate (Hassall and Dangerfield 1990). With the increase in no-till soybean acreage, it is possible that isopods are transitioning into key pest status for some production areas.

Currently, soybean producers lack management options to maintain soybean stands in presence of damaging isopod populations. Combining current control measures may be the best approach against stand loss from isopods. This research evaluates the effectiveness of chemical and cultural control combinations (seed treatment and planting date, planting date and seed size, seed treatment and crop residue removal, and seeding rate and seed treatment) for isopod pest control, and the effects of burning crop residue on stand densities and isopod populations in soybean under no-tillage management.

Soybean

Worldwide, soybean (*Glycine max* L.) Merr., is an economically important crop (Graham and Vance 2003). The United States is a major producer of soybean, accounting for 40% of worldwide soybean trade (Soy Stats 2009). In fact, the United States has 33% of the world oilseed production and had an export value exceeding \$20B in 2008 (Hungaria et al. 2005, Soy Stats 2009). Of its many uses, soybeans are a rich source of protein for human and animal consumption (Gracia et al. 1998; Genta et al. 2002), and are a source for biodiesel production (Kenneth 2001; Graham and Vance 2003; Hungaria 2005). Besides soybean-based commodities,

soybeans provide an added benefit to the field ecosystem. Soybean plantings benefit agricultural land by improving soil structure and fertility (Graham and Vance 2003). Soybean root nodules increase soil nutrients through the natural process of fixing nitrogen via symbiosis with soil rhizobial fungi (Graham and Vance 2003). Nitrogen-fixing roots provide an environmentally-friendly method for increasing nitrogen in nitrogen-poor soils.

Tillage and Effects on Soil Inhabitants

The current shift to no-till soybean cropping systems may be increasing plant susceptibility to pest damage. No-tillage management, also referred to as ‘conservation tillage’, is the practice of reducing soil disturbances and conserving crop residues on soil surfaces (Stinner and House 1990; Tebrugge and During 1999; Cruse et al. 2003). In most cases, residual crops cover over 30% of the soil surface, which benefits the soil by retaining moisture until the following planting while reducing grower inputs (Devine and McMurtrey 2006). No-till systems have been shown to reduce labor costs, fuel, and maintenance associated with machinery (Stinner and House 1990). Furthermore, dry crop residues can be harvested for use as livestock feed, medical, and energy industries (Graham and Vance 2003). Soybean residues account for a large portion of dry residue commodities (Doran et al. 1984). As such, adoption of no-till systems has exponentially increased, especially for soybean and corn systems (Stinner and House 1990; Doran et al. 1984; Bruce et al. 1990; Uri et al 1999; Halford et al 2001).

There are other benefits for conservation of crop residues. Crop residues reduce soil erosion (Teasdale 2007; Laloy and Biolders 2010) from 30-95% compared to conventional tillage (Randall et al. 2002; Cruse et al. 2003). Crop residues reduce erosion by blocking strong

winds that blow soil off the surface (Saxton et al. 1999). Crop residues also affect fertility by maintaining levels of soil carbon (C) and nitrogen (N) (Dick 1997; Havlin et al. 1990; Robert and Chan 1990; Kern and Johnson 1993; Dao 1998). This is important since balanced levels of soil C and N are important for maximum yields (Espinoza 1997; TebruEgge and DuEring 1999; Alkisi and Yin 1995; Marriott and Wander 2006; Teasdale 2007). As previously mentioned, leaving crop residues on the soil surface increases the infiltration and conservation of soil moisture, which is the result of reduced evaporation from exposure to wind and air temperatures (Daniel et al. 1999). Moreover, conservation of soil moisture is important for plant protection during dry conditions (Blevins et al. 1983). When residues are removed completely from the system, soil moisture is reduced, which negatively affects soybean yields (Doran et al. 1984; Linn and Doran 1984).

Soybean yields may also benefit from the effects of no-tillage management (Wilhelm et al. 1986). One study found that soybean yield was reduced when crop residues were removed completely compared to soybean yields with crop residue (Doran et al. 1984). The authors suggest that complete removal of residue made soybean plants susceptible to water and heat stress (Doran et al. 1984). Other studies indicate that presence of crop residue improves soil fertility, resulting in increased soybean yields (Mills and Witt 1989; Doran et al. 1984).

Conservation of crop residues may be beneficial to soil-inhabiting organisms (Cruse et al. 2003; Laloy and Biolders 2010). For example, Shapiro et al. (1999) reported that increased levels of crop residue on fields under corn-soybean rotation increased the populations of the entomopathogenic nematode, *Steinernema carpocapsae*. It has been shown that increased levels of crop residue increase populations of earthworms (*Lumbricus terrestris*), which are beneficial

to soil structure by increasing the infiltration of moisture into the soil (TebruEgge and DuEring 1999).

Crop residues not only protect beneficial arthropods, but also provide shelter for harmful pest species (Kogan and Turnipseed 1987; Wallner 1987; Koul et al. 2004). As such, no-till management may also be increasing crop susceptibility to arthropod pests in some crop systems (Stinner and House 1990). For example, populations of wireworm (*Melanotus cribulosus*), white grub (*Phyllophaga spp.*), flea beetle (*Epitrix cucumeris*), chinch bug (*Blissus leucopterus leucopterus*), and southern corn leaf beetle (*Myochrous denticollis*) have been associated with early-season damage in corn under no-till management (Wilde et al. 2004).

Invertebrate Pests

Soybeans host many types of pests that can limit yields. Early season pests, or those which attack soybean during its vegetative stages, such as soybean aphid (*Aphis glycines*), can restrict the photosynthetic capacity needed to mature and form reproductive structures (Ragsdale et al. 2007). Soil-dwelling or ground-dwelling pests such as slugs and isopods can reduce yields by damaging or killing soybean seedlings (Tulli et al. 2009). Late season pests, or those which attack reproductive structures such as bean leaf beetle, *Cerotoma trifurcate*, limit yield by damaging pod fill (Smelser et al. 1992).

Ground dwelling invertebrate pests represent a significant challenge to a wide range of cropping systems, especially those under no-tillage management which do not disturb the soil. For example, certain species of slugs are only minor pests of corn, unless the conditions provided by presence of crop residue in no-till fields allows them to increase their densities to damaging levels under wet conditions (Hammond 1985). In fact, the gray slug (*Agriolimax reticulates* and

Deroceras reticulatum) is known to achieve high population numbers in early season no-till fields and causes significant defoliation and stand reduction to soybean (Hammond 1985; Stinner and House 1999; Tulli 2009). In southern Australia, the black Portuguese millipede, *Ommatoiulus moreletii* (Lucas), has been reported to cause damage to canola crops (Paoletti et al. 2008). Millipedes predominantly feed on organic matter in the soil and have not been considered a problem in the past; however, some researchers suggest that a shift in the importance of pest species may be a response to climate change or to alterations in farming practices (Paoletti et al. 2008). Similarly, species of the terrestrial isopod (Crustacea: Isopoda), have occasionally been observed in outbreak populations that are capable of damaging crops in Australia (Vandel 1960; Saluso 2001). Cereal cropping systems within Australia are often continuously grown under no-tillage management (Stinner and House, 1990). The occurrence of isopod damage in no-till management attracted attention because isopods have recently been observed in damaging numbers in Kansas no-tillage soybean systems.

Isopods

Ground-dwelling terrestrial isopods have been shown to damage a number of agriculturally important crops, including alfalfa, sunflower, cereals, and soybean (Paris 1963; Byers and Bierlein 1984; Saska 2008; Honek et al. 2009; Tulli et al. 2009). Recent observations in soybean under no-tillage management in central Kansas revealed that isopod were feeding on succulent stem tissue beneath the cotyledons of seedlings, which separates the cotyledons from the emerging seedling and further results in plant death (Whitworth et al. 2008). Under significant isopod pressure, producers must replant damaged fields to obtain harvestable soybean stands. Generally, isopods are not considered a pest in soybean; however, changes in production

practices may be enabling a shift from a minor, or opportunistic, pest status to a perennial early-season pest (Wallner 1987) in some parts of Kansas. No-till soybeans are most susceptible due to the timing of the planting and presence of damp residue, which is ideal for isopod survival (Paris 1963). Isopods are not generally problematic in conventional-tilled fields because there is less soil moisture and less available shelter (Whitworth et al. 2008).

Terrestrial isopods are widely distributed, typically functioning as generalist decomposers of organic material (Brody and Lawlor 1984; Rushton and Hassall 1983; Morisawa et al. 2002). Organic materials, such as leaves and litter, also provide shelter and protection from extreme fluctuations in ambient temperature and humidity (Hassell and Dangerfield 1990). For example, during periods of high temperature and low humidity, isopods tend to remain inactive under layers of leaves (Brody and Lawlor 1984; Refinetti 1984). Terrestrial isopods have very porous integument that is sensitive to changes in the environment (Raham 1986; Fisher et al. 1997). Additionally, they have gill-like respiratory organs (pleopods), which require some moisture to function (Smigel and Gibbs 2008).

Other than climatic conditions, food quality is an important factor in regulating isopod populations (Rushton and Hassall 1983). Residual plant tissue on the soil surface is an ideal food source because isopods are susceptible to the negative effects from plant defense compounds (i.e. tannins) found in living plant tissue (Rushton and Hassall 1983). For example, Cameron and Lapoint (1978) reported that phenolic compounds, specifically tannins, inhibited the feeding of *A. vulgare* on Chinese tallow leaves during fall senescence. In a lab experiment, Cameron and Lapoint (1978) found that *A. vulgare* consumed more senesced leaves compared to intact leaves. Consequently, *A. vulgare* mortality rate was high due to starvation. Additionally, isopods are reported to prefer decayed tissue from dicotyledonous plants, rather than decayed tissues from

monocotyledonous plants, which is poorly digested (Rushton and Hassall 1983). However, some field populations have been observed consuming living plant materials, including: leaves, stems, flowers, and seeds of some plants (Paris and Sikora 1965; Byers and Bierlein 1984; Sasaka 2008). Food quality may influence isopod fitness. One study found that increased isopod body size was correlated to increasing size of seeds (*Cirsium arvense*) that were consumed (Saska 2008). Brody and Lawlor (1984) further suggest that large body size increases survival under extreme conditions. It is known that seasonal changes, along with food availability, influences feeding behaviors. For example, in extreme temperatures, isopod exposure is reduced by limiting foraging time, resulting in increased body sizes because the larger offspring may play a role in *A.vulgare* early survival especially in stress conditions (Brody and Lawlor 1984). Food availability is also known to effect generation time of isopods, where high levels of food availability are associated with outbreak populations of isopods (Caseiro et al. 2000), and changes in pest status (Wallner 1987). In the spring when the climatic conditions are cool, the populations of *A.vulgare* are active and can move over 20 m per night so they can get the high quality food which limits competition among populations, and significantly increases the fecundity and growth rate (Hassall and Dangerfield 1990). At high temperatures, *A.vulgare* populations reduce foraging time to avoid desiccation and remain below the surface of leaf layers with no food supply (Brody and Lawlor 1984), which increases the competition among the populations for the limited resources of food, with more exposure to climatic fluctuations and higher mortality. The growth rate is decreased significantly (Hassall and Dangerfield 1990) and the size of offspring becomes larger to increase the chance of survival (Brody and Lawlor 1984).

Integrated Pest Management

There are few management strategies available for maintaining yields in presence of damaging populations of isopods. To date, efforts have focused on integrated pest management (IPM) strategies for key pests of soybean (Kogan and Turnipseed 1987). These programs incorporate management tactics, such as cultural, mechanical, biological, and chemical to manage pests (Kogan and Turnipseed 1987). The evaluation of strategies against isopods is warranted, especially those which focus on combinations of cultural and chemical control, and those which complement the no-till cropping system.

Cultural controls are components of IPM programs that manipulate the cropping environment to reduce pest numbers or damage from their activities (Koul et al. 2004). Cultural controls are often preferred to chemical controls if they are cost effective, and in some cases are used to increase the effectiveness of chemical controls (Pimentel 1986). Cultural controls may include adjusting phenological asynchrony of the plant and pest (i.e. adjusting the planting date), seeding rate, seed size, or removal of residue in no-till systems. These control tactics may be used alone or in combination depending on the cropping system (Greene et al. 1985). For example, it has been shown that early sown wheat, which tillers before the onset of attack by wheat bulb fly (*Hylemia coarctata*), is able to compensate for damage compared to late-sown crops (Paoletti and Hassall 1999; Glen 2000; Drobne et al. 2008).

Cultural control practices have been successfully combined with chemical control in select cropping systems against pests (Greene et al. 1985). For example, small plots of soybean are planted earlier than the soybean crop to attracts large numbers of Mexican bean beetles (*Epilachna varivestis*) which are sprayed to protect the rest of the crop from beetles attack (Greene et al. 1985). Similar combinations of control measures have been shown to protect crop

yields in other systems. For example, Koch et al. (2005) found that early season bean leaf beetle feeding was controlled by use of timely planting dates, along with imidacloprid or thiamethoxam seed treatments. For soybean production, chemical control using the neonicotinoid class of insecticides is useful against a wide range of pests (Schutte et al. 1998; Erdelen et al. 1999). Imidacloprid may be effective against early-season isopods (Wilde et al. 2006) due to its low toxicity to mammals (Drobne et al. 2008), systemic capacity against piercing-sucking insects (Tomizawa and Casida 2003), and has long-lasting residual effects (Koch et al. 2004; Wilde et al. 2004). However, it is not ideal for producers to rely on a single class of insecticides for use against an outbreak pest. For example, it is reported that early planting of soybean is effective for controlling whitefly, *Besimia tabaci* (Shun-xiang et al. 2001). In another example, three seeding rates, 5, 7.5 and 10 kg / ha, were tested on no-till canola, seeding rates, 7 kg / ha for *Brassica napus* and 9 kg / ha for *Brassica rapa* significantly reduced feeding damage by flea beetles, *Phylotreta crucifera* and *P. striolata* (Dosdall et al. 1999). Sprenke et al. (1979) found that early planting of soybean, along with a high seeding rate, resulted in reduced populations of *Heliocoverpa zea* larvae and increased yields, which was associated with greater populations of natural enemies. Furthermore, two studies by Hammond (1985; 2000), reported that early-planted soybeans exposed to feeding slugs (*Agriolimax reticulatus*) had higher yields compared to late-planted soybeans under no-till conditions.

Specific to no-tillage management, burning crop residues has been a successful control measure for various pests (Hardison 1976; Miller 1979; McCullough et al. 1998). Prescribed burning of residues directly kills insect pests, or indirectly affects them by reducing food sources and shelters, and changing soil structure (McCullough et al. 1998). In some cases insects positively respond to burning or remain unaffected (Siemann et al. 1997; Moretti et al. 2004).

Hanula and Wada (2003) found that detritivores, such as isopods, were reduced in burned plots of longleaf pine (*Pinus palustris*) compared to unburned plots.

Seed size has also been found to impact the vigor of soybean seedlings. A study showed that in legumes and grasses there is positive relationship between larger size and seedling growth and yield (Fontes and Ohlrogge 1972). Smith and Camper (1970) reported that higher yields result from large compared to small soybean seeds. As such, stands from large seeds may escape from early-season isopod pressure by emerging faster than smaller seeds, thus improving soybean stand densities. However, this interaction needs further investigation.

Since the literature is limited for isopod management, and few studies have investigated management strategies in soybean fields in the presence of isopods, combinations of control measures against isopods in no-till soybean fields may lead to immediate solutions for mitigating stand losses caused by this emerging pest. Therefore, this research focuses on the evaluation of combinations of control measures against isopods, which have been shown to be effective for controlling other key pests in soybean production systems (Madison et al. 1995).

Objectives

It is unclear whether current trends in cropping practices, such as no-till management, are increasing the risk of damage to soybean from isopods feeding. If damaging numbers of isopods are associated with no-tillage management of soybean, then it is essential to determine if readily accessible pest control tactics are effective at reducing isopod damage. The goal of this study is to find immediate tactics to help the growers to increase soybean stand counts in the presence of isopod populations. As such, the objectives of my research were to:

1. Evaluate the effects of chemical and cultural control combinations (seed treatment and planting date, planting date and seed size, seed treatment and crop residue removal, and seeding rate and seed treatment) for maintaining soybean stand density in presence of isopods in no-till cropping systems. (Chapter 2).
2. Evaluate the effects of burning crop residue on isopod populations and soybean stand densities in no-till systems (Chapter 3).

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Chapter 2: Evaluate the effectiveness of chemical seed treatment and cultural control combinations for increasing soybean stand density in presence *Armadillidium vulgare* in no-till systems

Introduction

The isopod, *A. vulgare*, has been shown to damage a number of agriculturally important crops in the field where the population can switch between dead and live materials of plants; leaves, stems, flowers, and seeds (Paris & Sikora 1965, saska 2008). Recent observations in soybean under no-tillage management in central Kansas, revealed that *A. vulgare* was feeding on succulent stem tissue beneath the cotyledons of seedlings, causing significant stand reductions (R. J. Whitworth, personal communication). *A. vulgare* is mainly a detritivore that feeds on dead plants (Honek et al 2009), however, changes in production practices may be enabling a shift from a minor, or opportunistic, pest status to a greater impact pest especially that there are many studies mentioned *A. vulgare* as “granivory” seed or seedling feeders of different plants (Saska 2008, Honek et al 2009) such as Alfalfa (Byers and Bierlein 1984), sunflower, and soybean (Tulli et al 2009).

A trend in shifting pest status associated with changing production practices has also been observed for another isopod species, *Australiodillo bifrons*. Reduced tillage of wheat (*Triticum aestivum*) is growing in popularity due to its advantages over conventional tillage through the reduced costs and the conservation of soil and water (Radcliffe et al. 1988; Deen and Kataki 2003; Sisti et al. 2004). Although *A. bifrons* is not considered a key pest of wheat,

outbreak populations have been observed in Australia wheat production systems, which can cause feeding damage to seedlings. Little is known about their biology as a crop pest, but one study found that *A. bifrons* displays swarming behavior with direct attack on cereals by climbing seedlings and feeding on leaf tips (Paoletti et al. 2008). Damaging populations of isopods (*A. vulgare*) have been observed in soybean fields in isolated landscapes located in south-central Kansas. Most fields in this area of the state are under no-tillage management with corn-soybean rotation, and have a historical isopod problem (4-5 yr history). Soybean growers typically re-plant entire fields every year to get harvestable soybean plants.

In no-tillage management, crop residue may positively affect crop yields (Stinner and House 1990), increase seed germination and growth (Doran et al 1984), and enhance organic matter levels in the soil (Doran et al 1984). Conversely, increased organic matter improves the biological activity of soil inhabiting organisms (TebruÈgge and DuÈring 1999, Cruse et al 2003, Teasdale 2007), which may enhance the development, survival, or reproductive capacities of soil inhabiting pests (Kogan and Turnipseed 1987; Wallner 1987; Stinner and House 1990; Bugg 1991; Koul et al. 2004) including ground-dwelling arthropod pests (Stinner and House 1990). As such, no-till management of crops may be more conducive to damaging levels of isopod *A. vulgare*, which can feed on some crop seeds and become an agriculture seedling pest in no tillage systems such as no-till soybean (*Glycine max* L.) (Tulli et al 2009).

There are few control methods for isopods in crops (Paoletti and Hassall 1999; Drobne et al. 2008). Chemical control using the neonicotinoid class of insecticides, which are systemic compounds containing active ingredients imidacloprid or thiamethoxam (Schutte et al. 1998; Erdelen et al. 1999; Noon et al. 2006) are effective against early-season isopods but control is quite variable (Wilde et al. 2006). Conversely, the popularity of imidacloprid due to its low

toxicity to mammals (Drobne et al. 2008), systemic insecticidal capacity against piercing-sucking insects (Tomizawa and Casida 2003), and early season corn pests (Wilde et al 2004), and long-lasting residual effects (Koch et al. 2005; Wilde et al. 2004) makes it a possible choice for isopod management. Some seed treatments are effective at killing isopods, however, isopods need to feed on soybean seedlings to acquire lethal doses of toxin. If isopod numbers are significant and feeding pressure is high, then they may consume enough toxins before killing or injuring the plant (J. Whitworth, unpublished data). Another option that could improve the stand density of soybean plants exposed to isopod populations in no-till system is cultural controls such as seeding rate. For example, Dosdall et al. (1999) found that canola stands experienced less damage from flea beetles when seeding rates were increased. Moreover, Delobel et al. (1981) reported that planting sorghum at high densities reduced population densities of insect pest, sorghum shootfly (*Atherigona soccata*). In addition, cultural controls may enhance the efficacy of chemical controls such as imidacloprid and improve stand density of soybean plants. Consequently, the effects of cultural controls for maintaining soybean stand density in no-till soybean fields associated with isopod population can be investigated alone or in a combination with chemical seed treatment.

Other cultural practices including planting date, seed size, and residue management, may influence seedling vulnerabilities to arthropod pests, but lack study. More specifically, the effects of cultural controls alone or in a combination with chemical (imidacloprid seed treatment) for maintaining stands in presence of isopods lack sufficient field testing. Use of cultural controls for producers has been used to adjust the timing of emergence and harvest, which can also function to synchronize plant maturity (phenological asynchrony) under ideal environment conditions. For example, planting date can be used to lessen exposure to colder early-season temperatures,

but also reduce exposure to early-season arthropod pests and maintain stands of plants. For example, Dosdall et al. (1996) reported that root maggot (*Delia* spp.) infestations were reduced on canola by seeding in late May rather than in early or mid-May when insects were active. Seed size can also be investigated for maintaining stands. Hopper et al. (1979) reported that seed size can greatly affect soybean emergence rates; large seed sizes emerge faster than smaller ones. If so, we might hypothesize that plants from large seeds will escape from early-season isopod pressure by emerging faster than smaller seeds and protect seed germination. . Collectively, seed treatment, seeding rate, planting rate, and residue management may ultimately prove to be a good strategy for maintaining the stand of soybean plants in the presence of isopods in no-till soybean.

It is unclear whether current trends in cropping practices, such as no-tillage management, is increasing the risk of damage from isopod in no-till soybean. If damaging numbers of isopods are associated with no-tillage management of soybean, then it is essential to determine if current pest control tactics are effective in maintaining stand counts in no-till soybean fields associated with isopod presence. As such, the objective of this research was to evaluate the effects of chemical and cultural control combinations: 1) seed treatment and planting date, 2) planting date and seed size, 3) seed treatment and crop residue removal, and 4) seeding rate and seed treatment on soybean stand counts in the presence of *A. vulgare* populations. This research evaluates the effectiveness of chemical seed treatment and cultural control combinations for maintaining soybean stand density in the presence of isopods no-till systems.

Methods and Materials

Field sites and experimental design

Separate sets of adjacent soybean fields (hereafter referred to as Fields 1 and 2 for 2009; and Fields 3 and 4 for 2010) were used to investigate the effects of potential isopod control tactics on emerging soybean plant populations. All fields were located near Lindsborg, KS and were under a continuous corn-soybean rotation and watered using overhead irrigation. Prior to experimentation, fields were sampled for presence of isopods in order to evaluate treatments under the pressure of isopod feeding damage and all fields were chosen based on having a history of damaging populations of isopods.

To assess effects on soybean stand densities, a series of four experiments (in either a 2 x 2 or 2 x 3 factorial design) was used to manipulate chemical and cultural practices. In each experiment, treatments were arranged in a randomized complete block design (RCBD). Commercially available soybean seed (Pioneer 94Y01) was planted into blocks (n = 4), 6, 2-row plots that were 6 m long and 76 cm (30" row spacing) apart using a modified V-belt push planter (Almaco®, Nevada, IA) that was pulled through the plots using a garden tiller (Horse Garden Tiller, 305cc, Troy-Bilt, Cleveland, OH). Experiments were conducted in different years; experiments 1 and 4 were conducted twice during 2009 and 2010 growing seasons; however, experiments 2 and 3 were only conducted in 2009 and 2010, respectively. Planting dates were also varied between experiments; two planting dates (early = 18 May; late = 27 June) were in experiment 1, and two (early = 18 May; late = 30 June) in experiment 2, only early planting date (19 May 2010) was used in experiment 3, while late planting date (9 June) was used in experiment 4. In experiments 1, 3 and 4, the same chemical neonicotinoid class of insecticides,

which are systemic compounds containing active ingredients imidacloprid (Gaucho 480FS, Gustafson LLC; Dallas, TX) was used with three seed treatments; standard (50 g a.i./100 kg of seed or “50 g rate”) and high (100 g a.i. /100 kg of seeds or “100 g rate”) rates and an untreated control (UNT) seed. In the first experiment, varied planting dates were compared with seed treatments. The second experiment compared variable seed sizes, which were either “small” (7,164 seeds / kg) or “large” (5,622 seeds / kg) in size with planting dates. The third experiment compared the effects of seed treatment with the effects of crop residue, using only untreated soybean seed (large size). To examine the impact of residue covering newly planted rows, the presence of crop residue was compared with the absence of residue, which was removed over the seed bed mechanically by hand (i.e., physically pushing residue off the newly planted soybean seed). The reason for that method of removal was to mimic the real no-till system where the modern planters remove residue from only the row area but not from the field. In 6 plots, half of the plots were randomly assigned "covered" and were left "uncovered". Lastly, in the fourth experiment seed treatment was compared with seeding rate. Two Seeding rates were either a “standard” (354,610 seed / ha) or “high” (563,380 seed/ha) seeding rate, which was approximately two times the standard. To achieve the higher planting rate, the same modified V-belt push planter (Almaco®, Nevada, IA) was used but we modified the gear ratio to achieve a higher planting density.

Stand counts and statistical analysis

For all fields in either 2009 or 2010, stand counts were taken at 1 to 3 times during the early part of the growing season. Variability in sampling dates between fields and experiments was due to availability of field help and logistics for travelling to field sites in addition to environmental conditions. For stand counts on a given sample date, a 1 m section of row was

sampled from each row within plot. Data were analyzed for means and standard error using the PROC UNIVARIATE statement in statistical analysis software (SAS) (SAS Institute, version 9.2; Cary, NC). Analysis of variance was carried out using a PROC MIXED model in SAS with main treatment effects (planting date, seed treatment, seed size, and seeding rate) as the fixed factors, and block as the random factor at alpha level $\alpha = 0.05$ (SAS 2002). Mean separation was accomplished using Tukey's method for multiple comparisons (SAS 2002).

Results

Prior to experimentation, fields were sampled for presence of isopods in order to evaluate treatments under the pressure of isopod feeding damage by counting all *A. vulgare* present in 1 m² of residue within each block (n = 4). Consequently, in 2009 isopod densities ranged from 84 \pm 25 and 8 \pm 4 per m² across Fields 1 and 2, respectively, and in 2010 densities ranged from 300 \pm 44 and 19 \pm 5 per m² across Fields 3 and 4, respectively.

Planting date x seed treatment

Results from the first experiment were variable by year, field, and sampling date. Four fields, Fields 1 and 2 in 2009 and Fields 3 and 4 in 2010, were sampled at different dates. For 2009, there was a significant effect of seed treatment on soybean stands on sample date 29 May in Field 1, where plant counts were approximately 65% higher on 100 g rate treated plots compared to untreated control plots ($P \leq 0.05$) (Table 2.1, Fig. 2.1). There was a significant effect of seed treatment on stands on sample date 7 July in Field 1, where plant counts were approximately 64% higher on 50 g rate treated plots, compared to untreated control plots ($P \leq 0.05$) (Table 2.1, Fig. 2.1). There was also a significant interaction of seed treatment and planting

date on soybean stands on sample date 7 July in Field 2; where plant counts were significantly higher in early planted 50 g rate treatment (40% higher) and untreated control plots (29% higher) compared to late planted seed treated (both 50 and 100 g rates) plots ($P \leq 0.05$) (Table 2.1, Fig. 2.2). Seed treatment had a significant effect on soybean stands for sampling dates 17 June and 9 August in Field 4 during 2010 (Table 2.1). Soybean plant counts were approximately 65% higher for untreated control plots compared to both seed treatment plots on 17 June and soybean plant counts were approximately 15% higher on plots containing 50 g rate treatment compared to plots containing 100 g rate treatments and untreated controls on August 9 (Fig. 2.3). There were no other significant effects of planting date, seed treatment, or interactions for other sampling dates and/or fields.

Seed size x planting date

Results of experiment 2 varied between two Fields (1 and 2) and two sampling dates across one year 2009. There was a significant effect of seed size on soybean stands for sample date 29 May in Field 2, where soybean densities were approximately 40% higher in plots having small seed size compared to plots having large seed size ($P \leq 0.05$) (Table 2.2, Fig. 2.4). The effect of planting date was significant on 7 July in Field 1, where plant counts were on average 45% higher in plots that were late planted compared to early planted plots ($P \leq 0.05$) (Table 2.2, Fig. 2.5). There were no other significant main effects or interactions of main effects on soybean stands.

Seed treatment x residue

Results of experiment 3 varied between Fields 3 and 4, which were sampled at different dates across in 2010. There was a significant effect of seed treatment on soybean stands on 17

June in Field 4; where stands were on average 58% denser on untreated control plots and plots having a 50 g rate, compared to plots having the 100 g rate ($P \leq 0.05$) (Table 2.3, Fig. 2.6). There was also a significant effect of seed treatment on stands on 29 June in Fields 3 and 4; where stands averaged 32% denser plant counts in untreated plots and plots with 100 g rate treatment compared to plots having a 50 g rate in Field 3; and plant counts averaged 46% denser in untreated plots and plots having 50 g rate compared to plots with double the amount (i.e., 100 g rate) in Field 4 ($P \leq 0.05$) (Table 2.3, Figure 2.6). The effect of residue on soybean stands was significant for 17 June in Field 4; where plots without residue had approximately 27% denser plant counts compared to plots with residue ($P \leq 0.05$) (Table 2.3, Figure 2.7). There were no significant interactions for either sample date in either field.

Seed treatment x seeding rate

Results from Experiment 4 were variable by year, field, and sampling date. There was a significant effect of seed treatment for stands on 29 June in Field 4; where plant counts were on average 42% denser in plots having either seed treatment compared to untreated control plots ($P \leq 0.05$) (Table 2.4, Fig. 2.8). Seeding rate was significant on stands for 17 June (Field 3) in 2010 and 29 June (Field 4); where plant counts averaged 52% and 50% denser in plots having the 563,380 / ha rate compared to plots having the 354,610 / ha rate respectively ($P \leq 0.05$) (Table 2.4, Fig. 2.9). Seeding rate was also significant on stands for 29 May (Field 2) and 7 July (Field 1) in 2009; where plant counts averaged 38% denser for plots having 563,380/ha seeding rate compared to 354,610 / ha ($P \leq 0.05$) (Table 2.4, Fig. 2.9). There were also significant interactions of seed treatment and seeding rate on stands for both 2009 and 2010. For 2009, the interaction of seed treatment and seeding rate was significant on 29 May (Field 1) and 7 July (Field 2) ($P \leq 0.05$) (Table 2.4). For 29 May (Field 1), plant counts averaged 61% denser at the

high seeding rate (563,380 / ha) with 50 g rate seed treatment compared to plots with 100 g rate or seed treated and untreated control plots in low seeding rate (354,610 / ha) plots ($P \leq 0.05$) (Fig. 2.10). For 7 July (Field 2), plant counts averaged 45% denser for the high seeding rate (563,380 / ha) plots with seed treatments (both 50 and 100 g rates) compared to untreated control plots at high seeding rate and for treated and untreated plots having the low seeding rate (354,610 / ha) (Fig. 2.10). For 2010, the interaction of seed treatment and seeding rate was significant on 17 June (Field 4) and 29 June (Field 3) ($P \leq 0.05$) (Table 2.4). For 17 June (Field 4), plant counts averaged 45% denser at the high seeding rate (563,380/ha) with the 50 g rate compared to seed treated and untreated control plots at the low seeding rate ($P \leq 0.05$) (Fig. 2.10). For 29 June (Field 3), plant counts averaged 67% denser in the high seeding rate having no seed treatment or the 50 g rate compared to high seeding rate with 100 g rate, and for treated plots (both 50 g and 100 g rates) planted at the low seeding rate of 354,610 / ha (Figure 2.10).

Discussion

Cultural controls alone or in a combination with chemical (imidacloprid seed treatment) can be potentially implemented to maintain soybean stands for no-till fields associated with exposure to high isopod populations. If we calculate the expected numbers of soybean plants per m row with a standard seeding rate of 354,610 / ha, then our target or expected stand density is approximately 30 plants per m row assuming a 100% emergence rate. In most experiments on sample dates, this target density was not achieved; however, closest densities were more often found in plots planted at the highest seeding rate of 563,380 / ha.

In the first experiment, the effects of early- versus late-planting dates and neonicotinoid seed treatment were evaluated on soybean stands in fields having a known history of *A. vulgare* damage. In 2009, there was no clear pattern of increase in soybean densities from seed treatments. In two of three fields, stands were generally denser in seed-treated plots compared to untreated control plots, but there was no indication that seed treatment was related to greater stand densities or reaching the target density of 30 plants per m row. Moreover, in 2010 variable results across field locations and sampling dates suggest that seed treatment do not increase stand density. In 2010, although not significant, stand densities were generally higher in plots having a lower seed treatment rate 50 g rate compared to plots having the higher seed treatment rate of 100 g / 100 kg of seed. Moreover, in Field 4 on two of three sample dates, stands tended to be higher in the 50 g rate and control plots compared to the higher seed treatment rate, which suggests that the increased seed treatment rate does not correlate with increased soybean densities. Only in 2010, in early planted field 4 on sampling date 17 June and late planted fields 3 and 4 on sampling date 9 August, the stands approached the target number 30 plants per m row. These results may have been influenced by variation between fields in populations of isopods which ranged from 84 ± 25 and 8 ± 4 per m^2 across Fields 1 and 2 in 2009, 300 ± 44 and 19 ± 5 per m^2 across fields 3 and 4 in 2010, respectively. However, the relationship between densities of isopods and seed treatment rates on stand potential was not studied in this research, and future testing to determine this relationship is needed.

Planting date and seed treatment had a significant impact on soybean stands in Field 2 during 2009. Early-planted plots having the lower 50 g rate resulted in greater stand densities and approached the target numbers of plant of 30 plants per m row compared to late-planted plots having either seed treatment rate. The relationship of early-planted seed-treated soybeans having

greater plant stands may have resulted from increased isopod exposure to the systemic insecticide in seedlings during a time period when isopods are feeding actively, rather than later during the growing season as insecticide effects dissipate. In Field 1, stand densities were higher in late-planted plots compared to early-planted plots, however, late-planted plots didn't approach the target number of plants 30 plants per m row (data is not shown).

In the second experiment, seed size did not significantly impact stand density in three of four sample date by field combinations and never reached the target density of 30 plants per m row. This result is corroborated by those of Smith and Camper (1975), which reported that seed size had no impact on stands of soybean seedlings. Only in Field 2 on 29 May did stand counts in small seed-sized plots reach densities higher than large seed-sized plots; however, neither approached the target 30 plants per m row. It may have been possible that large seed size was more attractive for isopods to feed on because large seed tends to emerge faster than smaller seed (Hopper et al. 1979), which could have reduced stand counts if seedlings were exposed to isopods for longer periods of time. However, rate of emergence was not examined in this study and requires further testing to evaluate isopod exposure time and their preference feeding on different sizes of seed. Further testing is required to examine differences in emergence rates and how this applies to length of exposure to resident isopod populations.

There was no significant effect of crop residue on soybean stands in three of four field/sample date combinations. For Field 4 on June 17, 2010, there were significantly greater stand counts in plots without residue compared to plots with residue. Although it is not known if population densities of isopods were different between these plots, it is possible that the removal of residue negatively influenced isopod populations and/or feeding behavior. Studies have reported reduced numbers of some soybean pests in absence of residue (House and Stinner

1983). For example, slug populations tend to be a minor pest in no-till soybean fields (Hammond 1985 and 2000). In another study, it has been shown that slug populations tend to be lower where crop residue was burnt compared to unburned areas, which is probably due to the removal of food and shelter by burning (Glen et al. 1984; 1988; Glen & Wiltshire 1986; Christian et al. 1999). For soybean producers, removal of residue may not result in protection against soybean pests. Moreover, it has been shown that residue removal results in less abundance and diversity of natural enemies (Edwards 1984), which may impact isopod densities. A limitation of the current study was the unknown differences in residue between field sites, which could have been used to determine if residue impacted isopod densities between fields. Further testing would be useful to determine if residue removal affects stand counts or impact isopod populations or their feeding activity.

The higher seeding rate (563,380/ha) which was used for this study resulted in greater stand counts in both fields during 2009 and 2010 and more than the target number of plants (30 plants/m row) could be achieved in all fields in different sampling dates comparing to all standard seeding rate (354,610/ha) plots which didn't even approach the expected number 30 plants/m row. Although the results of interaction between seed treatment and seeding rates were varied between fields, greater stand counts were achieved in all fields when higher seeding rate (563,380/ha) was used. In both Fields 1 and 4, there was no significant difference between 3 seed treatments; UNT, low seed treatment (50 g AI/100 kg seed), and high seed treatment (100 g AI/100 kg seed), however, expected numbers of plants (30 plants/m row) in Field 1 and more than 30 plants/m row in Field 4 were resulted when higher seeding rate (563,380/ha) was used. Besides, more than target number of plants (30 plants/ m row) was resulted in Fields 2 and 3. In Field 2, higher stand was resulted in a combination between the high seeding rate (563,380/ha)

and either low seed treatment (50 g AI/100 kg seed), or high seed treatment (100 g AI/100 kg seed). In Field 3, the stand was greater in a combination between the high seeding rate (563,380/ha) and low seed treatment (50 g AI/100 kg seed) and UNT. It seems that high seeding rate may be a preferred control strategy for maximizing stand density in presence of feeding isopods. The combination of seeding rate and seed treatment may have additive effects on stand density because plant counts associated with plots under high seeding rate with and a low rate of seed treatment were greater (approximately 15%) than plant counts in plots under high seeding rate or a low rate of seed treatment alone. The additive effects of control strategies are known to exist for other crop/pest systems. For example, Glen et al. (1990, 1992) found that the best control of slugs in wheat was achieved by deeper sowing combined with a molluscicide broadcast on the soil surface immediately afterwards.

Soybean stand densities may have been influenced by field-level variation in isopod numbers, residue distribution, and field history. Although results from the four experiments were varied by location, year, and/or sample date, adjusting seeding rates may lead to a potential control strategy for maintaining stand counts of plants in the presence of isopod populations in no-till soybean fields. For example, doubling seeding rates to 563,380 / ha resulted in soybean densities close our target of 30 plants per m row. This can potentially reduce the number of trips a grower makes across a field (single, high-density versus multiple, low-density plantings). In doing so, growers may save time and money (e.g., fuel). Future studies that incorporate comparisons of plots with and without isopods would improve the interpretation of these results. Additionally, examining the relationship of season-long weather (temperature and humidity) in relation to stand counts and isopod densities may be helpful in understanding the differences in sample date variations in stand counts for the current study.

In general, seed treatment alone was not a reliable strategy because results were variable. Consequently, manipulating concurring cultural practices at the time of planting did not result in less variable emergence patterns. Future studies should address the inconsistencies in emergence that was observed across all fields and years. Identifying accessible tactics to enhance soybean densities in no-till soybean fields will only help soybean producers in Kansas mitigate losses caused by this early season pest. Also, it will be essential to understand the field-specific relationships of control strategies and stand protection.

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Tables and Figures

Table 2.1. ANOVA results for effects of seed treatment (ST) and planting date (PD) on total number of emerged soybean plants per m row in open-field plots in two fields in 2009 (Fields 1 and 2) and two fields in 2010 (Fields 3 and 4) near Lindsborg, KS.

Sample Date	Factor	df	Field 1		Field 2	
			<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>
29 May	Block	3,6	2.46	0.159	15.48	0.003
	ST	2,6	6.71	0.03	0.85	0.472
7 July	Block	3,15	1.2	0.345	0.51	0.679
	PD	1,15	9.38	0.009	23.68	< 0.001
	ST	2,15	5.32	0.018	4.41	0.031
	PD x ST	2,15	2.64	0.104	5.16	0.019
			Field 3		Field 4	
17 June	Block	3,6	2.17	0.193	0.40	0.758
	ST	2,6	0.3	0.749	8.06	0.02
29 June	Block	3,6	2.58	0.149	2.22	0.186
	ST	2,6	0.33	0.731	3.22	0.112
9 August	Block	3,6	0.28	0.838	0.86	0.519
	ST	2,6	0.49	0.636	7.93	0.021

Table 2.2. ANOVA results for effects of seed size (SS) and planting date (PD) on total number of emerged soybean plants per m row in open-field plots in two fields in 2009 (Fields 1 and 2) near Lindsborg, KS.

Sample Date	Factor	df	Field 1		Field 2	
			<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>
29 May	Block	3,3	0.06	0.978	2.73	0.215
	SS	1,3	0.03	0.88	28.72	0.013
7 July	Block	3,17	1.34	0.295	1.01	0.414
	PD	1,17	7.66	0.013	0.07	0.789
	SS	1,17	1.13	.0.302	1.85	0.192
	PD x SS	1,17	0.28	0.601	0.33	0.574

Table 2.3. ANOVA results for effects of seed treatment (ST) and residue (RES) or row cover on total number of emerged soybean plants per m row in open field plots in two fields in 2010 (Fields 3 and 4) near Lindsborg, KS.

Sample Date	Factor	df	Field 3		df	Field 4	
			<i>F</i>	<i>P</i>		<i>F</i>	<i>P</i>
17 June	Block	3,14	0.96	0.441	3,15	1.38	0.287
	ST	2,14	0.45	0.647	2,15	22.06	<0.0001
	RES	1,14	.0.10	0.76	1,15	6.88	0.019
	ST x RES	2,14	0.68	0.523	2,15	0.01	0.992
29 June	Block	3,15	.2.00	0.157	3,15	0.16	0.922
	ST	2,15	12.16	<0.0001	2,15	15.11	<0.0001
	RES	1,15	0.03	0.859	1,15	0.85	0.371
	ST x RES	2,15	1.24	0.318	2,15	0.17	0.848

Table 2.4. ANOVA results for effects of seed treatment (ST) and seed rate (SR) on total number of emerged soybean plants per m row in open-field plots in two fields in 2009 (Fields 1 and 2) and two fields in 2010 (Fields 3 and 4) near Lindsborg, KS.

Sample Date	Factor	df	Field 1		df	Field 2	
			F	P		F	P
29 May	Block	3,15	3.42	0.045	3,15	1.53	0.248
	ST	2,15	5.65	0.015	2,15	1.74	0.209
	SR	1,15	17.22	<0.001	1,15	47.61	<0.001
	ST X SR	2,15	9.09	0.003	2,15	0.33	0.725
7 July	Block	3,15	0.81	0.510	3,15	0.60	0.623
	ST	2,15	1.85	0.191	2,15	0.92	0.002
	SR	1,15	62.16	<0.001	1,15	128.86	<0.001
	ST X SR	2,15	0.62	0.554	2,15	15.55	<0.001
			Field 3			Field 4	
			F	P		F	P
17 June	Block	3,12	1.78	0.205	3,15	2.25	0.125
	ST	2,12	1.18	0.342	2,15	8.83	0.003
	SR	1,12	99.07	<0.001	1,15	43.49	<0.001
	ST X SR	1,12	3.63	0.081	2,15	8.32	<0.001
29 June	Block	3,15	0.35	0.793	3,15	1.61	0.229
	ST	2,15	5.96	0.013	2,15	6.06	0.012
	SR	1,15	11.58	0.004	1,15	25.14	<0.001
	ST X SR	2,15	10.08	0.001	2,15	2.87	0.088

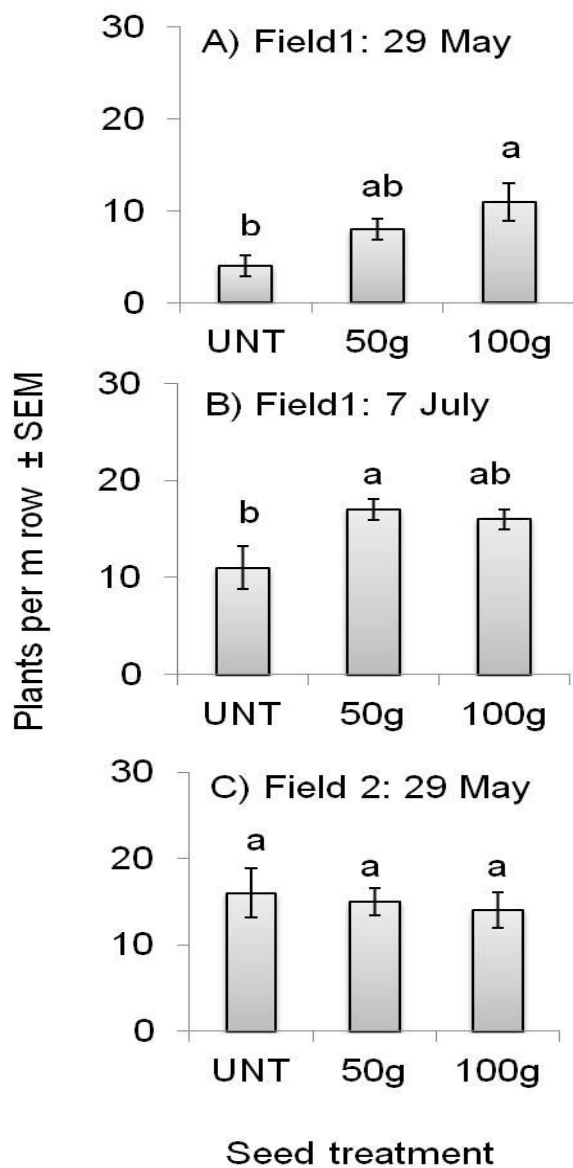
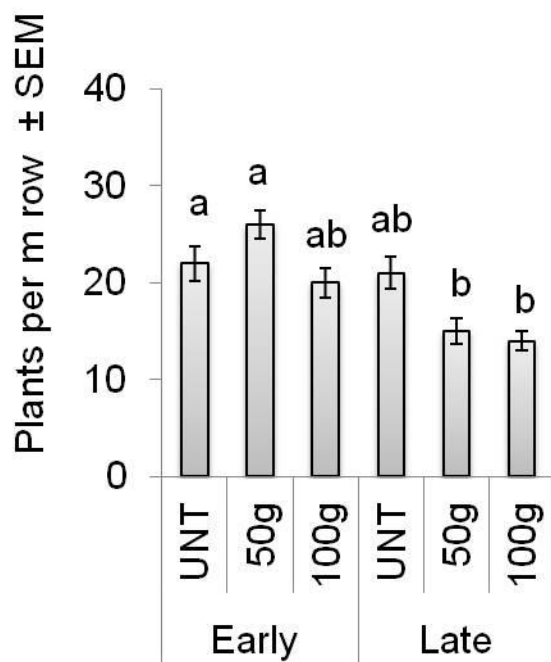


Figure 2.1. The effects of seed treatment [untreated control (UNT), standard 50 g a.i. / 100 kg of seed (50 g), and high 100 g a.i. / 100 kg of seed (100 g) and on mean number soybean plants per m row in Fields 1 and 2 in 2009. Expected numbers of plants was 30 per m row.



Seed treatment x Planting date

Figure 2.2. The effects of seed treatment [untreated control (UNT), standard or 50 g a.i. / 100 kg of seed (50 g), and high or 100 g a.i. / 100 kg of seed (100 g)] and planting dates (early = 18 May and late = 27 June) on mean number of soybean plants per m row in Field 2 in 2009. Expected numbers of plants was 30 per m row.

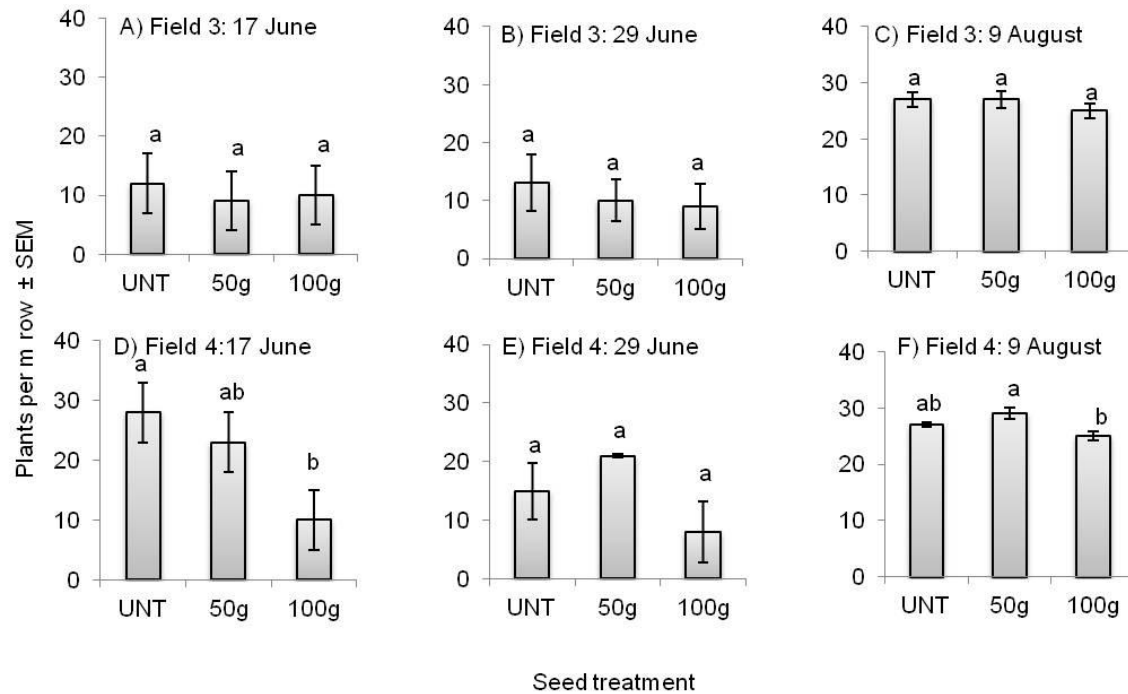


Figure 2.3. The effects of seed treatment [untreated control (UNT), standard 50 g / 100 kg of seed (50 g), and high 100 g / 100 kg seed (100 g)] on mean number soybean plants per m row in Fields 3 and 4 in 2010. Plots were planted early (18 May) in the first and second sampling dates of both Fields 3 and 4, while plots were planted late (27 June) in the third sampling date of both fields. The expected numbers of plants per m row was 30 plants.

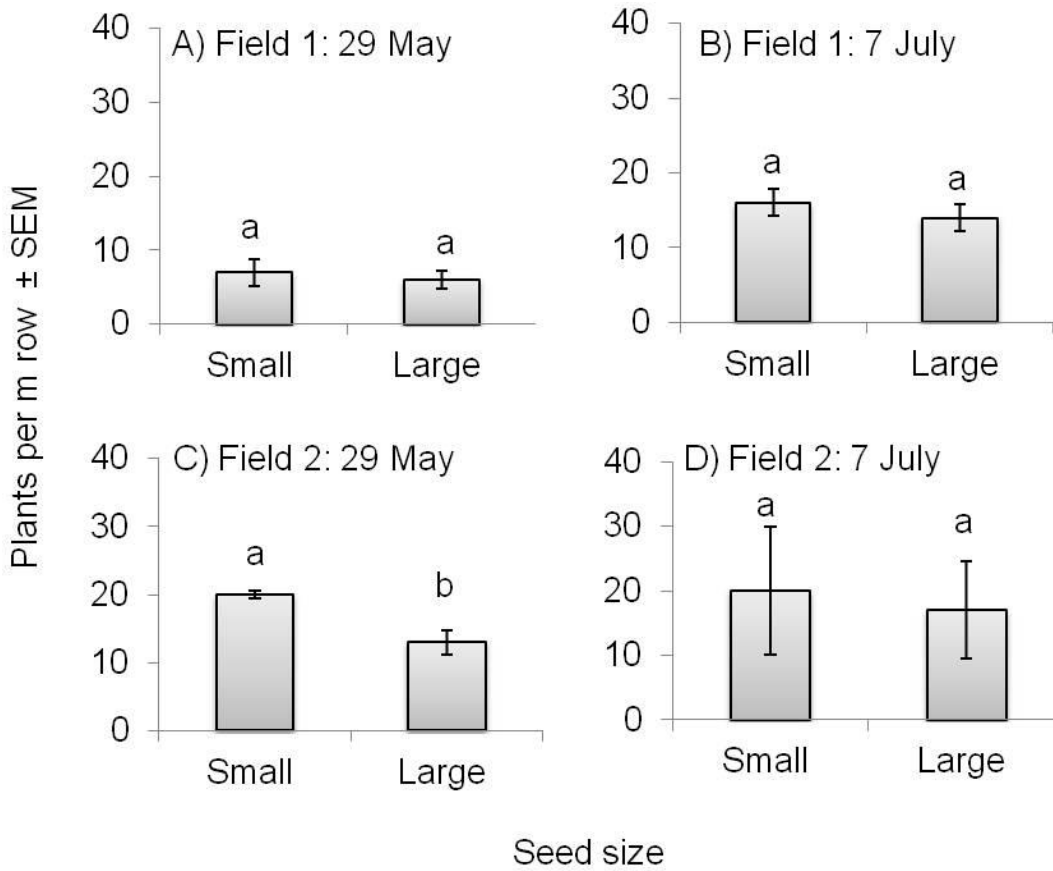


Figure 2.4. The effects of seed size (small vs. large) on mean number soybean plants per m row in Fields 3 and 4 in 2010. The expected numbers of plants per m row was 30 plants.

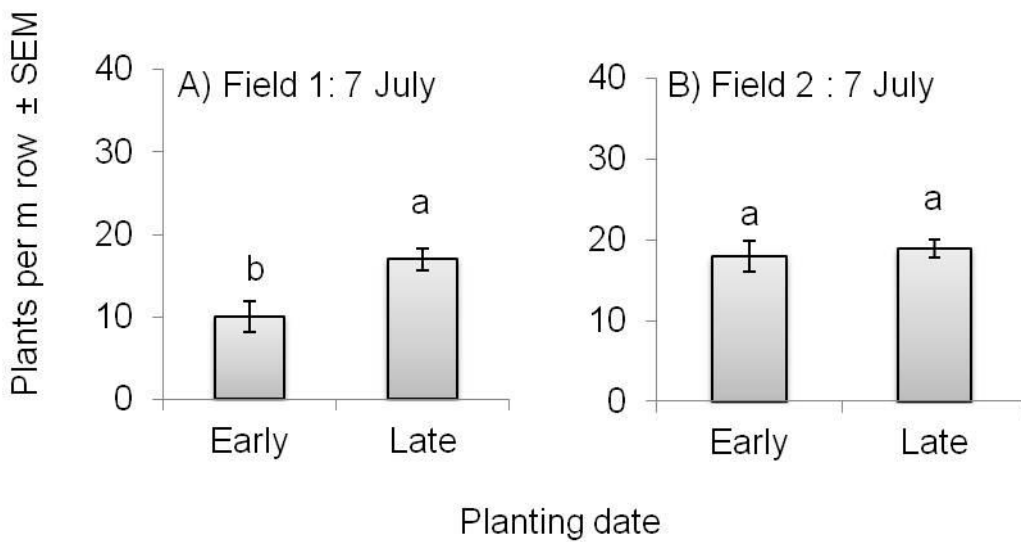


Figure 2.5. The effects of planting date (early vs. late) on mean number soybean plants per m row in Fields 1 and 2 in 2009. The expected numbers of plants per m row was 30 plants.

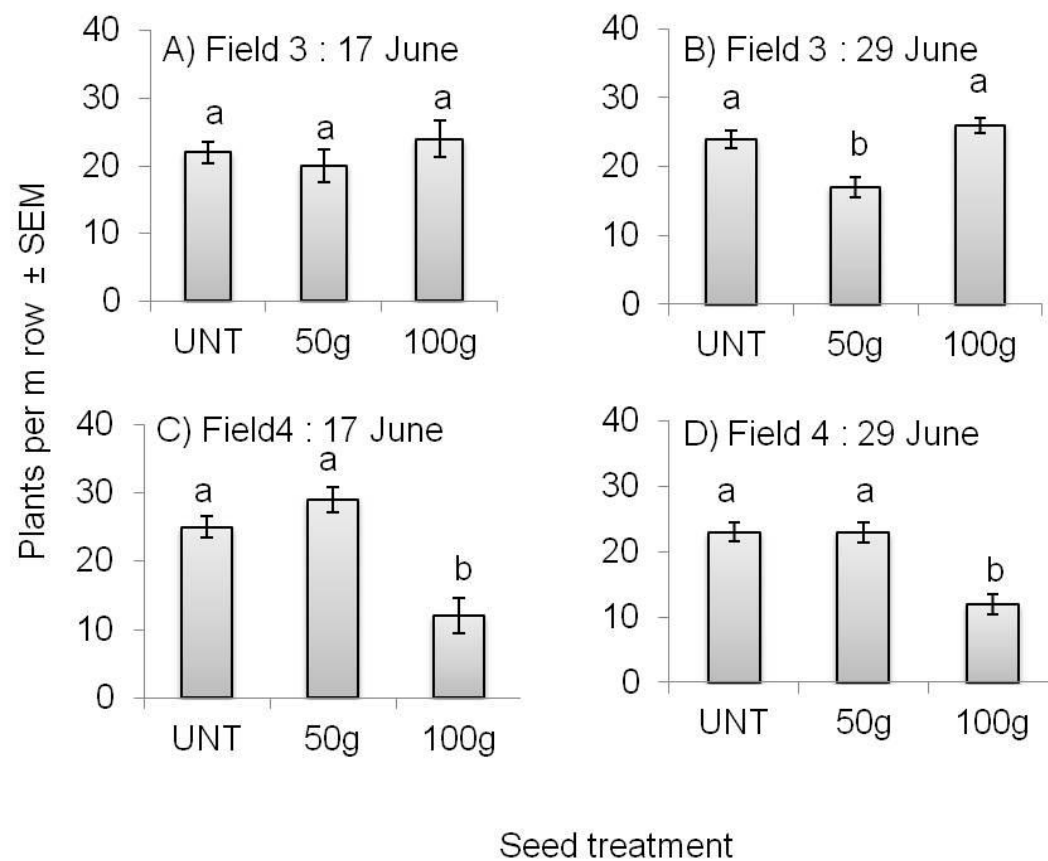


Figure 2.6. The effects of seed treatment [untreated control (UNT), standard 50 g a.i. / 100 kg seed, and 100 g a.i. / 100 kg seed] on mean number soybean plants per m row in Fields 3 and 4 in 2010. The expected numbers of plants per m row was 30 plants.

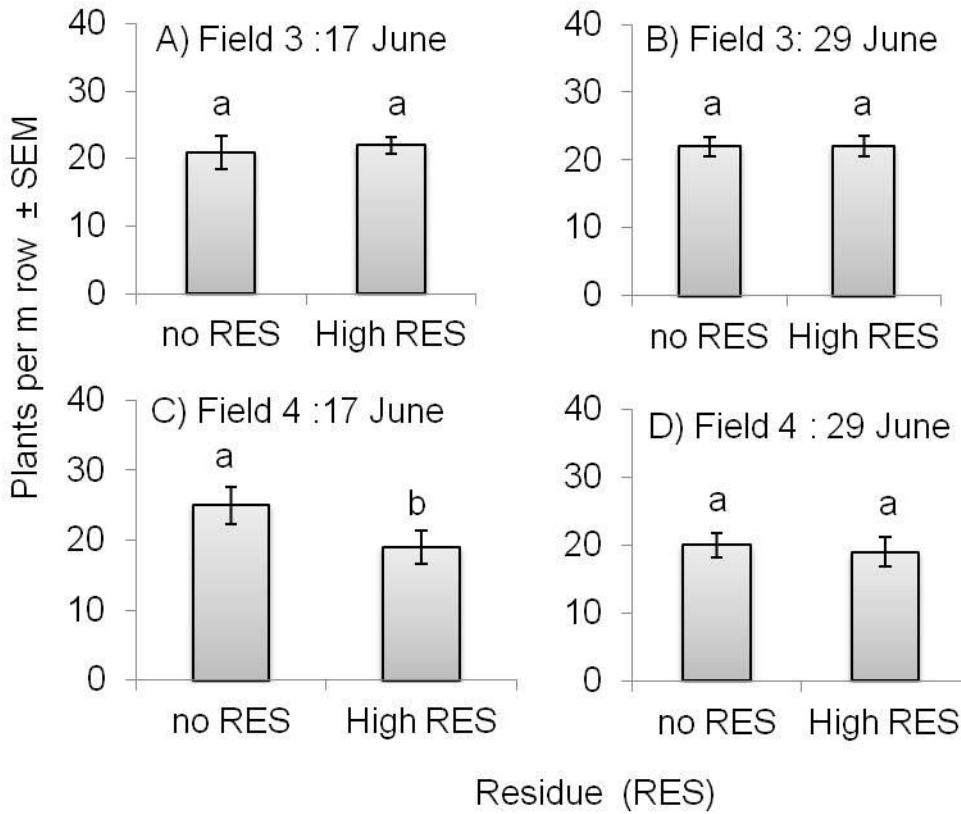


Figure 2.7. The effects of plant residue coverage the seed bed (no RES vs. high RES) on mean number soybean plants per m row in Fields 3 and 4 in 2010. The expected numbers of plants per m row was 30 plants.

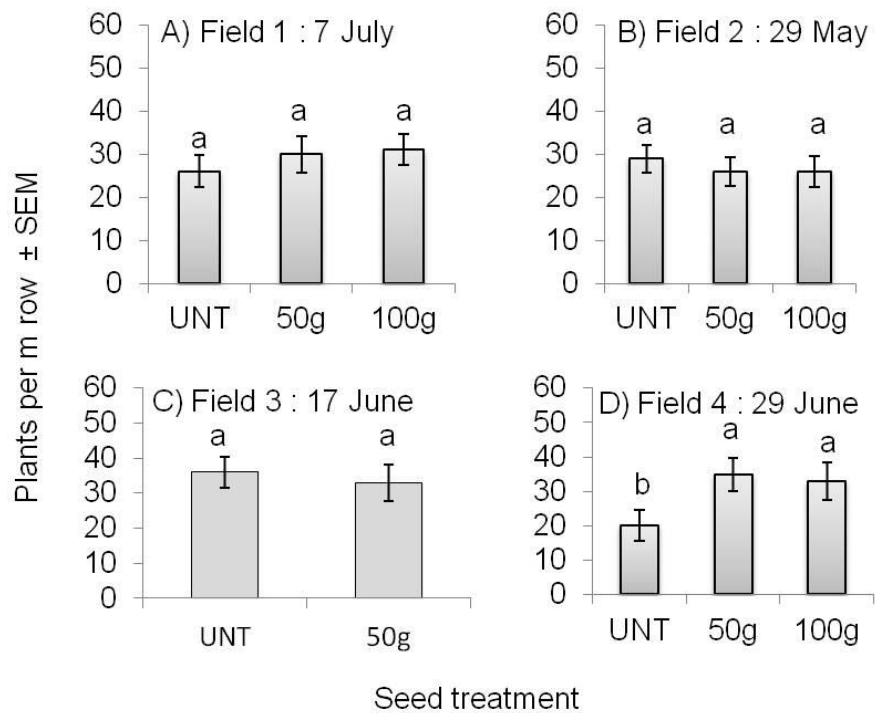


Figure 2.8. The effects of seed treatment [untreated control (UNT), standard 50 g a.i. / 100 kg seed (50 g), and high 100 g a.i. / 100 kg seed (100 g)] on mean number soybean plants per m row in Fields 1 and 2 in 2009 and Field 3 and 4 in 2010. The expected numbers of plants per m row was 30 plants.

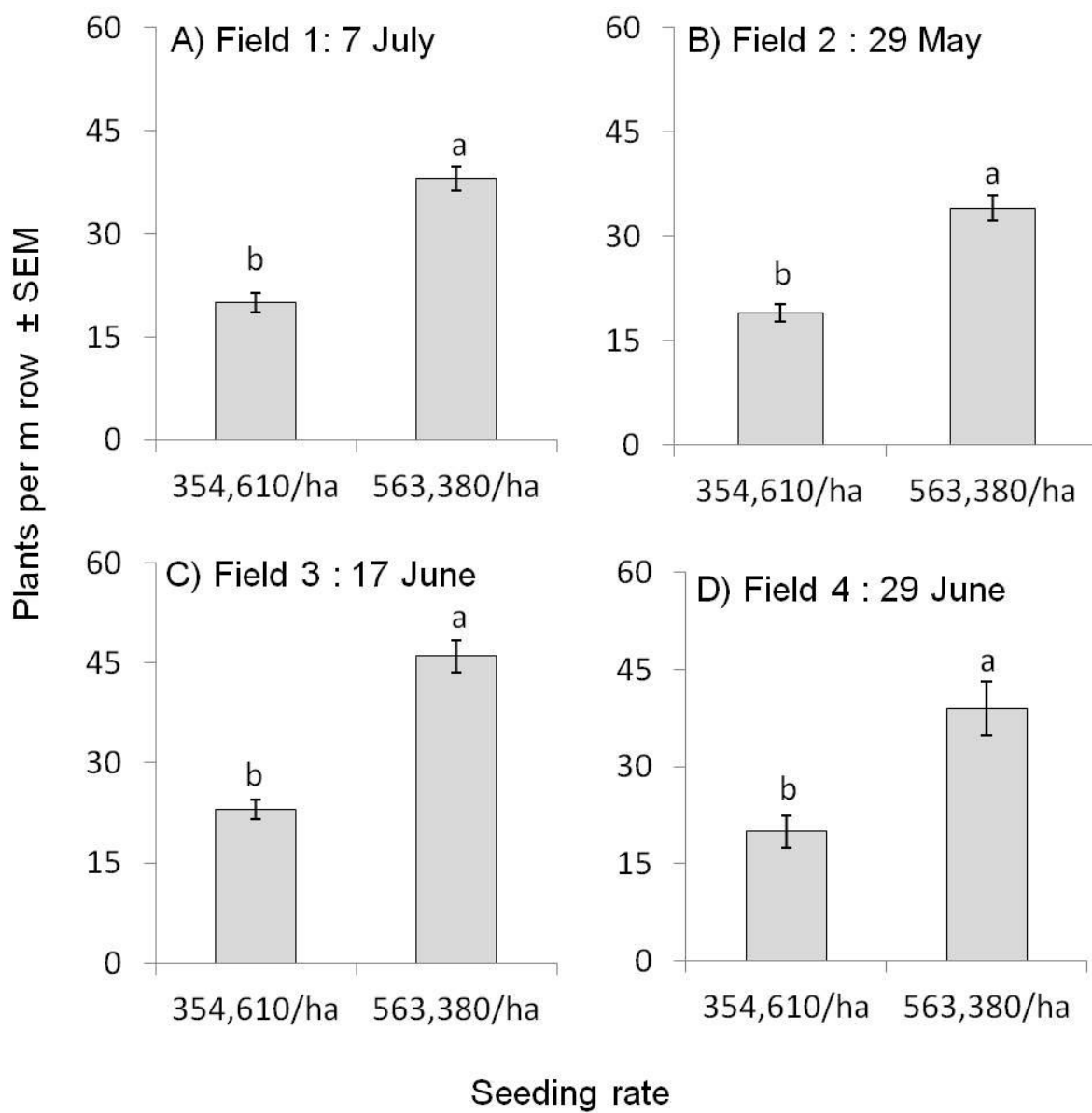


Figure 2.9. Effect of seeding rate [standard (354,610/ha) and high (563,380/ha)] on mean number soybean plants per m row in Fields 1 through 4. The expected numbers of plants per m row was 30 plants.

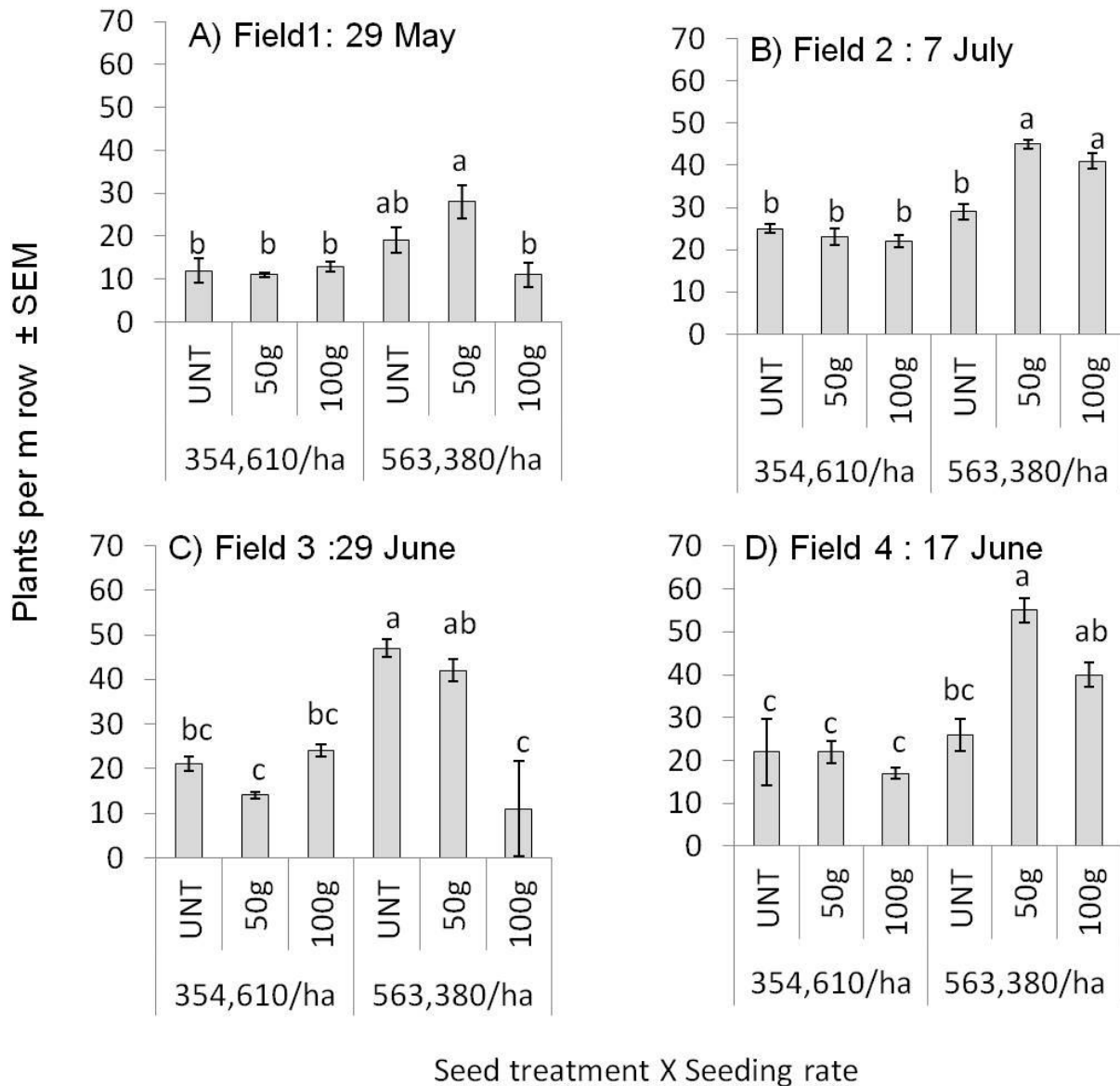


Figure 2.10. The effects of seed treatment [untreated control (UNT), standard 50 g a.i. / 100 kg seed (50 g) and high or 100 g a.i. / 100 kg seed (100 g)] and seeding rates [standard or 354,610 / ha versus high or 563,380 / ha] on mean number soybean plants per m row in Fields 1-4. The expected numbers of plants per m row was 30 plants.

Chapter 3: Evaluate the effects of burning crop residue on soybean stand densities and isopod, *Armadillidium vulgare*, pest populations under no-tillage management

Introduction

There is a lack of control methods for management of *Armadillidium vulgare* (Crustacea: Isopoda) in no-till soybean systems. As growers continue to adopt no-till (conservation tillage) cropping systems for soybean, control strategies must complement the no-till system, including methods for management of residue. Since presence of residue has been associated with increased population densities of ground-dwelling arthropods, including *A. vulgare* (Stinner and House 1990), there is an immediate need to evaluate residue management strategies that may impact soybean stands and mitigate losses caused by this emerging pest.

In no-till soybean production, presence of crop residue improves soil properties and reduces producer input costs (Doran et al. 1984). Presence of residue is shown to reduce erosion while increasing the infiltration and retention of soil moisture (Bruce et al. 1990; Tebruegge and Duerling 1999; Saxton et al. 2001). Moreover, residues increase soil organic matter, which is correlated with beneficial microbial activities of soil-inhabiting organisms (Cruse et al 2003; Marriott and Wander 2006; Teasdale 2007). For example, it has been shown that the densities of entomopathogenic nematode, *Steinernema carpocapsae*, increase in the presence of residues, which is considered as a biological control agent for many insect pests (Shapiro et al 1999). Earthworms are also reported to benefit from residues, which is important since their activities

promote soil moisture infiltration by creating pores through the soil profile (Tebruegge and Duering 1999, Cruse et al 2003).

Presence of crop residues has also been associated with protection of arthropod pests by providing a shelter and food source (Kogan and Turnipseed 1987; Wallner 1987; Bugg 1991; Koul et al. 2004). As such, no-till cropping systems may be increasing crop susceptibility to arthropod pests (Stinner and House 1990). For example, populations of wireworm (*Melanotus cribulosus*), and white grub (*Phyllophaga spp.*) have been shown to increase in the presence of crop residues, due to increased soil moisture and lower temperatures, which are ideal for arthropod development (Wilde et al. 2004). In general, residue management is important for reducing the risk of increasing damaging levels of soybean pests.

Crop residue can enhance the life of *A.vulgare* by providing shelter and food for *A.vulgare* populations (Rushton and Hassall 1983). Presence of crop residue has been associated with increased population densities of isopods and reduced stand density of soybean plants in production fields near Lindsborg, Kansas. Burning residue is one cultural control which can be used to impact the life of arthropods (Hanula and Wada 2002). Biederbeck et al. (1980) reported that the heat from burning residue penetrates the soil about one-half inch under the surface. Therefore, soil-borne insects that overwinter in the soil may be directly affected by burning (McCullough et al 1998). However, indirect effects to overwintering insects from burning may include changes in soil chemistry and/or structure (McCullough et al 1998). Burning crop residue has been a successful control measure for various pests in no-till systems (Hardison 1976; Miller 1979; McCullough et al. 1998; Young et al 1998). Burning not only impacts arthropods by killing them directly, but indirectly by disturbing their habitat availability, and/or reducing food resources (McCullough et al, 1998). Burning residue may expose arthropods to sub-optimal

climatic conditions, including fluctuations in temperature and humidity, which may slow development or reduce survival (Hassall and Dangerfield 1990; Siemann et al. 1997; Moretti et al. 2004). As such, burning of crop residues may be useful for controlling isopods in soybean. In fact, Hanula and Wade (2003) found that detritivores, such as isopods, were reduced in burned plots of mixed pine-wood species, compared to unburned plots.

It is unclear whether burning crop residue can affect *A. vulgare* populations and corresponding soybean stand densities under no-tillage management. Moretti et al (2004) investigated the effects of burning on the richness of many species including isopods in a region locates southern Switzerland, which has been affected by a regular winter fires and found that repeated fire has decreased isopods richness. Hanula and Wada (2002) reported that annual burning reduces the numbers of isopoda. If damaging numbers of isopods are associated with no-tillage management of soybean, then it is essential to determine if burning crop residue is effective at reducing isopod damage and maintaining stand density. As such, the objective of this study is to evaluate the effects of burning crop residue on isopod pest populations and soybean stand densities that are under no-tillage management. Therefore, we hypothesize that burning residue reduces isopod densities and will improve soybean densities based on direct mortality and indirectly by reducing food/shelter availability after residue removal. Furthermore, absence of residue should promote intra-specific competition for isopod populations, in turn, decreasing their overall growth rate (Hassall and Dangerfield 1990).

Methods and Materials

This study was conducted in 2009 and 2010 at field sites located near Lindsborg, KS. Separate sets of adjacent soybean fields (hereafter reported as Fields 1 and 2 for 2009; and Fields 3 and 4 for 2010) were used to investigate the effects of residue burning on isopod densities and

soybean densities following normal planting schedules. Field sites were under a long-term, corn-soybean rotation with overhead irrigation. Field sites were chosen based on presence of damaging isopod populations, where the producer had replanted each of the 5 years prior, due to seedling damage from isopod feeding. In each year, fields were planted to soybean (Pioneer 94Y01) and were maintained according to standard practices by the local producer.

To create residue treatments, a field was burned in a manner that left random unburned areas to result in 4 to 6 plots of each treatment (6 replicates of each treatment repeating on the block location within a field). Blocks were of unequal size, which was a result of the method of burning applied by the producer. Untreated control plots were left with high corn (previous crop) residue, while plots without residue were burned using areas of the field that were controlled burned. Control burning aims to reduce the residue with no damage to the planted crop.

To assess residue burning on isopod populations, treatment plots were sampled 21 May, 29 May, 2 June, and 10 June in Field 1 (2009); 18 June and 7 July in Field 2 (2009); 28 May, 7 June, and 10 June in Field 3 (2010), and 2 June in Field 4 (2010) to estimate isopod density. For sampling stand counts of soybeans and isopods density, sections of each field were divided into two areas, burned and unburned area. Each area was divided into four to six blocks and in each block six subsamples were taken and soybean densities (plants per m²) and isopod density were recorded. A square quadrant (1 x 1 m) made from 1.9 cm polyvinyl chloride (PVC) was dropped randomly in each treatment area and then soybean stands and isopods density were counted. To assess the effect of burning residue on soybean stand density, plant counts were conducted on the same isopod sampling dates. Counts were made by sorting through residue and soil surface, recording data for number of live soybean plants and for number of live and dead isopods per m² within each replicate. From collected isopods, dorsal and lateral photos of

specimens were taken and submitted to Dr. Stephano Taiti for identification (Istituto per lo Studio degli Ecosistemi, Italy).

Statistical analysis

Plant and isopod data was checked for normality prior to analyses. Plant and *A.vulgare* data for each sample date was analyzed for analysis of variance (ANOVA) with presence of residue as the main effect and quadrant replicate as the random factor (PROC MIXED, SAS Institute 2002). Data were analyzed for means and standard error using the PROC UNIVARIATE statement in statistical analysis software (SAS Institute, version 9.2; Cary, NC). Mean treatment comparisons were made using a Tukey's test method with significance $\alpha=0.05$ to compare treatment effects on plant counts and on isopod densities.

Results

The effect of burning residue was significant on isopod densities in Field 1 during 2009 for all sample dates ($P \leq 0.05$) (Table 3.1), where isopod densities averaged ten times higher in plots that were unburned vs. burned (Fig. 3.1). There was no effect of burning residue on isopod densities in Field 2 in 2009. In 2010, the effect of burning residue was only significant for the later sampling dates (7 June and 10 June) in Field 3 ($P \leq 0.05$) (Table 3.1), where isopod densities averaged ten times higher in plots that unburned vs. burned (Fig. 3.1). Burning residue was also significant on isopod densities in Field 4 during 2010 ($P \leq 0.05$) (Table 3.1), where isopods were detected in plots unburned but not in burned plots (Figure 3.1).

For 2009, the effect of burning residue was significant on soybean stand densities at all sample times in Field 1 ($P \leq 0.05$) (Table 3.2), where stand densities were on average 45%

higher in burned versus unburned plots (Fig. 3.2). Residue was also significant in Field 2 for the early sample date (18 June) in 2009 ($P \leq 0.05$) (Table 3.2), where stand densities were approximately 43% higher in plots burned compared to unburned (Figure 3.2). In 2010, the effect of burning residue was significant on soybean stands at the later sample dates (7 June and 10 June) ($P \leq 0.05$) (Table 3.2), where stand densities were on average 22% higher in plots unburned compared to burned (Fig. 3.2).

Discussion

The effect of burning residue was significant on isopod densities in one of two fields during 2009, with densities about ten times higher in plots that were left with residue. Although the results varied by field, isopod densities were detected at much higher numbers in Field 1 than Field 2 (F1: 84 ± 25 , F2: 8 ± 4). As such, the effects of residue removal may not be independent of differences in initial isopod densities. However, any significant effects from burning residue in Field 2 on isopod numbers may not have been conveyed if isopod densities were too low to provide meaningful differences between treatments. During 2010, there was also a significant effect of burning residue on isopod densities in Field 4, and two of three sample times in Field 3, where live isopods were not found in detectable levels in plots without residue. Although burning appears to have influenced the absence of isopods in burned plots, other possible explanations are unknown at this time. If live isopods had survived the burn, it is possible that they emigrated out of plots before isopod sampling was conducted.

We hypothesized that burning residue would reduce isopod densities. Our findings do not suggest that a reduction in isopod numbers by burning residue relates to higher stand densities. One study found that in no-till alfalfa, grass residue removal reduced the numbers of live *A.vulgare* about 75%, which was not correlated with increased stand densities (Faix et al 1981).

On the other hand, another study found that removal of residue in study plots within no-till fields which were cropped continuously in a corn or soybean rotation was correlated to reduced grain yield, compared to plots having residue where yields were higher (Wilhelm et al. 1986). The authors of the study suggest that the effects on crop yields of residue present in plots were related to reduced soil temperature and increased stored soil water (Wilhelm et al 1986). Our results may also be explained by burning effects on tritrophic interactions in soybean systems. For example, it has been shown that residue removal results in less abundance and diversity of natural enemies (Edwards 1984), which may impact isopod densities. Yields may have been negatively impacted by a loss of natural enemies, leaving seedlings vulnerable to other types of arthropod pests, or secondary outbreaks of a pest not affected by burning.

In our study, there were no clear relationship of isopod numbers and stand densities. This may have been due to their lifecycle, or overwintering habits, migration within a field, or specific feeding behaviors that reduced their exposure to burning effects. Moreover, varied study results may be explained by the biology of *A.vulgare*, where it has been shown that some populations actually benefit from less food availability. In some cases, females *A.vulgare* were found to be more likely to produce a second brood when starved (Brody, 1991). Furthermore, inconsistencies between fields and years may have been due to variations in the amount of remaining residue, where higher amounts of residue may have influenced the isopod densities. Moreover, differences in climate between 2009 and 2010 may have affected isopod densities, as well as the plant counts. Although average daily temperature for June (24 °C) in 2009 was similar to June during 2010 (25 °C), the total precipitation was 14.8 cm in June 2009, compared to 9.3 cm during June 2010 (available online: wdl.agron.ksu.edu/monthly). The variability of precipitation between years may have influenced isopod numbers and/or stand densities. For example, the

higher precipitation in 2009 could have been responsible for the higher populations of isopods in Field 1 during 2009.

Although results were not consistent between both fields, stand densities were greater in plots without residue compared to plots with residue during 2009. However, there was no clear pattern of burning residue effects between years. Therefore, it remains unknown if burning residue results in greater soybean stand densities. Therefore, further studies are needed in order to determine if burning residue and reduction of isopod numbers are, in fact, related. Future work may be improved for establishing this relationship by comparing plant counts in plots of high, low, and no isopod densities. To better understand the effects of burning residue on isopods and tritrophic interactions that may influence isopod populations in soybean, studies should be conducted on fields for multiple years. As such, we may find that temporary effects from one year of burning may be different from the effects of continuous burning over time.

The removal of residue by burning as a method for maintaining stand densities in the presence of isopods may be temporarily effective at reducing high *A.vulgare* numbers, possibly correlating to greater stand densities. However, thresholds for *A.vulgare* which indicate burning as a management tool are unknown since there are no bioeconomics models to determine relationship between yield loss and isopod density. Therefore, while burning may be important in reducing some soybean pests, it may not be the best long-term control option for isopods. Hanula and Wada (2002) reported that the effects of burning of residue on arthropods tend to be specific to species. For example, some ant species increase in population after burning, where other populations of other species tend to be reduced. The authors suggest that variability between species is due to developmental stage during exposure to burning. Developmental stages of isopods in this field study are not known, but could be useful to determine in future studies.

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Tables and Figures

Table 3.1. ANOVA results for effects of burning residue on total number of live isopods (mean number of isopods per m²) in Fields 1 and 2 in 2009 and Field 3 and 4 in 2010 near Lindsborg, KS.

Location	Sample Date	df	<i>F</i>	<i>P</i> -value
Field 1	21 May	1,10	53.91	< 0.001
	29 May	1,4	13.31	0.021
	2 Jun	1,22	60.03	< 0.001
	10 Jun	1,14	14.05	0.002
Field 2	18 Jun	1,12	0.2	0.664
	7 Jul	1,6	0.15	0.707
Field 3	28 May	1,20	2.18	0.155
	7 Jun	1,16	13.17	0.002
	10 Jun	1,45	12.16	0.001
Field 4	2 Jun	1,16	6.12	0.025

Table 3.2. ANOVA results for effects of burning residue on total number of emerged soybean plants (mean number of plants per m²) in Fields 1 and 2 in 2009 and Field 3 and 4 in 2010 near Lindsborg, KS.

Location	Sample Date	df	F	P-value
Field 1	21 May	1,11	17.1	0.001
	29 May	1,4	35.31	0.004
	2 Jun	1,22	10.88	0.003
	10 Jun	1,14	9.49	0.008
Field 2	18 Jun	1,12	18.52	0.001
	7 Jul	1,6	1.61	0.251
Field 3	28 May	1,20	3.78	0.066
	7 Jun	1,16	5.86	0.027
	10 Jun	1,46	13.46	0.001 >
Field 4	2 Jun	1,16	0.18	0.674

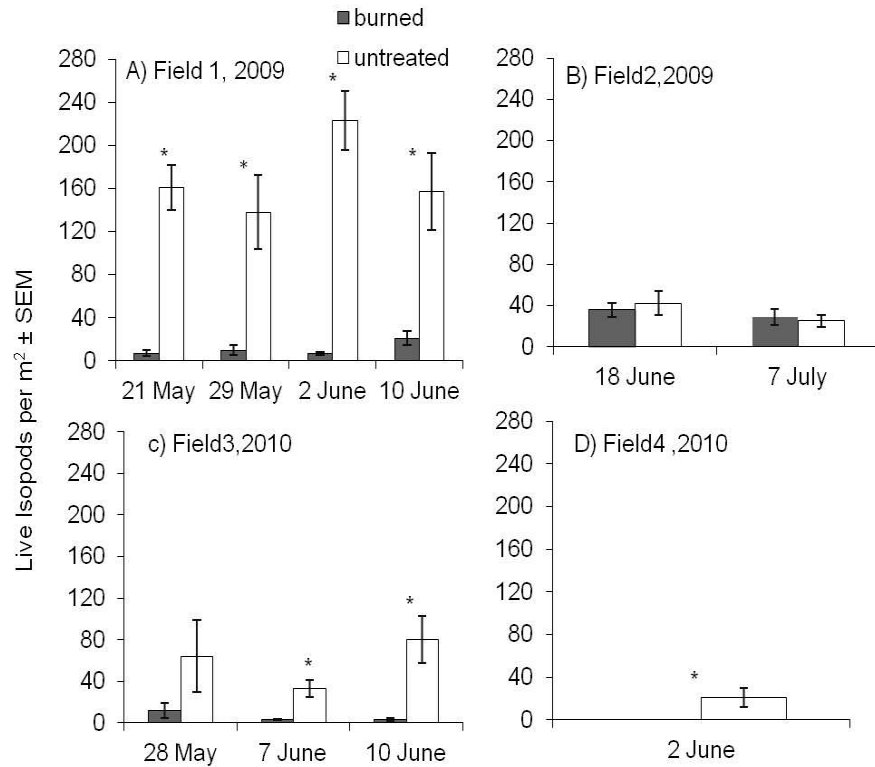


Figure 3.1. The effects of burning plant residue on mean number of live isopods per m² in Fields 1 and 2 in 2009 and Field 3 and 4 in 2010 near Lindsborg, KS. An asterisk indicates a significant difference between treatments within a sampling date at $P \leq 0.05$.

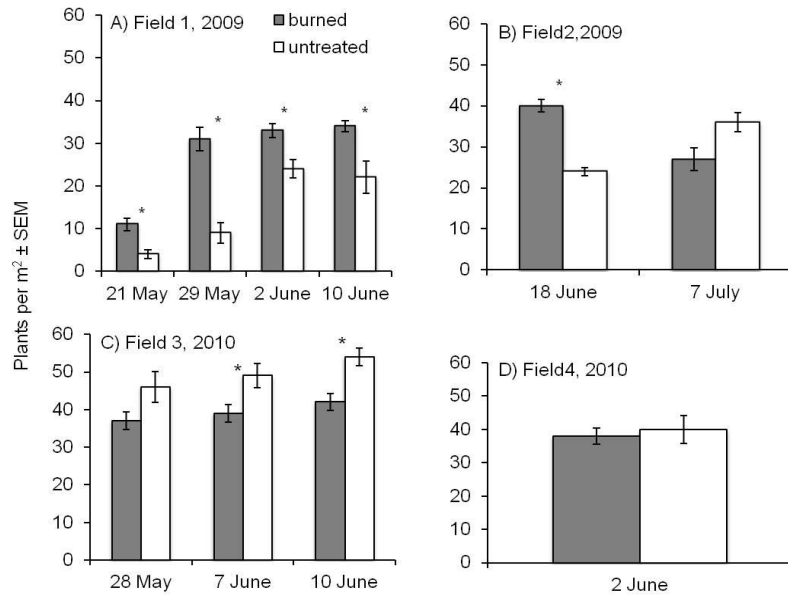


Figure 3.2. The effects of burning plant residue on mean number of emerged soybean plants per m² in Fields 1 and 2 in 2009 and Field 3 and 4 in 2010 near Lindsborg, KS. An asterisk indicates a significant difference between treatments within a sampling date at $P \leq 0.05$.