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SPRING INTERSEEDED WINTER ANNUAL RYE IN DRY BEAN CROPPING SYSTEMS: WEED CONTROL AND STEM ELONGATION

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By

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ABSTRACT

SPRING INTERSEEDED WINTER ANNUAL RYE IN DRY BEAN CROPPING SYSTEMS: WEED CONTROL AND AGRONOMIC TRAITS.

By

Steven A. Wagstaff

Public concern over herbicide contamination of water, surfactant effects on amphibians, and herbicide resistant weeds has led to increased interest in alternative weed control systems. In addition, direct-cut harvest-associated yield losses of dry bean (*Phaseolus vulgaris* L.) are of concern to some growers. Often, there is difficulty operating combine mechanisms near soil surfaces, in order to reach the lowermost bean pods. The objectives of this study were to evaluate the utility of an interseeded spring-planted rye (Secale *cereale* L.) cover for: (a) weed suppression, and (b) elongation of dry bean stems for potential reduction in harvest-associated yield losses. We hypothesized that a rye cover would shade dry bean plants, resulting in a stem elongation response.

Overall, interseeded rye cover reduced dry bean yields, above-ground biomass, and plant heights. Rye cover also suppressed above-ground weed biomass in several instances. However, despite overall reductions in dry bean plant vigor, treatments including rye cover resulted in significantly greater heights of lowermost dry bean pod attachment, indicating the presence of a stem elongation effect.

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CHAPTER 1: Literature Review

Introduction

Common bean (*Phaseolus vulgaris* L.) is an annual, herbacious plant grown for its edible bean from temperate to tropical climates worldwide. Common beans are primarily eaten fresh, e.g., green beans, or grown to physiological maturity and dried, as dry beans, for storage. Production and consumption of dry beans is far greater than that of green beans. In additon to the beans being eaten, the flowers and leaves may be harvested for consumption in some parts of Latin America as well as Central and Eastern Africa. Also, special heirloom "popping" cultivars are cultivated in Bolivia and Peru. These cultivars are believed to have been roasted on open fires for consumption, prior to the invention of pottery (and thus, boiling), by the natives of the Andean highlands (Singh 1999).

The common bean was originally domesticated, independently, in both ancient regions of Mesoamerica and the Andes sometime between 5000 and 7000 B.C. from morphologically and biochemically distinct populations (Chacon et al. 2005). Around 700 years ago, common beans were used extensively with squash and corn as part of the native American "Three Sisters" polyculture farming systems. Although there is uncertainty, it has been theorised that Spanish-Potugese sailors obtained and introduced common bean germplasm to Spain and other parts of Europe in late 1400 (Zeven 1997).

Today, as a major source of protein and starch for many developing nations, dry beans are an extremely important legume crop worldwide, and, in-fact, they are the most widely consumed grain legume in the world (Acosta-Gallegos *et al.* 2007). It has been documented that some per-capita consumptions in easterm Africa are over 60 kg per year (Gepts 2001; Miklas and Singh 2007). The protein present in dry bean accounts for 20-25% of seed weight (Ma and Bliss 1978). Addtionally, dry beans are an important source of mineral micronutrients (Calcium, Copper, Iron, Magnesium, Manganese, Phosphorous, and Zinc) as well as the vitamin, folate (Welch *et al.* 2000).

In addition to the nutritional importance of dry beans in developing nations, recent research points to the potential additional health benefits of dry bean consumption in developed nations. Many health-conscious countries are increasing dry bean consumption (Acosta-Gallegos *et al.* 2007), although consumer preference for market class may vary widely. Bean consumption has been linked to reduction in both total and low-density lipoprotein (LDL), or "bad", cholesterol levels (Anderson *et al.* 1984; Anderson 1987). In a recent study, Winham et al. (2007), concluded that eating pinto beans for eight weeks significantly lowered total and LDL cholesterol and thus, the risk of heart disease. In a separate study, Hangen and Bennink (2003) showed that consumption of black and navy beans reduced the incidence of colon cancer in rats.

In 2005, the United States ranked sixth in the world for production of dry edible beans, behind Brazil, India, China, Burma (Myanmar), and Mexico. The Americas collectively produced 6.5 million metric tons (MMT) with the majority of the production concentrated in the top three nations: Brazil (3 MMT), the United States (1.3 MMT), and Mexico (1.2 MMT) (Anonymous 2007).

Although many regions of the United States produce of dry beans, the majority of production is concentrated in the lower peninsula of Michigan and North Dakota. In

2006, Michigan ranked second in the United States for edible dry bean production, with an estimated wholesale value of $127,000,000 (Anonymous 2006). Forty-one percent of Michigan's 191,000 total dry bean acres were planted in black beans, making Michigan the top producer of black beans in 2006 (Anonymous 2006).

The wholesale value of the U.S. dry bean crop for 2007 was approximately $677,000,000 with an estimated 1.15 MMT harvested from 598,429 hectares planted. Although there was a 6.3% decrease in area planted from 2006 to 2007, there was a 22% increase in total wholesale value. In Michigan, wholesale value of the 2007 dry bean crop was $88,000,000, with 141,500 metric tons harvested from 78,917 hectares planted. (Anonymous 2008).

Dry Bean Agronomy

Dry beans are adapted to a wide range of temperatures, but as a short day crop, the optimum temperature range is between 18 and 24 °C. Cooler temperatures are undesirable and frost is not tolerated well. Dry beans are also adapted for a wide range of soil types, but are intolerant of saline or poorly drained soils (Anonymous 1997).

In Michigan, the crop is typically planted during the first week of June. A normal growing season will range from 100 to 130 days to maturity (Singh 1999). Desired plant populations range from 296,000 plants per hectare (ha) in drilled (19 cm) spacings to 148,000 plants per ha in wide row (76 cm) spacings. When planted in 62 cm rows, the plants may take several weeks to close their canopies across rows, although this may never occur in some fields. The seed should be planted between 2.5 and 5 cm deep. Growers are encouraged to plant certified seed to control seed-borne diseases such as baterial blight and anthracnose as well as to ensure genetic purity (Anonymous 1997).

Although dry beans are a legume, their fixation of nitrogen is considered to be highly variable due to environmental conditions and variablitity between varieties (Warncke *et al.* 2004). Michigan State University recommends applying 45 to 67 kg nitrogen per ha (N/ha) to dry bean crops. Growers utilizing narrow rows, irrigation, and other intense managment systems are encouraged to use a rate near 67 kg N/ha, while gorwers practicing less intense managment should utilize a rate closer to 45 kg N/ha. Phosphorus availablity should be at least 40 parts per million (ppm). Potassium recommendations are based on soil CEC (cation exchange capacity) and yield targets. The recommended soil test level is 135 ppm for a soil with a CEC of 4, regardless of yield goal. Additionally, growers should not apply fertilizer with seed, but should instead broadcast and incorporate fertilizer prior to planting or band between rows. Zinc deficiency, although uncommon, may be experienced in high pH soils (> pH 7.8) or following a sugarbeet crop due to lack of mycorrhizal-assisted nutrient mining of zinc (Warncke *et al.* 2004).

There are several different dry bean market classes, including: kidney, navy, pinto, and black beans. Although the beans within these various classes differ in size and shape, they are all recognized as the same species, *P. vulgaris*. There are three basic growth habits of dry bean varieties grown in the US (Figure 1.1). Type I, 'bush' varieties, are determinate, while Types II and III are indeterminate. Type II, 'upright' varieties exhibit an upright architecture, having most of their pods held above the ground. Type III, 'vine' varieties exhibit varying degrees of prostrate architecture, with the potential for many pods to touch the ground (Figure 1.1). In addition, there is a climbing type growth habit (type IV). Upright varieties grow up to 71 cm tall while vine varieties may obtain vine lengths of up to 3 m (Anonymous 1997).

Harvest Methodology

Most dry bean growers practice one of two types of harvest procedures, the pulling-windrow method or the direct combine method. Prior to modern breeding efforts, the predominantly prostrate architecture of available bean germplasm necessitated pulling and windrowing, requiring multiple pieces of equipment. Even with modern breeding efforts, the windrow method is still the most common harvest procedure. First, a bean puller is run through the field, cutting and pulling the beans as low on the stem as possible and laying them on the soil surface. Secondly, the plants are mechanically raked into long rows, or windrows. In Michigan, this procedure is done early in the morning, while dew is present, in order to minimize yield loss associated with pod shatter. The bean plants are allowed to sit in the windrows for several hours until the beans are dry before finally being threshed. In regions with drier fall climates than Michigan, such as parts of North Dakota, Idaho, and Washington, beans are cut and windrowed while green and immature and allowed to cure in the windrows for up to two weeks prior to threshing. The thresher separates the grain from the bean plant while leaving the remainder of the plant in the field, adding vital organic matter back into the system. Often, further cleaning with a winnower is required after this step.

Despite its common use, the pulling-windrow harvest method does pose serious risks and can have considerable drawbacks to growers in the Upper Midwest. While the beans are in windrow they are vulnerable to precipitation events. If beans in a windrow are rained on, there is a major possibility for grain quality degredation, disease-associated yield loss, sprouting seed, mold, and other quality reductions. In addition, due to multiple field passes with equipment, the process can be fuel-intensive and exacerbate soil compaction problems. Equipment, labor, and maintenance costs may be high. Also, due to the technical complexity of harvest, it can be difficult to time each phase correctly, especially under adverse environmental conditions (Nuland *et al.* 1983).

Another type of harvest procedure, which growers are increasingly adopting in Michigan, is the direct combine method. Direct harvest utilizes a combine, a piece of equipment that many growers already own, to cut and harvest beans. A rotary combine, often equipped with a floating-head, such as is used in soybean production, cuts and threshes the beans in one pass. Little modification of most combines is needed to execute this method. Modern upright bean varieties have made direct combine harvest feasible. Upright varieties, with most of their pods above the soil surface, make it much easier for a combine to cut plants and pull them into a threshing mechanism without cutting pods that touch the ground. The direct combine method simplifies the harvest procedure compared to windrowing and offers savings on fuel, labor, and equipment costs. Often, growers that utilize the direct combine method must roll their ground with a tractor-driven implement prior to planting because a uniformly flat and rock-free bed of soil is required for ease of combine operation and minimization of post-harvest losses. This method is desirable to some farmers in the Midwest due to weather related risks, shorter harvest windows, and high fuel costs (Kelly 2008).

While upright varieties have made direct harvest possible, harvest-associated yield losses are still of major concern. Regardless of the degree of upright architecture exhibited by any given variety, yield loss is possible. Even in the most upright of varieties, the lowest pods on the plant may still be below the cutter bar of the combine.

When compared to soybean, dry bean pods often have longer pods with more seeds, with the potential for pods to hang lower and loss from pod shatter to be greater. One study has shown that direct combine losses can range from 8% to 13.5%, while the windrow method typically results in losses of 3% to 12% (Harrigan and Poindexter 1999). Simply lowering the cutter bar to the level of the soil is not possible due to the potential of hitting the soil with the cutter-bar of a combine, or earth tag, which can damage equipment, slow harvest times, and reduce quality of the harvest. Therefore, combine operators are required to operate combine cutter-bars as low as possible while avoiding earth tag, a daunting task in fields with uneven topography.

Despite the potential benefits of direct harvest, most Michigan growers utilize the pulling-windrow method, although adoption of the direct harvest method is growing (Kelly 2008). Grower concern for yield losses as well as prior investments in windrow equipment may contribute to this lack of adoption. Also, when compared to the direct harvest, pulling-windrowing may result in less bean splitting due to increased seed cushioning from excess plant material (i.e. roots and lower stems) being processed within threshing mechanisms. Additionally, costs associated with purchasing new combine equipment may also be prohibitive.

Once the crop is harvested by either method, the grain will often undergo further cleaning procedures. Beans will also be polished to enhance their cosmetic appeal and ensure cleanliness. For long-term storage, the beans will be kept below 18% moisture by weight. If beans are stored at a higher moisture content, mold may significantly reduce quality. Although, if held for less than 6 months, a moisture content of 18% may be acceptable (Anonymous 1997). Likewise, too low of a moisture content can be problematic, resulting in increased seed damage during handling. Also, as moisture is reduced, cooking times increase and quality is diminished.

Weed Suppression

In addition to harvest methodology, weed suppression is another area of intense concern within dry bean production. In dry bean cropping systems, a considerable amount of time, energy, and money is invested in weed management. Vigorous control of early season weeds is imperative. Dry beans are quite susceptible to weed pressure, especially in early to mid-season while the canopies are still open (Urwin *et al.* 1996; Webber & Shrefler 2003). The critical weed-free period for dry bean may vary by location and environment. Based on an experiment in Ontario, Canada, Woolley *et al.* (1993) reported that the critical weed-free period was between the second trifoliate and first-flower stages. Woolley *et al.* also noted that variation was probable at other locations and in other years due to non-static environmental factors and weed densities. Ngouajio *et al.* (1997) found that, in Cameroon, the critical period occurred between emergence and second trifoliate leaf at two locations and between first trifoliate leaf and pod filling stages of bean growth in other locations. Yield losses attributable to weed pressure of up to 75% have been reported (Vangessel and Westra 1997).

Depending on specific farm management styles, a combination of chemical, mechanical, and cultural methods may be utilized to reduce weed competition. Examples of these methods include: herbicide application, tillage, rotary hoeing, hand hoeing, in-row cultivation, cover crop usage, narrow row spacing, and increased planting populations. Transgenic varieties of dry beans which are resistant to the herbicide glufosinate have been devoloped in Brazil, but have not been registered for use in commerical production (Aragão *et al.* 2002) due to percieved consumer adversity to purchasing genetically modified dry beans.

Cover Crops

Cover crops are vegetation grown for their abilities to protect and improve soil quality rather than for direct economic gain through harvest (Lal *et al.* 1991). Cover crops are an important agricultural tool and offer many potential benefits to the grower even beyond the defintion provided by Lal *et al.* (1991). In addition to improving soil quality, cover crops can also prevent nutrient leaching (Parkin *et al.* 1997; Shipley *et al.* 1992), reduce pathogenic and insect pests (Ingham 1993), sequester and add carbon into agricultural systems, reduce erosion (Edwards *et al.* 1993), provide nitrogen to succeeding crops, and suppress weed growth through competition and allelopathy (Teasdale *et al.* 1991).

However, despite the many potential benefits of cover crop usage, several negative impacts have been documented. Cover crops immobilize nutrients, increase labor and other costs, and increase the risk of certain pests (Luna 1993). Planting times may be delayed due to a slowed soil warming effect in the spring and also by heightened soil moisture due to increased infiltration (Teasdale 1998; Luna 1993).

There is a great variey of terminology used to describe cover cropping systems. Some of these terms describe the function of the crops, while others describe the method or timing of crop establishment. Much of the terminology can be combined and/or used interchangeably. The following portion of this review briefly explains a number of terms and some literature associated with cover cropping systems, but will ultimately focus on weed control through the use of living mulch cover crop systems.

Living Mulch

A living mulch is a cover crop that is grown along with a primary crop in the field, for all or part of the growing season. Competition is a major concern with living mulch systems because the mulch and the primary crop are forces to share resources. A living mulch is typically established, and occasionally suppressed, prior to primary crop establishment. Although, suppression may not be necessary if the living mulch is expected to senesce early in the developmental stages of the primary crop, thus significantly reducing or even eliminating inter-crop competition. Research into living mulch systems has tended to focus on weed control and managment of the mulches, and has showed mixed results (Ateh and Doll 1996; Eadie *et al.* 1992; Enache and Ilnicki 1992; Thelen *et al.* 2004).

Green Manure

Green manures have historically been used to add both nutrient and organic matter back into the soil and have been a subject of study for over 150 years. In 1843, the Rothamsted Experimental Station was established in England. In the US, the Morrow Plots research began at the University of Illinois in 1876. These research stations laid the foundation for our understanding of soil fertility and quality improvements with the use of cover crops. Unlike a living mulch, green manure is typically established and grown separately from the primary crop. Subsquently, the cover crop is plowed under or otherwise incorperated into the soil before planting the primary crop. These crops often include biennials, perennials, or mixtures of the two, and may be grown for two years or more before being incorporated. Various crops may be used depending on the goal of the grower. For instance, a legume manure may be used if the goal is to provide nitrogen for a succeeding crop, while winter rye may be used for its rapid accumulation of biomass if the grower seeks to add organic matter to the soil (Bowman *et al.* 1998).

Catch Crop

The primary function of a catch crop is to immobilize excess water soluable nutrients. Typically, the primary nutrient of concern is nitrate, which is often provided in excess of crop demands in the form of nitrogen fertilizers or manure. Nitrate leaching has been cited for contamination of groundwater, a potentially dangerous situation if consumed by humans, particularly infants (Spalding and Exener 1993). In particular, grass cover crops have been noted to sequester more nitrogen than legumes (Shipley et al. 1992). Aronsson and Torteson (1998) showed that an Italian Ryegrass (*Lolium perenne*) catch crop could potentially reduce total nitrogen leaching by 40 to 50% when properly established with spring cereal cash crops. In addition to potentially ameliorating the effects of water contamination, catch crops may also release nitrogen to successive crops if they are left to decompose in the field or turned under as a green manure (Jensen 1992).

Smother Crop

Smother crops are high biomass producing crops used primarily for weed control purposes. A smother crop is very similar to a living mulch in that it may be established and supressed before, simultaneously with, or subsequent to the seeding of a primary crop. Smother crops can suppress weeds through allelopathy and competition for moisture, light, and nutrients. Smother crops, as defined by Teasdale (1998) are analagous to living mulch.

Trap Crop

Trap crops are crops that are planted with the intention of luring insects and other pests away from cash crops. An important requirment for these crops is that they must be more attractive to the targets pest. Trap crops may be planted around the perimeter of the cash crop or intercropped within the cash crop. An early or late planting of the same species as the cash crop or a completely different species altogether may be used to suit different pest species. A trap crop may be a cash crop itself, or it's sole purpose may be to fuction as a trap crop. For example, alfalfa may be used as a trap crop for lygus bug in cotton production, while also being harvested for forage. Alfalfa is intercropped in strips within cotton plantings, and is only partially harvested while the threat of lygus bug (Lygus spp.) damage remains high (Stem 1969).

Spring-Seeded Cover Crop

Spring-seeded cover crops are established prior to the planting of a spring or summer crop and, for research purposes, are often considered a type of living mulch or smother crop. Field conditions, such as waterlogged soils, can make planting a difficult or even impossible task in some years. In addition, a spring cover may delay radiative soil warming (Teasdale 1998).

Frost-Seeded Cover Crop

Frost-seeding is a practice where a cover crop is broadcast seeded while the ground is still frozen, in late winter to early spring. The freeze and thaw cycles create surface cracks within the soil, which the seed is then drawn into, creating good seed-to-soil contact and enhancing germination and establishment (Barnhart 2002). A common practice is to frost-seed red clover into winter cereal grains (Mutch and Snapp 2003). Mutch *et al.* (2003) demonstrated successful suppression of ragweed by frost-seeding red clover into established winter wheat stands.

Winter Cover Crops

Winter cover crops are often established after a fall harvest to control soil erosion. In cooler climates, however, it may be advantageous to overseed before harvest of a primary crop. Often, the goal of the grower is to accumulate as much biomass as possible before winter, when the crop will be dormant or possibly winter-killed. In many regions, growers should plant these covers six weeks before a hard frost. (Bowman *et al.* 1998). Due to its winter hardiness, cereal rye is a popular winter cover in the North Central region of the United States (Bollero and Bullock 1994). Ruffo *et al.* (2004) investigated the effect of a winter rye crop, killed with herbicide approximately two weeks prior to no-till soybean planting. Not only did the rye not effect soybean yield it also "provided an environmental service" by immobilizing pre-season nitrate (Ruffo *et al.* 2004).

Summer Cover Crops

Summer cover crops are established and grown for a portion of the summer growing season. A warm season cover is often selected to fill a niche between the harvest of spring crops and before the planting of fall vegetable or grains. Summer cover crops are often grown for the purpose of suppressing weed growth or as a green manure.

Interseeded, Overseeded, Underseeded Cover Crops

Interseeded cover crops, also called either overseeded or underseeded cover crops, are seeded directly into a primary crop at any point from the time of establishment until the time of harvest. Competition is an important concern with interseeded systems as the cover and the primary crop must coexist. Many studies have documented cover crop competition within interseeded systems (Ateh and Doll 1996; Exner and Cruse 1993; Knake andf Slife 1965; Knake and Slife 1969; Kurtz *et al.* 1952; Thelen *et al.* 2004; Schmenk 1994).

Weed Control with Living Mulch

A specific type of cover crop, living mulch, has recently shown potential for integration with soybean (Ateh and Doll 1996; Thelen *et al.* 2004). Living mulch is a cover crop that is planted prior to, or simultaneously with, a primary crop, where-by the cover crop and primary crop grow together in the field for all or part of the growing season. Living mulch can suppress weeds through competition for resources such as sunlight, moisture, physical space, and nutrients as well as through allelopathy. However, living mulches must often be either suppressed or killed by application of herbicides or by mechanical methods to reduce competition with the primary crop (Ateh and Doll 1996; Hartwig and Ammon 2002).

Living mulches have been evaluated for use along with several crops other than common beans, with mixed success. Enache and Ilnicki (1990) found that the use of subterranean clover as a living mulch in a no-till system significantly reduced weed biomass and resulted in corn grain and silage yields comparable to conventionally tilled, no-mulch systems. Enache and Ilnicki (1992), in a later, expanded experiment, concluded that subterranean clover used as a living mulch significantly reduced weed biomass and did not adversely affect yield in several cropping systems: corn, sweet corn, cabbage, snap beans and tomato. In contrast, Echtenkamp and Moomaw (1989) reported that winter cereal rye used as a living mulch adversely affected corn grain yields due to its competition for both moisture and nutrients. Also, Sheaffer *et al.* (2002) explored the utility of annual medicago as a living mulch in soybean systems. Although annual medicago did suppress weeds, they reported that soybean yield was negatively impacted by the cover (Sheaffer *et al.* 2002). Despite the decreased soybean yield, Sheaffer *et al.* (2002) noted that "decreased purchase of herbicides and N fertilizers should reduce production costs and provide some compensation for the decreased grain yields and seed costs." Hartwig and Ammon (2002) reviewed several successful adaptations of living mulches in a variety of systems including both perrenial (vineyards and orchards) and common annual agronomic crops (corn, small grains and forages). Although living mulches were often successful, some form of suppression was often needed in order to minimize competition with primary crops (Hartwig and Ammom 2002). Competition for moisture, however, may potentially be overcome in select perrenial and annual croppings systems, such as vineyards and corn, due to their ability to tap subsoil moisture (Hartwig and Ammon 2002).

A spring-planted rye as a living mulch cover crop has the potential to address two previously discussed problems with dry bean production systems, direct cut harvest losses and weed control. Spring-planted rye does not undergo a period of vernalization, and thus, remains in a relatively prostrate vegetative state, minimizing competition with the crop. The less aggressive growth habit has been noted as a desirable trait for a living mulch as compared to fall-planted rye (Thelen *et al.* 2004). Despite the somewhat prostrate morphology of spring-planted rye, it has demonstrated the ability to reduce weed biomass by 93% as compared to no rye plots (Barnes and Putnam 1983).

This research focuses on the use of spring-planted cereal rye mulches to reduce weed infestation in dry bean cropping systems. In addition, the potential for reducing yield losses associated with direct combine harvest will be explored. It was hypothesized that a rye cover would shade developing bean plants and would result in more elongated dry bean architecture. Also, an elongated dry bean architecture may result in lower direct combine yield losses. It was further hypothesized that spring-planted cereal rye as a living mulch would provide weed control benefits through direct competition with weed species as well as through a mulch effect. This system may also be of particular interest to organic farmers who cannot use synthetic herbicides.

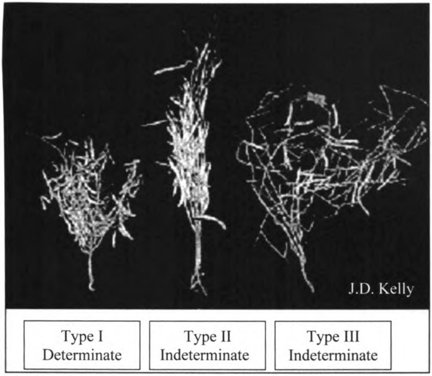

Figure 1.1 Architectural differences between growth habits within P. vulgaris.

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Chapter 2: Utility of Interseeded Winter-Annual Rye in Dry Bean Cropping Systems

Introduction

Public concern over herbicide contamination of water, surfactant effects on amphibians, and herbicide resistant weeds has led to increased interest in alternative weed control systems for crop production. Living mulches may prove to be an important tool for control of weeds and could reduce grower reliance upon chemical herbicides. Various applications of living mulches have been evaluated (Ateh and Doll, 1996; Eadie *et al.*, 1992; Enache and Ilnicki, 1992; Thelen *et al.*, 2004) with mixed results.

Cereal rye (*Secale cereale* L.) is a popular cover crop in the northern United States due to its cold hardiness. Rye, like other cover crops, may prevent nutrient leaching (Kaspar *et al.* 2007; Shipley *et al.,* 1992), reduce pathogenic and insect pests, sequester and add carbon to agricultural systems, reduce erosion (Edwards *et al.*, 1992), provide nitrogen to succeeding crops, and suppress weed growth. Rye suppresses weed growth through several mechanisms, including competition for water and nutrients, allelopathy, and physical competition (Teasdale, 1991).

While spring-planted cereal rye has shown potential for integration in soybean cropping systems as a living mulch (Ateh and Doll, 1996; Thelen *et al.*, 2004), it has not yet been evaluated within dry bean (*Phaseolus vulgaris* L.) cropping systems. Spring-planted rye does not undergo a period of vernalization, and thus, remains in a less vigorous, vegetative state, minimizing competition with the crop. The less aggressive growth habit has been noted as a desirable trait for a living mulch as compared to fall-planted rye (Thelen *et al.*, 2004).

Dry bean growers commonly utilize the windrowing-pulling method of harvest, which requires multiple passes with different pieces of equipment. A new method, direct combining, is gaining popularity in regions that experience significant rainfall during harvest time. These growers are concerned about quality losses, due to seed sprouting, and mold associated with precipitation events while bean plants are in windrows. Direct combine harvest is seen as a way to reduce fuel and labor costs as well as weather related risks because beans are not left exposed.

It was hypothesized that a spring-planted rye cover would shade bean plants and would result in an elongated dry bean architecture, commonly referred to as the "near-neighbor effect". Shading reduces energy for photosynthesis and lowers the ratio of red:far red light, which can trigger stem elongation in herbaceous plants (Smith, 1982). An elongated dry bean architecture could result in reduced direct combine yield losses due to bean pods being held higher off the soil surface, and thus more readily entering the combine mechanism.

The objectives of this study were to assess the utility of spring-interseeded rye for weed suppression and for potential reduction of direct-cut harvest-associated yield loss through elongation of the dry bean plant.

Materials and Methods

Field research was conducted at the Michigan State University Experiment Farm in Ingham County and at a farmer-cooperator farm in Gratiot County, Michigan for the two-year period, 2006 and 2007. The predominant soils at the Ingham county site were

Riddles-Hillsdale Sandy Loams in 2006 (fine loamy, mixed mesic Typic Hapludalf-coarse-loamy, mixed mesic Typic Hapludalf) and Capac Loam (fine-loamy, mixed, mesic Aeric Ochraqualfs) in 2007. The predominant soil at the Gratiot County site was Capac Loam in both years. The previous crops were soybean and corn in 2006 and 2007, respectively. The soil pH was 5.3 and 6.2 at Ingham and 6.5 and 6.4 at Gratiot for 2006 and 2007, respectively. The variety of dry bean was "Jaguar" black bean (Kelly *et al.*, 2001) and the variety of rye was "Wheeler" ('Wheeler', Michigan Agric. Exp. Stn., East Lansing, MI). Dry bean was planted in 19 cm rows at the Gratiot site and both 19 cm and 76 cm at the Ingham site. Target planting populations were 433,000 plants/ha in 19 cm rows and 194,000 in 76 cm rows. Planting dates were 6 June, 2006 and 4 June 2007 at both sites. Plot sizes were 3 m by 12.2 m. An inoculant containing *Rhizobium sp.* was applied at the recommended rate to all seed prior to planting (Nitrastik-D, LiphaTech Inc., Milwaukee, WI). In applicable treatments, rye was planted at 126 kg/ha.

The experimental design was a randomized complete block design with four replications at both sites with Ingham in a split-split plot configuration (Table 2.1) and Gratiot in a split plot configuration (Table 2). The main plots were cover crops: (a) rye planted on the same day as dry bean, and (b) no rye planted. The subplots were: (a) broad spectrum herbicide application, (b) broadleaf herbicide application, and (c) no herbicide application. The sub-sub plots (present only at Ingham) were: (a) 19 cm row spacing and (b) 76 cm row spacing. The Gratiot county site was only planted in 19 cm rows.

The Gratiot site was treated with glyphosate one month prior to planting in 2006 and two weeks prior to planting in 2007. Ingham site was disked three days prior to planting in 2006 and two days prior to planting in 2007. Broadleaf herbicide treatments consisted of Basagran (benzatone) at 0.28 kg a.i./ha + Raptor (imazamox) at 0.038 kg a.i /ha + 1% crop oil concentrate (COC) + spray-grade ammonia sulfate at 6.8 kg per 379 liters. Broad-spectrum treatment applications were identical to broadleaf treatments except Select (clethodim) was added at 0.11 kg a.i./ha. Herbicide applications were made on 26 June and 14 July in 2006 and 22 June and 16 July in 2007 at Gratiot. At Ingham, herbicide applications were made 1 July and 25 July in 2006 and 22 June and 16 July in 2007. One additional application was made at Ingham on 11 July in 2006 to suppress rye re-growth in treatments that received broad-spectrum applications. This additional application consisted of 0.11 kg a.i./ha Select (clethodim) + 1% COC.

Early (data not presented) and late season biomass readings were taken in both years of the study by hand-clipping plants at ground level from two randomly placed 0.5 m^2 quadrats per plot. Plants were hand sorted. Rye, bean, and weed biomass ratings were recorded, with weed biomass being classified by species. Early season biomass measurements were taken 19 June and 21 June in 2006 and 19 June and 21 June in 2007 at Ingham and Gratiot, respectively. Late season biomass measurements were taken 19 September and 21 September in 2006 and 18 September and 21 September in 2007 at Ingham and Gratiot, respectively. Plants were separated, and placed in a forced-air dryer until a constant weight was observed. The dry plant material was then weighed to obtain total dry matter.

Several plant measurements were taken on 17 Sept and 16 Sept in 2006 and 19 Sept and 18 Sept in 2007 at Ingham and Gratiot, respectively. These measurements included: height to the attachment point of the lowest and highest mature pods, total height of the plant, total mature pods per plant, and total mature seeds per plant.

Dry bean was harvested with a plot combine (Massey Ferguson, Duluth, Georgia) from the center 1.5 m transect of each plot, and yield was adjusted to 18% moisture. Post-harvest yield losses were assessed following harvest by counting the number of beans within two 0.5 m^2 quadrats that were randomly placed within the harvested 1.5 m transect. Unfortunately, these data were made unusable, possibly because of seed additions in the sampling area from the combine threshing mechanism or due to a small sampling area. Statistical analyses were performed using the statistical analysis software (SAS, version 9.1, SAS Institute Inc., Cary, NC). The MIXED procedure of SAS was used to develop a mixed linear model to fit the split-split plot design of the data at Ingham and the split plot design at Gratiot. Multiple comparisons between factor level combinations were performed using Bonferroni adjustments. Results are presented as estimated least squares means.

Results and Discussion (Ingham)

Dry bean biomass

Main effects of herbicide and year significantly impacted dry bean biomass at both Ingham and Gratiot sites. In addition, significant main effects of rye and rowspace were present at Ingham. Treatments with no rye cover resulted in significantly greater dry bean biomass when compared to plots with rye cover in 2006 and 2007 at Ingham (Table 2.2). These results are similar to those presented by Ateh and Doll (1996) and Thelen *et al.* (2004), who noted that interseeded rye reduced soybean vigor. Ateh and Doll (1996) noted significant reductions in soybean vigor in living mulch treatments in 2 of 3 years, with reductions ranging between 30-40% when rye was planted at 112 kg/ha.

Plots without herbicide treatment resulted in significantly lower dry bean biomass when compared to broad leaf and broad-spectrum herbicide treatments in all site-years (Table 2.2). Dry bean biomass was greater in 2006 than in 2007, which was likely due to drought stress in July of 2007 at both sites, resulting in reduction of dry bean vigor (Table 2.3).

Rye biomass

A significant main effect of herbicide was present within treatments containing rye cover (Table 2.2). Broad-spectrum herbicide treatments resulted in significantly less rye biomass when compared to no-herbicide and broad-leaf herbicide treatments in all site-years. Rye was suppressed but not killed by the broad-spectrum herbicide regime, which may have been due to reduced grass herbicide efficacy from tank mixing of chemicals within the treatment (ie: antagonism).

Grass weed biomass

Herbicide and rye-cover factors had a significant impact on grass weed biomass at both sites (Table 2.4). Broad-spectrum herbicide treatments resulted in significantly lower grass weed biomass than in broad-leaf and no-herbicide treatments in all site years. Treatments without rye cover resulted in significantly greater grass weed biomass than in treatments with rye cover in all site-years.

Broad-leaf weed biomass

A significant effect of year and a significant three-way interaction effect of rye, herbicide, and row-space factors was present at Ingham. In addition, a significant main effect of herbicide was present at Gratiot. In 2006, broad-leaf weed biomass was greater than in 2007 at Ingham (Table 2.5) which was likely due to drought related plant stress in July of 2007 (Table 2.4)

In treatments containing no rye cover and 19 cm row-space configurations, treatments with no herbicide application resulted in significantly greater biomass than in treatments containing broadleaf or broad-spectrum herbicide regimes at Ingham (Table 2.6). In treatments containing no rye cover and 76 cm row-space configurations, treatments with no herbicide application resulted in significantly greater biomass then in treatments containing broad-leaf or broad-spectrum herbicide regimes at Ingham (Table 2.7). In treatments planted in a 76 cm row-space configuration and with no herbicide application, rye cover resulted in significantly less biomass than in treatments with no rye cover at Ingham (Table 2.8). No-herbicide treatments resulted in significantly greater broad-leaf weed biomass than broad-leaf and broad-spectrum herbicide treatments at Gratiot (Table 2.9).

Dry Bean Plant Height

Significant main effects of rye, year, and herbicide were present at both sites. Plots with rye cover resulted in significantly lower plant heights than in plots with no rye cover in all site-years (Table 2.9), which is similar to dry bean biomass reductions associated with rye treatments. Plant height was greater in 2006 when compared to 2007 at both sites, which is supported by reductions in dry bean biomass in 2007. These reductions were likely associated with drought conditions at both sites in July of 2007. Dry bean plant height was significantly greater in broad-spectrum herbicide treatments than broad-leaf and no-herbicide treatments in all sites years (Table 2.9), indicating at least partial suppression of rye cover and weed species, and reduction of competition with dry bean.

Uppermost Pod Height

Significant main effects of rye cover and herbicide were present at both sites. An additional main effect of year was present at Gratiot. Plots with no rye cover resulted in significantly greater uppermost pod attachment height than in plots with rye cover in all site-years (Table 2.9), which may be attributable to the overall increase in plant height , and biomass associated with no-rye treatments. Broad-spectrum herbicide treatments resulted in significantly greater attachment heights than both no-herbicide and broad-leaf regimes in all site-years. At Gratiot, pod heights were greater in 2006 when compared to 2007, possibly due to drought in 2007 (Table 1.10). This effect of year is supported by reductions in dry bean biomass and overall height at Gratiot in 2007, as is likely due to drought conditions in 2007.

Lowermost Pod Height

Significant main effects of rye cover and herbicide were present. Treatments with no rye cover had significantly greater lowermost pod heights than in treatments containing rye cover in all site-years (Table 2.10), indicating a positive elongation effect. These increases amounted to a 1.9 cm increase in pod attachment height when averaged across all levels of year and herbicide factors. Lowermost pod attachment heights were also significantly greater in no-herbicide treatments when compared to broad-leaf herbicide treatments treatments at Ingham and broad-spectrum treatments at Gratiot (Table 2.10).

Yield

Herbicide regime and rye cover factors both had a significant effect on dry bean yield at both sites. In addition, a significant main effect of year was present at Gratiot. The broad-spectrum herbicide regime resulted in significantly greater yield than both broad-leaf and no-herbicide regimes at Ingham. (Table 2.2) Broad-leaf herbicide treatments resulted in significantly greater yields than no-herbicide treatments at Gratiot. The increased dry bean yield associated with these herbicides may be attributable to reduced competition from rye and weed species. Inter-seeded rye cover significantly reduced yield as compared to plots with no rye at both sites. These results are similar to those presented by Ateh and Doll (1996) and Thelen *et al.* (2004), who noted potential competition between soybean and interseeded rye. Dry bean yield was greater in 2006 than in 2007 at Gratiot (Table 2.10), which was likely due to drought conditions in 2007, and is supported by data confirming reduced dry bean plant height, biomass, and uppermost pod height in 2007.

Conclusions

Interseeded rye cover significantly reduced dry bean yields at both Ingham and Gratiot locations. Rye cover also significantly reduced dry bean plant and uppermost pod attachment heights, which may be attributable to overall reductions in bean height and biomass.

However, rye cover significantly increased lowermost pod attachment heights, indicating the presence of stem elongation, despite overall reductions in dry bean growth and vigor. Rye also significantly reduced broadleaf weed biomass at Ingham and grassy weed biomass at Gratiot, reinforcing the potential of rye as a weed suppression tool. Although rye cover was suppressed by broad-spectrum herbicide treatments, yield was still significantly less in those treatments than in broad-spectrum herbicide with no-rye cover treatments. These yield losses reflect incomplete suppression or rye and probable competition between the species.

Broad-spectrum herbicide treatments resulted in greater bean yield at both locations, which was likely attributable to suppression of rye and weed species, and the resulting reduction in competition. Broad-leaf herbicide treatments had no significant effect on yield when compared to no-herbicide treatments, which may be due to competition from rye and grass weed species. No-herbicide treatments significantly reduced dry bean biomass when compared to broad-spectrum and broad-leaf herbicide treatments at both locations, which is also likely attributable to competition from both grass and broadleaf weed species.

Overall, spring interseeded rye successfully suppressed weed biomass in some cases and increased the height of the lowest dry bean pod attachment point, however, these results are overshadowed by the lower dry bean yield, reduced height, and biomass associated with interseeded rye treatments.

If competition from rye cover were minimized, stem elongation could possibly occur without the associated yield losses noted within this study. This elongation effect could possibly be more pronounced if rye were suppressed more effectively and if dry bean vigor was improved. Future research should focus on reducing or eliminating this competition.

Table 2.1 List of treatments design at Ingham and Gratiot. 2006 and 2007.

Cover crop	Row spacing (cm)	Herbicide regime	
		Ingham site	Gratiot site
None	19	None Broad Leaf Broad-Spectrum	None Broad Leaf Broad-Spectrum
	76	None Broad Leaf Broad-Spectrum	- - -
Rye	19	None Broad Leaf Broad-Spectrum	None Broad Leaf Broad-Spectrum
	76	None Broad Leaf Broad-Spectrum	- - -

Table 2.2 Effects of rye cover crop and herbicide regime on bean biomass, rye biomass, weed biomass and dry bean yield at Ingham and Gratiot. 2006 and 2007.

Factor	Treatment	Bean dry biomass		Rye dry biomass		Monocot weed dry biomass		Dry bean yield	
		Ingham	Gratiot	Ingham	Gratiot	Ingham	Gratiot	Ingham	Gratiot
		------ (g/plant) ------		------ (kg/ha) ------					
Cover crop	No cover	119.48a*	108.3a	-	-	384a	722.5a	1107.3a	1294.7a
	Rye	36.2b	59.42b	-	-	270b	180.6b	223.9b	527.4b
Herbicide	Broad Leaf	87.5a	108.1a	1894.3a	834.7a	350.3a	484.3b	639.2b	1233.8b
	Broad-Spectrum	93.2a	123a	501.7b	226.3b	68.0b	75.2c	1040.7a	1728.8a
	None	52.9b	63.2b	1417.0a	963.2a	384.9a	1172.4b	435.2b	517.9c

*Within columns and factors (cover crop or herbicide), numbers followed by the same letter are not significantly different. (α=0.05)

Table 2.3 Effect of year on average bean dry-weight at Ingham and Gratiot. 2006 and 2007.

Year	Weight at Ingham (g/plant)	Weight at Gratiot (g/plant)
2006	88.2a*	117.9a
2007	67.5b	78.3b

*Numbers followed by the same letter within columns are not significantly different. (α=0.05)

Table 2.4 Monthly precipitation at Ingham and Gratiot (mm). 2006 and 2007.

	Ingham		Gratiot	
	2006	2007	2006	2007
April	59	47	51	79
May	142	106	161	58
June	74	141	100	41
July	93	13	129	67
August	143	132	57	99
September	75	53	85	49
Total	586	492	583	393

Table 2.5 Effect of year on dicot weed biomass at Ingham. 2006 and 2007.

Year	Weight (kg/ha)
2006	192.5a*
2007	68.8b

*Numbers followed by the same letter within columns are not significantly different. (α=0.05)

Table 2.6 Effect of herbicide, and row space on dicot weed biomass when no rye cover is present at Ingham. 2006 and 2007.

Type of cover	Row space	Herbicide	Weight (kg/ha)
None	19 cm	Broadleaf	87.4b*
		Broad spectrum	28.7b
		None	446.0a

*Numbers followed by the same letter within columns are not significantly different. (α=0.05)

Table 2.7 Effect of herbicide, and row space on dicot weed biomass when no rye cover is present at Ingham. 2006 and 2007.

Type of cover	Row space	Herbicide	Weight (kg/ha)
None	76 cm	Broadleaf	25.3a*
		Broad spectrum	72.8a
		None	987.4b

*Numbers followed by the same letter within columns are not significantly different. (α=0.05)

Table 2.8 Effect of rye cover and herbicide on dicot weed biomass in 76 cm row space configurations at Ingham. 2006 and 2007.

Row Space	Herbicide	Type of cover	Weight (kg/ha)
76 cm	None	None	987.2a*
		Rye	24.3b

*Numbers followed by the same letter within columns are not significantly different. (α=0.05)

Table 2.9 Effects of rye cover crop and herbicide regime on bean architecture and dicot weed biomass at Ingham and Gratiot. 2006 and 2007.

Factor	Treatment	Dry bean plant height		Top pod height		Lowermost pod height		Dicot weed dry biomass	
		Ingham	Gratiot	Ingham	Gratiot	Ingham	Gratiot	Ingham	Gratiot
		------------------------ (cm)						------(kg/ha)------	
Cover crop	No cover	37.8a*	35.3a	29.8a*	30.3a	11.0b*	11.8b	-	-
	Rye	28.8b	27.1b	22.25b	23.6b	12.9a	13.7a	-	-
Herbicide	Broad Leaf	32.1b*	32.3b	25.15b*	26.3b	11.4b*	16.1ab	-	88.3b*
	Broad-Spectrum	36.3a	37.1a	28.51a	29.5a	11.6ab	13.9b	-	195.0b
	None	31.4b	30.5b	24.41b	25.4b	12.9a	18.0a	-	773.9a

*Within columns and factors (cover crop or herbicide), numbers followed by the same letter are not significantly different. (α=0.05)

Table 2.10 Effects of rye cover crop and herbicide regime on bean archetecture and yield at Ingham and Gratiot. 2006 and 2007.

	Dry bean plant height		Uppermost pod height		Monocot weed dry biomass		Bean yield	
Year	Ingham	Gratiot	Ingham	Gratiot	Ingham	Gratiot	Ingham	Gratiot
	(cm)				(kg/ha)			
2006	35.13a*	39.2a	-	32.7a*	-	858.2a*	-	1302.3a*
2007	31.09b	31.4b	-	25.6b	-	159.2b	-	1028.2b

*Numbers followed by the same letter within columns are not significantly different. (α=0.05)

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Chapter 3: Utility of Interseeded Winter-Annual Rye in Organic Dry Bean Cropping Systems

Introduction

Organic growers do not use synthetic herbicides and instead typically rely on a combination of physical and cultural control of weeds. Many forms of physical control that are utilized in organic systems are more fuel intensive and less flexible than synthetic herbicide application. In addition, various forms of tillage have been shown to negatively impact soil structure (Arshad, 1999) and contribute to soil erosion (Oost *et al.* 2006).

Other types of physical control have also been adapted to organic systems including: flame weeding, mowing, and mulching. Organic growers may also utilize various forms of cultural weed control such as: cover crops, crop rotation, reduced tillage, and competitive crop agronomic trait selection (Bond and Grundy, 2001). Despite the seemingly many options for organic weed control there are serious shortcomings with many of these methods.

A type of cover crop, living mulches, may be a viable method of cultural weed control for organic growers. Various applications of living mulches have been evaluated with mixed crop yield results, yet all showed significant reductions of weed biomass (Ateh and Doll 1996; Eadie *et al.* 1992; Enache and Ilnicki 1992; Thelen *et al.* 2004).

While spring-planted rye has shown potential for integration in both organic and conventional soybean cropping systems as a living mulch (Ateh and Doll, 1996; Thelen *et al.*, 2003), it has not yet been evaluated within dry bean (*Phaseolus vulgaris* L.) cropping systems. Spring-planted rye does not undergo a period of vernalization, and thus, remains in a less vigorous, vegetative state, minimizing competition with the crop. The less agressive growth habit has been noted as a desirable trait for a living mulch as compared to fall-planted rye (Thelen *et al.*, 2004). Despite this less aggressive growth habit, Barnes and Putnam (1983) demonstrated that spring-planted rye reduced weed biomass by 93% when compared to no rye plots.

The objectives of this study were to assess the utility of spring-interseeded rye for weed suppression in organic dry bean cropping systems and for potential reduction of harvest-associated yield losses through elongation of the dry bean plant.

Materials and Methods

Field research was conducted at the Kellogg Biological Station in Kalamazoo County for the two-year period, 2006 and 2007. The crops were managed according to organic standards and the land certified organic by the Organic Crop Improvement Association. The previous crops were corn in 2006 and 2007. The soil was a Kalamazoo loam (fine-loamy, mixed, mesic Typic Hapludalfs) with pH was 6.8 and 6.9 for 2006 and 2007, respectively. The variety of dry bean was "Jaguar" black bean (Kelly, 2001) and the variety of rye planted was "Wheeler" ('Wheeler', Michigan Agric. Exp. Stn., East Lansing, MI). Dry bean was planted in 19 cm, 38 cm, and 76 cm rows. Target planting populations were 433,000 plants/ha in 19 cm rows, 301,000 plants/ha in 38 cm rows, and 194,000 plants/ha in 76 cm rows. Planting dates were 9 June 2006 and 31 May 2007. Plot sizes were 3 m by 12 m. An innoculant containing *Rhizobium sp.* was applied at the recommended rate to all seed prior to planting (Nitrastik-D, LiphaTech Inc., Milwaukee, WI). In applicable treatments, rye was planted at 126 kg/ha. The experimental design was a randomized complete block design with four replications (Table 3.1).

All plots were chiseled and disked prior to planting. All plots were also rotary hoed on 14 June, 22 June, and 30 June in 2006 and on 7 June and 13 June 2007. Applicable treatments were cultivated on 19 and 29 June in 2006 and 21 June in 2007. Due to drought, overhead irrigation was applied in the amount of 13 mm and 18 mm on 23 July and 27 July 2007, respectively. Pyganic insecticide (pyrethrum) was applied as needed for control of potato leafhopper (*Empoasca fabae* L.).

Early (data not presented) and late season biomass readings were taken in both years of the study by hand-clipping plants at ground level from two randomly placed 0.5 m^2 quadrants per plot. Rye, bean, and weed biomass ratings were recorded, with weed biomass being classified by species. Late season biomass measurements were taken on 5 September in 2006 and 28 August in 2007. Plants were separated, and placed in a forced-air dryer until a constant weight was observed. The dry plant material was then weighed to obtain total dry matter.

Several plant measurements were taken on 15 Sept in 2006 and 28 August in 2007. These measurements included: height to the attachment point of the lowermost and uppermost mature pods, and total height of the plant. Four plants were measured per plot. Dry bean was harvested with a plot combine (Wintersteiger, Ried/I., Austria) from the center 1.5 m transect of each plot, and yield was adjusted to 18% moisture. Post-harvest yield losses were assessed following harvest by counting the number of beans within two 0.5 m^2 quadrats which were randomly placed within the harvested 1.5 m transect but the data were unusable, possibly due to seed additions in the sampling area from the combine threshing mechanism or too small of a sampling area. Statistical analyses were performed using the statistical analysis software (SAS, version 9.1, SAS Institute Inc., Cary, NC).

The MIXED procedure of SAS was used to develop a mixed linear model to fit the design of the data. The lack of observations for the rye cover by row space by cultivation combinations prevented 3-way factorial analyses of the data (Table 1). The analyses were divided into two parts, as follows: (a) effect of rye cover and planting row space on response variables, conditional on no cultivation and, (b) effect of cultivation on response variables, considering only treatments with no rye cover and planted with a row spacing of 19 or 76 cm. Results are presented as estimated least squares means.

Results and Discussion

Bean Biomass

Significant main effects of year and rye cover were present. Biomass was significantly greater in 2006 than in 2007 (Table 3.2), which may be attributable to lack of precipitation in July 2007 (Table 3.3), and possible resulting growth suppression. Treatments containing rye cover resulted in significantly less biomass than in treatments with no rye cover indicating the presence of competition between rye and dry bean (Table 3.2). It is unclear if allelopathy was an important mechanism of competition between rye and dry bean, but competition for moisture and nutrients, although not tested, likely played a role. Ateh and Doll (1996) noted that spring-interseeded rye resulted in moisture reductions of up to 29% when compared to weed-free check plots.

Cultivated treatments resulted in significantly greater dry bean biomass than in treatments with no cultivation (Table 3.4), indicating a likely reduction in competition between dry bean and weed species.

Grass Weed Biomass

There were no significant effect on grass weed biomass. This is likely attributable to the low amounts of grassy weeds present at this location. Monocot weed species biomass amounted to 124 kg/ha in treatments with no rye cover, which is 83% less than the weight of dicot species within treatments with no rye cover, which averaged 735 kg/ha.

Broadleaf Weed Biomass

Significant main effects of rye cover and year were present. Treatments containing rye cover resulted in significantly less broadleaf weed biomass than in treatments without rye cover (Table 3.2) which may indicate competition between rye and weed species for water and nutrient resources, in addition to a possible allelopathic effect. Ateh and Doll (1996) documented overall weed biomass reductions of between 60-90% when comparing interseed rye plots with weed free check plots. Broad-leaf weed biomass was greater in 2006 than in 2007, which is likely attributable to dought conditions in 2007, and corresponds with reductions in dry bean and rye biomass in 2007 (3.2).

There was no significant effect of cultivation on broad-leaf weed biomass. Cultivation of in-row weeds proved to be difficult and many large broadleaf weeds were visually apparent in cultivated treatments.

Dry Bean Plant Height

Significant main effects of year and rye cover were present. There was significantly greater plant heights in 2006 than in 2007 which was likely due to low amounts of precipitation in 2007 as compared to 2006 (Table 3.5). Plant heights were significantly lower in treatments containing rye cover than in treatments without rye cover (Table 3.5). Ateh and Doll (1996) noted significant reductions in soybean vigor in living mulch treatments in 2 of 3 years, with reductions ranging between 30-40% when rye was planted at 112 kg/ha.

Cultivated treatments likely reduced competition from weed species and resulted in significantly greater plant heights when compared to treatments without cultivation (Table 3.4).

Height of Uppermost Dry Bean

Significant main effects of year and rye cover were present. There was significantly greater pod attachment heights in 2006 than in 2007 (Table 3.5). Heights were significantly lower in treatments containing rye cover than in treatments without rye cover (Table 3.5).

Treatments with cultivation resulted in significantly greater heights when compared to treatments without cultivation (Table 3.4), which could be attributed to competition for resources between the interseeded rye and dry bean plants.

Height to Lowermost Dry Bean Pod

A significant main effect of rye cover was present. Treatments containing rye cover resulted in significantly greater pod heights when compared to treatments without rye cover (Table 3.5), which could be attributed to competition for resources between the interseeded rye and dry bean plants. When compared to plots with no cover, rye cover resulted in an average pod attachment height increase of 1.3 cm when when averaged across year and row space.

Cultivated treatments resulted in significantly lower pod heights when compared to treatments without cultivation (Table 3.4), which could be attribuable to less shading from weed species, exhibiting a similar response to effect of rye cover on lowermost pod heights.

Yield

Significant main effects of year and rye cover were present. Yield was significantly greater in 2006 than in 2007, which is likely due to lack of precipitation in July 2007 (Table 3.6). Stunted plant growth was visually noted prior to irrigation in 2007. Within rye cover treatments dry bean yielded significantly less than in treatments with no rye (Table 3.6), which is similar to results presented by Ateh and Doll (1996) and Thelen *et al.* (2004), who noted reduced soybean yields in treatments with interseeded spring rye cover.

Conclusions

Interseeded spring rye cover competed heavily with dry bean, reducing it's overall vigor. Treatments containing rye significantly reduced dry bean yield, biomass, plant height, and height of uppermost dry bean pods. However, interseeded rye cover increased the height of the lowermost dry bean pod attachment point, despite overall suppression of growth. This elongation effect could possibly be more pronounced if rye were suppressed more effectively, leading to increased dry bean vigor. Rye also significantly suppressed weed growth. Plots containing rye had 66% less broadleaf weed biomass when compared to plots with no rye.

If this system could be adapted with a more complete method of rye suppression, it's viability would be improved. Such a system could potentially reduce harvest-associated yield losses, especially if a stem elongation response were more pronounced due to the probable resulting improvement in dry bean vigor. In addition, such a system could provide a less fuel and labor intensive method of weed control with environmental benefits. Future research should focus on methods of completely killing cover crops while also maintaining large quanitities of biomass above the soil surface throughout the growing season.

Table 3.1 List of treatment design at Kalamazoo. 2006 and 2007.

Row Space	Cultivation	Cover
19 cm	No	None
		Rye
38 cm	No	None
		Rye
	Yes	None
76 cm	Yes	None
	No	Rye

Table 3.2 Effect of year and rye cover crop on dry bean and dicot weed biomass at Kalamazoo, conditional on no cultivation. 2006 and 2007.

Factor	Treatment	Bean dry biomass	Dicot weed dry biomass
		------------(g/plant) -----------	-------------(kg/ha)------------
Year	2006	83.0a*	966.3a*
	2007	35.9b	404.2b
Cover crop	No cover	106.4a*	735.4a*
	Rye	12.5b	324.2b

*Within columns and factors (year or cover crop) numbers followed by the same letter are not significantly different. (α=0.05)

Table 3.3 Monthly precipitation at Kalamazoo (mm). 2006 and 2007.

	2006	2007
April	58	84
May	157	48
June	43	43
July	107	20
August	157	163
September	89	58
Total	611	416

Table 3.4 Effect of cultivation on dry bean biomass, plant height, and pod height at Kalamazoo. Conditional on no cover and no drilled row-spacing. 2006 and 2007.

Treatment	Bean dry biomass	Bean plant height	Top pod height	Lowermost pod height
	--(g/plant)--	----------------------(cm)---------------------		
No cultivation	43.3b*	25.5b	20.3b	11.9a
Cultivation	118.4a	37.0a	28.4a	10.6b

*Numbers followed by the same letter within columns are not significantly different. (α=0.05)

Table 3.5 Effect of year and cover crop on dry bean plant, top, and bottom pod height at Kalamazoo, conditional on no cultivation. 2006 and 2007.

Factor	Treatment	Plant height	Uppermost pod height	Lowermost pod height
		--------(cm)--------		
Year	2006	34.0a*	28.2a*	-
	2007	22.1b	16.2b	-
Cover crop	None	36.0a*	25.5a*	11.1b
	Rye	22.1b	18.9b	12.2a*

*Within columns and factors (year or cover crop) numbers followed by the same letter are not significantly different. (α=0.05)

Table 3.6 Effect of year and cover crop on dry bean yield at Kalamazoo, conditional on no cultivation. 2006 and 2007.

Factor	Treatment	Yield (kg/ha)
Year	2006	581.1a*
	2007	324.4b
Cover crop	No cover	1218.6a*
	Rye	208.7b

*Within columns and factors (year or cover crop) numbers followed by the same letter are not significantly different. (α=0.05)

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