Effect of Seeding Rate and Herbicides on Weed Control in Narrow-Row Pinto Bean

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AUTHORIZATION TO SUBMIT THESIS

This thesis of Kathrin D. LeQuia, submitted for the degree of Master of Science with a Major in Plant Science and titled "Effect of Seeding Rate and Herbicides on Weed Control in Narrow-Row Pinto Bean," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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ABSTRACT

A 2-year field experiment was conducted at the Kimberly Research & Extension Center in Kimberly, ID in 2016 and 2017. The purpose of the trial was to determine the effect of seeding rate and herbicides on weed control in narrow-row pinto bean. There were five seeding rates in 19-cm (narrow) rows: 25, 31, 37, 43, and 49 seeds m^{-2}. These seeding rates were compared to a standard seeding rate of 25 seeds m^{-2} in 56-cm (wide) rows, which is the common grower practice in southern Idaho. There were also five weed control treatments included in the study. Weed control was increased with sequential herbicide applications compared to a preemergent application used alone. In 2016, the hand-weeded control produced the highest yield. In 2017, the yield was higher at 37 and 49 seeds m^{-2} than at 25 seeds m^{-2} in the wide or narrow rows.

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Dedication

To my husband, Nick, and the other members of my family, thank you for your unwavering support throughout the past two years.

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INTRODUCTION

Weed control is a common problem in dry bean causing a decrease in yields. Cultural methods including decreased row spacing and increased seeding rates and can be used with herbicides to increase the competitive ability of dry bean. More research on the effectiveness of a combination of cultural and chemical methods is needed.

Objectives

There has been some previous research on decreased row spacing and increased seeding rate in various classes of dry bean (Blackshaw et al. 1999; Blackshaw et al. 2000; Malik et al. 1993). The objective of this study is to specifically study the effect of seeding rate and herbicides on narrow-row pinto bean grown in southern Idaho in an overhead irrigation system.

Organization

The following thesis is presented for partial fulfillment of the requirements for the degree, Master of Science with a major in Plant Science. The author or the thesis is Kathrin D. LeQuia. Dr. Don W. Morishita served as major professor and Drs. Olga S. Walsh and William H. Neibling served as committee members and provided technical consulting and manuscript review. Chapter 1 is a literature review concerning weed interference and the cultural and chemical methods of weed control in dry pinto bean. Chapter 2 is a manuscript to be submitted to the Journal of Weed Technology, entitled "Effect of Seeding Rate and Herbicides on Weed Control in Narrow-Row Pinto Bean." Chapter 3 was written with Michael L. Thornton and is a manuscript to be submitted as an extension publication, entitled "Season-long Weed Control in Edible Dry Bean Production."

CHAPTER 1. LITERATURE REVIEW

Weed interference in dry bean

Dry bean (*Phaseolus vulgaris* L.) struggles to compete with weeds (Brouwer et al. 2015; Hekmat et al. 2008; Malik et al. 1993; Pyenburg et al. 2010; Waters and Morishita 2001). The presence of weeds can decrease air flow in the crop canopy, which increases moisture and disease potential (Burnside et al. 1998). Weeds also decrease the 100-seed weight and the number of pods per plant (Malik et al. 1993). Burnside et al. (1998) found that 2.9 kg of weed biomass reduced dry bean by yield 1 kg ha^{-1}. Mesbah et al. (2004) reported that only 6 green foxtail (*Setaria viridis* L.) m^{-1} row reduced pinto bean yield in one out of two years. Barnyardgrass (*Echinochloa crus-galli* L.) interference decreased the growth rate of dry bean at the end of the growing season (Fennimore et al. 1984). Wall (1995) found that untreated common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.) reduced yield of navy bean by 40 to 71% (Wall 1995).

Hairy nightshade (*Solanum physalifolium* Rusby) is competitive and difficult to control in dry bean (Blackshaw et al. 1999). For example, hairy nightshade has been found to reduce the 100-seed weight of black bean (Blackshaw et al. 1999). Pinto bean biomass and yield decreased as density of hairy nightshade increased. Two hairy nightshade plants m^{-1} row reduced pinto bean yield 13%. One hundred plants m^{-1} row reduced the yield 77%. The presence of hairy nightshade for 3 weeks after dry bean emergence reduced pinto bean yields. One hairy nightshade plant can produce over 45,000 seeds causing rapid infestation (Blackshaw 1991).

The presence of uncontrolled weeds at the end of the growing season increases the amount of time required for windrowing and interfere with harvest equipment (Blackshaw et al. 1999; VanGessel et al 1998). In the presence of weeds, bean quality and yield are diminished (Hekmat et al. 2008; Pyenburg et al. 2010; Waters and Morishita 2001). For example, hairy nightshade berries can stain beans, causing an economic loss of approximately 12% (Burgert et al. 1973). Poor weed control can affect next year's crop by adding to the weed seed bank (Brouwer et al. 2015).

Cultural weed control in dry bean

A combination of methods is required for effective weed control in dry bean (Norris et al. 2002; Waters and Morishita 2001). Reliance on the sole use of herbicides can lead to resistance in the target species and weed species shifts. Cultural practices can increase the competitive ability of a crop against weeds. Some of these cultural practices include choosing a competitive variety, decreasing the row width and increasing the plant population (Waters and Morishita 2001). These practices can also help reduce herbicide usage and prevent the development of herbicide resistant weeds (Jha et al. 2017).

Upright, indeterminate varieties have fuller canopies and compete against weeds more effectively than other varieties (Blackshaw et al. 1999; Malik et al. 1993; Waters and Morishita 2001). Blackshaw et al. (1999) found that hairy nightshade grew taller than the viny variety but shorter than the upright variety that was used in their study. When hairy nightshade has a height advantage, they shade the beans and decrease photosynthetically active radiation (PAR) (Blackshaw et al. 1999). Additionally, indeterminate bean varieties are higher yielding compared to determinate varieties (Shaw 2009). Narrow row planting is another way to increase the uprightness of beans. Sankula et al. (2001) found that lima bean planted in 38-cm rows were more upright than those grown in 76-cm rows.

Variety choice could change the way dry bean growers in Southern Idaho harvest their beans. Currently, most growers who cut their beans before harvest use a Pickett one-step rod cutter to undercut the beans beneath the soil surface and put them into windrows. The beans dry for a week or more before harvest depending on the temperature. A combine with a pickup on its header lifts the beans off the ground and threshes them (M. Stanger, personal communication). The use of an upright variety creates the possibility of direct-harvesting pinto beans using a straight cut attachment on a combine similar to that used for harvesting small grains. This can decrease harvest time, equipment costs, damage, and labor expenses. However, there a possibility of a decrease in bean seed quality (Nowatzki 2013).

There is a large volume of research on soybean (*Glycine max* L. Merr.) planted in narrow rows. The advantages of planting in narrow rows include: 1) earlier canopy closure; 2) increased light interception; 3) decreased within-row intra-specific soybean competition; 4) increased pod distance from the ground to facilitate more effective harvest; 5) decreased soil erosion; and 6) increased yields. There are some disadvantages to planting soybeans in narrow rows. They include: 1) an increased expense for a grower who does not already have a grain drill; 2) non-uniform planting depth because many grain drills do not have depth gauge wheels; 3) a higher risk of lodging because they grow taller than those planted in wide rows; and 4) an increased risk of disease (Hesterman et al. 2015).

Planting soybean in narrows rows distributes the plants more equally than soybean grown in wide rows. A near-equidistant distribution allows the soybean to develop a greater leaf area index (LAI), and the canopy closes earlier in the growing season. A full canopy intercepts more light throughout the growing season, resulting in an increased growth rate, plant biomass, and yield. An early canopy closure in narrow rows compared to wide rows also reduces soil moisture loss (Pedersen 2007). Soybean in narrow rows improves their competitiveness with weeds early in the season and delays the critical time for weed control.

They also require a less intensive weed control program than soybean planted in wide rows (Knezevic et al. 2003). Photosynthetically active radiation measurements showed that weed emergence is closely related to the amount of light reaching the soil surface (Yelverton and Coble 1991). Weed germination following herbicides is decreased in narrow rows because of increased light interception by the canopy (Holt 1995; Urwin et al. 1996; Yelverton and Coble 1991). Harder et al. (2007) found that the number of weed seedlings decreased over time in 19- and 38-cm rows compared to 76-cm rows. This is likely an effect of decreased light intensity below the light compensation point for these weed seedlings within the soybean canopy (Harder et al. 2007). In addition to reduced impact on crop yield, increased weed control can have long-term impacts on future weed populations by decreasing weed seed production (Yelverton and Coble 1991).

Harvesting soybean in narrow rows is advantageous because a more equidistant distribution allows them to be more easily cut and fed into the combine (Pedersen 2007). Bertram and Pedersen (2004) found higher soybean yields in 19 and 38-cm rows compared to 76-cm rows. Similarly, Hock et al. (2006) found less weed biomass and a greater soybean yield in 19-cm row as opposed to 76-cm rows.

Some of the benefits of narrow row spacing in soybean also can be seen on dry bean grown in narrow rows. Blackshaw et al. (1999) found that black bean planted in 46-cm rows competed better against weeds than those in 69-cm rows. There was less hairy nightshade biomass in 23-cm rows compared to 69-cm rows in all three study years. There were also increased yields in two out of three study years in 23-cm rows compared to 69-cm rows (Blackshaw et al 1999). Holmes and Sprague (2013) reported improved weed control in black bean in 38-cm rows compared to 76-cm rows in two out of four study years.

Dry bean grown in narrow rows can decrease labor and equipment expenses (Blackshaw et al. 1999). For example, many growers could operate with less equipment by using the same planting and harvesting machinery used in cereal grains (Blackshaw et al. 2000). The disadvantages include decreased airflow, which may increase disease potential. It also increases time required for drying windrows before harvest (Brouwer et al. 2015; Waters and Morishita 2001). The use of narrow rows also removes the option of using between-row cultivation for weed control (Brouwer et al. 2015).

Increasing the seeding rate in narrow rows further helps soybeans and lentils (*Lens culinaris* Medik) to be more competitive against weeds (Arce et al. 2015; Liebman and Janke 1990). Increased seeding rate in soybean increased LAI (Bertram and Pederson 2004). Narrow-row spacing and increased seeding rates in soybean are associated with increased growth rates during early reproduction and higher soybean yields (Board and Harville 1992). In a study on soybean, Arce et al. (2009) found a linear negative relationship between seeding rate and weed biomass. They also found that soybean planted at 420,000 seed ha^{-1} produced a higher yield than 240,000 seed ha^{-1} at three locations in Iowa (Arce et al. 2009). Place et al. (2009) found better weed control at higher seeding rates in organic soybean production. In a small-red lentil study, Ball et al. (1997) found less weed density and biomass by increasing seeding rate in two study years. They also saw a yield increase in one of two study years.

There are many advantages to using an increased seeding rate in narrow rows in dry bean (Blackshaw et al. 1999). These practices allow the canopy to close earlier in the growing season. Earlier canopy closure enables dry bean to capture more PAR when the days are longer (Blackshaw et al. 2000). Additionally, increasing black bean seeding rate increased hairy nightshade control (Blackshaw et al. 1999). Increased dry bean yields were observed in all three study years when narrow row spacing was combined with increased seeding rate (Blackshaw et al. 2000). Malik et al. (1993) reported that although white bean planted at a high seeding rate had less pods per plant than those planted at a lower seeding rate, the beans yielded higher than those planted with the low seeding rate. (Malik et al. 1993).

Herbicide control in dry bean

For effective weed control in dry bean, herbicides are necessary in conjunction with cultural practices (Holmes and Sprague 2013). For example, common lambsquarters control was 8% higher in 38-cm rows compared to 76-cm rows with an imazamox plus bentazon postemergence (POST) treatment in black bean. Redroot pigweed control also was 8 to12% higher in 38-cm rows compared to 76-cm rows across multiple herbicide treatments. Row spacing did not appear to aid in control of annual grasses (Holmes and Sprague 2013).

Generally, herbicide combinations suppress weeds in dry bean more effectively than a single herbicide by itself (Blackshaw et al. 2000). Net returns were higher using a pre-plant incorporated (PPI) herbicide followed by a POST application compared to a POST only or tillage only treatment (Burnside et al. 1994). Using multiple herbicides with different modes of action can prevent the development of resistant weeds (Hekmat et al. 2008). For example, bentazon, a photosystem II inhibitor, can be used with imazamox, an acetolactate synthase inhibitor, to prevent selecting for resistant common lambsquarters and redroot pigweed (Hekmat et al. 2008).

Interest in developing new herbicides in dry bean is low because it is a minor crop for the majority of agricultural areas (Park and Hamill 1993). However, there are still several options for dry bean producers to consider.

EPTC has been shown to control barnyardgrass, green foxtail, and yellow foxtail (*Setaria glauca* P. Beauv) better than 90%. It also has shown 70 to 80% control of common lambsquarters and annual nightshade (*Solanum* sp.) species (Anonymous 2016).

Ethalfluralin has shown over 90% redroot pigweed, barnyardgrass, green foxtail, and yellow foxtail control. It also has shown 80 to 90% common lambsquarters control, but only 40 to 65% hairy nightshade control (Zollinger 2013). Amador-Ramirez et al. (2001) reported that ethalfluralin plus EPTC had increased weed control better than imazethapyr plus bentazon or dimethenamid-P.

Common lambsquarters and redroot pigweed control with bentazon can be variable ranging from 65 to 100% (Zollinger 2013). It also has shown some variability in hairy nightshade control, ranging from 65 to 90% (Zollinger 2013). Bentazon does not control any grass weeds such as barnyardgrass, green foxtail, or yellow foxtail (Blackshaw et al. 2000; Zollinger 2013).

Ethalfluralin applied PPI followed by bentazon POST after the first trifoliate stage is recommended for weed control in dry bean grown in Saskatchewan, Canada (Shaw 2009). Blackshaw et al. (2000) also observed consistent weed control by applying ethalfluralin PPI followed by a POST bentazon application. Ethalfluralin at 600 g a.i. ha^{-1} and bentazon at 700 or 900 g a.i. ha^{-1} effectively controlled hairy nightshade in all three study years (Blackshaw et al. 2000).

Imazamox has shown greater than 90% redroot pigweed, hairy nightshade, barnyardgrass, and green foxtail control. It also has shown greater than 80% yellow foxtail control, but somewhat variable common lambsquarters control ranging from 40 to 80% (Zollinger 2013). Blackshaw et al. (2000) reported that imazamox applied at 30 g a.i. ha^{-1}

effectively controlled hairy nightshade, green foxtail, and barnyardgrass. Blackshaw (1998) also found that imazamox at 13 to 15 g a.i. ha^{-1} reduced green foxtail biomass 90% in peas. Redroot pigweed biomass was reduced 90% with imazamox at 7 to 12 g a.i. ha^{-1}. 25 to 28 g a.i. ha^{-1} of imazamox was required to control common lambsquarters 90% (Blackshaw 1998). However, imazamox poses a risk of dry bean injury and carryover to sugar beet, canola, barley, potato, lentil and several vegetable crops (Anonymous 2015, Blackshaw et al. 2000).

Holmes and Sprague (2013) reported that imazamox plus bentazon provided 94% redroot pigweed control and 77% yellow foxtail, giant foxtail (*Setaria faberi* Herrm), and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] control. The imazamox plus bentazon treatment had less weed biomass than the other herbicide treatments in their study (Holmes and Sprague 2013). Wilson and Sbatella (2014) reported that a POST imazamox plus bentazon application at 35 g ai ha^{-1} plus 0.56 kg ai ha^{-1} controlled weeds more effectively than their other treatments. However, imazamox plus bentazon injured the crop in 2 out of 3 study years that lowered dry bean yield 11% and 25%, respectively, compared to dimethenamid-P at 0.73 kg ai ha^{-1} (Wilson and Sbatella 2014).

Dimethenamid-P has shown greater than 80% control of common lambsquarters, barnyardgrass, green foxtail, and yellow foxtail. It also has shown 65 to 90% control of redroot pigweed and hairy nightshade (Zollinger 2013). Dimethenamid-P applied PPI at 693 g ai ha^{-1} did not injure pinto bean, but when applied 17 days after emergence at 1386 g ha^{-1} crop injury was 7%. This injury decreased over time and did not affect the yield (Soltani et al. 2008). When tank-mixed with dimethenamid-P at 1000 g ai ha^{-1}, only 15 g ai ha^{-1} of imazethapyr was required to get the same level of control. They also found increased common lambsquarters and green foxtail control when imazethapyr and dimethenamid-P were applied together than when imazethapyr was applied by itself. Yield was higher in kidney bean when dimethenamid-P was tank-mixed with imazethapyr than when imazethapyr was applied by itself. There was no difference in yield of white bean between the treatments (Soltani et al. 2007).

In summary, the presence of weeds in dry bean increase the risk of disease, decrease yield, interfere with harvest, decrease bean quality, and add to the weed seed bank. Cultural weed control methods can help beans compete more effectively against weeds and prevent the development of herbicide-resistant weeds. Planting beans in narrow rows with an increased seeding rate can increase yields. Herbicides can be used alongside cultural methods to achieve effective weed control. Herbicide combinations are generally more effective than a single herbicide. EPTC, ethalfluralin, bentazon, imazamox, and dimethenamid-P are some of the herbicide options for weed control in dry bean. Other herbicides include halosulfuron, imazethapyr, pendimethalin, S-metolachlor, trifluralin, clethodim, fluazifop, quizalopfop P-ethyl, and sethoxydim.

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CHAPTER 2. EFFECT OF SEEDING RATE AND HERBICIDES ON WEED CONTROL IN PINTO BEAN IN NARROW ROWS

Abstract

Research has shown advantages of high seeding rates in narrow rows with black bean compared to standard wide rows. Currently, there is no research comparing seeding rates of pinto bean planted in narrow rows to standard wide rows. Therefore the objectives of this study were to: 1) determine the optimum dry pinto bean plant population in a narrow row planting configuration for growth and yield; 2) compare five pinto bean plant populations grown in narrow rows to pinto bean grown in standard rows; and 3) compare the weed control in response to herbicide treatments and pinto bean planted in five seeding rates in narrow row planting. The experiment was a 5 by 6 factorial randomized complete block design. Five weed control treatments consisting of a non-treated control, hand-weeded control, EPTC + ethalfluralin PRE EPTC + ethalfluralin PRE followed by (fb) dimethenamid-P POST at the first trifoliate growth stage, and EPTC + ethalfluralin PRE fb bentazon/imazamox POST were compared. There were 6 seeding rate treatments, five of which were planted at 25, 31, 37, 43, and 49 seed m^{-2} in 19-cm rows. The sixth treatment was planted at 25 seed m^{-2} in 56-cm rows. Data are presented separately by year due to differences between years. In 2016 there were no yield differences between seeding rates. In 2017 pinto bean yield was higher at 37 and 49 seed m^{-2} than 25 seed m^{-2} in 19- or 56-cm rows. Increased seeding rate in narrow rows is a cultural practice that can improve yield and weed control in dry pinto bean.

Nomenclature: pinto bean, *Phaseolus vulgaris* L.; EPTC; ethalfluralin; dimethenamid-P; bentazon; imazamox

Key words: Dry bean, narrow row spacing, integrated weed management, weed suppression.

Introduction

In the presence of weeds, dry bean quality and yield is diminished (Hekmat et al. 2008; Pyenburg et al. 2010; Waters and Morishita 2001). Weed interference decreases the 100-bean weight and number of pods per bean plant (Malik et al. 1993). Additionally, uncontrolled weeds negatively affect the next year's crop by adding to the weed seed bank (Brouwer et al. 2015). The sole use of herbicides, particularly using the same mechanism of action, can lead to resistance in the target species and selection for other weed species (Jha et al. 2017, Waters and Morishita 2001). Multiple methods, including cultural practices, are required for effective weed control in dry bean (Norris et al. 2002; Waters and Morishita 2001). These cultural practices include decreasing row width and increasing plant population (Waters and Morishita 2001).

The advantages and disadvantages of planting soybean in narrow rows has been summarized by Hesterman et al. (2015). Advantages include earlier canopy closure, increased light interception, decreased within-row soybean competition, and increased yields. The disadvantages are increased planting cost, increased risk of lodging, and increased risk of disease (Hesterman et al. 2015).

Research in dry bean involving narrow rows and increased seeding rates has been investigated to a lesser extent. Blackshaw et al. (1999) examined narrow rows (23-cm) and seeding rates on black bean in Alberta, Canada. They found that decreased row spacing and increased seeding rates allowed the canopy to close earlier in the growing season compared to 69-cm row spacing. Increasing the seeding rate of black bean also increased hairy nightshade control. The beans in 23-cm rows had less hairy nightshade biomass than the beans in 69-cm rows in all three study years. Beans grown in 23-cm rows had increased yields compared to

69-cm rows in two of three years. In a similar study, Blackshaw et al. (2000) reported increased ember small red dry bean yields when narrow row spacing was combined with increased seeding rate.

Pinto bean is the most common dry bean class grown in Idaho and the United States (Anonymous 2016). This study was conducted to determine if there are advantages to growing pinto bean at an increased seeding rate in narrow rows. The main objectives of this study were to: 1) determine the optimum dry bean plant population in a narrow row planting configuration for growth and yield; 2) compare five dry bean plant populations grown in narrow rows to dry bean grown in standard wide rows (56-cm); and 3) compare the weed control in response to dry bean planted in five seeding rates in narrow row planting and weed control treatments.

Materials and Methods

Research was conducted in 2016 and 2017 at the University of Idaho Kimberly Research and Extension Center in Kimberly, ID (42.55°N, -114.35°W). In 2016, the study site was a Portneuf silt loam (coarse-silty, mixed, superactive, mesic Durinodic Xeric Haplocalcids) with 23% sand, 58% silt, and 19% clay with a pH of 7.6, organic matter (OM) content of 2.1% and a cation exchange capacity (CEC) of 19.0 meq/100 g soil. In 2017, the study site was a Portneuf silt loam composed of 23% sand, 59% silt, and 18% clay with a pH of 7.9, an OM content of 2.0%, and a CEC of 19.0 meq/100 g soil. Beans were irrigated with an overhead solid-set sprinkler as needed based on evapotranspiration. Common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), hairy nightshade (*Solanum physalifolium* Rusby), green foxtail (*Setaria viridis* (L.) Beauv.), and barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.) were broadcast and incorporated with a roller harrow (Farmhand CM41 Cultimulcher, AGCO, 4205 River Green Parkway, Duluth, GA 30096) at 270 seed m^{-2} for each species on May 18 and May 30, 2016 and 2017, respectively. The study had 30 treatments in a 5 x 6 factorial randomized complete block design with 5 weed control treatments and 6 seeding rates (Table 1). Plots were 2.23 m by 7.62 m with 5 replications. Dry beans grown in narrow (19-cm) rows were planted with a Great Plains 3P806NT drill (Great Plains Ag U.S.A., 1525 E. North Street, Salina, KS 67401). The beans grown in wide (56-cm) rows, which is the standard row width in Idaho, were planted with a Monosem NG 4-row planter (Monosem Inc., 1001 Blake St., Edwardsville, KS 66111). Planting dates were June 2 and 5, 2016 and 2017, respectively. Targeted plant populations in 19-cm row plots were 25, 31, 37, 43, and 49 live plants m^{-2} and 25 live plants m^{-2} in the 56-cm row plots. The pinto bean variety was LaPaz (ADM 77 West Wacker Drive, Suite 4600 Chicago, Illinois 60601), which is an upright indeterminate Type II dry bean.

All herbicides were applied with a CO_2-pressurized bicycle-wheel sprayer at a rate of 140 L ha^{-1} at 179 kPa. Boom width was 2.23 m with 11001 flat fan nozzles (TeeJet Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189) spaced 28-cm apart. EPTC + ethalfluralin was applied preemergence (PRE) at 2.92 + 1.25 kg ai ha^{-1} in four of the six weed control treatments (Table 1). At the first trifoliate growth stage, dimethenamid-P at 0.84 kg ai ha^{-1} and a commercial premixture of bentazon & imazamox at 0.77 kg ai ha^{-1} were applied POST. In 2017, methylated seed oil (MSO) (was added to the bentazon & imazamox at a rate of 1% v/v. In 2016, glyphosate at 0.85 kg ae ha^{-1} plus ammonium sulfate (AMS) at 0.94 kg ai ha^{-1} were applied PRE to the entire study to control an initial stand of weeds. The EPTC + ethalfluralin and the glyphosate + AMS were incorporated with approximately 3.2-cm overhead irrigation water. A non-treated and hand-weeded control were included in the study. In both years, hand-weeding started 2 WAE and continued every 1 to 2 weeks until canopy closure. The 56-cm row plots were cultivated on June 29 and July 13, 2016 and July 6, 2017.

Bean density counts were taken on June 20, 2016 and June 20, 2017, 1 and 2 WAE, respectively. Visual evaluations for crop injury and weed control were taken 3 (early) and 7 (late) weeks after emergence (WAE) on June 29 and July 27, 2016 and 2 (early) and 5 (late) WAE on July 1 and July 17, 2017. Weed control and crop injury were rated on a scale of 0 to 100% with 0% for no weed control or crop injury and 100% as complete weed control or crop death. The weeds evaluated were common lambsquarters, redroot pigweed, hairy nightshade, green foxtail, and barnyardgrass. For ease of identification, control ratings for green foxtail and barnyardgrass were combined and reported as annual grass. Weed density counts were taken 3 and 7 WAE on June 28 and July 27, 2016 and 2 and 4 WAE on June 28 and July 13, 2017. Weeds were counted in a 0.125 m^2 quadrat within the row and a 0.125 m^2 quadrat between the rows in the 56-cm row plots. Weeds were counted in a 0.25 m^2 quadrat in the 19-cm row plots. The weeds were counted by species and added together to obtain a total weed density. Using an AccuPAR PAR/LAI Ceptometer (Decagon Devices Inc., 2365 NE Hopkins Court Pullman, WA 99163), leaf area index (LAI) was measured weekly from 5 to 11 WAE in 2016 and 4 to 10 WAE in 2017. LAI measurements were only taken in the hand-weeded controls of each seeding rate treatment because of light interference from the weeds and these measurements were used to compare LAI among the different dry bean seeding rates. Time was used as a variable in the data analysis. The measurements were discontinued each year when the leaves started to desiccate causing the LAI to decrease. As a means of determining the feasibility of direct-harvesting the crop, pod height above-ground was measured in 2016 and 2017. In 2017, lodging also was evaluated 12 WAE for the same purpose. Lodging in each plot was rated on a scale of 1 to 5, where 1 was vertically upright and 5 was prostrate on the ground. Pod height above-ground was measured 13 and 12 WAE in 2016 and 2017, respectively. The height was measured from ground level to the bottom of the lowest hanging pod on 10 randomly-chosen plants in each of the seeding rates in the hand-weeded control, EPTC + ethalfluralin PRE followed by (fb) dimethenamid-P POST, and EPTC + ethalfluralin PRE fb bentazon & imazamox POST in 2016 and in all plots in 2017. Weed biomass samples were taken 17 and 15 WAE in 2016 and 2017, respectively. Weed biomass was determined by harvesting all of the weeds in a 1 m^2 area cut at ground level, dried at 100° C for 48 hours, and weighed. Five representative bean plants were sampled from each plot to measure bean quality. Bean quality parameters included pods per plant, beans per pod, and 100-bean weight. Pods containing at least 1 bean were counted. After counting the pods on each plant, the beans were separated from the pods and sorted with a 1.9-cm by 0.4-cm sieve, counted, and weighed. The weights of these samples were later added to the plot yield weights.

Bean maturity was determined by the hardening of the beans in the pods. At maturity the beans were cut using a Pickett bean cutter (Pickett Equipment, 976 East Main Street, Burley, ID 83318) on17 WAE on October 5, 2016 and October 24, 2017. In the 56-cm row plots, the two center rows were cut the length of the plot (7.62 m). In the 19-cm rows, the center 0.95 m width of the plot was cut the length of the plot. Once dry enough to easily crack in hands, the beans were threshed with a Wintersteiger Delta plot combine (Wintersteiger Inc., 4705 W. Amelia Earhart Drive, Salt Lake City, UT 84116-2876) and the harvested bean weights were recorded.

All data were analyzed using the general linear mixed model PROC GLIMMIX procedure in SAS 9.4 (SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513-2414). Means were separated at $\alpha = 0.05$ using Least Square Means. Due to year interactions, all data was analyzed separately by year. The non-treated control was used for comparison in the visual weed control evaluations only. The hand-weeded control was omitted from the 2016 visual weed control evaluation, weed density, and weed biomass data analysis. The non-treated control and EPTC + ethalfluralin PRE treatment were omitted from the pod heights due to excessive weed pressure.

Results and Discussion

In 2016, there was no significant difference between the emerged bean densities in the standard planting rate of 25 seeds m^{-2} in wide rows or narrow rows seeded at 25 seeds m^{-2} (Table 2). In 2017, dry bean density in the 25 seeds m^{-2} wide and narrow rows averaged 22 and 24 plants m^{-2}, respectively, pooled across weed control treatments. As expected, in both years, emerged bean density was higher with each increase in seeding rate.

Crop Injury and Weed Control

Crop injury was not observed at the early or late evaluations in 2016 or 2017 (data not shown). This was fortunate because imazamox + bentazon in particular has been shown to pose an injury risk in dry bean (Wilson and Sbatella 2014).

In 2016, common lambsquarters, hairy nightshade and redroot pigweed control was generally poor (<70%) at both evaluation dates due to poor control of emerged weeds with glyphosate applied PRE (Tables 3 and 4). The poor weed control was likely due to inadequate time allowed for glyphosate, applied with the EPTC + ethalfluralin PRE, to become rainfast on the emerged weeds before sprinkler irrigation incorporated the soil-active herbicides.

At the early 2016 evaluation, common lambsquarters control was poorer in 25 seed m^{-2} wide rows than the other seeding rates pooled across weed control treatments (Table 3). This was similar to the findings of Blackshaw et al. (1999) that showed black bean competed against weeds better in 46-cm rows compared to 69-cm rows. There was no significant difference in common lambsquarters control between seeding rates at the late evaluation in 2016 or the early evaluation in 2017.

On the later 2017 evaluation date, common lambsquarters control was 88% and significantly greater in 25 seed m^{-2} wide rows than in 25 (narrow rows), 31, 37, and 43 seed m^{-2}, which averaged 80%. This was due to a cultivation in the 25 seed m^{-2} wide rows 3 weeks prior to the evaluation. Common lambsquarters control was greater (84%) in 49 seed m^{-2} than 78% control in 25 seed m^{-2} narrow rows. This higher seeding rate increased the beans ability to compete against common lambsquarters.

There was no significant difference in hairy nightshade or annual grass (green foxtail and barnyardgrass) control between seeding rates in the early or late evaluation in 2016 or 2017 (Table 3 and 4).

In 2016, there were no significant differences in redroot pigweed control between seeding rates at either evaluation date (Table 4). On the early 2017 evaluation date, redroot pigweed control was 77% in 25 seed m^{-2} narrow rows compared to an average 86% control in 37, 43, and 49 seed m^{-2} pooled across all weed control treatments (Table 4). The higher seeding rates ($\geq$37 seed m^{-2}) in narrows rows helped the beans reduce redroot pigweed interference. At the late evaluation in 2017, there was no significant difference in redroot pigweed control, which averaged 88%, between seeding rates.

There was no significant difference in common lambsquarters control between weed control treatments averaged across seeding rates in the 2016 early or late evaluation or the 2017 early evaluation date (Table 5). Common lambsquarters control at the 2017 late evaluation was 91% in the hand-weeded control and significantly higher than the other weed control treatments pooled across seeding rates (Table 5). However, control with EPTC + ethalfluralin PRE fb bentazon/imazamox POST was 87% and better than EPTC + ethalfluralin PRE only and EPTC + ethalfluralin PRE fb dimethenamid-P POST, which averaged 74%.

Even though hairy nightshade control was unacceptable (≤66%) at both evaluations in 2016, hairy nightshade control was greater with EPTC + ethalfluralin PRE fb bentazon/imazamox POST compared to the other two herbicide treatments, pooled across seeding rates (Table 5). This was consistent with findings by Wilson and Sbatella (2014) who showed a POST application of bentazon/imazamox to be their most effective weed control treatment. At the 2017 early evaluation, there was no significant difference in hairy nightshade control between weed control treatments. On the later evaluation date, hairy nightshade control with EPTC + ethalfluralin PRE fb bentazon/imazamox POST and the hand-weeded control averaged 94% compared to EPTC + ethalfluralin PRE only and EPTC + ethalfluralin PRE fb dimethenamid-P POST, which averaged 81%. The addition of bentazon/imazamox POST was effective controlling hairy nightshade as it continued to emerge through the growing season.

At the 2016 early evaluation, annual grass control was 70% with EPTC + ethalfluralin PRE fb bentazon/imazamox POST compared to 54% with EPTC + ethalfluralin PRE only, pooled across seeding rates (Table 5). By the 2016 late evaluation, annual grass control was 58% with EPTC + ethalfluralin PRE only compared to 87 and 90% with EPTC + ethalfluralin

PRE fb dimethenamid-P POST and EPTC + ethalfluralin PRE fb bentazon/imazamox POST, respectively. These results reinforce findings by Blackshaw et al. (2000) that showed sequential herbicides increase weed control in dry bean compared to a single herbicide. In 2017, annual grass control in the hand-weeded control was 81 and 85% at the early and late evaluations, respectively. This was significantly lower than the three herbicide treatments. Annual grass control with EPTC + ethalfluralin PRE only, EPTC + ethalfluralin PRE fb dimethenamid-P POST, and EPTC + ethalfluralin PRE fb bentazon/imazamox POST ranged from 91 to 97% control.

Redroot pigweed control at the early evaluation in 2016 and the early and late evaluations in 2017 responded to the weed control treatments but not to seeding rate (Table 6). Whereas, at the 2016 late evaluation there was a significant weed control treatment by dry bean seeding rate interaction for redroot pigweed control. At the 2016 early evaluation, redroot pigweed control was ≤42% for the three herbicide treatments. No control rating was taken in the hand-weeded control. Redroot pigweed control at the early evaluation in 2017 was greater with the three herbicide treatments than the hand-weeded control (88% vs 64%) pooled across seeding rates. This was due to newly emerged weeds early in the growing season. Redroot pigweed control at the late evaluation was 97% with EPTC + ethalfluralin PRE fb bentazon/imazamox POST and higher than the other weed control treatments pooled across seeding rates. EPTC + ethalfluralin PRE only had the poorest redroot pigweed control at 79%.

The weed control treatment by seeding rate interaction at the 2016 late evaluation was essentially due to one weed control value. In this case, redroot pigweed control with EPTC +

ethalfluralin PRE fb dimethenamid-P POST at 25 seeds m^{-2} narrow row was 85% compared to 55% in the 25 seeds m^{-2} wide row (Table 6).

Weed Densities

Common lambsquarters densities at the early and late 2016 and 2017 stand counts had a significant seeding rate by weed control treatment interaction (Table 7). At the 2016 early weed stand counts, common lambsquarters density in the non-treated control was 21 plants m^{-2} in 25 seeds m^{-2} wide rows compared to an average of 40 plants m^{-2} in the narrow row seeding rates from 25 to 43 seeds m^{-2} due to cultivation done in the wide row plots. Only at 49 seeds m^{-2} did common lambsquarters density equal the cultivated wide row treatment. The lower weed density in 25 seeds m^{-2} wide row plots was due to the ability to cultivate the weeds. Only with EPTC + ethalfluralin PRE fb bentazon/imazamox POST was common lambsquarters density in the narrow row seeding rates equal to 25 seeds m^{-2} wide rows. The only exception was the 37 seeds m^{-2} seeding rate, which had a higher density. By the 2016 late weed stand counts, most of the narrow row seeding rates had common lambsquarters densities that were equal to or lower than the 25 seeds m^{-2} wide row seeding rate. This was especially true with EPTC + ethalfluralin PRE fb dimethenamid-P or bentazon/imazamox POST.

Common lambsquarters density, at the 2017 early stand counts, in non-treated 25 seeds m^{-2} wide rows was 215 plants m^{-2} compared to 86 and 151 plants m^{-2} in 25 and 37 seeds m^{-2} (narrow rows), respectively, but was less dense than the 323 and 420 common lambsquarters m^{-2} in the 31 and 43 seeds m^{-2} respectively. This was similar to what was observed in the late stand counts taken in 2016. Common lambsquarters density in EPTC + ethalfluralin PRE only herbicide treatment had 22 plants m^{-2} in 25 seeds m^{-2} wide rows compared to 65 plants m^{-2} in seeding rates ≥ 37 m^{-2}. Only in EPTC + ethalfluralin PRE fb bentazon/imazamox POST were the two highest seeding rates equal to the 25 seeds m^{-2} wide row. As expected, the common lambsquarters density in the hand-weed control was not significantly different among any of the seeding rates in 2017.

Among the seeding rates in the non-treated control at the 2017 late stand counts, there was no difference in common lambsquarters density, with the exception of 43 seeds m^{-2}, which had more common lambsquarters than the other seeding rates. Common lambsquarters densities in almost all of the seeding rates among the herbicide treatments was not reduced by increasing the dry bean seeding rate.

At the 2016 early and late hairy nightshade stand counts, there was a seeding rate by weed control treatment interaction (Table 8). Hairy nightshade density at the early stand count, in the non-treated control, was 26 plants m^{-2} in 25 seeds m^{-2} wide rows and significantly higher than the 31, 37 and 49 seeds m^{-2} at 10, 9, and 5 plants m^{-2}, respectively. With EPTC + ethalfluralin PRE only, hairy nightshade density was equal to or lower than 25 seeds m^{-2} wide rows in all of the narrow row seeding rates. A similar pattern was observed where at least three of the five seeding rates had hairy nightshade densities equal to or lower than EPTC + ethalfluralin PRE fb dimethenamid-P or bentazon/imazamox POST in 25 seeds m^{-2} wide rows. By the late stand count, hairy nightshade density in all herbicide treatments at all seeding rates was equal to or lower than 25 seeds m^{-2} wide rows. The only exception was 25 seeds m^{-2} narrow rows in the EPTC + ethalfluralin PRE only, which had a higher density of 28 plants m^{-2} versus 12 plants m^{-2} in 25 seeds m^{-2} wide rows.

Unlike in 2016, hairy nightshade densities at the early and late stand counts in 2017 responded to the weed control treatments as a main effect (Table 8). The only difference in plant density pooled across all seeding rates was between the non-treated control and EPTC + ethalfluralin PRE fb bentazon/imazamox POST and the hand-weed control. Hairy nightshade density in 2016 or 2017 did not respond to dry bean seeding rates (data not shown).

Annual grass (barnyardgrass and green foxtail) stand counts in 2016 responded only to dry bean seeding rate at the late stand count (Table 9). The only difference in annual grass density between seeding rates was that the 25 seeds m^{-2} narrow row had more annual grass at 8 plants m^{-2} than any other treatment, which averaged 4 plants m^{-2} in the other seeding rates pooled across weed control treatments. It may be that the beans in the lowest seeding rate in narrow rows were less able to compete against the annual grass than the beans in higher seeding rates. It also was not cultivated as the wide rows were. At the late evaluation date in 2017, there was no significant difference between seeding rates (data not shown).

Redroot pigweed density at the 2016 late stand count was similar to the early annual grass stand count in 2016. Only 25 seeds m^{-2} narrow row had more redroot pigweed at 12 plants m^{-2} compared to all of the other treatments which were equal to or lower than 25 seeds m^{-2} wide rows pooled across weed control treatments (Table 9).

There was a significant weed control treatment by dry bean seeding rate interaction for annual grass density at the early stand counts in 2016 and 2017 (Table 10). At the late stand counts, the density response was to the weed control treatments only. Annual grass density at the 2016 early stand counts was much lower among the herbicide treatments compared to the non-treated control. With the exception of EPTC + ethalfluralin PRE fb dimethenamid-P POST, the dry bean seeding rates from 31 seeds m^{-2} and higher had grass densities equal to or better than the 25 seeds m^{-2} wide rows. It is unclear why the annual grass density response to increasing dry bean seeding rates in the EPTC + ethalfluralin PRE fb dimethenamid-P POST did not respond like the other treatments. At the 2016 late weed stand counts, the response was only to the weed control treatments, while dry bean seeding rate had no apparent effect. As expected, annual grass density was highest at 24 plants m^{-2} in the non-treated control compared to an average of 4 plant m^{-2} in the herbicide treatments pooled across seeding rates (Table 10). In 2017, the early annual grass stand counts were similar to the early counts in 2016, with the exception of the non-treated control, which did not respond to increasing dry bean seeding rates. Annual grass density in the herbicide treatments generally was equal to or lower than the 25 seed m^{-2} seeding rate in each respective herbicide treatment, with a few exceptions. At the late weed stand count in 2017, annual grass density was highest in the non-treated control at 54 plants m^{-2} compared to an average of 11 plant m^{-2} in the other weed control treatments.

A weed control treatment by dry bean seeding rate interaction was significant for the 2016 early and 2017 early and late redroot pigweed stand counts (Table 11). The 2016 late stand count responded to weed control treatment alone and as already discussed above, dry bean seeding rate. Redroot pigweed density, pooled across seeding rates at the 2016 late stand counts was 20 plants m^{-2} in the non-treated control compared to an average of 4 plant m^{-2} in the other weed control treatments.

Redroot pigweed density had a significant weed control treatment by seeding rate interaction at the early stand count in 2016 and both stand counts in 2017 (Table 11). In 2016 redroot pigweed densities were lower in all herbicide treatments, compared to the non-treated control at all dry bean seeding rates, except for the 49 seeds m^{-2} seeding rate. In the non-treated control, redroot pigweed density in 31, 43, and 49 seeds m^{-2} seeding rates was equal to or less than the 25 redroot pigweed m^{-2} in 25 seeds m^{-2} wide rows. In the EPTC + ethalfluralin

PRE, redroot pigweed density in all narrow row seeding rates, except 25 seeds m^{-2}, were equal to or lower than 4 plants m^{-2} in 25 seeds m^{-2} wide rows. In the EPTC + ethalfluralin PRE fb dimethenamid-P POST, redroot pigweed density was lower in 25 seeds m^{-2} wide rows at 1 plant m^{-2} than 25, 37, and 49 seeds m^{-2} narrow rows, respectively, and equal in density to 31 and 43 seeds m^{-2}. This was not expected since the addition of dimethenamid-P POST should have provided additional redroot pigweed control compared to EPTC + ethalfluralin PRE. In the EPTC + ethalfluralin PRE fb bentazon/imazamox POST, redroot pigweed density in 31, 37, and 49 seeds m^{-2}, was equal to the 3 plants m^{-2} in 25 seeds m^{-2} wide rows. By the late weed stand counts in 2016, all herbicide treatments averaged 4 plant m^{-2} compared to 20 plants m^{-2} in the non-treated control. In 2017, there was a weed control treatment by dry bean seeding rate interaction at the early and late redroot pigweed stand counts (Table 11). Redroot pigweed density at the 2017 early and late stand counts, was lower in each of the dry bean seeding rates within each herbicide treatment compared to the corresponding seeding rates in the non-treated control. Within each herbicide treatment, redroot pigweed density in 4 of the 5 seeding rates in each herbicide treatment was equal to or lower than the density of the 25 seeds m^{-2} seeding rates in each herbicide treatment. The exceptions to this was the EPTC + ethalfluralin PRE fb dimethamid-P at 25 seeds m^{-2} and EPTC + ethalfluralin PRE fb bentazon/imazamox POST at 43 seeds m^{-2}, which had 43 and 54 redroot pigweed m^{-2}, respectively. Similar to 2017 early stand counts, the 2017 late weed stand counts were equal in 4 of the 5 dry bean seeding rates. At the late stand counts, redroot pigweed densities were higher in the EPTC + ethalfluralin PRE and EPTC + ethalfluralin PRE fb dimethamid-P at 43 and 31 seeds m^{-2} seeding rates, respectively.

All of the individual weed species densities were combined to present a total weed density response. Analysis of these data showed a significant seeding rate by weed control treatment interaction for the early and late weed density counts in 2016 and 2017 (Table 12). At the early stand count in 2016, total weed densities in the non-treated control of the 31 and 49 seeds m^{-2} seeding rates were less than the 25 seeds m^{-2} wide rows. All of the herbicide treatments had lower total weed densities than the non-treated control at their corresponding dry bean seeding rates. EPTC + ethalfluralin PRE only and EPTC + ethalfluralin PRE fb bentazon/imazamox POST had total weed densities equal to or lower than the 25 seeds m^{-2} wide rows. The exceptions to that were the 25 and 43 seeds m^{-2} of EPTC + ethalfluralin PRE only and EPTC + ethalfluralin PRE fb bentazon/imazamox POST, respectively. Total weed densities at the 2016 late weed stand counts were similar to the early stand counts. In the non-treated control, total weed density was equal to the 25 seeds m^{-2} wide rows with only the highest dry bean seeding rate of 49 seeds m^{-2}. Among the herbicide treatments at least four of the five seeding rates had total weed densities equal to or less than the 25 seeds m^{-2} wide row seeding rates. At the 2017 early weed density counts, the non-treated control total weed densities were less at 355 plants m^{-2} in 25 seeds m^{-2} wide rows than the 31 and 43 seeds m^{-2} seeding rates, which had 495 and 517 plants m^{-2}, respectively. Interestingly, the 25 seeds m^{-2} narrow rows had a total weed density (17 plants m^{-2}) lower than the 25 seeds m^{-2} wide rows. Total weed densities in the herbicide treatments did not clearly respond to increasing dry bean seeding rates. In the EPTC + ethalfluralin PRE only, total weed densities in the 25 and 31 seeds m^{-2} were equal to 54 plants m^{-2} in 25 seeds m^{-2} wide rows. The rest of the higher seeding rates had higher total weed densities, averaging 108 plants m^{-2}. The two highest seeding rates, 43 and 49 seeds m^{-2}, in the EPTC + ethalfluralin PRE fb dimethenamid-P or bentazon/imazamox POST, had total weed densities equal to the 25 seeds m^{-2} wide rows of each corresponding herbicide treatment.

At the 2017 late weed stand counts in the non-treated control, total weed densities were higher than the corresponding dry bean seeding rates in each of the herbicide treatments (Table 12). However, the total weed densities of each seeding rate within herbicide treatments was higher than the 25 seeds m^{-2} wide rows. The only exception was the 49 seeds m^{-2} with EPTC + ethalfluralin PRE fb dimethenamid-P POST treatment, which had 54 plants m^{-2} in the 49 seeds m^{-2} seeding rate. In the hand-weeded control, total weed density was not significantly different between 25 seeds m^{-2} wide rows and the other seeding rates in 2016 and 2017, with the lone exception of 37 seeds m^{-2}, which had more total plants at the early stand counts.

Weed Biomass and Leaf Area Index

Total weed biomass was not significantly affected by dry bean seeding rates in 2016 (data not shown). However, total weed biomass was affected by the weed control treatments in 2016 (Table 13). The non-treated control weed biomass was 37 and 29% greater than EPTC + ethalfluralin PRE fb dimethenamid-P POST and EPTC + ethalfluralin PRE fb bentazon/imazamox POST, respectively, pooled across seeding rates.

In 2017, weed biomass had a significant weed control treatment by seeding rate interaction (Table 13). Total weed biomass in some dry bean seeding rates within each of the herbicide treatments was lower than those corresponding seeding rates in the non-treated control. In the EPTC + ethalfluralin PRE only, weed biomass was lower than the non-treated control in only the 43 seeds m^{-2} seeding rate. With EPTC + ethalfluralin PRE fb dimethenamid-P POST, total weed biomass in the 43 and 49 seeds m^{-2} was lower than the same seeding rates in the non-treated control, weed biomass in the EPTC + ethalfluralin PRE fb bentazon/imazamox POST at all seeding rates was lower than the corresponding seeding rates in the non-treated control. Comparisons within a weed control treatment showed the non-treated control had a total weed biomass of 8,232 kg ha^{-1} in 25 seeds m^{-2} wide rows compared to an average of 5,409 kg ha^{-1} in seeding rates ≥ 31 seeds m^{-2}. In the EPTC + ethalfluralin PRE only, weed biomass was 5,031 kg ha^{-1} in 25 seeds m^{-2} wide rows compared to 2,947 kg ha^{-1} in 43 seeds m^{-2}. In the EPTC + ethalfluralin PRE fb dimethenamid-P and bentazon/imazamox POST and the hand-weeded control, weed biomass was not significantly different between 25 seeds m^{-2} wide rows and the other seeding rates.

Since LAI was only measured in the hand-weeded controls, the data analysis did not include weed control treatments as a variable. Only dry bean seeding rate was compared. In 2016, the LAI was lower in 25 seeds m^{-2} wide rows at 0.79 compared to an average of 0.88 in all other seeding rates pooled over time (Table 14). In 2017, the LAI was higher at 0.89 in 49 seeds m^{-2} than an average of 0.80 in all other seeding rates. The LAI was lower at 0.75 in 31 seeds m^{-2} than an average of 0.82 in 25 (narrow rows), 37, and 43 seeds m^{-2}.

Bean Quality Parameters, Lodging, and Pod Heights

In 2016, the bean plants had more pods in 25 seeds m^{-2} narrow rows at 12.1 pods $plant^{-1}$ than in seeding rates ≥37seeds m^{-2}, which had an average of 9.9 pods $plant^{-1}$ pooled across weed control treatments (Table 15). The bean plants had less pods in 49 seeds m^{-2}, with 9.1 pods $plant^{-1}$ compared to an average of 11.6 pods $plant^{-1}$ in 25 seeds m^{-2} wide rows and narrow rows and 31 seeds m^{-2} narrow rows. As the seeding rate increased, dry beans grown in a seeding rate ≥37 seed m^{-2} were not able to produce as many pods $plant^{-1}$ as the beans in the lower seeding rates. This was most likely due to intraspecific competition.

In 2016, the bean plants had more pods at 13.8 pods plant^{-1} in the hand-weeded control than an average of 10.0 pods plant^{-1} in the other weed control treatments pooled across seeding rates (Table 16). The bean plants in the non-treated control had 8.7 pods plant^{-1}, which was less than the other weed control treatments. This is in agreement with Malik et al. (1993) who found white bean pods plant^{-1} decreased with higher weed pressure.

In 2017, there was a significant weed control treatment by seeding rate interaction for pod numbers per plant (Table 16). Several of the weed control treatments had more pods plant^{-1} than the non-treated control. Those treatments included EPTC + ethalfluralin PRE only with 31 seeds m^{-2}, EPTC + ethalfluralin PRE fb dimethenamid-P POST with 25 seeds m^{-2} in wide rows, EPTC + ethalfluralin fb bentazon/imazamox POST with 25 seeds m^{-2} wide and narrow rows, and 31 and 37 seeds m^{-2}, and the hand-weed control at all dry bean seeding rates except 49 seeds m^{-2}.

There were no significant differences in lodging between seeding rates, which averaged 2.1 (data not shown). It was expected that if lodging occurred, it would be in response to the dry bean seeding rates, but that was not the case. Lodging did respond to weed control treatments and was lowest, at 1.3, in the non-treated control and highest in the EPTC + ethalfluralin PRE fb bentazon/imazamox POST at 2.7 compared to an average of 2.1 in the other weed control treatments pooled across seeding rates (Table 17). The reduced lodging in the non-treated control was due to the bean shoots attaching and vining on the weeds. EPTC + ethalfluralin PRE fb bentazon/imazamox POST had fewer weeds to prop up the beans. The hand-weeded plots also did not have weeds to prop up the beans, but the plants within the hand-weeded plots appeared to be stouter, possibly due to lack of weed competition.

There were no significant differences in bean pod height above ground level between seeding rates in 2016 or 2017 (data not shown). However, overall pod height above ground level averaged 5.9 and 10.6 cm in 2016 and 2017, respectively. The exact reason for the large numerical difference between the two years is not known. There were no significant differences of pod heights among weed control treatments in 2016 or 2017 (Table 17). In 2016 and 2017, the number of beans pod^{-1} was not significantly different in response to dry bean seeding rates (Table 15).

In 2016, the number of beans pod^{-1} was not significantly different in response to weed control treatment (Table 17). In 2017, there were 3.7 beans pod^{-1} in the non-treated control compared to an average of 4.1 beans pod^{-1} in the other weed control treatments pooled across seeding rates. Heavy weed competition affects dry bean's ability to produce beans (Malik et al. 1993).

In 2016, the 100-bean weight was not significantly affected by weed control treatment or dry bean seeding rate (Tables 15 and 17). In 2017, 100-bean weight was greater in the hand-weeded control at 35.6 g than an average of 33.2 g in the other weed control treatments pooled across seeding rates (Table 17). Additionally, the two PRE herbicide treatments followed by a POST herbicide application had higher 100-bean weights than the PRE only or non-treated control. This difference in one of the two years indicates the influence of weed interference on dry bean quality. Dry bean seeding rate in 2017 had no effect on 100-bean weight.

Yield

Dry bean yield in 2016 was not significantly different among seeding rates (Table 15). However, there was a dry bean yield response to seeding rate in 2017. The yield was greater in 31, 37, 43 and 49 seeds m^{-2} at 3,135, 3,546, 3,399 and 3,672 kg ha^{-1}, respectively compared to 25 seeds m^{-2} wide rows at 2,049 kg ha^{-1} pooled across weed control treatments.

In 2016, the dry bean yield was greatest in the hand-weeded control at 6,333 kg ha^{-1} compared to an average of 3,702 kg ha^{-1} in the other weed control treatments pooled across seeding rates (Table 17). This was because the hand-weeded control was the most effective throughout the growing season. In 2017, there were no significant differences in dry bean yield among weed control treatments pooled across dry bean seeding rates.

Increasing dry bean seeding rate and planting dry bean in narrow (19-cm) row spacing are cultural practices that may help dry bean growers more effectively control weeds and increase yields. Due to inconsistencies in the data from year to year in this study, more research is needed to make strong management recommendations. Research on increased seeding rates in different climates and locations could confirm the benefits of increased seeding rates in dry beans.

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Table 2.1. Herbicides and adjuvants used in 2016 and 2017.

Herbicide and adjuvant	Application rate	Trade name	Manufacturer
Glyphosate	0.85 kg ae ha^{-1}	Roundup PowerMax	Monsanto Co., 800 N. Lindbergh Boulevard, St. Louis, MO
EPTC	2.92 kg ai ha^{-1}	Eptam 7E	Gowan Company, P.O. Box 5569, Yuma, AZ
Ethalfluralin	1.25 kg ai ha^{-1}	Sonalan HFP	Gowan Company, P.O. Box 5569, Yuma, AZ
Dimethenamid-P	0.83 kg ai ha^{-1}	Outlook	BASF Ag Products, P.O. Box 13528, Research Triangle Park, NC
Bentazon/ imazamox	0.77 kg ai ha^{-1}	Varisto	BASF Ag Products, P.O. Box 13528, Research Triangle Park, NC
Methylated seed oil	1% v/v	Superspread MSO	Wilbur-Ellis Co., P.O. Box 16458, Fresno, CA
Ammonium sulfate	0.94 kg ai ha^{-1}	BroncMax	Wilbur-Ellis Co., P.O. Box 16458, Fresno, CA

Table 2.2. Dry bean stand counts in response to dry bean seeding rate pooled across weed control treatments near Kimberly, ID.

	Stand count[a]	
Seeding rate[b]	2016	2017
seed m^{-2}	---plants m^{-2}---	
25 (wide row)	24 a	22 a
25	23 a	24 b
31	29 b	29 c
37	35 c	35 d
43	40 d	40 e
49	42 e	44 f

[a]Means followed by the same letter are not significantly different at $\alpha = 0.05$ using least square means.
[b]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.3. Common lambsquarters and hairy nightshade control in response to dry bean seeding rate pooled across weed control treatments near Kimberly, ID.

	Weed control[a]							
	Common lambsquarters				Hairy nightshade			
	2016		2017		2016		2017	
Seeding rate[b]	Early	Late	Early	Late	Early	Late	Early	Late
seed m^{-2}	%							
25 (wide row)	9 b	26 a	84 a	88 a	3 a	34 a	97 a	90 a
25	25 a	10 a	73 a	78 c	15 a	42 a	95 a	84 a
31	20 a	7 a	78 a	80 bc	7 a	21 a	92 a	88 a
37	22 a	12 a	72 a	81 bc	16 a	40 a	97 a	86 a
43	25 a	13 a	77 a	82 bc	22 a	44 a	96 a	86 a
49	16 a	13 a	78 a	84 ab	16 a	33 a	94 a	89 a

[a]Means followed by the same letter within the early or late weed control evaluations are not significantly different at $\alpha = 0.05$ using least square means. Early weed control evaluations were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. Late weed control evaluations were completed 7 and 5 weeks after emergence in 2016 and 2017, respectively.
[b]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.4. Annual grass and redroot pigweed control in response to dry bean seeding rate pooled across weed control treatments near Kimberly, ID.

	Weed control[a]							
	Annual grass				Redroot pigweed			
	2016		2017		2016		2017	
Seeding rate[b]	Early	Late	Early	Late	Early	Late	Early	Late
seed m^{-2}	%							
25 (wide row)	54 a	90 a	93 a	95 a	15 a	64 a	82 ab	89 a
25	65 a	81 a	93 a	91 a	29 a	72 a	77 b	87 a
31	67 a	77 a	88 a	91 a	18 a	51 a	82 ab	86 a
37	69 a	85 a	96 a	92 a	37 a	65 a	86 a	90 a
43	64 a	84 a	94 a	92 a	33 a	55 a	87 a	85 a
49	56 a	75 a	90 a	91 a	32 a	46 a	87 a	90 a-

[a]Means followed by the same letter within the early or late weed control evaluations are not significantly different at $\alpha = 0.05$ using least square means. Early weed control evaluations were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. Late weed control evaluations were completed 7 and 5 weeks after emergence in 2016 and 2017, respectively.

[b]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.5. Common lambsquarters, hairy nightshade, and annual grass control in response to weed control treatments pooled across dry bean seeding rate near Kimberly, ID.

		Weed control[a]											
		Common lambsquarters				Hairy nightshade				Annual grass			
		2016		2017		2016		2017		2016		2017	
Treatment[b]	Rate	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
	kg ai ha^{-1}	---%											---
Non-treated control	-	-	-	-	-	-	-	-	-	-	-	-	-
EPTC + ethalfluralin	2.92 + 1.25	19 a	15 a	80 a	73 c	12 b	24 b	95 a	81 b	54 b	58 b	92 a	92 b
EPTC + ethalfluralin fb dimethenamid-P	2.92 + 1.25 fb 0.83	21 a	13 a	76 a	74 c	15 b	31 b	91 a	80 b	61 ab	87 a	91 a	97 a
EPTC + ethalfluralin fb bentazon/imazamox	2.92 + 1.25 fb 0.77	20 a	13 a	76 a	87 b	26 a	66 a	97 a	95 a	70 a	90 a	93 a	96 a
Hand-weeded control	-	-	-	75 a	91 a	-	-	98 a	93 a	-	-	81 b	85 c

[a]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$ using least square means. The early weed control evaluations were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late weed control evaluations were completed 7 and 5 weeks after emergence in 2016 and 2017, respectively.
[b]Abbreviations: fb, followed by.

Table 2.6. Redroot pigweed control in response to weed control treatments alone at the early evaluation in 2016 and both evaluations in 2017 and in response to weed control treatments and dry bean seeding rate at the 2016 late evaluation near Kimberly, ID.

			Redroot pigweed control[a]			
			2016		2017	
Treatment[b]	Rate	Seeding rate[c]	Early	Late	Early	Late
	kg ai ha^{-1}	seed m^{-2}	------------------------%--------------------			
Non-treated control	-	25 (wide row)	-	-	-	-
		25		-		
		31		-		
		37		-		
		43		-		
		49		-		
EPTC + ethalfluralin	2.92 + 1.25	25 (wide)	23 b	53 b-e	88 a	79 c
		25		34 de		
		31		53 b-e		
		37		29 de		
		43		40 cde		
		49		24 e		
EPTC + ethalfluralin fb dimethenamid-P	2.92 + 1.25 fb 0.83	25 (wide)	25 b	55 bcd	87 a	88 b
		25		84 a		
		31		28 de		
		37		70 abc		
		43		40 cde		
		49		25 de		
EPTC + ethalfluralin fb bentazon/imazamox	2.92 + 1.25 fb 0.77	25 (wide)	42 a	75 ab	89 a	97 a
		25		75 ab		
		31		72 abc		
		37		80 ab		
		43		79 ab		
		49		71 abc		
Hand-weeded control	-	25 (wide)	-	-	64 b	88 b
		25		-		
		31		-		
		37		-		
		43		-		
		49		-		

[a]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$ using least square means. The early weed control evaluations were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late weed control evaluations were completed 7 and 5 weeks after emergence in 2016 and 2017, respectively.
[b]Abbreviations: fb, followed by.
[c]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.7. Common lambsquarters density in response to weed control treatments and dry bean seeding rate near Kimberly, ID.

			Common lambsquarters density[a]			
			2016		2017	
Treatment[b]	Rate	Seeding rate[c]	Early	Late	Early	Late
	kg ai ha^{-1}	seed m^{-2}	------------------plants m^{-2}----------------			
Non-treated control	-	25 (wide row)	21 c	24 c-f	215 c	108 bc
		25	32 b	32 a-d	86 fgh	86 c-f
		31	34 b	44 a	323 b	140 ab
		37	50 a	23 a-d	151 de	86 c-f
		43	44 a	44 a	420 a	161 a
		49	19 c	20 c-g	205 cd	86 c-f
EPTC + ethalfluralin	2.92 + 1.25	25 (wide)	4 i	20 c-g	22 no	11 jkl
		25	20 c	32 a-d	43 j-n	11 jkl
		31	8 efg	24 c-f	43 i-n	43 e-i
		37	10 def	24 c-f	65 g-k	54 e-i
		43	8 efg	24 c-f	65 g-k	43 e-i
		49	10 def	16 efg	75 f-i	54 e-i
EPTC + ethalfluralin fb dimethenamid-P	2.92 + 1.25 fb 0.83	25 (wide)	8 efg	28 bcd	22 no	11 jkl
		25	19 c	40 ab	86 fgh	65 d-h
		31	12 de	12 g	75 fgh	75 c-g
		37	24 c	16 efg	108 ef	66 d-h
		43	5 hi	16 efg	65 g-j	54 e-i
		49	9 efg	20 c-g	11 o	11 jkl
EPTC + ethalfluralin fb bentazon/imazamox	2.92 + 1.25 fb 0.77	25 (wide)	7 f-i	20 c-g	32 l-o	4 l
		25	6 ghi	12 fg	54 g-l	43 e-i
		31	10 def	20 c-g	75 fgh	75 c-g
		37	13 d	16 efg	129 e	97 cd
		43	7 f-i	20 c-g	32 k-o	32 h-k
		49	9 efg	20 c-g	43 j-n	32 h-k
Hand-weeded	-	25 (wide)	-	-	54 h-m	8 l
		25	-	-	43 i-n	4 l
		31	-	-	32 l-o	8 kl
		37	-	-	75 fgh	4 l
		43	-	-	22 mno	11 jkl
		49	-	-	43 i-n	6 l

[a]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$ using least square means. The early weed density counts were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late weed density counts were completed 7 and 4 weeks after emergence in 2016 and 2017, respectively. Numbers were rounded to the nearest whole number except for those <1.

[b]Abbreviations: fb, followed by.

[c]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.8. Hairy nightshade density in response to weed control treatments and dry bean seeding rate in 2016 and to weed control treatments alone in 2017 near Kimberly, ID.

			Hairy nightshade density[a]			
			2016		2017	
Treatment[b]	Rate	Seeding rate[c]	Early	Late	Early	Late
	kg ai ha^{-1}	seed m^{-2}	------------------plants m^{-2}----------------			
Non-treated control	-	25 (wide row)	26 bc	2 fgh	3 a	6 a
		25	21 cd	8 c-g		
		31	10 g-j	12 b-e		
		37	9 hij	3fgh		
		43	28 b	4 e-h		
		49	5 k	0.4 h		
EPTC + ethalfluralin	2.92 + 1.25	25 (wide)	23 bc	12 bcd	3 a	3 ab
		25	56 a	28 a		
		31	24 bc	20 ab		
		37	8 ijk	4 e-h		
		43	17 de	12 b-e		
		49	14 efg	12 b-e		
EPTC + ethalfluralin fb dimethenamid-P	2.92 + 1.25 fb 0.83	25 (wide)	11 f-i	8 c-g	3 a	2 ab
		25	13 e-h	8 c-g		
		31	29 b	16 bc		
		37	21 cd	12 b-e		
		43	7 jk	12 b-e		
		49	8 ijk	8 d-g		
EPTC + ethalfluralin fb bentazon/imazamox	2.92 + 1.25 fb 0.77	25 (wide)	14 efg	8 c-g	5 a	1 b
		25	14 ef	1 h		
		31	11 f-i	2 fgh		
		37	14 efg	2 fgh		
		43	26 bc	8 b-e		
		49	11 f-i	2 gh		
Hand-weeded	-	25 (wide)	-	-	2 a	0.4 b
		25	-	-		
		31	-	-		
		37	-	-		
		43	-	-		
		49	-	-		

[a]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$ using least square means. The early weed density counts were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late weed density counts were completed 7 and 4 weeks after emergence in 2016 and 2017, respectively. Numbers were rounded to the nearest whole number except for those <1.

[b]Abbreviations: fb, followed by.

[c]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.9. Annual grass (barnyardgrass and green foxtail), and redroot pigweed density in response to dry bean seeding rate pooled across weed control treatments in dry bean near Kimberly, ID.

	Annual grass density[a]	Redroot pigweed density
	2016	
Seeding rate[b]	Late	
seed m^{-2}	----plants m^{-2}----	
25 (wide row)	1 b	8 bc
25	8 a	12 a
31	4 b	8 bc
37	4 b	8 bc
43	4 b	3 c
49	4 b	4 c

[a]Means followed by the same letter within the early or late weed control evaluations are not significantly different at $\alpha = 0.05$ using least square means. The early weed stand counts were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late weed stand counts were completed 7 and 4 weeks after emergence in 2016 and 2017, respectively. Numbers were rounded to the nearest whole number except for those <1.

[b]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.10. Annual grass density in response to weed control treatments and dry bean seeding rate at the early stand counts in 2016 and 2017 and weed control treatments alone at the late 2016 and 2017 stand counts near Kimberly, ID.

			Annual grass density[a]			
			2016		2017	
Treatment[b]	Rate	Seeding rate[c]	Early	Late	Early	Late
	kg ai ha^{-1}	seed m^{-2}	-------------------plants m^{-2}----------------			
Non-treated control	-	25 (wide row)	29 b	24 a	22 f-l	54 a
		25	40 a		97 bc	
		31	13 cd		140 a	
		37	32 b		129 ab	
		43	35 ab		43 de	
		49	17 c		86 c	
EPTC + ethalfluralin	2.92 + 1.25	25 (wide)	6 fg	4 b	2 l	11 b
		25	11 de		20 h-l	
		31	2 ijk		11 f-l	
		37	0.8 k		11 f-l	
		43	0.9 jk		22 f-l	
		49	8 ef		3 kl	
EPTC + ethalfluralin fb dimethenamid-P	2.92 + 1.25 fb 0.83	25 (wide)	2 ijk	2 c	2 l	3 b
		25	14 cd		11 f-l	
		31	5 f-i		22 f-l	
		37	6 fg		6 i-l	
		43	2 ijk		32 efg	
		49	5 f-i		22 f-l	
EPTC + ethalfluralin fb bentazon/imazamox	2.92 + 1.25 fb 0.77	25 (wide)	5 f-i	2 c	5 jkl	2 b
		25	2 ijk		5 jkl	
		31	2 ijk		3 kl	
		37	2 ijk		11 f-l	
		43	3 hij		3 kl	
		49	2 ijk		1 l	
Hand-weeded	-	25 (wide)	-	-	6 i-l	10 b
		25	-		22 f-l	
		31	-		65 cd	
		37	-		22 f-l	
		43	-		11 f-l	
		49	-		32 efg	

[a]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$ using least square means. The early weed stand counts were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late weed stand counts were completed 7 and 4 weeks after emergence in 2016 and 2017, respectively. Numbers were rounded to the nearest whole number except for those <1.
[b]Abbreviations: fb, followed by.
[c]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.11. Redroot pigweed density in response to weed control treatments and dry bean seeding rates at the early stand count in 2016 and both counts in 2017; and weed control treatment pooled across dry bean seeding rates near Kimberly, ID.

			Redroot pigweed density[a]			
			2016		2017	
Treatment[b]	Rate	Seeding rate[c]	Early	Late	Early	Late
	kg ai ha^{-1}	seed m^{-2}	--------------------plants m^{-2}---------------			
Non-treated control	-	25 (wide row)	25 c	20 a	97 c	54 cd
		25	54a		75 cd	108 a
		31	23 c		151 a	97 ab
		37	36 b		140 ab	43 de
		43	24 c		65 cde	65 bcd
		49	8 de		108 bc	86 abc
EPTC + ethalfluralin	2.92 + 1.25	25 (wide)	4 g-k	4 b	4 k	2 g
		25	7 d-g		8 jk	10 fg
		31	4 g-k		22 g-k	11 fg
		37	2 jkl		11 h-k	22 fg
		43	0.8 l		22 g-k	32 ef
		49	4 g-k		8 jk	6 g
EPTC + ethalfluralin fb dimethenamid-P	2.92 + 1.25 fb 0.83	25 (wide)	0.7 l	4 b	11 h-k	2 g
		25	3 h-k		43 efg	22 fg
		31	2 jkl		8 ijk	54 cd
		37	9 d		11 h-k	11 fg
		43	2 jkl		5 k	22 fg
		49	6 e-h		22 g-k	22 fg
EPTC + ethalfluralin fb bentazon/imazamox	2.92 + 1.25 fb 0.77	25 (wide)	3 h-k	4 b	4 k	2 g
		25	10 d		22 g-k	1 g
		31	5 f-i		4 k	3 g
		37	3 h-k		11 h-k	4 g
		43	7 d-g		22 g-k	5 g
		49	5 f-i		8 ijk	5 g
Hand-weeded	-	25 (wide)	-	-	22 g-k	2 g
		25	-		43 efg	1 g
		31	-		22 g-k	6 g
		37	-		54 def	6 g
		43	-		32 fgh	5 g
		49	-		32 fgh	10 g

[a]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$ using least square means. The early weed stand counts were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late weed stand counts were completed 7 and 4 weeks after emergence in 2016 and 2017, respectively. Numbers were rounded to the nearest whole number except for those <1.

[b]Abbreviations: fb, followed by.

[c]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.12. Total weed density in response to weed control treatments and dry bean seeding rate in 2016 and 2017 near Kimberly, ID.

			Total weed density[a]			
			2016		2017	
Treatment[b]	Rate	Seeding rate[c]	Early	Late	Early	Late
	kg ai/ha	seed m^{-2}	------------------plants m^{-2}----------------			
Non-treated control	-	25 (wide row)	105 c	40 c	355 b	215 cd
		25	156 a	80 a	183 c	291 ab
		31	85 d	64 ab	495 a	334 a
		37	113 bc	56 b	312 b	226 bcd
		43	121 b	60 ab	517 a	301 a
		49	43 fgh	28 cde	312 b	226 bcd
EPTC + ethalfluralin	2.92 + 1.25	25 (wide)	48 hij	28 cde	54 hij	32 l-q
		25	99 c	64 ab	65 g-j	54 j-n
		31	40 ghi	32 cd	75 f-j	97 f-i
		37	22 l	12 ghi	108 d-g	118 fg
		43	26 kl	16 fgh	108 d-g	118 fg
		49	29 k	24 def	97 d-i	86 g-j
EPTC + ethalfluralin fb dimethenamid-P	2.92 + 1.25 fb 0.83	25 (wide)	22 l	12 ghi	65 g-j	32 l-q
		25	47 fg	24 def	129 cde	108 fgh
		31	49 f	20 d-h	108 d-g	140 de
		37	61 e	20 d-h	151 cd	97 f-i
		43	15 m	20 d-h	86 f-j	97 f-i
		49	28 k	16 fgh	54 hij	54 j-n
EPTC + ethalfluralin fb bentazon/imazamox	2.92 + 1.25 fb 0.77	25 (wide)	30 k	16 fgh	54 hij	22 opq
		25	33 ijk	16 fgh	97 d-i	75 h-k
		31	28 k	8 hi	97 d-i	97 f-i
		37	32 jk	12 ghi	161 c	129 ef
		43	44 fgh	16 fgh	86 f-j	65 i-l
		49	28 k	4 i	75 f-j	54 j-n
Hand-weeded	-	25 (wide)	-	-	86 f-j	32 l-q
		25	-	-	97 d-i	11 q
		31	-	-	54 hij	32 l-q
		37	-	-	140 cd	22 opq
		43	-	-	65 g-j	43 k-o
		49	-	-	75 f-j	43 k-o

[a]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$ using least square means. The early weed stand counts were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late weed stand counts were completed 7 and 4 weeks after emergence in 2016 and 2017, respectively. Numbers were rounded to the nearest whole number except for those <1.

[b]Abbreviations: fb, followed by.

[c]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.13. Weed biomass in response to herbicides and seeding rates near Kimberly, ID[a].

Treatment[b]	Rate	Seeding rate[c]	Weed biomass 2016	Weed biomass 2017
	kg ai/ha	seed m^{-2}	--------------------kg ha^{-1}	----------------
Non-treated control	-	25 (wide row)	5,605 a	8,232 a
		25		7,241 ab
		31		5,890 bc
		37		5,219 cde
		43		5,432 cde
		49		5,095 cde
EPTC + ethalfluralin	2.92 + 1.25	25 (wide)	4,642 ab	5,031 c-f
		25		3,192 f-i
		31		5,743 bcd
		37		4,958 c-f
		43		2,947 ghi
		49		3,959 d-g
EPTC + ethalfluralin fb	2.92 + 1.25 fb	25 (wide)	3,546 b	3,654 e-h
dimethenamid-P	0.83	25		4,024 c-g
		31		4,028 c-g
		37		5,490 b-e
		43		2,792 g-j
		49		2,362 g-k
EPTC + ethalfluralin fb	2.92 + 1.25 fb	25 (wide)	3,955 b	616 klm
bentazon/imazamox	0.77	25		2,117 g-l
		31		1,505 i-m
		37		2,028 h-m
		43		840 j-m
		49		1,740 i-m
Hand-weeded	-	25 (wide)	-	275 m
		25		284 lm
		31		203 m
		37		290 lm
		43		337 lm
		49		315 lm

[b]Abbreviations: fb, followed by.
[a]Means followed by the same letter within a column are not significantly different at α = 0.05 using least square means.

Table 2.14. Leaf area index in response to dry bean seeding rate pooled over time in dry bean near Kimberly, ID.
[a]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$ using least square means. [b]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

	Leaf Area Index[a]	
Seeding rate[b]	2016	2017
seed m^{-2}		
25 (wide row)	0.79 b	0.79 bc
25	0.86 a	0.82 b
31	0.90 a	0.75 c
37	0.87 a	0.82 b
43	0.89 a	0.81 b
49	0.88 a	0.89 a

[b]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.15. Pod counts, bean counts, 100-bean weights, weed biomass, and yield in response to seeding rate pooled across weed control treatments in dry bean near Kimberly, ID[a].

	Pod counts	Bean counts		100-bean weight		Yield	
Seeding rate[b]	2016	2016	2017	2016	2017	2016	2017
seed m^{-2}	--pods $plant^{-1}$-	------------beans pod^{-1}--------		-----------------g--------------		---------------kg ha^{-1}-------------	
25 (wide row)	11.3 ab	3.8 a	4.0 a	36.0 a	34.1 a	3,395 a	2,049 c
25	12.1 a	3.8 a	4.1 a	36.0 a	34.4 a	4,415 a	2,690 bc
31	11.3 ab	3.5 a	4.0 a	35.9 a	33.6 a	4,799 a	3,135 ab
37	10.2 bc	3.6 a	4.0 a	37.0 a	33.1 a	3,380 a	3,546 a
43	10.3 bc	4.0 a	3.9 a	36.4 a	33.5 a	4,493 a	3,399 ab
49	9.1 c	3.6 a	4.1 a	35.7 a	33.0 a	4,572 a	3,672 a

[a]Means followed by the same letter within the early or late weed control evaluations are not significantly different at $\alpha = 0.05$ using least square means.
[b]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.16 Pod counts in response to herbicides and seeding rates near Kimberly, ID[a].

Treatment[b]	Rate	Seeding rate[c]	Pod counts 2016	Pod counts 2017
	kg ai/ha	seed m^{-2}	------------------pods $plant^{-1}$	-------------
Non-treated control	-	25 (wide row)	8.7 c	6.7 j-m
		25		6.8 j-m
		31		4.8 m
		37		5.2 lm
		43		5.2 lm
		49		5.5 lm
EPTC + ethalfluralin	2.92 + 1.25	25 (wide)	10.0 bc	9.2 g-k
		25		9.4 g-j
		31		11.5 e-h
		37		7.4 i-m
		43		9.2 g-k
		49		5.7 klm
EPTC + ethalfluralin fb dimethenamid-P	2.92 + 1.25 fb 0.83	25 (wide)	10.5 b	10.6 f-i
		25		10.1 f-j
		31		9.4 g-j
		37		8.1 h-m
		43		8.8 i-k
		49		9.8 g-j
EPTC + ethalfluralin fb bentazon/imazamox	2.92 + 1.25 fb 0.77	25 (wide)	10.7 b	15.4 a-d
		25		16.9 abc
		31		13.9 c-f
		37		15.2 a-d
		43		10.6 f-j
		49		9.4 g-j
Hand-weeded	-	25 (wide)	13.8 a	18.2 ab
		25		18.6 a
		31		14.6 b-e
		37		16.8 abc
		43		12.6 d-g
		49		10.2 f-j

[b]Abbreviations: fb, followed by.
[a]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$ using least square means.
[c]Wide row spacing was 56 cm. All other seeding rates were planted in 19-cm row spacing.

Table 2.17. Lodging, pod heights, bean counts, 100-bean weight, and yield in response to weed control treatments pooled across dry bean seeding rates near Kimberly, ID[a].

Treatment[c]	Rate	Lodging[b]	Pod height		Bean count		100-bean weight		Yield	
		2017	2016	2017	2016	2017	2016	2017	2016	2017
	kg ai ha^{-1}		-------cm----------		--- beans pod^{-1}----		---------g-----------		--------kg ha^{-1}-------	
Non-treated control	-	1.3 c	-	-	3.5 a	3.7 b	36.8 a	32.8 cd	3,278 b	2,535 a
EPTC + ethalfluralin	2.92 + 1.25	2.3 b	-	-	3.5 a	4.0 a	35.5 a	32.2 d	3,788 b	3,006 a
EPTC + ethalfluralin fb dimethenamid-P	2.92 + 1.25 fb 0.83	2.1 b	6.5 a	10.2 a	3.6 a	4.2 a	35.8 a	34.2 b	3,819 b	3,345 a
EPTC + ethalfluralin fb bentazon/imazamox	2.92 + 1.25 fb 0.77	2.7 a	5.8 a	9.8 a	3.9 a	4.2 a	36.0 a	33.4 bc	3,917 b	3,306 a
Hand-weeded		2.0 b	5.5 a	9.2 a	3.9 a	4.0 a	36.5 a	35.6 a	6,333 a	3,239 a

[a]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$ using least square means.
[b]Lodging was evaluated in 2017 only on a scale from 1 = no lodging to 5 = complete lodging.
[c]Abbreviations: fb, followed by.

CHAPTER 3: ACHIEVING SEASON-LONG WEED CONTROL IN EDIBLE DRY BEAN PRODUCTION

Introduction

Idaho currently ranks 6th in the nation for edible dry bean (*Phaseolus vulgaris* L.) production and was valued at $69.2 million in 2016 (USDA 2017). Based on grower response to surveys by the Idaho Bean Commission (2014, 2018), hairy nightshade (*Solanum physalifolium* Rusby) and season-long weed control were ranked among the biggest challenges in dry bean production. Hairy nightshade is considered the most troublesome weed in dry bean production in southern Idaho and other parts of North America (Bassett and Munro 1985; Blackshaw 1991; Idaho Bean Commission 2014). Previous studies have shown that as few as two hairy nightshade plants per 3 feet of row competing with the crop for water, nutrients, and light through the growing season are enough to decrease dry bean yield by 13% (Blackshaw 1991). Hairy nightshade not only competes with dry beans during the growing season causing yield losses (Bassett and Munro 1985; Blackshaw 1991; Blackshaw and Esau 1991; Rich and Renner 2009) but can also create challenges during harvest by plugging the combine harvester. Furthermore, the crushed berries of hairy nightshade can stain the beans, which reduces the quality and market value (Rich and Renner 2009; VanGessel et al. 1998; Waters and Morishita 2001).

Raptor (imazamox) is the most effective, currently labeled, postemergence herbicide for controlling hairy nightshade and other weeds in dry beans. However, its drawback for many growers is the rotation restriction to sensitive crops such as sugar beets (*Beta vulgaris* L.) and potatoes (*Solanum tuberosum* L.). A need exists for season-long weed control in dry beans that is not solely dependent on herbicides. Use of integrated weed management (IWM) practices combining herbicides with cultural and mechanical control methods could possibly allow choosing herbicide(s) with fewer or no crop rotation restrictions while still obtaining the level of control provided by Raptor. One of the IWM methods which may help obtain successful season-long control would be enhancing the competitiveness of dry beans. Cultural practices to consider include fertilizer placement, seeding rate, time to canopy closure, row spacing and plant architecture, i.e. growth habit, branching pattern, and plant canopy. Canadian and Midwestern U.S. studies in soybean and various classes of dry beans, have shown that planting in narrow rows instead of traditional wide-row spacing improves the competitiveness of the crop against weeds (Blackshaw et al. 1999; Blackshaw et al. 2000; Holmes and Sprague 2013; LeQuia 2018; Rich and Renner 2009; Thornton 2016; Yelverton and Coble 1991; Young et al. 2009). There also have been studies supporting the practice of higher seeding rates as a means of increasing competitiveness in narrow-row crops (Arce et al. 2009, Bertram and Pederson 2004, Blackshaw et al. 1999, Blackshaw et al. 2000, Place et al. 2009). However, growing conditions in southern Idaho are quite different from conditions in these study locations. For example, Idaho's low humidity, semi-arid climate requiring irrigation creates a much different environment than the relatively higher humidity and rain fed conditions in Midwestern dry bean production areas where growers do not rely on irrigation. Therefore, Idaho studies are needed to develop appropriate IWM practices for successful, season-long control of weeds, including hairy nightshade.

Weed Control

A row spacing study was conducted in 2014 and 2015 at the University of Idaho Kimberly Research and Extension Center with the goal of determining the effect of row spacing, plant architecture, and herbicide combinations on season-long weed control and pinto bean yield. Four herbicide treatments plus a non-treated weedy control and a hand-weeded control were included in the trial (Table 1). Herbicides included Basagran, Eptam, Outlook, Prowl H_2O, and Sonalan in various two-way preemergence (PRE) and sequential postemergence (POST) combinations. Weedy control treatments were included in the yield analyses for comparison only. Two pinto bean cultivars were selected based on their plant architecture. 'Sequoia' has a Type II upright growth habit, and 'Othello' has a Type III viny or trailing growth habit. The two varieties were planted in narrow rows with a grain drill in 6-inch and 7.5-inch row spacing in 2014 and 2015, respectively (Figure 1). Both varieties also were planted in wide-row spacing with a standard row crop planter with 22-inch row spacing (Figure 1). The seeding rate for narrow and wide rows was the same at 95,000 seeds/A. Cultivation was performed in the wide-row, but not narrow-row treatments. Visual weed control evaluations were conducted of four weed species present in the study both years. Hairy nightshade, common lambsquarters (*Chenopodium album* L.), green foxtail (*Setaria viridis* L.), and redroot pigweed (*Amaranthus retroflexus* L.) control were rated on a 0% (no control) to 100% (complete death) scale twice during the growing season: at mid-season and one month later. There were no differences in weed control between 2014 and 2015 so a combined analysis of data was performed.

In 2016 and 2017, a separate seeding rate in narrow rows study was conducted at the Kimberly Research and Extension Center. The purpose of this experiment was to determine if increasing seeding rates of beans planted in narrow rows in conjunction with herbicides, could increase weed control and dry bean yield compared to a standard seeding rate in wide rows. The variety used in this study was 'La Paz', which is an upright indeterminate Type II pinto bean. This was chosen with the intent of being able to swath or direct-harvest the crop. The beans were planted at 100,000, 125,000, 150,000, 175,000 and 200,000 seeds/A in narrow 7.5-inch rows and at 100,000 seeds/A in wide 22-inch rows. Five weed control treatments consisting of a non-treated weedy control, a hand-weeded control, and three herbicide treatments were included in the trial. The three herbicide treatments were Eptam + Sonalan applied PRE-alone, and Eptam + Sonalan applied PRE followed by sequential POST applications of Outlook or Varisto. Like the row spacing study, the beans planted in wide rows were cultivated, but the beans planted in narrow rows were not. Visual weed control evaluations of hairy nightshade, common lambsquarters, redroot pigweed, and green foxtail, were conducted twice during the growing season: early (1st trifoliate growth stage) and late (two weeks after the first evaluation). The results from 2016 and 2017 are presented separately due to statistical differences in the data between years.

Hairy nightshade

In the row spacing experiment, hairy nightshade control was affected by row spacing, variety, and weed control treatment (Table 1). Averaged across the two varieties, hairy nightshade control with Eptam + Sonalan applied PRE-alone to beans grown in narrow rows had the poorest control at the early- and late-evaluations with 31 and 50% control, respectively, followed by the second poorest control of 61 and 72%, respectively, with the same PRE-alone herbicide treatment in the wide-row spacing. This difference in control between the same herbicide treatments, but different row spacing was most likely due to being able to cultivate in the wide but not the narrow rows. In contrast, herbicide treatments that included a POST sequential application, in both narrow and wide rows, controlled hairy nightshade better than PRE-alone. There were no differences in control among these herbicide combinations between row spacings. This suggests that, even without in-season cultivation, planting dry beans in narrow rows increases competitiveness with hairy nightshade compared with that in wide rows, and can provide effective hairy nightshade control when combined with POST sequential herbicides. This is consistent with a study in soybean where narrow rows helped to reduced weed interference and increased subsequent yield compared to wide rows (Norris et al. 2009).

Hairy nightshade control also was influenced by differences in plant architecture between the two dry bean varieties. Averaged across herbicides and row spacing, early and late hairy nightshade control was 90% or greater in Othello compared to 86% control in Sequoia. This suggests that Othello, which has a viny, trailing growth habit, is more competitive with hairy nightshade than Sequoia, which has an upright, erect growth habit and a more open canopy.

Regardless of herbicide combinations and timings or row spacing, hairy nightshade control in the dry bean variety with the viny, trailing growth habit (Othello) was better than Sequoia, the variety with the more upright and open canopy. In addition, when pinto beans were planted in narrow rows, competition against hairy nightshade was seemingly increased enough for control of the weed by PRE fb POST herbicide applications to be comparable to that in wide rows, which included an in-season cultivation.

In the seeding rate experiment, the overall weed control in 2016 was poor to fair. There was no difference in hairy nightshade control between dry bean seeding rates in any of the weed control evaluations (Table 2). Even though the broadleaf weed control was mostly unacceptable (<70%), there were some differences among weed control treatments (Table 3). At the early evaluation in 2016, hairy nightshade control was better with Eptam + Sonalan applied PRE fb Varisto applied POST at 26% than Eptam + Sonalan PRE or Eptam + Sonalan

PRE fb Outlook POST which controlled hairy nightshade only 12 and 15%, respectively (Table 3). Similarly, at the late evaluation, hairy nightshade control was better with Eptam + Sonalan PRE fb Varisto POST at 66% than Eptam + Sonalan PRE-alone or Eptam + Sonalan PRE fb Outlook POST at 24 and 31% control, respectively. Unacceptable levels of weed control in 2016 were due to failure to control weeds prior to planting. At the early evaluation in 2017, there were no differences in hairy nightshade control between weed control treatments. However, at the late evaluation, the hand-weeded control and Eptam + Sonalan PRE fb Varisto POST had better control at 93 and 95%, respectively, than Eptam + Sonalan PRE alone or Eptam + Sonalan PRE fb Outlook POST at 81 and 80% control, respectively.

Other weeds

Common lambsquarters, green foxtail, and redroot pigweed control in the row spacing study was affected only by the weed control treatments (Table 4). Similar to hairy nightshade control, Eptam + Sonalan PRE alone had the poorest control of these three weed species at both evaluation dates. Otherwise, control of these three species with herbicide treatments that included a POST sequential herbicide application was better and ranged from 83 to 94%. Common lambsquarters and redroot pigweed control with Eptam + Outlook PRE fb Sonalan + Basagran POST and redroot pigweed control with Prowl H_2O + Outlook PRE fb Basagran POST was better than Eptam + Sonalan PRE fb Outlook + Basagran POST at the early- and late-evaluations (Table 4). Overall, the addition of a POST sequential herbicide application to the PRE-applied herbicides was needed to provide effective season-long control of any of the four weeds in this study.

In the seeding rate experiment, weed control in 2016 was very poor due to the poor control of existing weeds when the study was initiated. There were no differences in common lambsquarters, green foxtail, or redroot pigweed control between seeding rates in 2016 and no differences in green foxtail control in 2017 (Table 5). At the late evaluation in 2017, common lambsquarters control was 88% in the standard wide rows, which was better than the narrow rows seeded with 100,000 to 175,000 seeds/A. These treatments averaged 80% control. The better control in the wide rows was likely due to a cultivation made before the evaluation. Common lambsquarters control was better at 200,000 seeds/A at 84% than at 100,000 seeds/A in narrow rows (78%). The 2017 results show that increased seeding rate can help beans to compete better against common lambsquarters and redroot pigweed. At the early evaluation in 2017, redroot pigweed control was better at 150,000 to 200,000 seeds/A, averaging 87% control, compared to 77% control with 100,000 seeds/A in narrow rows.

There were no differences in common lambsquarters control between weed control treatments in 2016 or at the early evaluation in 2017 (Table 6). At the late evaluation in 2017, common lambsquarters control was best in the hand-weeded control at 91%, followed by Eptam + Sonalan PRE fb Varisto POST at 87%. Green foxtail control at the early evaluation in 2016, was better with Eptam + Sonalan PRE fb Varisto POST at 70% than Eptam + Sonalan PRE only at 54%. At the late evaluation in 2016, green foxtail control was better with Eptam + Sonalan PRE fb Outlook POST and Eptam + Sonalan PRE fb Varisto POST at 87 and 90% control, respectively than Eptam + Sonalan PRE only, which averaged 58% control. In the early evaluation in 2017, green foxtail control averaged 92% with the three herbicide treatments. At the late evaluation in 2017, green foxtail control was best with Eptam + Sonalan PRE fb Outlook POST and Eptam + Sonalan PRE fb Varisto POST, at 97 and 96% control, respectively. Redroot pigweed control at the early evaluation in 2016 was unacceptable with all herbicide treatments (Table 7). At the late evaluation in 2016, there was an interaction between weed control treatments and seeding rates for redroot pigweed control. With Eptam + Sonalan applied PRE alone, redroot pigweed control was unacceptable and averaged 39% across all seeding rates. With Eptam + Sonalan PRE fb Outlook POST, redroot pigweed weed control was 84 and 70% in 100,000 and 150,000 seeds/A. Redroot pigweed control with all other seeding rates in this herbicide treatment was unacceptable. Redroot pigweed control was slightly better with Eptam + Sonalan PRE fb Varisto POST and ranged from 71 to 80% will all of the seeding rates. In 2017, redroot pigweed control at the early evaluation was poorest in the hand-weeded control at 64%. Eptam + Sonalan applied PRE alone, Eptam + Sonalan PRE fb Outlook POST, and Eptam + Sonalan PRE fb Varisto POST averaged 88% control. At the late evaluation, redroot pigweed control was best with Eptam + Sonalan PRE fb Varisto POST at 97%. Eptam + Sonalan PRE fb Outlook POST and the hand-weeded control were equal at 88% control. Overall, a sequential application of Eptam + Sonalan PRE fb Varisto POST was the most effective weed control treatment for the weeds in this experiment.

Dry bean yield

Overall impact of weeds

In dry bean studies conducted in other areas of the U.S. and in Canada, yields of the weedy control treatments that did not receive herbicides and were weedy through the entire growing season were reduced 29 to 84%, compared to the yield of hand-weeded treatments, depending upon the bean market class and location (Arnold et al. 1996; Blackshaw and Esau 1991; Blackshaw et al. 2000; Ugen et al. 2002). In the row spacing study, pinto bean yield was reduced as much as 56% in wide rows and 77% in narrow rows when the weeds were not controlled (Table 8). In the seeding rate study, the yield was reduced 52% when the weeds were not controlled compared to the hand-weeded control averaged across the seeding rates (Table 9).

Herbicide treatment

Due to differences in results between the two years of in the row spacing study, yields were analyzed separately and are presented by year. In 2014, Eptam + Sonalan PRE alone had the poorest weed control, and as expected corresponding lowest yield, regardless of row spacing, compared with yields of the POST sequential treatments which had provided season-long weed control (Table 8). Eptam + Outlook PRE fb Sonalan + Basagran POST and Eptam + Sonalan PRE fb Outlook + Basagran POST in narrow rows had yields greater than Eptam + Sonalan PRE only. In the wide rows, all treatments with a sequential POST application had yields greater than Eptam + Sonalan PRE only. Dry bean yields in the narrow rows were statistically equal to yield in the wide rows. The only exception was the yield in the narrow rows of the hand-weeded control were more than 30% greater than the wide row yield of the hand-weeded control (Table 8). In 2015, there were no yield differences between Eptam + Sonalan PRE alone and any POST sequential treatments, even with differences in weed control between these treatments. In contrast to 2014, bean yields in 2015 were higher in the narrow rows with herbicide treatments that included a POST sequential herbicide compared to the same treatments in the wide rows. It should be noted that the weed pressure in 2015 was relatively lower than in 2014, which resulted in less season-long weed competition. As a result, there were no crop yield differences between Eptam + Sonalan PRE alone and the POST sequential treatments in 2015. This implies that when weed pressure is high, a POST sequential application will increase weed control and subsequent yield compared with using PRE herbicides alone. In both years, the POST sequential treatments resulted in comparable yields and those yields were not less than that of the hand-weeded control, where weeds were controlled throughout the season. In 2015, the bean yield in the hand-weeded control was the same in both narrow and wide row, but there were statistical yield differences between narrow and wide-row spacing with all POST sequential treatments. The dry bean yield results from the two years of this study strongly suggest that narrow rows yield higher than wide rows. One insight gained from this study is that although the seeding rate for the narrow rows was the same as in the wide rows (95,000 seeds/A), this resulted in some gaps in the plant stand in the narrow rows because a grain drill will randomly drop seed unlike a row planter which will drop seed precisely, particularly early in the growing season (Figures 1 and 2).

In the seeding rate study, the hand-weed control yield in 2016 was highest at 5,650 lb/A. (Table 9). Dry bean yield also was not different between the non-treated weedy control and the herbicide treatments in 2017.

Row spacing

Reducing row spacing from 30-inches to anywhere between 7.5- to 15-inches has been shown to increase yields in other studies conducted across North America with several different bean classes (Blackshaw et al. 2000; Cox and Cherney 2011; Holmes and Sprague 2013). When dry beans are grown in narrow rows, using the standard harvesting practices of undercutting and windrowing beans can be eliminated. Narrow rows provide the opportunity to cut beans with a swather or to direct-harvest beans. This can reduce fuel costs, reduce or eliminate picking up dirt clods that wear down harvesting equipment, and save time. However, yield loss is sometimes greater in direct-harvest compared to conventional methods depending on variety, especially with varieties that produce pods close to the soil surface (Osorno et al. 2013). Beans with Type III viny growth habit would be especially prone to seed loss because of the difficulty getting the sickle bar on the header under the lowest hanging pods. Environmental conditions, equipment setup, and operator can also make a difference. Direct-harvest or swathing yield loss can be avoided or reduced with a more upright variety (Type I or II growth habit) that produce pods higher off the ground. Additionally, the use of equipment such as flexible cutterbars and pickup reels that operate closer to the soil can reduce seed even more (Orsono et al. 2013).

In both years of the seeding rate study, the dry bean yield was not different between the beans grown in wide rows at 100,000 seeds/A and the beans grown in narrow rows at 100,000 seeds/A (Table 10).

Seeding Rate

There have been seeding rate studies on various classes of dry beans in Canada. In one study, with Ember small red bean, Blackshaw et al. (2000) found that increased seeding rates in narrow rows allowed the canopy to close earlier in the growing season allowing the beans to intercept more light. Yields were higher when increased seeding rates were used in conjunction with narrow rows (Blackshaw et al. 2000, Malik et al. 1993).

In the seeding rate study, there were no statistically significant yield differences among seeding rates in 2016. There was however, a numerical trend towards higher yields with higher seeding rates, especially compared to the wide row seeding rate (Table 10). In 2017, dry bean yield was significantly higher with the beans planted at 125,000 to 200,000 seeds/A compared to the wide row seeding rate at 100,000 seeds/A. Thus, compared to the standard wide row seeding method, growing dry beans in narrow rows offers a potentially higher yield with seeding rates greater than or equal to 125,000 seed/A.

Plant architecture

In another Canadian study, a navy bean variety with an upright growth habit always attained a yield higher than the viny or trailing navy bean variety in the presence of hairy nightshade (Blackshaw et al. 1999). As stated earlier, in our row spacing study where two pinto bean varieties were compared, Othello with the viny or trailing growth habit yielded higher in both narrow and wide rows compared to Sequoia with the upright and open canopy (Table 11). In other words, unlike navy beans, a viny or trailing pinto bean variety was more competitive with hairy nightshade than an upright pinto bean variety. However, dry bean plant architecture has not been studied to a large extent and it is unknown how other dry bean classes or other pinto bean varieties would react in this scenario. A viny or trailing variety may not allow direct-harvest or swathing if the pods hang too close to the ground.

Conclusion

Season-long weed control can be achieved in edible dry bean production in Idaho with the addition of a POST sequential application, especially in fields with high weed pressure. Furthermore, due to the increased competitiveness with weeds in narrow- vs wide-row spacing, POST sequential applications in narrow-row beans can control weeds as well or better than in wide-row spacing even when the POST sequential applications are combined with cultivation. Even though POST sequential applications increase the production cost, their subsequent increase in yield can offset the added cost, particularly in narrow-row spacing. More research on the economic feasibility of planting beans in narrow rows is needed. Dry beans grown in narrow-row spacing generally had higher yields than wide-row spacing and can become a viable option especially with upright varieties that produce pods high enough above the soil surface to facilitate direct-harvest or swathing. Increased seeding rates, from

125,000 to 150,000 seeds/A in narrow rows can help beans compete more effectively against weeds including common lambsquarters and redroot pigweed.

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Table 3.1. Hairy nightshade control in response to herbicide treatments in narrow- and wide-row spacing averaged across pinto bean varieties and years, near Kimberly, ID.

			Hairy nightshade control[a]			
			Early evaluation		Late evaluation	
Treatment[b]	Rate	Cost[c]	Narrow[d]	Wide	Narrow	Wide
	product/A	$/A	-------------------	------- % -------	-------------------	
Weedy control	-	-	-	-	-	-
Eptam + Sonalan	3 pt + 3 pt	$35.31	31 e	61 d	50 c	72 b
Eptam + Outlook fb Sonalan + Basagran	3 pt + 14 fl oz fb 3 pt + 1 pt	$66.97	92 ab	93 a	95 a	94 a
Eptam + Sonalan fb Outlook + Basagran	3 pt + 3 pt fb 14 fl oz + 1 pt	$66.97	91 abc	92 ab	95 a	92 a
Prowl H_2O + Outlook fb Basagran	2 pt + 14 fl oz fb 1 pt	$43.10	91 abc	92 ab	93 a	94 a
Hand-weeded	-		87 bc	86 c	95 a	93 a

[a]There was a significant interaction between weed control treatment and row spacing for hairy nightshade control and the data are averaged across variety and year. Means followed by the same letter within a column are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$. Visual control was rated on a 0 (no control) to 100% (completely dead) scale.
[b]All of the weed control treatments were compared to the weedy control. Basagran applications included 3.27 pt/A of Bronc Max and 1.5 pt/A of Super Spread MSO. Abbreviations: fb, followed by.
[c]All costs were based on the University of Idaho Agricultural Economics publications-Idaho Crop Input Price Summary for 2015 and Custom Rates 2013-2014 for Idaho Agricultural Operations. Cost includes adjuvants added to Basagran treatments. Application cost with a ground sprayer is $7.00 per acre per application and custom cultivation cost is $19.67 per acre per cultivation.
[d]Narrow-row spacing in 2014 and 2015 was 6 and 7.5 inches, respectively. Wide-row spacing was 22 inches, both years and included an in-season cultivation.

Table 3.2. Hairy nightshade control in response to seeding rate averaged across weed control treatments near Kimberly, ID.

	Hairy nightshade control[a]			
	2016		2017	
Seeding rate[b]	Early	Late	Early	Late
Seed	%			
100,000 (wide row)	3 a	34 a	97 a	90 a
100,000	15 a	42 a	95 a	84 a
125,000	7 a	21 a	92 a	88 a
150,000	16 a	40 a	97 a	86 a
175,000	22 a	44 a	96 a	86 a
200,000	16 a	33 a	94 a	89 a

[a]Hairy nightshade control was averaged across weed control treatments. Means followed by the same letter within a column are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$. Visual control was rated on a 0 (no control) to 100% (completely dead) scale. There was a seeding rate by year interaction. Thus, the data are presented by year. The early evaluations were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late evaluations were completed 7 and 5 weeks after emergence in 2016 and 2017, respectively. Means followed by the same letter within a column are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$.

[b]Wide-row spacing was 22 inches. All other row spacing was 7.5 inches.

Table 3.3. Hairy nightshade control in response to weed control treatments averaged across seeding rates in dry beans near Kimberly, ID.

		Hairy nightshade control[a]			
		2016		2017	
Treatment[b]	Rate	Early	Late	Early	Late
seeds/A	product/A	---%	---	---	---
Weedy control	-	-	-	-	-
Eptam + Sonalan	3 pt + 3 pt	12 b	24 b	95 a	81 b
Eptam + Sonalan fb Outlook	3 pt + 3 pt fb 1 pt	15 b	31 b	91 a	80 b
Eptam + Sonalan fb Varisto	3 pt + 3 pt fb 1.3 pt	26 a	66 a	97 a	95 a
Hand-weeded		-	-	98 a	93 a

[a]All of the weed control treatments were compared to the weedy control. [b]Visual control was rated on a 0 (no control) to 100% (completely dead) scale. Hairy nightshade control was averaged across seeding rates and presented by year since there was a weed control treatment by year interaction. Means followed by the same letter within a column are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$. The hand-weeded control was not included in 2016. Early hairy nightshade control evaluations were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late evaluations were completed 7 and 5 weeks after emergence in 2016 and 2017, respectively.

[b]Application of Varisto included 3.27 pt/A of Bronc Max and 1.5 pt/A of Super Spread MSO. Abbreviation: fb, followed by.

Table 3.4. Common lambsquarters, green foxtail and redroot pigweed control in response to weed control treatments averaged across pinto bean varieties, row spacing, and years near Kimberly, ID.

		Weed control[a]					
		Common lambsquarters		Green foxtail		Redroot pigweed	
Treatment[b]	Rate	Early	Late	Early	Late	Early	Late
	product/A	---%---					
Weedy control	-	-	-	-	-	-	-
Eptam + Sonalan	3 pt + 3 pt	62 c	34 c	70 b	64 b	70 c	70 c
Eptam + Outlook fb Sonalan + Basagran	3 pt + 14 fl oz fb 3 pt + 1 pt	90 a	89 a	91 a	93 a	93 a	93 a
Eptam + Sonalan fb Outlook + Basagran	3 pt + 3 pt fb 14 fl oz + 1 pt	84 b	83 b	89 a	92 a	87 b	86 b
Prowl H_2O + Outlook fb Basagran	2 pt + 14 fl oz fb 1 pt	88 ab	88 ab	91 a	94 a	92 a	93 a
Hand-weeded	-	86 ab	90 a	87 a	92 a	90 ab	93 a

[b]All of the herbicide treatments were compared to the weedy control. The weedy control value (0%) was not included in the data analysis. Abbreviations: fb, followed by. All treatments with Basagran included 3.27 pt/A of Bronc Max and 1.5 pt/A of Super Spread MSO.
[a]Weed control was averaged across variety, row spacing and year. Means followed by the same letter within a column are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$. Visual control was rated on a 0 (no control) to 100% (completely dead) scale.

Table 3.5. Common lambsquarters, green foxtail, and redroot pigweed control in response to seeding rate averaged across weed control treatments near Kimberly, ID.

	Weed control[a]											
	Common lambsquarters				Green foxtail				Redroot pigweed			
	2016		2017		2016		2017		2016		2017	
Seeding rate[b]	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
seeds/A	%											
100,000 (wide row)	9 b	26 a	84 a	88 a	54 a	90 a	93 a	95 a	15 a	64 a	82 ab	89 a
100,000	25 a	10 a	73 a	78 c	65 a	81 a	93 a	91 a	29 a	72 a	77 b	87 a
125,000	20 a	7 a	78 a	80 bc	67 a	77 a	88 a	91 a	18 a	51 a	82 ab	86 a
150,000	22 a	12 a	72 a	81 bc	69 a	85 a	96 a	92 a	37 a	65 a	86 a	90 a
175,000	25 a	13 a	77 a	82 bc	64 a	84 a	94 a	92 a	33 a	55 a	87 a	85 a
200,000	16 a	13 a	78 a	84 ab	56 a	75 a	90 a	91 a	32 a	46 a	87 a	90 a

[a]Weed control was averaged across weed control treatments and are presented by year due to a seeding rate by year interaction. Means followed by the same letter within a column are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$. Visual control was rated on a 0 (no control) to 100% (completely dead) scale. The early evaluations were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late evaluations were completed 7 and 5 weeks after emergence in 2016 and 2017, respectively. Means followed by the same letter within a column are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$.

[b]Wide-row spacing was 22 inches. All other row spacing was 7.5 inches.

Table 3.6. Common lambsquarters and green foxtail control in response to weed control treatments averaged across seeding rate near Kimberly, ID.

Treatment[b]	Rate	Weed control[a]							
		Common lambsquarters				Green foxtail			
		2016		2017		2016		2017	
		Early	Late	Early	Late	Early	Late	Early	Late
	product/A	%							
Weedy control		-	-	-	-	-	-	-	-
Eptam + Sonalan	3 pt + 3 pt	19 a	15 a	80 a	73 c	54 b	58 b	92 a	92 b
Eptam + Sonalan fb Outlook	3 pt + 3 pt fb 1 pt	21 a	13 a	76 a	74 c	61 ab	87 a	91 a	97 a
Eptam + Sonalan fb Varisto	3 pt + 3 pt fb 1.3 pt	20 a	13 a	76 a	87 b	70 a	90 a	93 a	96 a
Hand-weeded		-	-	75 a	91 a	-	-	81 b	85 c

[a]Weed control was averaged across seeding rates and are presented by year due to a weed control treatment by year interaction. Means followed by the same letter within a column are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$. Visual control was rated on a 0 (no control) to 100% (completely dead) scale. The hand-weeded control was not included in the 2016 data analysis. Early weed control evaluations were completed 3 and 2 weeks after emergence in 2016 and 2017, respectively. The late evaluations were completed 7 and 5 weeks after emergence in 2016 and 2017, respectively.
[b]Varisto application included 3.27 pt/A of Bronc Max and 1.5 pt/A of Super Spread MSO. Abbreviation: fb, followed by.

Table 3.7. Redroot pigweed control in response to weed control treatments averaged across seeding rates at the early evaluation in 2016 and both evaluations in 2017; and redroot pigweed control in response weed control treatment by seeding rate interaction at the late evaluation in 2016 near Kimberly, ID.

			Redroot pigweed control[a]			
			2016		2017	
Treatment[b]	Rate	Seeding rate[c]	Early	Late	Early	Late
	product per acre	seeds per acre	--------------------%--------------------			
Weedy control	-	100,000 (wide rows)	-	-	-	-
		100,000		-		
		125,000		-		
		150,000		-		
		175,000		-		
		200,000		-		
EPTC +	2.92 +	100,000 (wide)	23 b	53 b-e	88 a	79 c
ethalfluralin	1.25	100,000		34 de		
		125,000		53 b-e		
		150,000		29 de		
		175,000		40 cde		
		200,000		24 e		
EPTC +	2.92 +	100,000 (wide)	25 b	55 bcd	87 a	88 b
ethalfluralin fb	1.25 fb	100,000		84 a		
dimethenamid-P	0.83	125,000		28 de		
		150,000		70 abc		
		175,000		40 cde		
		200,000		25 de		
EPTC +	2.92 +	100,000 (wide)	42 a	75 ab	89 a	97 a
ethalfluralin fb	1.25 fb	100,000		75 ab		
bentazon/imazamox	0.77	125,000		72 abc		
		150,000		80 ab		
		175,000		79 ab		
		200,000		71 abc		
Hand-weeded	-	100,000 (wide)	-	-	64 b	88 b
		100,000		-		
		125,000		-		
		150,000		-		
		175,000		-		
		200,000		-		

[a]Weed control was averaged across seeding rates at the early evaluation in 2016 and the early and late evaluation in 2017 and are presented by year due to a weed control treatment by year interaction. At the late 2016 evaluation, there was a signification weed control treatment by seeding rate interaction. Means followed by the same letter within a column are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$. Visual redroot pigweed control was rated on a 0 (no control) to 100% (completely dead) scale.

[b]Varisto application included 3.27 pt/A of Bronc Max and 1.5 pt/A of Super Spread MSO. Abbreviations: fb, followed by.

[c]Wide-row spacing was 22 inches. All other row spacing was 7.5 inches.

Table 3.8. Dry bean yield in response to herbicide treatments in narrow- and wide-row spacing averaged over pinto bean varieties and analyzed separately for 2014 and 2015 near Kimberly, ID.

		Bean yield[a]			
		2014		2015	
Treatment[b]	Rate	Narrow[c]	Wide	Narrow	Wide
	product/A	pounds per acre			
Weedy control	-	894 f	1315 f	2293 g	2334 fg
Eptam + Sonalan	3 pt + 3 pt	2590 de	1975 e	3071 abc	2786 cde
Eptam + Outlook fb	3 pt + 14 fl oz fb	3775 ab	3135 bcd	3173 a	2642 e
Sonalan + Basagran	3 pt + 1 pt				
Eptam + Sonalan fb	3 pt + 3 pt fb	3636 abc	3085 cd	3009 a-d	2598 ef
Outlook + Basagran	14 fl oz + 1 pt				
Prowl H_2O + Outlook fb	2 pt + 14 fl oz fb	3034 cd	3144 bcd	3093 ab	2736 de
Basagran	1 pt				
Hand-weeded	-	3928 a	2977 d	2813 b-e	2813 b-e

[a]Bean yield was averaged across variety. There was an interaction between weed control treatments, row spacing, and year. The data were analyzed by year. Means followed by the same letter within a year are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$.
[b]Basagran applications included 3.27 pt/A of Bronc Max and 1.5 pt/A of Super Spread MSO. Abbreviations: fb, followed by.
[c]Narrow-row spacing in 2014 and 2015 was 6 and 7.5 inches, respectively. Wide-row spacing was 22 inches, both years.

Table 3.9. Dry bean yield in response to weed control treatments averaged across seeding rates in dry bean near Kimberly, ID.

Treatment[b]	Rate	Yield[a]	
		2016	2107
	product per acre	------------------------pounds per acre-------------------------	
Weedy control	-	2,925 b	2,262 a
Eptam + Sonalan	3 pt + 3 pt	3,380 b	2,682 a
Eptam + Sonalan fb Outlook	3 pt + 3 pt fb 1 pt	3,407 b	2,984 a
Eptam + Sonalan fb Varisto	3 pt + 3 pt fb 1.3 pt	3,495 b	2,950 a
Hand-weeded	-	5,650 a	2,890 a

[a]The yield data are averaged across dry bean seeding rates and are presented by year since there was a weed control treatment by year interaction. Means followed by the same letter within a column are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$.

[b]Varisto application included 3.27 pt/A of Bronc Max and 1.5 pt/A of Super Spread MSO. Abbreviations: fb, followed by.

Table 3.10. Dry bean yield in response to seeding rate averaged across weed control treatments in dry bean near Kimberly, ID.

	Yield[a]	
Seeding rate[b]	2016	2017
seeds per acre	-----------------------------pounds per acre	---------------------------------
100,000 (wide rows)	3,029 a	1,828 c
100,000	3,395 a	2,400 bc
125,000	4,415 a	2,797 ab
150,000	4,799 a	3,164 a
175,000	3,380 a	3,033 ab
200,000	4,572 a	3,276 a

[a]The yield data are averaged across weed control treatments and presented by year since there was a seeding rate by year interaction. Means followed by the same letter within a column are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$.
[b]Wide-row spacing was 22 inches. All other row spacing was 7.5 inches.

Table 3.11. Dry bean yield in response to variety by row spacing interaction averaged across herbicide treatments and years near Kimberly, ID.

Variety	Bean yield[a]	
	Narrow[b]	Wide
	-----pounds per acre-----	
Othello	3192 a	3058 a
Sequoia	2692 b	2199 c

[a]There were no herbicide treatment or year interactions so row spacing data were pooled across treatment and years. Means followed by the same letter are not statistically different using a Least Square Means analysis performed at $\alpha = 0.05$.
[b]Narrow-row spacing in 2014 and 2015 was 6 and 7.5 inches, respectively. Wide-row spacing was 22 inches, both years.

Figure 3.1. Pinto bean planted in narrow- (top) and wide-row (bottom) spacing. Photos were taken July 9, 2015. Difference in color between photos is due to camera exposure and time of day the photos were taken.

Figure 3.2. Pinto bean planted in narrow- (top) and wide-row (bottom) spacing. Photos were taken August 14, 2015. Difference in color between photos is due to camera exposure and time of day the photos were taken.