Effect of Row Spacing, Plant Architecture, and Herbicides on Weed Control in Pinto Bean (*Phaseolus vulgaris*)

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AUTHORIZATION TO SUBMIT THESIS

This thesis of Michael L. Thornton, submitted for the degree of Master of Science with a Major in Plant Science and titled "Effect of Row Spacing, Plant Architecture, and Herbicides on Weed Control in Pinto Bean (*Phaseolus vulgaris*)," 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 study was conducted to determine the effect of row spacing, plant architecture, and postemergence sequential herbicide treatments on season-long weed control in dry bean under sprinkler irrigation. Two row spacings, narrow row (15 and 19 cm) and wide row (56 cm), were compared along with two pinto bean varieties ‘Sequoia’ (Type II growth habit) and ‘Othello’ (Type III growth habit), and six weed control treatments. Weed control in PRE applications alone was unsatisfactory. Hand-weeded and POST sequential application averaged 91% control. Weed interference was reduced in narrow rows combined with POST sequential applications or in wide rows combined with POST sequential applications and cultivation. Narrow rows generally yielded higher than wide rows. However, more weeds were found in narrow rows versus wide rows likely due to cultivation. All treatments yielded higher than the weedy control. PRE only applications yielded significantly lower than POST sequential herbicide applications.

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DEDICATION

To the one I go home to every day, I would like to thank my beautiful wife, Katelynn for her loving support and amazing smile, through this journey.

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INTRODUCTION

Season-long weed control in edible dry bean production is difficult because dry bean is not considered a strong competitor with weeds. Integrated weed management practices, including prevention, mechanical, chemical, biological, and cultural tactics, that increase dry bean competitiveness can improve weed control and dry bean yield. It is not yet known how the interactive effects of row spacing, plant architecture, and herbicides would affect weed control and yield in sprinkler-irrigated pinto bean grown in southern Idaho.

Objectives

Several studies in soybean and other dry bean classes have examined the effect of reduced row width and postemergence sequential applications and to a lesser extent, plant architecture, on weed control and yield (Blackshaw et al. 1999; Blackshaw et al. 2009; Holmes and Sprague 2013; Rich and Renner 2009; Yelverton and Coble 1991; Young et al. 2009); however, no study of this nature has been conducted in southern Idaho, where the low humidity, dry climate, and overhead irrigation creates a much different environment. Therefore, the objectives of the two year field study were to determine the effect of row spacing, plant architecture, and herbicides on weed control and yield in a sprinkler-irrigated pinto bean production system.

Organization

The following thesis consists of a literature review, a manuscript prepared for submission to a refereed journal, and a manuscript prepared for submission as a peer-reviewed extension publication presented for partial fulfillment of the requirements for the degree, Master of Science with a major in Plant Science. The author of the thesis is Michael L. Thornton. Dr. Don W. Morishita served as major professor and Dr. Pamela J.S. Hutchinson and Dr. Shree P. Singh served as committee members and provided assistance for technical consulting and manuscript review. Chapter 1 is a review of literature concerning hairy nightshade biology and weed interference in dry bean, weed control in dry bean, and narrow row soybean and dry bean production. Chapter 2 is the manuscript to be submitted to the Journal of Weed Technology, entitled “Effect of Row Spacing, Plant Architecture, and Herbicides on Weed Control in Pinto Bean (*Phaseolus vulgaris*)”. Chapter 3 is an extension publication manuscript entitled “Season-long Weed Control in Edible Dry Bean Production”.

CHAPTER 1. LITERATURE REVIEW

Hairy nightshade biology and weed interference in dry bean

Hairy nightshade (*Solanum physalifolium* Rusby) is considered to be the most troublesome weed in dry bean (*Phaseolus vulgaris* L.) production in Idaho and in other areas of North America (Blackshaw 1991; Bassett and Munro 1985; Idaho Bean Commission 2014). Nightshade species, including hairy nightshade, black nightshade (*S. nigrum* L.), and Eastern black nightshade (*S. ptychanthum* Dunal) have the ability to germinate throughout the growing season when sufficient moisture exists, thus competing with dry bean for sunlight, water, and soil nutrients (Bassett and Munro 1985; Blackshaw 1991; Blackshaw and Esau 1991; Carvalho and Christoffoleti 2008; Rich and Renner 2009). This in turn reduces dry bean yield. As few as two hairy nightshade per meter of row length reduced dry bean seed yield an average of 13% (Blackshaw 1991; Burnside et al. 1993). Hairy nightshade interference the first 3 weeks after crop emergence was sufficient to reduce bean yield between 20% and 30% (Blackshaw 1991; Mesbah et al. 2004).

Herbicides that initially controlled hairy nightshade usually increased pinto bean yield above that of the weedy control, but yields were still less than that of the hand-weeded control and the treatments providing season-long weed control (Blackshaw and Esau 1991), indicating that season-long control is necessary to obtain maximum yields. Nightshade plants usually continue germinating after preemergence (PRE) herbicides have begun to lose their effectiveness, even when there is shading by the bean canopy, because seeds are not photoblastic (Holmes and Sprague 2013; Waters and Morishita 2001; Zhou et al. 2005). Nightshade species are also aggressive weeds for dry bean producers because escaped plants can grow vigorously late in the season as the crop canopy senesces and affect harvesting operations (Burnside et al. 1993; 1998). Nightshade berries can stain harvested bean and allow dirt and other debris to adhere to bean seed during harvest, thereby lowering bean quality and market value (Rich and Renner 2009; VanGessel et al. 1998; Waters and Morishita 2001).

Hairy nightshade is a prolific seed producer and will produce approximately 300,000 seeds m^{-1} at about 30 plants per meter of row (Blackshaw 1991) and can produce up to 1755 berries on a large plant with an average of 20 to 28 seeds per berry (Bassett and Munro 1985). Seeds from hairy nightshade can remain viable in the soil for 10 years or more (Burnside et al. 1996).

Broadleaf weed control in dry bean is often unsatisfactory and bean yield data has indicated that redroot pigweed (*Amaranthus retroflexus* L.) and common lambsquarters (*Chenopodium album* L.) were strong competitors with pinto bean. In fact, yield comparisons between hand-weeded treatments and weedy controls have shown that redroot pigweed and common lambsquarters combined to reduce yield by 71 and 85% in 1988 and 1989, respectively (Blackshaw and Esau 1991).

Arnold et al. (1996) found that weeds emerging with pinto bean were strong competitors, and reduced yields by 60 and 66% in 1989 and 1990, respectively. Weeds that emerge before the bean crop were more competitive than later emerging weeds (Carvalho and Christoffoleti 2008; Rich and Renner 2009). Blackshaw and Esau (1991) found that bean yields in weedy controls were reduced by 84% and 81% in 1988 and 1989, respectively, compared to hand-weeded controls. In a study by Ugen et al. (2002), mean bean yield reductions caused by competition with weeds ranged from 29 to 48%. In a more recent study, where dry bean was planted in different row spacings (23 cm and 69 cm) and densities (20 and 50 plants m^{-1}), weedy treatments reduced yield by 47, 79, and 64% compared to hand-weeded dry bean, over a three year period (Blackshaw et al. 2009).

Broadleaf weeds have been shown to have a more detrimental effect on dry bean and soybean (*Glycine max* (L.) Merr.) yields than grassy weeds (Hock et al. 2006; Mesbah et al. 2004). Mesbah et al. (2004) further states that yield reductions from season-long presence of 0.5 sunflower (*Helianthus annuus* L.) plants per meter of row was six times greater than 1 green foxtail (*Setaria viridis* L.) plant per meter of row.

Weed control in dry bean

Weed control is one of the most difficult and critical pest management issues in dry bean production. In fact, the quantity and quality of dry bean harvested is highly dependent on successful weed management (Hekmat et al. 2008; Soltani et al. 2009). Dry bean is a short-season crop and its relatively poor competitiveness with annual weeds is well documented, therefore, good weed management is essential for successful crop production (Blackshaw and Esau 1991; Blackshaw and Molner 2008; Hekmat et al. 2008; Wall 1995). The critical weed-free period for dry bean can begin as early as 3 weeks after planting (WAP) and can last until 7 WAP (Burnside et al 1998; Mesbah et al 2004; Waters and Morishita 2001). Dry bean production has relied heavily on tillage and herbicides for weed management because dry bean is a poor competitor with weeds (Burnside et al. 1993, 1998). Dry bean cultivation at 3 and at 5 to 6 WAP should provide effective weed control if weeds in the row can be covered by rolling soil into the row with the cultivator (Burnside et al. 1998).

Dry bean growers commonly use a pre-plant or a PRE followed by a postemergence (POST) herbicide, plus one to three inter-row cultivations (Arnold et al. 1996; Blackshaw et al. 1999). According to Mesbah et al. (2004), growers should not rely only on POST herbicides alone but also use preplant, PRE, and/or an early POST sequential application to prevent bean yield losses. In soybean, sequential application of a reduced rate of soil-applied trifluralin with POST fluazifop or a reduced rate of soil-applied trifluralin or pendimethalin followed by hand hoeing 35 days after sowing provided better control of a broad spectrum of weeds than trifluralin applied alone (Chhokar and Balyan 1999). Wilson et al. (2014) found similar results in great northern dry bean where a POST application of imazamox plus bentazon reduced weed density by 83%, which was greater than flumioxazin (PRE), pendimethalin (PRE), or halosulfuron plus bentazon (POST). Holmes and Sprague (2013) also found that in black bean, imazamox plus bentazon had the most consistent weed control in comparison to poorly incorporated PRE herbicides. Reduced POST herbicide rates, such as bentazon, imazethapyr, or thifensulfuron, were most effective when applied early during weed growth or as sequential applications (Wall 1995). Herbicides suppressed weed emergence more than mechanical treatments throughout the growing season because weeds often emerged after mechanical weed control (Amador-Ramirez et al. 2002). Blackshaw et al. 2009 found that herbicide combinations exhibited good potential to improve weed control in dry bean. Delaying weed emergence, and therefore, increasing the competitiveness of dry bean by using herbicides, mechanical weed control, and other weed management tactics integrated into a weed management program is critical to obtaining optimum yields.

Narrow row soybean and dry bean production

Using narrow row spacing to increase the competitiveness of soybean and edible dry bean with weeds has been studied to some extent in the Midwest and Canada. According to research in Michigan by Hesterman et al. (2015), there are six advantages to growing soybean in narrow rows: increased light interception, reduced intraspecific (within-row) plant competition, earlier canopy closure, reduced soil erosion, higher podding on the stem, and increased yields.

Drilled soybean in 19 cm wide rows can have a higher yield potential compared to soybean planted with a row crop planter in 38 and 76 cm wide rows (Cox and Cherney 2011). In soybean, narrow-row yield responses result from increased pod number created by greater light interception and crop growth rate between first flowering and seed initiation. Much of this increased pod number results from more branch nodes and pods (Board and Harville 1994). Faster canopy closure in narrow-row soybean compared with that in wider row spacing can enhance weed control measures by reducing weed seed germination and suppressing weed growth due to increased sunlight interception and shading by soybean (Esbenshade et al. 2009; Nelson and Renner 1998; Norris et al. 2009; Yelverton and Coble 1991; Young et al 2009). Soybean canopy closure occurred about 20 days later in 76-cm wide rows than in 19-cm rows, providing a longer shade-free environment, resulting in higher weed biomass in 76-cm wide rows compared to 19-cm wide rows (Hock et al. 2006). In fact, Harder et al. 2007 found that the number of emerged weeds declined over time in 19 and 38-cm rows compared with 76-cm rows as a likely consequence of the light intensity below the soybean canopy being reduced below the light compensation point for these weed seedlings. Young et al. (2009) also found that planting soybean in narrow rows compared to wide rows enhanced weed control and that common waterhemp (*Amaranthus rudis* Sauer) control was increased as soybean row spacing was decreased due to more rapid closure of the soybean canopy. Norris et al. 2009 found that although yield potential with narrow and wide rows did not show differences, but for weed control, narrow rows did reduce interference of weeds. Soybean culture in narrow rows will not allow the option of POST cultivation, and thus involves the exclusive use of and reliance on PRE and/or POST broadcasting of herbicides (Heatherly et al. 2001).

Narrow spaced rows provided quicker canopy formation than wide rows and can reduce weed resurgence after POST herbicides are applied. Rapid and complete soybean canopy formation reduces the amount of light reaching the soil surface, which can suppress weed resurgence (Yelverton and Coble 1991). Orlowski et al. (2012) found better yield, light interception, and weed control for the most part in narrow rows. Thus, enhancing the competitiveness of soybean by planting in narrow rows may reduce the number of herbicide applications (Young et al. 2009).

Planting soybean in narrow rows (19 cm) improved early season crop tolerance to weeds, delayed the critical time for weed removal, and required less intensive weed management programs than in wide rows (76 cm) (Hock et al. 2009; Knezevic et al. 2003). Soil residual herbicides or sequential applications of glyphosate to control late-emerging weeds may not be necessary in narrow-row (19 cm) soybean because shade inhibits the growth of many, but not all weeds. Eastern black nightshade interference can be alleviated by planting narrow rows, and planting narrow rows (19 cm) decreased Eastern black nightshade production by an average of 80% when compared to wide rows (76 cm), over two sites (Rich and Renner 2009).

Schneiter and Nagle 1980 found that potential dry bean yields may be increased if grown in closely spaced rows (25 cm) and Holmes and Sprague (2013) found that narrow rows (38 cm) often resulted in increased dry bean yield compared with wide rows (76 cm). In a study in Canada dry bean competitiveness was increased by reducing row spacing and increasing plant density. The results of this study found that in the hand-weeded control, yield was greater when dry bean was grown in 23-cm than in 69-cm rows across all herbicide treatments, including the weedy control. The use of an upright cultivar, narrow rows, and high plant density improved competitiveness with weeds, but without the use of herbicides or cultivation, dry bean yield remained unacceptably low. In weedy dry bean, narrow rows (23 cm) and high plant densities increased yield somewhat but, were lower than treatments with herbicide applications (Blackshaw et al. 2009).

Sankula et al. (2001) found that lima bean (*P. lunatus* L.) grown in wider rows (76 cm) had better weed control than in narrow rows (38 cm) partly due to cultivation in wider rows. Blackshaw et al. (2009) found that narrow row (23 cm) dry bean production would preclude or greatly inhibit inter-row cultivation to control weeds. Even though narrow spaced rows cannot be cultivated to control weeds with the ease of more conventional spaced rows (51 or 76 cm), that problem may be nullified to a certain extent, since dry bean (both navy and pinto) grown in narrow rows (25 cm), especially at higher populations, tend to shade and crowd out most of the later developing weed seedlings (Schneiter and Nagle 1980).

Narrow row (23 cm) compared to wide rows (69 cm) in dry bean always resulted in less hairy nightshade biomass, and a concurrent increase in dry bean yield occurred in 2 of 3 years (Blackshaw et al. 1999). In dry bean, narrow rows (38 cm) often improved common lambsquarters control when herbicide control was less than complete and improved Powell amaranth (*Amaranthus powellii* (S.) Wats.) and redroot pigweed control and reduced mid-season populations compared with wide rows (76 cm). Although row width had an effect on common lambsquarters, Powell amaranth, and redroot pigweed control, it did not have a significant effect on Eastern black nightshade control, which is different from narrow-row soybean where Eastern black nightshade interference was reduced. Narrow rows did not reduce weed biomass in the weedy control to levels similar to those of the most effective herbicide treatments in this study, however, narrow rows can play a significant supplementary role in weed control and can improve control of upright broadleaf weeds. Weed suppression from dry beans planted in narrow rows was not strong enough to replace herbicide applications but can enhance weed control when the two practices are integrated (Holmes and Sprague 2013).

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CHAPTER 2. EFFECT OF ROW SPACING, PLANT ARCHITECTURE, AND HERBICIDES ON WEED CONTROL IN PINTO BEAN (*Phaseolus vulgaris*)

Abstract

Weed control is one of the most challenging and critical pest management issues in dry bean production. In order to maintain optimum yields, an integrated weed management plan is necessary. A 2-year field study was conducted to determine the effect of row spacing, plant architecture, and PRE and POST sequential herbicide treatments on season-long weed control in dry bean under sprinkler irrigation. Two row spacings, narrow row (15 and 19 cm) and wide row (56 cm), were compared along with two pinto bean varieties 'Sequoia' (Type II growth habit) and 'Othello' (Type III growth habit), and six weed control treatments. All treatments yielded higher than the weedy control. Control of common lambsquarters, green foxtail, hairy nightshade, and redroot pigweed in PRE application alone ranged from 31 to 72% and was less than control by treatments including a POST sequential application, which ranged from 83 to 95%. Weed interference was reduced in narrow rows in combination with POST sequential applications or in wide rows in combination with POST sequential applications and cultivation. Narrow row beans generally yielded higher than wide rows for both varieties. Othello usually yielded more than Sequoia which led to the conclusion that the upright growth of Sequoia did not provide as much competition against weeds as did the viny, trailing Othello.

Nomenclature: common lambsquarters, *Chenopodium album* L.; green foxtail, *Setaria viridis* (L.) Beauv; hairy nightshade, *Solanum physalifolium* Rusby; redroot pigweed, *Amaranthus retroflexus* L.; pinto bean, *Phaseolus vulgaris* L.

Key words: Dry bean, integrated weed management, tank mixes, weed suppression.

Introduction

Idaho currently ranks 5th in the nation for edible dry bean production (USDA 2015) and dry bean seed produced in this area is sought by producers in the Midwest because the drier climate can reduce disease pressure (Anonymous 2015). An increasing concern among growers is season-long weed control, especially of hairy nightshade (*Solanum physalifolium* Rusby), in dry bean production (Idaho Bean Commission 2014). Season-long emergence of hairy nightshade can reduce dry bean yield due to competition for sunlight, water and nutrients (Blackshaw and Esau 1991; Carvalho and Christoffoleti 2008; Rich and Renner 2009). Hairy nightshade also causes harvest issues by plugging the harvester and quality issues when the fruit are crushed and the juice stains the beans (Burnside et al. 1998; Rich and Renner 2009; VanGessel et al. 1998).

Dry bean is not considered a strong competitor against weeds, especially hairy nightshade. A study of the interference of hairy nightshade in dry bean grown in Canada found that dry bean yield was reduced by over 80% in the weedy control competing season-long versus the hand-weeded control (Blackshaw and Esau 1991). Previous studies have shown that as little as two hairy nightshade per meter of row length reduced yield by 13% (Blackshaw 1991; Burnside et al. 1993), and in another study, uncontrolled weeds decreased yield by 47 to 79% compared to the hand-weeded control (Blackshaw et al. 2009).

Reducing weed interference in dry bean is essential for obtaining optimum yields (Blackshaw and Esau 1991; Blackshaw and Molner 2008; Wall 1995), and can be better accomplished by using an integrated weed management plan. Growers typically spray a preemergence (PRE) herbicide followed by two or three cultivations throughout the growing season (Arnold et al. 1996; Blackshaw et al. 1999). Several studies evaluating reduced row width, in soybean and dry bean (black, small red, and navy) have shown that the crop receives a competitive advantage over weeds when the row is narrowed due to faster canopy closure and increased light interception than with wide-row beans (Blackshaw et al. 1999; Blackshaw et al. 2009; Holmes and Sprague 2013; Rich and Renner 2009; Yelverton and Coble 1991; Young et al 2009). Studies also show that reducing row width is not sufficient to completely reduce the weed population by itself but can be effective when combined with herbicides (Blackshaw et al. 2009; Holmes and Sprague 2013). In general, these studies show that narrowing the row increases yield versus wide rows (Blackshaw et al. 2009; Cox and Cherney 2011; Holmes and Sprague 2013).

It is not known if narrow row spacing increases the competitiveness of all classes of dry bean grown under sprinkler irrigation, however. Pinto bean accounts for 35% of the dry bean grown in Idaho, which makes it the most widely grown bean class in the state (USDA 2015). The objectives of this Idaho study, therefore, were to: 1) determine the effect of row spacing and plant architecture on weed control and pinto bean yield; and 2) compare the influence of sequential herbicide applications on season-long weed control of hairy nightshade and other weeds.

Materials and Methods

A study was conducted in 2014 and 2015 at the University of Idaho Kimberly Research and Extension Center, Kimberly, ID (42.55°N, -114.35°W). Soil in the 2014 research area was a Portneuf silt loam containing 39.2% sand, 42% silt, 18.8% clay, 1.4% organic matter, and pH of 8.2. Soil in the 2015 research area was a Portneuf silt loam containing 19% sand, 61.3% silt, 19.7% clay, 1.5% organic matter, and pH of 8.1. A total of 24 weed control treatments was established in a 2 by 2 by 6 factorial randomized complete block design with 2 row widths, 2 pinto bean varieties with different plant architecture, and 4 herbicide combinations plus 2 controls. The plots were 2.23 m (four rows) wide by 7.62 m long with four replications. A mixture of hairy nightshade, common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), and green foxtail (*Setaria viridis* (L.) Beauv.) seed was broadcast throughout the study area at a rate of 270 seed m^{-2} for each species and incorporated with a roller harrow (Farmhand CM41 Cultimulcher, AGCO, 4205 River Green Parkway, Duluth, GA 30096) before planting. In 2014, narrow row width was 15 cm and in 2015 it was 19 cm. Narrow row beans were planted using a Great Plains 3P600 drill in 2014 and a Great Plains 3P806NT drill in 2015 (Great Plains Ag U.S.A., 1525 E. North Street, Salina, KS 67401). Wide row beans were planted at 56 cm row spacing in 2014 with a custom 4-row plot planter (University of Idaho, Kimberly Research and Extension Center, 3806 N 3600 E, Kimberly, ID 83341) and in 2015, a Monosem NG Plus4 4-row planter (Monosem Inc., 1001 Blake St., Edwardsville, KS 66111) was used. Planting dates were June 3, 2014 and June 10, 2015, with a live plant population target of 235,148 plants ha^{-1}. The two pinto bean varieties used in the study were Sequoia (Idaho Bean Seed Co., P.O. Box 1072, 3639 N 2700 E, Twin Falls, ID 83303-1072), which has a Type II upright growth habit, and Othello (Burke et al. 1995), which has a Type III viny or trailing growth habit.

Herbicide treatments were applied with a CO_2-pressurized bicycle-wheel sprayer calibrated to deliver 140 L ha^{-1} at a pressure of 179 kPa. Boom length was 2.23 m with 11001 flat fan nozzles (TeeJet, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189) spaced 28 cm apart. Herbicides evaluated were EPTC (Eptam 7E, Gowan Company, P.O. Box 5569, Yuma, AZ 85366-5569) in combination with ethalfluralin (Sonalan HFP, Gowan Company, P.O. Box 5569, Yuma, AZ 85366-5569) or dimethenamid-P (Outlook, BASF Ag Products, P.O. Box 13528, 26 Davis Drive, Research Triangle Park, NC 27709-3528) and pendimethalin (Prowl H_2O, BASF Ag Products, P.O. Box 13528, 26 Davis Drive, Research Triangle Park, NC 27709-3528) in combination with dimethenamid-P as PRE applications. POST applications included bentazon (Basagran, Arysta Life Science North America, LLC, 15401 Weston Parkway, Suite 150, Cary, NC 27513) alone or in combination with ethalfluralin or dimethenamid-P. Ammonium sulfate (AMS) (Bronc Max, Wilbur-Ellis Co., P.O. Box 16458, Fresno, CA 93755) and methylated seed oil (MSO) (Superspread MSO, Wilbur-Ellis Co., P.O. Box 16458, Fresno, CA 93755) were added to all POST treatments at a rate of 1.67 kg ai ha^{-1} and 1% v/v, respectively. In 2014 but not 2015, glyphosate (Roundup PowerMax, Monsanto Co., 800 N. Lindbergh Boulevard, St. Louis, MO 63167) at 0.85 kg ae ha^{-1} + AMS at 0.94 kg ai ha^{-1} was mixed in with the preemergence (PRE) applications to control an initial flush of weeds. The PRE application was applied on June 5, 2014 and on June 11, 2015. Herbicides were then incorporated with approximately 1.25 cm of sprinkler irrigation one hour after application. Sequential postemergence (POST) herbicides were applied at the dry bean 1 to 2 trifoliate leaf stage on June 26, 2014 and on June 29, 2015. In 2015, clethodim (Select Max, Valent U.S.A. Corporation, P.O. Box 8025, Walnut Creek, CA 94596-8025), at 0.17 kg ai ha^{-1}, was added to all POST applications to control emerged grasses. After these POST applications, the study area was again sprinkler irrigated, complying with the labeled four-hour rain fast period for bentazon (Anonymous 2013), with approximately 1.25 cm of water to incorporate the herbicides. A hand-weeded and a weedy control were included in the trial. Hand-weeded controls in the narrow and wide rows were weeded approximately two weeks after emergence and then every two weeks until canopy closure, as more weeding would have been more detrimental due to the possibility of canopy damage, than helpful. To more closely simulate a commercial weed management program, wide rows were cultivated on July 1 and July 15 in 2014, and on July 10 in 2015 and included the hand-weeded and weedy controls.

Weed density counts in 2014 were conducted 18 and 32 days after the last application (DALA) on July 14 and 28, respectively. Crop injury and weed control were evaluated visually on a 0 to 100 scale with 0 being none and 100 being total control 15 and 48 DALA on July 11 and August 13, 2014, respectively. Weed density counts in 2015 were taken 16 and 30 DALA on July 15 and 29, respectively. Crop injury was evaluated visually 9, 18, and 30 DALA on July 8, 17, and 29, 2015, respectively. Weed control was evaluated visually 30 and 58 DALA on July 29 and August 26, 2015, respectively. Weed density in the weedy control was determined by counting the weeds in a 0.28 m^{-2} area due to high weed densities. In 2014, the narrow row treatments, which were not cultivated, weed densities were counted in a 3 m^{-2} area (0.4 m by 7.62 m). In wide row treatments, which were cultivated, the entire plot was counted. Weed density counts were conducted in the same areas in each plot before the second cultivation and 10 days after the second cultivation, respectively. In 2015, weed density counts in the weedy controls were done similar to 2014, but the rest of the treatments were recorded by counting the whole plot for both the narrow- and wide-row spacings. All density data were by species and converted to a per sq m value.

For harvest each year a Pickett bean cutter (Pickett equipment, 976 East Main Street, Burley, ID 83318) was used to cut the center two rows in the wide row treatments and the center 1.1 m of the narrow row treatments the length of the plot (7.62 m). Beans were allowed to dry in the field for approximately 7 days after cutting and then threshed with a

Wintersteiger Delta plot combine (Wintersteiger Inc., 4705 W. Amelia Earhart Drive, Salt Lake City, UT 84116-2876) September 18 and 24 in 2014 and 2015, respectively.

Weed control and yield data were analyzed using the generalized linear mixed model or PROC GLIMMIX procedure in SAS 9.4 (Stroup 2015). Weed control was combined over both years due to no year effect. The weedy control treatment was not included in analyses of weed control but was included in yield analyses. The hand-weeded control was included in the weed control analyses because hand-weeding ceased at canopy closure, while the herbicide treatments might have provided season-long control so comparisons were of interest. Due to the large proportion of zeroes in the weed density raw data, a valid statistical analysis could not be performed. Thus, the data have been summarized as means, in lieu of a formal statistical analysis.

Results and Discussion

There was no crop injury observed at the first evaluation in 2014 and the last evaluation in 2015 (data not shown). Crop injury at the other evaluation dates ranged from 0 to 5%. Although there were some significant differences between herbicide treatments for crop injury each year, these were not believed to be biologically significant.

As mentioned, all weed control data is pooled across years. Hairy nightshade weed control had 2-way interactions: herbicide treatment by row spacing at both evaluation timings (Table 1) and herbicide treatment by variety at the late evaluation only (Table 2). In response to herbicide treatment by row spacing, EPTC + ethalfluralin PRE in both narrow and wide row spacing had the poorest control at 31 and 61%, respectively (Table 1). This greater control in wide versus narrow row between the same herbicide treatments, but different row spacing could be due to cultivating the wide rows. There were no other herbicide treatments with differences in hairy nightshade control between the narrow and wide row spacing. Interestingly, hairy nightshade control in the wide row spacing hand-weeded control was lower than the herbicide treatments that included a sequential POST herbicide. At the late evaluation EPTC + ethalfluralin PRE alone in the narrow row spacing had the poorest control (50%) followed by the same herbicide treatment in wide row spacing (72%), similar to the early evaluation. All of the POST sequential herbicide treatments and the hand-weeded control ranged from 92 to 95% with no significant differences among them. There were no significant differences between a given POST herbicide in narrow-row vs the same treatment in wide-row spacing, which shows that even though in-season cultivation is eliminated, narrow row spacing can be effective for controlling hairy nightshade in combination with POST sequential herbicides. This is consistent with a study by Norris et al. (2009), where they found that in soybean, narrow rows reduced weed interference compared with interference in wide rows.

In the variety by herbicide treatment interaction for hairy nightshade control, EPTC + ethalfluralin PRE had the poorest control at 60 and 63% in the Sequoia and Othello varieties, respectively (Table 2). Hairy nightshade control with the other four POST sequential herbicide treatments in either varieties ranged from 91 to 96%. However, hairy nightshade control with EPTC + ethalfluralin PRE fb dimethenamid-P + bentazon POST and pendimethalin + dimethenamid-P PRE fb bentazon POST in Sequoia was significantly lower (91%) than control by the same herbicide treatments in Othello, which averaged 95 and 96% control, respectively. The differences in control between the two varieties with the same herbicide treatments might be indicating that Othello with its trailing, viny growth is more competitive than the upright-growing Sequoia, however, since control in either variety was greater than 90%, the differences probably did not have a biological effect on the outcome of the study. Hairy nightshade control also was affected by variety at both evaluation times (data not shown). Hairy nightshade control in Othello was 88 and 92% compared to 83 and 89% in Sequoia averaged over row spacing, herbicide treatment, and year. This again suggests that Othello, with its viny or trailing growth, is more competitive with hairy nightshade than Sequoia, which has the upright growth. In response to row spacing alone (data not shown) hairy nightshade was controlled better in the wide rows (88%) than in the narrow rows (84%) at the early evaluation date. As mentioned previously, this difference could be because of cultivating the wide- but not the narrow-rows.

There were no interactions for common lambsquarters, redroot pigweed, and green foxtail control and herbicide treatment was the only significant effect at both evaluation dates (Table 3). Thus, the weed control ratings were averaged across row spacing, variety, and year and are presented in response to herbicide treatment alone. EPTC + ethalfluralin PRE alone provided the poorest control of all three weed species at the early and late evaluation dates compared with control by the treatments which included a POST sequential. Common lambsquarters control with EPTC + dimethenamid-P PRE fb ethalfluralin + bentazon POST was 90 and 89% at the early and late evaluation dates, respectively, and significantly higher than EPTC + ethalfluralin PRE fb dimethenamid-P + bentazon POST. However, EPTC + dimethenamid-P PRE fb ethalfluralin + bentazon POST was not significantly better than the other two treatments, at both evaluation dates. Redroot pigweed control with EPTC + ethalfluralin PRE fb dimethenamid-P + bentazon POST was significantly lower than all other treatments (87% early and 86% late) with the exception that at the early evaluation it was statistically equal to the hand-weeded control. The hand-weeded control also was statistically equal to the other treatments. Of these three weed species, the variety effect was only significant for redroot pigweed control at the late evaluation. Control in Othello averaged 90% compared to Sequoia, which averaged 87%, pooled across herbicide treatment, row spacing and year (data not shown). As with hairy nightshade, the differences in redroot pigweed control between varieties likely had little biological effect. Green foxtail control with EPTC + ethalfluralin applied PRE only was lower (70%) at both evaluation dates than all of the other herbicide treatments, which averaged 91%.

As mentioned, statistical analysis of weed density by species was found to be invalid because more than 25% of the weed counts by species were zeroes. Thus, the weed density data are presented as means by species in response to herbicide treatment, row spacing, and variety over both years without statistical analyses (Tables 4 and 5). Densities by species are presented to support the visual weed control evaluations. For example, wide-row, PRE alone treatments had relatively less hairy nightshade densities than narrow-row, PRE treatments (Table 5) which seemed to translate to generally greater hairy nightshade control in wide- vs narrow-row most likely due to cultivation in the wide- but not narrow-row treatments. As could be expected, the greatest relative difference in weed densities for each species was between the weedy control and any of the herbicide treatments as well as the hand-weeded control. Although, green foxtail and redroot pigweed densities at the later counting date in the wide-row spacing were not relatively different from densities of those weed species in the POST sequential herbicide treatments at that time (Table 4 and 5), the PRE alone treatments usually had a relatively higher average weed density than did the POST sequential herbicide treatments for all four species. Therefore, sufficient weed densities were present to reduce the PRE only yields relative to those of the other treatments (Table 6). In comparing the hand-weeded controls to the weedy controls, densities numerically reduced yield by 56 and 77% in 2014 and by 17 and 18% in 2015, respectively when averaged across varieties and row spacing. This is consistent with previous research where weedy controls reduced yield from 29 to 84% compared to the yields of hand-weeded controls (Blackshaw et al. 2009; Blackshaw and Esau 1991; Ugen et al. 2002).

Unlike weed control, there was a year interaction with dry bean yield, therefore, the data are presented by year (Table 6). In 2014, the weedy control yield was significantly lower than in all other herbicide treatments in both row spacing treatments, but there was no difference in the weedy control yield between narrow- and wide-row spacing. This is consistent with previous research that showed that narrow rows alone are not sufficient to reduce weed pressure and the addition of herbicides is required for effective control (Blackshaw et al. 2009; Holmes and Sprague 2013). In our study, two of the three POST sequential treatments in the narrow-row yielded better than PRE alone treatments and in wide rows, all POST sequential treatments yielded better than PRE alone (Table 6). These results indicate that POST sequential herbicides applications are needed for season-long control in dry beans. Yield in the narrow-row hand-weeded control was significantly higher than the wide-row hand-weeded control, which supports the idea that narrow row spacing provides a yield advantage without any weed interference. In all remaining herbicide treatments, the narrow-row spacing had yields which were not different than yields of the corresponding wide-row spacing treatments. However, there were some interesting, relative yield differences between wide and narrow rows for some of those corresponding herbicide treatments which could strengthen the idea that narrow-row spacing combined with herbicides provides more effective weed control and subsequent increased dry bean yields as compared to wide-row spacing with herbicides in combination with cultivation. For example, the P-value comparing wide and narrow row dry bean yield in EPTC + ethalfluralin PRE was $P = 0.0596$. The P-value comparing EPTC + dimethenamid-P PRE fb ethalfluralin + bentazon POST and EPTC + ethalfluralin PRE fb dimethenamid-P + bentazon POST was $P = 0.0566$ and $P = 0.0687$, respectively. Although these were not statistically different at $P \leq 0.05$ there is a trend for narrow-row spacing yielding higher than that of wide-row spacing.

As in 2014, PRE alone narrow- and wide-row yields were the same in 2015 and so were weedy control treatments in narrow- vs wide-rows (Table 6). However, in 2015, not only were there no differences between bean yields of POST sequential and PRE-alone yields in the same row spacing, one of the wide-row, POST sequential treatment yields was not different than that of the wide-row, weedy control (Table 6). That exception was the EPTC + ethalfluralin PRE fb dimethenamid-P + bentazon POST treatment. Those different results in 2015 than in 2014 were likely due to relatively lower weed densities in 2015 compared to densities in 2014 (data not shown). In agreement with this speculation, the three narrow-row POST sequential treatments in 2015 all had dry bean yields significantly higher than their wide-row counterpart unlike what happened in 2014 when there were no differences between corresponding narrow- and wide-row herbicide treatment yields. Also unlike 2014, the hand-weeded yields in narrow- vs wide-row were similar in 2015.

Dry bean yield also was affected by a variety by row spacing interaction (Table 7). Othello yielded higher than Sequoia averaged over treatments and years. Reports of dry bean yield differences between these two varieties vary depending on the source and year. In some variety trials, Othello yielded better, and in some trials Sequoia yielded better (Anonymous 2007; 2009; 2010; 2011; 2012; 2013). In our study, Othello may have yielded higher than

Sequoia because it is more competitive with weeds due to its viny growth habit compared to the more upright architecture of Sequoia. In fact, Othello yields in the narrow- and wide-row spacing were statistically the same and those yields were higher than Sequoia in the respective row spacings, and Sequoia in narrow row yielded higher than wide-row Sequoia even though the wide rows were cultivated. In contrast, Blackshaw et al. (1999) found that in navy bean, the upright variety always attained a higher yield than the viny or trailing variety in the presence of hairy nightshade. Our study suggests that in pinto bean the opposite is true. More pinto bean varieties and market classes should be tested.

As was expected in our study, a PRE application by itself usually did not provide season-long weed control in either narrow- or wide-row spacing pinto bean. The addition of a POST sequential herbicide application can provide season-long weed control of hairy nightshade and other weed species. Weed interference was reduced enough when pinto dry bean was planted in narrow rows with POST sequential herbicide applications and no cultivation, to have similar weed control and yields as wide-row plant pinto bean with POST sequential herbicide applications and cultivation. Overall, our study showed that narrow-row spacing can be beneficial in an integrated weed management plant by reducing interference and increasing subsequent pinto bean yield.

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Table 1 Hairy nightshade control in response to narrow and wide row spacing by herbicide treatment pooled across variety and year, near Kimberly, ID.

		Weed control[b]			
		Early evaluation		Late evaluation	
Treatment[a]	Rate	Narrow[c]	Wide	Narrow	Wide
	kg ai ha^{-1}	--------------------------------------%	--------------------------------------		
Weedy control	-	-	-	-	-
EPTC + ethalfluralin	2.92 + 1.25	31 e	61 d	50 c	72 b
EPTC + dimethenamid-P fb	2.92 + 0.73 fb	92 ab	93 a	95 a	94 a
ethalfluralin + bentazon	1.25 + 0.83				
EPTC + ethalfluralin fb	2.92 + 1.25 fb	91 abc	92 ab	95 a	92 a
dimethenamid-P + bentazon	0.73 + 0.83				
Pendimethalin + dimethenamid-P fb	1.05 + 0.73 fb	91 abc	92 ab	93 a	94 a
bentazon	0.83				
Hand-weeded	-	87 bc	86 c	95 a	93 a

[a]Abbreviations: fb, followed by. All treatments with bentazon included ammonium sulfate at 1.67 kg ai ha^{-1} and methylated seed oil at 1% v/v.
[b]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.
[c]Narrow row spacing in 2014 and 2015 was 15 and 19 cm, respectively. Wide row spacing was 56 cm in both years.

Table 2 Hairy nightshade control at the late rating in response to herbicide treatment by variety pooled across row spacing and year near Kimberly, ID.

Treatment[a]	Rate	Variety[b] Othello	Sequoia
	kg ai ha^{-1}	----------------------------%----------------------------	
Weedy control	-	-	-
EPTC + ethalfluralin	2.92 + 1.25	63 c	60 c
EPTC + dimethenamid-P fb	2.92 + 0.73 fb	95 a	93 ab
ethalfluralin + bentazon	1.25 + 0.83		
EPTC + ethalfluralin fb	2.92 + 1.25 fb	95 a	91 b
dimethenamid-P + bentazon	0.73 + 0.83		
Pendimethalin + dimethenamid-P fb	1.05 + 0.73 fb	96 a	91 b
bentazon	0.83		
Hand-weeded	-	93 ab	95 a

[a]Abbreviations: fb, followed by. All treatments with bentazon included ammonium sulfate at 1.67 kg ai ha^{-1} and methylated seed oil at 1% v/v.
[b]Means followed by the same letter are not significantly different at $\alpha = 0.05$ using least square means.

Table 3 Common lambsquarters, green foxtail and redroot pigweed control in response to herbicide treatments pooled across variety, row spacing, and year near Kimberly, ID.

		Weed control[b]					
		Common lambsquarters		Green foxtail		Redroot pigweed	
Treatment[a]	Rate	Early	Late	Early	Late	Early	Late
	kg ai ha^{-1}	-----%					-----
Weedy control	-	-	-	-	-	-	-
EPTC + ethalfluralin	2.92 + 1.25	62 c	34 c	70 b	64 b	70 c	70 c
EPTC + dimethenamid-P fb ethalfluralin + bentazon	2.92 + 0.73 fb 1.25 + 0.83	90 a	89 a	91 a	93 a	93 a	93 a
EPTC + ethalfluralin fb dimethenamid-P + bentazon	2.92 + 1.25 fb 0.73 + 0.83	84 b	83 b	89 a	92 a	87 b	86 b
Pendimethalin + dimethenamid-P fb bentazon	1.05 + 0.73 fb 0.83	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

[a]Abbreviations: fb, followed by. All treatments with bentazon included ammonium sulfate at 1.67 kg ai ha^{-1} and methylated seed oil at 1% v/v.
[b]Means followed by the same letter within a column are not significantly different at $\alpha = 0.05$ using least square means.

Table 4 Weed densities of common lambsquarters and green foxtail presented as means in response to herbicide treatment, row spacing, variety, and year near Kimberly, ID.

		Weed density[a,b]															
		Common lambsquarters								Green foxtail							
		17 DALA				31 DALA				17 DALA				31 DALA			
		Narrow[c]		Wide		Narrow		Wide		Narrow		Wide		Narrow		Wide	
Treatment[d]	Rate	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O
	kg ai ha^{-1}	plants m^{-2}															
Weedy control	-	53	44	11	11	25	24	8	17	34	24	17	8	14	28	6	15
EPTC + ethalfluralin	2.92 + 1.25	6	4	2	5	9	7	2	2	8	8	2	2	7	6	1	2
EPTC + dimethenamid-P fb ethalfluralin + bentazon	2.92 + 0.73 fb 1.25 + 0.83	2	1	1	1	2	1	1	1	2	2	1	1	2	2	1	1
EPTC + ethalfluralin fb dimethenamid-P + bentazon	2.92 + 1.25 fb 0.73 + 0.83	2	1	1	1	2	1	1	1	4	2	2	2	2	2	1	1
Pendimethalin + dimethenamid-P fb bentazon	1.05 + 0.73 fb 0.83	2	2	1	1	1	1	1	1	1	3	1	1	1	2	1	1
Hand-weeded	-	6	5	1	2	2	1	1	1	7	6	1	2	3	2	1	1

[a]These data are presented as means only because a large proportion of zeros in the raw data precluded a formal statistical analysis.
[b]Abbreviations: fb, followed by. DALA, averaged days after the last application in 2014 and 2015 for the two weed density counts. The actual density counting times in 2014 were 18 and 32 DALA and for 2015, 16 and 32 DALA. S and O are ‘Sequoia’ and ‘Othello’ varieties, respectively.
[c]Narrow row spacing in 2014 and 2015 was 15 and 19 cm, respectively. Wide row spacing was 56 cm in both years.
[d]All treatments with bentazon included ammonium sulfate at 1.67 kg ai ha^{-1} and methylated seed oil at 1% v/v.

Table 5 Weed densities of hairy nightshade and redroot pigweed presented as means in response to herbicide treatment, row spacing, variety, and year near Kimberly, ID.

		Weed densities[a,b]															
		Hairy nightshade								Redroot pigweed							
		17 DALA				31 DALA				17 DALA				31 DALA			
		Narrow[c]		Wide		Narrow		Wide		Narrow		Wide		Narrow		Wide	
Treatment[d]	Rate	S	O	S	O	S	O	S	O	S	O	S	O	S	O	S	O
	kg ai ha^{-1}	------------------------------plants m^{-2}------------------------------															
Weedy control	-	35	42	7	12	10	12	4	3	15	14	6	4	9	19	3	6
EPTC + ethalfluralin	2.92 + 1.25	19	13	3	6	8	3	2	1	4	2	1	1	3	5	1	1
EPTC + dimethenamid-P fb	2.92 + 0.73 fb	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1
ethalfluralin + bentazon	1.25 + 0.83																
EPTC + ethalfluralin fb	2.92 + 1.25 fb	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
dimethenamid-P + bentazon	0.73 + 0.83																
Pendimethalin + dimethenamid-P fb	1.05 + 0.73 fb	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
bentazon	0.83																
Hand-weeded	-	4	7	1	1	1	1	1	1	1	3	1	1	1	1	1	1

[a]These data are presented as means only because a large proportion of zeros in the raw data precluded a formal statistical analysis.
[b]Abbreviations: fb, followed by. DALA, averaged days after the last application in 2014 and 2015 for the two weed density counts. The actual density counting times in 2014 were 18 and 32 DALA and for 2015, 16 and 32 DALA. S and O are ‘Sequoia’ and ‘Othello’ varieties, respectively.
[c]Narrow row spacing in 2014 and 2015 was 15 and 19 cm, respectively. Wide row spacing was 56 cm in both years.
[d]All treatments with bentazon included ammonium sulfate at 1.67 kg ai ha^{-1} and methylated seed oil at 1% v/v.

Table 6 Dry bean yield in response to row spacing by herbicide treatment pooled over varieties and analyzed separately by year; 2014 and 2015 near Kimberly, ID.

		Bean yield[a]			
		2014		2015	
Treatment[b]	Rate	Narrow[c]	Wide	Narrow	Wide
	kg ai ha^{-1}	kg ha^{-1}			
Weedy control	-	1,002 f	1,473 f	2,570 g	2,616 fg
EPTC + ethalfluralin	2.92 + 1.25	2,904 de	2,214 e	3,442 abc	3,123 cde
EPTC + dimethenamid-P fb ethalfluralin + bentazon	2.92 + 0.73 fb 1.25 + 0.83	4,232 ab	3,514 bcd	3,556 a	2,961 e
EPTC + ethalfluralin fb dimethenamid-P + bentazon	2.92 + 1.25 fb 0.73 + 0.83	4,075 abc	3,458 cd	3,373 a-d	2,912 ef
Pendimethalin + dimethenamid-P fb bentazon	1.05 + 0.73 fb 0.83	3,400 cd	3,524 bcd	3,467 ab	3,066 de
Hand-weeded	-	4,403 a	3,337 d	3,153 b-e	3,153 b-e

[a]Means followed by the same letter within each year are not significantly different at $\alpha = 0.05$ using least square means.
[b]Abbreviations: fb, followed by. All treatments with bentazon included ammonium sulfate at 1.67 kg ai ha^{-1} and methylated seed oil at 1% v/v.
[c]Narrow row spacing in 2014 and 2015 was 15 and 19 cm, respectively. Wide row spacing was 56 cm in both years.

Table 7 Dry bean yield in response to variety by row spacing pooled over herbicide treatment and year near Kimberly, ID.

	Bean yield[a]	
Variety	Narrow[b]	Wide
	-------------------------kg ha^{-1}------------------------	
Othello	3,578 a	3,427 a
Sequoia	3,018 b	2,465 c

[a]Means followed by the same letter are not significantly different at α = 0.05 using least square means.
[b]Narrow row spacing in 2014 and 2015 was 15 and 19 cm, respectively. Wide row spacing was 56 cm in both years.

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

Introduction

Idaho currently ranks 5th in the nation for edible dry bean (*Phaseolus vulgaris* L.) production and was valued at $71.2 million in 2014 (USDA 2015). Based on grower response to a survey by the Idaho Bean Commission (2014), hairy nightshade (*Solanum physalifolium* Rusby) and season-long weed control were ranked among the biggest challenges to 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 light, water, and nutrients season-long 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 when harvesting by plugging the harvester and the berries 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 hairy nightshade and other weeds in dry beans. However, it’s 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 choice of herbicide(s) with not as many follow crop restrictions while still obtaining the level of control provided by Raptor. One of the IWM methods which may help obtain successful season-long control could be enhancing the competitiveness of dry beans. Cultural practices to consider for this result include fertilizer placement, seeding rate, time to canopy closure, row spacing and plant architecture, i.e. growth habit, branching pattern, and plant canopy. Canada 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 present in the trials (Blackshaw et al. 1999; Blackshaw et al. 2009; Holmes and Sprague 2013; Rich and Renner 2009; Yelverton and Coble 1991; Young et al. 2009). However, growing conditions in southern Idaho are quite different from conditions in these study locations. For example, our 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 in order to develop appropriate IWM practices for successful, season-long control of weeds, including hairy nightshade, in our growing conditions.

Weed Control

A field study was conducted at the University of Idaho Kimberly Research and Extension Center, Kimberly, ID with the goal of determining the effect of herbicides, row spacing and plant architecture combinations on season-long weed control and pinto bean yield. Four herbicide weed control treatments and a nontreated weedy and a hand-weeded control were included in the trial (Table 1). Herbicides tested were Basagran, Eptam, Outlook, Prowl H_2O, and Sonalan in various two-way preemergence (PRE) and sequential postemergence (POST) combinations. Weedy control treatments were only included in the yield analyses for comparisons. Two pinto bean cultivars ‘Sequoia’, which has a Type II upright growth habit, and ‘Othello’, which has a Type III viny or trailing growth habit, were planted in narrow or wide-row spacing. Narrow row beans were planted with a grain drill in 6-inch in 2014 and 7.5-inch row spacing in 2015 (Figure 1). Beans grown in the wide row spacing were planted both years with a standard row crop planter set for 22-inch row spacing (Figure 1). The seeding rate for narrow and wide rows was the same at 95,000 seeds per acre. Cultivation was performed in the wide-row, but not narrow-row test plots. Visual weed control evaluations of four weed species present in the trials, hairy nightshade, common lambsquarters (*Chenopodium album* L.), green foxtail (*Setaria viridis* L.), and redroot pigweed (*Amaranthus retroflexus* L.), were conducted on a 0% (no control) to 100% (complete death) scale twice during the growing season: one early (midseason) and one late (one month after the early evaluation). There were no differences between weed control in 2014 and 2015 so a combined analysis of data was performed.

Hairy nightshade

Hairy nightshade control was affected by herbicide treatment, row spacing, and variety. Averaged across varieties, control by Eptam + Sonalan applied PRE alone to beans grown in narrow rows had the poorest control at the early- and late-evaluation time with 31 and 50%, respectively, followed by the second poorest control of 61 and 72%, respectively, with the same PRE-alone herbicide treatment in the wide-row spacing (Table 1). 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 the PRE application 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 as compared to wide rows (Norris et al. 2009).

Hairy nightshade control in our study was also influenced by differences in the two dry bean varieties. Averaged across herbicides and row spacing, early and late hairy nightshade control was 90% or greater in Othello than the 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 has a more open canopy.

Other weeds

Unlike hairy nightshade, the control of common lambsquarters, green foxtail, and redroot pigweed was affected by herbicides but not row spacing or dry bean variety (Table 2). As with hairy nightshade control, Eptam + Sonalan applied PRE alone had the poorest control of these other three weed species at the early- and late-evaluation dates. Otherwise, control of these three species by treatments which included a POST sequential herbicide application was better and ranged from 83 to 94%. Common lambsquarters, and redroot pigweed control at the early- and late-evaluation by Eptam + Outlook PRE followed by (fb) Sonalan + Basagran POST and redroot pigweed control by Prowl H_2O + Outlook fb Basagran was greater than control by Eptam + Sonalan fb Outlook + Basagran (Table 2). 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. Regardless of herbicide combinations and timings or row spacing, hairy nightshade control in the dry bean variety with the viny, trailing growth habit was better than control in 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.

Dry bean yield

Overall impact of weeds

In studies conducted in other dry bean production areas of the US and Canada, yields of the control treatments which did not receive herbicides and were weedy during the entire growing season can be reduced by 29 to 84%, compared with yields of hand-weeded treatments, depending upon the bean market class and location (Arnold et al. 1996; Blackshaw and Esau 1991; Blackshaw et al. 2009; Ugen et al. 2002) In our study, pinto bean yield differences between the hand-weeded and weedy controls was as much as 56% in wide rows and 77% in narrow rows (Table 3).

Herbicide treatment

Due to differences in results between the two years of our study, yields were analyzed separately by year. Although the PRE applied alone had the poorest weed control in both 2014 and 2015, it only had the lowest pinto bean yield in 2014 (Table 3), which is not consistent with previous studies where treatments with the poorest control had the lowest yields (Blackshaw et al. 1999; Blackshaw et al. 2009; Holmes and Sprague 2013). In 2014, the PRE applied alone had the poorest weed control, and as expected corresponding lowest yield compared with yields of the POST sequential treatments which had provided season-long weed control (Table 3). In 2015, however, there were no yield differences between the PRE applied alone and any POST sequential treatments, even with differences in weed control between these treatments. 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 the PRE applied alone and POST sequential treatments in 2015 indicating that when weed pressure is high, a POST sequential application will increase weed control and subsequent yield compared with when PRE herbicides are applied without POST sequential herbicides. In both years, POST sequential treatments had comparable yields and those yields were not less than that of the hand-weeded control, where weeds were controlled throughout the season.

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. 2009; 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, where undercutters knife the plant root 1 to 2 inches below the soil surface while the bean rod breaks partially cut roots and lifts the plants from the soil, can be eliminated. Direct harvesting beans or cutting above-ground and swathing beans becomes necessary, where beans are cut off at ground level. Some benefits of direct harvest are reduction in fuel costs, equipment requirements, compaction, and time. However, yield loss is sometimes greater in direct harvest compared to conventional methods depending on variety, especially Type III as it will trail on the ground making it difficult for the header to get under the plants, causing pods to be cut. Environmental conditions, setup of equipment, and operator can also make a difference. Direct harvest 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, and with the use of proper equipment, such as, flexible cutterbars and pickup reels that operate closer to the soil and save more seed (Orsono et al. 2013).

In 2014, although of Eptam + Sonalan PRE alone, and two of the three POST sequential treatments: Eptam + Outlook fb Sonalan + Basagran, Eptam + Sonalan fb Outlook + Basagran in narrow rows compared with the same treatment in wide rows were not statistically different, there was a large numerical yield difference between treatments in narrow- vs the same in wide-rows (Table 3). 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 of the 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 per acre), 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 (Figure 1 and 2). Therefore, more research is needed to determine if higher seeding rates can be beneficial in narrow-row planted dry beans.

Plant architecture

In a Canadian study, a navy bean variety with an upright growth habit always attained a higher yield than the viny or trailing navy bean variety in the presence of hairy nightshade

(Blackshaw et al. 1999). As stated earlier, in our 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 4). In other words, unlike navy beans, a viny or trailing pinto bean variety is more competitive with hairy nightshade than an upright pinto bean variety. However, dry bean architecture has not been studied to a large extent and it is unknown how other dry bean classes and other pinto bean varieties would react in this scenario.

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 provide control as good as control in wide-row spacing when POST sequential applications are combined with cultivation. Even though POST sequential applications initially cost more, their subsequent increase in yield can offset the added cost. Narrow row spacing generally had higher yields than wide row spacing and can become a viable option when direct harvest issues can be resolved, especially with varieties that have viny, trailing growth habits. Although Othello with the viny, trailing growth most likely competed with weeds better than the upright growing Sequoia resulting in lower Sequoia than Othello yields, it is unknown how other pinto bean varieties and dry bean classes would respond in a similar study.

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Table 1 Control of hairy nightshade in response to herbicide treatments in narrow- and wide-row spacing pooled across pinto bean varieties and years, near Kimberly, ID.

			Weed control[b]			
			Early evaluation		Late evaluation	
Treatment[a]	Rate	Cost[c]	Narrow[d]	Wide	Narrow	Wide
	product/A	$/A	%			
Weedy control	-	-	-	-	-	-
Eptam + Sonalan	3 pt + 3 pt	$36.18	31 e	61 d	50 c	72 b
Eptam + Outlook fb	3 pt + 14 fl oz fb	$71.35	92 ab	93 a	95 a	94 a
Sonalan + Basagran	3 pt + 1 pt					
Eptam + Sonalan fb	3 pt + 3 pt fb	$71.35	91 abc	92 ab	95 a	92 a
Outlook + Basagran	14 fl oz + 1 pt					
Prowl H_2O + Outlook fb	2 pt + 14 fl oz fb	$45.60	91 abc	92 ab	93 a	94 a
Basagran	1 pt					
Hand-weeded	-		87 bc	86 c	95 a	93 a

[a]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.

[b]Visual control was rated on a 0 (no control) to 100% (completely dead) scale. There was an interaction between herbicide treatments and row spacing, so treatments were not pooled across row spacing. There were no variety or year interactions so data are pooled across these two effects. Narrow- and wide-row treatment means followed by the same letter within the early or late weed control evaluations are not statistically different according to a Least Square Means performed at $\alpha = 0.05$.

[c]All costs were based on the University of Idaho Agricultural Economics publications-Idaho Crop Input Price Summary for 2014 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 2 Control of common lambsquarters, green foxtail and redroot pigweed in response to herbicide treatments pooled across pinto bean varieties, row spacing, and years near Kimberly, ID.

		Weed control[b]					
		Common lambsquarters		Green foxtail		Redroot pigweed	
Treatment[a]	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	3 pt + 14 fl oz fb	90 a	89 a	91 a	93 a	93 a	93 a
Sonalan + Basagran	3 pt + 1 pt						
Eptam + Sonalan fb	3 pt + 3 pt fb	84 b	83 b	89 a	92 a	87 b	86 b
Outlook + Basagran	14 fl oz + 1 pt						
Prowl H_2O + Outlook fb	2 pt + 14 fl oz fb	88 ab	88 ab	91 a	94 a	92 a	93 a
Basagran	1 pt						
Hand-weeded	-	86 ab	90 a	87 a	92 a	90 ab	93 a

[a]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.
[b]Visual control was rated on a 0 (no control) to 100% (completely dead) scale. There were no variety, row spacing, or year interactions so herbicide treatment are pooled across these effects. Means followed by the same letter within a column are not statistically different according to a Least Square Means performed at $\alpha = 0.05$.

Table 3 Dry bean yield in response to herbicide treatments in narrow- and wide-row spacing pooled 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	----------------	----------------	lb ac^{-1} ----------------	----------------
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]There was a herbicide treatment by row spacing interaction and no variety interactions so treatment means are pooled across varieties but not row spacing. There was a year interaction and data were sorted by year and analyzed separately within year. Means followed by the same letter within each year are not statistically different according to a Least Square Means performed at $\alpha = 0.05$ using.

[b]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.

[c]Narrow row spacing in 2014 and 2015 was 6 and 7.5 inches, respectively. Wide row spacing was 22 inches, both years.

Table 4 Dry bean yield in response to variety by row spacing interaction pooled over herbicide treatments and years near Kimberly, ID.

Variety	Bean yield[a]	
	Narrow[b]	Wide
	------------------------------lb ac^{-1}------------------------------	
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 according to a Least Square Means performed at α = 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 1 Pinto bean planted in narrow (top) and wide (bottom) row 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 2 Pinto bean planted in narrow (top) and wide (bottom) row 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.