Cultivar-specific Weed Management Programs for 'Russet Burbank' and 'Bannock Russet' Potato Production in Wisconsin

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ADDITIONAL INDEX WORDS. *Solanum tuberosum*, s-metolachlor, metribuzin, rimsulfuron, glyphosate, cultivation, weed suppression

SUMMARY. Field trials were conducted at Hancock, WI, in 2008 and 2009 to determine reduced-herbicide weed management programs for 'Russet Burbank' and 'Bannock Russet' potato (*Solanum tuberosum*) based on cultivars' developmental characteristics. Six treatments applied to each cultivar included: preemergence (PRE) broadcast s-metolachlor and metribuzin (the industry standard); PRE in-row banded s-metolachlor and metribuzin with cultivation at 15% canopy development; postemergence (POST) broadcast rimsulfuron and metribuzin; POST between-row banded glyphosate; POST in-row banded rimsulfuron and metribuzin with cultivation at 15% canopy development; and cultivation alone at 15% canopy development. In 2008 and 2009, for both cultivars, visual assessments indicated weed suppression was reduced when glyphosate was POST between-row banded, compared with other treatments, and weed suppression was consistently high when rimsulfuron and metribuzin were POST broadcast. As expected, in-row weed control was consistently poor when glyphosate was between-row POST banded, providing no in-row weed control. Regardless of cultivar or year, in-row weed control was comparable to or better than the industry standard when herbicides were broadcast or in-row banded with cultivation at 15% canopy development. Potato yield was poor when glyphosate was POST between-row banded and when cultivation was used without herbicide application. Yield was consistently high when herbicides were POST broadcast, which provided no reduction in treated area from the industry standard of PRE broadcast. In both years, 'Russet Burbank' yield was greatest when herbicides were POST in-row banded with cultivation at 15% canopy development; 'Bannock Russet' yield was greatest when herbicides were PRE in-row banded with cultivation at 15% canopy development. Cultivar-appropriate weed management systems that band herbicides over the crop row in combination with cultivation would provide a two-thirds decrease in herbicide application from the industry standard without risk of yield loss.

Wisconsin is ranked fourth in U.S. potato production, behind Idaho, Washington, and North Dakota, with 63,500 acres planted in 2009 [U.S. Department of Agriculture (USDA), 2010a]. The 2009 U.S. potato crop was worth \$3.52 billion, and potato production in Wisconsin brought in about \$246 million (USDA, 2010a), accounting for about 5% of the state's total agricultural revenue. Wisconsin is also home to several potato processing and packaging facilities, providing added value from the crop. As with any crop, weed control is

an important factor in the viability of potato production. However, few herbicide options are available to potato producers. Potato growers use herbicides targeted at both broadleaf and grass weeds, most of which follow three modes of action: photosystem II inhibitors, acetolactate synthase inhibitors, and acetyl CoA carboxylase inhibitors. This limitation has made the development of herbicide-resistant weeds especially worrisome. The

current worldwide count of herbicide-resistant weeds has been documented as 68, 107, and 37 weed species, respectively, for each of the abovementioned modes of action (Heap, 2010).

Overreliance on herbicide use can pose ecological, environmental, and economic concerns to producers (Goldburg, 1992). Thus, research has been conducted with the goal of developing alternative integrated weed management techniques in potato and other vegetable cropping systems. Such techniques include changes in crop density (Bussan et al., 2007; Conley et al., 2001; Love et al., 1995), incorporation of green manure (Boydston and Hang, 1995), and cultivation (Bellinder et al., 2000). These techniques aim to reduce energy input while maintaining yields achieved with traditional herbicide regimes. Research in crops such as corn (*Zea mays*), soybean (*Glycine max*), and wheat (*Triticum aestivum*) have also examined how cultivar selection may also be used as a means of weed control by choosing cultivars that are inherently more competitive with, or more tolerant of, commonly encountered or key weed species (Begna et al., 2001; Challaiah et al., 1986; Didon, 2002; Lindquist and Mortensen, 1998; So et al., 2009b; Traore et al., 2002; Vandeley and Gill, 2004). In a recent study investigating the yield and competitive ability of wheat cultivars in Australia, Vandeley and Gill (2004) noted that although modern cultivars are generally higher yielding when compared with older cultivars in the absence of weeds, older cultivars seem to have a competitive advantage over weeds.

Increased competitive capabilities in crops can also be achieved by selecting for certain physiological characteristics. Traits such as rapid growth can lead to resource preemption on the part of the crop, thus increasing the competitive ability of a plant (Goldberg, 1990; Jordan, 1993). Weed suppression, or crop interference, may be more effective than weed tolerance because

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This material is based upon work supported by the National Institute of Food and Agriculture, under ID number 1318.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
2.2417	ton/acre	Mg·ha ⁻¹	0.4461

the suppressive ability of a crop reduces the weed population, whereas tolerance may eventually increase weed seed populations (Jordan, 1993). Characteristics that make a crop more capable of light interference can be combined with integrated weed management programs that aim at reducing herbicide use by taking advantage of a cultivar's natural competitive ability and growth rate. It is commonly thought that greater canopy cover and faster canopy development in crops, along with greater crop height, are associated with greater competitive ability because these traits allow for greater light interference of the crop (Begna et al., 2001; Challaiah et al., 1986; Connell et al., 1999; Didon, 2002; Lindquist and Mortensen, 1998; Seavers and Wright, 1999; Siddique et al., 1989; So et al., 2009a; Traore et al., 2002).

Although limited research has been conducted examining such trait characteristics in potato, some research has been conducted examining integrated weed management using other techniques such as cultivation (Bellinder et al., 2000; Boydston and Vaughn, 2002; Chitsaz and Nelson, 1983; Connell et al., 1999; Eberlein et al., 1997; Nelson and Giles, 1989). The response of potato cultivars to cultivation has varied. Some studies show that repeated cultivation can lead to reduced tuber quantity and quality, while other studies show no such effect. An optimal weed management regime may combine herbicides and cultivation with cultivars that respond to different treatment combinations.

The current standard weed control program in potato includes a hilling operation at ground-crack, or preemergence, immediately followed by broadcast application of a grass- and a broadleaf-specific herbicide. Herbicide use in the conventional program may be reduced by applying less herbicide to the area between potato rows. Between-row cultivation after potato emergence combined with in-row banding of herbicides may be an optimal management technique because the cultivation will cause minimal to no damage to the crop while the herbicide application will target only those weeds that would directly compete with the potato plants for nutrients, water, and light. As the between-row spacing is often twice as wide as the potato rows themselves, this would immediately provide a reduction in herbicide use of

two-thirds from the industry standard of broadcast herbicide application, which may be more economically effective for growers. Such a method would take advantage of the competitive ability of specific cultivars once they have reached a height and development stage to provide light competition with weeds. However, potato cultivars with different growth rates may differ in the optimal timing of herbicide application. 'Russet Burbank', an industry standard cultivar, is known for its rapid emergence and canopy development, while 'Bannock Russet', a cultivar released in 2000, emerges later and develops more slowly. The objective of this study is to develop a cultivar-specific, reduced-herbicide weed management program for 'Russet Burbank' and 'Bannock Russet' through the evaluation of integrated weed management programs that are specific to the growth characteristics of each of the two cultivars based on timely management tactics instead of prescriptive herbicide applications.

Materials and methods

Field studies were conducted at the Hancock Agricultural Research Station in Hancock, WI, on a Plainfield loamy sand (sandy, mixed, mesic, Typic Udipsamment) with 0.8% organic matter and a pH of 6.9 in 2008 and 2009 using a split-plot design with each treatment replicated four times. Reduced-input weed management programs (Table 1) were evaluated in two russet-type cultivars: Russet Burbank, the industry standard, and Bannock Russet, a 2000 release. Weed management programs were chosen to exploit known differences between potato cultivars in their unique developmental characteristics. Potatoes were grown using conventional grower practices, including soil fertility, irrigation, and insect and disease management practices, with the exception of weed management treatments outlined below. Potatoes were planted on 21 Apr. 2008 and on 23 Apr. 2009; potatoes were harvested on 22 Sept. 2008 and on 15 Sept. 2009. Main plots were potato cultivar with weed management treatments randomly assigned within each main plot. Each treatment measured 12 × 20 ft and included four potato rows spaced 3 ft apart.

Programs 1, 2, 3, and 5 all included the application of broadleaf and grass herbicides. The industry standard

(program 1) and program 2 involved herbicide application immediately after hilling (hill-spray, to be referred to as PRE), applied 8 May 2008 and 11 May 2009. Programs 3, 4, and 5 involved herbicide application when weeds were in the two- to four-leaf growth stage (postemergence, to be referred to as POST), applied 10 June 2008 and 4 June 2009. Applications banded over the potato row (later referred to as in-row banding) were applied to the 12-inch top of the potato hill, leaving 24 inches untreated between each potato row. Applications banded between the potato rows (later referred to as between-row banding) treated the 24-inch space between potato hills, leaving 12 inches on top of the hill untreated. Cultivation was conducted with a spider gang cultivator commonly used in potato cropping systems before the introduction of herbicides.

VISUAL WEED SUPPRESSION ASSESSMENTS. Visual assessments of weed suppression were conducted in each plot 46 d after planting (DAP) and 64 DAP in 2008 and 54 DAP and 63 DAP in 2009 to measure the treatment effect. Weed suppression was evaluated in the dominant weed species by visual estimation of weed cover of selected dominant species ranging from 0% (no weed control) to 100% weed control both in the potato row (in-row) and between the first and second potato rows (between-row) in each four-row experimental plot. Percent weed suppression of each weed species was averaged across four replicates for each plot and subjected to Friedman's test because the assumptions of normality and constant variance required for analysis of variance (ANOVA) were not met. Due to limited data, Wilcoxon signed-rank test could not be conducted to make post hoc pairwise comparisons. SAS (version 9.2; SAS Institute, Cary, NC) was used for all statistical analyses. Significance for all analyses was defined as $P \leq 0.05$.

WEED BIOMASS. Weeds were harvested from a randomly selected 2 × 2 ft subset in each plot 121 DAP in 2008 and 104 DAP in 2009, after potato canopy closure. In-row weed biomass was harvested from the second potato row; between-row weed biomass was harvested at the same time between the second and third potato rows. Weeds of all species present in the selected area were harvested, dried, and weighed. Data were subject to ANOVA using

Table 1. Program number, weed management programs, application method and timing, and percent herbicide reduction from the industry standard of weed management treatments applied to potato at the Hancock Agricultural Research Station in Hancock, WI, in 2008 and 2009.

Weed management program no.	Weed management program	Weed management program application method and rate (kg·ha ⁻¹ a.i.) ^z	Timing of weed management program application	Herbicide reduction (%) ^y
1	Hilling s-Metolachlor Metribuzin	Broadcast Broadcast at 1.07 kg·ha ⁻¹ Broadcast at 0.56 kg·ha ⁻¹	Potato emergence Hill-spray Hill-spray	0
2	Hilling s-Metolachlor Metribuzin Cultivation	Broadcast Banded over potato row at 0.36 kg·ha ⁻¹ Banded over potato row at 0.19 kg·ha ⁻¹ Between-row	Potato emergence Hill-spray Hill-spray 15% potato canopy	67
3	Hilling Rimsulfuron Metribuzin	Broadcast Broadcast at 0.02 kg·ha ⁻¹ Broadcast at 0.56 kg·ha ⁻¹	Potato emergence Postemergence Postemergence	0
4	Hilling Glyphosate	Broadcast Banded between potato row at 0.58 kg·ha ⁻¹	Potato emergence 15% potato canopy	33
5	Hilling Cultivation Rimsulfuron Metribuzin	Broadcast Between-row Banded over potato row at 0.007 kg·ha ⁻¹ Banded over potato row at 0.19 kg·ha ⁻¹	Potato emergence 15% potato canopy Postemergence Postemergence	67
6	Hilling Cultivation	Broadcast Between-row	Potato emergence 15% potato canopy	100

^z1 kg·ha⁻¹ = 0.8922 lb/acre.

^yPercent herbicide reduction of total seasonal herbicide use calculated on the basis of spray area relative to industry standard program represented in program 1.

SAS with treatment and potato cultivar as main effects. Means were separated using Fisher's protected least significant difference (LSD) test with SAS when F tests were significant at $\alpha = 0.05$. All weed biomass data were natural log transformed for analyses. Analyses were conducted separately for each year because year was found to have a significant interactive effect with treatment. Significance was defined as $P \leq 0.05$.

POTATO TUBER YIELD. All plots of a given year were harvested at the same time, 154 DAP in 2008 and 145 DAP in 2009. Total marketable potato yield was collected from the second 20-ft-long row of each plot and consisted of all tubers harvested except those with more than slight defects designated as culls as per USDA guidelines (USDA, 2010b). Data were subject to ANOVA with treatment, potato cultivar, and a treatment-cultivar interaction as effects. Means were separated using Fisher's protected LSD test with SAS when F tests were significant at $\alpha = 0.05$. Analyses were conducted separately for each year because year was found

to have a significant interactive effect with treatment. Significance was defined as $P \leq 0.05$.

Results and discussion

BETWEEN-ROW WEED CONTROL VISUAL ASSESSMENTS. In 2008, there were four dominant species of weeds growing between potato rows: common ragweed (*Ambrosia artemisiifolia*), yellow foxtail (*Setaria pumila*), wild buckwheat (*Polygonum convolvulus*), and common lambsquarters (*Chenopodium album*). In 2009, there were two dominant species of weeds growing between potato rows: common ragweed and wild buckwheat.

Between-row weed control was consistently greater than 90% in 'Russet Burbank' and 'Bannock Russet' with rimsulfuron and metribuzin POST broadcast, and with rimsulfuron and metribuzin POST in-row banded with cultivation at 15% canopy development (Tables 2 and 3). Weed control was consistently 85% or greater in 'Russet Burbank' and 'Bannock Russet' with s-metolachlor and metribuzin PRE in-row banded with cultivation at 15% canopy development.

Between-row weed control was consistently poor when glyphosate was POST between-row banded, particularly in 'Bannock Russet' (Tables 2 and 3). Weed control in 'Russet Burbank' when cultivation was used without herbicides was greater than 80% with the exception of the early rating in 2009; between-row weed control using this treatment was consistently less than 70% in 'Bannock Russet'. The poor between-row weed suppression attained from cultivation without the use of herbicides is likely due to the lack of residual weed control from this method. The physical removal of weeds before canopy closure did not provide any control for weeds that emerged after 15% canopy closure. Similarly, glyphosate does not provide residual weed control and thus provides no protection from weeds that emerge postapplication (Askew et al., 1998; Keeling et al., 1998).

IN-ROW WEED CONTROL VISUAL ASSESSMENTS. In early June 2008 (46 DAP), there were two dominant weed species: common ragweed and yellow foxtail. In late June 2008 (64 DAP), there were four dominant

Table 2. Between-row visual assessments of percent weed control of most prevalent weed species in 'Russet Burbank' and 'Bannock Russet' potato plots in 2008 in Hancock, WI.

Weed control technique	Timing ^z	Application	Cultivation timing	Common ragweed			Yellow foxtail			Wild buckwheat			Common lambsquarters						
				Bannock Russet		Burbank	Bannock Russet		Burbank	Bannock Russet		Burbank	Bannock Russet		Burbank				
				Between-row weed control 46 d after planting (%) ^y															
s-Metolachlor, metribuzin	PRE	Broadcast	At potato emergence	100	100	100	100	98	100	99	100	100	100	100					
s-Metolachlor, metribuzin	PRE	In-row banded	At potato emergence, 15% canopy	100	100	100	100	93	100	99	100	100	100	100					
Rimsulfuron, metribuzin	POST	Broadcast	At potato emergence	100	100	100	100	100	100	100	100	100	100	100					
Glyphosate	POST	Between-row banded	At potato emergence	83	69	79	79	55	84	69	86	69	86	69					
Rimsulfuron, metribuzin	POST	In-row banded	At potato emergence, 15% canopy	100	93	99	99	98	100	98	100	100	100	93					
N/A ^x	N/A	N/A	15% canopy	96	75	91	91	65	94	68	96	76	96	76					
			<i>P</i> value ^w	<i>P</i> < 0.0001			<i>P</i> = 0.0006			<i>P</i> < 0.0001			<i>P</i> < 0.0001						

Table 3. Between-row visual assessments of percent weed control of most prevalent weed species in 'Russet Burbank' and 'Bannock Russet' potato plots in 2009 in Hancock, WI.

Weed control technique	Timing ^z	Application	Cultivation timing	Between-row weed control 54 d after planting (%) ^y						Between-row weed control 63 d after planting (%)					
				Common ragweed			Wild buckwheat			Common ragweed			Wild buckwheat		
				Russet Burbank	Bannock Russet	Russet Burbank	Russet Burbank	Bannock Russet	Russet Burbank	Russet Burbank	Bannock Russet	Russet Burbank	Russet Burbank	Bannock Russet	Russet Burbank
s-Metolachlor, metribuzin	PRE	Broadcast	At potato emergence	81	59	81	81	60	83	50	83	50	83	50	83
s-Metolachlor, metribuzin	PRE	In-row banded	At potato emergence, 15% canopy	89	93	89	89	93	94	85	95	85	95	85	95
Rimsulfuron, metribuzin	POST	Broadcast	At potato emergence	94	94	94	94	94	95	95	95	95	95	95	95
Glyphosate	POST	Between-row banded	At potato emergence	68	34	68	68	33	75	43	75	43	75	43	75
Rimsulfuron, metribuzin	POST	In-row banded	At potato emergence, 15% canopy	95	95	95	95	95	98	96	98	96	98	96	98
N/A ^x	N/A	N/A	15% canopy	65	66	64	64	64	86	48	86	48	86	48	86
			<i>P</i> value ^w	<i>P</i> = 0.0002			<i>P</i> = 0.0003			<i>P</i> = 0.0013			<i>P</i> = 0.0013		

^zPRE = before weed emergence, immediately after potato hilling; POST = after weed and potato emergence.^yBetween-row weed biomass was harvested between the second and third potato rows after potato canopy closure. Weed control rated on a scale of 0% (no control) to 100% (plant death).^xN/A = no herbicide was applied.^wProbability values are based on Friedman's tests.

were expected because the potato plants form a dense canopy that closes across the hill, creating between-row weed control through resource competition.

In 2009, between-row weed biomass in 'Russet Burbank' was better than or comparable to the industry standard in all treatments except cultivation without the use of herbicides. Between-row weed control in 'Bannock Russet' was better than the industry standard when herbicide was POST broadcast or POST banded with cultivation at 15% canopy development. 'Bannock Russet' canopy size is generally smaller than 'Russet Burbank', and the cultivar may benefit from postemergence herbicide application, which would provide supplemental midseason weed control for between-row weeds.

IN-ROW WEED BIOMASS. Regardless of cultivar or year, cultivation alone provided inadequate weed control, resulting in biomass that was comparable to ('Bannock Russet' in 2009 only) or poorer than the industry standard (Table 7). Our findings are consistent with those of Bellinder et al. (2000), who determined that weed control was reduced when hilling and cultivation were used without the use of herbicide, but that weed control can be increased by combining banded herbicide with cultivation.

In 2008, weed biomass when glyphosate was POST between-row banded was greater than the industry standard and comparable only to weed biomass using cultivation alone. However, in 2009, weed biomass was comparable to the industry standard when glyphosate was POST between-row banded. Such differences are not surprising given the year-by-treatment interaction. The difference between years may be due to differences in weed communities, along with differences in weed seeds present in the soil of the fields used in each of the 2 years.

Weed biomass was comparable to or lower than the industry standard for both cultivars in both years for three treatments: s-metolachlor and metribuzin PRE in-row banded with cultivation at 15% canopy development; rimsulfuron and metribuzin POST broadcast; and rimsulfuron and metribuzin POST in-row banded with cultivation at 15% canopy development. Although there was no significant difference in weed control among these three treatments because

Table 4. In-row visual assessments of percent weed control of most prevalent weed species in 'Russet Burbank' and 'Bannock Russet' potato plots in 2008 in Hancock, WI.

Weed control technique	Timing ^z	Application	Cultivation timing	Common ragweed			Yellow foxtail			Wild buckwheat			Common lambsquarters			
				In-row weed control 46 d after planting (%) ^y			In-row weed control 46 d after planting (%) ^y			In-row weed control 46 d after planting (%) ^y			In-row weed control 46 d after planting (%) ^y			
				Russet Burbank	Bannock Russet	Russet Burbank	Russet Burbank	Bannock Russet	Russet Burbank	Russet Burbank	Bannock Russet	Russet Burbank	Russet Burbank	Bannock Russet	Russet Burbank	Bannock Russet
s-Metolachlor, metribuzin	PRE	Broadcast	At potato emergence	100	100	100	100	100	100	100	100	100	100	100	100	
s-Metolachlor, metribuzin	PRE	In-row banded	At potato emergence, 15% canopy	100	100	100	100	100	100	100	100	100	100	100	100	
Rimsulfuron, metribuzin	POST	Broadcast	At potato emergence	100	98	98	98	93	93	93	93	93	93	93	93	
Glyphosate	POST	Between-row banded	At potato emergence	53	33	48	48	33	33	33	33	33	33	33	33	
Rimsulfuron, metribuzin	POST	In-row banded	At potato emergence, 15% canopy	95	98	94	94	98	98	98	98	98	98	98	98	
N/A ^x	N/A	N/A	15% canopy	66	61	73	73	49	49	49	49	49	49	49	49	
			<i>P</i> value ^w	<i>P</i> = 0.0051			<i>P</i> = 0.0033			<i>P</i> = 0.0033			<i>P</i> = 0.0033			
				In-row weed control 64 d after planting (%)												
s-Metolachlor, metribuzin	PRE	Broadcast	At potato emergence	100	94	100	93	100	94	100	94	100	94	100	94	
s-Metolachlor, metribuzin	PRE	In-row banded	At potato emergence, 15% canopy	100	100	100	100	100	100	100	100	100	100	100	100	
Rimsulfuron, metribuzin	POST	Broadcast	At potato emergence	98	96	100	96	100	96	100	96	100	96	100	96	
Glyphosate	POST	Between-row banded	At potato emergence	63	10	68	6	68	0	68	0	68	0	68	0	
Rimsulfuron, metribuzin	POST	In-row banded	At potato emergence, 15% canopy	93	95	95	95	93	95	93	94	93	94	93	94	
N/A	N/A	N/A	15% canopy	89	25	86	25	89	18	89	18	89	18	89	18	
			<i>P</i> value	<i>P</i> = 0.0134			<i>P</i> = 0.0469			<i>P</i> = 0.0269			<i>P</i> = 0.0269			

^zPRE = before weed emergence, immediately after potato hilling; POST = after weed and potato emergence.^yIn-row biomass was harvested from the second row potato hill after potato canopy closure. Weed control rated on a scale of 0% (no control) to 100% (plant death).^xN/A = no herbicide was applied.^wProbability values are based on Friedman's tests.

of herbicide application timing in 2008, POST banded herbicide proved more effective than PRE application in 2009 for 'Bannock Russet'. The marginal benefit of POST banding in 2009 but not in 2008 may be due to a difference in weed community between years (Traore et al., 2002) and to the later emergence and slower growth rate of 'Bannock Russet' (Love et al., 1995). Given that there were no significant differences among the four best weed control treatments in both 'Bannock Russet' and 'Russet Burbank', growers may be able to reduce herbicide use from the industry standard of preemergence broadcast s-metolachlor and metribuzin without compromising weed control. In-row banded herbicide with cultivation at 15% canopy development would reduce herbicide use by 67%.

POTATO YIELD. With the exception of 'Russet Burbank' in 2009 in which we observed no differences among treatments, potato yield was always lowest when glyphosate was POST between-row banded, and when using cultivation alone (Table 8). The yield obtained in these two lowest yielding treatments differed between the two cultivars while the yield obtained in the highest yielding treatments did not differ significantly between the two cultivars. Colquhoun et al. (2009) showed that 'Bannock Russet' may be especially sensitive to weed competition because the cultivar yielded less than other cultivars under weedy conditions as compared with weed-free conditions. This may be due to the later emergence and slower growth rate of the cultivar, giving weeds an early advantage if not properly managed. The lower yield in 'Bannock Russet' plots may be analogous to the findings of Seavers and Wright (1999) that yield reduction in grain species was inversely correlated with a cultivar's competitive capability, and studies in soybean (Jordan, 1993) indicating that a cultivar's ability to suppress weed growth is more important than the ability to tolerate weed presence. Love et al. (1995) found that reducing the space between potato rows may decrease tuber yield in 'Russet Burbank', but resulted in a slight increase in yield in the smaller 'Frontier Russet'. Future studies may examine how reducing the space between rows may influence yield in 'Bannock Russet', which may be more

Table 5. In-row visual assessments of percent weed control of most prevalent weed species in 'Russet Burbank' and 'Bannock Russet' potato plots in 2009 in Hancock, WI.

Weed control technique	Timing ^z	Application	Cultivation timing	In-row weed control 54 d after planting (%) ^y						In-row weed control 63 d after planting (%)					
				Common ragweed			Wild buckwheat			Common ragweed			Wild buckwheat		
				Russet Burbank	Bannock Russet	Russet Burbank	Russet Burbank	Bannock Russet	Russet Burbank	Russet Burbank	Bannock Russet	Russet Burbank	Russet Burbank	Bannock Russet	Russet Burbank
				Burbank	Russet	Burbank	Russet	Burbank	Russet	Burbank	Russet	Burbank	Russet	Burbank	Russet
s-Metolachlor, metribuzin	PRE	Broadcast	At potato emergence	81	60	81	89	60	89	86	50	86	89	50	85
s-Metolachlor, metribuzin	PRE	In-row banded	At potato emergence, 15% canopy	89	93	89	93	93	95	95	85	95	95	85	85
Rimsulfuron, metribuzin	POST	Broadcast	At potato emergence	94	94	94	94	94	94	95	95	95	95	95	95
Glyphosate	POST	Between-row banded	At potato emergence	69	34	69	34	34	75	75	43	75	75	43	43
Rimsulfuron, metribuzin	POST	In-row banded	At potato emergence, 15% canopy	96	96	96	96	96	98	98	96	98	98	96	96
N/A ^x	N/A	N/A	15% canopy	64	66	64	64	64	86	47	47	86	86	48	48
			<i>P</i> value ^w	<i>P</i> = 0.0002			<i>P</i> = 0.0003			<i>P</i> = 0.001			<i>P</i> = 0.001		

^zPRE = before weed emergence, immediately after potato hilling; POST = after weed and potato emergence.^yIn-row biomass was harvested from the second row potato hill after potato canopy closure. Weed control rated on a scale of 0% (no control) to 100% (plant death).^xN/A = no herbicide was applied.^wProbability values are based on Friedman's tests.

competitive with narrow row spacing because of its late emergence and smaller canopy. Although choosing a cultivar that performs well at specified row spacing may be advantageous to farmers, altering row spacing may not serve as a viable weed control option because the row spacing of planting and harvesting equipment is not easily changed.

Regardless of cultivar and year, potato yield was comparable to that obtained though the industry standard weed control protocol when rimsulfuron and metribuzin were POST broadcast. While POST broadcast application does not necessarily reduce chemical input compared with the industry standard of PRE broadcast herbicide application, there may be benefits to POST application. Herbicide programs reliant solely on POST application can be based on weed scouting rather than prescribed treatment. However, as stated above, this study demonstrates that it may not be viable to substitute cultivation alone for herbicide application.

In 'Russet Burbank', yield was also greatest in both years when rimsulfuron and metribuzin were POST in-row banded with cultivation at 15% canopy development. This may indicate that POST application of herbicide occurs within the critical weed period and still aides in full canopy development for 'Russet Burbank' (Connell et al., 1999). Although some work has raised concerns that repeated cultivation, while beneficial for weed control, can reduce tuber yield (Bellinder et al., 2000; Eberlein et al., 1997; Nelson and Giles, 1989), our findings indicate that hilling combined with cultivation at 15% canopy development did not reduce tuber yield, which is in keeping with findings (Boydston and Vaughn, 2002; Connell et al., 1999) that the proper herbicide combined with cultivation will result in the highest yield. Thus, our data show that a 67% reduction in herbicide resulting from POST in-row banding combined with cultivation at 15% canopy development may be implemented without yield or weed control reduction.

In 'Bannock Russet', yield was also greatest in both years when s-metolachlor and metribuzin were PRE in-row banded with cultivation at 15% canopy development. Although there was minimal difference in in-row weed control between pre- and postemergence

Table 6. Between-row weed biomass harvested from 2 × 2 ft (0.61 m) subsets in ‘Russet Burbank’ and ‘Bannock Russet’ potato plots in 2008 and 2009 in Hancock, WI.

Weed control technique	Timing ^z	Application	Cultivation timing	Between-row weed biomass 2008 (kg·ha ⁻¹) ^y		Between-row weed biomass 2009 (kg·ha ⁻¹)	
				Russet Burbank	Bannock Russet	Russet Burbank	Bannock Russet
s-Metolachlor, metribuzin	PRE	Broadcast	At potato emergence	1	5	1 de ^x	43 a
s-Metolachlor, metribuzin	PRE	In-row banded	At potato emergence, 15% canopy	1	5	3 cde	13 abc
Rimsulfuron, metribuzin	POST	Broadcast	At potato emergence	1	2	1 de	7 bcd
Glyphosate	POST	Between-row banded	At potato emergence	2	1	1 e	24 ab
Rimsulfuron, metribuzin	POST	In-row banded	At potato emergence, 15% canopy	1	1	1 e	4 cde
N/A ^w	N/A	N/A	15% canopy	1	1	9 abc	40 a
			<i>P</i> value for treatment effect	<i>P</i> = NS ^v		<i>P</i> = 0.0108	
			<i>P</i> value for cultivar effect	<i>P</i> = NS		<i>P</i> < 0.0001	
			<i>P</i> value for treatment–cultivar interactive effect	<i>P</i> = NS		<i>P</i> = NS	

^zPRE = before weed emergence, immediately after potato hilling; POST = after weed and potato emergence.

^yWeed biomass was collected in 2 × 2 ft subsets of each subplot. Between-row weed biomass was harvested 121 d after planting (DAP) in 2008 and 104 DAP in 2009 from between the second and third potato rows; 1 kg·ha⁻¹ = 0.8922 lb/acre.

^xTreatment means followed by the same letter do not differ significantly within a year according to a Fisher's protected least significant difference test performed at *P* ≤ 0.05. Data were natural log transformed for analyses. Non-transformed means are shown in the table for clarity.

^wN/A = no herbicide was applied.

^vProbability value was not significant (greater than 0.05).

Table 7. In-row weed biomass harvested from 2 × 2 ft (0.61 m) subsets in ‘Russet Burbank’ and ‘Bannock Russet’ potato plots in 2008 and 2009 in Hancock, WI.

Weed control technique	Timing ^z	Application	Cultivation timing	In-row weed biomass 2008 (kg·ha ⁻¹) ^y		In-row weed biomass 2009 (kg·ha ⁻¹)	
				Russet Burbank	Bannock Russet	Russet Burbank	Bannock Russet
s-Metolachlor, metribuzin	PRE	Broadcast	At potato emergence	1 d ^x	6 cd	3 de	22 ab
s-Metolachlor, metribuzin	PRE	In-row banded	At potato emergence, 15% canopy	1 d	3 cd	6 cd	7 cd
Rimsulfuron, metribuzin	POST	Broadcast	At potato emergence	2 cd	14 bc	4 de	6 cd
Glyphosate	POST	Between-row banded	At potato emergence	87 ab	512 a	10 bcd	106 a
Rimsulfuron, metribuzin	POST	In-row banded	At potato emergence, 15% canopy	4 cd	8 c	1 e	1 e
N/A ^w	N/A	N/A	15% canopy	152 ab	443 a	43 ab	93 a
			<i>P</i> value for treatment effect	<i>P</i> < 0.0001		<i>P</i> < 0.0001	
			<i>P</i> value for cultivar effect	<i>P</i> = 0.0017		<i>P</i> = 0.0054	
			<i>P</i> value for treatment–cultivar interactive effect	<i>P</i> = NS ^v		<i>P</i> = NS	

^zPRE = before weed emergence, immediately after potato hilling; POST = after weed and potato emergence.

^yWeed biomass was collected in 2 × 2 ft subsets of each subplot. In-row biomass was harvested 121 d after planting (DAP) in 2008 and 104 DAP in 2009 from the second row after potato canopy closure; 1 kg·ha⁻¹ = 0.8922 lb/acre.

^xTreatment means followed by the same letter do not differ significantly within a year according to a Fisher's protected least significant difference test performed at *P* ≤ 0.05. Data were natural log transformed for analyses. Non-transformed means are shown in the table for clarity.

^wN/A = no herbicide was applied.

^vProbability value was not significant (greater than 0.05).

application, ‘Bannock Russet’ yield may ultimately benefit from PRE weed control, though weed biomass in ‘Bannock Russet’ was lower when herbicide was POST banded in 2009. A 67%

reduction in herbicide through PRE in-row banded herbicide with cultivation at 15% canopy development can be implemented without significant reduction in yield or weed control.

Despite differences in growth characteristics of the two cultivars, we were able to maintain yield and weed control in both ‘Russet Burbank’ and ‘Bannock Russet’ while

Table 8. Total marketable potato yield (tons/acre) of ‘Russet Burbank’ and ‘Bannock Russet’ plots in 2008 and 2009 in Hancock, WI.

Weed control technique	Timing ^z	Application	Cultivation timing	Marketable potato yield 2008 (tons/acre) ^y		Marketable potato yield 2009 (tons/acre)	
				Russet Burbank	Bannock Russet	Russet Burbank	Bannock Russet
s-Metolachlor, metribuzin	PRE	Broadcast	At potato emergence	25.4 a ^x	25 ab	20.5 abc	16.5 d
s-Metolachlor, metribuzin	PRE	In-row banded	At potato emergence, 15% canopy	20 cd	21.9 abcd	21.9 ab	21 abc
Rimsulfuron, metribuzin	POST	Broadcast	At potato emergence	24.1 abc	25 ab	18.7 bcd	19.2 abcd
Glyphosate	POST	Between-row banded	At potato emergence	19.2 d	12.9 e	18.3 cd	12.9 e
Rimsulfuron, metribuzin	POST	In-row banded	At potato emergence, 15% canopy	21.9 abcd	20 cd	20 abc	21.9 a
N/A ^w	N/A	N/A	15% canopy	21.4 bcd	13.4 e	18.7 bcd	12 e
			<i>P</i> value for treatment effect	<i>P</i> < 0.0001		<i>P</i> < 0.0001	
			<i>P</i> value for cultivar effect	<i>P</i> = 0.0061		<i>P</i> = 0.0003	
			<i>P</i> value for treatment–cultivar interactive effect	<i>P</i> = 0.0037		<i>P</i> = 0.0016	

^zPRE = before weed emergence, immediately after potato hilling; POST = after weed and potato emergence.

^yTotal marketable yield consisted of all tubers harvested except those with more than slight defects designated as culls as per U.S. Department of Agriculture (2010b); 1 ton/acre = 2.2417 Mg·ha⁻¹.

^xTreatment means followed by the same letter do not differ significantly within a year according to Fisher’s protected least significant difference test performed at *P* ≤ 0.05. Analysis was conducted separately for each year.

^wN/A = no herbicide was used.

reducing herbicide application area by 67%. ‘Russet Burbank’, which our data shows to be more tolerant of weed pressure, treated with POST in-row banded herbicide with cultivation at 15% canopy development yielded consistently high in both years, while PRE in-row banded herbicide with cultivation at 15% canopy development yielded high in 2009. ‘Bannock Russet’, which our data shows to be less tolerant of weed pressure, treated with PRE in-row banded herbicide with cultivation at 15% canopy development yielded high in both years, while POST in-row banded herbicide with cultivation at 15% canopy development yielded well in 2009. The year-to-year variation indicates that more trials may be needed to determine if timing of banded application is a key factor in maintaining yield and weed control in either or both of these cultivars. However, there is strong evidence that ‘Russet Burbank’ and ‘Bannock Russet’ can be grown using banded rather than broadcast herbicide application without compromising yield or weed control.

Potato growers who produce cultivars with smaller canopies such as ‘Bannock Russet’ may find cultivar-specific management especially useful. Although ‘Russet Burbank’ generally

yielded more than ‘Bannock Russet’ and formed a larger canopy allowing for greater weed suppression, growing a cultivar based on such characteristics may not always be possible as cultivars are often selected by buyers based almost exclusively on end-use characteristics.

In the upper midwestern United States, herbicides are ground-applied making banding a simple alternative to broadcast application; however, in other parts of the country where herbicides are applied to potato cropping systems by chemigation banded herbicide application may not be cost-effective or practical. Additionally, cultivation may increase the risk of erosion, yield loss, and root pruning, and cultivation can be delayed from the optimal timing because of wet soil and inclement weather, which may result in reduced weed control. Despite these hurdles, an integrated weed management program that incorporates reduced herbicide application through banding could provide long-term benefits, including slowing the selection rate for herbicide-resistant weed populations. Adoption of such practices could also reduce herbicide use in a way that is compliant with end-use and retailer demands for reduced-input products from potato growers.

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