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Alternative Weed Management Systems Control Weeds in Potato (*Solanum tuberosum*)[1]

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Abstract: Five weed management systems utilizing combinations of cover crops, herbicides, and cultivation were tested in potato in 1994 and 1995 in central Washington. A standard herbicide treatment of metribuzin applied preemergence (PRE) at 0.4 kg ai/ha (standard herbicide weed management system [STD]) was compared with (1) fall-planted winter rye followed by metribuzin at 0.4 kg/ha applied in a band in the potato hill, followed by reservoir tillage (rye cover crop with herbicide-banded and reservoir-tilled weed management system [RYESTD]); (2) cultivation with tine-tooth harrow followed by hilling with shovels and rolling cultivators (total-cultivation weed management system [CULT]); (3) fall-planted rapeseed followed by reservoir tillage (rapeseed cover crop and reservoir-tilled weed management system [RPSD]); and (4) reservoir tillage alone (reservoir-tilled weed management system [RESTIL]). In both years, early-season weed density and final weed biomass were lower in the STD, RYESTD, and CULT systems than in RPSD and RESTIL. Total tuber yield and yield of U.S. #2 or better were greatest in the RYESTD and STD systems in both years. The CULT system reduced early-season weed densities, but tuber yield was reduced 15% in 1994, and yield of U.S. #2 or better was reduced 25% in 1995 compared with the STD system. The RPSD system reduced early-season in-row weed density from 60 to 70% and final weed biomass from 29 to 40% compared with a nontreated check, i.e., a no–cover crop, no-cultivation, no-herbicide weed management system, but tuber yield was 27 to 30% lower than in the STD system. The RYESTD system was an effective alternative weed management strategy that controlled weeds, decreased PRE-applied herbicide inputs 66%, and maintained tuber yield.

Nomenclature: Metribuzin; potato, *Solanum tuberosum* L.; rapeseed, *Brassica napus;* rye, *Secale cereale* L.

Additional index words: Banding, cover crops, cultivation, integrated weed management, glyphosate, reservoir tillage, tillage.

Abbreviations: BR, between row; CHECK, no–cover crop, no-cultivation, no-herbicide weed management system; CULT, total-cultivation weed management system; IR, in row; PRE, preemergence; RESTIL, reservoir-tilled weed management system; RPSD, rapeseed cover crop and reservoir-tilled weed management system; RYESTD, rye cover crop with herbicide-banded and reservoir-tilled weed management system; STD, standard herbicide weed management system.

INTRODUCTION

Weed control in potato is accomplished primarily with a combination of herbicides and cultivation (Eberlein et al. 1997; United States Department of Agriculture, ERS 1999). A common weed control system in potato production in the Western United States is a combination of a timely harrow (drag off) and hilling operation plus a herbicide application. In addition, potato fields in Washington State are commonly reservoir tilled. Reservoir tillage equipment consists of a ripping shank in the furrow, followed by a rotating wheel with paddles that form pits in the furrows between potato hills. Reservoir tillage is primarily done to decrease water runoff and improve water infiltration. The benefits of reservoir tillage on weed control have not been previously reported.

Public concern about undesirable pesticide impacts on the environment has led to increased emphasis on reducing pesticide use in crop production systems. More U.S. potato hectares are treated with the herbicide me-

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Table 1. Components and associated costs (in parentheses) of weed management systems tested in potato in 1994 and 1995.[a]

System	Cover crop	Herbicide	Tillage	Total cost ($/ha)
STD	None	Metribuzin, broadcast ($22/ha)	None	22.00
RYESTD	Rye ($37/ha)	Glyphosate ($22/ha) Metribuzin, banded ($7.30/ha)	Reservoir tilled ($39.50/ha)	105.80
RPSD	Rapeseed ($26/ha)	Glyphosate ($22/ha)	Reservoir tilled($39.50/ha)	87.50
CULT	None	None	Tine harrow ($26/ha) Rehill with rolling cultivator and shovels ($49/ha)	75.00
RESTIL	None	None	Reservoir tilled ($39.50/ha)	39.50
CHECK	None	None	None	0.00

[a] Costs of herbicides, cover crop seed, and tillage were determined from surveying local growers and suppliers. Costs of preparing seedbed and planting cover crop, cover crop incorporation, and herbicide application are not included.

tribuzin than any other pesticide (Guenthner et al. 1999), and over 90% of the Pacific Northwest potato acreage is treated with herbicides (United States Department of Agriculture, ERS 1999). In corn (*Zea mays*), onion (*Allium cepa* L.), and soybean [Glycine max (L.) Merr.], combining cultivation with banded herbicide application can reduce herbicide input and weed control costs substantially, while maintaining weed control and crop yield, compared with broadcast herbicide applications (Eadie et al. 1992; Krausz et al. 1995; Shock and Seddigh 1998). However, similar studies have not been reported in potato.

Potato seed pieces are planted deeper than most annual crops and can withstand several aggressive cultivations to remove weeds before potato plants emerge (Vangessel and Renner 1990). Cultivation and hilling may increase soil erosion, injure potato, increase soil compaction, and bring weed seeds to the soil surface (Nelson and Giles 1986; Rioux et al. 1979). Despite these undesirable effects of cultivation, 86% of U.S. potato acreage is cultivated for weed control (United States Department of Agriculture, ERS 1999).

Use of cover crops in crop rotations has many benefits including weed suppression (Gallandt et al. 1999). A fall-planted, spring-incorporated cover crop of rapeseed suppressed early-season weeds in potato, pea, and soybean (Al-Khatib et al. 1997; Boydston and Hang 1995; Krishnan et al. 1998). In those studies, cultivation was not combined with the use of a cover crop, and late-season weed biomass was substantial. *Brassica*-cover crops used alone or combined with low-input chemical control have also shown the potential for providing control of nematodes and soil-borne diseases (Al-Khatib and Boydston 1999; Eberlein et al. 1998; Mayton et al. 1996; Mojtahedi et al. 1993; Olivier et al. 1999; Vaughn 1993). Winter rye has been used in numerous studies as a weed-suppressing cover crop (Barnes and Putnam 1983; Putnam 1988; Yenish et al. 1995), and rye residues suppressed early-season weeds in reduced tillage potato (Wallace and Bellinder 1989).

Our study was conducted to evaluate potato yield and weed control using several weed management systems that combined weed-suppressive fall-planted cover crops, cultivation, reservoir tillage, and band-applied herbicides to reduce herbicide inputs in potato.

MATERIALS AND METHODS

The experiment was conducted as a randomized complete block design with four replications. Studies were located in central Washington State on a Quincy (Typic Torripsamments) sand, containing 0.5% organic matter and pH 7.0. Five weed management systems were compared for weed control in potato in 1994 and 1995 (Table 1). Plots were 3.5 by 9 m^2 in 1994 and 3.5 by 18 m^2 in 1995. Russet Burbank potato was planted in rows spaced 86 cm at a density of 71,000 seed pieces/ha on April 18, 1994 and April 19, 1995. Potato was grown under sprinkler irrigation, and plots were fertilized according to soil tests and university recommendations.

In the standard herbicide weed management system (STD), metribuzin was broadcast applied preemergence (PRE) at 0.4 kg ai/ha on May 10, 1994 and May 11, 1995. In 1994, plots were sprinkler irrigated with 0.65 cm of water immediately after herbicide application, and in 1995 plots received 0.68 cm of rainfall on the day of application. Metribuzin was applied with a bicycle CO_2 sprayer delivering 190 L/ha at a pressure of 190 kPa through six flat fan nozzles spaced 51 cm apart.

In the rye cover crop with herbicide-banded and reservoir-tilled weed management system (RYESTD), rye cv. 'Wheeler' was drilled on 16-cm centers at 106 kg/ha on August 30, 1993 and at 122 kg/ha on September 12, 1994. The following spring, glyphosate was applied at 1.1 kg ai/ha on April 8, 1994 and April 10, 1995 to kill rye. Rye biomass was determined by drying and weigh-

ing plants clipped from a 1-m^2 quadrat per plot just before incorporation. Rye residues were incorporated into the soil with a tractor-mounted roto-tiller operated 12-cm deep 2 to 3 d after glyphosate application. Metribuzin was applied at 0.4 kg/ha in a 30-cm band over the potato hill on May 10, 1994 and May 11, 1995. Herbicide was applied with a bicycle CO_2 sprayer delivering 190 L/ha at a pressure of 190 kPa through 8,002 even flat fan nozzles centered over each potato hill. Plots were reservoir tilled with a Dammer Diker[3] on May 24, 1994 and May 25, 1995 when the potato plants were 15-cm tall.

In the rapeseed cover crop and reservoir-tilled weed management system (RPSD), rapeseed, cv. 'Jupiter' was broadcast seeded at 10 kg/ha on August 5, 1993 and at 12 kg/ha on August 29, 1994. Rapeseed was killed with glyphosate at 1.1 kg/ha on April 8, 1994 and April 10, 1995, and rapeseed was incorporated 12-cm deep into the soil using a tractor-mounted roto-tiller 3 d later. Rapeseed biomass was determined by drying and weighing shoots clipped from a 1-m^2 quadrat per plot just before incorporation. Plots were reservoir tilled on May 24, 1994 and May 25, 1995 when the potato plants were 15-cm tall.

In the total-cultivation weed management system (CULT), hills were harrowed with a tine-tooth, power harrow on May 10, 1994 and on May 11, 1995, when weeds were just beginning to emerge and potato shoots were 5 to 8 cm below the soil surface. Plots were hilled with rolling cultivators and shovels on May 27, 1994 and May 26, 1995. No herbicide was applied or additional tillage performed.

The final system consisted of one reservoir tillage on May 10, 1994 and May 11, 1995, when small weeds were just beginning to emerge and prior to potato emergence (reservoir-tilled weed management system [RESTIL]). No additional cultivation, green manure crop, or herbicides were used. A nontreated check, in which a no-cover crop, no-cultivation, no-herbicide weed management system (CHECK) was used, was also included.

Early-season weed density was determined on May 18, 1994 and May 24, 1995 by counting the number of emerged plants in two 0.23 m^2 quadrats per plot, one centered in the row (IR) and one centered between the rows (BR). Weed biomass was determined on August 31, 1994 and August 22, 1995 by drying and weighing shoots from three 1-m^2 quadrats, centered between the two middle rows of each plot.

Potato tuber yield was determined by digging and weighing tubers from 6 m of the two middle rows of each four-row plot on September 21, 1994 and September 18, 1995. Tuber size distribution and grading were determined from an 18-kg subsample from each plot, and specific gravity was measured on 10 tubers weighing 230 to 280 g from each plot.

Data from both years were combined and subjected to analysis of variance (ANOVA), and treatment means were separated by the least significant difference test at the 5% level. When ANOVA indicated a significant year by treatment effect, the data from each year were presented separately.

RESULTS AND DISCUSSION

Fall-seeded rapeseed and rye produced 5,400 and 3,600 kg/ha shoot dry weight, respectively, in 1994 and 5,300 and 7,200 kg/ha, respectively, in 1995. The lower production of rye in 1994 than in 1995 was partly caused by uncontrolled grazing by deer in 1994. Root biomass of rapeseed and rye was not measured, but may suppress weeds as much or more than shoots (Eberlein et al. 1998, Hoffman et al. 1996). The main weeds present in 1994 were green foxtail [*Setaria viridis* (L.) Beauv. #[4] SETVI], barnyardgrass [*Echinochloa crus-galli* (L.) Beauv. # ECHCG], redroot pigweed (*Amaranthus retroflexus* L. # AMARE), hairy nightshade (*Solanum sarrachoides* Sendtner # SOLSA), and common lambsquarters (*Chenopodium album* L. # CHEAL). In 1995, the major portion of the weed population consisted of redroot pigweed, common lambsquarters, hairy nightshade, and Russian thistle (*Salsola iberica* Sennen & Pau # SASKR).

There was a significant year by weed control treatment interaction for early-season IR and BR weed density, therefore each year is presented separately. In both years, early-season IR weed density was greatest in the RESTIL and CHECK systems and ranged from 81 to 109 plants/m^2 in 1994 and from 25 to 37 plants/m^2 in 1995 (Table 2). No herbicide, cover crop, or IR cultivation was used in these two weed management systems. Reservoir tillage implements can be equipped with wings near the ripping shank to throw soil on the hill and bury small weed seedlings, but the implement used in these experiments did not contain wings. Weed emergence was delayed, and early-emerged weeds were smaller in RPSD and RYESTD plots than in RESTIL plots, so RPSD and

[3] Ag Engineering and Development Co. Inc., Kennewick, WA.

[4] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

Table 2. Early-season weed density and late-season weed biomass in potato grown using six different weed management systems in 1994 and 1995.[a]

	Weed density					
	In Row		Between Rows		Weed biomass	
Treatment	1994	1995	1994	1995	1994	1995
	no./m²				g dry wt/m²	
STD	33 b	2 c	7 c	3 c	75 c	35 c
RYESTD	11 b	2 c	4 c	4 c	150 c	50 c
CULT	1 b	5 c	0 c	7 c	225 c	75 c
RPSD	24 b	15 bc	45 a	21 b	740 b	730 b
RESTIL	109 a	25 b	3 c	0 c	1140 a	935 ab
CHECK	81 a	37 ab	30 b	34 a	1045 a	1225 a

[a] Means within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's protected LSD test.

RYESTD plots were reservoir tilled 14 d later than RESTIL plots in both years.

In both years, early-season IR weed density was reduced similarly in the STD, RYESTD, RPSD, and CULT systems, compared to the CHECK system, and ranged from 1 to 33 plants/m² (Table 2). Most weed seedlings that emerged in the STD and RYESTD systems were shorter, and growth was restricted through the season (data not shown). More rapeseed residues were noticeable IR than BR, and the reduction in IR weed density in the RPSD system may have been caused by concentrating rapeseed residues in the hill with the planter closing disks during planting. Rapeseed residues have reduced early-season weed densities in previous studies (Al-Khatib et al. 1997; Boydston and Hang 1995; Krishnan et al. 1998).

Early-season BR weed density was greatest in the CHECK and RPSD systems and ranged from 21 to 45 plants/m² in these two systems in 1994 and 1995 (Table 2). RPSD plots had not been reservoir tilled when early-season weed density was measured. Early-season BR weed density was lowest in the STD, RYESTD, CULT, and RESTIL systems and ranged up to 7 plants/m². The low early-season BR weed density in the RYESTD system may have been caused by the presence of decaying rye residues which have suppressed weeds in numerous studies (Barnes and Putnam 1983; Lanfranconi et al. 1993; Putnam 1983; Wallace and Bellinder 1989). In the STD system, metribuzin reduced the emergence of early-season BR and IR weeds. Reservoir tillage and ditching shovels reduced early-season BR weed densities in the RESTIL and CULT systems, respectively.

Final weed biomass was greatest in the CHECK and RESTIL systems in both years and ranged from 935 to 1225 g/m² dry weight (Table 2). The early-season weed suppression BR in the RESTIL system did not decrease the late-season weed biomass. The RPSD system decreased late-season weed biomass compared with the CHECK system, but over 700 g/m² dry weight was still produced in both years. Rapeseed residues reduced the final weed biomass in potato further in a previous study in which weed densities were lower (Boydston and Hang 1995). Final weed biomass was reduced by 78 to 94% in the CULT system compared with the CHECK system and averaged 225 and 75 g/m² dry weight in 1994 and 1995, respectively (Table 2). Final weed biomass was lowest in the STD and RYESTD systems in both years (Table 2).

There were significant year by treatment interaction effects on the final tuber yield and the yield in various tuber weight classes, therefore data are shown for each year (Table 3). The final potato tuber yield and the yield of U.S. #2 or better tubers were greatest in the STD and RYESTD systems and averaged 61.5 and 59.5 metric ton (MT)/ha in 1994 and 62.3 and 63 Mt/ha in 1995, respectively (Table 3). Tuber yield in 1995 and yield of U.S. #2 or better in 1994 in the CULT system were the same as in the STD system. However, tuber yield in 1994 and yield of U.S. #2 or better in 1995 were 15 and 25% lower, respectively, in the CULT system compared with the STD system. A lower tuber yield was likely in the

Table 3. Potato tuber yield and tuber size distribution of potato grown under six weed management systems near Paterson, WA, in 1994 and 1995.[a]

	Tuber yield in weight categories											
	< 113 g		113 to 226 g		226 to 340 g		> 340 g		Total tuber yield		Yield ≥ U.S. #2[b]	
Treatment	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995
	metric ton/ha											
STD	10.8 ab	9.5 b	34.4 a	28.1 a	13.1 a	20.3 a	1.5 b	3.8 ab	61.5 a	62.3 a	48.7 a	52.5 a
RYESTD	11.3 ab	10.0 b	37.2 a	24.4 a	9.0 b	18.8 a	0.3 c	8.5 a	59.5 a	63.0 a	46.5 a	51.7 a
CULT	7.3 b	16.6 a	21.8 b	25.9 a	14.3 a	10.0 b	5.5 a	3.5 b	52.2 b	56.5 a	41.7 a	39.2 b
RPSD	17.8 a	12.6 ab	24.8 b	21.3 ab	0.3 c	7.5 bc	0.0 c	3.8 ab	42.9 c	45.7 b	24.9 b	32.6 bc
RESTIL	11.0 ab	12.8 ab	2.8 c	17.3 b	0.0 c	4.5 bc	0.0 c	1.0 b	14.1 d	37.2 b	2.8 c	22.9 c
CHECK	7.8 b	13.8 ab	0.8 c	8.0 c	0.3 c	0.8 c	0.0 c	0.0 b	8.8 d	22.9 c	0.9 c	8.8 d

[a] Means within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's protected LSD test.

[b] U.S. #2 according to United States Department of Agriculture potato-grading standards.

CULT system because of a combination of competition from later-emerging weeds, root pruning, soil compaction, and covering of emerged potato plants with soil during hilling. Potato tuber yields were reduced in a previous study compared with hand-weeded checks when cultivation was the only method of weed control, and if weed densities were high (145 plant/m^2) (Eberlein et al. 1997). Nelson and Giles (1986) reported that cultivation reduced potato tuber yields up to 31%, whereas Chitsaz and Nelson (1983) reported no negative effects of cultivation on potato yield.

Uncontrolled weeds in the RPSD, RESTIL, and CHECK systems reduced total tuber yield and yield of U.S. #2 tubers or better compared with the STD and RYESTD systems in both years (Table 3). The lower tuber yields in the RPSD, RESTIL, and CHECK systems were mainly caused by lower tuber yields in the 113- to 226-g and 226- to 340-g weight categories (Table 3). Total tuber yield, yield of U.S. #2 or better, and yield of tubers in the 113- to 226-g weight category were greater in the RPSD system than in the RESTIL and CHECK systems in 1994 and in the CHECK system in 1995, which reflects the lower final weed biomass observed in the RPSD system than in the RESTIL and CHECK systems. In addition to the weed-suppressive effects from rapeseed, mineralized nitrogen from the decaying rapeseed residues and suppression of soil-borne diseases may have contributed to the increased tuber yield of the RPSD system compared with the CHECK system. Total tuber yields in the CHECK system were 86 and 63% lower than in the STD system in 1994 and 1995, respectively (Table 3). There were no differences in potato specific gravity among weed control systems in either year (data not shown), which averaged 1.089 and 1.086 in 1994 and 1995, respectively.

This study demonstrates the benefits of cultivation, cover crops, and metribuzin for controlling weeds in potato and preventing yield losses associated with weeds. The STD system controlled weeds and prevented tuber yield losses and would be the easiest and least costly system for growers to implement (Table 1). However, the many known benefits of cover crops would not be realized in the STD system. The RYESTD system, which combined the use of rye residues, banded metribuzin, and reservoir tillage, controlled weeds in potato equal to a standard broadcast application of metribuzin, while reducing metribuzin input by 66%. Many potato growers apply herbicides through sprinkler irrigation systems, therefore adoption of banding herbicide applications may be slow unless the savings in herbicide costs by banding outweigh the cost savings and convenience of applying herbicides through sprinkler irrigation systems.

The RPSD system did not suppress weeds enough in this study to prevent tuber yield loss, but yields were greater than in the RESTIL and CHECK systems. This suggests that the rapeseed residue did provide some weed suppression. However, on the basis of early-season BR weed densities, rye residues suppressed weeds more than rapeseed residues. Combining rapeseed or other cover crop residues with cultivation and reduced rate or banded herbicides may offer results similar to those obtained with the RYESTD system in these studies. Other benefits of rapeseed, such as suppression of nematodes and diseases, may make it an appealing cover crop. The addition of cover crops into a crop production system increases input costs because of cover crop seedbed preparation, planting, seed costs, and glyphosate application required to kill the cover crop (Table 1). However, some growers plant a cover crop of winter wheat to reduce soil erosion, and so are already incurring these costs.

The CULT system controlled weeds early in the growing season, but potato yield was not consistently maintained, and input costs were substantially higher than in the STD system (Table 1). Growers who currently combine early-season cultivation with herbicides applied after the final hilling may be able to forego a herbicide application in some years without sacrificing the potato yield. However, these results suggest that the use of a combination of cover crops, cultivation, and herbicides can control weeds, reduce PRE-applied herbicide inputs, and maintain potato yield.

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