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Managing Weeds with Reduced Herbicide Inputs: Developing a Novel System for Onion

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1. Introduction

Weeds are a major challenge in crop production. Often weeds cause significant yield losses and even a few weeds producing seeds can cause weed problems in subsequent years. For example, sicklepod (*Senna obtusifolia)* average seed production is 8,000 seeds per plant (English and Oliver, 1981). Chemical weed control methods have been shown to be one of the most cost effective weed control options (Pike et al., 1991). Herbicides dominated the pesticides used in the United States during 2004 and accounted for two-thirds of the approximately $8.5 billion spent on agricultural pesticides (Padgitt et al., 2000). However, with the weed control benefits from herbicide usage also came environmental and health concerns. These concerns have resulted in much research on the safety of each chemical. Most of these environmental and health concerns are dealt with prior to herbicide registration. Manufacturers conduct numerous experiments in order to accurately determine product utility, market value, and regulatory needs. These experiments include toxicity trials to a wide range of organisms to determine the product's safety to plants, animals, and environmental fate. In addition, an enormous amount of testing is done for product quality and efficacy. Considering the vast investment that a manufacturer has incurred prior to product launch and the relatively short period of time to recoup their investment before the product is off patent, it becomes crucial that a product is registered quickly and at the lowest effective use rate. Recommending rates above this rate would potentially lead to widespread rate reductions, while recommending rates below this rate would potentially lead to widespread performance issues. With either scenario, the manufacturer's ability to recoup their investment becomes greatly reduced.

2. Industry perspective

Doyle and Stypa (2004) indicated that herbicide rates are selected on the basis of maximized product value. Therefore, a rate structure is selected which provides an optimum investment return for the conditions of the target market. In other words, rates are selected that will satisfy producer weed control expectations under the environmental conditions where the crop(s) is generally grown. For many of the commodity crops, these growing conditions can vary greatly and are considered when the product rate structure is selected. In addition, manufacturers realize that weed species differ in their susceptibility to a specific herbicide and that the labeled rate for this herbicide may be higher than what is needed for certain weed species, but because the rate range selected needs to be efficacious to as many weeds as possible, rates will be high for some weed species.

3. Weed management decisions

When chemical weed control decisions are made, many questions need to be considered, including the need to spray an herbicide, which product to use, and when, where and how to apply that product. In all of these considerations, there are opportunities to reduce the risks associated with herbicide use. However, a producer will not adopt these practices if there is a resulting crop yield loss, increase in field weed populations, uninsured profitability, or increased environmental risk. Unfortunately, as agricultural profit margins decrease, producers search for ways to control input costs which includes how they manage weeds.

For most field cropping systems, herbicide usage comprises approximately 20 to 30% of the input costs (Derksen et al., 2002). One may wonder if the cost-cutting approach of applying herbicides at reduced rates is worth the risk. However, in Canada, a 10% reduction in herbicide usage, without crop yield reduction or increased field weed populations would save producers $85 million. This 10% herbicide use reduction could occur by either avoiding the need to apply the herbicide because weed densities were kept below economic threshold levels or by reducing herbicide rates. Eliminating herbicide use would alleviate the potential controversy with off-label applications, but would only be successful for the most vigorous and competitive cropping systems (Van Acker et al., 2001).

Deciding when to control weeds requires detailed knowledge of the weed populations in the field, the potential interference from those weeds, and the potential benefit obtained from controlling the weeds. When producers relied on preemergence herbicides for weed control in a specific crop, it was important to scout for weeds prior to harvest so that the weed potential for the following year could be assessed. However, over the past 20 years or so with the introduction of postemergence herbicides, this reliance has changed (Blackshaw et al., 2006).

3.1 Early weed identification

It is critical that weed species be identified early in the season. This can be accomplished by routinely scouting fields, but can also be challenging since many species have similar appearances at the cotyledon stage. Numerous training aids are available to ensure that unfamiliar species are identified correctly and that appropriate management options are employed. Whole fields should be scouted and weed patches, low spots and field margins should be considered separately, since they do not represent the entire field. Scouting these fields later in the season will provide valuable information on the species and numbers of weeds that have escaped control and added to the weed seed reservoir. This information is needed for long-term weed management planning.

4. Yield loss factors

Yield loss from weeds depends on many factors including competitive abilities of the crop and weeds. Adequate weed control with reduced herbicide rates can be successful by increasing the competitiveness of the cropping system and incorporating an integrated weed management system (Mohler, 2001; Mulugeta and Stoltenberg, 1997; Swanton et al., 2008). Fodor et al., (2008) showed that a competitive crop utilizes resources before the weeds. This will only occur if a good crop stand is established for a vigorous growing crop. They concluded that crop rotation, seedbed preparation, crop type and variety selection, seed quality and treatment, seeding rate and stand density, seeding date, fertilizer rate and placement, and pest and disease control influenced crop competitiveness and that the failure to manage all components promoted weed competition with the crop. Similar research has identified cereal traits such as plants taller than their neighbors, with many horizontal leaves and a vigorous root system as traits that would enable these plants to effectively capture light, water and nutrients from neighboring plants and contribute to plant competitiveness (Donald and Hamblin, 1976; Lemerle et al., 2001). The field pea (*Pisum sativum*) 'Jupiter' had the greatest tolerance to competition and the ability to suppress weed growth compared to 10 cultivars ranked low to medium in their tolerance to competition and their ability to suppress weeds (MacDonald, 2002). Unfortunately, cultivar studies have shown to vary considerably between years and locations (Cousens and Mokhtari, 1998).

5. Competitive cropping system components

Components of a competitive cropping system include: diverse crop rotations, competitive crop cultivars, higher seeding rates, reduced row spacing, specific fertilizer placement, and the use of green manures or cover crops (Derksen et al., 2002; Blackshaw et al., 2006). Lemerle et al. (1995) ranked several annual winter crops for their competitiveness against annual ryegrass (*Lolium multiflorum*) in Australia. Oats (*Avena sativa*) was determined to be the most competitive with only 2 to14 % yield reduction from annual ryegrass at a density of 300 plants/m^2. Rye (*Secale cereale*) was the second most competitive crop with a yield reduction of 14 to 20%. Both field pea and narrowleaf lupine (*Lupinus angustifolius)* were the least competitive with 100% yield reduction. In Canada, the competitive ranking of crops from highest to lowest was: barley = rye > oats > canola (*Brassica spp.)* = wheat (*Triticum aestivum*) > peas = flax (*Linum sitatissimum).* Thus the competitiveness of a crop can vary depending upon growing conditions and the weed species.

5.1 Diverse crop rotations

Diverse crop rotations and the use of green manures or cover crops have historically been recognized to be beneficial for crop production. Rotating between distinctly unrelated crops will result in higher grain yields compared to continuous cropping of wheat (Table 1). For example, seeding wheat to an area that was barley (*Hordeum vulgare*) the year before resulted in a 12.5% increase, on average, in wheat yield compared to continuous wheat. However, if wheat was seeded to an area that was soybean (*Glycine max*) the previous year, the average wheat yield increase, compared to continuous wheat, was 42.9%. Some of the benefits from a well-planned, diverse, crop rotation include: reduced insect and disease problems, improved soil fertility, improved soil tilth and aggregate stability, better soil water management, reduced soil erosion, and reduced allelopathic effects. Diverse crop rotations can also discourage weed establishment and reduce weed seed production due to different planting and harvest times that disrupt the weed species lifecycles.

	Wheat yield, t/ha								
Previous crop	1977	1978	1979	1980	1981	1982	1983	1984	8-yr. avg.
Wheat	1.5	1.7	2.4	2.5	2.3	2.6	2.9	1.1	2.1
Barley	1.8	1.7	2.4	2.5	2.8	3.1	3.2	1.2	2.4
Flax	2.1	2.5	2.4	2.4	2.5	3.2	2.9	2.5	2.6
Corn	2.1	2.2	2.9	2.5	3.0	3.6	2.6	2.6	2.6
Soybean	2.8	2.9	2.8	2.8	3.0	3.2	3.6	3.0	3.0
Sunflower	2.0	2.2	3.0	2.8	3.0	2.6	2.9	3.0	2.7
Sugarbeet	2.3	2.3	2.8	2.6	3.0	2.9	3.5	3.2	2.8

Table 1. Wheat yields under conventional tillage when seeded the year following the various previous crops, Fargo, ND. Adapted from Peel, 1998.

5.2 Cover crops and living mulches

Producers have used cover crops to give a crop a competitive edge over weeds. Planting the correct cover crop after the harvest of a crop will help to reduce erosion, reduce nutrient leaching, improve soil structure, and suppress weed emergence. Gallandt (2009) measured common lambsquarters (*Chenopodium album*) weed seed rain for four years in a vegetable rotation of broccoli (*Brassica oleracea*) and winter squash (*Cucurbita moschata*) managed with no cover crop (control), fall cover crop (fall CC), two consecutive years of red clover (2-yr. CC), and alternate years of vegetable and cover crops with a summer fallow (alt.-yr. CC) (Figure 1). It was suggested that the alternate years of vegetable and cover crops with a summer fallow had lower common lambsquarters seed rain because the fallowing periods during the cover crop years depleted the seedbank, thus prevented common lambsquarters from increasing.

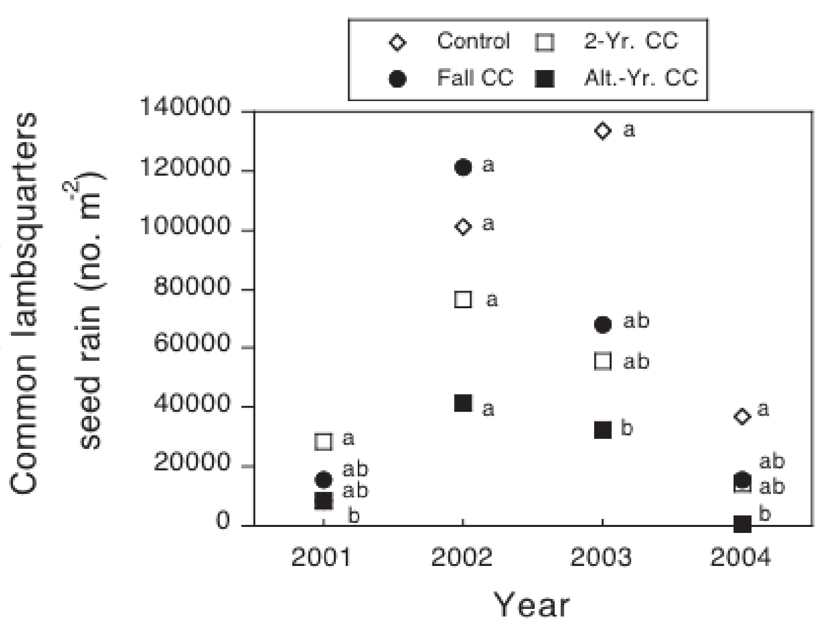

Fig. 1. Effect of cover crop systems on common lambsquarters seed rain in 2001 through 2004. Means within a year with different letters are significantly different from each other at the P ≤ 0.05 level (Tukey's HSD). Adapted from Gallandt, 2009.

Cover crops have been used as living mulches for weed management. Perennial living mulches such as crownvetch (*Securigera varia*), flatpea (*Lathyrus sylvestris*), birdsfoot trefoil (*Lotus corniculatus*), and white clover (*Trifolium repens*) do not have to be reseeded each year and can be used to conserve nitrogen, reduce soil erosion, and increase soil organic matter, while they reduce weed population and crop yield losses due to weeds (Hartwig and Ammon, 2002).

5.3 Crop density

In general, an increase in crop density will increase the crop's competitiveness against weeds. This increase in crop density can occur by increasing the seeding rate, decreasing the space between rows, or both. Increasing wheat seeding rate from 175 to 280 plants/m^2 increased wheat yield while reducing wild oat biomass and seed production (Stougaard and Xue, 2004). However, Anderson et al. (2004) showed that if higher seeding rates were being used to improve the competitiveness of a wheat crop, it is important to optimize the seeding rate for yield and quality based on pre-seeding rainfall and growing season rainfall (Table 2). There is also an economical seeding rate optimum. Increasing the seeding rate of canola can allow the crop to compete better with weeds, but increasing the seeding rate above 150 seeds/m^2 reduced the profitability of the crop (Upadhyay, 2006).

PSR (mm)	GSR (mm)	Yield expectation (t/ha)	Minimum population needed (plants/m^2)	Approximate sowing rate (kg/ha)
0	150	1.50	60	22
	200	2.25	90	39
	250	3.00	120	56
100	200	2.55	102	47
	250	3.30	132	65
	300	4.05	162	86
200	250	3.60	144	76
	300	4.35	174	92
	350	5.10	204	116

Table 2. Estimates of minimum wheat plant population (plants/m^2) based on pre-seeding rainfall (PSR, mm) and rainfall in the growing period (GSR, mm) in Western Australia. Adapted from Anderson et al., 2004.

Another method to increase the stand density is by reducing the spacing between rows. Reduced row spacing has been shown to increase the crop competitiveness over weeds (Tharp and Kells, 2001; Willingham et al., 2008). Often the narrower-row spacing and reduced herbicide rate had similar weed control as the same crop at the wide-row spacing regime and herbicide applied at the manufacturer's suggested use rate.

The use of the twin-row system is another way to reduce the spacing between rows and has also resulted in increased yields for several row crops (Grichar et al., 2004; Willingham et al., 2008.) The twin-row system resulted in greater ground cover, leaf area indices, light interception at the canopy, and crop growth rate compared to the single wide-row system.

However, Grichar (2007) showed that narrower row spacing or twin-row planting does not always result in higher yields or increased net returns (Table 3). In addition, broadleaf crops seem to be less sensitive to row spacing than cereals. Thus, it is important to match the row spacing and seed rate in order to obtain a plant density that optimizes crop yield and competition against weeds.

Seeding rate (seeds/30.5 cm)	Row spacing	El Campo	Pt. Lavaca	El Campo	Pt. Lavaca
		2003		2004	
6	38-inch	5.4	5.2	5.6	4.8
	twin	11.1	9.8	11.3	8.6
10	38-inch	8.7	9.1	7.7	5.7
	twin	17.1	16.5	16.8	14.1
15	38-inch	7.1	7.4	6.7	5.5
	twin	14.8	14.2	14.1	10.7
$LSD_{0.05}$		1.2	1.8	1.0	2.0

Table 3. Soybean plant populations (plants/30.5 cm) as influenced by row spacing and seeding rates in 2003 and 2004 at El Campo and Pt. Lavaca, TX. Adapted from Grichar, 2007.

5.4 Fertilizer placement

The importance of specific fertilizer placement for a competitive crop was indicated by Fodor et al., (2008) when they concluded that a competitive crop utilizes resources before the weeds. They compared three planting dates for winter wheat and two nitrogen rates as a spring top-dressing application. Results indicated that delayed planting led to reduced wheat growth and greater weed biomass production and that the higher rate of nitrogen resulted in fewer weeds for the early and optimum time seeded plots. In contrast, the higher rate of nitrogen resulted in more weeds for the late seeded treatment.

6. Integrated weed management principles

Integrated weed management systems primarily utilize specific weed assessment; weed population ecology; understanding of economic thresholds; knowing the critical period for control; knowing the competitiveness of the crop; and understanding an herbicide's biologically effective dosage (Knezevic et al., 2002; Liebman and Gallandt, 1997; Swanton et al., 2008). The critical period of weed control is the span of time during the crop growth cycle when weeds must be controlled to prevent yield losses (Mohler, 2001). The best time to control weeds and the length of the critical period depend on a number of variables including weed emergence timing, weed densities, the competitive ability of weeds compared to crops, and environmental factors. Knezevic et al. (2002) suggested a standardized method for data analysis of critical period for weed control trials so that uniform decisions could be made on the weed control need and application timing, and to obtain efficient herbicide use from both biological and economical perspectives.

Unfortunately, most competitive studies have been conducted with agronomic crops. These crops have many weed management options and the ability to utilize several competitive cropping system components. For example, a multiyear study was conducted to compare weed management in wheat, barley, canola, and field pea using full or reduced herbicide rates, crop rotation, seeding date, seeding rate, and fertilizer timing (Blackshaw et al., 2005a, 2005b). They reported that after four continuous years, the weed seed bank did not differ when 50% of the herbicide rate was used as long as the crops were seeded early, at a high crop seeding rate, and with spring-applied banded fertilizer. The most obvious question is what components of a competitive cropping system and integrated weed management methods could be used to reduce herbicide inputs in a noncompetitive crop?

7. Poor crop competitiveness of onion

Onion (*Allium cepa*) is considered a poor competitive crop because the plant generally emerges later than many cool-season weeds and is very susceptible to weed canopy coverage and competition for light (Dunan et al., 1999). Morphological traits of onion include a shallow root system, slow establishment period, and long, narrow, erect leaves. These morphological traits have resulted in blow-out areas or extensive damage to newly emerged onion seedlings when high winds or storms pass through an area (Greenland, 2000). To reduce wind erosion, growers plant barley between the onion rows as a companion crop. The barley emerges quickly in comparison to onion, but also further complicates weed management issues since the grower does not want to reduce barley germination, but will need to kill the barley before it competes with onion. The barley is killed with an application of a postemergence grass herbicide when plants are 4 to 6 in tall. The companion crop has reduced onion establishment issues associated with wind erosion, but also requires additional herbicide input. Additionally, rainfall and wet conditions may delay the grass herbicide application, causing competition between barley and onion, resulting in reduced onion yield (Hatterman-Valenti and Hendrickson, 2006).

Weed competition is a severe problem throughout onion establishment and maturation (Swaider et al., 1992). The inability of onion to morphologically produce a sufficient canopy allows early-season in-row weeds, such as common lambsquarters and redroot pigweed (*Amaranthus retroflexus*), to substantially reduce yield (Boydston and Seymour, 2002).

7.1 Critical period for weed removal

The effect of day length on onion bulb initiation was the most important factor determining the critical period for weed removal (Bond and Burston, 1996). Growth switches from leaf production to bulb development for long-day onion varieties when day length reaches 14 to 16 hours. Weed competition before bulb development slows leaf production, which reduces bulb size at harvest. Weeds uncontrolled in the onion row at emergence and 2 weeks after emergence resulted in complete loss of the onion crop (Wicks et al., 1973). Bond and Burston (1996) concluded that optimum time to control weeds varied from 21 to 56 d after 50% crop emergence, but single and multiple hand-weeding did not consistently prevent yield losses.

Herbicides applied once, either preemergence or postemergence, are not sufficient for season-long broadleaf weed control and adequate onion yields (Ghosheh, 2004). The long season needed to grow large-diameter onion allows for successive flushes of weeds, which makes consecutive weed control activities necessary. Additionally, most herbicides cannot be applied to onion until the two-true-leaf stage due to label restrictions.

8. Herbicide micro-rate introduction

Micro-rate herbicide treatments in onion were developed from the pioneering research of North Dakota State University and University of Minnesota extension specialist Dr. Alan G. Dexter in sugarbeet (*Beta vulgaris*) (Woznica et al., 2004). The micro-rate program uses herbicides applied at reduced rates approximately 50 to 75% compared to recommended rates and reapplied three to five times at 5- to 7-day intervals (Zollinger et al., 2008). Smaller broadleaf weeds were easier to control and required less herbicide to control with the micro-rate program. Also, crop safety increased and less herbicide per area per season was used. Multiple applications also widened the application window allowing the grower to control multiple weed flushes. In addition, the micro-rate program increased the economic return from the purchase of less herbicide (Dale, 2000).

8.1 Micro-rate evaluation on onion

Early season similarities in establishment and herbicide sensitivity for sugarbeet and onion suggested that the micro-rate program may be adapted to onion. Initial testing occurred in the greenhouse to evaluate any postemergence herbicide with activity on annual broadleaf weeds. Reduced rate applications were made to onion, common lambsquarters, and redroot pigweed in the cotyledon to first-true-leaf stage. Any herbicide that caused severe injury to onion was eliminated. Herbicides for field testing were narrowed to four: acifluorfen, bromoxynil, metribuzin, and oxyfluorfen at 0.25X, 0.13X, and 0.06X, where "X" was the lowest labeled herbicide rate, with either two or three sequential applications at a 7-day interval. Initial applications were made when broadleaf weeds reached the first-true-leaf stage. Depending on the year and location, onion were not emerged, in the loop stage, or in the flag-leaf stage when the first micro-rate application was made. A hand-weeded control and grower standard practice were included for comparison.

The grower standard practice consisted of a preemergence application of DCPA immediately following planting and a postemergence application of bromoxynil and oxyfluorfen at the onion two-leaf stage. Dimethamid-P, bromoxynil and oxyfluorfen were applied to the entire study at the onion five-leaf stage. Best management practices were used for planting, fertility, irrigation, and pest control, and were identical for all plots at each location. Weekly weed counts were taken to evaluate weed control compared to the conventional herbicide standard and the hand-weeded check. A visual evaluation was taken approximately 2 weeks after the standard application to evaluate mid-season weed control using a 0 to 100% scale, where 0 is equal to no visible injury or no control and 100 equal to complete kill.

8.2 Weed control evaluations

The high rate of bromoxynil (70 g/ha) applied twice or three times provided the greatest early season control of common lambsquarters (Table 4) (Loken and Hatterman-Valenti, 2010). The similar control between two and three weekly applications suggested that ideally, the producer would have seen that there wasn't an additional weed flush after the second week, thus would not have made the third application.

The high rate of bromoxynil and the high rate of oxyfluorfen provided the greatest early season control of redroot pigweed (Table 4). Three sequential micro-rate applications provided greater control than two sequential micro-rate applications averaged over all herbicides (data not shown). Some redroot pigweed continued to emerge after the last micro-rate application, suggesting that additional micro-rate applications should be considered to control later flushes and may be used to replace a standard bromoxynil plus oxyfluorfen application.

Onion injury was not observed the first year, but in the second year, onion treated with oxyfluorfen displayed approximately 15% injury. These seedling plants (one- to two-leaf) had leaves that were constricted at the soil surface. Constricted leaves occasionally resulted in onion seedling death, but most plants initiated the next true leaf after injury and outgrew the symptoms. Slight injury (approximately 5%) was noticed from bromoxynil at these locations, and all plants outgrew the injury symptoms. Environmental conditions may have contributed to this injury because the average daily temperatures from April to May during the second year were 1.7 °C cooler, with numerous cloudy days that may have enhanced herbicide injury.

		Common lambsquarters		Redroot pigweed	
Herbicide	Rate	Two[a]	Three	Two	Three
	g/ha	%			
Bromoxynil	18	35[c]	49	43	66
Bromoxynil	35	60	82	66	89
Bromoxynil	70	92	99	89	97
Oxyfluorfen	18	31	44	38	49
Oxyfluorfen	35	49	71	55	81
Oxyfluorfen	70	69	78	75	95
Metribuzin	5	38	35	34	38
Metribuzin	10	31	41	34	47
Metribuzin	21	38	54	48	63
Acifluorfen	18	32	32	31	44
Acifluorfen	35	30	38	32	54
Acifluorfen	70	43	56	62	76
DCPA[b]		79		58	
Hand weeded		100		100	
LSD (0.05)		13		12	

[a] Two and three refer to the number of applications in the micro-rate system.
[b] Conventional herbicide management check, DCPA (preemergence) at 11 kg/ha, bromoxynil (postemergence) at 280 g/ha, and oxyfluorfen (postemergence) at 1,120 g/ha.
[c] Visual estimates of weed control using a 0 to 100% scale, where 0 is equal to no visible control and 100 equal to complete kill.

Table 4. Effect of micro-rate herbicide treatments averaged across five locations on common lambsquarters and redroot pigweed percent control 2 weeks after the standard herbicide application to onion at the two-leaf stage. Adapted from Loken and Hatterman-Valenti, 2010.

Onion total yield generally mimicked weed control data, with the greatest total yield from those treatments that provided the greatest early-season broadleaf weed control, namely the three weekly herbicide applications (data not shown). Onion treated with oxyfluorfen (high rate, three applications) had the greatest large-grade and total yield, although total yield was similar to the yield with DCPA (Table 5) (Loken and Hatterman-Valenti, 2010). There was an herbicide by environment interaction for large-grade onion yield, which was attributed to the yield fluctuations in bromoxynil treatments due to common purslane (*Portulaca oleracea*) competition. Common purslane was present at two of the five locations. Bromoxynil does not control common purslane, therefore, at these locations; large-grade onion yield went from comparable or greater yields in comparison with oxyfluorfen treatments to significantly lower yields.

		Cull[a]		Small		Medium		Large		Total	
Herbicide	Rate	Two[b]	Three	Two	Three	Two	Three	Two	Three	Two	Three
	g/ha	t/ha									
Bromoxynil	18	0.1	0.2	3.8	4.5	4.2	3.8	1.9	0.8	9.9	9.3
Bromoxynil	35	0.2	0.1	4.0	4.3	4.3	7.5	1.1	4.7	9.6	17.0
Bromoxynil	70	0.0	0.1	3.9	4.0	10.0	9.9	5.2	6.0	20.0	20.0
Oxyfluorfen	18	0.2	0.3	3.4	3.3	5.6	6.6	1.5	4.8	11.0	15.0
Oxyfluorfen	35	0.2	0.2	3.9	3.8	7.7	9.3	6.2	13.0	18.0	26.0
Oxyfluorfen	70	0.1	0.1	3.7	3.0	8.2	9.1	11.0	18.0	23.0	31.0
Metribuzin	5	0.3	0.1	2.7	2.7	1.4	2.8	0.0	0.3	4.5	5.8
Metribuzin	10	0.2	0.3	2.3	3.8	2.3	3.3	0.9	0.7	5.6	8.1
Metribuzin	21	0.2	0.2	2.5	3.8	3.8	5.1	5.6	4.9	12.0	14.0
Acifluorfen	18	0.3	0.2	2.4	3.2	2.1	3.4	0.3	0.6	5.0	7.4
Acifluorfen	35	0.2	0.2	3.3	4.3	3.1	5.2	0.2	0.6	6.9	10.0
Acifluorfen	70	0.4	0.1	3.9	4.1	7.4	7.6	5.2	6.7	17.0	19.0
DCPA[c]		0.2		3.4		11.0		13.8		28.0	
Handweeded		0.1		4.7		12.0		9.9		26.0	
LSD (0.05)		0.2		NS		2.6		3.3		4.8	

[a] Cull: split or diseased bulbs, small: bulb diameter less than 2.5 cm, medium: bulb diameter 2.5-5.7 cm, large: bulb diameter greater than 7.6 cm.
[b] Two and three refer to the number of applications in the micro-rate system.
[c] Conventional herbicide management check, DCPA (preemergence) at 11 kg/ha, bromoxynil (postemergence) at 280 g/ha, and oxyfluorfen (postemergence) at 1,120 g/ha.

Table 5. Effect of micro-rate herbicide treatments averaged across five locations on cull-, small-, medium-, large-grade, and total onion yield. Adapted from Loken and Hatterman-Valenti, 2010.

9. Strip-tillage in onion

The use of strip-tillage has also been investigated to eliminate the use of a companion crop and the postemergence herbicide application to kill the companion crop. Strip-tillage, leaving wheat stubble between rows, was compared to conventional tillage with two preemergence herbicide treatments and two micro-rate herbicide treatments for two years. The remaining wheat stubble provided the needed structure to reduce wind erosion and the untilled area between onion rows may have reduced hairy nightshade (*Solanum sarachoides*) emergence (Table 6) (Gegner, 2009). Peachey et al. (2006) found at least an 88%

reduction in hairy nightshade populations when spring tillage was eliminated. In addition, the micro-rate treatments provided better hairy nightshade control. Micro-rate treatments also controlled early-season common lambsquarters and redroot pigweed (data not shown). A standard, mid-season herbicide application of bromoxynil and oxyfluorfen at 280.4 g/ha and 1120 g/ha, respectively, when onion reached the three-leaf stage, controlled mid-season, broadleaf weeds as well as many of the broadleaf weed escapes from the preemergence herbicide treatments, and resulted in no yield differences. However, in one of the two years, greater large-diameter onion, marketable onion, and total onion yields occurred with strip-tillage compared to conventional tillage (Table 7) (Gegner, 2009).

Herbicide		2007	2008
1WA2A		------------- plants/m²	----------
	Pendimethalin	100 a[c]	53 b[c]
	DCPA	50 b	132 a
	Oxyfluorfen	0 c	4 c
	Bromoxynil	3 c	11 c
1WA4A			
	Pendimethalin	0 a	33 b
	DCPA	0 a	50 a
	Oxyfluorfen	1 a	0 c
	Bromoxynil	1 a	0 c

[a] 1WA2A, 1 week after 2nd micro-rate herbicide application.
[b] 1WA4A, 1 week after 4th micro-rate herbicide application.
[c] Means for each application timing and year followed by the same letter are not significantly different according to Fisher's Protected LSD (0.05).

Table 6. Effect of herbicide on hairy nightshade density 1WA2A[a] and 1WA4A[b] at Oakes, ND, during 2007 and 2008. Adapted from Gegner, 2009.

Location		Small[a]	Medium	Large	Total	Marketable
Oakes 2007		-------------------	-------------------	t/ha	-------------------	-------------------
	Strip-till	10.8 a[b]	32.8 a	49.3 a	93.0 a	82.1 a
	Conventional	14.3 a	33.1 a	31.8 b	79.2 b	65.0 b
Oakes 2008						
	Strip-till	7.6 b	25.6 a	25.3 a	58.4 a	50.8 a
	Conventional	10.2 a	24.6 a	22.2 a	56.9 a	46.8 a

[a] Small: bulb diameter less than 2.5 cm, medium: bulb diameter 2.5-5.7 cm, large: bulb diameter greater than 7.6 cm.
[b] Means within each column and year followed by the same letter are not significantly different according to Fisher's Protected LSD (0.05).

Table 7. Effect of tillage on onion grade, total yield, and total marketable yield at Oakes during 2007 and 2008. Adapted from Gegner, 2009.

10. Conclusions

These results and other research conducted at North Dakota State University have shown that bromoxynil or oxyfluorfen applied at micro-rates can provide early-season annual broadleaf weed (common lambsquarters and redroot pigweed) control in onion and potentially replace the use of DCPA. The use of micro-rates also reduces the amount of bromoxynil and oxyfluorfen applied to onion. Conservation research results suggest that strip-tillage and bromoxynil or oxyfluorfen applied as micro-rates may be used to eliminate the use of a companion crop and further reduce the amount of herbicides applied to a noncompetitive crop such as onion without sacrificing yield or increasing weed numbers the following year. There is a continuous research effort to investigate ways to further reduce herbicide inputs in a noncompetitive crop such as onion. It is anticipated that adjuvant use and/or tank-mixing herbicide micro-rates would allow even lower herbicide rates and further reduce herbicide inputs when growing onion.

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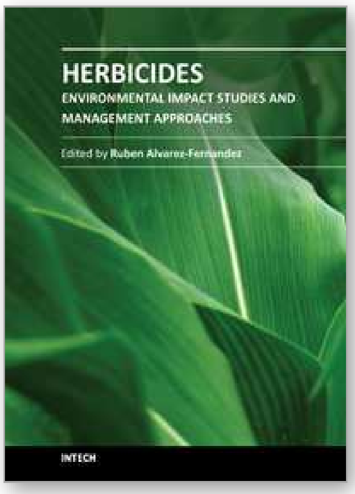

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Weeds severely affect crop quality and yield. Therefore, successful farming relies on their control by coordinated management approaches. Among these, chemical herbicides are of key importance. Their development and commercialization began in the 1940's and they allowed for a qualitative increase in crop yield and quality when it was most needed. This book blends review chapters with scientific studies, creating an overview of some the current trends in the field of herbicides. Included are environmental studies on their toxicity and impact on natural populations, methods to reduce herbicide inputs and therefore overall non-target toxicity, and the use of bioherbicides as natural alternatives.

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