Plant Biotechnology:
Current and Potential Impact
For Improving Pest Management
In U.S. Agriculture
An Analysis of 40 Case Studies
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Herbicide Tolerant Potato

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19. POTATO

Herbicide Tolerant

Production
Northwest states of Idaho (395,000A), Washington (170,000A) and Oregon (56,000A) have 621,000 acres planted to potatoes, representing 43% of U.S. acreage. Fifty-four percent of U.S. production of potatoes is located in these three states: 25.6 billion pounds per year (42,000lbs/A). The value of potato production in the three states is $1.3 billion per year, ($2,100/A) [8].

Weed Species
Weeds compete with potatoes for light, water, and nutrients and interfere with harvest operations. Dense weed infestations restrict the growth of potato plants, which results in undersized tubers. Potatoes are slow to emerge, offering little competition to weeds from the time of planting until the leaves fill the row [23]. All fields in which potatoes are grown contain billions of weed seeds [14].

The most common and troublesome weed species in Northwest potato production include annual grasses (barnyardgrass, foxtails), annual broadleaves (nightshade, lambsquarters, pigweeds, kochia) and perennials (quackgrass, Canada thistle) [1]. Table 19.1 shows estimates of the percent acreage of Pacific Northwest potatoes infested with specific weed species and the potential potato yield loss if the individual species are not controlled.

As can be seen, most fields (90%) are infested with the three common broadleaf species (lambsquarters, pigweeds and nightshades) and with the two most common grass weed species (foxtails, barnyardgrass). A smaller percentage of acres are infested with perennials including Canada thistle.

Fields with poor weed control can yield 20-40% less than their full productive potential. Annual nightshades are especially troublesome in potato crops since they survive well below the canopy of potato plants and often develop at the same growth rate. Perennial weeds limit yields more than annual weeds because perennials grow more vigorously.

Research has documented that one redroot pigweed or barnyardgrass per meter of row reduces tuber yield 19-33% [20]. Allowing foxtails to compete with potatoes for two weeks following crop emergence reduces marketable tuber yield by 29% [22]. Mixtures of annual weeds, primarily foxtails and pigweeds,
reduce potato yields an average of 54% when weeds emerge one week after planting and compete all season [24]. Following crop emergence, a two-week delay in the removal of quackgrass reduces marketable potato yields by 27% [23].

**Weed Control - Historical**

Prior to the introduction of chemical weed killers, potato producers relied primarily on the use of cultivators for removing weeds. Potatoes were not planted in rows, but were planted individually, about three feet apart on all sides. Cultivators, thus, were able to pass both ways in a field, on all four sides of each plant, to remove weeds [15]. Although timely cultivations provided adequate weed control, considerable plant damage and root pruning by the cultivation equipment lowered yields.

Up until about 1960, insignificant amounts of herbicides were used in Northwest potato fields. The increased use of solid set sprinkler irrigation created greater interest in chemical weed control. Effective chemical weed control eliminated the need for moving irrigation pipe, once it was set in the field [3]. Previously, growers had to remove the irrigation pipe each time they cultivated. By the late 1960’s chemical weed control had become an integral part of potato production. The use of herbicides reduced the need for numerous cultivations, eliminated the need for planting the potatoes individually and led to increased potato yields. By facilitating the control of weeds in rows of potatoes, herbicide use led to potatoes being planted closer together, thereby doubling yields [15].

**Herbicide Use**

The primary weed control practice in Pacific Northwest potato production is a combination of a timely hilling operation plus one or more herbicide applications [30]. As a result, over 90% of Pacific Northwest potato acreage receives at least one herbicide application.

In the Northwest, cultivation and herbicides are used during the second and third week after planting in order to keep weed pressure down. Most of the herbicide applications are made after hilling just prior to potato emergence. These herbicides must be applied via chemigation or incorporated with the appropriate amount of water shortly after application to move them into the weed seed germination zone and activate them before weeds emerge. Timing the hilling operation to take full advantage of the residual activity of soil-applied herbicides also is important for maximizing weed control in potato production. Building the
hill two or three weeks after planting, then applying herbicides as soon after hilling as possible, usually provides weed control later into the season than building the hill at planting and applying herbicides shortly thereafter [13].

Metribuzin has been a standard component in weed management programs in Northwest potatoes for the last twenty years because it is effective on many broadleaf weeds (lambsquarters, pigweeds, ragweed) and grasses (crabgrass, barnyardgrass, foxtail) [12]. (Metribuzin was used on 60% of Idaho’s, 41% of Oregon’s and 55% of Washington’s potato acreage in 1979 [5].) Metribuzin controls a broad spectrum of broadleaf and grass weeds common to the Pacific Northwest, but its use has led to increased populations of metribuzin-tolerant weed species such as hairy nightshade and cutleaf nightshade and to the development of triazine resistant weed populations [12]. Metribuzin can be applied either preemergence (before weed emergence) or postemergence (after the weeds have emerged). Most other potato herbicides will not control emerged weeds and are limited to applications preemergence to the weeds (metolachlor, EPTC, trifluralin, pendimethalin).

Use of metribuzin postemergence is limited because of potato varietal sensitivity, with short-season red or white potato cultivars being less tolerant. Also, three consecutive days of sunny weather are needed before applying metribuzin postemergence in order to avoid crop injury [12]. Injury symptoms include a yellowish cast to the potato field and slight leaf margin necrosis.

In 1989 a triazine resistant biotype of Powell amaranth was discovered near Jerome, Idaho in a potato field that had been treated with metribuzin [16]. Triazine resistant Powell amaranth can be controlled with soil applied herbicides such as EPTC, metolachlor, pendimethalin, and trifluralin.

Most of the herbicides must not be applied to potato foliage because of the potential for crop injury. And most must be applied prior to weed emergence. Due to the poor competitive ability of potatoes early in the season, growers rely primarily on soil-applied herbicides which are generally combined for control of annual broadleaf and grass weeds as they germinate. Most perennials tolerate herbicides used on potatoes. Early season tillage usually limits perennial weeds.
Since nightshades and potatoes are in the same plant family, most herbicides that control nightshades are injurious to potatoes [14]. Season long control of hairy nightshade is difficult to achieve because the weed germinates throughout the growing season [31]. Nightshade infestations have increased in part because several herbicides commonly used in potatoes such as trifluralin, pendimethalin, and metribuzin do not control these species adequately [34]. EPTC and metolachlor control early germinating nightshades but nightshades that germinate after herbicides have dissipated escape control. Hairy nightshade that escapes control with herbicides applied preplant incorporated or preemergence or that germinate and emerge after soil applied herbicides have dissipated cannot be controlled adequately with postemergence metribuzin applications.

For many years, potato growers could use only two herbicides for postemergence weed control: sethoxydim and metribuzin. Sethoxydim controls only grass weeds and metribuzin does not provide consistent control of troublesome Solanaceous weeds such as hairy nightshade nor does it control triazine resistant weeds such as Powell amaranth. In 1996, a new herbicide active ingredient was registered for potatoes, rimsulfuron, which also can be applied either preemergence or postemergence, and controls a number of both broadleaf and grassy weeds. Research has demonstrated that rimsulfuron has activity on grass and broadleaf weeds, with weed control being optimum when combined with metribuzin [19]. Research demonstrated that rimsulfuron provides much better hairy nightshade control than does metribuzin; however rimsulfuron does not control cutleaf nightshade [4]. Rimsulfuron is very effective on pigweed. Rimsulfuron also does not provide acceptable postemergence control of common lambsquarters or Russian thistle, ubiquitous weeds in Northwest potato fields [4].

ALS resistant kochia and Russian thistle are now widespread in Southern Idaho, therefore rimsulfuron needs to be combined with other herbicides for their control. Rimsulfuron plus metribuzin may not provide acceptable hairy nightshade control when populations are high [32]. In heavily infested fields three way mixtures improve control. EPTC and metolachlor are effective grass herbicides and provide some hairy nightshade control. Research demonstrated that 95% control of hairy nightshade and foxtails could only be achieved with three way mixtures of metribuzin, rimsulfuron, and pendimethalin, metolachlor or EPTC. If the predominant weeds are pigweeds and /or lambsquarters, then rimsulfuron plus metribuzin may provide satisfactory control. However, in fields heavily infested with hairy nightshade and/or foxtail, rimsulfuron plus metribuzin may not provide adequate control. In heavily
infested fields, adding EPTC, metolachlor, or pendimethalin to rimsulfuron plus metribuzin can improve hairy nightshade and green foxtail control.

In addition to ground applications, preemergence application of EPTC, metolachlor, pendimethalin, trifluralin, metribuzin or rimsulfuron can be applied through irrigation systems [33].

Northwest potato growers apply 2.3 pounds of herbicide active ingredient per acre per year. 1999 herbicide use data for Idaho, Oregon, and Washington potato growers are displayed in Table 19.2. Typically, two active ingredients are applied to each potato acre [11]. Metribuzin is applied to the majority of the acres. Growers use pendimethalin, trifluralin, EPTC, or metolachlor prior to weed emergence if they expect a problem grass weed species (such as barnyardgrass or foxtails), for which metribuzin is less effective. Rimsulfuron is used either preemergence or postemergence to improve control of grasses (including quackgrass) and certain broadleaf weed species that escape metribuzin applications. It is estimated that Northwest potato growers spend approximately $14.7 million per year for herbicides (or $24 per acre). (See Table 19.3) Because of the increased need to use additional herbicides (such as EPTC) for control of troublesome weed species, the average herbicide use rate doubled on Northwest potato acreage between 1979 and 1999 (see Table 19.4).

Cultivation
In addition to the use of herbicides, Northwest potato growers cultivate during the season for weed control: 90-93% of the potato acreage usually is cultivated an average of two times for weed control purposes [11]. One of the primary weed species targeted for late season cultivation is nightshade. Typically, some nightshade plants escape control with preemergence herbicides and some nightshade plants germinate after the soil-applied herbicides have dissipated [10]. The use of cultivation usually ceases by row closure four to six weeks after emergence.

As potato plants grow, they are hilled by moving soil into the row with a cultivator or tiller. This buries weeds that are in the rows and uproots weeds between the rows. A universal practice in the Northwest, to encourage rapid emergence, is to plant potato seed pieces four to seven inches below the surface. Regardless of planting depth, seed pieces ultimately should be about six to eight inches beneath the top of the final hill. To accomplish this, ridging or hilling is done as the plants develop. Adequate hilling is
important so that when tubers develop, they are covered with sufficient soil to avoid sun damage (greening and sunscald) and to manage infection by early and late blight fungus [18]. Greening occurs when developing tubers are exposed to sunlight. In some areas of the Northwest, multiple hilling operations are used to build up the hill and for weed control. The last cultivation forms the final hill and should move enough soil around the base of the potato plants to cover and kill any small weeds [18].

Mechanical cultivation does not remove weeds within the row and may damage potato plants by pruning roots, and, as a result, reduce yields [9]. Cultivators’ compact soil, breaking down soil structures and decreasing aeration and water infiltration. Numerous studies have documented reduced weed control and potato yields with cultivation alone, as compared with herbicides combined with cultivation [21]. In Idaho, side-by-side comparisons have shown that growers who followed normal cultivation practices lost 12-20% of total yield potential with only two cultivations [25].

Multiple cultivations for hairy nightshade control have not been practical because of deleterious effects on tuber yield and quality [15].

**Glyphosate Tolerant Potatoes**

A number of potato cultivars have been transformed with an EPSPS gene from a soil bacterium that confers tolerance to glyphosate applications. This allows the use of glyphosate, the active ingredient in Roundup herbicide, to be used over the top of potatoes without crop damage. Research in 1999 with glyphosate (Roundup) tolerant potatoes determined that two sequential glyphosate applications (of 0.75 lb AI) provided 96% hairy nightshade and green foxtail control and 100% control of redroot pigweed, common lambsquarters, kochia, volunteer oat, Russian thistle, common purslane and barnyardgrass. No crop injury was observed as a result of glyphosate treatments. Glyphosate at 0.75 + 0.75 lb/AI/A applied sequentially resulted in significantly greater US No. 1 and total tuber yields than rimsulfuron plus metribuzin (.023 + .38 lbAI/A) applied early postemergence [17]. Total potato yields were 29% higher in the plots treated with the two sequential glyphosate applications than in those treated with a combination of rimsulfuron and metribuzin.

In a study conducted in 2000 and 2001 in glyphosate-tolerant Ranger Russet potatoes, there was no significant difference in US No. 1 and total tuber yields resulting from applications of preemergence rimsulfuron + metribuzin (.023 + .5 LbAI/A) applied immediately after hilling and incorporated with
irrigation water; early postemergence applied rimsulfuron + metribuzin (.031 + .5 LbAl/A); or glyphosate at .75 + .75 LbAl/A applied sequentially [13].

Estimated Impacts

There are three scenarios where growers could use glyphosate with glyphosate tolerant potatoes: a total glyphosate postemergence program, early postemergence applications of glyphosate mixed with a residual herbicide, or preemergence herbicides followed by late postemergence glyphosate application [35]. It is assumed that potato growers in the Northwest would add one application of glyphosate (.75 lb ai/a) in a tank mix with residual herbicides which are applied early postemergence. All current herbicide uses and cultivations would continue to be made. The cost of the glyphosate application is estimated at $7.50/a. A technology fee of $25/a is assumed. The added glyphosate application would represent an increased cost of $20 million/yr and an increase of herbicide use of 465,000 lbs/yr. It is assumed that potato yields would increase by 2% as a result of adding the one application of glyphosate, which would control weeds that are not currently controlled with preemergence herbicides alone [13]. The 2% increase in potato yields represent an additional 840 lbs/a with an additional $42/a in income, which implies an aggregate increase of $26 million/yr. These estimates were assigned to Oregon, Idaho and Washington in proportion to acreage.
### TABLE 19.1

**WEED SPECIES INFESTATIONS: NORTHWEST POTATO ACREAGE**

<table>
<thead>
<tr>
<th>Weed Species</th>
<th>% Acres Infested</th>
<th>Potential % Yield Loss Uncontrolled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lambsquarters</td>
<td>90</td>
<td>20</td>
</tr>
<tr>
<td>Pigweeds</td>
<td>90</td>
<td>20</td>
</tr>
<tr>
<td>Nightshades</td>
<td>90</td>
<td>30</td>
</tr>
<tr>
<td>Foxtails</td>
<td>75</td>
<td>45</td>
</tr>
<tr>
<td>Barnyardgrass</td>
<td>90</td>
<td>30</td>
</tr>
<tr>
<td>Russian Thistle</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Kochia</td>
<td>40</td>
<td>25</td>
</tr>
<tr>
<td>Quackgrass</td>
<td>5</td>
<td>70</td>
</tr>
<tr>
<td>Canada Thistle</td>
<td>25</td>
<td>40</td>
</tr>
</tbody>
</table>

Source: [27], [28], and [29]

### TABLE 19.2

**HERBICIDE USE IN NORTHWEST POTATOES (1999)**

<table>
<thead>
<tr>
<th>Active Ingredient</th>
<th>IDAHO % Treated</th>
<th>LBS AI (000)</th>
<th>OREGON % Treated</th>
<th>LBS AI (000)</th>
<th>WASHINGTON % Treated</th>
<th>LBS AI (000)</th>
<th>TOTAL LBS AI (000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPTC</td>
<td>41</td>
<td>597</td>
<td>36</td>
<td>81</td>
<td>40</td>
<td>231</td>
<td>909</td>
</tr>
<tr>
<td>Metolachlor</td>
<td>11</td>
<td>95</td>
<td>14</td>
<td>13</td>
<td>3</td>
<td>8</td>
<td>116</td>
</tr>
<tr>
<td>Metribuzin</td>
<td>82</td>
<td>166</td>
<td>46</td>
<td>11</td>
<td>3</td>
<td>8</td>
<td>238</td>
</tr>
<tr>
<td>Pendimethalin</td>
<td>25</td>
<td>78</td>
<td>35</td>
<td>14</td>
<td>26</td>
<td>31</td>
<td>123</td>
</tr>
<tr>
<td>Rimsulfuron</td>
<td>16</td>
<td>1</td>
<td>21</td>
<td>1</td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>5</td>
<td>7</td>
<td>32</td>
<td>8</td>
<td>27</td>
<td>27</td>
<td>42</td>
</tr>
</tbody>
</table>

**Total**          | **944**         | **128**      | **358**          | **1,430**    |

Source: [2]
### TABLE 19.3

**HERBICIDE EXPENDITURES: NORTHWEST POTATOES (1999)**

<table>
<thead>
<tr>
<th>Active Ingredient</th>
<th>Lbs Al/Yr (000)</th>
<th>$ /Lb Al¹</th>
<th>$ (000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPTC</td>
<td>909</td>
<td>4.90</td>
<td>4454</td>
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<tr>
<td>Metolachlor</td>
<td>116</td>
<td>9.26</td>
<td>1074</td>
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<tr>
<td>Metribuzin</td>
<td>238</td>
<td>26.56</td>
<td>6321</td>
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<tr>
<td>Pendimethalin</td>
<td>123</td>
<td>8.45</td>
<td>1039</td>
</tr>
<tr>
<td>Rimsulfuron</td>
<td>2</td>
<td>790.40</td>
<td>1581</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>42</td>
<td>6.10</td>
<td>256</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1430</strong></td>
<td></td>
<td><strong>14,725</strong></td>
</tr>
</tbody>
</table>

¹ From [6] [7]

### TABLE 19.4

**HERBICIDE USE IN NORTHWEST POTATOES SUMMARY (1979& 1999)**

<table>
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<tr>
<th></th>
<th>IDAHO</th>
<th>OREGON</th>
<th>WASHINGTON</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LBS Al (000)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1979</td>
<td>290</td>
<td>56</td>
<td>142</td>
<td>488</td>
</tr>
<tr>
<td>1999</td>
<td>944</td>
<td>128</td>
<td>358</td>
<td>1429</td>
</tr>
<tr>
<td><strong>Acres Treated</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(000)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>335</td>
<td>65</td>
<td>102</td>
<td>502</td>
</tr>
<tr>
<td>1999</td>
<td>395</td>
<td>56</td>
<td>170</td>
<td>621</td>
</tr>
<tr>
<td><strong>Acres Treated (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>82</td>
<td>80</td>
<td>90</td>
<td>83</td>
</tr>
<tr>
<td>1999</td>
<td>92</td>
<td>100</td>
<td>98</td>
<td>94</td>
</tr>
<tr>
<td><strong>LBS Al/A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>1.05</td>
<td>1.08</td>
<td>1.54</td>
<td>1.16</td>
</tr>
<tr>
<td>1999</td>
<td>2.60</td>
<td>2.29</td>
<td>2.14</td>
<td>2.44</td>
</tr>
</tbody>
</table>

Source: [2][ 5]
References


6. 2000 Cultural and Chemical Weed Control in Field Crops, University of Minnesota Extension Service, BU-3157-S.


