Weed Management for Maize

- Weed identification
- The cost of weeds
- Weed seeds
- Non chemical weed management
- Managing herbicides
- Biosecurity
FAR Focus 11
Weed Management for Maize

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1. Background
Weed management is the most challenging component of maize agronomy in New Zealand.

Many maize farmers have developed successful management practices for weed control but there are instances when weeds become a problem. These include times when herbicide programmes fail because of environmental conditions, weeds become resistant to recommended herbicides or the crop is being grown on leased land where weed control has been poor in the past.

This FAR Focus draws on information from five years of investment into weed research. It covers the principles of weed management and provides guidance for the successful control of broadleaf and grass weeds in the maize crop.

Effective weed control in maize requires attention to detail. If weeds get away there are immediate and on-going losses for the maize grower.

Successful weed control is important for achieving maximum yield in maize grain and silage crops. Weeds that are not controlled compete for light and the crop’s nutrient and water resources, and yield losses may be up to 70% of the potential yield. The critical time for weed control in maize is between crop emergence and canopy closure. Weeds may emerge at any time during this period but are more likely to appear after rain.

When maize is grown on new cropping ground, broadleaf weeds are the most prevalent, but after several years of continuous maize cropping, grass weeds become the dominant weed type. Grass weeds tend to be more competitive than broadleaf weeds.

Uncontrolled weeds also contribute to the weed seed bank. Depending on the species, seeds dropped in a single season may remain viable for many years with on-going costs of control and yield losses reducing profitability of the farm.

The weed seed bank in maize fields is often large and weed germination can start before the maize is planted. Sequential germinations can occur through spring and summer but once the crop is at canopy closure the weed growth is impacted by poor light and the maize will have a competitive advantage.

Figure 1. Grass and broadleaf weeds in a young maize crop.
2. Weed identification
Successful weed management depends firstly on knowing what you are trying to manage. This may not be as easy as it sounds as most weed management practices depend on an early strike at the weed, when it has just two to four leaves. At this growth stage all weeds may look similar, especially grass weeds.

The best approach is to use an identification guide either electronic or hard-copy.

FAR’s Ute Guides for grass and broadleaf weeds have photos of the most common weeds at their seedling stages and as mature flowering plants. These guides are small enough to fit in your pocket or a ute glove box.

Phone ‘apps’ are another option for quick identification in the field. There are a number available; two that are being used on New Zealand farms are the Bayer Weed Spotter and BASF Weed ID.

Knowledge of previous weed issues in the paddock, farm and region can prepare you for the range of species that you are likely to see.

If you find a weed on your farm that you have never seen before, it is good biosecurity practice to get it identified. Either dig it out or take photos of its leaves and flowers and notify the FAR office, weed scientists at AgResearch, or your regional council that you have something you are uncertain of on your farm. It is far better to be told that what you’ve found is commonplace than to ignore a potential biosecurity incursion and find that you have an expensive eradication programme to manage (see Biosecurity, page 26).
3. The cost of weeds
The cost of weeds

AgResearch scientists have been conducting herbicide trials comparing different options for weed control in maize silage and grain crops for a number of years. These trials always include yield measurements and a treatment with no weed control.

Their results enable us to estimate the cost of poor weed control to the farm business. In eight trials over four years, silage yields for the no-herbicide treatment averaged 44% and grain yields averaged 39% of the yields in the standard pre-emergence herbicide treatments (acetochlor + atrazine).

These results can be used to estimate the loss of income in the first year of production with poor weed control (Tables 1 and 2).

Table 1. Economic analysis for maize silage

<table>
<thead>
<tr>
<th></th>
<th>Well managed maize silage crop</th>
<th>Weedy maize silage crop</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No crop loss associated with weeds</td>
<td>56% crop loss</td>
</tr>
<tr>
<td>Yield T/ha</td>
<td>22</td>
<td>9.7</td>
</tr>
<tr>
<td>Crop value $/T</td>
<td>$230.00</td>
<td>$230.00</td>
</tr>
<tr>
<td>Income $/ha</td>
<td>$5 060.00</td>
<td>$2 231.00</td>
</tr>
<tr>
<td>Field Costs $/ha</td>
<td>$2 396.00</td>
<td>$2 200.00</td>
</tr>
<tr>
<td>Gross margin $/ha</td>
<td>$2 664.00</td>
<td>$31.00</td>
</tr>
</tbody>
</table>

Table 2. Economic Analysis for maize grain

<table>
<thead>
<tr>
<th></th>
<th>Well managed maize grain crop</th>
<th>Weedy maize grain crop</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No crop loss associated with weeds</td>
<td>61% crop loss</td>
</tr>
<tr>
<td>Yield T/ha</td>
<td>12.9 (wet)</td>
<td>4.7 (wet)</td>
</tr>
<tr>
<td></td>
<td>10.5 (dry)</td>
<td>4.1 (dry)</td>
</tr>
<tr>
<td>Crop value $/T*</td>
<td>$453.00</td>
<td>$453.00</td>
</tr>
<tr>
<td>Income $/ha</td>
<td>$4 756.50</td>
<td>$1 857.30</td>
</tr>
<tr>
<td>Field Costs $/ha</td>
<td>$2 396.00</td>
<td>$2 200.00</td>
</tr>
<tr>
<td>Cartage Cost - $18/T</td>
<td>$232.20</td>
<td>$84.60</td>
</tr>
<tr>
<td>Drying Cost - $46/T</td>
<td>$593.40</td>
<td>$216.20</td>
</tr>
<tr>
<td>Total Cost $/ha</td>
<td>$3 221.60</td>
<td>$2 500.80</td>
</tr>
<tr>
<td>Gross margin $/ha</td>
<td>$1 534.90</td>
<td>-$643.50</td>
</tr>
</tbody>
</table>

*Average Manawatu maize grain price from Profarmer September 2013.
4. Weed seeds
Key points:

- The weed seed bank is the heart of the annual weed problem in the crop and an important component of the life cycle of annual weeds.
- Aerial seed banks may also contribute to the weed bank on cropping ground.
- Seed banks will decline rapidly if there is a deliberate strategy to stop annual weeds from setting and dropping seed.
- Changes in the rotation are important because they increase the range of herbicides that can be used for the target weeds.
- Weed seed survival depends on the seed morphology, burial depth and the soil environment.
- It is important to control weed seed production in non-cropped areas.

The weed seed bank

The term seed bank refers to places where seeds collect or remain until germination occurs. In cropping systems, the soil seed bank is the most important source of weed seeds but farmers must also be aware of aerial seed banks that can deposit air-borne weed seeds onto their land from some distance.

Given that a single fathen plant can produce 500,000 seeds, the annual deposits into the bank are potentially very high and this is compounded by weed seed longevity, which for some species may be many years.

For these reasons the most important aspect of long-term sustainable weed management is the prevention of seed production from weeds within the crop and crop surrounds.

What happens to weed seeds in the seed bank?

The weed seed bank is the heart of the annual weed problem in the crop and an important component of the life cycle of annual weeds. Understanding what happens to seeds in the seed bank can assist management strategies for weed control.

It is fortunate for farmers that very few of the seeds in the seed bank ever emerge and produce a plant that sets a new generation of seed. Most seeds will die, decompose or be eaten before germinating.

Seed predation is greatest when weed seeds remain on the soil surface where they are easily accessible to foraging insects, rodents and birds. It is important to provide areas of biodiversity on the farm as habitats for beneficial insect foragers. Crop residues in no-till systems provide shelter for foraging insects like ground beetles and crickets, but this must be balanced with their downside which is the provision of habitat for slugs.

Buried seeds are less available to foragers, but large numbers succumb to attack from saprophytic soil microbes and seed pathogens, especially in wet soils. Seed coats are designed to protect the embryo from desiccation but weaken when the seed is subjected to wetting and drying as the soil environment changes.

Lethal germination occurs when seeds germinate from a deep depth and seedlings exhaust their energy reserves and die before reaching the soil surface. However, many buried weed seeds are able to delay their germination until cultivation practice brings them closer to the soil surface. New Zealand research has shown that the seed of Scotch Thistle, buried at depths greater than 40 mm, persisted for 16 to >50 years and germinated once they were moved to the soil surface.

Figure 3. Headland weeds.
**Weed management starts with the seeds**

Seed banks will decline rapidly if there is a deliberate strategy to stop weeds setting seed, so farmers need to use a combination of techniques to reduce the size of the weed seed bank.

The first step is to identify the problem weeds and develop a multi-year approach to their management.

Approaches may include:

- **Stale seed beds.** The fallow period between two crops is an ideal time to control weeds. A stale seed bed is created when the soil is prepared for planting and then fallowed for a couple of weeks. Weed seeds near the surface germinate and can be controlled effectively with non-selective herbicides such as glyphosate.

- **False seedbeds** are similar to stale seedbeds but the weeds emerging after the fallow are killed by cultivation. This may be a less successful approach than a stale seed bed, as the soil disturbance may stimulate a second germination.

- **Mechanical topping or mowing** to remove seed-heads before the seeds set and mature. Growth regulators may also be used to control seed production.

- **Herbicide programmes.**

- **Crop rotation diversity** which enables a wider range of herbicides to be used.

- **Post-harvest seed destruction.** Machines such as the Harrington seed destructor have been developed and used in Australia to destroy weed seeds in grain crop residue after combining.

- **Cleaning of harvesting equipment and machinery before entering “clean” fields.**

- **Stubble burning.**

**Headland weed control**

Uncontrolled headland areas are a rich source of seeds that contribute to the weed seed bank. The management of headlands and fence-lines is often overlooked during the season. They often receive a clean-up spray with glyphosate at the start of the season but weeds may stay uncontrolled until after harvest. Weeds grow and distribute their seeds at the edge of the crop. Subsequently they are spread from this area further into the paddock with repeated cultivation.

A simple control option is to leave a narrow area of unsprayed pasture or to plant a non-invasive species such as lucerne, clover or prairie grass in the crop boundary. This area may be mowed if practical or sprayed with suitable chemicals to control invasive grass weeds such as yellow bristle grass.

These strips have a number of benefits. They have a direct economic value for hay and silage production and indirect benefits for the farm from the opportunity to reduce soil compaction by providing a “road” for machinery during crop management and harvest, and a habitat for beneficial insects.

![Lucerne planted as a non-invasive species on the headland](Figure 4. Lucerne planted as a non-invasive species on the headland (part of an on-going FAR trial in Waikato).)
An on-going FAR study is being conducted to determine the longevity of the seed of seven annual grass weeds and two annual broad leaf weeds in situ in soil. The trial began in 2007 and seeds have been retrieved from their burial sites every year. The last set of seeds will be retrieved from each site in the summer of 2013/14.

The focus of the work was mainly on grass weed seed survival, but two persistent broadleaf weeds were also included. The weeds were:

- Broom corn millet (*Panicum miliaceum*)
- Witchgrass (*P. capillare*)
- Smooth witchgrass (*P. dichotomiflorum*)
- Summer grass (*Digitaria sanguinalis*)
- Barnyard grass (*Echinochloa crus-galli*)
- Rough bristle grass (*Setaria verticillata*)
- Yellow bristle grass (*S. pumila*)
- Thorn apple (*Datura stramonium*)
- Apple of Peru (*Nicandra physalodes*)

**Locations**
Eight burial sites were chosen to represent the main maize production areas in New Zealand. These include:

- Northland Dairy Development Trust, Northland
- Waikato Arable Research Site, Waikato
- Plant & Food Research Station, Hawke’s Bay
- Private farms in Bay of Plenty, Poverty Bay, Manawatu, Motueka and Canterbury.

**Methods**
Approximately 200 seeds of each grass weed species, 200 seeds of apple of Peru and 50 seeds of thorn apple were weighed into fine mesh bags. These were bundled together and placed into 250 mm long tubes at two different depths within the tube.

The tubes were buried vertically with their tops flush with the soil surface, which resulted in one bundle of seed being buried 50 mm from the soil surface and the other at 200 mm depth. Once a year, in early summer, five tubes are dug out from each site, the seeds are retrieved and mixed with seed raising media before being spread out into polystyrene trays for germination in the glasshouse. The emerged seedlings are counted four to six weeks after planting.

**Results after four years burial**
The results for all weed seeds at all locations, after four years burial are presented in tables 3 and 4.
Table 3. Persistence of seed after four years burial at a depth of 50 mm in eight different locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil Texture</th>
<th>Thorn apple</th>
<th>Apple of Peru</th>
<th>Broom corn millet</th>
<th>Yellow bristle grass</th>
<th>Barnyard grass</th>
<th>Rough bristle grass</th>
<th>Smooth witch grass</th>
<th>Summer grass</th>
<th>Witch grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northland</td>
<td>Clay</td>
<td>58</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>45</td>
<td>1</td>
<td>59</td>
</tr>
<tr>
<td>Waikato</td>
<td>Silt loam</td>
<td>75</td>
<td>30</td>
<td>0</td>
<td>9</td>
<td>10</td>
<td>18</td>
<td>37</td>
<td>2</td>
<td>17</td>
</tr>
<tr>
<td>Bay of Plenty</td>
<td>Sandy loam</td>
<td>68</td>
<td>36</td>
<td>14</td>
<td>7</td>
<td>3</td>
<td>12</td>
<td>63</td>
<td>19</td>
<td>71</td>
</tr>
<tr>
<td>Gisborne</td>
<td>Clay loam</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>28</td>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>Hawkes Bay</td>
<td>Silt loam</td>
<td>62</td>
<td>8</td>
<td>35</td>
<td>30</td>
<td>25</td>
<td>31</td>
<td>51</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Manawatu</td>
<td>Fine sandy loam</td>
<td>31</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>55</td>
<td>8</td>
<td>53</td>
</tr>
<tr>
<td>Nelson</td>
<td>Sandy loam</td>
<td>74</td>
<td>56</td>
<td>6</td>
<td>32</td>
<td>43</td>
<td>32</td>
<td>49</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td>Lincoln</td>
<td>Silt loam</td>
<td>66</td>
<td>44</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>46</td>
<td>11</td>
<td>60</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>54</td>
<td>26</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>13</td>
<td>47</td>
<td>14</td>
<td>46</td>
</tr>
</tbody>
</table>

Table 4. Persistence of seed after four years burial at a depth of 200 mm in eight different locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil Texture</th>
<th>Thorn apple</th>
<th>Apple of Peru</th>
<th>Broom corn millet</th>
<th>Yellow bristle grass</th>
<th>Barnyard grass</th>
<th>Rough bristle grass</th>
<th>Smooth witch grass</th>
<th>Summer grass</th>
<th>Witch grass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northland</td>
<td>Clay</td>
<td>83</td>
<td>66</td>
<td>24</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>61</td>
<td>1</td>
<td>63</td>
</tr>
<tr>
<td>Waikato</td>
<td>Silt loam</td>
<td>70</td>
<td>56</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>43</td>
<td>41</td>
<td>3</td>
<td>45</td>
</tr>
<tr>
<td>Bay of Plenty</td>
<td>Sandy loam</td>
<td>91</td>
<td>66</td>
<td>25</td>
<td>22</td>
<td>22</td>
<td>43</td>
<td>69</td>
<td>43</td>
<td>78</td>
</tr>
<tr>
<td>Gisborne</td>
<td>Clay loam</td>
<td>69</td>
<td>23</td>
<td>38</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>30</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>Hawkes Bay</td>
<td>Silt loam</td>
<td>70</td>
<td>31</td>
<td>25</td>
<td>16</td>
<td>35</td>
<td>53</td>
<td>50</td>
<td>27</td>
<td>44</td>
</tr>
<tr>
<td>Manawatu</td>
<td>Fine sandy loam</td>
<td>76</td>
<td>4</td>
<td>19</td>
<td>3</td>
<td>41</td>
<td>31</td>
<td>57</td>
<td>31</td>
<td>48</td>
</tr>
<tr>
<td>Nelson</td>
<td>Sandy loam</td>
<td>81</td>
<td>50</td>
<td>27</td>
<td>29</td>
<td>33</td>
<td>37</td>
<td>37</td>
<td>28</td>
<td>39</td>
</tr>
<tr>
<td>Lincoln</td>
<td>Silt loam</td>
<td>94</td>
<td>52</td>
<td>43</td>
<td>12</td>
<td>71</td>
<td>51</td>
<td>45</td>
<td>57</td>
<td>62</td>
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<tr>
<td>Average</td>
<td></td>
<td>79</td>
<td>44</td>
<td>27</td>
<td>13</td>
<td>28</td>
<td>32</td>
<td>49</td>
<td>24</td>
<td>51</td>
</tr>
</tbody>
</table>
5. Non-chemical weed management
Key points:

- Sustainable weed management is improved if a range of control practices are used.
- Precision technologies such as GPS, and crop sensing have increased the efficiency of mechanical weeder.
- Stubble burning reduces the number of viable seeds on the soil surface and improves the efficacy of pre-emergent herbicides by reducing the amount of crop residue on the soil surface.

Mechanical weeding

The plough was the first implement used by farmers to prepare the soil for planting. It turns the soil and buries crop and weed residues and weed seeds. It is still the most commonly used mechanical weeding device between crops in the rotation.

A number of mechanical weeder were developed to remove young weeds within the crop but these lost favour with farmers when herbicides were first introduced. However farmers soon learned that a dependence on one form of weed control was not sustainable, and success was dependent on using a range of approaches.

The efficiency of within-crop, mechanical weeders (both their work rate and their ability to kill weeds and not the crop) has improved with the development of precision agricultural technologies such as GPS auto-steer and crop sensing.

There are two main approaches to mechanical weeding. Contiguous weeders uniformly weed the entire field, whereas inter-row weeders manage weeds between the rows of a row-crop. Maize farmers can use inter-row weeders designed to manage weeds in the row up until the maize crop is one metre high. Inter-row weeders of the future are likely to have computerised crop recognition technologies enabling the weeds to be differentiated from the crop. Spot applications of herbicide will deal to weeds within the row.

The most effective weed management in the future is likely to be a combination of mechanical and chemical control, carried out in one pass through the crop. This might be a band spray of the row and mechanical weeding in the inter-row, as with all weed management, timing will be a key to success.

Stubble burning

Stubble burning, not often practiced by maize growers, can be used to reduce the viability of weed seeds left on the soil surface after a crop has been harvested.

A 2013 Review of the role and practices of stubble burning in New Zealand, including alternative options and possible improvements, commissioned by Environment Canterbury and written by FAR, notes the following benefits of stubble burning in arable crops:

- Improved efficacy of pre-emergent herbicides. This is particularly important in reduced tillage systems where the presence of significant levels of crop residues on, or close to, the soil surface can reduce the control achieved by the commonly used soil and soil/foliage acting herbicides.

- The destruction of freshly shed viable weed seeds, particularly of annual grass weed seed. In some grass species the dormancy of freshly shed seed, surviving the stubble burning was reduced. These weeds can then be controlled by cultivation or with herbicides prior to the next crop being sown.

Check with your local council for the rules for stubble burning before setting fire to your crop residue.

Crop rotation

Diversity in the crop rotation is an important strategy for sustainable weed management. Continuous cropping which favours one plant family, e.g. maize followed by annual ryegrass, can provide an environment that selects for weed species with characteristics similar to those of the main crop, e.g. grass weeds. A varied rotation, with a range of plant families, enables the use of a wider range of herbicides to target problem weeds.

If the opportunity to vary the rotation is limited, consider changing the planting and harvest times for your crops. A later planting for the maize and the selection of a shorter maturing hybrid can offer the opportunity to vary the timing of stale seed beds and herbicide applications.
6. Managing herbicides
Key points:

Factors that affect the success of a pre-emergence herbicide programme include:

- Planting time. Early maize crops are more likely to need a follow-up post-emergent herbicide.
- The weed spectrum. Some weeds have developed resistance to atrazine.
- Soil characteristics. Tilth and organic matter levels can affect the adsorption of the herbicide.
- Soil temperature and moisture. Herbicides break down faster under warm, moist soil conditions.
- Premature breakdown of the herbicide’s active ingredient. This can be caused by chemical degradation (faster in acid), or herbicide volatilisation from wet soils.
- Enhanced degradation. Some herbicide active ingredients can be more rapidly broken down to non-herbicidal by-products by soil microbes after several years of use in the same location.
- Crop residues. These can act as a barrier, preventing the herbicide reaching the soil surface.
- Side dressing may disrupt the action of soil-applied herbicides.

Weeds emerging in the crop before canopy closure compete for resources and reduce yield. These should be controlled with post-emergent herbicides before they establish and set seed.

Pre-emergence programmes

Weeds in New Zealand maize are most commonly controlled by a mixture of pre-emergence herbicides. These control weeds as they germinate, before they emerge. A successful pre-emergence programme provides weed control during the sensitive time for the crop, from emergence to canopy closure.

The most common combination of pre-emergence herbicides is a mixture of a triazine herbicides, such as atrazine or terbutylazine, for broadleaf weed control, and a chloroacetanilide such as alachlor, metalochlor and acetochlor for the control of grass weeds.

The herbicide mixture is applied to soil where it must be activated before it can be taken up by the emerging weed seedlings. Activation is achieved by one of three means;

1. Incorporation into the soil to a depth of 10-15 cm with cultivation equipment as soon as possible after application.
2. By waiting for rain or applying irrigation soon after application.
3. If the soil surface is wet at the time of application, activation will occur without the need for 1 or 2.

Broadleaf weed herbicides are absorbed through the roots and therefore must be distributed in the rootzone. Grass weed herbicides are absorbed through the emerging coleoptile and therefore need to be concentrated near the soil surface.

Both groups require moisture for activation so soil moisture levels should be good or the application should be timed when rain is likely.

In reduced tillage crops the crop residue may act as a mulch to suppress weeds. If herbicides are required it is important to realise that their efficacy may be reduced by the amount of crop debris on the soil surface. This debris is a physical barrier to the herbicide, preventing good contact with the soil. A post-emergent herbicide programme may be a better option in this situation.

The effectiveness and duration of activity of pre-emergence herbicides depends on a number of factors, including:

- The weed spectrum present, including herbicide resistant weeds (e.g. atrazine resistant fathen and willow weed).
- Tilth and organic matter levels can affect the adsorption of the herbicide.
- Soil temperature, which effects microbial degradation.
- Breakdown of the herbicide’s active ingredient by chemical degradation, photodecomposition and herbicide volatilisation.
- Disruption of the chemical barrier by side dressing.

After applying the pre-emergence herbicide programme, it is important to assess how well weeds are being controlled in the crop, so post-emergent herbicides can be applied in a timely manner if necessary. Early sown crops are more likely to need follow-up post-emergent treatments because the time until canopy closure is longer than in a later sown crop.
If a pre-emergence herbicide programme fails and environmental conditions are not to blame; then it is possible that enhanced microbial degradation of the herbicide is occurring.

If some weeds die but others are unaffected, then it is possible that there is a problem with herbicide resistance.

**Resistance management**

Herbicide resistance is a major concern for all cropping farmers both internationally and in New Zealand. Overseas, resistance in broad leaf and grass weed species has been reported in ten out of the thirteen major herbicide groups.

In New Zealand some weeds that are common in maize production e.g. fathen (Chenopodium album), willow weed (Persicaria maculosa) and black nightshade (Solanum nigrum) have developed resistance to atrazine (Group C1 – refer Appendix 1). Fathen has also developed resistance to dicamba (Group O2).

The strategy to minimise the risk of the development of resistance is simply to avoid the repeated use of the same chemicals from the same mode of action grouping. This is not so easy when the choice of herbicides is small. Correct identification of the weed species is important, as is an understanding of the mode of action of the chemical and its application requirements. Getting these factors right contributes to the likelihood of the herbicide application being successful. Weeds that survive a herbicide treatment may have characteristics that contribute to its survival, these will be passed on to its progeny resulting in a herbicide resistant bio-type.

Appendix 1 has a table with all herbicides registered for weed control in maize.

**Case Study**

**Glyphosate resistant ryegrass**

Glyphosate is often used repeatedly in orchards and vineyards for controlling weeds in the rows and is applied repeatedly along fence lines, in non-cropped areas on the farm and roadsides for weed control. It has also become an important part of our agronomic system for reduced tillage and for spraying out winter ryegrass paddocks prior to planting. If resistant ryegrass establishes in New Zealand we will be at risk of losing a cost-effective management strategy for our cropping systems.

The first case of glyphosate resistant ryegrass was found in Australia in 1996. Since then a further 24 glyphosate resistant weeds have been reported worldwide. In 2012 a FAR led, MPI Sustainable Farming Fund project began, with the aim of preventing glyphosate resistance developing in New Zealand. An initial part of the project was to increase awareness of glyphosate resistance and to conduct a nationwide survey for weeds showing resistance to glyphosate.

In 2013, members of the SFF research team based at AgResearch and Massey University confirmed they had found both glyphosate-resistant annual ryegrass and glyphosate-resistant perennial ryegrass in Marlborough. Other suspected cases of resistant weeds are currently being investigated.

Weed species that have developed resistance overseas and are of concern to New Zealand farmers include:

- Fleabanes, developed resistance in 11 countries
- Annual ryegrass, developed resistance in 5 countries and in New Zealand
- Perennial ryegrass, developed resistance in Argentina and in New Zealand
- Summer grass, developed resistance in 9 countries
- Amaranthus, developed resistance throughout USA

Glyphosate kills plants by inhibiting the production of an important enzyme, EPSPS (5-enolpyruvoylshikimate-3-phosphate synthase).

Resistance to glyphosate can develop through a variety of mechanisms. Some plants have mutations within or to the EPSPS herbicide target site so that the active ingredient becomes ineffective, others alter the translocation pathways within the plant to sites where it can do no harm. This variability makes it difficult to develop a simple test to confirm glyphosate resistance.

Testing must be done by collecting suspect plants, growing them on and subjecting them to sprays of known concentrations of glyphosate.

The most likely scenario for the development of glyphosate resistance in New Zealand is in weeds that are in areas that are repeatedly sprayed with glyphosate and nothing else.

Such areas include:

- Roadsides and railways
- Vineyards
- Fence lines, yards, parks, and waste areas
- Orchards
- Crop headlands
- Areas managed under minimum tillage

**Figure 6.** Glyphosate resistant annual ryegrass collected in Marlborough after Glyphosate 360 applications at 0, 1, 2, 4, and 8 L/ha.
Reducing the risk of glyphosate resistance in non-cropping land

It is important that every four or five applications of glyphosate includes a chemical from a different family. For example select one from the following list:

- Metsulfuron (Escort®), amitrole, oxyfluorfen (Oxy250SC), oxadiazon, (Foresite®) or herbicide combinations such as Tag™ G2.

**NB** These chemicals should only be applied to non-cropping areas.

A non-herbicide option is the use of non-invasive but suppressive species e.g. prairie grass or clovers in uncropped areas.

Enhanced microbial degradation

Enhanced microbial degradation occurs when soil microbes rapidly degrade the herbicide to ineffective components. Enhanced degradation of atrazine has been confirmed at six locations in Waikato, Gisborne and Bay of Plenty. The residual efficacy of atrazine at these sites has been reduced from weeks to days, and weed control is compromised.

The degradation rate of atrazine was determined in a laboratory study managed by AgResearch, which compared samples’ decay rates in sterilised and unsterilised soils. The soils came from farms with a long history of continuous maize production and severe weed control problems. These were compared to the atrazine decay rates in a soil with no history of herbicide use.

Decay rate is measured as; DT50. This is the time it takes for the applied concentration of atrazine to halve (50%), measured in days.

The results show that the degradation of atrazine is faster in the unsterilised soils, particularly at higher temperatures. This indicates that the major breakdown pathway for the degradation of atrazine in these soils is microbial degradation (Table 5).

The pathway of enhanced degradation is complex. It involves a range of microbial species and a number of steps. The ability to rapidly degrade an herbicide is passed from one microbial species to the next through a plasmid pathway. A plasmid is a small collection of genes on a piece of genetic material (DNA or RNA). It has no life of its own but exists within the bacterial cytoplasm where it is able to replicate independently of the bacterial chromosome. The plasmid genes provide the bacterium with a selective advantage, such as the ability to degrade complex herbicide molecules into simple compounds for an energy source. Plasmids are passed between individuals by a process called conjugation and can survive outside the host organisms.

This process is not confined to a single microbial species. Many soil microbes can develop the ability to degrade atrazine and once they do so, it becomes an inherited and remembered characteristic even if atrazine is not present in the soil.

<table>
<thead>
<tr>
<th>Region</th>
<th>Temperature</th>
<th>10°C</th>
<th>20°C</th>
<th>30°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsterilised DT50 (days)</td>
<td>Sterilised DT50 (days)</td>
<td>Unsterilised DT50 (days)</td>
<td>Sterilised DT50 (days)</td>
</tr>
<tr>
<td>Waikato (control soil-no history of atrazine use) Horotiu silt loam</td>
<td>50</td>
<td>80</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Waikato Horotiu silt loam</td>
<td>18</td>
<td>50</td>
<td>5</td>
<td>37</td>
</tr>
<tr>
<td>Manawatu Kairanga fine sandy loam</td>
<td>27</td>
<td>65</td>
<td>10</td>
<td>41</td>
</tr>
<tr>
<td>South Waikato Otorohanga silt loam</td>
<td>16</td>
<td>80</td>
<td>6</td>
<td>50</td>
</tr>
<tr>
<td>Gisborne Waihirere silt loam</td>
<td>18</td>
<td>55</td>
<td>7</td>
<td>37</td>
</tr>
<tr>
<td>Bay of Plenty Ohinepanea loamy sand</td>
<td>55</td>
<td>55</td>
<td>13</td>
<td>31</td>
</tr>
<tr>
<td>Waikato Matamata clay loam</td>
<td>18</td>
<td>50</td>
<td>5</td>
<td>37</td>
</tr>
</tbody>
</table>

Table 5. DT50 values (days) for sterilised and unsterilised samples of each of the test soils at three temperatures
Maize pre-emergence programmes rely heavily on the activity of two herbicide active ingredients: atrazine and acetochlor. Enhanced degradation of acetochlor has been found outside a factory producing acetochlor in China where residues were repeatedly dumped on the soil. This indicates that acetochlor is vulnerable to microbial degradation. Attempts to replicate the enhanced degradation of acetochlor on New Zealand soils, under forced laboratory conditions, involving 18 sequential doses of acetochlor to soils held at 30°C, were unsuccessful. This is good news for growers, as it would be a concern if both of our pre-emergent active ingredients were being rapidly degraded by soil microbes. However we must be aware that this could be a future possibility.

Herbicide residues

Effective weed control with persistent herbicides is a balancing act between having the herbicide in the soil long enough for it to control weeds during the season of application and it disappearing before it can impact on the next crop, if it is susceptible.

Many factors relating to the soil, the climate and characteristics of the herbicide affect its breakdown and disappearance. Occasionally the active ingredient in the herbicide can persist in the soil and cause problems for the following crop. Examples have been noted of herbicide residual damage in newly establishing autumn crops following maize silage. This damage can often be related to the timing of the last herbicides in the crop, and soil and climatic conditions.

From 2009-2011 AgResearch scientists undertook trials examining the effect of rainfall and its timing on the persistence of nicosulfuron on a number of different soils. The conclusions were:

- When applied at the recommended label rate of 60 g active ingredient (a.i)/ha, nicosulfuron persisted in the soil from six to more than 15 weeks. This depended on the soil type and the amount and timing of rainfall after herbicide application.
- Residues of nicosulfuron disappeared faster in soils with low pH and high organic matter levels.
- Rainfall amount within two weeks of application of the herbicide was the major influence on dissipation of nicosulfuron residues in all soils.
- Simulated heavy rainfall (50 mm) in the first week or two after application or for several consecutive weeks, was more effective in reducing residues than repeated light (10 mm) or moderate (25 mm) rainfall, or heavy rainfall applied after two weeks.

Growers must be aware of the risk of nicosulfuron residues if it has been dry in the month following application and if their soils have a pH greater than 7.

Testing for herbicide residues in soil

A simple bioassay can be done to check for herbicide residues. Carefully take a slice of the top 50 mm of soil, place in a seed tray and plant a quick growing, herbicide sensitive brassica species such as turnip or radish. Use some soil from a non-herbicide area for a comparison. Herbicide residues will soon be apparent from checked growth and damage to the young seedlings.

Application technique also comes into consideration with herbicide residues – try and minimise overlaps as much as possible.

Post-emergence herbicides may also persist for longer when applied to large weeds which take longer to die and release the herbicide back to the soil.

Herbicide application

All herbicide applications, both pre and post-emergence, require good practices to achieve a good result – dead weeds.

The most important of these is to read the label fully and to follow the instructions for timing, application rate and spray volume, soil conditions (tilth, soil structure and organic matter content), recommended adjuvants, and personal and environmental safety requirements during mixing, application and wash-down.

All application equipment should be calibrated, and forward speeds should be linked to the terrain and ground conditions. One of the principle reasons for poor herbicide efficacy is boom flex and bounce when forward speeds are too fast.

Worn nozzles give poor coverage and should be replaced. Consider replacing them with low pressure air induction (AI) nozzles. These are a good option as they produce larger droplets that are less prone to drift and more likely to reach their target before evaporating. Nozzle performance charts provide a good summary of the performance characteristics and should be available wherever you buy your spray equipment.

Application timing is very important. Pre-emergence herbicides must be applied before weeds emerge. Post-emergence applications must be applied before the weeds are too large and the maize canopy intercepts too much of the spray volume.
Interactions with the soil

The effectiveness of the herbicide after it has been applied depends on its concentration and persistence in the soil. These factors are affected by the properties of the herbicide, weather conditions, and soil factors such as texture, pH, moisture and organic matter.

Herbicides have electrical charges that cause them to bind to the positive or negative charges on soil and organic matter particles. This process is called adsorption and it varies with soil pH, soil organic matter content, and climate. Soils with high cation exchange capacities (CEC), high levels of organic matter or clay are the most adsorptive. These soils may require higher rates or more frequent herbicide applications than sandy and coarse soils. Coarse, sandy soils are less adsorptive and herbicides will be more effective. However their persistence might be reduced during heavy rain.

Herbicide efficacy may be reduced in cloddy and light fluffy soils.

Herbicides can be lost from the soil profile by leaching and surface run-off. Soil structure and texture and the solubility of the herbicide affects the risk of leaching losses and care must be taken to prevent the contamination of ground-water by leached herbicides.

High nutrient loadings in the soil can reduce herbicide activity.

Managing post-emergent sprays

Key points:

• Weeds should be sprayed when they are between 20% and 40% ground cover.
• It is better to spray too early than too late. Weeds emerging with the crop are more competitive than those that emerge later. Larger weeds are harder to kill.
• Always use sprayers set up for inter-row spraying. Target the weed and don’t waste spray by spraying the maize plants.
• An early post-emergent application of mesotrione or topromezone followed two to four weeks later by nicosulfuron provided similar weed control to a pre-emergent treatment (acetochlor or atrazine) followed by a post-emergent herbicide when required.

Pre-emergence herbicides with soil-residual action are the key tool for effective weed control in maize crops. Occasionally these do not control all the weeds in the crop and post-emergent herbicides must be used to complete the job.

The MPI SFF project Sustainable weed management in maize explored the solutions to avoid and/or overcome problems related to:

1. Enhanced herbicide degradation
2. Poor herbicide activation under dry conditions
3. Herbicide carryover
4. Herbicide resistance

The aim of the project was to develop alternative and sustainable weed control programmes that rely more on post-emergence herbicides to help avoid the above issues.

Achieving reliable and effective weed control solely through post-emergence herbicides is more complicated and a number of challenges must be overcome to improve their success rate.

This is because post-emergence herbicides:

• Control a narrower spectrum of weeds
• Control weeds for a shorter period of time
• Are sensitive to weed size and shape
• Are affected by crop size (the crop canopy can limit herbicide application and penetration)
• Are less effective under adverse weather conditions
• May have residue carry-over problems in some soils, if applied very late or in dry years
The three year work programme determined which post-emergent herbicides, applied singly or as mixtures, provided the best weed control and the effect of timing and weed densities on the herbicide performance.

In years 1 and 2 the work effort was in identifying the best herbicides or herbicide mixtures for controlling grass and broadleaf weeds in maize crops. A focus was put on application timing and the effect of weed size and density on efficacy.

In year 3, two sites (Waikato and Bay of Plenty) were used to refine the best herbicide programmes.

**Trial results**

The Bay of Plenty trial site had a very high weed density with a maximum of around 1700 weeds/m². These were dominated by grass weeds, particularly summer grass, with broadleaf weeds, mainly fathen, contributing about 20% of total weed numbers.

Final cultivation occurred about a week prior to planting, and maximum weed emergence occurred between two and three weeks post-crop emergence (WPE).

The first and second post-emergence herbicides applications coincided with this peak weed emergence and the third post-emergence application was a week later.

The main broadleaf weed, fathen, had peak emergence 2 WPE while summer grass peaked a week later. The site weed details and results of the post-emergent herbicide applications are given in tables 6 and 7.

The Waikato trial was planted on 15 November 2012 and broadleaf and grass weed species emerged almost simultaneously. Weed densities at the Waikato trial site at Tamahere were moderate with <400 weeds/m² at its peak emergence at 5 WPE. Broadleaf weeds, predominantly fathen and amaranthus, made up 70% of the total weed composition. The remainder were summer grass and smooth witch grass.

The main broadleaf weed fathen had peak emergence around 3 WPE, two weeks earlier than the summer grass (at 5WPE). However grass species developed quickly and about one third of the summer grass plants present at 2 WPE were tillering.

The first post-emergence application at 2 WPE was applied to grass weeds that ranged from 2 leaves showing to plants with 2 tillers already produced. The second and third post-emergence applications at 3 and 5 WPE were applied to progressively larger weeds, summer grass having 4 and 7 tillers at 3 and 5 WPE respectively and fathen averaging 100 and 300 mm in height at 3 and 5 WPE respectively. The site weed details and results of the post-emergent herbicide applications are given in tables 8 and 9.

**Table 6.** Crop and weed details at the time of post-emergence spraying at the Bay of Plenty site

<table>
<thead>
<tr>
<th>Spray timing Weeks post crop emergence (WPE)</th>
<th>Maize</th>
<th>Fathen</th>
<th>Summer grass</th>
<th>Weed density</th>
<th>Weed cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>H (mm)</td>
<td>Lf# (V#)</td>
<td>H (mm)</td>
<td>Lf#</td>
<td>Ø (mm)</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
<td>5 (3)</td>
<td>30</td>
<td>4-5</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>150</td>
<td>6 (4)</td>
<td>50</td>
<td>12</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>7 (5)</td>
<td>135</td>
<td>8-100</td>
<td>50</td>
</tr>
</tbody>
</table>

1H = Height; 2Lf# = Number of leaves; 3V# = V-leaf stage of maize; 4Ø = diameter; 5t = number of tillers
### Table 7. Average percent control of all weeds in different treatments at the Bay of Plenty site

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate</th>
<th>Application time</th>
<th>Assessment Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>16 Nov</td>
</tr>
<tr>
<td>Untreated</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>atrazine + acetochlor (Pre-em)</td>
<td>3000 mL + 3000 mL</td>
<td>Pre-em</td>
<td>98</td>
</tr>
<tr>
<td>atrazine + acetochlor (Pre-em) nicosulfuron2 (Post-em)</td>
<td>3000 mL + 3000 mL</td>
<td>Pre-em + Post-em (4 WPE)</td>
<td>99</td>
</tr>
<tr>
<td>mesotrione2 + atrazine (Early) nicosulfuron2 (Late)</td>
<td>200 mL + 1000 mL 80 g</td>
<td>2 WPE (Early) 5 WPE (Late)</td>
<td>72</td>
</tr>
<tr>
<td>paraquat/diquat</td>
<td>30 mL/10 L</td>
<td>2 WPE</td>
<td>75</td>
</tr>
<tr>
<td>paraquat/diquat</td>
<td>30 mL/10 L</td>
<td>3 WPE</td>
<td>n/a</td>
</tr>
<tr>
<td>paraquat/diquat</td>
<td>30 mL/10 L</td>
<td>4 WPE</td>
<td>n/a</td>
</tr>
<tr>
<td>topramezone2 + atrazine</td>
<td>300 mL + 1000 mL</td>
<td>2 WPE</td>
<td>79</td>
</tr>
<tr>
<td>topramezone2 + atrazine</td>
<td>300 mL + 1000 mL</td>
<td>3 WPE</td>
<td>n/a</td>
</tr>
<tr>
<td>topramezone2 + atrazine</td>
<td>300 mL + 1000 mL</td>
<td>4 WPE</td>
<td>n/a</td>
</tr>
<tr>
<td>mesotrione + nicosulfuron</td>
<td>1300 mL</td>
<td>2 WPE</td>
<td>73</td>
</tr>
<tr>
<td>mesotrione + nicosulfuron</td>
<td>1300 mL</td>
<td>3 WPE</td>
<td>66</td>
</tr>
<tr>
<td>mesotrione + nicosulfuron</td>
<td>1300 mL</td>
<td>4 WPE</td>
<td>n/a</td>
</tr>
<tr>
<td>mesotrione2 + atrazine</td>
<td>200 mL + 1000 mL</td>
<td>3 WPE</td>
<td>n/a</td>
</tr>
<tr>
<td>nicosulfuron2</td>
<td>80 g</td>
<td>3 WPE</td>
<td>25</td>
</tr>
<tr>
<td>LSD (P&lt;0.05)</td>
<td></td>
<td></td>
<td>8.506</td>
</tr>
</tbody>
</table>

1WPE = weeks post crop emergence  
2Nicosulfuron was applied with adjuvant Bonza® (0.5% v/v); mesotrione with the adjuvant Synoil (1% v/v) and topramezone with the adjuvant Hasten (0.5% v/v).

### Table 8. General crop and weed details at the time of post-emergence spraying at the Waikato site

<table>
<thead>
<tr>
<th>Spray timing (WPE)</th>
<th>Maize</th>
<th>Fathen</th>
<th>Summer grass</th>
<th>Weed density</th>
<th>Weed cover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>'1H (mm)</td>
<td>'2Lf#' (V#)</td>
<td>H (mm) (Plants/m²)</td>
<td>(%)</td>
<td>Lf# (t) (Plants/m²)</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>4 (2)</td>
<td>35</td>
<td>140</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>500</td>
<td>7 (5)</td>
<td>224</td>
<td>70</td>
<td>12 (3)</td>
</tr>
<tr>
<td>5</td>
<td>770</td>
<td>10 (7)</td>
<td>377</td>
<td>180</td>
<td>30 (7)</td>
</tr>
</tbody>
</table>

1H = Height; 2Lf# = Number of leaves; V# = V-leaf stage of maize; t = number of tillers
Table 9. Average percentage control of all weeds in different treatments at the Waikato site

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate</th>
<th>Application time</th>
<th>Percentage control assessments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4 1WPE 5 WPE 6 WPE 7 WPE 11 WPE</td>
<td>20 Dec 29 Dec 7 Jan 14 Jan 11 Feb</td>
</tr>
<tr>
<td>Untreated</td>
<td></td>
<td></td>
<td>0 0 0 0 0</td>
</tr>
<tr>
<td>atrazine + acetochlor (Pre-em)</td>
<td>3000 mL + 3000 mL</td>
<td>Pre-em</td>
<td>96 83 73 70 67</td>
</tr>
<tr>
<td>atrazine + acetochlor (Pre-em)</td>
<td>3000 mL + 3000 mL</td>
<td>Pre-em + Post-em (4 WPE)</td>
<td>96 84 89 89 93</td>
</tr>
<tr>
<td>nicosulfuron2 (Post-em)</td>
<td>200 mL + 1000 mL 80 g</td>
<td>2 WPE (Early)</td>
<td>96 81 87 90 97</td>
</tr>
<tr>
<td>paraquat/diquat</td>
<td>30 mL/10 L</td>
<td>2 WPE</td>
<td>93 73 72 67 57</td>
</tr>
<tr>
<td>paraquat/diquat</td>
<td>30 mL/10 L</td>
<td>3 WPE</td>
<td>84 90 83 81 70</td>
</tr>
<tr>
<td>paraquat/diquat</td>
<td>30 mL/10 L</td>
<td>5 WPE</td>
<td></td>
</tr>
<tr>
<td>nicosulfuron2</td>
<td>80 g</td>
<td>2 WPE</td>
<td>74 63 60 54 57</td>
</tr>
<tr>
<td>nicosulfuron2</td>
<td>80 g</td>
<td>3 WPE</td>
<td></td>
</tr>
<tr>
<td>nicosulfuron2</td>
<td>80 g</td>
<td>5 WPE</td>
<td></td>
</tr>
<tr>
<td>mesotrione2 + atrazine</td>
<td>200 mL + 1000 mL</td>
<td>2 WPE</td>
<td></td>
</tr>
<tr>
<td>mesotrione2 + atrazine</td>
<td>200 mL + 1000 mL</td>
<td>3 WPE</td>
<td></td>
</tr>
<tr>
<td>mesotrione2 + atrazine</td>
<td>200 mL + 1000 mL</td>
<td>5 WPE</td>
<td></td>
</tr>
<tr>
<td>topramezone2 + atrazine</td>
<td>300 mL + 1000 mL</td>
<td>3 WPE</td>
<td></td>
</tr>
<tr>
<td>mesotrione + nicosulfuron</td>
<td>1300 mL</td>
<td>3 WPE</td>
<td>84 94 95 97 97</td>
</tr>
<tr>
<td>LSD (P&lt;0.05)</td>
<td></td>
<td></td>
<td>3.7 11.3 9.7 14.0 21.8</td>
</tr>
</tbody>
</table>

1WPE = weeks post crop emergence
2Nicosulfuron was applied with adjuvant BoNew Zealanda (0.5% v/v); mesotrione with the adjuvant Synoil (1% v/v) and topramezone with the adjuvant Hasten (0.5% v/v).

Overall conclusions from the trials over three seasons

Uncontrolled weeds had a large influence on growth and development of maize plants, but the extent varied with the time of planting and seasonal growing conditions. Weeds that emerge with the crop are more competitive than those which emerge after the maize has established.

Under good growing conditions, i.e. when it is warm and moisture is not limiting, maize can withstand a higher level of weed cover before exhibiting stress of competition.

Broadleaf weeds are less competitive than grass species. Maize can withstand a higher level of broadleaf weed cover than that of grass weeds before its growth is inhibited.

Maize growth can be reduced by a grass weed cover of 20-50%. If the weed flora is mainly broadleaf species and growing conditions are favourable, the crop growth may not be affected until weed cover reaches well over 50%.

Timing of application of the post-emergence herbicides is of critical importance, especially if the pre-emergence treatment is ineffective. If applied too late, weed competition can reduce leaf expansion and sunlight interception, with loss of potential yield.

In general, post-emergence applications made at 2-3 WPE performed better than those applied at 4-5 WPE or later. Herbicide efficacy declined as the application was delayed. Maize silage and grain yields declined with increasing delay in herbicide application timing.
Averaged over several trials, an early post-emergence treatment of mesotrione followed two to four weeks later by nicosulfuron, provided weed control similar to the current standard pre-emergence treatment (acetochlor + atrazine) combined with a post-emergence herbicide where required. In 2012, the new herbicide topramezone also provided a similar high level of efficacy.

The role of adjuvants

Adjuvants include any substance added to the spray tank to change the physical properties of the spray mixture and the performance of the herbicide. They include stickers, surfactants (wetters and spreaders), penetrants, oils and water conditioners.

All products have built-in adjuvants in their formulation, which control the performance of the herbicide. These products have been formulated to deliver the best result for the herbicide under the recommended label rates. The efficacy of the herbicide may be reduced if the label herbicide rate (g or ml/litre) and water rate (litres/ha) are not adhered to.

Information about the correct adjuvant and its application rate is provided on the herbicide label. The choice of adjuvant is important, it must be compatible with both the herbicide and the target. The wrong adjuvant increases the risk of poor performance and crop injury.

Always check the label recommendations and the manufacturer’s recommendations about the most suitable adjuvant for mixing with a particular product.

Surfactants work by reducing the surface tension of the spray solution, this enables the spray droplets to spread beyond their initial contact area. Increased coverage gives better herbicide absorption.

Stickers are materials that increase the chance that the spray droplets will stick to the leaf surface rather than bouncing off the leaf. Stickers are often water-soluble polymers, acrylic latex or resins. Wetting or spreading agents are often combined with stickers to improve coverage. These may also make the herbicide more rain resistant.

Some adjuvants slow down the drying time for spray droplets, these are called humectants. Some work by drawing water from the atmosphere, others are oil-based. Herbicide absorption into the leaf only occurs when the herbicide is in solution, a slower drying rate enables more absorption.

Penetrants increase the movement of the herbicides into the leaf cuticles by softening or dissolving cuticular waxes. Some penetrants work by reducing the viscosity of the water carrier to a point where it can enter a leave though the stomata (microscopic breathing holes in the leaf). Penetrant adjuvants are often a complex mixture of surfactants and paraffinic petroleum or modified vegetable oils.

It is recommended that all adjuvants be added as the last step to the spray mixture to prevent foaming.

Perennial weeds

Perennial weeds are spread by seed and the transfer of vegetative material such as root fragments and bulbs which are commonly spread by cultivation machinery. It is therefore a priority to remove all soil and plant material from cultivation equipment before entering clean cropping areas.

The successful control of perennial weeds may require a number of management strategies and take several seasons. Herbicides are often less than 100% successful and follow-up treatment is required.

FAR and AgResearch trials have developed control strategies for the following perennial weeds.

Cornbind (*Fallopia convolvulus*)
Cornbind generally spreads from fence lines first into the headland area and then into the main crop area. Maintaining control in the fence lines and headlands is a priority. Dicamba is the most effective post emergence herbicide but generally is not 100% effective. Glyphosate may be applied with high clearance spray rigs in maize grain crops as they approach harvest, following black layer.

**Figure 10.** Cornbind (*Fallopia convolvulus*).

Oxalis species

No agrichemical is fully effective at controlling oxalis. At the FAR arable site in the Waikato an established oxalis population was reduced from a 90% infestation to 5% over a five year period through a targeted strategy. This involved applying post-emergence sprays of mesotrione (including terbuthylazine + synoil in the mix) and nicosulfuron in alternate years. It is important to alternate the herbicides to prevent herbicide resistance developing in grass weeds.

A post- harvest clean up spray with glyphosate can be useful if the oxalis still has green leaves.
Californian thistle (*Cirsium arvense*)
Primisulfuron, nicosulfuron, dicamba and clopyralid effectively control this weed in maize.

**Figure 14.** Californian thistle (*Cirsium arvense*).

**Indian doab** (*Cynodon dactylon*)
Indian doab is the most difficult perennial weed to control in maize. It is tolerant to high rates of glyphosate and nicosulfuron. Paraquat simply burns off the foliage for a short time. More research is required to develop successful control strategies for this weed. In the meantime, this weed is best managed by using harrows to drag the old stolons to the side of the field where they can be manually removed and destroyed.

**Figure 15.** Indian doab (*Cynodon dactylon*).

**Purple and yellow nutgrass** (*Cyperus rotundus*)
Herbicides are only partially effective and the best post emergence option is Halosulfuron-methyl (Sempra®). Clean up post-harvest applications of glyphosate can be used if there is sufficient green leaf remaining on the nutgrass plants. A winter crop of oats or similar may reduce the incidence of these weeds in the following maize crop.

**Figure 11.** Fishtail oxalis (*Oxalis latifolia*) in a young maize crop.

**Docks** (*Rumex sp*) and **Buttercup** (*Ranunculus repens*)
Use pre-cultivation and pre-plant clean up spray mixtures of glyphosate and thifensulfuron-methyl (e.g. Harmony®) for killing docks and buttercups. Maize planting must be delayed for at least 14 days after treatment. Nicosulfuron has some activity against docks.

**Figure 12.** Docks *Rumex obtusifolius*.

**Couch/twitch** (*Elytrigia repens*)
Nicosulfuron has good activity against this weed but follow-up applications are often required to treat late emerging plants. Postharvest clean up sprays with glyphosate can be useful where the weed still has green leaf.

**Figure 13.** Couch/twitch (*Elytrigia repens*).

**Mercer grass** (*Cenchrus clandestinus*) and **Kikuyu** (*Pennisetum clandestinum*)
As above for couch, only a higher rate is recommended and treatment over at least two years will be required.

**Figure 16.** Mercer grass (*Cenchrus clandestinus*) and Kikuyu (*Pennisetum clandestinum*).
7. Biosecurity
Key points:

• Farmers have a key role in preventing new weeds establishing and spreading within New Zealand.
• It is important to develop a biosecurity plan for your property.
• Weed seeds are moved between properties on farm machinery and in animal feeds. Watch out for new weeds on your property after machinery movements and the importation of animal feeds.
• If you find a new weed on your property get it correctly identified and get rid of it.

With the exception of pink bindweed (*Calystegia sepium*), none of the persistent, problem weeds found on New Zealand arable farms are indigenous species. Many arrived with the early European settlers, either inadvertently with soil and farm machinery or were deliberately introduced for reasons that seemed like a good idea at the time.

Today, border security procedures reduce the likelihood of weed incursions from outside of New Zealand but nevertheless, with increasing international trade and travel there is an on-going risk that new weeds will enter the country and establish on our farms. Once established, eradication if it is possible, is time consuming and extremely expensive.

Farmers are often the first to notice the arrival of new plants on their farms. If and when this happens it is extremely important to be pro-active in alerting industry professionals, processors and/or regional council staff, so that the plant can be identified and the risk associated with its presence can be assessed.

Some difficult to control weeds such as broom corn millet and yellow bristle grass are confined to a small number of regions throughout New Zealand. Farmers outside of these regions need to be aware that there is a continual risk that seeds from these weeds can be transported on machinery and within balage and silage to new regions.

All farms should develop their own farm biosecurity plan. This needs to assess the risks associated with the movement of people, machinery, seeds and animal feeds on the farm and develop protocols for reducing these risks.

For example the plan should outline:

• Requirements for machinery clean down and movement on and off the farm.
• Requirements for personnel visiting a crop.
• Certification of seeds.
• Specifications for imported feeds.
• Procedures for containing an unwanted weed or pest on the farm.

The following case studies illustrate the challenges of controlling a weed once it establishes on arable land. As farm systems become integrated and animal feeds are traded between the arable and pastoral sectors, there is an increased risk that weed seeds will be moved between regions.

Vigilance, identification and early eradication are important to prevent these weeds establishing in new regions.
Case-study

Broom corn millet (*Panicum miliaceum* L.)

Broomcorn millet is one of the world’s oldest cultivated cereals. Today it is widely grown in the northern hemisphere for human consumption and bird seed.

In 1970, a wild biotype with black seeds emerged and quickly became weedy, producing more dry matter, reaching a greater height and producing twice as much seed. This bio-type has become a persistent weed problem on cropping land due to its early shattering.

The first reported incidence of this plant in New Zealand was in a domestic garden in Marlborough, where it is thought to have grown from bird seed. It is unfortunate that it was not controlled at this point, as from there it spread into local sweet corn crops and was soon spread into other regions by the movement of people and harvesting machinery. It is now a major pest in commercial sweet corn crops in Marlborough, Hawkes Bay and Gisborne, and has also been reported in maize crops in these regions.

**Characteristics of broom corn millet**

- Fast growing and can set viable seed within six weeks of emergence.
- An emergence study found that viable plants can emerge from seed buried at 120mm. In some soils the emergence was recorded from burial depths of 170mm.
- Germination occurs at air temperatures between 13°C to 34°C, and New Zealand testing showed the highest germination rates were between 27°C and 34°C.
- Deep burial of broom corn millet reduces its ability to establish competitively with the crop.
- Broom corn millet is extremely hardy, able to survive for long periods under suitable conditions. Accelerated aging experiments showed that broom corn millet seed is able to maintain its viability for about 50 days at high humidity and 45°C. However buried seed studies showed that most seed that is near the surface will germinate at the first opportunity, this will quickly deplete the seed bank of this weed species.
- Post-emergence herbicide applications must be timed to catch the plants when they are young and more than one application will probably be required.

**Pre-emergence herbicides only provide two to three weeks residual activity.**

- It competes with the crop strongly for water, nutrients and sunlight, reducing yield.

**Control measures**

If broom corn millet is not on your land, it is important to keep a watch for it, and if it is found, prevent it from setting seed.

The most likely transfer of seed between paddocks will be on farm machinery, especially harvesters. Seeds may also arrive on your land via surface water flow.

Two field trials were carried out in Havelock North and Tolaga Bay sweetcorn crops to compare a range of pre- and post-emergence herbicide treatments and their mixtures.

Both trials demonstrated the need for a post-emergence treatment as the pre-emergence treatments did not control the late germinating broom corn millet plants.

In the Havelock North trial, excellent control of the weed was obtained with a single post-emergence application of nicosulfuron, following a pre-emergent programme.

In Tolaga Bay, two post-emergence applications were required, timed three weeks apart (each a week after heavy rain).

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**Table 10. Best control for broom corn millet in sweetcorn**

<table>
<thead>
<tr>
<th>Region</th>
<th>Pre-emergent programme</th>
<th>Post emergent Programme</th>
<th>Level of control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hawkes Bay</td>
<td>Atrazine @ 0.6 kg a.i./ha plus Acetochlor @ 2.5 kg a.i./ha Applied 8 November</td>
<td>Nicosulfuron 60 g a.i./ha + surfactant 0.5% Applied 4 December</td>
<td>100%</td>
</tr>
<tr>
<td>Gisborne</td>
<td>Glyphosate @ 540g a.i./ha Applied 15 December</td>
<td>Nicosulfuron 60 g a.i./ha + surfactant 0.5% applied 4 January reapplied 24 January</td>
<td>100%</td>
</tr>
</tbody>
</table>

---

Figure 16. Broom corn millet in flower.
Case-study

Velvetleaf (*Abutilon theophrasti*)

Velvetleaf has been reported intermittently in New Zealand, but until now, vigilance and control has prevented the weed from becoming widely established. It is believed that it entered New Zealand as a contaminant in a seed line, possibly grain and soy bean imported for poultry feeds.

The latest incursion is larger and more challenging. Field trials have shown that atrazine has limited efficacy, suggesting that these plants could be an atrazine-resistant bio-type.

Velvetleaf was deliberately introduced into North America in the 18th century from China for its fibre. It has now become their foremost broadleaf weed in maize and soy bean crops. If uncontrolled, it can reduce yields by up to 34% and costs the industry hundreds of millions of dollars to control.

The latest New Zealand incursion was reported in a Waikato maize crop. It was spotted by a farmer, who took the responsible action of getting the weed identified. Thorough scouting by staff from FAR, the regional council and AgResearch confirmed that the weed was well established both in the crop and along the fence lines. It was likely that it had been there for more than one season.

Velvetleaf was recently declared an Unwanted Organism by the Ministry for Primary Industries. This means all infestations must be reported and eradicated. In Waikato the Waikato Regional Council has accepted responsibility for this under its Pest Management Plan. Active effort is going into preventing the spread of the weed throughout the region.

Characteristics of velvetleaf

- Velvetleaf is a hot weather, annual weed that grows quickly from seeds germinating throughout the growing season.
- The fastest growth occurs six to eight weeks after weed emergence and in favourable conditions, velvetleaf plants will catch up and grow taller than the surrounding crop.
- Its only redeeming feature is that it is frost-tender.
- Velvetleaf is self-compatible and pollination occurs on the first day of flowering. The seeds mature two to three weeks later and each plant can produce up to 17,000 seeds per plant. Seeds will continue to ripen on the plant after it is pulled out.
- The seeds have a hard seed coat and can remain dormant in the soil for 50-60 years. They can survive in silage for more than three months and remain viable after passing through the digestive tracts of animals.
- It is shade tolerant and can produce seed and infest a maize paddock while growing under the dense canopy.

Control measures

Scouting and rogueing is the first option for control, but will only be successful if weed numbers are small and the plants are destroyed after removal.

Because velvetleaf germinates throughout the season it is difficult to eradicate with herbicides. Successful control depends on spraying it at the 2-4 leaf stage.

Overseas research has shown that pre-emergence applications of atrazine have variable success rates so must be followed with post-emergent treatments.

Velvetleaf has developed resistance to atrazine in the USA; other active ingredients should be used if atrazine is unsuccessful in its control.

Velvetleaf seedlings are most susceptible at the 2-4 leaf stage and both nicosulfuron and atrazine give good control. A mixture of dicamba and mesotrione was slightly more effective on the larger plants but velvetleaf plants can quickly grow taller than the spray boom and these plants were not controlled. In New Zealand field trials plants larger than this survived. Plant size, application rate and choice of adjuvant are critical for success.

Post-emergent herbicides have little residual activity on velvetleaf and do not suppress further germinations. It will be necessary to continue a post-emergent programme throughout the season, using specialist equipment as the crop increases in height.

![Figure 17. Velvetleaf with mature seed heads.](image-url)
Case-study

Yellow bristle grass (*Setaria pumila*)

Yellow bristle grass, a native of southern China, is becoming an increasingly troublesome weed in New Zealand. It is now present throughout the North Island and in Nelson and Marlborough in the South Island, and weed distribution models indicate that it has a wide potential distribution throughout much of the country, but not in alpine regions.

It started as a common roadside weed. Mowing spread the seed over fence lines and it is now commonly found in pastures and cropping ground. Once established, it is a prolific seed producer and it can become the dominant pasture species within a few years. It is particularly invasive in Waikato, Taranaki, Bay of Plenty and South Auckland.

Characteristics of yellow bristle grass

- A C₄ grass and a summer growing annual which reproduces only by seed.
- The optimal air temperatures for germination are between 16°C and 35°C, from mid-October to mid-January.
- Early seed heads appear in late December and are produced through the summer.
- The seed heads are barbed and are carried in fur and clothing as well as being dispersed by water and soil movement.
- Most seeds near the soil surface survive for only a few years under field conditions.
- In grazed pasture, ingested seeds survive their trip through the rumen to be deposited in the dung. They can survive for up to three months in effluent and will be spread around the farm in effluent irrigations. They do not compete with strong ryegrass pastures but will establish in any gaps within the pasture, especially old dung pats.
- Yellow bristle grass is commonly found in maize silage crops but harvested seed in sealed silage has a low survival rate and is unlikely to live after three months. FAR's most recent research has shown that seed survival is reduced to one week in well-sealed silage stacks.
- Seeds may be spread from affected properties to clean properties by seasonally grazed stock, outsourced feed supplements (hay and baleage), roadside grazing, agricultural contracting machinery, road reserve mowers, road works machinery and other vehicles.

Control measures

The most important control mechanism is to do something before seed is set.

Small infestations may be treated with glyphosate at all growth stages but the seeds will not be killed. Manual removal is also a good option.

Yellow bristle grass can be controlled in pasture with the selective herbicide, Puma® S. However, maize is not tolerant to Puma® S and so it cannot be used in the crop. Headland infestations can be controlled by keeping a strip of pasture or other suppressive species and confining the spray to the strip area.

Post emergence applications of nicosulfuron or trimezone to the outer headland rows of the maize crop will generally be effective at removing yellow bristle grass and other grass weeds. However, new germinations may occur after rain, requiring additional herbicide applications for control and reduction of seed deposits to the weed seed bank.

Figure 18. Mature yellow bristle grass.
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Trevor James

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FAR, June 2013

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Appendix 1

Selective herbicides registered for use in maize.

*To avoid the development of resistance, alternate between successive crops with herbicides from different chemical groups.*

<table>
<thead>
<tr>
<th>Chemical Group</th>
<th>Mode of action</th>
<th>Chemical Name</th>
<th>Products</th>
<th>Primary Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triketone (F2)</td>
<td>Inhibits HPPD enzyme</td>
<td>mesotrione, topramezone</td>
<td>Callisto®, Arietta®</td>
<td>Broadleaf + some grasses, Hemlock, fathen, Grasses + some broadleaved</td>
</tr>
<tr>
<td>ALS Inhibitor (B)</td>
<td>ALS inhibitor</td>
<td>flumetsulam, halosulfuron, nicosulfuron, primisulfuron</td>
<td>Preside™, Valdo®, Sempra®, Astound®, Neeko™, Latro®, Guardian®</td>
<td>Some broadleaved, Purple nutsedge, Couch, fathen, summergrass, witch grass, bristle grass</td>
</tr>
<tr>
<td>Nitrile (C3)</td>
<td>Photosystem II inhibitor</td>
<td>bromoxynil</td>
<td>Emblem®,</td>
<td>Broadleaf</td>
</tr>
<tr>
<td>Phenyl-pyridazine (C1)</td>
<td></td>
<td>pyridate</td>
<td>Tough®</td>
<td>Fathen</td>
</tr>
<tr>
<td>Substituted urea (C2)</td>
<td></td>
<td>linuron</td>
<td>Afalon® FL, Linex® Flo</td>
<td>Some broadleaved, Some broadleaved</td>
</tr>
<tr>
<td>Triazine (C1)</td>
<td></td>
<td>atrazine, cyanazine, terbuthylazine</td>
<td>Atrazine, Bladex®, Bruno™, Cyprex, Gardoprim®, Tyllanex®</td>
<td>Broadleaf, Broadleaf, Broadleaf, Broadleaf + some grasses, Broadleaf</td>
</tr>
<tr>
<td>Triazolinones (E)</td>
<td>Inhibition of PPO</td>
<td>saflufenacil</td>
<td>Sharpen®</td>
<td>Broadleaf</td>
</tr>
<tr>
<td>Triazinone (C1)</td>
<td>Photosystem II inhibition</td>
<td>metribuzin</td>
<td>Sencor®, Jazz™, Metzin</td>
<td>Broadleaf, Broadleaf, Broadleaf</td>
</tr>
<tr>
<td>Dinitroaniline (K1)</td>
<td>Inhibits tubulin</td>
<td>pendimethalin</td>
<td>Stomp®, Xtra, Pend-X™, Ruck™, Vienna</td>
<td>Broadleaf + grasses, Broadleaf + grasses</td>
</tr>
<tr>
<td>Benzoic (O2)</td>
<td>Synthetic auxins</td>
<td>dicamba</td>
<td>Banvel®, Ace™, Acumen™, Sylon®</td>
<td>Bindweed, California thistle, fathen, Bindweed, California thistle, fathen</td>
</tr>
<tr>
<td>Picolinic (O3)</td>
<td>Synthetic auxins</td>
<td>clopyralid</td>
<td>Versatill®, Archer®, Cobber®, Tango™, Void™</td>
<td>Bathhurst burr, California thistle, Volunteer potato</td>
</tr>
<tr>
<td>Acetanilide (K3)</td>
<td>Cell division</td>
<td>acetochlor, alachlor, dimethenamid, metolachlor, propachlor</td>
<td>Roustabout®, Ace™, Sylgen®, Corral®, Lasso®, MTech, Dual Gold®, Ramrod® Flow</td>
<td>Grasses + some broadleaved, Grasses + some broadleaved, Grasses + some broadleaved, Annual grasses, Grasses + some broadleaved</td>
</tr>
</tbody>
</table>