Weed management for developing countries

Addendum 1
Weed management in vegetables

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INTRODUCTION

Vegetable growing imposes a particular weed-management approach. Vegetable areas are usually small, but produce high-value crops that are commercially and gastronomically appreciated. Fruit and leaf crops provide important income for farmers and workers at local or regional levels. Providing evidence of small surfaces used for growing vegetables, in Spain for the year 1999 the area covered 395 300 ha, with a production of about 12 million tonnes.

Irrigation is another typical characteristic of these crops in Mediterranean or arid areas. The type of irrigation used also conditions weed management because of the many systems available: traditional irrigation through flooding or by furrows, and the more modern sprinkling, drip and infiltration irrigation. Herbicides have different behaviour. Their incorporation is affected by water and crop selectivity can thus be substantially reduced.

Traditional vegetable-growing areas are usually situated adjacent to waterways, flood plains, river deltas, marsh zones, and, if herbicides are used, their environmental impact and usage conditions must be taken into account.

A number of vegetables are produced under plastic mulching, which may affect herbicide behaviour, reducing its volatility and condensation phenomena, and crop selectivity could be modified.

As a result of all these problems and because of the small areas under vegetables, chemical companies are not very interested in developing specific herbicides for weed management in these crops. This lack of interest may also bring about the discontinuance of some selective herbicides, such as naphtalam, bensulide, and others from the European market. In the United States there is also concern regarding herbicides used for minor crops. One of the projects there, IR-4, has a mandate to provide weed management solutions to vegetable growers in the United States (Arsenovic and Kunkel, 2001).

Another aspect related to the complexity of herbicide use is its soil persistence that can seriously affect the next crops in the rotation as a result of soil residues or carryover. Vegetable rotations are very fast and intensive in many places, and herbicide toxicity can affect the next crop if the cycle of the previous crop is short enough.

We have to consider all these aspects, as well as consumer concerns on the probable presence of pesticide residues in fruit, leaves and roots of these crops and the strict limitations for marketing and export that can invalidate the hard labour and endurance of many workers. Therefore, a careful use of herbicide is compulsory, and good field practices must be followed, especially when recognition of a labelled production is desired.

There is a great interest in the integration of tilling practices with chemical control because of the reduction of the herbicide impact and the cost of hand-labour. While herbicides play an important role in a very mechanized, open air, extensive horticulture, hand-weeding is a
common practice in vegetable cultivation, even following herbicide treatment (e.g. green beans may need 5-15 h/ha and transplanted tomatoes, 50-90 h/ha).

WEED FLORA

The composition of present weed flora in vegetables needs to be well determined. Based on this data, we shall then be able to prepare the best control methods to be implemented. It is well known that weeds are very well adapted to the crop that they infest, because of their morphological and phenological characteristics. An example of this situation is the case of carrots where umbelliferous species as *Ammi majus*, *Torilis* spp., *Scandix pecten-veneris*, *Daucus* spp. are the dominant ones. A spring crop can be infested by two generations of species: first by cold-temperature-adapted, such as *Capsella bursa-pastoris*, *Chenopodium album* and *Polygonum aviculare*, and later by the summer thermophiles *Portulaca oleracea*, *Solanum nigrum*, *Cyperus rotundus* and *Amaranthus retroflexus*.

Some annual species with a short cycle such as *Sonchus oleraceus*, *Poa annua*, *Senecio vulgaris*, *Stellaria media* are also likely to create problems in some vegetables at certain stages of the crop rotation.

Weed communities may have various species, but many of them are more adapted to a particular crop. For example: *Echinochloa crus-galli*, *Amaranthus* spp., *Chenopodium album*, *Polygonum aviculare*, *Portulaca oleracea* and *Solanum nigrum* are dominant in transplanted tomatoes. However if this crop is direct-seeded, early emergence grass weeds such as *Alopecurus myosuroides*, *Avena* spp., *Lolium* spp. and several species of *Brassicaceae* and *Asteraceae* are more frequent.

Similarly, frequent weeds in early-seeded onion are *Capsella bursa-pastoris*, *Sinapis arvensis*, *Poa annua*, *Sonchus* spp., *Polygonum aviculare*. In transplanted onion, or later seeded crops, *Echinochloa* spp., *Portulaca oleracea*, *Solanum* spp., *Setaria* spp. are also frequent. Parasitic weeds can be also a problem in vegetable crops (*Orobanchaceae* in legumes, *Asteraceae* and lettuce; *O. ramosa* in *Solanaceae* and cucurbits; *Cuscuta* spp. in legumes, tomato, carrots, onion, asparagus) (García-Torres, 1993). Some key weeds are characteristic of an area, region or country (e.g.: *Galinsoga parviflora* in Poland, *Polygonum arenastrum* in Israel, *Ambrosia artemisiifolia*, *Cirsium arvense* and triazine-resistant *Amaranthus hybridus* in France, *Abutilon theophrasti* in Italy, *Cyperus rotundus* in Portugal, Spain and Morocco (Tei *et al.* 1999 and 2002).

Major problems in vegetables are caused by broadleaf weeds because grass weeds are much better managed in rotation or they can be successfully eliminated with the use of selective foliar-applied herbicides.

With a sound knowledge of weed phenology and other factors (temperature, rainfall and irrigation scheme) at the local level, it is possible to predict when and in which crop certain weeds will raise problems. Obviously, in a plastic-protected crop, weed emergence takes place earlier and weed growth tends to be greater.
WEED COMPETITION

Only a few vegetables are good competitors with weed flora because they quickly cover the soil, topping the weed growth. Examples are cabbage (Brassica spp.) or artichokes. But most vegetables, such as Liliaceae, carrots or peppers in temperate latitudes, grow slowly and they cover the soil very sparsely, suffering strong weed competition not only for water, nutrients and light, but even for space. Thus, if weed control is not carried out timely, there will be no production at all. There are many examples of problems in crop-yield reduction (Labrada, 1996) that indicate the great sensibility of vegetables to early weed competition and the need to control weeds at early crop stages.

Weed competition is especially dramatic when a direct-seeded vegetable is grown. The critical period of weed competition (i.e. the period during which weed control has to be carried out) is usually longer in direct-seeded than in transplanted crops. For example, if transplanted pepper has to be weeded from the second week until the third month after transplant to prevent a 10 percent yield loss, direct-seeded pepper must be weeded during the first four months after emergence to prevent the same loss (Medina, 1995). Some traditional techniques are thought to increase crop competitiveness (e.g. transplant, earthing-up). Obviously, weather conditions and weed density have a great influence on the length of critical periods. A cold wave affecting spring vegetables can provoke slow growth, higher competition and greater yield losses.

SEED BEDS

Many vegetables are grown in seed beds to develop suitable seedlings for transplanting in the field. Soils dedicated to seed beds are usually light, with good tilth, and fertilized to obtain a good plant emergence. Seed beds are usually flood-irrigated and plastic-protected. Many weed control techniques are already described in the work of Labrada, (1996). Here we add some possibilities for weed management.

Stale seed beds

Stale (‘false’) seed beds are sometimes used for vegetables when other selective weed-control practices are limited or unavailable. Success depends on controlling the first flush of emerged weeds before crop emergence, and on minimal disturbance, which reduces subsequent weed flushes. Basically, this technique consists of the following:

1. Preparation of a seedbed 2–3 weeks before planting to achieve maximum weed-seed germination near the soil surface.
2. Planting the crop with minimum soil disturbance to avoid exposing new weed seed to favourable germination conditions.
3. Treating the field with a non-residual herbicide to kill all germinated weeds (William et al. 2000) just before or after planting, but before crop emergence.

Recommended herbicides are bypiridylums, glyphosate, sulfoxate and glufosinate-ammonium, among others. In light-textured soils, such as sand or in artificial planting media, herbicide treatments are risky for crops (especially in tomato). With glyphosate or sulfoxate it is recommended that either of these be applied ten days before planting. It is also possible to treat the soil with metham sodium, but planting must be delayed until the oil is free of
metham, usually after 20 days. The use of this fumigant is very effective against Solanum nigrum in tomatoes.

Solarization

It is an effective method for the control of soil-borne diseases and pests that can control also many weeds. The method has been previously described by Labrada (1996). The soil must be clean, surface-levelled and wet, previously to being covered with a thin (0.1–0.2 mm) transparent plastic and very well sealed. The soil must be kept covered during the warmer and sunnier months (30–45 days). Soil temperatures must reach above 40° C to exert a good effect on various soil-borne pests, including weed seeds. Soil solarization is a broad-spectrum control method, simple, economically feasible and environmentally friendly. It does not affect soil properties and usually produces higher yields (Campiglia et al. 2000). There are also some disadvantages in its implementation. For example, previous irrigation is a requirement, (or frequent and abundant rain) and the soil must be kept solarized (non-producing) for a period of at least one month. Results are often variable, depending on weather conditions. Cold (high latitude) or cloudy places are usually not suitable for implementing solarization. Some species can tolerate solarization (e.g. deep rooted perennials: Sorghum halepense, Cyperus rotundus, Equisetum spp. and also some big weed seeds such as legumes). After solarization the plastic must be recovered, and the use of deep or mouldboard tillage must be avoided. This system is more suitable for small areas of vegetables, but it has been mechanized for extensive areas of tomatoes. Soil solarization is widely used under plastic greenhouse conditions in southern Spain. Biofumigation consists in the incorporation of fresh manure into the soil in plots to be solarized. The breakdown of the organic matter produces toxic gases under the plastic and enhances the biocide effects. Normally the soil should be removed after solarization or biofumigation to enable the gases to escape from the soil before planting takes place (Monserrat, 2001).

Chemical control in seed beds

There are even less registered herbicides for seed beds than for planting crops. Some of the recommended herbicides are described by Labrada (1996). Table 1 shows some new additions.

There are several post-emergence grass-killers (usually known as ‘fop’ and ‘dim’ families) that could be used well in vegetable seedbeds, as for example, cycloxydim (for onion, cruciferous crops), cletodim (onion, tomatoes), fluazifop-butyl (tomato, pepper, lettuce, leek, onion). Rates must be low to avoid any problem of phytotoxicity (De Liñán, 2002).

Herbicide treatments under plastic cover are always hazardous and careful application should be carried out. Under plastic, high levels of moisture and elevated temperature are common and plants grow very gently. Selectivity could be easily lost and phytotoxicity symptoms may occur, while sometimes they are just temporary. The effects are often erratic. The best way to deal with it is to be prudent and make some trials before a general treatment.
Table 1. Selective pre-emergence and early post-emergence herbicides for vegetable seedbeds.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Dose (kg a.i. / ha)</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clomazone</td>
<td>0.18 – 0.27</td>
<td>Pepper, cucumber</td>
</tr>
<tr>
<td>DCPA</td>
<td>6.0 – 7.5</td>
<td>Onion, cole crops, lettuce</td>
</tr>
<tr>
<td>Metribuzin</td>
<td>0.15 – 0.5</td>
<td>Tomato</td>
</tr>
<tr>
<td>Napropamide</td>
<td>1.0 – 2.0</td>
<td>Tomato, pepper, eggplant</td>
</tr>
<tr>
<td>Pendimethalin</td>
<td>1.0 – 1.6</td>
<td>Onion, garlic</td>
</tr>
<tr>
<td>Proamide</td>
<td>1.0 – 2.5</td>
<td>Lettuce</td>
</tr>
<tr>
<td>Propachlor</td>
<td>5.2 – 6.5</td>
<td>Onion, cole crops</td>
</tr>
</tbody>
</table>

b) Post-emergence (crops with at least 3 leaves)

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Dose (kg a.i. / ha)</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clomazone</td>
<td>0.27 – 0.36</td>
<td>Pepper</td>
</tr>
<tr>
<td>Ioxinil</td>
<td>0.36</td>
<td>Onion, garlic, leek</td>
</tr>
<tr>
<td>Linuron</td>
<td>0.5 – 1.0</td>
<td>Asparagus, carrots</td>
</tr>
<tr>
<td>Metribuzin</td>
<td>0.075 – 0.150</td>
<td>Tomato</td>
</tr>
<tr>
<td>Oxfluorfen</td>
<td>0.18 – 0.24</td>
<td>Onion, garlic</td>
</tr>
<tr>
<td>Rimsulfuron</td>
<td>0.0075 – 0.015</td>
<td>Tomato</td>
</tr>
</tbody>
</table>

DIRECT-SEEDED AND TRANSPLANTED CROPS

Crop rotation

Crop rotation is the programmed succession of crops during a period of time in the same plot or field. It is a key control method to reduce weed infestation in vegetables. Crop rotation was considered for a long time to be a basic practice for obtaining healthy crops and good yields. This concept was mistakenly eliminated with the use of more agrochemicals. At present, however, crop rotation is gaining interest and is of value in the context of integrated crop management. Classically, crop rotations are applied as follows:

1. Alternating crops with a different type of vegetation: leaf crops (lettuce, spinach, cole), root crops (carrots, potatoes, radish), bulb crops (leeks, onion, garlic), fruit crops (squash, pepper, melon).
2. Alternating grass and dicots, such as maize and vegetables.
3. Alternating different crop cycles: winter cereals and summer vegetables.
4. Avoiding succeeding crops of the same family: Apiaceae (celery, carrots), Solanaceae (potato, tomato).
5. Alternating poor- (carrot, onion) and high-weed competitors (maize, potato).
6. Avoiding problematic weeds in specific crops (e.g. Malvaceae in celery or carrots, parasitic and perennials in general).

Examples of crop rotations are as follow (Zaragoza et al. 1994):

In temperate regions:  
Pepper - onion - winter cereal  
Melon - beans - spinach - tomato  
Tomato - cereal - fallow  
Lettuce - tomato - cauliflower  
Potato - beans - cole - tomato- carrots  
Melon - artichoke (x 2) - beans - red beet - wheat - cole
In tropical regions:  Tomato - okra - green bean  
Sweet potato - maize - mung bean

Introducing a fallow in the rotation is essential for the control difficult weeds (e.g. perennials), cleaning the field with appropriate tillage or using a broad-spectrum herbicide. It is also important to avoid the emission of weed seeds or other propagules.

**Mixed cropping**

Growing two or more crops at the same time and adjacent to one another is called mixed cropping, or intercropping. Crop cycles must coincide totally or partially (relay-cropping). The advantages are a better use of space, light and other resources, a physical protection, a favourable thermal balance, better plant defence against some pests and fewer weed problems because the soil is better covered. Inconveniences are intercrop competition, difficult management and mechanization, a greater need for hand-labour, incomplete control of weeds. Sometimes the results are less productive than cultivating just one crop alone. Usually the ‘companion’ crops are fast and low-growing plants, creeping and erect plants, or symbiotic species. Some examples are:

In temperate regions:
- lettuce + carrots;
- cole crops + leeks, onion, celery, tomato;
- maize + beans, soya.

In tropical regions: this technique is very well adapted to the traditional agricultural system:
- maize + beans + squash, manioc;
- tomato + pigeon pea, manioc;
- sugar cane + onion, tomato.

**Preventive measures**

These can be very useful (but, unfortunately, are always forgotten), closely connected with crop rotations and necessary when no direct measures of weed control can be taken for economic reasons. They are based on a reduction in the soil-seed and propagules bank and the early awareness of the infestations.

It is necessary to avoid the invasion of new species through the use of clean planting material and to prevent seed dispersal on the irrigation water, implements and machines. A written record of the weed situation in the fields is very useful. Another aspect is to impede perennial weed dispersal (or parasitic weeds) through the opportune use of treatments and tillage and the use of drainage tillage to prevent propagation of some species that need high moisture levels. (*Phragmites* spp., *Equisetum* spp., *Juncus* spp.) It is also necessary to scout the field edges to prevent invasions, acting only when necessary, and bearing in mind the usefulness of the edges and borders to control erosion and hosting useful fauna (Zaragoza, 2001).
Land preparation and tillage

As Labrada (1996) stated, suitable land preparation depends on a good knowledge of the weed species prevalent in the field. When annual weeds are predominant (Crucifers, Solanum, grass weeds) the objectives are unearthing and fragmentation. This must be achieved through shallow cultivation. If weeds have no dormant seeds (Bromus spp.), deep ploughing to bury the seeds will be advisable. If the seeds produced are dormant, this is not a good practice, because they will be viable again when they return to the soil surface after further cultivation.

When perennial weeds are present, adequate tools will depend on the types of rooting. Pivot roots (Rumex spp.) or bourgeois roots (Cirsium spp.) require fragmentation and this can be achieved by using a rotovator or cultivator. Fragile rhizomes (Sorghum halepense) require dragging and exposure at the soil surface for their depletion, but flexible rhizomes (Cynodon dactylon) require dragging and removal from the field. This can be done with a cultivator or harrow. Tubers (Cyperus rotundus) or bulbs (Oxalis spp.) require cutting when rhizomes are present and need to be dug up for exposure to adverse conditions (frost or drought). This can done with mouldboard or disk ploughing. Chisel ploughing is useful for draining wet fields and reducing the infestation of deep-rooted hygrophilous perennials (Phragmites, Equisetum, Juncus). This is why reliable weed information is always necessary.

The success of many weed-control operations depends upon the timing of its implementation (Forcella, 2000). The opportunity for mechanical operation is indeed essential. Action must be taken against annual weeds before seed dispersion takes place. Tillage efficacy against perennials is higher when the plant reserves move up (e.g. Convolvulus arvensis in springtime. In autumn there are more fragment rootings) (Nogueroles and Zaragoza, 1999).

Good practices in mechanical operations must look at optimal conditions, including the following:

- planting density must be in function of the weeding-tool working width;
- choice of adequate tools necessary for the work;
- paying attention to the weed and crop stage and avoiding delays in interventions;
- regulating the work depth, advance speed, attack angle;
- moisture content is important; look for the right tilth;
- do not increase the soil erosion: avoid parallel tillage to the slope direction line;
- foresee climatic conditions after completion of work. Avoid tillage if rainfall is expected.

In Germany, very limited negative side effects have been produced with the use of mechanical weed control. Average plant losses after hoeing, ridging plus harrowing time were 3.0–3.5 percent (Laber et al. 2000).

Another typical operation that requires mechanical tillage is herbicide soil incorporation. Some very volatile herbicides commonly used in vegetables (e.g. trifluraline) must be thoroughly incorporated in the soil at an adequate depth (5–7 cm). The implement used for herbicide incorporation must be in good condition. For example, rotavator blades must be sharpened. L-shaped blades are the best choice for chemical incorporation. For correct incorporation the soil must be neither too wet nor too dry. In the first case it is convenient to change the rotavator by a flexible or rigid tine harrow. Unbroken pieces of manure or soil clods can reduce the treatment efficacy (Kempen, 1989).
Mulching material

The use of plastic mulching is very popular in many vegetable-growing areas. A non-transparent plastic is used to impede the transmission of photosynthetic radiation through the plastic to the weeds so that the development of weeds is then arrested. Advantages are also a better moisture conservation as a reduction in irrigation needs means a reduction in nitrogen leaching, a better soil structure conservation, and an increase in the vegetable yield in an arid climate. Inconveniences are mainly the price of plastic (although it can be reused) as well as management costs. Some perennial weeds are not controlled (e.g. *Cyperus* spp., *Convolvulus arvensis*) and interrow cultivation or treatments are necessary. It is obligatory to remove the plastic residues from the field in the form of waste (burning is prohibited). Black plastic mulching on the crop rows and interrow cultivation is a satisfactory option for organic tomato and melon growers in Southern Europe. Other organic materials (bark, straw, plant residues) can be used, especially if there is a cheap source available nearby. Their advantages are similar to plastic, but weeds can easily manage to reach the surface if the layer is not thick enough. Depending on the materials used, there can be specific problems (e.g. danger of fire with the use of straw, and wind or flooding can remove mulching materials). Some materials can increase the population of crop enemies: rodents, snails. Of course, some manual weeding is often still necessary (Nogueroles and Zaragoza, 1999).

Chemical weed control

The best approach to minimize inputs and to avoid any environmental problems is to apply herbicides in the crop row to a width of 10–30 cm (Labrada, 1996). Band application reduces herbicide use by up to 75 percent compared to an overall application. Weeds along the cropping row are then controlled and the interrow ones can be removed through cultivation. Table 2 shows the selective herbicide options that can be used in vegetables.

Diphenamid was a good herbicide for vegetables but is no longer commercialized. None of these herbicides are effective in the control of perennial weeds. Halosulfuron is a new compound selective on cucurbits and other vegetables with action against *Cyperus* spp. (Webster, 2002).

Sometimes a combination of two herbicides having a different weed-control spectrum may be used. Mixtures of different herbicide are possible (e.g. isoxaben + trifluralin, DCPA + propachlor, bensulide + naptalam) to achieve better efficacy, but previous trials are necessary. Some herbicides can be tested against the parasitic *Cuscuta* spp., such as DCPA, pendimethalin, pronamide and imazethapyr (Garcia-Torres, 1993).

For the selective control of grass weeds in vegetable crops the use some foliar active herbicides is recommended, such as cicloxidim (against annuals: 0.1–0.25 kg a.i./ha, perennials: 0.3–0.4), cletodym (0.1–0.2), fluazifop-butyl (annuals: 0.15–0.25, perennials: 0.5+0.25), haloxyfop-methyl (0.05–0.2), propaquizafop (0.1–0.2), quizalofop (annuals: 0.05–0.125, perennials: 0.1–0.2). It should be noted that one application will not be sufficient against perennials. Their foliar activity is enhanced by adding a non-ionic surfactant or adjuvant (Kempen, 1989; William *et al.* 2000; De Liñán, 2002).

The use of any herbicide in vegetables requires previous tests to verify its effectiveness in local conditions and selectivity to available crop cultivars.
Table 2. Selective herbicides for weed control in vegetable crops

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Dose kg a.i./ha</th>
<th>Treatment moment (1)</th>
<th>Weeds (2)</th>
<th>Crops (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alachlor</td>
<td>2.4</td>
<td>Post</td>
<td>Gd</td>
<td>Brassica crops, onion</td>
</tr>
<tr>
<td>Benfluazalin</td>
<td>1.17-1.7T</td>
<td>PPI</td>
<td>Gd</td>
<td>Lettuce, garlic</td>
</tr>
<tr>
<td>Benisulide</td>
<td>5.5-7.2</td>
<td>Pre</td>
<td>Gd</td>
<td>Cucurbits</td>
</tr>
<tr>
<td>Bentazon</td>
<td>0.75-1</td>
<td>Post</td>
<td>D</td>
<td>Green peas, green beans</td>
</tr>
<tr>
<td>Chlorothal-dimethyl (DCPA)</td>
<td>5.25-9.00</td>
<td>PP/Pre/Post</td>
<td>Gd</td>
<td>Onion, lettuce, cole, tomato, green beans</td>
</tr>
<tr>
<td>Clomazone</td>
<td>0.18-0.54</td>
<td>PP/Post</td>
<td>Gd</td>
<td>Pepper, green peas</td>
</tr>
<tr>
<td></td>
<td>0.18-0.27</td>
<td>Pre</td>
<td>Gd</td>
<td>D. s. pepper, cucumber, squash, pumpkin</td>
</tr>
<tr>
<td>Clopyralid</td>
<td>0.70-0.92</td>
<td>Post</td>
<td>D</td>
<td>Asparagus</td>
</tr>
<tr>
<td>Diuron</td>
<td>0.4-2.4</td>
<td>Post</td>
<td>Dg</td>
<td>Asparagus</td>
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<tr>
<td>Ethalfluralin</td>
<td>0.8-1.7</td>
<td>PP</td>
<td>Gd</td>
<td>Tomato, pepper, beans, squash</td>
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<tr>
<td>Halosulfuron</td>
<td>24-48 (g)</td>
<td>Pre/Post</td>
<td>Dg</td>
<td>Squash, cucumber</td>
</tr>
<tr>
<td>Ioxinil</td>
<td>0.36-0.60</td>
<td>Post</td>
<td>D</td>
<td>Onion, leek, garlic</td>
</tr>
<tr>
<td>Isoxaben</td>
<td>0.1-0.12</td>
<td>PPI</td>
<td>D</td>
<td>Onion, garlic</td>
</tr>
<tr>
<td>Linuron</td>
<td>0.50-1.25</td>
<td>Pre</td>
<td>Dg</td>
<td>Carrot, artichoke, asparagus, faba bean</td>
</tr>
<tr>
<td>Metabetiazuron</td>
<td>1.75-2.45</td>
<td>Pre/Post</td>
<td>Gd</td>
<td>Onion, garlic, faba bean, peas</td>
</tr>
<tr>
<td>Metribuzin</td>
<td>0.35-0.52</td>
<td>PP/Post</td>
<td>GD</td>
<td>Tomato, asparagus</td>
</tr>
<tr>
<td></td>
<td>0.10-0.35</td>
<td>Pre/Post</td>
<td>GD</td>
<td>D. s. tomato, carrots, peas</td>
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<tr>
<td>Napropamide</td>
<td>1.57-2.02</td>
<td>PP/Post</td>
<td>Gd</td>
<td>Tomato, pepper, artichoke</td>
</tr>
<tr>
<td>Naptalam-Na</td>
<td>2.16-2.88</td>
<td>Pre</td>
<td>Dg</td>
<td>Melon and cucurbits</td>
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<td>Oxifluoren</td>
<td>0.36-0.48</td>
<td>Pre/Post</td>
<td>Dg</td>
<td>Onion, garlic, cole crops</td>
</tr>
<tr>
<td></td>
<td>0.24-0.48</td>
<td>PP</td>
<td>Dg</td>
<td>Tomato, pepper</td>
</tr>
<tr>
<td>Pendimethalin</td>
<td>1.32-1.65</td>
<td>PP/PPI</td>
<td>GD</td>
<td>Artichoke, cole, lettuce, leek, pepper, tomato, onion, green peas</td>
</tr>
<tr>
<td></td>
<td>0.66-0.99</td>
<td>Pre</td>
<td>Gd</td>
<td>D. s. onion</td>
</tr>
<tr>
<td></td>
<td>0.66-1.65</td>
<td>Post</td>
<td>GD</td>
<td>Onion</td>
</tr>
<tr>
<td>Phenczdipam</td>
<td>0.55-1</td>
<td>Pre/Post</td>
<td>Dg</td>
<td>Beets, spinach</td>
</tr>
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<td>Piridate</td>
<td>0.22-0.33</td>
<td>Post</td>
<td>D</td>
<td>Brassica crops</td>
</tr>
<tr>
<td>Prometryne</td>
<td>0.50-1.50</td>
<td>Pre/Post</td>
<td>Dg</td>
<td>Artichoke, celery peas, pepper, tomato, carrot</td>
</tr>
<tr>
<td>Pronamide</td>
<td>0.70-1.50</td>
<td>Pre/Post</td>
<td>Gd</td>
<td>Chicory, lettuce, endive</td>
</tr>
<tr>
<td>Propachlor</td>
<td>4.5</td>
<td>Pre</td>
<td>Gd</td>
<td>Brassica crops, onion</td>
</tr>
<tr>
<td>Rimsulfuron</td>
<td>7.5-15 (g)</td>
<td>Post</td>
<td>GD</td>
<td>Tomato</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>0.59-1.44</td>
<td>PPI</td>
<td>Gd</td>
<td>Beans, carrots, celery, cole crops, artichoke, onion, pepper, tomato</td>
</tr>
</tbody>
</table>

Notes:

3) Usually it refers to transplanted crops. Cole crop (Brassica) means broccoli, brussels sprout, cabbage, cauliflower, kale, turnip, rutabaga and radish. Selectivity may vary. D. s. means direct seed.
Carryover effects of residues in soil

Some herbicides have long persistence and may affect the succeeding crop in the rotation. To avoid this, the use is recommended of either mouldboard ploughing or two crossed cultivator passes after the crop harvest to mix the treated and non-treated soil layers and thus dissipate the herbicide residues. Product labels must always be consulted with regard to the planting of sensitive crops following herbicide treatments.

In warm and wet climates the residues usually dissipate rapidly, but in all cases caution is necessary. Some examples of recommendations given in product labels are as follows:

Napropamide: After a period of two months, and after tillage, it is possible to sow peas, green beans, faba beans, cereals, fodder grass, sugar beet and flax.

Metribuzin: After a period of three months and after tillage, it is possible to sow several crops, except cucurbits, crucifers, lettuce, strawberry, sunflower, peas, beet and tobacco.

Trifluralin: After tillage it is possible to sow: peas, French beans, faba beans, cole, lentils, artichoke, potato, barley, sunflower, alfalfa, clover and carrots. Spinach, beet, oats, maize and sorghum should not be sown before a period of 12 months.

Good practices in the use of herbicides

A summary of a ‘decologue’ of good practices in the use of herbicides in extensive vegetable crops can be made (Zaragoza, 2001):

- Periodically inspect the fields and assess the weed importance. Identify correctly the main weeds.
- The weed and crop stage of growth must be taken into account.
- Careful selection of the product and dosage, bearing in mind points one and two.
- Read the product label and follow the recommendations.
- Avoid adverse conditions at the time of application: wind, temperatures, rainfall. Do not delay treatment.
- Quality of the spraying is obtained by the correct calculation of dosage (surface to be treated must be well measured) and by the spraying equipment, which must be calibrated and in good condition (especially nozzles and manometer).
- Band or patch application to save herbicide and reduce residues.
- Keep to the environmental norms: avoid spills, drift, respect the edges, water ways, sensitive areas. Triple-rinse all empty cans or containers and do not re-use them.
- To avoid propagation of resistant species, the same herbicide or herbicides with the same mode of action must not be used repeatedly.
- It is essential to integrate the chemical weed control with opportune, surface tillage. Take preventive measures, especially early problem identification.

Integrated weed management strategy for specific vegetable crops

Some advanced agricultural areas have developed integrated weed management systems. Some general strategies are summarized here (William et al. 2000).

Green beans and peas: Harvested legumes must be free of Solanum berries, thistle buds, Amaranthus stems, or crucifer pods. Crop rotations, close row spacings, early season weed
control and cultivation (except in rocky or clod soils) are combined with herbicides to minimize weed competition and contamination of product. A single post-emergence treatment can suppress weed competition or potential contamination of harvested peas.

**Carrots and celery:** Carrots suppress weeds when row spacings, population densities, cultivation and application of a single herbicide are combined. Cultivation also prevents sunburnt or green carrots roots by throwing soil over the roots.

**Table or red beets:** A combination of early season weed control, closely spaced rows, dense population, and cultivation will suppress mid- to late-season weed emergence after the crop canopy develops.

**Crucifer and cole crops:** Weed suppression in crucifers begins by rotating crops that demand different weed control practices to disrupt weed life cycles. Row spacing and plant density vary both to achieve head size, depending on the market, and in order to suppress weeds. Early-season weed control includes applying a herbicide and/or cultivation(s).

**Cucurbit crops:** Weed management in cucurbits means planning and integrating several practices. Crop rotations and pre-planting control of susceptible weeds must be carried out. Many growers practise stale seed beds followed by cultivation, except in excessively wet seasons. Row spacings that enhance canopy development and cultivation may be supplemented with a herbicide application within the crop row. Often rye windbreaks are planted between rows and incorporated during the last cultivation.

**Leaf crops (lettuce, escarole, spinach):** Direct-seeded lettuce requires a couple of cultivations and a hand-thinning or weeding, whereas transplanted lettuce matures in 45 days following one or two cultivations with minor hand-weeding.

**Garlic and onion:** Garlic requires an almost perfect weed control since it emerges slowly, matures over a period of 10–11 months, and never forms a canopy with its short, vertical leaf arrangement: Growers, therefore, often control all weedy vegetation immediately prior to crop emergence, apply a selective soil-applied herbicide for winter weed control, and additional treatments are carried out during spring, depending on specific weed infestations. In onion, weeds are managed with selective herbicides combined with frequent cultivation. Winter cover crops enhance both soil and weed management.

**Tomato and pepper:** Weeds can be managed through preparatory tillage and a pre-planting herbicide in transplanted crops. Black plastic mulch can help to reduce the chemical need. Interrow tillage or post-emergence herbicide can control weeds later on. In direct-seeded crops, more intensive chemical treatments will be necessary. Management of *Solanum nigrum* (one of the worst weeds in tomato) should bear in mind the following points:

- chemical control in the previous crops where it is easier; (beet, carrot, celery, spinach);
- that it prevails more in transplanted than in direct-seeded tomatoes;
- stale seed bed before tomato planting is recommendable;
- row application of soil-acting herbicides at planting (pendimethalin, oxifluoren) integrated by interrow hoeing and/or by split low-dose treatments with metribuzin + rimsulfuron against *S. nigrum* at very early stages (up to two leaves) (Tei *et al.* 1999).


