Organic Weed Control

A Practical Guide

January 2000

Contents

Table of Figures

1. Introduction

Weed control has been identified in many surveys of organic growers and farmers as being their number one problem, often by over 80% of respondents. Good weed control is essential for a successful organic enterprise. However, the amount of detailed information on organic weed control is often sparse and more often covers 'what' needs to be done rather than 'how' to do it. This report aims to address that gap with information on both what needs to be done and how to do it.

This report originated as a series of separate articles in the Canterbury Commercial Organics Group newsletter http://www.environment.org.N.Z./ccog/default.htm.

1.1 Weeds, enemy or ally?

Weeds are often seen as the enemy that have to be controlled, preferably eliminated. Good farmers are often viewed as those that have nothing on their farms except crops. Weeds are seen as an indication of failure. Things in agricultural / ecological systems are rarely that simple however. An example of the complexity of farm ecosystems comes from cereal crops in the South of England. Increased use of herbicides in the crop and non-crop areas, such as hedgerows, resulted in a dramatic reduction in the number and type of weeds. However, this caused an even greater reduction in the number of species, and populations of, beneficial insects (those that kill crop pests). This resulted in an increase in pest populations, requiring more pesticides to be used, resulting of increased costs. The effect of using more herbicides was pest outbreaks! This kind of effect is neither intuitive or easy to predict, but is common in agro-ecosystems. By not spraying field margins, and growing one meter wide strips of tussocky grasses such as Yorkshire fog and coltsfoot at 100 m intervals across the field, beneficial insects were re-introduced into the crop and kept the numbers of crop pests below economic damage levels, without the use of pesticides.

Weeds are therefore both an enemy, and an ally. An organic system that aims for the total eradication of weeds is likely to run into difficulties, and vice versa, abandonment of weed control will lead to severe crop losses. A balance is therefore needed. Organic systems need to have a diverse range of plants in field margins, and while controlling crop weeds, total elimination would be counter productive.

1.2 Integration of the farm system

Weed control on organic farms cannot be considered in isolation from other aspects of the farm. This is also true in conventional systems but to a much lesser extent. A conventional producer can often consider the requirements (e.g., fertiliser, pest, disease and weed control) of each crop with little need to take into account the effects of previous crops or the effect on the following crops. Organic farming strongly relies on an integrated systems approach. Careful thought is required on how any one action will be affected by, and will affect, the rest of the farm over a period of many years. Organic weed control cannot, therefore, be achieved by following a 'recipe', as can be done with chemical weed management where a specific weed problem has a specific herbicide. It requires a good understanding of how all of the different parts of the farm systems operate and interact to achieve good weed management.

Many of the techniques for controlling weeds have major impacts on other parts of the farm system, such as soil structure, nutrients, machinery requirements, and which other crops that can be grown. Therefore the techniques described in this report need to be considered in light of the whole farm system. The farm system also has to be integrated with the economic and market environments, adding further levels of complexity.

Each farm system is therefore unique. Even the same crop grown in different areas of the farm may require different approaches. Therefore, a thorough understanding of the principals and techniques of organic weed control are required, to make decisions on a case by case basis.

1.3 The big picture

With the need for a systems approach for organic weed control planning has to start with the highest system levels and descend to the lower system levels. These system levels include (in descending order):

1. rotations;
2. soil nutrients and structure;
3. crop and pasture choice;
4. cultivations;
5. sowing, planting and related techniques;
6. machine weeding;
7. hand weeding.

A key point is that the cost of weed control increases, often considerably, as you progress down the list. A well designed rotation ‘costs’ very little for a large level of weed control, hand weeding, on the other hand, is often prohibitively expensive.

Some texts on organic weed control only consider hoeing and other post planting operations. Sole reliance on such operations to achieve weed control will cause problems. Having of the very best hoeing equipment, such as steerage hoes, brush and flame weeders is no guarantee of achieving good weed control. The best equipment is useless unless the rest of the weed control system is in place.

2. Rotations

Many articles on how to do X Y or Z in organics often start with rotations; this happens so often non-organic farmers could be excused for thinking it is some kind of mantra! It is also often difficult to see how such a simple practise can be so important, but it is an essential foundation of organic production. Rotations work by introducing different ecological systems to a piece of land so that no one part of any one ecological system can dominate. This often summed up as rotations introduce diversity. In an ecosystem, which is what farms are, some species will do well and others will fare badly. For example, in winter cereals black grass and wild oats can be a problem because the time of cultivation and crop type favour those weeds. In comparison horticultural crops do not suffer from such weeds as they are mostly spring sown. If similar crops, or livestock, are produced continuously in the same place then the populations of problem weeds will increase, often dramatically. By growing different crops in succession, no one weed is given the chance to proliferate, because some years it will be favoured, but in other years it will be disadvantaged. The corollary is that rotations that include a wide range of different crops, not just those that have a long time between the same crop, will be more effective at controlling weeds (and other problems) than rotation which contains only similar types of crops. For example, a vegetable holding with a rotation of seven years could end up with weed problems despite an apparently long rotation. This is because of the large number of similarities between the crops. The introduction of a pasture phase with, or without, livestock or autumn sown cereals would reduce those weeds that flourish in the pure vegetable rotation.

The key to a good rotation is to alternate between crops that have different:

- cultivation and planting dates;
- rooting habits;
- volume and type of top growth;
- lengths of production;
- cultivation requirements;
- harvesting requirements;
- weeding requirements.

Livestock are a valuable component of a rotation to improve weed control. Green manures and cover crops are also important and ideally a range of these should be used.

2.1.1 Cultivation and planting dates

Weeds have specific times when they prefer to germinate, for example, the field poppy is an autumn germinating species. Therefore, spring sown cereal crops have a much lower populations of poppies compared to autumn sown crops. By varying cultivation and planting dates you will select different weed species, ensuring that none are selected year after year.

2.1.2 Rooting habit

Rooting habit is less commonly considered as a means of improving weed control, and for many annual crops it is a negligible factor. However, for some situations, such as pasture, it is quite important. For example, lucerne, which has a very tough deep root that can compete with perennial weeds such as Californian thistle. Therefore, planting competitive crops with similar root habits to the existing weeds can reduce weed numbers. On the flip side weeds with similar root systems as the crop plants will also be more vigorous competitors with the crop.

2.1.3 Volume and type of top growth

The volume and type of top growth has a big impact on weed control, not only because of direct effects such as shading weeds out, but also because more robust crops allow the use aggressive weeding machines. For example, onions are very poor competitors and will suffer disastrous yield reductions if weeds are not effectively controlled, especially in the early stages of crop growth. Due to the delicate nature of onions only a limited number of weeding machines can be used, mostly those that are less aggressive. In comparison, weed suppressing crops, e.g., potatoes, quickly cover the entire soil surface swamping out weeds, and weeding machines, such as tine weeders, can be used that are more aggressive and that kill more weeds more efficiently.

2.1.4 Length of production

The length of time a crop is in the ground favours some weeds over others. Perennial crops e.g., pasture and orchards suffer more from perennial weeds, such as docks, while short term crops suffer more from annual weeds. Having several years in cropping helps to kill perennials, while longer term crops, such as pasture, allow annual weed seeds to die. There are exceptions however, for example, Californian thistle if not vigorously controlled in the cropping phase can rapidly increase in size.

2.1.5 Cultivations

Different cultivations can have a profound effect on weed populations. For example, ploughing has different effects on weeds compared to surface tillage. Ploughing buries the weed seeds that were on the soil surface and brings up dormant seeds from lower down in the soil profile. Surface tillage does not mix up seeds from different levels in the soil.

A key point to work out the cultivation approach to achieve the best weed control, is that seeds can only germinate in the top few centimetres of soil. If few weeds go to seed in a crop then avoid cultivations that bring up soil from lower down the soil profile as this will bring up previously dormant seed which will be ready to germinate. If large numbers of weeds go to seed, especially annuals, then ploughing will bury them where they are unable to germinate. However, if ploughing is used again within a few years much of the buried seed will be brought back up and germinate.

2.1.6 Harvesting requirements

The different harvesting requirements of different crops can have a big impact on weed control. Many of the broad acre crops, such as peas or cereals, do not require the soil to be disturbed for harvesting. Such crops allow the use of undersowing, typically an overwinter green manure or pasture mixture, so that once the crop is harvested the undersown plants are already established and will out compete the weeds. If undersowing is not used, direct drilling into the crop remains is possible or minimal cultivations followed by drilling. At the opposite extreme are root crops that involve the lifting and mixing of large quantities of soil. This results in weed seeds being mixed through the soil profile which, together with the soil disturbance, will produce a greater weed strike that soils that have been undisturbed at harvest time. Potentially valuable weed control can therefore be gained in weed susceptible crops by growing a crop that can be undersown the previous year, and then using minimal, shallow, cultivations to destroy the undersown crop.

2.1.7 Weeding machinery

Different weeding machines control different weed species with varying efficiencies. For example, flame weeders do not kill many monocotyledonous, but do kill most dicotyledonous weeds. Reliance on one type of machine for weed control will result in a build up of the types of weeds ‘resistant’ to that control method. For example, reliance on a flame weeder for weed control will result in grass weeds dominating. Ring the changes. If possible use different machines within the same crop, and definitely try to use different types of weeding machines for different crops.

2.1.8 Green manures and cover crops

Green manures and cover crops can be very useful for weed control. They can be grown where there is a weed problem allowing the weeds to grow with them. Both are then grazed off by stock or cultivated into the soil before seeding occurs. This reduces the weed seed bank, so fewer weeds germinate in the following crops. Green manures are often very competitive and can weaken perennial weeds, and increase the time annuals take to reach maturity. Several short term green manures coupled with the right cultivations can rapidly clean up a piece of land and also improve soil humus content and nutrient levels.

2.1.9 Livestock

Having a mixture of livestock is valuable for weed control. For example, on cattle only properties weeds such as dock and ragwort can be problematic. Sheep can control such weeds if they are correctly used in the rotation. Pigs also have the potential to effectively deal to weeds with creeping roots or stems near the surface, e.g., twitch and creeping buttercup, however, pigs can do considerable damage to wet soils, which can increase the numbers of deeper rooted perennial weeds such as California thistle.

2.2 Tweaking rotations

Tweaking rotations is essential. Rotations are often viewed as being fixed, you design your rotation and then stick to it. Apart from the obvious factors, for example, some parts of the farm are better suited to particular crops or livestock such as flat land or hills, the past history of fields will determine what to do with them next. Rotations can be re-designed on an annual basis for each field, to take into account the field history and future needs. A field that has a weed problem will require different cultivations and crops, compared to a clean field even if this means that cropping plans have to be changed. For example, in a field where fat hen has gone to seed, ploughing followed by potatoes, which are relatively easy to control weeds in, would be a sensible choice. This will bury much of the seed, and that which does remain will be killed with cultivations, hoeing and be out competed by the potatoes. An alternative approach could be to surface till, gain two to three weed strikes, and put the field down to grass and let livestock control those weeds that do emerge.

So while a good rotation is the foundation for weed control, it is not the complete answer. However, without a good rotation other weed control techniques will have a limited effect.

3. Soil Nutrients, pH and Structure

Soil nutrients, pH and soil structure are not often considered when it comes to organic weed control. This is in part because a key aim of organics is to ensure a healthy well balanced soil so sub-optimal nutrients, pH and structure should not be a problem on organic farms. Also, in a well designed organic system other factors have a bigger effect on weed populations than soil nutrients and structure. However, if soil nutrients, pH or soil structure move too far away from optimum they can become the overriding cause of a weed problem and unless they are addressed, other weed control techniques will have less impact.

3.1 Soil nutrients and pH

Some weeds are able to prosper in soils with nutrient or pH levels that are sub-optimal for, or even adversely effect, crop plants. For example, annual nettles can tolerate acid soils and lower light levels so they tend to thrive under pine trees where the constant fall of needles makes the soil more acid. It is this relationship which give rise to the ‘folk law’ in organic circles that you can tell a lot about a soil from the weeds/plants growing there. While there is some truth in this, and it can be helpful as a field guide, it in no alternative for soil testing. For a detailed list of indicator plants “Organic Farming” by Nicolas Lampkin p165 is an excellent reference.

While it is important to have sufficient levels of nutrients in a soil, the ratio between nutrients, particularly the major nutrients, is also important. The ratio of potassium and calcium to magnesium, for example, is widely recognised as being important, as an imbalance can lead to hypomagnesaemia in dairy cattle. Sections of the organic movement, particularly some American consultants e.g., Neal Kinsey, place considerable emphasis on ensuring that all soil nutrients are in balance. Soil and plant nutrition is a very large subject however, and is beyond the scope of this article, see the book “Neal Kinsey's hands -on agronomy” for more information.

Slightly sub-optimal nutrient and pH levels can favour some weeds but rarely to the extent that it becomes the overriding cause of weed problems. Widely sub-optimal nutrient levels can cause weeds to overrun crops. In both cases soil analysis and remedial nutrient applications is required.

Regular (at least every three years) soil analysis should be taken to ensure that such conditions are prevented. There are a number of soil analysis labs targeting both conventional and organic farmers, that operate a variety of soil analyses, of various levels of detail, and based on various philosophies of soil and plant nutrition. These advertise in a range of farming and growing magazines.

3.2 Soil Structure

The relationship between soil structure and weed problems is similar to that of nutrients, i.e., sub-optimal soil structure will not help weed control but it is rarely the overriding cause of problems. Poor structure will have a bigger impact on other aspects of production, e.g., cultivation costs and lower yields, and it will tend to be these that drive the need to improve structure. By definition organic farms should be maintaining a good soil structure regardless.

To relieve soil structural problems in the long term organic matter with a high carbon : nitrogen ratio must be added to the soil. This can be in the form or composts and manures, or via pasture or woody green manures such as cereals. In the short term, cultivations can over come poor structure, but most cultivations adversely effect soil structure in the longer term.

However, a group of weeds which that significantly benefit in soils with common structural problems are those that spread via deep underground stems or roots, such as Californian thistle. These underground stems prosper in conditions of poor soil structure, such as plough pans, that adversely effect crops. Poor structure, compaction and cultivation pans can also lead to waterlogged soil which can promote water loving weeds such as buttercups.

Subsoiling (deep ripping) can remove compaction and cultivation pans. However, subsoiling must be done at the correct soil moisture level of moderately dry. If it is done when the soil is too wet it will cause more compaction, and if the soil is too dry it will have a limited effect. Friable soils such as sands can be sub-soiled over a wider range of moisture levels than cohesive soils such as clay. Friable soils are also less prone to pans than the heavier soils. The only accurate way to tell if soil moisture is at the correct level for subsoiling is to dig a hole where the implement has passed and visually check for good fracturing and a lack of smearing or compaction.

Anaerobic layers and cultivation pans are most frequently created by ploughing, particularly when large amounts of crop residues are buried. Alternatives include surface cultivations, grazing crop debris off with stock, and shallow ploughing. No/zero till techniques have shown that leaving residues on the surface has considerable advantages in terms of soil structure. Ploughing, therefore, is not essential, is frequently detrimental and should be reduced or avoided.

Waterlogging can promote the growth of marshy species such as buttercup and rush. Improving drainage by cultivation, subsoiling, mole ploughing and artificial drains can alleviate such problems. However, naturally boggy areas can be important wildlife habitats and it important not to drain these areas.

3.3 Crop and Pasture Choice

Crop and pasture choice are also often overlooked in relation to organic weed control, partly as they have a smaller effect than other aspects of weed control, such as rotation design and weeding machinery, plus crop choice is often constrained by market outlets.

Pasture species can have a major effect on weeds. The traditional New Zealand pasture of ryegrass and while clover, while quick to establish, is a poor competitor, particularly in dry summer conditions because it is shallow rooted. It is also the grass most susceptible to grass grub, and the endophytes which make it more resistant to the grub also make it toxic to stock!

Other grasses such as timothy while slower to establish are deeper rooting, more competitive and non-toxic to stock. Deep rooting perennial weeds are potentially a major pasture weed in organic systems, e.g., docks. These deep rooting plants are able to access moisture and nutrients beyond the reach of grasses and while clovers. They remain green even while the pasture around them is dead and then are able to dominate the sward. Palatable species that can complete with them, such as chicory and lucerne, which have deep roots, can reduce their numbers. They also provide feed when grass has stopped growing in dry conditions. It is also important to ensure that such deep rooted weeds do not go to seed, and mowing or roguing shortly before flowering is vital.

For crops where there is leeway in the choice of cultivars, qualities to aim for are:

- rapid establishment;
- vigorous growth;
- more prostrate and/or leafy types;
- long straw cereals.

Cultivars also need to be well matched to the climate and soil type.

For many broadacre crops a 10% increase in the sowing rate is recommended, to increase the competitive effect of the crop and also to compensate for losses due to mechanical weed control.

The use of crop mixtures, when possible, is very valuable and is gaining in popularity in Europe and the States. Crop mixtures involve mixing two or more cultivars of the same crop, or mixing two or more different crops together, e.g., a cereal and bean. There are other benefits to be gained beyond increased weed control from using crop mixtures such as reduced populations of pests and diseases and greater yields (which can be up to 20% more) than if the crops were grown separately but on the same area of land. Problems with using crop mixtures are mostly due to a lack of market acceptance.

4. Cultivations and seedbed preparation

Cultivation can have a huge effect on weed control and compared to managing weeds via rotations, soil nutrients, and structure, cultivations can be easily varied to address the needs of different crops, and weed problems. A good example comes from an organic farm in the UK. It was converted from a run down dairy farm straight to intensive vegetables and herbs. The first year saw excellent crop growth and few weeds, year two saw considerably more weeds and by year three huge amounts of fat hen and red root were swamping most crops and the farm was closed. The new tenant, by changing cultivations from a spading machine, which mixed the top 30 cm of soil, to deep ripping, no mixing or inverting of the soil and minimal surface cultivation, reversed the situation and within 2 years weeds levels were very low. Cultivation on its own however, cannot achieve good weed control. In the example above there was also an almost religious zeal at avoiding weeds going to seed. Cultivation must be used in conjunction with other controls such as rotations, crop choice and hoeing to achieve good control. Cultivations also alter soil properties such as organic matter, structure, and porosity, so while one technique may be optimal for weed control it may have other negative effects. For example, a full fallow which can significantly reduce weeds, also harms soil structure and causes considerable loss of soil humus and nitrogen.

4.1 Primary cultivation choices for perennial weed control

To decide on what cultivations to use to achieve optimum weed control a knowledge of a field’s weed history is essential. This must be coupled with a good understanding of the weeds physiology i.e., how they grow and reproduce. A critical first step is to check if there are any perennial weeds present. For the purpose of controlling them with cultivations perennials can be grouped into four types:

- tap roots e.g., dock;
- shallow creeping stems or roots, e.g., couch/twitch;
- deep creeping stems or roots, e.g., Californian thistle;
- corms, tubers bulbs etc., e.g., oxalis.

The primary approach to controlling perennials with cultivation is to exhaust the plant by separating the above-ground and underground parts and then exhausting the food reserves in the underground part. Tap rooted and shallow creeping perennials are generally easier to control while the deep creeping and tuber, corm and bulb types are often the most difficult.

4.1.1 Tap rooted weeds

Fallowing is a technique where a field is shallow cultivated (3-6 cm) every time the weeds produce above-ground growth. This can be done for a month or so (bastard fallows) or the whole summer, which ever is required to kill the weeds. Fallows are very effective, especially on the shallower and vertical rooting weeds (and also annuals), however, they are very hard on the soil. They also remove land from production. Fallows are therefore best used only were a serious problem exists.

Many tap rooted weeds will be unable to recover if the root is destroyed to a depth of 10 cm or more, which can be achieved by deep rotovation or using undercutter bars. Ploughing is not effective as the top part of the stem is not destroyed and although buried, plants frequently survive.

4.1.2 Shallow creeping weeds

For shallow creeping weeds it is important that cultivation depth does not exceed the depth of the roots or stems. Deeper cultivations, especially those that mix or invert the soil such as ploughing will spread the weed deeper into the soil making control more difficult. Useful control techniques include the use of spring tined cultivators that bring the weed to the surface to desiccate or powered machines such as rotovators that chop the weed up. Repeated treatments will be required as soon as new shoots are produced. Soils and the weather should ideally be dry making re-rooting more difficult. Stock, such as sheep, can be a valuable as they often relish the succulent underground parts eating and therefore killing them. They should be put onto a field as soon after cultivation as possible.

4.1.3 Deep creeping weeds

Deep creeping weeds, especially well established patches, will not be controlled by a short fallow. Control is normally only achieved by a full fallow or a combination of techniques. Subsoiling / deep ripping can be a valuable part of a control strategy, in that it breaks up the underground stems or roots therefore forcing them to use up reserves producing new shoots. However if this is not followed by fallowing, hard grazing or mowing then it can exacerbate the problem as the extra top growth will store more reserves. Undercutter bars can be valuable in controlling these deeper weeds as it allows the emerging parts to be cut off deeper in the soil than can be achieved with grubbers and rotary hoes, with lower draft and less damage to the soil. Subsoilers can be converted to an undercutter by welding a piece of high tensile or spring steel, about 1 cm thick by five-eight cm wide, between the legs. Such a bar should be angled only very slightly above the horizontal and have a sharpened leading edge, to reduce draft.

Ploughing rarely has much effect on these weeds as the creeping parts are below plough depth and the compaction and cultivation pans that result from ploughing can make matters worse.

The food reserves of some deep rooting weeds vary during the season. This may often reach a minimum between spring and summer when overwintered reserves have been used up and limited amounts have been laid down from summer growth. It can be desirable to wait till underground reserves are at their lowest before starting control to gain the maximum weed control for minimum cost.

4.1.4 Corms, bulbs, tubers etc

Corm, bulb, tuber etc. forming weeds are fortunately a limited problem in commercial situations, however, they are often the most difficult to control. The storage organ can often remain dormant for many years therefore surviving fallows. Stock can help control some species as they are palatable. Some have growth patterns where the old storage organ is used up before new ones are made, providing a window when they are more susceptible to control via cultivation. Persistence and a through understanding of the individual weeds lifecycle are essential to gain control.

4.2 Primary cultivation: Choices for annual weed management

Having considered what perennial weeds exist in a field the next task is to assess the field's history of annual weeds. This has to be combined with an understanding of the weeds' lifecycles, their seeds' longevity and how their dormancy operates, to decided on the best cultivation approach. Some annual weeds have very tough long lived seeds and can survive for more than 40 years before germinating. Others last only a year or two. In addition some seeds are innately dormant, i.e., they will not germinate for a number of years regardless of germination conditions. Others have enforced dormancy i.e., they will become dormant if conditions are not correct for germination, but will rapidly spring to life when conditions are right. Germination is dependent on the correct levels and mixture of; moisture, oxygen, carbon dioxide, temperature, and in some weeds the presence or absence of light. The net effects of these requirements is that seeds often have distinct periods when they will germinate. For example, many weeds only germinate in spring. Seed will not germinate below certain depths, with smaller seeds only germinating in the top 5 cm of soil, and large ones, e.g., grasses, from greater depths. The specifics of each weed and its seeds need to be ascertained before deciding on the best course of action. Nic Lampkin's Organic Farming is a good reference.

Fields that have had weeds go to seed in the previous few years need considerably more attention than fields that have been kept clean. Even low levels of weeds that have seeded in a field, e.g., less than 1000 fat hen plants / ha, can create a considerable weed problem. In 'clean' fields, where there has been no or limited seeding the previous season, inversion or vertical mixing of the soil should be avoided as this will bring up un-germinated seeds. Where moderate levels of seeding have occurred turning over or mixing the soil can be useful if such techniques have not been used in the last yew years to bury large numbers of long lived seeds. However this can store problems for later years, and if the weeds do not have innate dormancy it may be more advantageous in the long term to keep the seeds on the surface where they can be encouraged to germinate and then destroyed by cultivation before planting the crop.

Where high levels of seeding have occurred, care should be taken about using the ground for cropping, particularly with un-competitive crops. Very vigorous crops that can be easily weeded, such as potatoes, could be considered, a period of fallow, or a series of quick growing green manures. A return to pasture if the weeds are palatable to stock and will be controlled by grazing or mowing is another choice. If such options are not possible ploughing with complete inversion of the soil will bury seeds beyond germination depth. Old dormant seeds will be exposed, however, these readily germinate with the introduction of good germinating conditions allowing successful use of stale and false seedbeds.

Therefore, a balance exists between the amount and type of seed on the surface and the amount and type of buried seed. This balance dictates whether inversion or surface cultivation are used.

Occasionally growers are tempted to plant a crop into a seedbed that already has weeds growing in it, with the belief that they can be controlled later. This can occur after an overwinter fallow that has been hampered by wet weather, for example. This is very inadvisable. Even if there are only low levels of weeds and/or they are very small it will be very hard to gain control. It is strongly recommended never to sow or plant into existing weeds, regardless of their size or numbers. Always start with clean ground.

4.3 Secondary cultivation: Choices for annual weed management

Having decided on the primary form of cultivation, secondary cultivation(s) are often required to further enhance weed control. As noted previously, cultivation choices are not just based on weed control, but must also take into account other factors such as soil condition, crop type and planting tilth, some of which may conflict with each other. For example, creating a fine deep tilth for a root crop will bring dormant weed seeds up to the germination zone.

The difference between primary and secondary cultivation is often fuzzy. In this report primary cultivations refer to initial ‘land breaking’ cultivations such as subsoiling and ploughing, and also surface working during a fallow. Secondary cultivation refers to cultivations designed to produce a seedbed once a primary tilth of sufficient depth and fineness is created and perennial weeds have been controlled.

One of the key aims of secondary cultivations for weed control is to keep the depth of cultivation within the germinating depth of the weeds. For most small seeds this rarely exceeds 5 cm. Cultivation below this depth will bring up new viable seeds and should be avoided. Typical equipment includes rollers, harrows, light spring tine equipment and some PTO powered equipment. The aim is to encourage as many seeds as possible to germinate prior to the crop germinating, i.e., grow the weeds first and then grow the crop.

4.3.1 Stale and false seedbeds

Approaches to weed control by secondary cultivation can be divided into two techniques, false seedbeds and stale seedbeds. Both begin with cultivation(s) designed to produce a firm, fine tilth with good capillary rise that maximises weed seed germination. The false seedbed technique (Figure 2) involves a second cultivation to kill the weeds after they have emerged but before they develop four true leaves. This second cultivation is often the same as the one that created the initial seedbed and ideally makes another seedbed all in one pass. A stale seedbed (Figure 1) involves killing the weeds that emerge without disturbing the soil, by using a ‘flame weeder’, for example. There are two variations of the stale seedbed technique. The traditional one involves creating the seedbed, then after a period of about a week the crop is drilled. This period is lengthened in slow germinating conditions or for fast germinating crops. The weeds have a head start over the crop and therefore emerge first. They are then killed as close to crop emergence as possible. In the second variant, the stale seedbed is set up and one or more flushes of weeds are produced and killed before drilling commences. Weed germination is encouraged by irrigation on one or more occasions.

In both stale and false seedbeds it is essential that optimum germination conditions exist. A key factor is soil moisture. If the soil is dry irrigation should be used, otherwise the weed seeds will remain dormant and when it rains or irrigation is eventually used, the weeds will germinate with the crop . Although it may appear a waste of money to irrigate bare land, the increased level of weed control achieved gives a good return on expenditure. This pre-drilling irrigation in dry conditions will also assist the germination and emergence of the crop, particularly small seeded horticultural crops that are shallow drilled and can be trapped by soil caps created by post drilling irrigation on silty soils.

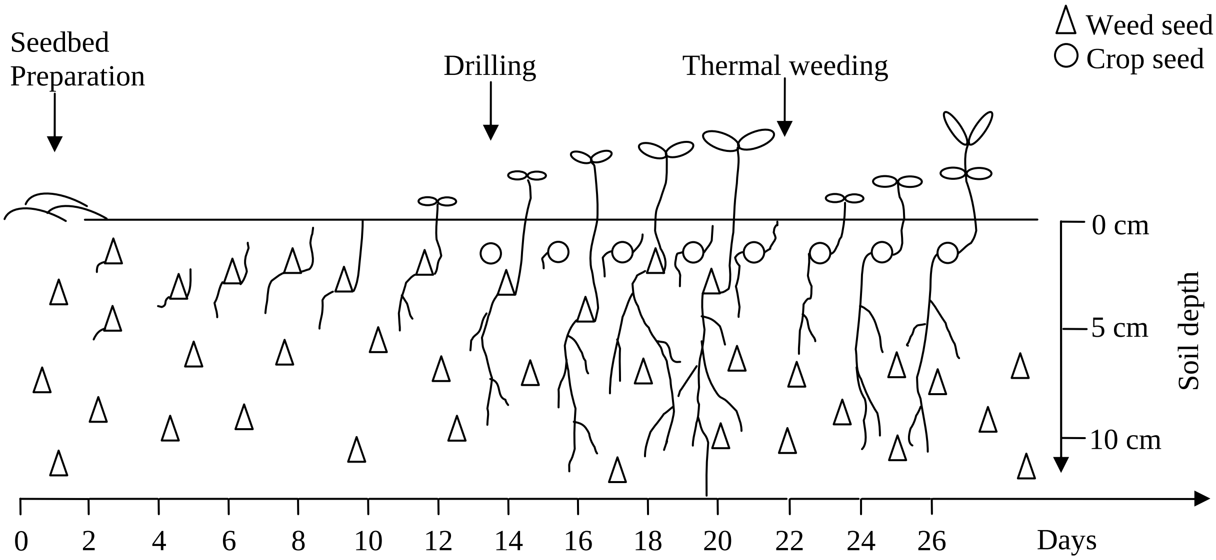

Figure 1. Illustrative scheme of a stale seed bed: Final seedbed is prepared, weed seeds in top 5 cm of soil germinate, crop is sown, weed seedlings emerge, immediately prior to crop emergence weed seeds are killed by thermal weeder, crop emerges from weed free soil. (After Lampkin, N. (1994). Organic farming. Ipswich, Farming Press Books).

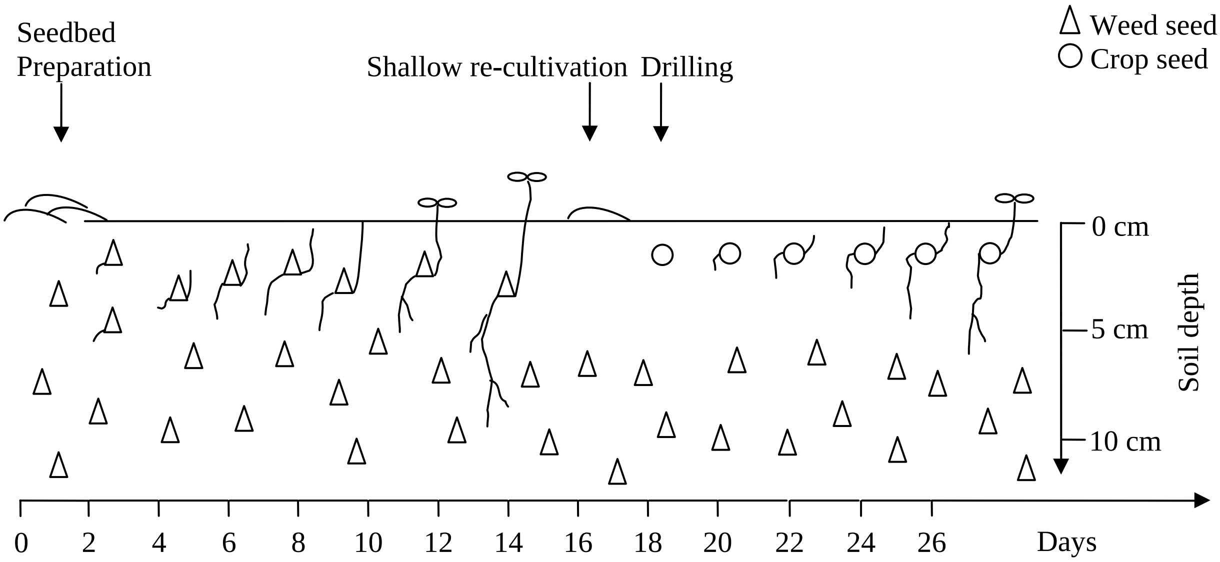

Figure 2. Illustrative scheme of a false seed bed: A seedbed is prepared, weed seeds in top 5 cm of soil germinate and then emerge, the soil is then re-cultivated with the minimum disturbance necessary to kill weed seedlings, the crop is then sown germinates and emerges from mostly weed free soil.

Another critical factor for optimum results with the stale seedbed technique is a smooth even seedbed. Both flame weeders and herbicides approved for certified organic systems are less effective where the seedbed surface is rough or cloddy as the soil lumps 'shadow' emerging seedlings protecting them. Drilling often disturbs what was a smooth seedbed and a light smooth roll post drilling is recommended.

To ensure a timely weed kill, when using stale seedbeds, several small areas of crop should encouraged to germinate early to give clear warning when to flame weed. This can be achieved using a sheet of glass raised slightly off the soil by a couple of centimetres, frost cloth (crop covers), or a cloche. Glass sheets must not be left in direct contact with the soil as this will cause the soil to over heat and kill the seeds or emerging seedlings. Which ever technique is used to speed up germination, it needs to be put in place immediately after drilling to ensure the greatest effect. Also several areas of the crop should be tested in different locations in the field, in case some areas germinate faster than others. An alternative is to sow at a slightly higher rate and wait till the first crop seedlings emerge and then kill both them and the weeds allowing the rest of the crop to emerge. This method is considerably more risky as the time between realising that flaming is required and it being to late to flame is shorter. It is not advised for quick germinating crops. In all cases the crop should be checked at least daily for signs of emergence.

The key to which technique to use depends on the amount of weed seed in the germination zone, its propensity to innate dormancy and the type and value of the crop. Stale seedbeds are generally more expensive due to the use of flame weeders, or organic approved herbicides, so these are generally reserved for high value crops. High levels of weed seed, seeds that have innate dormancy, slow germinating crops or uncompetitive crops will benefit from one or more false seedbeds followed by a stale seedbed. Where there are fewer weeds, lower value and/or more competitive crops, a false seedbed alone should be sufficient.

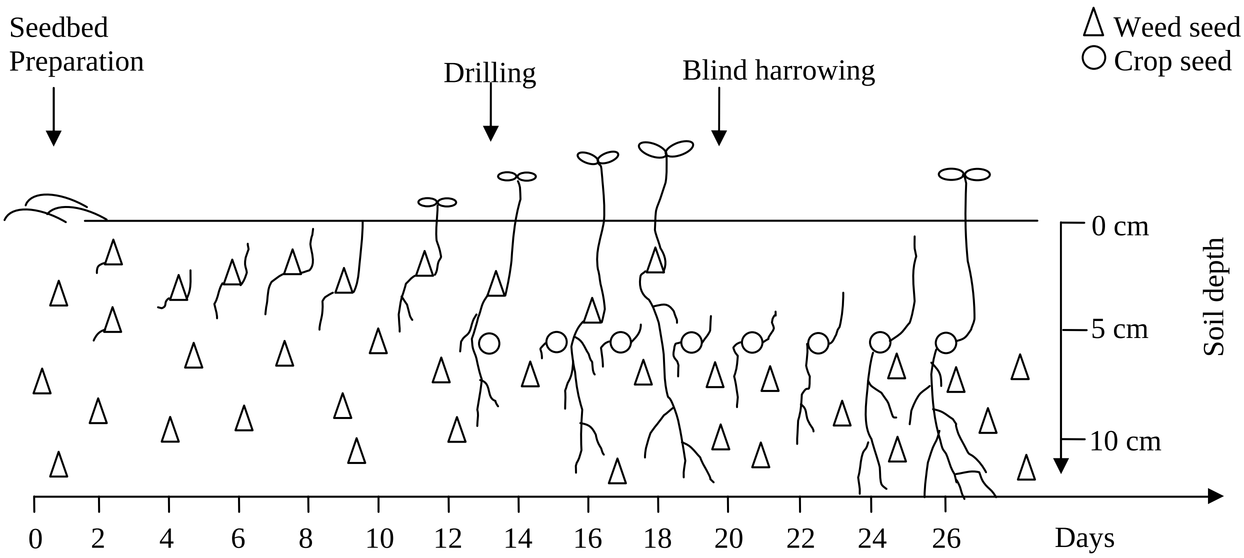

Figure 3. Illustrative scheme of blind harrowing: Final seedbed is prepared, weed seeds in top 5 cm of soil germinate, crop is deeply sown, weed seedlings emerge, before the crop's plumule gets too close to the surface weed seedlings are killed by a harrow or other shallow cultivator, crop emerges from mostly weed free soil. (After Lampkin, N. (1994). Organic farming. Ipswich, Farming Press Books).

4.3.2 Blind harrowing

Blind harrowing can be viewed as a kind of hybrid between false and stale seedbeds . However it is only practical for larger seeded, deeper drilled and robust crops such as cereals that can survive being driven over during the pre-emergence period. It can be it used on more delicate crops such as beans, but it kills germinating crop plants in the tractor wheelings so is not recommended as a standard treatment.

A seedbed is created then after a variable period of delay, which can be zero, the crop drilled ideally deeper than five centimetres. Then before the crop plumule breaks the soil surface, ideally while it is still two centimetres or more below the surface a harrow, tine weeder or similar device, is used to cultivate the soil surface to kill the weeds. A wide implement is required to minimise the amount of wheelings in the field, and maximise the area covered for the time taken. If blind harrowing is used seeding rates can be increased by 5-10% to make up for any losses from the harrowing and reduced emergence. Seed rates are also increased in crops suitable for blind harrowing to compensate for losses from post emergence weed control.

For blind harrowing seeds should be drilled at deeper depths than normal but not so deep that it causes more than 5% reduction in emergence. This increases the amount of time between weed and crop emergence and also ensures the seed is below cultivation depth.

4.3.3 Minimisation of cultivations for fallows, stale and false seedbeds

When using a fallow, stale or false seedbed techniques it is important that the minimum number of cultivations are used and the soil is left bare for the minimum amount of time to gain the level of weed control required. Leaving soil bare and performing cultivations all damage the soil through lost of nutrients and organic matter, damage to the soil structure and increased compaction. Ideally the lightest tractor required for the job, with the minimum ballast should be used. Low pressure tyres will also reduce compaction and minimise the retardation of crop growth and yield. Particular care should be taken in spring or late summer/autumn when water may be draining from the soil as nutrients mobilised by cultivations have increased potential to be lost from the soil through leaching.

4.3.4 Light and germination

Night time cultivation is an area that has attracted quite a bit of attention over the last two decades. A number of experiments were done, mainly in Europe, comparing cultivating at night and the day, or using machines that were shrouded to make them light proof. The principals behind cultivation in the absence of light are well understood. Some seeds, for example, poppy, need light to germinate. This behaviour can be used to reduce such weeds in the crop by ensuring the seeds are not exposed to light during soil disturbance.

There are two complimentary techniques. For false or stale seedbeds cultivation should be done to maximise the amount of light hitting the soil during cultivations. This will encourage weeds to germinate so they can then be killed. For final, non-stale seedbeds, cultivations should be done at night or with shrouded equipment to minimise weed emergence. Some species are very sensitive to light and even moonlight or tractor lights can trigger germination. Results, however, have been mixed. Some experiments and farmers have reported significant improvements in weed control where others have found little or no effect. This is probably because there are many variables associated with this technique and weed emergence as a whole. For example, the proportion of weeds that are effected by light, the level of darkness in the cultivation zone, the general conditions for weed emergence, and innate dormancy will all affect the result. It may be worth experimenting with on your own farm to see if it has any potential for you.

5. Sowing, planting, mulches and covers

While sowing and planting have a more minor (and often neglected) role to play in controlling weeds in organic systems, they are still an important part of the overall weed control strategy. If they are not given suitable attention it may result in problems later on.

5.1 Timing of sowing and planting

Most weeds have a time of the year when their germination rate is highest. Most peak in the spring with a second flush at the start of autumn. In comparison, a few, such as cleavers and black grass, predominately germinate in the autumn. Crops also have preferred germination times and conditions when they can rapidly germinate and out grow weeds. For a limited number of crops, mostly cereals and large seeded crops e.g., peas or maize, it is possible to sow at the time of minimum weed germination and maximum crop growth, therefore gaining valuable weed control. For example, a change from autumn sown cereals to spring sown where there is a high level of autumn germinating weeds will considerably reduce weed populations. In other crops, e.g., maize, avoiding early sowings when the crop germinates slowly is valuable. More precise use of these techniques are limited by the need for detailed knowledge of each fields' weed germination pattern, variations in the weather, changing field conditions, and the compromises required to meet crop and market scheduling.

5.2 Sowing rates

Most sowing rates have been optimised for conventional systems, where the interaction been crop and weeds is not an important factor. For a number of broad acre crops, such as legumes and cereals a 5 to 15% increase in the sowing rate can significantly improve the competitiveness of the crop over the weeds, predominately by reducing the time taken for the crop to form a canopy which shades out weeds underneath. This technique is of limited use in intensive crops, such as carrots, as sowing rates/populations are a major determinant of final crop size which is constrained by market specifications.

5.3 Row spacings

Row spacings are predominately determined by the type of post emergence hoeing equipment used and the crop being grown.

5.3.1 Broad acre crops

For many broad acre crops such as legumes and cereals the same spacings as conventional crops are used. However there can be advantages in other spacings. Some farmers drill their rows 30 cm apart, i.e., twice the normal row width, doubling the amount of seed sown in each row and then use modified sugar beet hoes in-between the crop rows. While costly in terms of capital equipment and a slower rate of work in the field this technique provides very good weed control, especially in fields with a high weed seed burden. This drilling arrangement can also be useful when using implements such as harrows and tine weeders. These rely on the crop being relatively 'immune' to the weeding action. By increasing the density of the crop in the row this can reduce crop damage by the weeder, it increases the ability of the crop to swamp weeds in the row where the weeder is less effective, and it reduces the percentage of the field in crop rows so there is more open soil where weeds are more easily killed. For this to be successful the crop needs to be fast growing and dense so that it can create a complete crop canopy over the interrow areas and out-compete weeds that germinate after the last pass of the weeding equipment. Wider rows also mean that tractor wheels can fit in the interrow space so reducing damage to the crop. An alternative is cross drilling where the crop is drilled first in one direction, then over-drilled at 90 degrees to the first drilling. This helps establish a crop canopy quicker, especially on wider spaced crops, but it is unsuitable for a number of crops and weeding regimes.

5.3.2 Row crops

For farms growing a range of row crops, such as vegetables, there are considerable benefits to be gained by standardising on a single interrow spacing for most or all of the crops. While crops produce greater yields when they are planted on the 'square' (i.e., the interrow space equals the intrarow space). Weeding can be a considerable proportion of the cost of production of organic row crops, both in terms of time and capital equipment. The lost of yield on a per ha basis due to standardised row spacings, is more than compensated for by the decreased cost of field operations. Many drills, planting rigs, and weeding equipment, such as hoes, take a considerable time to set up. The down time required to change equipment from one spacing to another can often take as long as the fieldwork, and at times, such as spring, when there is much work to be done, it is a bad use of valuable time. The benefits of a standardised row spacing increases as the number of crops grown increases, the areas of each crop decreases and the number of separate plantings increases. Standardisation often means that more effective, and often more expensive, equipment can be purchased, as only one machine rather than several is required. It also means that novel crops can be introduced, or uneconomic crops discarded, with minimum cost, due to there being few changes to equipment or growing practices.

5.4 Accuracy in row crops

The need for very accurate drilling and accurate set up of machines cannot be over emphasised for row crops that will be hoed with an interrow weeding machine after the crop has emerged. The margin or error for most hoeing operations is five centimetres or less. Deviations of two to three cm in the setup of drills or hoes therefore cuts the margin of error by half resulting in crop loss. The tolerance for setting up any equipment used for drilling or hoeing row crops should be less than one centimetre. Symmetry of crops rows around the centre line of the tractor / bed is as critical. Symmetry means that the left side of the bed or equipment is an exact mirror image of the right side. This means that post drilling operations can be done from either the same, or opposite direction, as the crop was drilled, saving considerable time and hassle in the field and also reducing crop loss due to mistakes. It is essential that not only the drills and hoes are set up symmetrically on their tool bar, but the centre line of the tool bar is exactly halfway between the tractor wheels (i.e., the centre line of the tractor) and that there is no sideways movement of the equipment in relation to the tractor, i.e., check chains and stabiliser bars must all be tight.

Many people when setting up seed drills measure the distance between the drill units or hoes along the tool bar. A vital final check should be to measure the distance between the drill coulters or the hoes where they engage the soil. This should be done by measuring from a single outside coulter or hoe across all the others, not from one to the next. Coulters and hoes should also be checked at this point for excessive sideways movement; more than one cm of movement is likely to be a problem and should be fixed.

Very straight rows and driving are also vital, (except for contour cropping!) because it allows faster work later on and reduces crop loss and driver effort. Straight rows require only minor infrequent corrections by the driver, bent rows require constant adjustment. Straight driving also means that the inter-bed space is always the same ensuring that hoeing equipment covers the inter-bed areas without endangering the next crop row or leaving gaps.

5.5 Accuracy in broad acre crops

Accuracy in broad acre crops, while not as tight as the tolerances for row crops, is still important. The most critical part is accurate matching up of drilling bouts to ensure no gaps occur between the runs, at headlands or on corners. Crop competition accounts for a significant proportion of weed control in broad acre crops. Bare patches can produce considerable quantities of weeds that are difficult to control, and produce a copious quantities of seed. Width / bout markers are a valuable aid to ensure accurate matching of successive drilling runs.

5.6 Plastic and paper (sheet) mulches

While less common in New Zealand, sheet mulches are widely used in Europe in both conventional and organic systems. They provide very effective weed control for the life of the material. However the high cost of the material and laying mean that it is only economic for higher value crops that grow for a whole season or perennials. Plastic mulches are not very envionmentaly friendly and are often time consuming to remove. They also pose a disposal problem as they are difficult to recycle due to contamination from soil and organic mater, they must be burnt at very high temperatures to avoid producing toxic combustion products such as PCB's, so they mostly end up in landfills. Paper mulches suffer none of these drawbacks, as they are be incorporated into the soil to decompose. However, they are often more expensive than plastics, have a shorter life span and until recently many suffered from expansion and contraction problems with wetting and drying cycles causing them to work their way out of the soil and pull plants out.

The effectiveness of mechanical sheet mulch layers varies considerably and it well worth while trailing a machine under the conditions it will be used on your property or talking to several farmers that use them in a similar situation to you.

5.7 Crop covers (frost cloth)

Again these are less common in New Zealand while widespread in Europe. They have limited role in weed control, however they can cause considerable problems. The increased temperature and moisture found under covers often provides ideal conditions for weed germination and growth. It is vital therefore to very regularly check covered crops to make sure weeds do not gain the upper hand, as crops can easily be lost or large weeding costs incurred due to the 'out of site out of mind' effects of crop covers. For high value, difficult to weed, or early sown or planted crops, crop covers can be used as part of the stale seedbed technique to stimulate weed germination prior to flame weeding. The covers are placed on the soil immediately after cultivation to increase the speed and number of weed seedlings that germinate so more weeds are killed before planting.

5.8 Solarisation

This can be a very effective technique, as it has a similar effect as steam sterilisation of the soil. Sheets of very thin clear plastic are laid on the soil and dug in, they are then left for 4-8 weeks during hot sunny weather. Areas where there is inconsistent sunshine levels may find the effect of solarisation to be limited. The plastic causes the temperature of the soil to raise enough to kill weed seeds. The soil needs to be kept moist during this time and for large areas, under sheet irrigation is advised. Crops are sown or planted after the sheets are removed without disturbing the soil. With any technique that heats the soil there may well be a range of negative impacts on the soil flora and fauna, organic matter and nutrient levels.

6. Weeding machinery

There are a large number of post crop emergence weeding machines on the market, unfortunately many are only available directly from Europe or the USA. There are two broad classes of equipment for annual crops, broad acre and interrow machines. Broadacre machines work by having a weeding action which the crop is immune to but kills the weeds. Interrow machines only work in the areas between the crop plant rows, and generally kill all plants in that area. There are also a small number of weeding machines for perennial crops such as fruit, nuts and vines.

Most of the weeding machines, with a few exceptions, are most effective at killing weeds up to the time the weeds have zero to three true leaves. Once weeds get bigger than this the percentage of weeds killed decreases significantly. This is because larger weeds are physically tougher, they have more food reserves and can therefore develop new roots. Some farmers believe that the best time to weed is before the weeds have emerged. However, some research has indicated that this post-germination but pre-emergence weeding kills a lower percentage of weeds than when the weed seedlings have emerged. The highest percentage kill was at the cotyledon stage, i.e., before the first true leaves developed. Machines vary in how fast the percentage kill decreases as the weeds mature. For broadacre machines the percentage kill decreases very rapidly, while the interrow machines, with their more aggressive action, the kill rate decreases more slowly. Some of the very aggressive machines, such as the horizontal axis brush hoe, or rotary hoes can kill adult plants, but at decreased work rates. Even with the ability of these machines to kill large weeds it is not sound practice to leave weeding till weeds are bigger. In all cases best overall results will be achieved when weeds have up to four true leaves.

Most machines work best in hot dry conditions. This is because they do not actually destroy the weed, (e.g., by cutting in half or ripping roots and leaves off) but just leave the whole seedings on the soil surface. If the soil is moist or wet and or the weather is overcast then the seeds can re-establish. Even for those machines that are more aggressive, kill rates will be higher with dry soil and hot windy conditions. There is therefore a tricky balance to strike between waiting for good weeding weather and the weeds getting to big. There are no hard and fast rules for deciding and each case has to be judged, using past experience, the weather, the population, species and size of weeds, and the type and state of the crops.

Most machines work better with fine, stone free seedbeds. There are exceptions, for example, a spoon weeder will work better in slightly courser looser tilths or where there are soil caps, which it breaks up most effectively.

6.1 Broadacre machines

6.1.1 Tine weeders (finger weeders)

Tine weeders consist of a large number of spring steel rods (tines) between 0.5-1 cm thick bent at 90° about 10 cm from the end (Figure 4). They work by vibrating rapidly backwards and forwards ‘chiselling’ through the soil. This action flicks out small weed seedlings. Tine weeders were designed for use in cereals where the large, deep drilled seed, is out of the reach of the tines, and the flexible vertical shoot ‘moves out the way’ as the tines pass. They work best on larger, deeper seeded crops that are have flexible stems, e.g., peas and cereals. They are less effective against grass weeds, and they have little effect on established weeds. There are a number of different manufacturers making tine weeders, some have a range of different models. These machines are widely used and can be highly effective, however different brands vary in their effectiveness. The tine angle / spring pressure can be altered on most machines to allow for different crops and soil conditions. On some machines individual tines can be changed to deal with non-flat field profiles, e.g., raised beds. On others all the tines are adjusted at once, and a few have both options. Widths vary, some very wide ones are available exceeding 15 m in width. Forward speed needs to be quite fast, up to 8 km hour to get the most effective weed kill. Some crops, especially at later growth stages will need to be weeded more slowly to avoid crop damage. Dry soils and dry weather are important to get a good weed kill.

Figure 4. Spring tine weeder

6.1.2 Spoon weeders

Spoon weeders, also know as rotary weeders or rotary hoes, consist of a number of flat, thin, steel spokes emanating from a hub to form a wheel (Figure 5). The end of each spoke is curved and has a thin 'spoon' like tip. It works by the wheels being driven round by contact with the ground. As each spoke hits the ground the curve in the end of the spoke means the spoon enters the soil vertically with little soil disturbance. As the wheel continues to turn the curve means the spoon changes to a horizontal position. As it exits the soil it lifts a cone of soil and weed seedlings directly above itself and throws it into the air. The seedings being lighter come down last and desiccate on the surface. The spoon weeder, like the tine weeder, also works best in large seeded, deeply drilled crops. Spoon weeders are used extensively in the USA, including in no-till systems, where there are various models designed to cope with high trash levels. There are a range of working widths going up to about 10 m. Spoon weeders are heavier that the same width tine weeder.

Figure 5. Spoon weeder / rotary hoe with close-up of spoon tips

6.2 Interrow machines

While there are a wide variety of approaches and machines for interrow hoeing, the issue of where and how to mount them and ensuring accuracy is common to them all. With the need for narrow tolerances, discussed in Section 5.4, it is often difficult to achieve the necessary steering accuracy when a weeder is mounted on the back of, and steered by, the tractor.

6.2.1 Front, mid and rear mounted hoes

The ideal mounting position for interrow equipment is between the front and back wheels of the tractor. However for standard tractors this is impossible. There are a number of specifically designed tractors and tool carriers which can mid mount interrow hoes, such as Fendts. Mid mounting has the advantage that movement of the steering wheel produces the smallest changes in the position of the hoes compared to front or rear mounted machines. It is also the closest to the driver so they have the best field of view of the crop rows. Some machines have an off-centre driving position so the driver has an unobstructed view of the crop without having to lean sideways, which can be very uncomfortable. If more than a few hectares of crops are being grown the value and flexibility of a small tool carrier can outweigh its cost several fold.

Front mounted hoes have the advantage that the crop can be viewed by the driver and while more sensitive to steering wheel movements than mid mounted they are less sensitive than rear mounted hoe. The disadvantages are that either front three point linkages or special mounting attachments are required, which are often expensive.

Rear (three point linkage) mounted equipment has the advantage of being able to fit on standard tractors. However, with the close tolerances found on most row crop they need to have someone steering them. This doubles labour costs. Exceptions to this are where the crops are in ridges, where the tolerances are less and the equipment tends to steer itself by following the ridges, or on broad acre crops set up for hoeing on wide rows using a tractor which has centre articulated steering (e.g., Holder) which means that the hoe will accurately follow the tractors steering path.

6.2.2 The effect of weeding machine depth on weeding efficiency

Field surfaces are quite uneven over fairly small distances e.g., tens of centimetres. Many interrow weeders have precise depth requirements if they are to work efficiently. If they go too deep or shallow the percentage of weeds killed can decrease very rapidly. Some weeders consist of simple horizontal toolbar(s) to which individual weeder 'units' such as hoes or discs are attached. On such machines it is important that each weeding unit (e.g., a hoe blade), or a small groups of units are able to independently adjust their depth. This is normally achieved by a parallelogram between the toolbar and weeding unit and a small depth wheel. While this is complex it allows the height to vary without changing the pitch. Changing the pitch of weeding units, such as sweep hoes, reduces their effectiveness. Alternatives to parallelograms include simple hinges where the vertical leg of each weeding unit is on the end of a 10-40 cm horizontal bar. The horizontal bar reduces the amount of change in pitch when the unit pivots on its hinge. Systems where each weeder unit cannot individually adjust it depth should be avoided as they often result in uneven weeding.

6.2.3 Clamps and hoe attachments

Some weeders rely on a single clamp to change more that one adjustment of a hoe unit, e.g., depth, horizontal position, and yaw. This makes it difficult, slow and frustrating when changing one adjustment as other adjustment settings get accidentally changed as well. Ideally each adjustment should be changeable without affecting any other adjustment setting. The maximum recommended number of adjustment settings that can be changed with one clamp is two.

6.2.4 Steerage hoes

The traditional machine for interrow hoeing was the steerage hoe. At their simplest these consist of a horizontal tool bar to which vertical legs are clamped with hoe 'L' shaped hoe blades at the bottom, to machines with independently floating legs and quick width adjustments. Operating at the correct depth is critical for hoe blades to achieve a good weed kill. Too deep and they go under the weeds, to shallow and they pass over them. It is therefore recommended to use independently floating hoes. Hoes do not work well in trashy conditions. Clumps of dead grass, for example, can quickly block them significantly reducing weed kill and damaging crop plants. The design of hoe blades is critical to achieve a good result, with the minimum crop damage and with the least clogging.

Figure 6 shows a well designed ‘L’ hoe blade for use in small seeded crops. The side wall has a shallow downward sloping cutting edge to help it cut through trash. The side wall is also long and deep, with a curve away from the crop at the back end to ensure that soil is kept off crop seedings. The horizontal blade is flat on the ground so it has an ability to regulate its own depth. This also means that soil flows over it rather than along it. The blade is also angled backwards quite sharply which gives it a better slicing action on the weeds and reduces the chance of larger weeds catching. But it also increases soil flow along its length which can build up as a ridge at the end of the blade. In comparison the left-hand hoe in Figure 7 is not suitable for hoeing small crop plants. It has an upward sloping front edge on the side wall which means it tends to collect trash which then wraps around the vertical shaft damaging the crop. The side wall is very short and shallow with a distinct cutaway at its end which funnels a stream of soil into the crop row which can bury it. The right-hand hoe in Figure 7 has a short downward pointing front edge which is better at dealing with trash than the left-hand one but not as effective as the hoe in Figure 6. Its blade is angled sharply up from the horizontal making it more difficult for the soil to flow over it, so it tends to flow along the blade instead. However the backwards angle is more shallow which means soil tends to want to flow over it rather than along. It is also more strongly constructed than the left hand hoe. The right-hand hoe in Figure 7 is better suited to large robust crops such as maize or sweetcorn where depositing 1-2 cm of soil in the row will not damage such a crops but will bury small weed seedlings therefore killing them.

Figure 6. Good design of hoe blade

Figure 7. Poorer designs of hoe blades

An alternative to L blade hoes is the rather uncommon ‘T hoe (Figure 8) where the hoe leg is attached to the middle of the rear edge of the blade. The advantages of this blade compared to the L hoe is there is less soil disturbance next to the crop so it is possible to hoe closer to the row. Also as the crop grows and spreads into the interrow area the blade can reach underneath the crop maintaining a larger weed free area, and if weeds do bind on the leg they are furthest from the crop so reducing the chance of them damaging it. However, as the point nearest the crop is hidden by soil it is vital to have additional sighting guides which the operator lines up with the crop row such that the hoes pass either side of the crop. Further, unlike L hoes which are generally have a forged construction, the T hoe is made from pieces of flat bar. The horizontal blade is 2-3 mm thick, depending on steel type, and 3-4 cm wide with a sharpened front edge and with a 5-10° rake angle (amount of lift from the horizontal) and 45° plus sweep angle (the angle of the cutting face to a line perpendicular to the direction of travel), with increasing angle having a greater slicing effect and reduced chance of weeds binding to the blade. Blade length is dependant on row width and sweep angle. The leg can be flat, round or square bar as in (Figure 8). Ideally the leg should have a slight forward bend at the bottom to improve soil flow over the blade.

Figure 8. T hoe with the leg attached to the middle of the rear edge of the blade

While interrow hoes have been used successfully for many years they have a number of limitations. They:

- have difficulty dealing with surface trash and tend to block up;
- do not work well in stony conditions;
- need a dryish soil to work well and clog up in damp soil.

There are increasing numbers of interrow machines that operate on different principles.

6.2.5 Basket weeders

These have wheel like ‘baskets’ constructed from ‘U’ shaped lengths of high tensile wire fastened to a hub. The baskets fit in between the crop rows and are mounted on a horizontal shaft. The two sets of baskets are connected by a 2:1 ratio chain drive that forces the back set of baskets to turn faster than the speed of travel. The faster turning basket scuffs weeds out of the ground therefore killing them (Figure 9). Basket weeders have the advantages of being simple, ground driven, comparatively cheap, with low maintenance and require virtually no adjustment once built. They do not perform well in hard or stony soils, although they will handle larger stones, more trash and damper soil than interrow hoes. If there is good penetration of the soil by the basket weeder it can kill weeds up to 3 cm tall (depending on species). However, kill rates decrease considerably with increasing weed size, so weeding should ideally be done at zero to three true leaves. At slower speeds there is very little soil spill into the row although this increases with speed. Forward speeds are limited by driving accuracy and soil spill into the row. They can not be adjusted for different row widths except by replacing the baskets.

6.2.6 Brush weeders

There are two types of brush weeder on the market; vertical and horizontal axis. Both machines use brushes made from thick, very tough plastic bristles.

The horizontal axis weeder has a single horizontal shaft on which circular brushes are mounted (rather like the large brush underneath a road sweeper) that fit between crop rows i.e., there are gaps in the brush where the crop goes (Figure 10). The brushes are PTO powered and rotate in the direction of travel 2-4 times forward speed. Crops are protected by metal tunnels situated between the brushes.

The vertical axis weeder has a number of hydraulically powered vertical shafts, one each side of the crop row with a round brush on the end similar to the gutter brushes on the side of road sweepers. These can rotate in either direction therefore moving soil into or out of the crop row. When rear mounted, both machines require a person to sit and steer the machine.

Figure 9. Basket weeder

Figure 10. Horizontal axis brush hoe

Brush weeders, due to their vigorous working action, are very effective at killing weeds and can kill large weeds. The use of flexible bristles means they are effective on stony soils and in wet conditions that would stop other weeders from working. They are however expensive, have a large number of moving parts and need adjusting for different conditions. In dry conditions they generate a lot of dust making the job of steering the hoe unpleasant. Forward speeds needs to be matched with rotor speed. While it is theoretically possible to achieve high forward speeds with fast rotor speeds, accurate steering at speed is difficult due to the weight of the machine and also the working depth becomes more variable, therefore reducing weed kill.

Both machines can accommodate a wide number of rows and row widths. However they are time consuming to adjust. It is impractical to change the horizontal axis machine's setup on a regular basis. The crop tunnels on the horizontal axis machine can gather up spreading crop foliage (e.g., lettuce and carrots) very effectively, allowing the machine to be used on more mature crops. On the vertical axis machine, minor adjustments in row width, to accommodate different crop sizes, are practical, changing the numbers of rows or the inter row spacing is not.

6.2.7 Rotovator (rotaryhoe) hoes

To clarify some terminology; what are commonly called rotaryhoes in N.Z. (e.g., as made by Howard) are more generally called rotovators as they cultivate soil rather than hoe crops. However they can also be used as hoes. These are divided into two main types. Full width rotors with ‘missing’ blades or multiple independent rotors.

Full width types look like a normal rotovator, however, the shaft has an incomplete set of blades with gaps for the crop will be. ‘Knife’ blades are normally used instead of the traditional ‘L’ blade. These machines are generally used on potatoes or other robust ridge grown crops. The machines also often have ridge formers on the back to remake the ridge.

Independent rotor types have a number of small rotors (about the size found on pedestrian controlled equipment) with ‘L’ or ‘speed’ blades. These are mounted on a toolbar and powered from a shaft attached to the tool bar which in turn is powered by the PTO. The individual rotovators fit between the crop rows. They are designed for use on wider spaced crops or ridge crops. They will destroy large weeds due to their very aggressive action, and can cope with wet conditions and more stony soils, with associated increased machine wear. On the negative side they are hard on the soil, and if set too deep will bring up dormant weed seed. They are also expensive, have lots of moving parts and therefore have require higher maintenance requirements. Forward speeds for the independent unit machines are similar or slightly faster than brush weeders.

6.2.8 Rolling cultivators

These consist of sets of ‘spiders’, cast steel ‘wheels’ about 30 cm in diameter with 10 curved teeth radiating from a centre hub in a spiral, see Figure 11. The sets of spiders are attached to a tool bar via a spring loaded arm that allows the cultivator to maintain a constant depth. The spiders are set at an angle to the direction of travel forcing them turn and to disturb the soil surface and therefore kill weeds. The vigour of the action is varied by altering the angle of the spider set. Rolling cultivators are widely used in the USA and Europe on both ridges and on the flat. They are more suited to larger seeded more robust crops such as beans and sweetcorn that are grown on wider row spacings. The spider sets come in fixed widths. Adjustment for different row widths is achieved by having several sets of spiders between crop rows. Forward speeds can be quite high as the machine is ground driven, and the action becomes more vigorous with speed. Speed is limited by driving accuracy and equipment bounce.

Figure 11. Rolling cultivators

Figure 12. Torsion weeders

Figure 13. Potato weeder

6.2.9 Potato ridgers

Many growers and farmers new to growing potatoes or other ridge crops make the mistake of buying any old set of ridging bodies believing they will achieve a good result. This is not the case. Old or badly designed sets of ridging bodies will not achieve a good ridge nor weed kill. Any set of ridgers should also have a set of tines for pulling down ridges on the same tool bar. This means that in a single pass the sides of the ridge are pulled down, and then put up again ensuring a good ridge shape with maximum weed kill. Common types of tines are short straight tines set in a 'V' formation (see Figure 13) or spring tines (similar to a tine weeder) set in a fan shape. Many ridgers also have a grubber tine at the bottom of the furrow to loosen up the soil compacted by the tractor wheels.

6.2.10 Less common weeding machines

There are a wide number of other interrow machines available. These are often made by a single manufacturer and have limited availability. Examples include; spyders™ a cross between a concave disk and a single spider from a rolling cultivator, torsion weeders which consist of a spring steel rod designed to break up the soil (and therefore kill weeds) in the crop row (Figure 12), and finger weeders that consist of a number of rubber 'fingers' mounted on a cone wheel that weeds in-between crop plants. The lack of widespread take up of such machines is an indication that there are problems with their efficacy or economics, however many of the growers that use them consider them to be good machines. It is recommend that producers, especially those new to organics, try well proven and widely available machines before trialling more unusual weeders.

6.2.11 Hand wheel hoes

For the new grower considering growing on a few acres with limited capital, hand pushed wheel hoes are very effective. They consist of one or two wheels about 30-40 cm in diameter, attached to a small tool frame, on which a wide range of sweep hoe blades, ridging bodies etc. are mounted, and to which a pair of handles are attached (Figure 14). These are often called Planet Juniors, after a brand from the U.S.A. Many old ones exists, but new ones are also being made. Good design features to look out for are large wheels (especially pneumatic) which are easier to push and ergonomic handles that keep the wrist straight to reduce fatigue and physical damage to arms and hands. These machines will hoe much greater areas, with a higher weed kill rate, and lower crop damage than a hand hoe.

Figure 14. Hand push hoe

Figure 15. Perennial crop weeder

6.2.12 Hand weeding

If all other aspects of weed control have been successful hand weeding should be minimal and in competitive crops, such as carrots, it can be avoided. If needed it requires skill to do the job effectively and efficiently. Staff should be trained to recognise different types of weeds and how to kill them. Tools need to be chosen to suit the weeds, crop and the size of both. Hand hoes, small knives, and fingers all have their place. Hand weeding is also very had work and best done in short periods by gangs of weeders. Where hand work, either with fingers, knives or similar tools, is needed over large areas it can be valuable to use mobile platforms. These are normally mounted on a tractor, allow workers to sit or lie down on cushions, and provide protection from the sun wind and rain. They make the task easier for the staff improving their moral and also ensures that work rates are maintained.

6.3 Perennial crops

There are a number of perennial crops where weeds need to be controlled between plants within the crop row, for example, apples and vines, without damaging the plants. These weeding machines work by having a mechanism that ensures the weeding head does not touch the crop or support posts. There are two types of systems to ensure this, either a sensing ‘wand’ situated in front of the weeding head which when it touches a plant stem, post or other solid object, operates a hydraulic, pneumatic or electronic system to move the weeding head out of the way, or a simple spring loaded mechanical linkage system attached to a guide wheel that steers the weeding head round the obstruction. Weeding heads vary from large sweep blades (Figure 15) to powered heads with a more aggressive action.

7. Conclusion

This report has covered the spectrum of weed control in organic farming systems. It has emphasised the importance of looking at weed control from a systems perspective, with emphasis on rotations, crop choice and cultivations as the main means and most economic way to control weeds. Post planting techniques such as machine weeding are the icing on the cake, when it comes to organic weed control. If the key elements are well implemented then effective weed control in organic systems is more than achievable.

8. Other sources of information

Bio-Gro http://www.biogro.co.N.Z./

Blake, F. 1994. Organic Farming and Growing. Crowood Press, Swindon.

Bowman, G. 1997. Steel in the field: A farmers guide to weed management tools. Sustainable agriculture Network,

Davies, B., D. Eagle & B. Finney. 1993. Soil management, 5 ed. Farming Press Books, Ipswich.

Hudson, R. L. 1983. Ecological agriculture: review and annotated bibliography. Federated Farmers of New Zealand, Wellington, N.Z.

Kinsey, N. 1993. Neal Kinsey's hands -on agronomy. Acres U.S.A. Kansas City, USA.

Lampkin, N. 1994. Organic Farming. Farming Press Books, Ipswich. (highly recommended)

Organic Farming magazine (previously new farmer and grower) Published by the Soil Association in the UK,

Organic Products Exporters Group http://www.organicsnewzealand.org.N.Z./

Soil and Health Assn. of N.Z. http://www.soil-health.org.N.Z./

Soil Association Ltd. (UK) http://www.soilassociation.org/

9. Glossary

Cotyledon	A "seed leaf" of a plant, which either stores or absorbs food
Cover crops	Crop plants grown to protect the soil rather than generate income
Cotyledons	One of the first, or seed, leaves (there may be one, two, or more); the foliar portion of the embryo as found in the seed
Dicotyledonous	A flowering plant with two cotyledons, e.g., peas, beans, carrots, brassicas.
Dormancy	A period in which a seed or plant does not grow, awaiting necessary environmental conditions such as temperature, moisture, nutrient availability, etc.
Emergence	The time at which a developing seedling first extends its leaves above the soil
Germination	The time at which a seed spits its seed coat and extends its first root
Green manures	Crop plants grown to be returned to the soil to increase humus or nutrient (especially nitrogen) levels.
Interrow	The area of ground between rows of crop plants

Intrarow	The area of ground between crop plants within the row
Knife blades	Blades used on rotovators that have a straight profile
L blades	Blades used on rotovators that have a right angle bend half way along their length
Leaching	The loss of soluble nutrients from soil via water draining from the soil
Monocotyledonous	A plant with one cotyledon or seed leaf, e.g., grasses, maize, onions.
Post emergence	The period of time after crop seedling have emerged above the soil
Pre emergence	The period of time after a crop has been drilled but before the crop seedlings have emerged above the soil
PTO	The Power Take Off on a tractor
Speed blades	Blades used on rotovators that have a gradual bend along their length
True leaves	The leaves produced by a seedling after the cotyledons
Weed seed bank	Viable weed seeds in the soil
Viable seeds	Seeds that have the potential to germinate and grow into plants but have not done so because of dormancy.