Organic Weed Management: A Practical Guide.

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2. Introduction

Weed management 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 management is essential for a successful organic enterprise. However, the amount of detailed information on organic weed management is often sparse and more often covers 'what' needs to be done rather than 'how' to do it. This aims to address that gap with information on both what needs to be done and how to do it.

2.1. 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. This in turn 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 in increased costs. The effect of using more herbicides was pest outbreaks! This kind of effect is neither intuitive nor 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 management 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 managing crop weeds, total elimination would be counter productive.

2.2. Integration of the farm system

Weed management 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 management) 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 management 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 managing 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 management are required, to make decisions on a case by case basis.

2.3. The big picture

With the need for a systems approach for organic weed management planning has to start with the highest system level and descend to the lowest system level. 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. crop production techniques;
7. machine weeding;
8. hand weeding.

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

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

3. 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 crop ecosystems to a piece of land so that no part of any one ecosystem 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 managing 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 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:

- 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 management. Green manures and cover crops are also important and ideally a range of these should be used.

3.1. 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 planting dates you will select different weed species, ensuring that none are selected year after year.

3.2. Rooting habit

Rooting habit is less commonly considered as a means of improving weed management, 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 root forms that are similar to the 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.

3.3. Volume and type of top growth

The volume and type of top growth has a big impact on weed management, 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 managed, 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.

3.4. 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.

3.5. 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 best cultivation approach for maximising weed management is that most seeds can only germinate in the top five centimetres of soil. If few weeds went to seed in the previous 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 three years much of the buried seed will be brought back up and germinate.

3.6. Harvesting requirements

The different harvesting requirements of different crops can have a big impact on weed management. 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 management 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.

3.7. Weeding machinery

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

3.8. Green manures and cover crops

Green manures and cover crops can be very useful for weed management. 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 humus content and nutrient levels.

3.9. Livestock

Having a mixture of livestock is valuable for weed management. 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 Californian thistle. Chickens are also excellent at clearing up weedy areas and crop remnants with the additional benefit of clearing up crop pests such as slugs and also eating weed seeds. Foul such as geese and ducks that feed on grass can be used to control grass weeds in orchards, vineyards and under cane and bush fruit.

3.10. 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 should be redesigned 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 manage weeds in, would be a sensible choice. This will bury much of the seed, and that which does remain will be killed by 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 management, it is not the complete answer. However, without a good rotation other weed management techniques will have a limited effect.

4. Soil nutrients, soil structure, ph and composts

Soil nutrients, pH and soil structure are not often considered when it comes to organic weed management. 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 management techniques will have limited impact.

4.1. 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 gives 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 is 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 base cations (potassium, calcium, magnesium and sodium), for example, is widely recognised as being important, as an imbalance can lead to hypomagnesaemia and other metabolic disorders in livestock. Effects on plants and soil are often harder to see but can still be important for soil structure, and the growth of more susceptible plants including clover and pine trees.

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.

4.2. 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 management 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, weeds that spread via deep underground stems or roots, such as Californian thistle can gain a competitive advantage in compacted soils and those with 'plough pans'. Poor structure, compaction and cultivation pans can also lead to waterlogged soil which can promote water loving weeds such as buttercups and rushes.

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 clearly shown that leaving residues on the surface and not inverting the soil has considerable advantages in terms of soil structure and organic matter levels. Ploughing is not essential, and is frequently detrimental to soil structure and organic matter and its use should be minimised or avoided.

4.3. Composts and Manures

Composts and animal manures can contain large numbers of weed seeds and other plant reproductive material such as corms or bulbs. It is important that compost or manure is hot composted if it contains significant amounts of weed seed, other reproductive material, or weed species absent from the land on to which the material will be applied.

5. Crop and pasture choice

Crop and pasture choice are also often overlooked in relation to weed management, partly as they have a smaller effect than other aspects of weed management, 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 white 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 common ryegrass endophyte can cause stock health issues including ryegrass staggers. Other grasses such as timothy while slower to establish are deeper rooting, more competitive and non-toxic to stock. Deep rooting perennial weeds e.g., docks, are potentially a major pasture weed in organic systems. These deep rooting plants are able to access moisture and nutrients beyond the reach of grasses and white 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% - 20% 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 (polycrops), 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 management 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.

6. Cultivations and seed bed preparation

Cultivation can have a huge effect on weed management 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 management. 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 tools such as rotations, crop choice and hoeing to achieve good management. Cultivations also alter soil properties such as organic matter, structure, and porosity, so while one technique may be optimal for weed management 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.

6.1. Primary cultivation choices for perennial weed management

To decide on what cultivations to use to achieve optimum weed management 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 managing 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 managing 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 manage while the deep creeping and tuber, corm and bulb types are often the most difficult.

6.1.1. 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.

6.1.2. 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 management more difficult. Useful management 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.

6.1.3. Deep creeping weeds

Deep creeping weeds, especially well established patches, will not be controlled by a short fallow. Management is normally only achieved by a full fallow or a combination of techniques. Subsoiling / deep ripping can be a valuable part of a management 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 managing 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 management to gain the maximum weed management for minimum cost.

6.1.4. 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 manage. The storage organ can often remain dormant for many years therefore surviving fallows. Stock can help manage 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 management via cultivation. Persistence and a thorough understanding of the individual weeds lifecycle are essential to gain control.

6.2. 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 five 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 one to four 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 seed beds.

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 seed bed that already has weeds growing in it, with the belief that they can be managed later. This can occur after an overwinter fallow that has been hampered by wet weather. 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.

6.3. Secondary cultivation: Choices for weed management

Having decided on the primary form of cultivation, secondary cultivation(s) are often required to further enhance weed management. As noted previously, cultivation choices are not just based on weed management, 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 seed bed 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 management 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.

6.3.1. Stale and false seed beds

Approaches to weed management by secondary cultivation can be divided into two techniques, false seed beds and stale seed beds. Both begin with cultivation(s) designed to produce a firm, fine tilth with good capillary rise that maximises weed seed germination. The false seed bed technique involves a second cultivation to kill the weeds after they have emerged. This second cultivation is often the same as the one that created the initial seed bed and ideally makes another seedbed in one pass.

A stale seed bed involves killing the weeds that emerge without disturbing the soil, e.g., by using a 'flame weeder'. There are two variations of the stale seed bed technique. The traditional one involves creating the seed bed, 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 seed bed 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 seed beds 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 management achieved gives a good return on the cost of irrigation. 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.

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

To ensure a timely weed kill, when using stale seed beds, 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 seed beds 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 seed beds followed by a stale seed bed. Where there are fewer weeds, lower value and/or more competitive crops, a false seed bed alone should be sufficient.

6.3.2. Blind harrowing

Blind harrowing is a hybrid between false and stale seed beds. A stale seed bed is created and the crop drilled. Then a few days before emergence a harrow, tine weeder or similar device, is used to cultivate the soil surface to kill the weeds. This is only practical for deeper drilled and robust crops such as cereals that can survive being driven over during the emergence period. It can be it used on more delicate crops such as beans, but it kills germinating crop plants in the tractor wheelings. 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 are frequently increased by 5-10% to make up for any losses from the harrowing. Seed rates are also increased in crops suitable for blind harrowing to compensate for losses from post emergence weed management.

For stale seed beds and blind harrowing seeds are often drilled at the deepest depth that they can successfully germinate from. This maximises the amount of time between weed and crop emergence. Also in the case of blind harrowing or post emergence weeding it ensures the crop seed is out of reach of the weeding equipment.

6.3.3. Minimisation of cultivations for fallows, stale and false seed beds

When using a fallow, stale or false seed bed 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 management required. Leaving soil bare and cultivating 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.

6.3.4. 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 seed beds 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 seed beds, 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 management 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.

7. Sowing, planting, mulches and covers

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

7.1. 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 management. 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.

7.2. Sowing rates

Most sowing rates have been optimised for conventional systems, where the interaction between 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.

7.3. Row spacings

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

7.3.1. 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 management, 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.

7.3.2. 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.

7.4. 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.

7.5. 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 manage, and produce a copious quantities of seed. Width / bout markers are a valuable aid to ensure accurate matching of successive drilling runs.

7.6. 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 management 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 is well worth while trialling 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.

7.7. Solarisation

This can be a very effective technique. It has a similar effect as steam 'sterilisation' of the soil. Sheets of 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 rise high enough to kill weed seeds. The soil needs to be kept moist during this time and for large areas, under sheet trickle / drip irrigation is advised. Crops are sown or planted after the sheets are removed and 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. Solarisation also tends to result in a flush of nutrients which should be managed by immediately establishing the crop after plastic removal, to prevent nutrient loss.

8. Perennial crops

8.1. Understory and beneficial plants

A key initial decision, when designing weed management systems for perennial crops, such as apples, grapes, and raspberries, is whether to keep the area under the crop free of vegetation or not. In organic systems it is considered poor practice to leave the earth bare of plant cover for any length of time, due to the damage caused to the soil. However, in some perennial crops, competition from plants close to the crop may result in significant reductions in crop yield or quality. Despite this, different non-crop plants can vary considerably in the effect they have on crop yield and or quality. For example, deep rooting plants, such as cow parsley, do not compete with apple trees as much as grass, the roots of which occupy the same soil zones as the tree roots. Research work on crop and non-crop interaction in non-organic production systems that has shown crop yield losses, have frequently been based on a grass sward, either mown or un-mown. It is not, therefore, always possible to apply the results of such trials to organic systems using deep rooted understory plants. In addition, less crop-competitive understory plants can out-compete other plants, such as grasses, that could compete more strongly with the crop. Alternatively, in some situations, for example grape vines in areas of higher rainfall, excessive crop vigour can be a problem. Beneficial plants, that compete with the crop for water and other resources, can reduce crop vigour thereby improving crop quality and reducing crop husbandry costs.

Such non-crop plants have additional beneficial effects apart from controlling weeds. Plants such as cow parsley, comfrey, yarrow, goldenrod, tansy, wild carrot, buckwheat, broad bean, alyssum, coriander and phacelia provide habitats and food for beneficial insects that can control pests. They can also contribute to disease management by providing a physical barrier to disease spores being released from overwintering infected crop debris. When the plants are mulched and begin to rot, the decomposition process can help break down crop residue and therefore, kill overwintering disease spores. Some plants, such as brassicas, produce sulphur-containing root exudates that are biologically active and can suppress soil-borne pest and diseases.

Typically in top-fruit systems, such as apples, flowering understory plants, as listed above, are used with a mown grass and clover sward between the rows. The understory is cut down four or five times per season to prolong flowering, thereby providing season long pollen and nectar sources for beneficial insects. Ideally only alternate rows are cut at any one time, with the uncut rows mown when the previously cut rows have begun flowering again, thereby ensuring a continual supply of pollen and nectar. To facilitate orchard access the grass and clover sward between the crop rows is mown more regularly to a height of about five centimetres. With suitable equipment the clippings can be directed into the tree rows to transfer nutrients into the tree rooting area.

In vineyards beneficial flowering plants can be grown both between and under the crop rows, depending on whether competition with the crop is beneficial or not.

In systems where a mown grass understory is required foul such as geese and ducks, that only feed on grass and invertebrates, can be a useful grass management tool. Consideration must be given to the possibility of contamination of the crop with faecal matter. Systems to avoid this must be implemented and or the foul removed sufficiently in advance of harvest to prevent contamination.

8.2. Mulching

In soft fruit, such as raspberries, and blueberries, any non crop plants growing among the crop complicates harvesting, due to the non-crop foliage hiding the crop, and increases disease risk, due to decreased air-flow through the crop. Such crops are more difficult to mechanically weed as many are often low growing, bushy, have multiple stems and or send up new stems from underground each year. Mulching with either synthetic or organic materials is the most favoured approach.

For crops that have a single or tightly bunched stems, such as gooseberries, a permanent, plastic, light proof mulch is highly effective. Ideally these should be of the woven type, as these allow water and air to pass through them and are also physically tougher that extruded sheets so are less prone to damage. When plastic sheets are laid it is important that the buried edge of the sheet is not proud, or even slightly below the adjacent ground as this will facilitate mowing, and reduce the likely hood of damage to the sheet. Weeds often establish in the hole made in the sheet for planting the crop. The use of a 'collar' which consists of a piece of mulch, that is about 5-15 cm larger than the planting hole, with a slit cut in it to its centre, placed round the crop stem with the slit fasted with staples or pins, will stop weeds from establishing round the crop stem. Plastic mulches can be effective at killing established weeds. However, well established perennials can take several years to die and can force sheets out of the ground as they produce a mass of foliage in an attempt to capture sunlight. Creeping weeds will often find their way out from under the sheet through small holes in the sheet and the planting hole, even if it has a collar. Therefore, it is best to ensure that established weeds are killed prior to laying the mulch.

In some situations painting, the sheets white will significantly increase the amount of light received by the crop and potentially increase yields. However, this will also reduce soil temperatures the lessen the frost protection effect of black mulches.

For other crops, such as raspberries, that have multiple stems that emerge from the soil, organic mulches are the key weed management technique. Organic mulches can also be successfully used in orchards and vineyards. Organic mulches include compost, which is increasingly commercially available from municipal green waste recycling systems. This has the added benefit of also providing balanced nutrients to the crop thus feeding it at the same time. It is essential that it has been fully hot composted to ensure that no weed seeds or other reproductive material is present. More woody materials such as sawdust and bark are also effective mulches. Consideration must be given to the potential for nitrogen robbery from the soil as microbes break down the mulch. In addition, when acidic materials are used, such as pine bark, extra lime may be required to maintain an optimal pH within the mulched area. A recent innovation is the use of a *papier mache* type mulch that is sprayed onto clean soil forming an unpenetratable barrier against weeds. This also has the attribute of being a light colour so reflecting light to the crop. If a dark mulch was required, e.g., to aid frost protection, suitable colouring materials could be added.

With all these mulches it is important they are of sufficient thickness to prevent weeds seeds from germinating, and preventing any that do from reaching the surface. A minimum of five cm is needed with seven to eight cm being optimal. The exception is *papier mache* mulch due to it setting to form a solid barrier. Also mulches are more effective if they are applied in winter before weeds have started germinating. A key method by which mulches suppress weeds is to make the weed seeds 'think' they are deeper in the soil profile than they actually are. As noted before, most weed seeds can only germinate in the top five cm of the soil. Mulch has the effect of 'deepening' the soil profile so what was the soil surface is 'moved down' the soil profile by a distance equivalent to the mulch depth. If mulch is applied in winter the weed seeds never experience conducive germination conditions as they are buried too deep. Conversely, if mulch is applied in spring, weeds will experience suitable germination conditions so some will germinate. Once germinated, weeds are able to emerge from a considerable depth of soil, often from 10-15 cm. This is often greater than the depth of the mulch so the weeds will emerge through the mulch.

Organic mulches are only effective at stopping weeds from germinating. They are not effective at controlling established, especially perennial, weeds. The ground to be mulched must therefore be completely free of established weeds before applying the mulch, including dormant perennial weeds. If the un-mulched areas, e.g., the centre grass strip, contains creeping and spreading weeds, such as couch / twitch grasses these will often invade the mulched area and then spread very rapidly, due to the lack of competition. Such spreading weeds must be removed from the un-mulched area.

Mulches vary in their ability to stop weed seeds that land on their surface, e.g., air borne seeds or seeds from the un-mulched areas, from germinating. Compost is a very conducive substrate for weed seeds to germinate on, while in comparison course pine bark is most un-conducive. It is possible to layer different types of mulch to take advantage of their different effects. For example, compost could be laid on the ground, to provide a dense air excluding layer that also provides nutrients to the crop, and then toped with a layer of course pine bark on which weeds have difficulty germinating.

In all cases mulches need to be replenished on a regular basis, e.g., between one and five years, to maintain sufficient depth. Replenishment rates vary on how fast the mulch decomposes, with composts requiring more frequent replenishment than woody products like sawdust.

8.3. Weeding machines

If a plant free area is required under the crop and mulching is not feasible there are a number of mechanical weeding options. There are a number of hoe designs that use a sensing device, e.g., a wand attached to a micro switch, to detect where the tree, vine stem, or crop post is, which then activates a mechanism that moves the weeding device round the obstruction. For example see Figure 12. The weeding device can be a simple hoe blade as in Figure 12 or as complex as a powered device such as a rotovator. Alternatively thermal weeders could be used. In the last few years companies, in both New Zealand and Australia, have developed steam weeders for use in orchards and vineyards. These have the advantage over open flame weeders of reduced fire risk, the ability to kill a wider range and size of weeds and greater energy and operating efficiency. With both hoe and thermal weeders the ability to kill perennial weeds, weeds that regrow from root fragments, such as docks, or creeping weeds such as couch is somewhat limited. Also they are less effective at killing larger annual weeds. Regular treatments throughout the year are therefore required. These should be timed so that the weeding occurs before the weeds reach a size when 100% control in a single pass would not be achieved.

9. Crop production techniques

In addition to production techniques the primary purpose of which is weed management, other aspects of production can have secondary effects that can improve or worsen weed management.

9.1. Irrigation

Differing irrigation approaches can have a considerable impact on weed management. As mentioned in section 6.3.1 irrigation is important for stale and false seed bed techniques. In addition the use of more ‘precise’ irrigation technologies such as drip and trickle can result in much lower weed germination compared to alternatives such as overhead sprinklers. For example, the use of buried drip tape for irrigation of potatoes means that irrigation does not wet the top few centimetres of soil so reducing weed seed germination compared to overhead irrigation that often floods the soil surface. There are also additional benefits including a reduced amount of water applied and a reduction in fungal diseases that need wet foliage to be able to infect the crop.

9.2. Crop covers (frost cloth)

These are less common in New Zealand while widespread in Europe. While they have a limited role in weed management 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 check covered crops very regularly 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 false and stale seedbed techniques to stimulate weed germination. 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.

9.3. Harvest

In crops where the weeds are not killed by the harvesting operation, e.g., leaf vegetables, it is important to kill the weeds as soon as possible after harvest to minimise further production of seed. This can be achieved by mowing / mulching and or cultivations. In situations where many weeds or large weeds have ripe but unshed seeds removal of the weeds, e.g. by cutting and bailing, can significantly reduce problems in future years.

In crops that re-grow after harvest, e.g. silver beet, chives, parsley, an immediate post-harvest flame weed can kill the weeds while the crop survives. It is important that it is done within a few hours of harvest otherwise the re-growing leaves will have scorched edges. This can also be used as a recovery technique in the same crops if they are over-run with weeds. The weeds are mulched to just above ground level and then flame weeded. Generally the speed of the flame weeder is much slower than for pre-emergence flaming to ensure a good weed kill. This technique may also have potential when such crops are suffering from diseases e.g. leaf fungi or pests e.g. aphids as the flame weeding can kill the pest and destroy the infected leaf material.

For grain and seed crops the old technique of weed seed capture is being revived. The header is fitted with additional equipment that collects the weed seeds after they are separated from the grain and chaff. The weed seeds are then destroyed. Alternatively only the chaff and seeds are separated in the field and a static off site seed cleaning unit is used to separate crop from weed seeds. Dramatic declines in weed numbers have been gained with this technique.

10. 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, broadacre and interrow machines. Broadacre machines work by having a weeding action which the crop is relatively 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 wet or overcast then the weeds 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.

10.1. Broadacre machines

10.1.1. 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 1). 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.

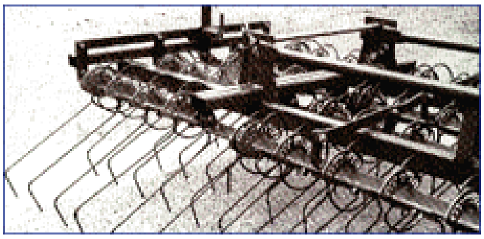

Figure 1. Spring tine weeder

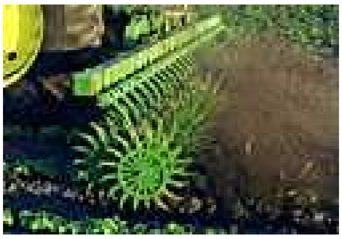

Figure 2. Spoon weeder / rotary hoe

10.1.2. 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 2). 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.

10.2. 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 7.4, it is often difficult to achieve the necessary steering accuracy when a weeder is mounted on the back of, and steered by, the tractor.

10.2.1. 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 Fendt. 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 crops they need to be steered, by a person, an automated guidance system, or by a soil ridge or groove.

Where crops are grown on ridges and when accuracy is not quite so critical, e.g., potatoes, equipment is often designed to steer itself, by following the ridges. For some non-ridged crops, mainly larger seeded quick growing species, e.g. squash, the drill can be fitted with a tine that makes one or more 'V' notches in the soil. Guide wheels on the hoe sit in and follow these notches thus steering the hoe. Another variation is a system that makes very precise, raised beds, with sloping sides which seed drills and hoeing equipment use as a guide.

Hoes which need a person to steer them are cheaper to purchase than automated guidance systems, however, it doubles staff costs, and due to the intense concentration required and the constant movement of the crop past the hoe operators often can not work for more than about two hours without significant increases in mistakes.

The last few years has seen huge growth and improvement in automated guidance systems. Most use digital cameras and image recognition software to work out where the crop rows are in relation to the hoe and then move the hoe or steer the tractor as required. Options vary from systems where the hoe and guidance system are tightly integrated, through to a machine that sits between the three point linkage and the hoe and moves the hoe relative to the tractor. The latter systems have the advantage that they can be used with any three point linkage machine, while all in one solutions can not.

On wide row, broad acre crops, set up for hoeing, a tractor which has centre articulated steering (e.g., Holder) allows the hoe to accurately follow the tractors path thus significantly reducing crop damage on corners and bends.

10.2.2. 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 or 'telescope unit' between the toolbar and weeding unit and a small depth wheel. While these are 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.

10.2.3. 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.

10.2.4. 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 3 shows a well designed 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 more a slicing action on the weeds, but also tends to encourage soil to flow along it and build up at the end of the blade in a ridge. In comparison the left-hand hoe in Figure 4 is badly designed. 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. If the crop is small this can bury it. The right-hand hoe in Figure 4 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 3. 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 4 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. Different types of hoes suit different crops.

Figure 3. Well designed hoe blade

Figure 4. Poorly designed hoe blades

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, they do not work well in stony conditions, they need a dryish soil to work well and clog up in damp soil. There are an increasing number of interrow machines that operate on different principles.

Figure 6. Basket weeder

Figure 5. Horizontal axis brush hoe

Figure 7. Vertical axis brush hoe

10.2.5. 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 6). 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 stones, trash and damp soil better than 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. Crop tunnels are useful for spreading crops, e.g., carrots and lettuce, or where soil spill is a problem. Standard baskets can not be adjusted for different row widths, however special baskets can. The time and cost of adjustment can be considerable and with the substantially higher price of adjustable baskets, in most cases having two or more machines permanently fixed at one setting is preferable to regularly adjusting one.

10.2.6. 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. Recent research has indicated the value of a small percentage of steel bristles to reduce soil build up in the brushes.

The horizontal axis weeder has a single horizontal shaft on which circular brushes are mounted (similar to the large brush on road sweepers) that fit between crop rows i.e., there are gaps in the brushes where the crop goes (Figure 5). 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 (Figure 7). 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 steer them.

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 more time consuming.

10.2.7. Rotovator (rotaryhoe) hoes

To clarify the 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. '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. 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.

10.2.8. 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 8. 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.

10.2.9. 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 10) 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.

Figure 8. Rolling cultivators

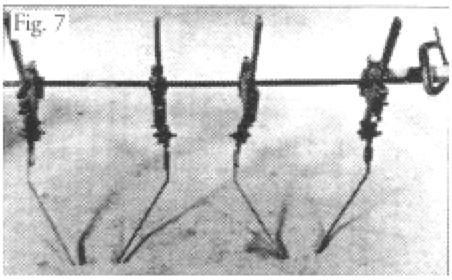

Figure 9. Torsion weeders

Figure 10. Potato weeder

10.2.10. 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 9), 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, purchase well proven and widely available machines before considering more unusual weeders.

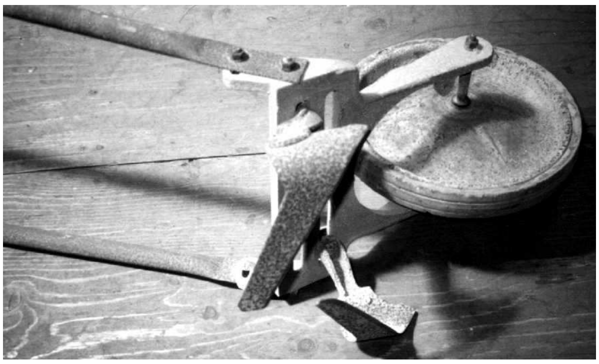

Figure 11. Hand push hoe

Figure 12. Perennial crop weeder

10.2.11. 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 11). 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 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.

10.2.12. Hand weeding

If all other aspects of weed management 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 mobile platforms are essential. These are normally mounted on a tractor, allowing workers to sit or lie down on cushions or slung fabric, 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.

10.2.13. Thermal weeders

Until recently most thermal weeders were based on gas powered burners. The best designs generally use ‘liquid’ rather than ‘gas’ phase burners as these are much less prone to pressure drops and incorporate a shroud or hood to retain heat and protect the flames from wind. In the last few years steam based machines of various types have been designed in New Zealand, Australia and Europe. Steam has a number of advantages over flame weeders in that steam is much more efficient at conducting heat, has better penetration into foliage, operates better in windy and wet conditions, is safer and some machines can be used to weed over plastic and even paper without causing damage.

10.3. Perennial crops

There are a number of perennial crops where weeds need to be managed 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 12) to powered heads with a more aggressive action.

11. Conclusion

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

12. Other sources of information

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New Zealand Guide to organics. Written by CRI scientists. www.guidetoorganics.com

OPENZ (Organic Products Exporters of NZ Inc.) Online Library. Organic info pack, organic management of weeds, organic pest and disease management, and organic soil management at www.organicsnewzealand.org.nz.

Organic Farming magazine (previously new farmer and grower) Published by the Soil Association in the UK. Dedicated to providing information of practical on farm use for commercial organic farmers and growers.

Organic Monitor provides strategic research & marketing consulting on the international organic food industry www.organicmonitor.com

Organic Pathways is a New Zealand organic web portal with organic market and industry directory www.organicpathways.co.nz

Organic trade services is an organic industry portal and news feed www.organicts.com

Soil and Health Assn. of N.Z. www.soil-health.org.nz

Soil Association Ltd. (UK) www.soilassociation.org

13. 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.