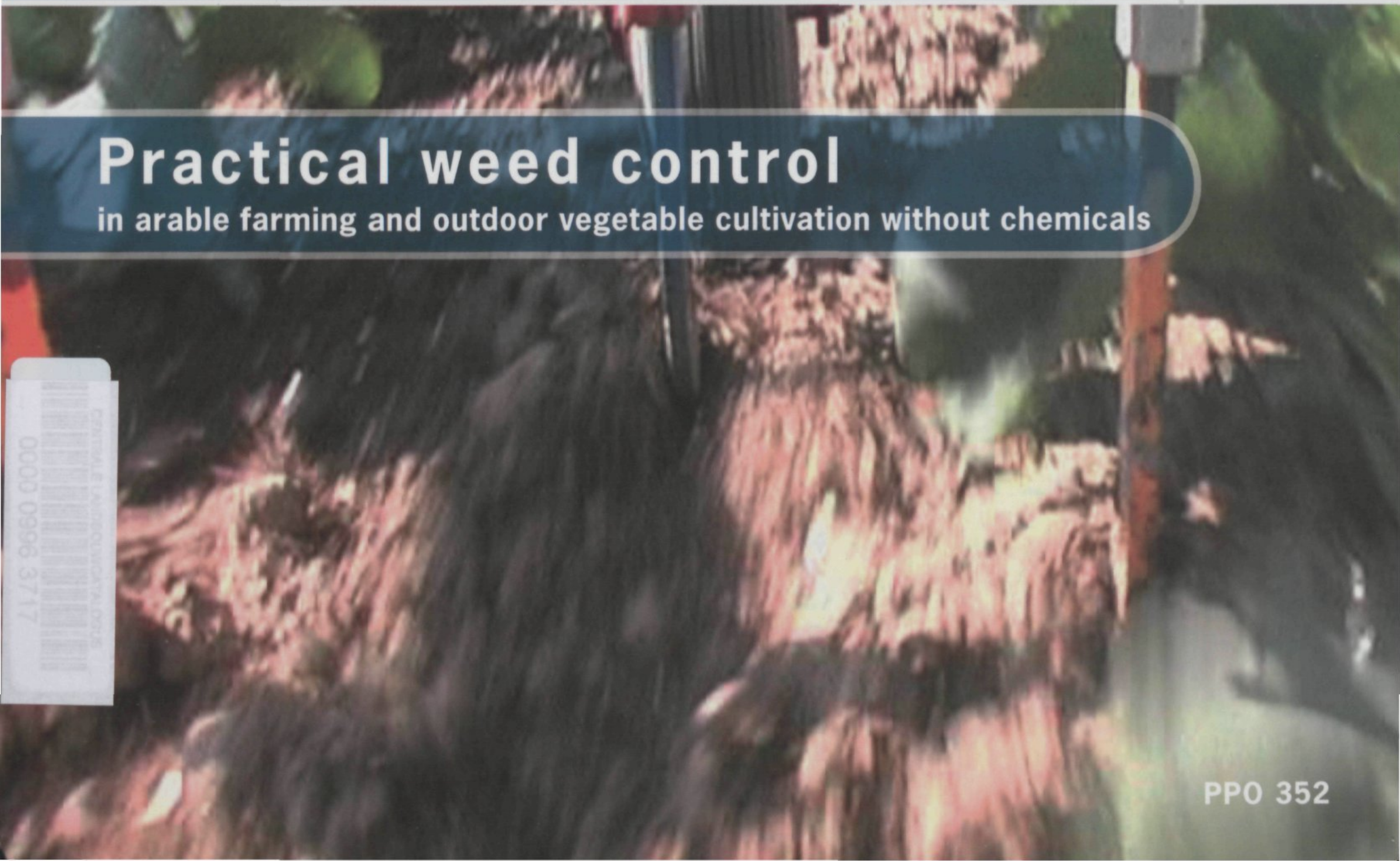
APPLIED PLANT RESEARCH

WAGENINGEN UR

Practical weed control

in arable farming and outdoor vegetable cultivation without chemicals



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Colophon

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Foreword

Arable farmers and outdoor-vegetable growers have always been confronted with the major problem of weed control in all their operations. Although the introduction of herbicides has resulted in a drastic reduction in the amount of labour involved in weed control the use of these chemicals have never rendered weed control a mere side-line activity. Moreover, the use of herbicides is accompanied by problems. Herbicides have a significant environmental impact, some weeds have developed a resistance to these chemicals, and their use has resulted in the selection of weeds that are tolerant of the standard herbicides used for specific crops. In addition, the cultivation of an increasingly number of minor crops is complicated by the lack of appropriate herbicides for the control of all weed species. In combination, these problems provide more than enough cause to give serious consideration to the opportunities for weed control that avoid the use of chemicals, and to the integration of these alternative methods in the farm's operations.

Organic farmers are confronted with much more complex weed control issues compared to control using herbicides and the management of the cultivation of their crops confronts them with much greater challenges. Weed control on an organic farm imposes stringent requirements in every facet of application: it requires professionalism, excellent organizational skills, a clear perception of the problem, and an explicit farm strategy. The strategic element relates to the approach adopted to control weeds, i.e. the selection of an appropriate crop-rotation cycle, the management of the fields – before, during and after the cultivation of the crops – and the development of an optimum approach for each type of crop. Or, in other words, it is necessary to know what the problem is, where the weeds need to be controlled, how the weeds are to be controlled, and which level of control is required.

Moreover farmers will not only wish to control weeds; they will also want to ensure a long-term reduction of the weed 'problem'.

The authors of this Manual have succeeded admirably in their endeavours to bring together the wide range of knowledge and experience of non-chemical weed control possessed by machinery manufacturers, entrepreneurs, researchers and consultants in a well-organized and concise manner that renders the information accessible to a wide readership.

In doing so they have made this knowledge and experience available to many organic and traditional farmers – farmers who will certainly be able to benefit from the information provided in this Manual. In addition, this publication offers the 'green' education sector a wealth of extremely useful information.

Consequently I can strongly recommend this Manual to everyone!

Frank Wijnands,
Cluster Leader, Organic Agriculture, Wageningen UR

Weed control without herbicides!

Which types of machinery are available? How do they work? Which crops can they be used for, and which settings are required?
Answers to these and other questions about non-chemical weed control are given in this 'Practical Weed-control' Farmer's Manual which brings the knowledge, experience and assessments of users, machinery specialists and researchers together in a form ideally suited to use by farmers and growers. The information is made available in an efficiently-structured and accessible manner.
This publication is based on a similar manual published in Switzerland. Daniel Baumann and Regula Bauermeister were primarily responsible for the content and layout of the original manual, '**Unkrautpraxis**' (published in German). This publication focused on horticultural crops. During the preparation of this publication Daniel Baumann and Regula Bauermeister worked closely with Piet Bleeker (PPO-Lelystad) and other experts.
In 2002 the Ministry of Agriculture, Nature Management and Food Quality's Research Programme Steering Committee issued an assignment for the preparation of a practical weed-control manual in the Dutch language. The content of 'Unkrautpraxis' was modified and was expanded to include arable crops. The next step to make this knowledge and experience available to the European agricultural community is this English edition of Practical weed control. The content of the Prevention and Weeds sections was also greatly expanded.

The Machinery Section was expanded to include the latest technology.

David van der Schans and Piet Bleeker.

Professional weed control

Are you looking for information about preventive measures, the dispersal of weeds and issues related to weeds, the appropriate approach for a specific crop, or about the principle used by a specific type of farm machinery? If so, selecting the appropriate tab will bring you to the information you need.
The **blue** section contains information about measures to impede or restrict weed development. These will enable you to retain control of the weed pressure, and the consistent implementation of these preventive measures will save you a great deal of time and money. The **green** section contains background information about the dispersal of weeds and the damage caused by weeds. This information will help you decide the priority you wish to assign to weed control when other issues also require your attention.
The **orange** section contains guidelines for weed control in a large number of arable and horticultural crops. The tabs offer you ready access to the information about the relevant crop group.
The most suitable type of farm machinery and the requisite settings are given for each crop group and each weed stage. The Machinery Section contains further specifications of the machinery and the necessary settings.
The **yellow** section contains a concise description of the types of machinery, including a paragraph on steering systems. This section contains a detailed description of the approach, uses and principle of each type of farm machinery, accompanied by a large number of illustrations. The concluding **brown** section contains the index.

PREVENTION

Preventive measures

A series of preventive measures can be implemented to restrict weed problems in the crop. Preparations for these measures will need to be made whilst planning the cropping, since the preventive measures are related to the other cultivation measures. The additional attention this requires will be recouped in the form of fewer weeding hours during the cultivation of the crop.

Measure	Notes	Effect
Choice of variety	Choose strongly-competitive varieties with a rapid initial development.	•
Planting rather than sowing	For example, onions: Sow 6 - 7 seeds in soil blocks. Plant at the 3 - 4 leaf stage.	•••
Prevent seed production	Prevent seed production by the weeds. Fields relatively free of weeds need to be kept weed-free. Use compost and manure that do not contain weed seeds.	•• ••
Choosing the field	Avoid using fields with a lot of weeds for weakly-competitive crops (such as carrots/onions). Avoid the use of fields with perennial weeds (such as thistles, common dock and couch grass) for the cultivation of perennial crops (such as green asparagus or perennial herbs).	••• •••
Preparing the seedbed	Till the soil using a method that turns the soil over (ploughing). Plan sufficient time for a false seedbed. Produce a suitable and level seedbed with a fine soil structure. This will simplify sowing, and will reduce the number of weed-control measures.	••• ••• •••
Crop sequence	Bare fallow fields will prove most effective on land with a high pressure of perennial weeds. Plan an extensive crop rotation including grass-clover and green manure crops. Alternate strongly-competitive crops with weakly-competitive crops.	••• •• •
Soil cover	Various types of mulch reduce weeds. Undersowing and intercropping suppress weeds.	••• •
Accurate sowing and planting	Tailor the sowing or planting of the crop to mechanical weed control. Use high-quality seed with a good germination capacity or high-quality plant material, and provide suitable water supplies. Keep uniform sowing depth and row distance.	•••
Growth of the crop	The competitive ability of the crop will increase with the rate of its development. For this reason it is important to till the soil carefully to ensure that the top soil is sufficiently loose and that the lower layer is sufficiently firm to anchor the seeds or plant material. In addition, the soil must contain sufficient fertilizer and moisture.	••

• = little effect •• = moderate effect ••• = great effect

One of the many benefits offered by appropriately-planned crop rotation is the suppression of weeds. The frequent occurrence of particular weed species is strongly related to the cultivation of specific groups of crops. Spring-germinating weeds are offered particularly favourable conditions in crops which are sown in the spring. Winter cereals sown in the autumn will encounter problems with other weed species.

The adoption of a wide crop-rotation cycle will result in a varied weed population which contains few weed species that have adapted to the individual crops. In a narrow crop rotation of monoculture the weed population will adapt to the crop(s) grown on the land. Although the weed population then consists of a restricted number of weed species these species will nevertheless proliferate rapidly. Narrowing the crop rotation promotes the number of problem weeds that have adapted well to the crops. The main effect achieved by crop rotation is the suppression of weeds by the cultivation of strongly-competitive crops alternating with weakly-competitive crops.

The number of weed seeds in soil used for the cultivation of a crop exhibiting a marked suppression of weed growth will generally decrease by between some 2 - 50% per annum, dependent on the weed species and the soil cultivation.

A successful long-term weed-control strategy is possible only by the inclusion of strongly-competitive crops alongside the weakly-competitive crops in the crop-rotation cycle. Crops exhibiting a marked suppression of weed growth include perennial ley, grass-clover, and green manure crops.

Strongly-competitive crops need to develop an appropriate homogenous soil cover. In addition, it is important to alternate the cultivation season by including autumn, spring and summer crops.

Spring-germinating seeds such as fat-hen, orache, redshank, field pennycress, and black nightshade develop in summer crops planted at a greater row width. In the absence of effective control methods weeds can proliferate at a tremendous rate in crops with a weakly-competitive initial development, such as carrots and onions. Weeds that form seeds can multiply very rapidly in potato and cereal crops (manual weeding is difficult). For this reason crop-rotation cycles need to allocate sufficient time before the cultivation of the crop, and between the crops, so as to offer an opportunity for a false seedbed and the cultivation of green manure crops.

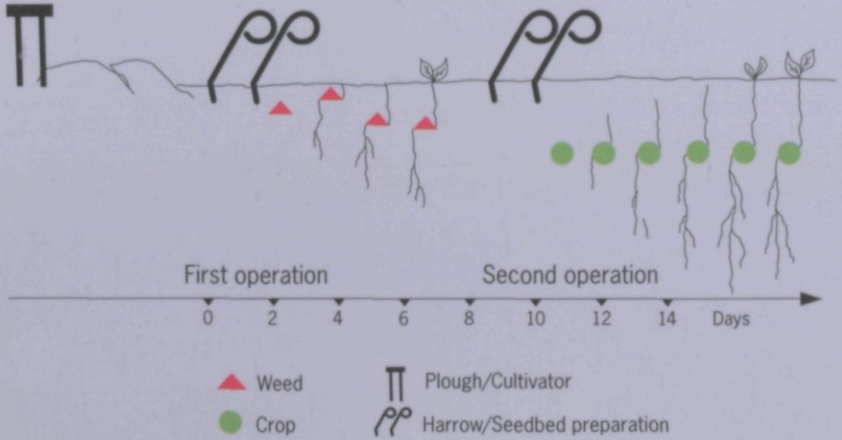
When cultivating perennial crops such as asparagus and rhubarb care needs to be taken to select a plot free of perennial weeds such as corn sow thistle, common dock and couch grass.

Crop rotation is important to prevent the development of problem weeds.

The thorough preparation of the seedbed, by means of what is referred to as a 'false seedbed', offers an excellent means of controlling germinating weeds before the crop is sown or planted. The false seedbed must be prepared at least ten days before the crop is sown or planted. Ploughing the soil encourages weed seeds to germinate. Harrowing machinery is then used to control germinating weeds prior to sowing or planting the crop; the soil should be cultivated as shallowly as possible, although this depends on the crop's sowing/planting depth. The cultivation depth should not exceed 2 cm, otherwise further weed seeds will be brought to the surface from deeper soil levels. When the soil conditions and the time permit then this procedure can be repeated several times prior to the establishment of the crop.

Preparation of a false seedbed.
Give consideration to the soil structure.

Measure:	**False seedbed**
Scope:	Sown and planted crops.
Machines:	Pasture harrow, chain-link harrow, full-field hoe, and other machines for the preparation of sowing and planting beds such as a rotary harrow.
Notes:	Restricted effect with soil temperatures below 10°C. Covering the machines used for the preparation of the final sowing or planting bed to exclude light can limit the further germination of weeds. Weed seeds that require light exposure will not germinate. Most weed seeds respond to exposure to light.



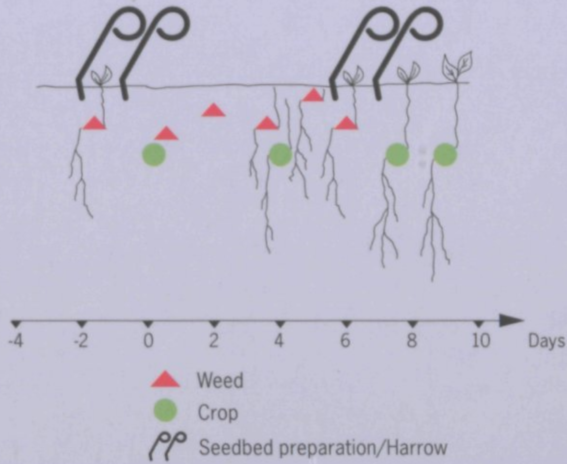
Harrowing between sowing and emergence

Harrowing during the period between sowing and the emergence of the shoots is feasible only when the germinating seeds of the crop are deeper than the harrow's cultivation depth.
In an ideal situation the crop is given an edge over weeds by sowing the seed in weed-free soil, preferably in combination with the preparation of a false seedbed. This method is effective in controlling both germinating weed seeds and weeds at the cotyledon stage. In blind harrowing the tines of the harrow are set parallel to the surface, with a cultivation depth of between 2 and 3 centimetres.

Difference between harrowing/ not harrowing between sowing and emergence.

Chain-link harrows are ideally suited for use between sowing and the emergence of peas.

Measure: **Blind harrowing**
Scope: Almost all sown crops.
Machines: Spring-tine harrow and chain-link harrow.
Notes: Fairly aggressive harrowing is possible with deep-sown crops such as beans, peas, sweet corn, and spinach. However, care is needed with shallow-sown crops such as spring-sown onions and sugar beet; in addition, the cultivation depth is of great importance.
Take special care with crops that germinate extremely rapidly!



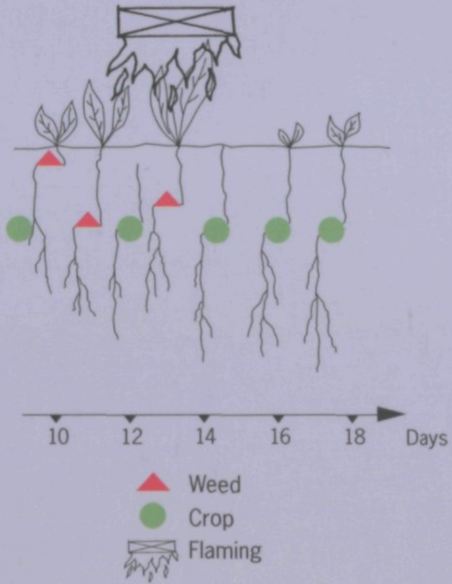
Flame weeding before the emergence of the shoots

Flame weeding before the emergence of the crop uses the same principle as blind harrowing. The correct time for flame weeding can be determined by covering small areas of soil with film or panes of glass ('sprouting windows'). In warm and humid weather these will need to be checked regularly from the fifth day, depending on the crop. The entire field must be flame weeded as soon as the first crop plants are visible in the sprouting window. Since the germination of crop plants can be irregular it will be necessary to carry out these tests in several locations. Flame weeding should be implemented only when weeds are present.

Pre-sprouting window used as an aid for flame weeding.

Flame weeding with spring-sown onions.

Measure:	**Flame weeding**
Scope:	Weakly-competitive crops with a long germination period, such as carrots, onions, beetroot and salsify.
Machines:	Flame weeder.
Notes:	Maximum sowing depth 3 cm.



The most vulnerable period for weed development is the period from planting or sowing until the achievement of soil cover >80 %. The risks and the costs are inversely proportional to the length of this period. Instead of sowing directly in the field the seeds are sown in trays and the plants are raised indoors. Planting instead of sowing reduces the duration of the vulnerable period by about a month. Transplanted crops require one-third of the hand-weeding hours needed for sown crops. However, planting is expensive, ranging from about € 1,500 for beet to some € 3,750 for spring-sown onion. As a result of the more rapid growth and better distribution of the plants fewer plants are required for a good yield.
Further optimization can be achieved by sowing spring-sown onions in small clusters rather than even sowing. It is then possible to hoe or flame weed in the crop rows. A system is being developed in which cluster sowing is combined with plant recognition and weed control in the crop rows.

Table 1. Remaining number of hand-weeding hours required per hectare after mechanical control (PPO-OBS experimental farm. Nagele, The Netherlands).

	Sown onion		Sugar beet	
	sown	soil block	sown	paper pot
1997	316	83		
1998	255	97		
1999	65	26	108	20
2000	96	30	32	18
2001			128	45

A number of examples in which the sowing or planting time can exert a great influence on the weed-control methods are:

- Any black-grass and mayweed plants in late-sown winter cereals (after 1 November) will still be small enough for control with (intensive) harrowing in the early spring. This is much more difficult with early sowing.
- Early crops of vining peas contain much lower numbers of black nightshade than later crops. Black nightshade germinates relatively late in the year.
- Fewer operations are necessary to keep late-sown green maize (10 - 15 May) free of weeds as compared to early-sown green maize (end of April). The number of operations can be reduced by about 25 %, and the final result of the control measures is better. This does not have any consequences for the yield of early maize varieties.
- On average, chitted potatoes achieve full ground cover two weeks earlier. This removes the need for one mechanical operation. In combination with late soil cultivation, sometimes avoids the need for any further mechanical control during the cultivation of the crop.
- Seed priming of carrot and chicory results in more rapid emergence, i.e. a few days. However, it is not clear whether a more rapid emergence is beneficial in situations in which flame weeding is used before crop emergence.

Undersowing with a living mulch covers the soil and suppress germinating weeds. It also serves as a bait crop for pests, and prevents the leaching of nitrates and suppresses weed growth after harvesting. The crop needs to be at a more advanced stage of growth with respect to the mulch crop. Undersowing can be used only with strongly-competitive crops such as (sweet) corn, sugar beet, cereals, cole crops, and leeks. The mulch crop should be sown at a time that it will not compete with the main crop. Competition with the main crop can result in a reduced yield and quality. The mulch crop is sown a number of weeks after the main crop has been sown or planted. A mixture of perennial ryegrass and white clover (200 - 300 gram per are) is a suitable undersow. After harvesting this winter-hardy undersow also protects the soil from erosion, nutrient leaching, and weed formation.

Leeks with clover undersow.

Late-germinating weeds unlikely to produce seeds can also be left as a living mulch. However, this is possible only when the weeds do not produce seeds. Undersowing also has a beneficial effect on pests; for example, field pennycress serves as a trap crop for flea beetles. Predator insects thrive in undergrowth.

Benefits:
- Improves the soil structure
- Trap crop for harmful insects
- Shelter, hibernation opportunity and alternative source of food for beneficial insects
- Protects from erosion
- Reduces nitrogen leaching

Take account of:
- Mutual competition
- The nematode control strategy and soil diseases
- Risk of weed growth and poor development of the undersow

Leeks can also be grown in mixed cropping with celery or turnip-rooted celery. Intercrops will cover the soil more quickly and thoroughly than leeks grown alone. Studies have revealed that the intercropping of leeks and celery results in a significant improvement in the suppression of weeds. The critical period is significantly shorter, and a smaller number of late-germinating weed species can flower and form seed as compared to the single-crop cultivation of leeks. Both crops are planted simultaneously and, for leeks and leaf celery, are also machine harvested at the same time.

Mulch impedes the emergence of weeds. Mulch also keeps the crop clean and dry, which is of particular importance to leaf crops that grow close to the ground, such as lettuce and strawberries.
In the past, non-ecological plastic films were often used for this purpose. These plastics consumed large amounts of energy during both their manufacture and disposal as waste. Nowadays mulch films such as paper and biodegradable plastic are available on the market. Natural materials such as straw, wood chippings and weed-free compost can also be used as mulch. In addition, dispersible and liquid mulch products are under development. The use of mulch products is profitable solely with perennial crops and those that yield high returns.

The application of mulch only in the crop rows will reduce the costs; mechanical weeding can be used between the rows.
Mulch effects on the temperature and moisture level of the soil. The temperature of the soil will be higher when covered by black plastic film as compared to a layer of chopped straw. The mulch will also exert an influence on the levels of minerals and moisture, depending on the type of soil and the season. Moreover the risk of damage caused by night frosts in the spring will be increased by using mulch. This risk is greatly dependent on the insulation effect of the specific mulch and the conditions.

Summary of the types of mulch available on the market.

Product	Material	Feasible uses	Advantages and disadvantages	
Various	Paper	Planted crops with little competitive strength and crops that need to be harvested in a 'clean' condition, such as strawberries, lettuce, and fennel.	+	No detrimental effects on the growth of the crop. Good suppression of weeds. Dry and clean product.
			-	Tears easily whilst being laid. Expensive. Rapid decay of edges inserted in the soil.
Biodegradable films	Natural starch or biodegradable plastic	As for paper; also suitable for gherkins, pumpkins and glasshouse crops.	+	No detrimental effects on the growth of the crop. Readily suited to laying using machines. Good suppression of weeds, clean product on harvesting. No disposal fees.
			-	Growth of weeds in plant holes. As expensive as PE film, but cheaper than paper. Can tear more readily than PE film.
Plastic film	PE-film	As for biodegradable films	+	As for biodegradable films, but with disposal fees.
			-	Not ecological. Costs of clearance and disposal. Growth of weeds in plant holes.

Compost	Weed-free compost or black soil	Layer of at least 3 cm required. Can be used once in crop-rotation cycles. In view of the use of minerals these materials are governed by the manure legislation.	+	No detrimental effect on the growth of crops. Has a fertilizing effect.
			-	In view of the presence of minerals the compost can also constitute an excellent growing medium for weeds when used for longer periods. A large quantity of minerals is applied. This can cause bottlenecks with respect to the manure legislation.
Chopped straw	Straw	Outdoor crops. Apply a thick layer of between 3-5 cm (15-18 tonnes straw/ha).	+	Easy to apply when the surface is still bare after planting (for example, bulb crops). Cheapest covering material (€1,750, inclusive of application and chopping).
			-	Retarded growth due to nitrogen capture and lower soil temperature. Increased risk of damage caused by night frosts. Second growth of cereals and, on occasion, weeds. Nitrogen capture after harvesting due to straw residues. Additional costs on disposal.
Animal Star	Straw	Dispersible granules for planted crops with little competitive strength and for sown crops (from the three-leaf stage).	+	Biodegradable. Weed suppression > 4 months. Metering possible. Simple to use.
			-	Can have a detrimental effect on the growth of the crop due to nitrogen capture; the soil remains cold for a longer period in the spring. Expensive (approx. € 5,000/ha). Nitrogen capture, also after ploughing under following harvesting.

Liquid products are currently under development. Liquid products offer the benefit of being able to treat a large surface within a relatively short period of time. However, the disadvantage is that they may not be sprayed over the plants.

WEEDS

When it is possible to make reliable estimation of the damage that weeds will cause to a crop it will be easier to establish whether the costs incurred in weed control will be outweighed by the lost income due to the reduced quantity and quality of the crop.

Weeds cause:

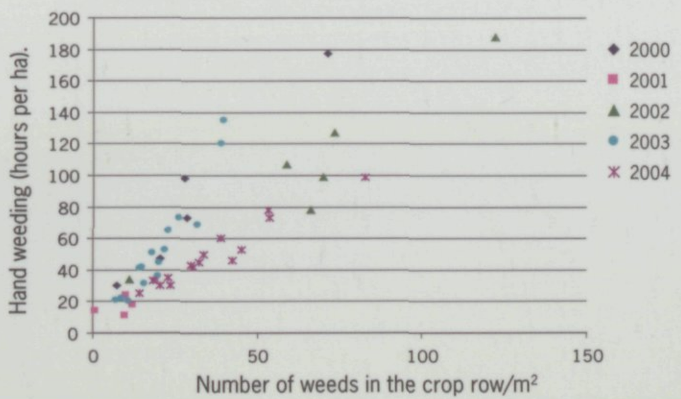
- Reduced yields due to:
  - competition for light, nutrients and water. These losses can reach 100%. The extent of the damage depends on:
    - the crop's growth phase at the time the competition begins
    - the crop's competitive ability
    - the weed species
    - the weed density
  - allelopathy: some weed species release chemicals that retard the germination and development of the crop
  - parasitic weeds (dodder lives on other plants)
  - multiplication of nematodes, diseases and pests
- Impediments to harvesting: for example, annual nettle in strawberries picked by hand; cleavers and bindweed when harvesting with a combine harvester and chopper
- Reduction of the quality of the harvested product
  - disease pressure due to the moist microclimate in the crop, for example with Botrytis
  - higher drying costs
  - toxic berries from black nightshade in processed peas or animal feeds such as green maize
  - contamination of crop seed by weed seeds
  - risk of rejection by processors

Crops that are overrun by weeds in an early phase and exhibit slow initial development, such as carrots and onions, can be entirely lost. Crops that have a lead since they have been planted or exhibit a rapid rate of development, such as maize and cereals, are much less susceptible to damage. The damage to these types of crops amounts to a maximum of between 10 and 40% of the yield.

Measures to prevent damage can be costly. When mechanical weeding is ineffective then the only remedy is hand weeding. With some crops this will be the largest cost.

There is a close relationship between the weed density in the crop rows and the number of hours of hand weeding required to control the weeds. The toleration of seed formation by weeds will result in additional weed-control costs in the future.

Relation between weed pressure and hand weeding (hours).



Germination period

Weed seeds germinate at different times of the year. A knowledge of the germination periods of the various weed species can help in predicting the effectiveness of weed-control measures.
Problems occur with those species that germinate and emerge during the period in which the crop is emerging and is still relatively open.
The following figure is based on a classification of the weed species according to their germination period. The weeds in Group 1 germinate throughout the year.
Consequently problems with these species often occur in the stubble.

The species in groups 2 and 3 germinate primarily in the autumn and early spring; they develop in crops that are sown in the autumn or early spring. Groups 4 and 5 germinate in the spring. Control of these species is of importance to crops that are sown or planted in the spring. The species in Group 6 are of particular importance to crops sown late in the spring.
The knowledge of the germination period can be used to assess whether the preparation of a false seedbed in a given period will be worthwhile. A false seedbed can be used to control only those weed species that germinate in that period.

Classification of groups of weed species according to their germination period:

Group 1: shepherd's purse, common chickweed, annual meadow-grass, groundsel, field penny-cress, crane's bill, speedwell, red deadnettle and common sow thistle

Group 2: black-grass, green field-speedwell and loose silkey-bent

Group 3: annual nettle, cleavers, mayweed and field pansy

Group 4: common orache, hempnettle and knotgrass

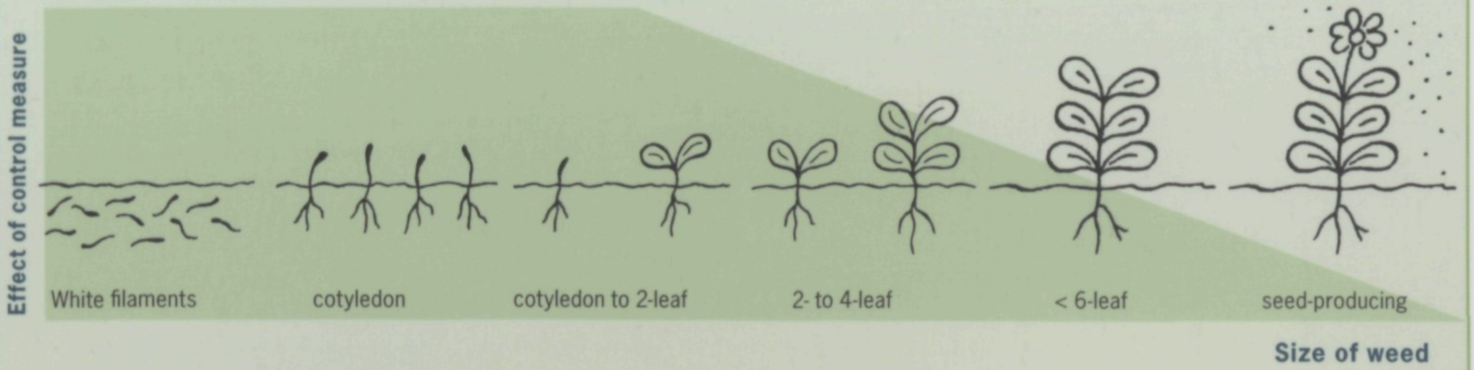
Group 5: fat-hen, redshank, pale persicaria and black bindweed

Group 6: black nightshade, smooth crabgrass, green bristlegrass, sun spurge and cock's foot

The effective control of weeds requires the adoption of cultivation measures focused on ensuring that the crop is always one step ahead of the weeds.
In general, the ease of controlling weeds is inversely proportional to their size. Almost all weed-control measures are more effective with weeds in the cotyledon phase. In addition, a number of measures can have sufficient effect on larger weeds with a maximum of four leaves.
A significant difference in the size of the crop and the weeds is of particular importance with control measures that also affect the crop, such as harrowing or soil cultivation using a finger weeder or torsion weeder. The larger crop plants are less susceptible to these forms of cultivation as compared to weeds in the cotyledon phase. Weeds at the cotyledon stage are much more susceptible to damage than weed plants at the two to four leaf stage. The most important factor determining the success of a control measure is the use of that measure whilst the weeds are still small.
Carry out the weed-control measure as soon as the crop can withstand the operation.

Rules of thumb

- The crop must always be one step ahead of the weeds.
- The smaller the weeds, the more effective the measure.



Seed production

Weeds must produce (virtually) no seeds if an increase in the weed population is to be avoided. Weed species that produce large quantities of seed must be controlled before they form viable seeds.
The seeds in unripe seed pods are often already viable.
The most seeds are produced by weeds that emerge early during the cultivation of the crop. Weeds that escape control will often grow to a very large size. Weeds that germinate later in the season will be suppressed by the crop, and will produce few seeds.

The following formula can be used to make a rough estimate of the seed production of small weeds:

$$\text{Number of seeds} = \frac{300 \times \text{dry weight of the weeds}}{\text{weight of 1000 seeds}}$$

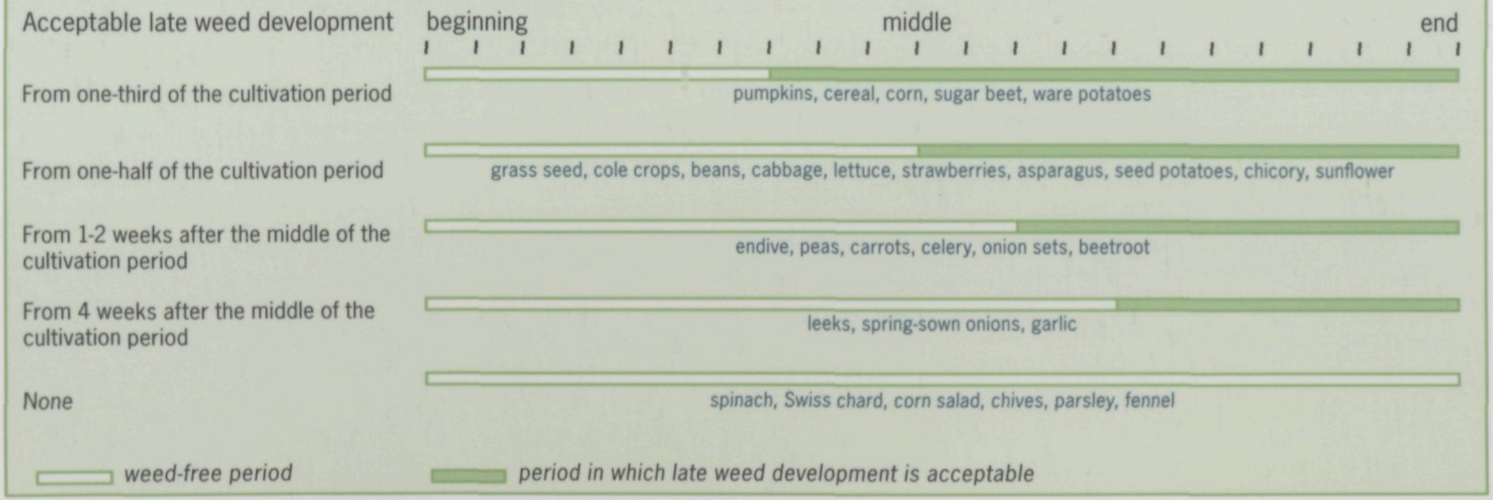
In addition, the seeds of species with a high seed weight possess more vitality as a result of their larger food reserves. This enables them to germinate and emerge from greater depths in the soil. They are also more difficult to control with mechanical weeding in comparison to species with a low seed weight.

Species	Max. seed production per plant (number/plant)	Weight of one thousand seeds (g)	Period of seed formation (month numbers)	Decline in number of viable seeds per annum (%)
Cock's foot	13,000	1.5	7, 8, 9	50
Shepherd's purse	40,000	0.1	5, 6, 7, 8, 9, 10	27
Mayweed	34,000	0.3	7, 8, 9, 10	10
Annual nettle	1,500	0.5	7, 8, 9, 10	
Groundsel	7,000	0.3	entire year	34
Speedwell	300	4.2	4, 5, 6	18
Fat-hen	500,000	0.7	7, 8, 9, 10	11
Redshank	800	2.7	7, 8, 9	
Annual meadow-grass	500	0.4	entire year	24
Knotgrass	200	2.7	7, 8, 9	16
Common chickweed	15,000	0.6	entire year	26
Black bindweed	1,000	5.0	7, 8, 9, 10	
Black nightshade	330,000	0.8	8, 9, 10	37

The period during which the field must be kept weed-free depends on the type of crop. In general it will be unnecessary to keep the field weed-free throughout the entire cropping period. It is important that the crop is kept free of weeds whilst the plants are young. Crops that develop rapidly do not give germinating weeds an opportunity to develop to a stage that they can damage the crop plants. However, it will be necessary to prevent the weeds from producing seeds. The requisite weed-free period is different for each type of crop, and depends on the crop's competitive ability.

In principle a weed-control programme during the first half of the cropping period will suffice. However, crops with only a low or moderate competitive ability will also need to be kept weed-free during the first two to four weeks after the mid-point of the cultivation period to prevent the weeds from producing seeds or from impeding the ripening and harvesting of the crop.
Leaf vegetables have stringent quality requirements and will need to be kept free of weeds throughout the cropping period.

When do weeds not cause significant damage?



Broad-leaved weeds

Weed species such as common chickweed, field penny-cress, black nightshade, redshank and fat-hen multiply only by the production of seed. They are weeds that flower once and do not have any underground storage organs; they usually live for one season.
Annual weeds must be controlled before they produce seeds.
Most species produce a large number of seeds. The seed's germination capacity varies greatly from species to species. The seeds of weeds that have relatively large and hard oil-containing seeds, such as black nightshade and redshank, can remain viable for decades.

Small seeds remain viable for between one to five years. The number of seeds in the top soil can increase greatly when weeds are able to produce seeds without disturbance. The cultivation of the soil continually brings new seeds to the surface. Most weed seeds in the top 2 cm of the soil are able to germinate. Larger seeds will be able to germinate from a greater depth than small seeds. Measures designed to exhaust the reserve of seeds in the soil include the control of weeds before they flower, the use of strongly-competitive crops in the crop sequence, shallow soil cultivation, and the repeated use of a false seedbed.

Fat-hen.

Redshank.

Mayweed.

Grasses

Seed-propagated grass weeds such as cock's foot, black-grass and silky apera are more difficult to control with mechanical weeding; the machines have difficulty in pulling on them, and they develop strong roots. They often germinate late in the season, as a result of which a false seedbed is ineffective. Many grass species grow quickly, since they germinate later in the season when temperatures are higher. They are extremely competitive. They must be detected and controlled in good time.

The growing point of grasses is located at or below the soil surface. As a result it is more protected than broad-leaved weeds. Consequently flame weeders are less effective on grasses.

Grass, clover and green manure crops can cause re-growth problems in a succeeding crop. Damage can be avoided by refraining from the use of ryegrass (in particular, Italian ryegrass), or by incorporating it into the soil in good time.

Black-grass

Meadowgrass.

Cock's foot.

Perennial weeds such as couch grass, creeping thistle, sow thistle, dock, field bindweed, creeping yellow cress and coltsfoot multiply primarily by vegetative growth. They also produce seeds that enable them to become established on new land. In addition, they can be introduced via planting material and machines. Seedlings are controlled using the same techniques as for annual weeds. When these seedlings are not controlled and their underground organs develop and they will then multiply by vegetative growth. The best time for control, depending on the species, is between one and three weeks after the emergence of the seedling and before they develop the underground organs. The smaller the underground storage organ, the more rapidly it will become exhausted. New shoots grow from the underground storage organs, using the carbohydrates stored there. The most effective manner to control perennial weeds is to bring underground organs to the surface to dessicate. The best weed-control approach for fields with a patchy weed distribution is to mark the locations with perennial weeds and then to control these weeds throughout the entire cultivation season.

Perennial weeds that are not controlled can multiply by a factor of ten in just one year. When the weeds are present on a field in large numbers the density can decline between 70 and 90% during a year in which the land is left bare fallow.

The opportunities for the effective control of perennial weeds in crops vary between the weed species and the types of crops. Control is most effective when the weeds are in active growth and are continually developing new shoots.

Couch grass grows throughout the year, provided that the soil temperature is above 10°C. This species can be controlled before sowing and after harvesting.

Corn sow thistle is active between the end of April and the end of July. The control measures must be implemented during this period, which usually coincides with the sowing, germination and development of the crop. Even when all new shoots developing in the crop are weeded every 14 days the number of weeds will only decline by 30%. Perennial weeds are much more difficult to control than annual weeds.

Sow thistle.

Creeping thistle.

Control options for perennial weeds

Cultivation duration sowing/planting	long early	long late	short early	short late	long (incl. winter) autumn
Crops	beets, ware potatoes, winter carrots, onion, celery, spring-sown cereals	headed cabbage, leeks, corn, pumpkins	peas, spinach, lettuce, cauliflower, broccoli	beans, endive, cauliflower, broccoli	cereals, grass seed
Couch grass	AM	BM/AM	AM	BM/AM	DC/AM
Corn sow/creeping thistle	DH	BM/DH/DC	DH/AM	WM/DC	DC
Coltsfoot	DH	BM/DH/DC	DH	BM	DC
Creeping yellow cress	DH	BM/DH	DH/AM	DH/AM	DC/AM
Common dock	DH/AM	BM/DH/AM	DH/AM	BM/DH/AM	DC/DH/AM
Bindweed species	DH/DC	BM/DH/DC	DH/AM	BM/DH/AM	DC

BM = *before cultivation, mechanical* AM = *after cultivation, mechanical* DC = *during cultivation, competition* DH = *during cultivation, hand*

Kvik-up rotary tooth cultivator lays couch grass rhizomes on the ground.

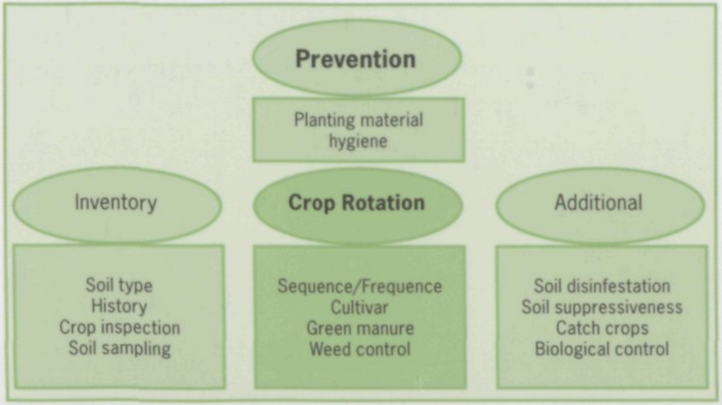
A rotary tiller is also able to lay rhizomes on the ground.

Weeds and nematodes

Some 1200 species of nematodes are present in the soil and waters of temperate Europe. About one hundred species of nematodes are harmful to plants. There are no means available to rectify visible damage caused by nematodes. Nematode populations develop slowly in comparison with insects and fungi, and actively distribute themselves to only a limited extent. *The farm operations need to include measures to reduce the risk* of infection and control the multiplication of harmful nematodes. The major elements of the nematode control strategy are shown in the following figure. This strategy is based on an inventory, i.e. 'knowing what you've got'. Sophisticated use of this knowledge can then be made in the crop-rotation plan, i.e. during the decision-making on issues such as the types of crops, varieties, the sequence, and the use of green manure crops.When it is not possible to find a solution then it will be necessary to implement supplementary measures to gain control of the nematode population.
Nematodes can multiply on both crop plants and weeds. Studies carried out by Plant Research International revealed that more than 164,000 Columbia root-knot nematodes (Meloidogyne chitwoodi) developed on one black nightshade with 20 grams of roots in just eight weeks.
The multiplication of a nematode species on a weed population depends on the weed species, the growing season, the growth duration, and the intensity of the root penetration. The effect of a carefully-considered crop-rotation cycle that limits the multiplication of nematodes can be nullified by the presence of a weed species that enables nematodes to multiply. An example is known in which carrots were damaged by the Northern root-knot nematode (Meloidogyne hapla), despite previously growing a cereal that did not promote the multiplication of this nematode species. In this example the problem was caused by broad-leaved weeds in the cereal crop. Re-growth of crop plants can also nullify the effect of crop-rotation. In addition to serving as a source of food, weeds can also be a source of viruses for virus-transmitting nematode species such as Trichodoridae, Longidorus and Xiphinema. Tobacco rattle virus (TRV), which can be transferred by Trichodoridae, can proliferate in weed species such as shepherd's purse, black nightshade, and common chickweed. Moreover this virus can be *dispersed further in the weed seed, and virus-free nematode populations* can become charged with the virus. Consequently poor weed control can, for example, be responsible for TRV in potatoes, notched leaf in gladioli, or rattle in tulips. Insufficient research has been carried out to provide a complete summary of the host-plant status of the various weed species for the most important nematode species.

For this reason the golden rule is: **always control weeds in good time!**

Diagram of the nematode control strategy.



Winter mortality plays an important role in the reduction of the nematode population. Weeds on fallow land that is not kept bare in the winter will enable many more nematodes to survive the winter than in bare soil.
The life cycle of a nematode varies from between four to more than eight weeks depending on the soil temperature and the growth rate of the crop. Clearing all weeds from the land every four weeks greatly retards or prevents the multiplication of nematodes via weeds (Meloidogyne). Free-living nematodes such as Trichodoridae and lesion nematodes only puncture roots or leave a dying plant and seek a new host plant.

Weed control can only retard their multiplication.
The mechanical control of larger weeds results in the slow death of the plants, as a result of which nematodes are able to survive for a longer period of time. Smaller weeds die more rapidly. Consequently regular weed control is required.

Or, in other words:
The nematode control strategy can achieve results only with effective weed control!

Gladioli re-growth results in the multiplication of Columbia root-knot nematodes.

Black nightshade results in the multiplication of Columbia root-knot nematodes.

Dispersal of weeds in manure

Weed seeds are distributed over arable land in the animal manure spread over the fields. The manure is contaminated with weed seeds via the litter in stalls, fodder (grass, green maize, and cereals), and in the raw materials used for concentrated feeds. A large number of weed seeds will be harvested together with green maize or grass grown in weed-infested fields. Organic cattle farms often use litter in the cattle sheds. Organic straw can be quite severely contaminated with weed seeds, whilst natural hay can contain seeds of undesirable plant species such as docks. This litter, together with fodder residues, passes directly into the manure. Farmers using animal manure need to know where the manure came from if they are to estimate the risk of introducing weed seeds on the land. Weed seeds can also be dispersed by the use of slurry.

Probability of survival of weeds in cattle feed and manure:

- Seeds lose their germination capacity on ensilage. After about 4 to 6 weeks the seeds of virtually all species will be dead at the centre of the silage heap.
- Concentrated feed is usually ground and pressed. 60-75% of the seeds of common amaranth do not survive this process.
  Extracted soymeal undergoes a heat process. This process is fatal for all seeds.
- The fatality rate on the passage of seeds through an animal's digestive system ranges between 70% and 95%.
- The survival of weed seeds in slurry depends on the weed species, the storage period, and the temperature. Virtually all seeds will be dead after eight weeks at 10°C. At 4°C this is achieved after sixteen weeks. The extent to which weed seeds can survive in solid manure is not known.
- The germination capacity of weed seeds is also diminished by the fermentation, composting or drying of manure.

Methods to limit the spread of weed seeds:

- Keep feed crops free of weeds.
- Keep silage closed for at least six weeks after ensilage.
- Use weed-free litter.
- Store manure for at least eight weeks before applying it to the land.
- Compost solid manure.

In practice, some cattle farmers devote extra attention to ensuring straw and natural hay are weed free. In some instances the manure is composted to prevent the introduction or spread of docks on pastures.

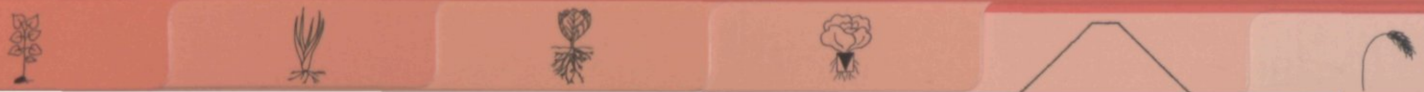
New weed species can be introduced with manure.

CROPS

The type of farm machinery deployed depends on the type of the crop and the size of the weeds.
This Section reviews farm machinery that works the soil within the plant rows. No attention is given to the control of weeds growing between the crop rows. This issue is discussed in the farm machinery section.
The crops are classified into six groups.
A diagram of a weeding strategy is given for each group.
Research and practical experience have demonstrated that the following strategies are effective in controlling weeds.
The choice of the farm machinery and the settings depends on a number of factors.

Specific crop, farm, field and weather factors all play a major role, and will in turn require specific adjustments to the settings. A lot of experience is needed for some soil cultivation methods. These are indicated by a triangle containing an exclamation mark. Detailed information about the machinery and the settings is given in the next Section. The following tables include references to issues such as the method, the requirements imposed on the sowing or planting bed, and the suitability for use in various crops.
The following classification into groups of crops has been drawn up for the purposes of the discussion of the various strategies. Potatoes and sown crops grown using ridge cultivation are discussed separately.

Sown – large seeds widely-spaced in the rows	Sown – small seeds narrowly-spaced in the rows	Planted – vertical growth	Planted – low lateral growth	Ridge cultivation	Cereals and grass seeds
Beans	Carrots	Broccoli	Endive	Potatoes	Grass seed
Peas	Chicory	Brussels sprout	Chines cabbage		Spring-sown cereals
Maize	Onions	Cauliflower	Fennel	Carrot	Winter cereals
Pumpkin	Red beet	Curly kale	Lettuce	Chicory	
Sugar beet	Spinach	Leek	Module onion		
Sunflower		Leaf-turnip/rooted celery	Onion sets		
		Red cabbage	Strawberry		
		Savoy cabbage			
		White cabbage			



Explanation of drawings

Crop	Weed	Machinery	Setting
Precision sowing > 3 cm deep	White filaments	Harrow	Harrow tines, angle forward
Plant rooted 1 - 4 leaves	cotyledon	Finger weeder Torsion weeder	Weeder elements separated
4 - 6 leaves 20 cm height	cotyledon to 2 - leaf	Pneumat	Weeder elements against each other - overlap
> 60% soil cover	2 - 4 leaves	Ridger	Hoeing, slight ridging
	6 leaves	Hand weeding	[1] Risk of covering small crop-plants
	Flowering and seed-bearing		[2] Finger/torsion weeder on hard soil: take care with cultivation depth
			[3] High ridges for sunflower and maize Low ridges for pulses, beets, etc.

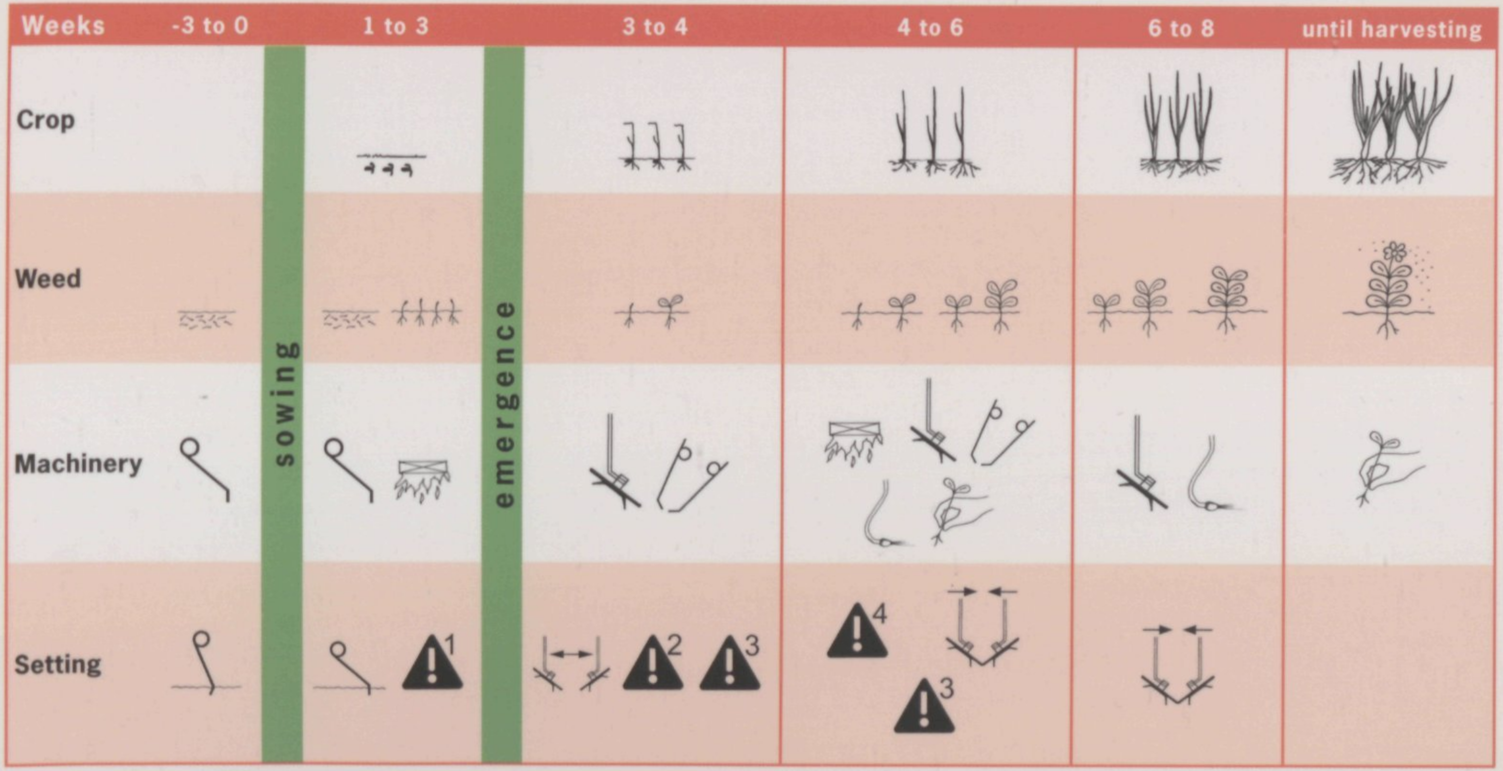
Sown – large seeds – widely-spaced in the rows (beans, maize, peas, pumpkin, sugar beet and sunflower)

Weeks	-3 to 0		1 to 2		3 to 5	to 60% soil cover	until harvesting
Crop		sowing		emergence			
Weed							
Machinery							
Setting					⚠[1]	⚠[2] ⚠[3]	

Explanation of drawings

Crop	Weed	Machinery	Setting
Germination	White filaments	Harrow	Harrow tines, angle forward
cotyledon	cotyledon	Finger weeder Torsion weeder	Harrow tines at vertical setting
1 - 3 leaves	cotyledon to 2 - leaf	Pneumat	Weeder elements separated
3 - 5 leaves	2 - 4 leaves	Flame weeding	Weeder elements against each other - overlap
30-100% soil cover	6 leaves	Hand weeding	⚠1 Harrow as shallow as possible, above sowing depth
	Flowering and seed-bearing		⚠2 With small crops and loose soil elements approx. 1 cm apart
			⚠3 With small crops and crust formation drive slowly and use discs
			⚠4 Flame weeding in the crop solely for onion and chicory (onion 4 - 6 leaves and chicory 3 - 4 leaves). Results in reduced yield.

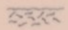
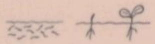
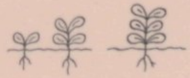
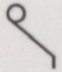
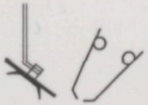
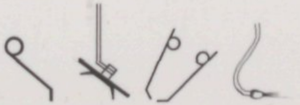
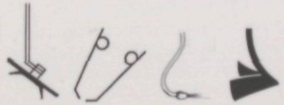
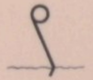
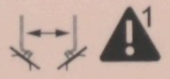
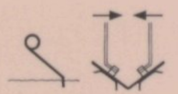
Sown – small seeds – narrowly-spaced in the row (chicory, carrot, onion, redbeet, spinach)



Explanation of drawings

Crop	Weed	Machinery	Setting
Tray plants	White filaments	Harrow	Harrow tines, angle forward
Rooted plant	cotyledon	Finger weeder Torsion weeder	Harrow tines at vertical setting
Diameter 5 - 20 cm	cotyledon to 2 - leaf	Pneumat	Weeder elements separated
> 30% row distance closed	2 - 4 leaves	Ridger	Weeder elements against each other - overlap
	4 - 6 leaves	Hand weeding	Pronounced ridging
	Flowering and seed-bearing		1 When the plants are not yet rooted and weeds germinate. Do not contact the plants!

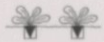
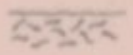
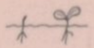
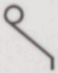
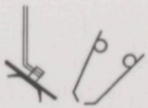
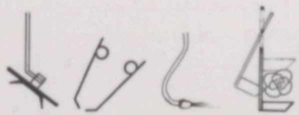
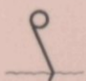
Planted – vertical growth (broccoli, Brussels sprouts, cauliflower, celery, curly kale, leeks, red cabbage, Savoy cabbage, white cabbage)

Weeks	-3 to 0		1	2 to 3	3 to 4	until harvesting
Crop						
Weed		planting				
Machinery						
Setting						

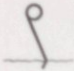
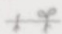
Explanation of drawings

Crop	Weed	Machinery	Setting
Module plants/ soil blocks	White filaments	Harrow	Harrow tines, angle forward
Rooted plant to 20 cm diameter	cotyledon to 2 - leaf	Finger weeder Torsion weeder	Weeder elements separated
> 50% row distance closed	2 - 4 leaves	Pneumat	Weeder elements against each other - overlap
	Flowering and seed-bearing	Intra-row weeder	⚠ 1 When the plants have not yet rooted. Do not contact the plants!
		Hand weeding	⚠ 2 When using a Pneumat make sure that soil is not blown into the plant's heart!

Planted – low lateral growth (Chinese cabbage, endive, fennel, lettuce, module onion, onion sets, strawberry)

Weeks	-3 to 0		1	2 to 5	until harvesting
Crop		planting			
Weed					
Machinery					
Setting					

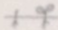
Explanation of drawings

Crop	Weed	Machinery	Setting
 Potato sprouted	 White filaments	 Harrow	 Harrow tines, angle forward
 Emergence	 cotyledon to 2 - leaf	 Finger weeder	 Weeder elements against each other - overlap
 Foliage crown 15 cm diameter	 2 - 4 leaves	 Ridgers	⚠ 1 On clay soils ridge when plant emerges
 70% soil cover	 Flowering and seed-bearing	 Rotary cultivator	⚠ 2 Alternating harrowing smooth and ridging, repeat with newly emerged weeds
		 Angle hoe	⚠ 3 Ridge up to cover weeds on the ridge
		 Hand weeding	

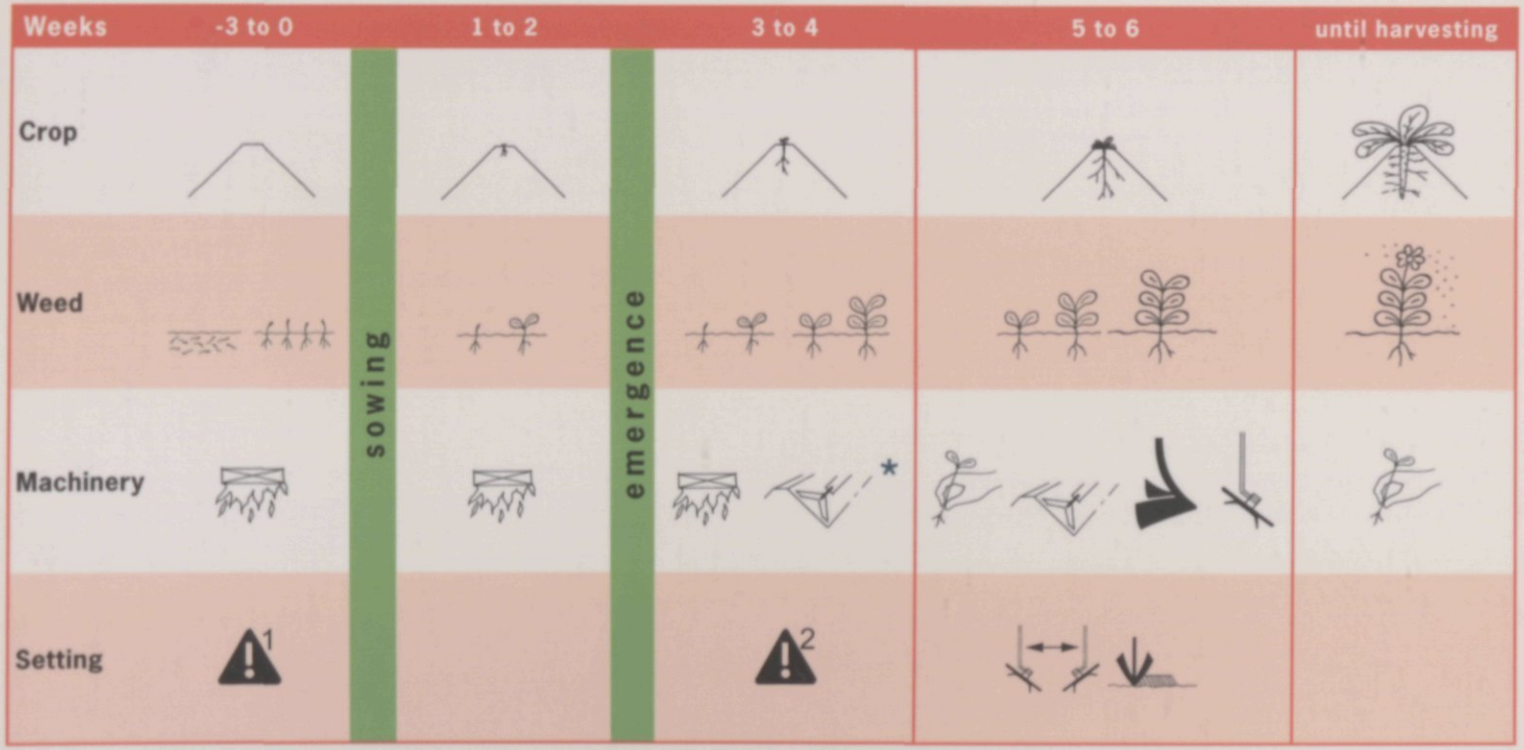
Ridge cultivation (potatoes)

Weeks	-3 to 0		1 to 4			4 to 5	5 to 7	until harvesting
Crop		planting and slight ridging			emergence			
Weed								
Machinery			Clay	Sand				
Setting			1	2			3	

Explanation of drawings

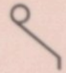
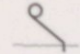
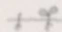
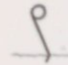
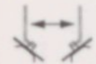
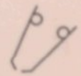
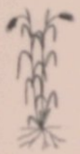
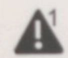
Crop		Weed		Machinery		Setting	
	Ridge cultivation		White filaments		Flame weeding		
	Germination		cotyledon		Ridgers		Ridge slightly
	cotyledon through 4 leaves		cotyledon to 2 - leaf		Angle hoe		
	6 leaves to 40% cover		2 - 4 leaves		Finger weeder		Weeder elements separated
	40% cover ready for harvesting		6 leaves		Hand weeding		
			Flowering and seed-bearing				Only with high weed pressure
							Emergency measure: results in reduced yield

Ridge cultivation (carrots, chicory)



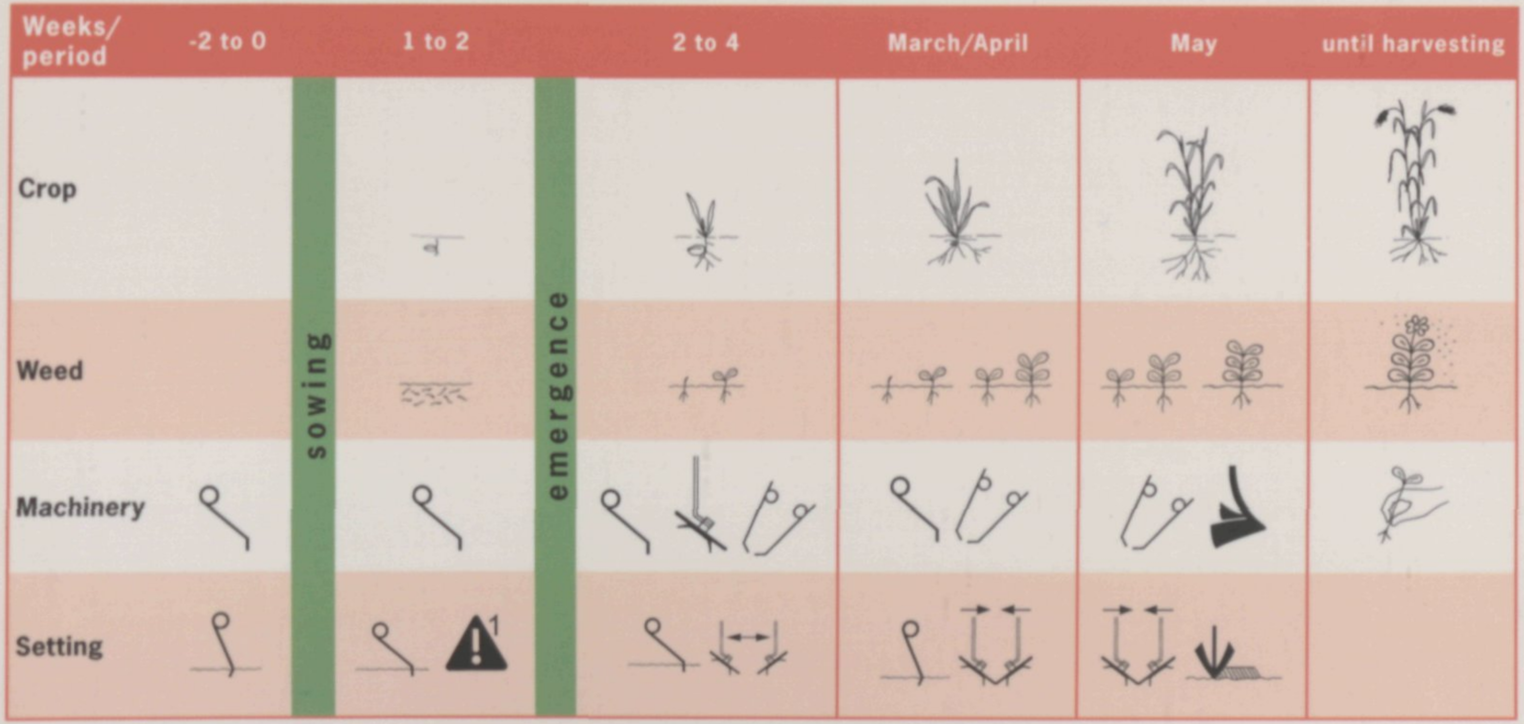
*On light soil discs can also be used instead of angle hoes.

Explanation of drawings

Crop		Weed		Machinery		Setting	
	Germination		White filaments		Harrow		Harrow tines at vertical setting
	2 - 4 leaves		cotyledon to 2 - leaf		Finger weeder		Harrow tines, angle forward
							Weeder elements separated
	End og tilling		2 - 4 leaves		Torsion weeder		Weeder elements against each other - overlap
	Seed heads start to form		6 leaves		Ridgers		Ridge slightly
	Ripening		Flowering and seed-bearing		Hand weeding		Shallow, preferably chain-link harrow

Mechanical weed control is effective with these crops with a row spacing of 25 cm or more.

Cereals (winter and spring-sown) and grass seed



Sow winter cereals late in the season so that the risk of weed development before the winter is small.
Sow spring-sown cereals as early as possible to ensure that the crop has an edge on weeds that germinate early in the spring.

FARM MACHINERY

Bury crop residues and prevent re-growth of the preceding crop.
Good ploughing is the best form of tillage for covering residues of the preceding crop.

Weeding can start when the crop rows are just visible and the weeds have begun to germinate. The smaller the weeds, the better the result.

The sowing or planting bed must be level, finely-textured, and loose. Uneven, coarse, heavy, hardened or compacted soil will greatly complicate mechanical weed control.

Only cultivate only the top centimetres of the soil. The shallower the cultivation, the fewer the number of weed seeds that will germinate and emerge after cultivation.

Whenever possible cultivate the soil in dry conditions. Dry conditions followed by drying weather will prevent the re-growth of weeds.

With many weed seeds a brief exposure to light will initiate germination. Soil cultivation results in this exposure. Covering machinery exclude light when preparing the seed or plant bed couldl result in a 30–70 percent reduction in the number of weed seeds that germinate.

Hoeing closer to the crop row will keep a larger area free of weeds.

For example: weeding 1 cm closer to the crop row in onion with a row spacing of 25 cm keeps another 6.5 % of the area free of weeds.
This will save between 10 and 30 hours weeding per ha. Consequently a system that can be steered accurately in combination with the maximum hoeing width and a slower tractor speed will readily result in savings!

It is simpler to cultivate narrower uncultivated strips in the crop row with intra-row weeders.
Good maintenance and accurate adjustments of sowing and planting machines are essential to achieve a uniform distance between the crop rows.

A clear view of the machinery. This is only possible with a toolbar with a lifting or front-mounted cultivator or suspension between the tractor's axles. A steering system is required for rear-mounted cultivators.

With some crops a small loss of plants through the use of weeders in the crop row will be unavoidable. This loss can be compensated by increasing the planting number by between 2 to 5 percent.

In general: **the aggressiveness of the soil cultivation on the weeds increases with the tractor speed – however, this is also true for the effect on the crop.**

Weed control in the row of crop plants constitutes a challenge. In favourable conditions a spring-tine harrow or a chain-link harrow can be used to control germinating weeds in some crops.
Several crops incur little or no damage from harrowing after the emergence. However, at some point during cultivation all crops will suffer damage from harrowing. Hoeing between the crop rows will then need to be combined with weeders in the rows. These are available on the market in many versions. The best known are finger weeders and torsion weeders. Ridging also uproots or covers weeds in the rows.
Intra-row weeders are effective solely against small weeds.

The crop plants need to have an edge on the weeds: planted crops will, by definition, be ahead of the weeds. Intra-row weeders can be deployed both very effectively and early during the cultivation of these crops.
With sown crops the success of intra-row soil cultivation will depend on the effectiveness of earlier soil-cultivation operations and the rate of growth of the young crop.
A continually increasing number of intra-row weeders are being introduced on the market. The following sections discuss these innovations and review their advantages and disadvantages in comparison with finger and torsion weeders.

Torsion weeder in spring-sown onions.

Finger weeder in broccoli.

'Radis' intra-row weeder in iceberg lettuce.

Mechanical weed control is relatively simple between the crop rows. In general, this is carried out using hoes mounted on a toolbar. The width of the toolbar and the number of hoe blades depends on the width of the working passage and on the row spacing of the planting or sowing machine. The knack lies in hoeing as close as possible to the crop rows without damaging the crop. The distance between the crop rows and the precise control of the machinery determines the width of the hoes. Some disturbance will occur in the plant rows with of crust formation and high tractor speeds.

Hoe in winter wheat.

The hoes mounted on the toolbar can be either rigid blades or spring tines (vibrating hoe). A number of hoes can be fitted between two rows when the distance between the rows is 25 cm or more. The major benefit offered by this approach is the continually variable hoeing width. Together with the working width of the hoes between the crop rows, the soil cultivation achieved with the hoes is also of importance. The ideal hoeing depth is 1 to 2 cm.
Rigid hoes cut off the weeds, and cultivate the soil to a minimum extent. Vibrating hoes cultivate the soil to a greater extent and create a germination bed for further weeds. The soil will be aggressively cultivated at high tractor speeds. A sharp, rigid hoe will result in the least cultivation of the soil when used at a tractor speed of about 6 km per hour.
Mounting the hoes on a parallelogram ensures that they follow the soil contours closely. The most uniform hoeing depth can be achieved with a minimum distance between the hoe and the rotor wheels. The location of the toolbars relative to the tractor and steering systems are discussed in a separate section. In addition to hoes, rotary tine cultivators (weed-fix), roller-type hoes, inter-row rotary cultivators (for large weeds), brush weeders or inter-row weed flamers can also be used.

Risk of the spread of pests and diseases

Mechanical weed control can have both a positive and a negative effect on pests and diseases. However, there is little research data available that proves these effects. Of the many trials carried out with various forms of mechanical weed control only four had sufficient disease present for the measurement of an effect. These trials revealed that injuries caused to lettuce and strawberries by *Sclerotinia spp.*, *Botrytis spp.* and *Phytophthora spp.* were not exacerbated by mechanical control. In fact, mechanical control appeared to have a slightly beneficial effect on Sclerotinia.

Organic growers state one benefit of mechanical weed control is a reduction of cabbage root fly and fungal diseases, since the soil cultivation results in a more open and less moist crop.

Growers have great concerns about infections and the dispersal of diseases.

Concerns about the possible spread of fungal and bacterial diseases in potato and onion crops is often cited as a reason for refraining from mechanical cultivation in crops. Often these concerns are unjustified. Most diseases develop only a considerable time after mechanical weed control operations. Weed control is carried out in relatively dry conditions, conditions which are unfavourable for the dispersal of diseases. Many diseases do not require injured tissue for infection. Often they are dispersed much more efficiently by methods other than via mechanical equipment.

Lettuce leaves, which are large and lie on the soil, offer an ideal location for the development of Sclerotinia.

Cultivating the soil reduces the incidence of Sclerotinia infections.

Mechanical weed control and night-frost damage

Examples have been documented in which frost damage occurred in the exact areas in which potatoes had been hoed shortly before the frost. These examples increase growers' concerns about the possible detrimental effects of mechanical cultivation on their crops. These incidents limit the procedures used in practice.

However, a number of considerations are of importance:

- Night-frost damage caused by loose top soil occurs only on nights in which there is a great deal of outgoing radiation and little turbulence.
- An insulating layer of weeds has the same insulation effect as a layer of loose soil. Consequently fruit growers keep the soil bare.
- Allowing the soil to settle for a few days, or a shower of rain, will negate the increased risk of frost damage since the soil once again closes up and conducts heat.
- Hoeing and harrowing cause a slightly increased risk in comparison with ridging, which immediately compacts the soil again. Research has confirmed that the latter does not result in an additional risk.

Left, cultivated and with frost damage; right, uncultivated and no frost damage.

In addition to soil cultivation, the type of soil and the moisture supply can also result in great differences in night-frost damage.


Spring-tine harrow in green maize.


The 1.5 m-wide sections follow the surface contours closely, and can be adjusted separately.


Chain-link harrow, harrowing between sowing and emergence.

Principle	Uproots seedling weed and covers them with a thin layer of soil.
Requirements imposed on sowing/ planting bed	- level, medium-fine to fine, no large clods or clumps of grass. - suitable for all types of soil.
Row spacing	Independent of the row spacing.
Effect in the row/ridging	- spring-tine harrow: reasonable to good. - chain-link harrow: reasonable to good with first soil cultivation before emergence and small crop plants. Risk of crop damage with larger crop plants.
Optimum weed stage	Cotyledon to 2-leaf, very little effect on clumps of grass and perennial weeds.
Optimum crop size	- between sowing and emergence of the crop. The cultivation depth must be less than the sowing depth. - well-rooted crop plants: in general, from the 2-leaf stage. Risk of crop damage, in particular with broad-leaved crops. - transplanted crops must be allowed an opportunity to become established. - with properly planted module plants soil cultivation can begin shortly after planting.

Suitable for use with the following crops	Beans, celery, cereals, cole varieties, grass seed, green maize, leeks, potatoes, sown onions, spinach and sweet corn.
Capacity	2.5 ha per hour with a 6-metre working width. Working widths of up to 24 metres are possible.
Speed	3 - 12 km per hour.
Settings	The effect of chain-link harrows is, determined primarily by the tractor speed depending on the soil, crop and the weeds. The best working depth for chain-link harrows is 2 to 3 cm. This can be set by the adjustment of the harrow's support wheels. Shallow harrowing is of great importance to restrict the germination of further weed seeds. The effect can be varied by adjusting the angle of the tines. Usually the best result will be obtained with tines angled slightly forwards. The aggressiveness of the cultivation is in part determined by the tractor speed. While harrowing pay attention to the working depth and the effect on the crop. The aggressiveness (tractor speed) must be adjusted to the crop. Harrowing almost always results in the loss of plants (2 - 5 percent). Take account of this loss when sowing or planting the crop.  **Harrow tines vertical** Less aggressive cultivation. The risk of following the crop row is often slightly increased, as a result of which there is an increased risk of crop damage.  **Harrow tines angle forward** Usually the best result will be obtained with the tines angled slightly forwards. The forward angle of the tines can be increased or decreased as required for the soil, weeds and crop.
Soil requirements	The soil must not be too wet, and must be readily suited to cultivation. When the soil is compacted hoeing followed immediately by harrowing can result in a substantial improvement in the weed control within the crop rows. These soil-cultivation methods can be combined in a single operation.
Combination with other machinery	Hoeing in combination with harrowing can result in a substantial improvement of the overall weed-control effect. The weeds are uprooted more easily, and the risk of weed re-growth is reduced since less soil remains on their roots.
Crop damage	Prevent small crop plants from becoming covered with soil. Excessively deep harrowing can result in crop damage. Crops with broad leaves are exposed to greater risk.


Hoe beam with parallelograms and hoe blades.


Accessory for ridging with a hoe.

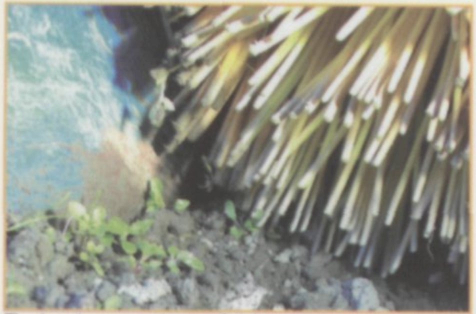

Hoeing/ridging controls small weeds in the crop rows.

Principle	Cuts off weeds 1 to 2 cm below the surface. When used in combination with ridging plates loose soil can be move into the crop row to cover small weeds.
Requirements imposed on sowing/planting bed	Level, loose and moderately fine soil. Fitting discs or tunnel plates will protect small crop plants.
Row spacing	From 15 cm, select hoes compatible with the row spacing.
Effect in the row/ridging	At higher tractor speeds (> 3 km per hour) duckfoot hoes will, result in a slight ridging effect, depending on the speed and the soil.
Optimum weed stage	Cotyledon to 4-leaf plant; also effective against large well-rooted weeds and grasses.
Optimum crop size	Use discs of tunnel blades to protect crop plants in the cotyledon to 4-leaf stages. Then continue until the crop plants are damaged or the crop covers the soil completely.
Suitable for use with the following crops	All crops sown or planted in rows with a row spacing of 15 cm upwards.
Capacity	Depending on the crop, working width and tractor speed. Ranges between 0.5 and 2 ha per hour.

Speed	4 - 7 km per hour. With steering system up to 15 km per hour.
Settings	Sharp blades. With light soils use a low pressure on the parallelogram. The spring pressure required to retain the hoe at the requisite depth increases with the heaviness of the soil. Adjust the spring tension to the soil structure. The available settings of the spring depend on the type of parallelogram.  The spring tension can be used to adjust the pressure of the parallelogram against the implement.  The optimum working depth of hoes is 1 to 2 centimetres. The depth of the hoes can be adjusted relative to the rotor wheels.
Soil requirements	Fairly dry soil. Put off hoeing when the soil sticks to the hoes. The hoes will have difficulty penetrating heavy, capped dry soil. In such instances begin whilst the soil is still moist.
Combination with other machinery	Finger weeder, torsion weeder, harrow, ridger, crumbler, etc.
Crop damage	- By soil covering. Covering is a risk with small crop plants when high tractor speeds are used in combination with slight ridging. Use protection discs or tunnels. - Prevent damage to the roots by shallow hoeing carried out in good time. With regular hoeing roots will not grow in the shallow top layer of loose soil.
Ridge cultivation	Angle hoes. Special hoe implements are available with guide wheels which can be used to hoe along the ridges.  Late ridging clears up a lot of weeds.  Angle hoes for ridge cultivation.

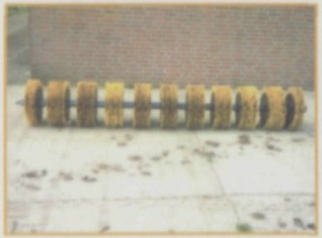
Brush weeder for use between the crop rows.

Crop-protection tunnel.



The brushes uproot superficial weeds.

Principle	Uproots and weeds shallowly.
Requirements imposed on sowing/planting bed	A level sowing or planting bed, since the brushes do not follow the soil contours independently of each other.
Row spacing	- 25 - 75 cm. - use a different brush set for each row spacing.
Effect in the row/ridging	Slight ridging can be achieved by slightly raising the crop-protection tunnels a little. This is possible with larger crop plants.
Optimum weed stage	Cotyledon to 4-leaf stage.
Optimum crop size	When using a crop-protection tunnel, from the seedling stage and until the cultivation causes damage to the crop.
Suitable for use with the following crops	All crops sown or planted in rows from a row spacing of 25 cm width.
Capacity	0.5 to 1 ha per hour.

Speed	2 - 4 km per hour.
Settings	The brushes have a fixed width. Changing the brushes is difficult. Consequently a different brush set will be required for crops with a different row spacing. Larger crop-protection tunnels will be required to be able to work near the rows of large crop plants. The brushes should rotate only slightly faster than the tractor speed, otherwise too much dust will be generated. A higher rotational speed will not improve the effect; however, the bristles will wear more rapidly, and the risk of collapse will increase.  Set of brushes for each row spacing which can be changed in their entirety.  Brush weeders can also be used for fairly large crop plants.
Soil requirements	The soil must not be too hard or too fine. When the soil is too hard the brush weeder will remove only the part of the weeds above the soil, and the weeds will readily re-grow. When the soil is too hard for hoeing, brush weeders can be used to remove the part of the weeds above the soil. When used on wet soil the effect will diminish as a result of soil sticking to the bristles.
Crop damage	Crop damage can be minimized by using crop-protection tunnels. The use of brush weeders with leaf vegetables results in a risk of contamination of the crop with dust.
Alternatives	Hoes, inter-row rotary cultivators and the weed-fix.


Inter-row rotary cultivator with fixed closed hoods.


Inter-row rotary cultivator in green maize.


Inter-row rotary cultivator in cereal.

Principle	Uproots and covers weeds with soil.
Requirements imposed on sowing/planting bed	Few requirements are imposed on the sowing or planting bed in comparison with other weed-control machinery. The soil needs to be reasonably level and workable.
Row spacing	The row spacing is difficult to adjust. A specific working width must be available for each row spacing. The machine can be used for row spacings from 30 cm upwards.
Effect in the row/ridging	No effect in the crop row.
Optimum weed stage	- cotyledon to 15 cm. - use with more prolific weeds and larger weeds.
Optimum crop size	From the seedling stage until the inter-row rotary cultivator causes damage to the crop plants.
Suitable for use with the following crops	All crops sown or planted in rows with a row spacing of 30 cm upwards.
Capacity	0.75 ha per hour with 3 - metre working width.

Speed	3 - 7 km per hour.
Settings	Select the best setitngs, choose a suitable combination of rotational speed of the cultivator and tractor speed, depending on the weed density and size. Working depth 2 to 3 cm. Working the soil too deeply increases the risk of the germination of further weed seeds. The inter-row rotary cultivator can, in combination with ridgers, also be used for ridge cultivation.  A specific inter-row rotary cultivator width will be required for each row spacing.  The final effect will be improved by operating the cultivator blades at the minimum possible depth.
Soil requirements	The soil must not be too wet, and must be readily suited to cultivation.
Crop damage	Root damage when the cultivation is too deep (> 4 cm) close to the crop row.
Alternatives	Preference is given to hoes. Use the inter-row rotary cultivator when the weeds are too large or very dense. With some crops the brush weeder or weed-fix are suitable alternatives.

Rear view of Weed-fix.

Weed-fix in cabbage.

Detail of Weed-fix.

Principle	Uproots and covers weeds with soil.
Requirements imposed on sowing/planting bed	The sowing or planting bed must be level. The rotors do not follow the soil contours independently of each other.
Row spacing	- suitable for use with all crops sown or planted in rows and offering sufficient room between the rows; for row spacing from 50 cm upwards. - adjust the working width by moving the two rotors working between two rows closer to or further from each other, and by turning the rotor tines inwards or outwards.
Effect in the row/ridging	The protective hoods can be raised once the crop plants are large enough; the rotors will then introduce soil into the crop rows and cover small weeds.
Optimum weed stage	Cotyledon to 4-leaf stage.
Optimum crop size	From the seedling stage until the machine causes damage.
Suitable for use with the following crops	All crops sown or planted in rows with a row spacing of 50 cm upwards.

Capacity	0.75 ha per hour with 3 - metre working width.
Speed	3 - 8 km per hour.
Settings	An optimum combination of rotational speed and tractor speed can be sought for the specific weed density and size of weeds. Working depth 2 to 3 cm. Working the soil too deeply results in a risk of the germination of further weed seeds. The degree of ridging can be varied by adjusting the height of the protective hoods and the speed of the rotors.  **Adjusting the working width (1)** Slide two rotors closer to or further from each other.  **Adjusting the working width (2)** Turn the tines on the rotor to increase or decrease the cultivation width.
Soil requirements	The soil must be readily workable and drying.
Crop damage	The risk of crop damage is low. Pay attention to the amount of soil moved into in the crop rows, in particular when the crop plants are still small.
Alternatives	The hoe, inter-row rotary weeder and brush weeder for larger crop plants, such as cabbage; with hard soil preference may be given to the weed-fix.

Finger weeder in drilled onions.

Various dimensions and hardnesses are available.

Finger weeder in sugar beet.

Principle	Uproots weeds and ejects them from the crop row.
Requirements imposed on sowing/planting bed	Level and loose soil.
Row spacing	- 25 - 35 cm (small finger weeder). - from 35 cm (large finger weeder).
Effect in the row/ridging	- good on light to medium-heavy clay soils. - not suitable for soil that is too hard.
Optimum weed stage	Cotyledon to 2 - leaf.
Optimum crop size	When properly rooted: from the 2 - leaf stage.
Suitable for use with the following crops	Almost all crops sown or planted in rows with a sufficient distance between the rows.
Capacity	1.0 ha per hour with 3 - metre working width.

Speed	4 ~ 12 km per hour.
Settings	The crop row must pass precisely between the finger weeders. The aggressiveness of the cultivation increases with decreasing distance between the fingers. With young crops fit the fingers at a distance of 2 cm from each other. Reduce the distance between the fingers once the plants are firmly rooted. The fingers may overlap with sturdy crops (maximum of 5 cm).  Fingers free of each other.  Fingers touch each other.  Fingers overlap each other.
Soil requirements	The soil must be readily workable, and preferably drying. Soil that is too wet will stick between the fingers and the drive. Preference is given to the use of harder fingers on heavy clay soil and softer fingers on light soil.
Crop damage	Make sure that the plants are planted correctly and sufficiently deep, and that the soil has been pressed down firmly. Soil cultivation too-early can uproot the plants.
Combination with other machinery	Extremely effective in combination with flat hoes between the rows. Use of the finger weeder in combination with a torsion weeder will control larger weeds. The use of a steering system will help ensure that the crop row is kept between the finger weeders. Hoeing closer to the row improves the effect.
Alternatives	Harrow, torsion weeder or Pneumat.
Ridge cultivation	Cultivation with the finger weeder is possible when the top of the ridge is sufficiently wide (12 - 15 cm).

Torsion weeder

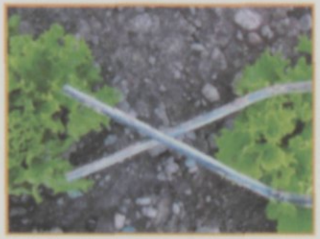
Torsion weeder in sown onions.

The tines cultivate the soil along the crop row.

Torsion weeder in strawberries.

Angling the tip of the tines downwards improves the effect.

Principle	Uproots and weeds shallowly.
Requirements imposed on sowing/planting bed	Level and loose soil.
Row spacing	From 25 cm.
Effect in the row/ridging	- good with loose soil. - not suitable for heavy soil that is too hard.
Optimum weed stage	Cotyledon to 2 - leaf.
Optimum crop size	Well-rooted crops until the crop plants grow together.
Suitable for use with the following crops	Most crops sown or planted in rows with a row spacing of 25 cm upwards.
Capacity	1.0 ha per hour with 3 - metre working width.

Speed	4 – 12 km per hour.
Settings	The crop must pass precisely between the tines of the torsion weeder. The aggressiveness of the cultivation increases with decreasing distance between the tips of the two spring tines. The crop damage decreases with increasing tractor speed. The spring tines can overlap each other (1-5 cm) when the crop plants are well rooted. An optimum effect is obtained with the tips of the tines angled slightly downwards.  **Low-disturbance setting.** The spring tines do not overlap.  **High-disturbance setting.** The spring tines overlap each other by a great amount. When the tines are in the soil they are pushed apart by the tractor speed and the crop.
Soil requirements	The soil must be readily workable, and preferably drying. The effect will be poor in very heavy clay soil, since the spring tines will not be able to penetrate the soil. This is also the case with panned soil that has dried and become hard. Use 7-mm thick tines in light soil, 10-mm thick in heavy soil.
Crop damage	The crop plants will need to be well rooted if they are not to be uprooted.
Combination with other machinery	Larger weeds can also be controlled when the torsion weeder is used in combination with a finger weeder. The use of flat hoes cultivating the soil as closely as possible to the row will improve the cultivation of the soil in the crop rows. The use of a steering system will help ensure that the crop row is kept between the tines of the torsion weeder.
Alternatives	Harrow, finger weeder, or Pneumat.
Tractor speed	The tractor speed must be adjusted according to the conditions. In general, the soil cultivation will be more aggressive at low than at high speeds. Higher speeds push the tines apart, thereby sparing the crop.

Pneumat in sown onions.

Pneumat in sugar beet.

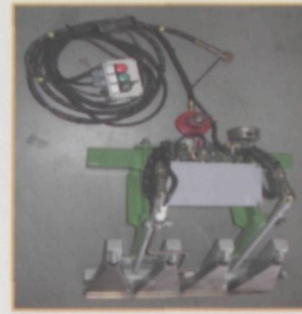
Nozzles behind the hoes.

Principle	Uproots, weeds superficially, and uses air to blow small weeds out of the crop row. The compressed air is obtained from a compressor driven by the power take-off.
Requirements imposed on sowing/planting bed	Level and loose soil.
Row spacing	25 - 75 cm.
Effect in the row/ridging	- good with loose soil. - no ridging effect.
Optimum weed stage	Cotyledon to 4-leaf.
Optimum crop size	Well-rooted crops until the crop plants grow together.
Suitable for use with the following crops	Most crops sown or planted in rows with a sufficient row spacing.
Capacity	1.0 ha per hour with 3 - metre working width.

Speed	4 – 12 km per hour.
Settings	The crop must pass precisely between the Pneumat's nozzles. The aggressiveness of the cultivation increases with decreasing distance between the nozzles and increasing air pressure. The crop damage decreases with increasing tractor speed. A pressure of as much as 10 atmospheres can be used with plants that are rooted securely. However, the tractor speed will then need to be sufficiently high. The best effect is obtained when the settings of the working depth, air pressure and the tractor speed are tailored to each other. It will be necessary to take due account of the tractor's power. The compressor uses a lot of power, in particular with versions for multiple crop rows.  The best effect is obtained when the nozzles are exactly opposite each other.  Pressure can be adjusted readily with the help of a good manometer.
Soil requirements	The best results are obtained with really loose soil. However, when it is possible to hoe sufficiently close to the rows the soil will usually be broken enough to ensure a good result.
Crop damage	- the crop must be sown or planted at a sufficient depth, otherwise plant loss is more likely. - when used with leaf vegetables such as lettuce the nozzles will need to be shielded to prevent contamination of the plants with soil.
Combination with other machinery	The Pneumat can be used only in combination with a hoe. The nozzles are attached to the hoes.
Alternatives	Harrow, finger weeder, or torsion weeder.
Tractor speed	The tractor speed must be adjusted to suit the conditions, crop, air pressure and working depth.


Full-field flame weeder.


Inter-row flame weeder.


Detail of necessary equipment with burners.

Principle	Disrupts and destroys the cells in a above ground plant tissues.
Requirements imposed on sowing/planting bed	Level, and not too coarse (no large clods).
Row spacing	Inter-row flame weeder: from a row spacing of 30 cm, full-field flame weeder: independent of the row spacing.
Effect in the row	Full-field flame weeder: good, inter-row flame weeder: none.
Optimum weed stage	Cotyledon to 2 - leaf.
Optimum crop size	- before emergence: all crops. - after emergence: spring-sown onions 4 - 6 leaves, and chicory 3 - 4 leaves (emergency measure).
Suitable for use with the following crops	- **before emergence**, full field: slowly-germinating seeds. - **after emergence**, full field: sown leek, spring-sown onions, chicory. - **flame-weeding between the rows**: all crops with sufficient space between the rows, from 30 cm upwards.
Capacity	1.0 ha per hour with 3 - metre working width.

Speed

3 – 6 km per hour (gas consumption 80 - 120 litres per ha).

Crop damage

Take care with the use of flame weeders. Flame weeding after the emergence of onions can delay growth and, consequently, ripening. This can result in a lower yield. In addition, the risk of diseases is increased. The risk is reduced when flame weeding is carried out as early as possible. There is a risk of plant loss from emergence until the flag-leaf stage. The risk of lower returns due to plant loss is greater with chicory.

Settings

Fingerprint test

The fingerprint test is the most important aid in adjusting the flame weeder's settings, i.e. the flame-weeding speed, gas pressure, and position of the flamer. On pressing the treated – and still green – weed leaf a lasting imprint must remain on the leaf; if this is not the case, then the treatment was insufficient. In the absence of a lasting imprint it will be necessary to reduce the tractor speed or increase the gas pressure. The tractor speed can be increased in the event of scorched brown leaves or leaves that are still smouldering after flame weeding. The tractor speed for flame weeding is 3 - 6 km per hour. At higher speeds the effect is very limited, even on very small weeds.

Pre-sprouting window

What is referred to as a 'pre-sprouting window' can be used to predict the precise time of crop emergence.
A sheet of glass or plastic film is laid over a small area of the sown field. The soil temperature is higher under the cover, as a result of which the crop seeds will germinate a few days earlier than the remainder of the seeds in the uncovered soil. This method can be used for an accurate determination of the time for flame weeding.

Important for a good effect

Small weeds:	Annual weeds are susceptible to heat to the 4-leaf stage. Most broad-leaved weeds are more susceptible than grasses.
Dry plants:	Water droplets on the leaves can reduce the effect of heat.
Wind:	A suitably shielded machine is very important in the event of wind.
Fine sowing bed:	Large clods shade weeds. This increases the risk of poor control of weeds under or behind clods.
No effect on:	Perennial weeds such as creeping and common sow thistle or larger grasses (beyond the 2-leaf stage) and broad-leaved weeds with more than four true leaves.

The effect of weed control increases with every additional centimetre of hoeing. The unhoed strip in which the crop grows must be as narrow as possible. Crop plants may not be damaged by the weeding equipment. Weeders in the row such as finger and torsion weeders achieve better results when the weeders are kept in the same position relative to the crop row. When steering using the sight on a toolbar mounted on the front of a tractor then 3-4 cm play will readily be required to prevent damage to the crop. Consequently a strip of at least 6-8 cm width will not be hoed in the row. More accurate steering can reduce the width of the unhoed strip to about 4 cm. Steering systems have been developed for the accurate control of weeding machinery. Toolbars are usually mounted on the front of tractors. The driver has an excellent view of the toolbar and the sight, and there is sufficient space for the machinery. However, the disadvantage is that a minor correction in the direction in which the tractor is moving results in a much greater correction in the position of the hoe. A toolbar mounted between the front and rear wheels of the tractor can be steered with much greater accuracy. However, most tractors offer insufficient space; moreover the driver in the cabin has an insufficient view of the underside of the tractor. Although special implement carriers have been developed for hoeing machinery, the high costs have resulted in little interest in their use. When weeding machinery is mounted on the rear of the tractor the driver cannot see anything that is happening behind him or her, as a result of which a margin of 8 cm or more is often maintained between the plants and the hoe blade.
This results in unhoed strips of at least 16 cm wide around the crop row.

Mutsaers QI.

Crop-guided hoes.

Mechanical steering systems

Weeding equipment mounted rigidly to the front of the tractor responds with a movement in excess of the driver's steering correction. Consequently this makes the steering inaccurate. Frank Mutsaers has designed an ingenious steering system which resolves this disadvantage; the centre of rotation of the hoes is located immediately behind the toolbar. With the Mutsaers QI steering system a steering correction made by the driver results in a smaller correction of the position of the hoe. The driver is then able to steer as accurately as with a toolbar mounted between the front and rear wheels of a tractor or implement carrier. Hoeing close to the crop rows is also possible by allowing the hoe to be guided by the crop. The system has been developed so that beets with 4 leaves and the ridges of furrow drills can be used to control the guides. This steering system suffers from the disadvantage that it cannot be combined with finger or torsion weeders.

Ecodan.

Optical systems

During the past few years a great deal of progress has been made with systems using cameras and software to process the camera images. These systems are comprised of a camera which 'looks' at the plant row(s) a few metres in front of the hoe. The camera is mounted on the toolbar. The software uses the image to calculate the position of the row. The toolbar is mounted on a sideshift fitted to the tractor. The sideshift's controls correct the position of the camera and, in so doing, the position of the hoes relative to the plant row.

Systems using image recognition to determine the position of individual plants are under development. When there is a considerable distance between the crop plants in the row a hoe can then be controlled to cultivate the soil between the plants, or flame weeders can be used to burn weeds between the crop plants.

Robocrop.

Mutsaers in dwarf beans.

Side view of steering system.

Principle	The toolbar is mounted on the front of the tractor. The centre of rotation is located immediately behind the toolbar. This active control system is used to follow one crop row by means of a sight. As a result of the additional steering effect of this system the sight indicates the direction in which the hoes are moving, and consequently their position in a short while. This simplifies any corrections that may be required, and the tractor can be driven faster and with greater accuracy. The accuracy is comparable with a toolbar mounted between the front and rear wheels of a tractor or implement carrier.
Applicable for	All crops sown or planted in rows with a row spacing of about 25 cm upwards.
Optimum crop size	Comparable with a conventional hoe. Cultivation can begin as soon as the crop is visible in the rows. Preference is given to the use of discs or protective covers with small crop plants
Settings	The machine must be level. The machine must also be able to move freely in the mountings. Some knowledge of and experience with the adjustment of the settings is required. The system will not achieve an optimum effect with uneven or mitted soil and where the resistance of the soil is variable.
Speed	Depending on the required hoeing accuracy between 6 and 15 km/hour.


Maize is not a problem.


Crop guidance needs to be very precise with small beets.


Guide bars in sugar beet.

Principle	Guide bars run along the crop row. These keep the hoe between the rows at a precise distance a few centimetres from the crop row. The hoe distance from the row can be adjusted, depending on the system and the firmness of the crop.
Applicable for	Almost all crops sown or planted in rows with a sufficient distance between the rows (> 50 cm).
Optimum crop size	The plants need to be sufficiently sturdy to position the guide bars.
Settings	The hoe width can be adjusted, depending on the system and the firmness of the crop.
Speed	Depending on the firmness of the crop from between 5 to 12 km/hour.
Note	Work is in progress on a crop-guided system that is also suitable for use with finer crops.

Ecodan in sugar beet.

Camera.

Monitor in the cabin.

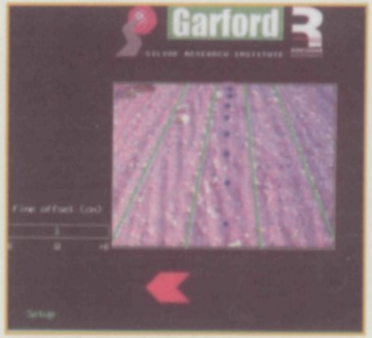
Detail of the monitor.

Principle	One or more video cameras, a very fast processor and a monitor in the tractor are used to determine the position of the crop row. The sideshift mounted between the tractor and the implement maintains the hoe in a constant position relative to the crop row.
Applicable for	All crops sown or planted in rows with a row spacing of about 25 cm upwards.
Optimum crop size	- when the crop plants in the crop row are large enough to be detected by the camera (usually from the 2-leaf stage). - the camera must be able to detect soil between the crop rows, otherwise the camera will be unable to determine the position of the crop rows.
Settings	The monitor can be used to correct minor differences between the information detected by the camera relative to the toolbar.
Speed	Depending on the crop and the precision between 6 and 15 km/hour.
Note	The steering system can be combined with almost all kinds of toolbars. The Ecodan's image recognition system is based on the use of 1 or 2 cameras. The pattern of one or two rows is analyzed. This pattern is used to steer the toolbar.


Robocrop in sown onions.


Camera.

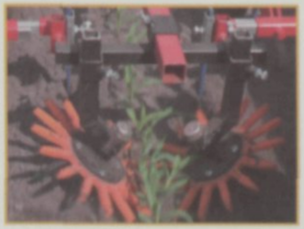

Monitor in the cabin.



Detail of the monitor.

Principle	A camera scans a number of crop rows in front of the hoe. These images, together with the advance setting of the row arrangement, constitute the basis for the control of a hydraulic system that guides the hoe accurately between the rows.
Applicable for	All crops sown or planted in rows with a row spacing of about 25 cm upwards.
Optimum crop size	Hoeing can begin once the camera and image-recognition software are able to distinguish between the soil and the crop plants. This is usually from the 2-leaf stage.
Settings	The monitor in the tractor can be used to correct the row spacing and minor deviations of the hoe relative to the crop row.
Speed	Depending on the crop and the precision between 6 and 15 km/hour.
Note	The steering system can be combined with almost all kinds of toolbars. Soil must be visible between the crop rows, otherwise it will be impossible to determine the position of the crop row. The image recognition of the Garford (Robocrop) system is based on the use of one camera. The images are used to determine the row pattern across a width of 150 cm. This row pattern controls the sideshift.

Machinery	Hoes (fixed or sprung)	Inter-row rotary cultivator	Brush weeder	Weed-fix
				
Principle	Undercuts weeds, uproots superficially, and ridges slightly	Uproots and chops the weeds	Uproots and lays the weeds on the surface	Uproots and covers weeds with soil
Working depth	Makes the soil loose to a depth of 1 - 3 cm	Makes the soil loose to a depth of 2 - 6 cm	Makes the soil loose to a depth of 1 - 3 cm	Makes the soil loose to a depth of 2 – 4 cm
Requirements imposed on the sowing/planting bed	Level sowing and planting bed	Imposes few requirements	Level sowing and planting bed. Elements do not move independently	Level sowing and planting bed. Elements do not move independently up and down
Row spacing	-15 -75 cm - to be adjusted on the basis of the row spacing	At least 40 cm (most 50 or 75 cm)	- 25 -75 cm - a separate toolbar with brushes is required for each row spacing	- 50 -75 cm - rotor and tines can be adjusted
Effect in the row/ ridging	- no effect in the crop row - a slight ridging effect with duckfoot blades and higher tractor speeds	- no effect in the crop row - no ridging effect	- no effect in the crop row - no ridging effect	- no effect in the crop row - soil can be moved into the crop row by raising the protective hoods
Indicative price (2005)	€ 8,500 (6 m, 12 rows, with ducksfoot blades)	€ 9,000 (3 m, 6 rows)	€ 8,500 (3 m, 6 rows, protection tunnels)	€ 10,000 (3 m, 4 rows)
Addresses	see page 75	see page 75 (no. 14)	see page 75 (no. 2)	see page 75 (no. 18)

Machinery	Harrow	Finger weeder	Torsion weeder	Flame weeder
				
Principle	Uproots and covers weeds with soil	Uproots and ejects weeds from the crop row	Uproots and covers weeds with soil	Plant foliage is destroyed by the heat
Working depth	Makes the topsoil loose (1 - 3 cm)	Makes the topsoil loose (1 - 3 cm)	Makes the topsoil loose (1 - 3 cm)	None
Requirements imposed on the sowing/planting bed	- very level, medium-fine to fine, no large clods or clumps of grass - good for loose and light to medium-heavy soil	Level and loose soil without large clods	Level and loose soil without large clods	Very level, no large clods
Row spacing	Not dependent on the row spacing	- 25 - 35 cm (small discs) - from 35 cm (large discs)	25 - 75 cm	- > 30 cm - independent of the row
Effect in the row	- spring-tine harrow: medium to good - chain-link harrow: medium to good, follows the soil contours closely	- good, combine with hoeing	- good, combine with hoeing	- flame weeder, full field: good - Inter-row flame weeder: none
Indicative price	€ 3,500 (6 m 7-mm thick tines)	€ 600 per row (€ 3.600, 6 rows)	€ 125 per row (€ 750, 6 rows)	€ 20,000 (flame weeder, full field) 3 m working width
Addresses	see page 75	see page 75 (no. 7, 13, 17)	see page 75 (no. 7)	see page 75 (no. 9, 10)

Machinery	Powered harrow	Radis intra-row weeder	Pneumat
			
Principle	Uproots weeds in the crop row	Undercuts weeds, also in the crop row	Uses air to blow weeds out of the crop row
Working depth	- makes the soil loose to a depth of 3 cm - very intensive	Makes the soil loose to a depth of 1 - 3 cm	Makes the soil loose to a depth of 1 - 3 cm
Requirements imposed on the sowing/planting bed	- suitable for light to medium-heavy soil - planting bed must be level	Very level. The hoes are fitted to one parallelogram per bed	- thoroughly smoothed and level. The depth setting is of particular importance with fine crops - suitable for light to medium-heavy soil
Row spacing	- 50 - 75 cm (short spring pins) - from 75 cm	30 - 75 cm	From 20 cm
Effect in the row	- comparable with finger/torsion weeders - the weeds may be a little larger, increased risk of crop damage	Very good when the crop plants are significantly larger than the weeds	Good, slightly more aggressive than finger and torsion weeders
Indicative price	€ 5,000 (1.5 m, 2 rows)	€ 16,000 (1.5 m, 4 rows wide)	€ 9,000 (6 rows)
Addresses	see page 75 (no. 5)	see page 75 (no. 12, 16)	see page 75 (no. 15)

Machinery	Acrobaatweeder	Powered spring-tine harrow	Bio-weeder
			
Principle	Uproots weeds in the crop row	Uproots weeds; also in the crop row	Uproots and ejects weeds from the crop row
Working depth	Makes the soil loose to a depth of 1 - 3 cm	Makes the surface loose	Makes the surface loose
Requirements imposed on the sowing/planting bed	Suitable for heavy clay soil, but also works on all other soil types	As a result of the moving tines of the harrow less stringent requirements are imposed on the seedbed as compared to traditional spring-tine harrows	The best effect is obtained on level soil
Row spacing	From 50 cm	Not dependent on the row spacing	From 25 cm
Effect in the row	Also thoroughly loosens compacted soil; often gives the best weed-control under these conditions. Can be used with two elements in series on sandy soils	The tines of the harrow move back and forth through the crop row. An optimum effect can be achieved by a combination of the correct tractor speed and reciprocal speed of the tines of the harrow	A combination of finger weeders and propelled harrows remove weeds from the crop row
Indicative price	€ 450 per row (€ 2.700 6 rows)	€ 13,500 (4.5 m)	Price on request
Addresses	see page 75 (no. 3, 17)	see page 75 (no. 1)	see page 75 (no. 4)


LIOT

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The wide range of harrows and hoes have an equal number of manufacturers and sales organizations; consequently it is recommended that you contact your dealer for advice about the type and make most suitable for your farm and your conditions. The www.agritica.com website can also be of use in finding the appropriate machinery and companies also on the site www.organicweeds.org.uk is a list with machinery sites.

1	Agro Techniek Holland BV, Delfweg 36, NL-2211 VM Noordwijkerhout, The Netherlands	www.agro-techniek.com
2	Bärtschi-Fobro AG, Dorf 1, Postfach 1, CH-6152 Hüswil, Switzerland	www.fobro.com
3	Brienen,LMB, Kerkplein 15, NL-5835 AT Beugen, The Netherlands	www.brienenbeugen.nl
4	Broekema Landbouwtechniek, Brammershoopstraat 20, NL-7858 TC Eeserveen, The Netherlands	0599 287333
5	Christiaens Agro Systems, Heldenseweg 15A, NL-6086 PD Neer, The Netherlands	www.christiaensagro.com
6	Dijk.Innovatie, Liederholthuisweg 7, NL-8131 PW Wijhe, The Netherlands	E-mail: dijk.innovatie@planet.nl
7	Frato Machine Import, Woeziksestraat 635, NL-6604 CK Wijchen, The Netherlands	www.frato.nl
8	Garford Farm Machinery, Frognall, Deeping St James, Peterborough, PE6 8RR, United Kingdom	www.garford.com
9	Greenburner, D'Urbans, Framlingsham, Suffolk, IP13 9RP, United Kingdom	www.greenburner.com
10	HOAF Infrared Technology, Munsterstraat 14, NL-7575 ED Oldenzaal, The Netherlands	www.hoaf.nl
11	Homburg Machinehandel BV, Postbus 5, NL-9050 AA Stiens, The Netherlands	www.homburg-holland.com
12	Kooiman Mechanisatie, Handelsweg 10, NL-1619 BJ Andijk, The Netherlands	E-mail: nannekooiman@wxs.nl
13	Kress & Co. GmbH, Eberdinger Strasse 37, D-71665 Vaihingen, Germany	www.kress-landtechnik.de
14	Kruse, Stobbenkamp 42, NL-7631 CP Ootmarsum, The Netherlands	www.kruse.nl
15	L. Lütkemeyer, Gartenstrasse 13 D-33397 Rietberg, Germany	E-mail: sleutkemeyer@lear.com
16	Steketee BV, Lieve Vrouwepoldersedijk 1A, NL-3243 LA Stad aan 't Haringvliet, The Netherlands	www.steketee.com
17	Sarl Radis Mécanisation, Quartier Rouquefure, F-84400 Apt, France	E-mail: daussan.christian@wanadoo.fr
18	Struik Wieringermeer BV, Schelphorst 67, NL-1771 SM Wieringerwerf, The Netherlands	www.struikholland.nl