CA 77

MECHANICAL WEED CONTROL IN ARABLE CROPS

ITAB
Institut Technique de l'Agriculture Biologique

OPTIMISING AND PROMOTING MECHANICAL WEED CONTROL
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OPTIMISER ET PROMOUVOIR LE DÉSHERBAGE MÉCANIQUE

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PREFACE

This guide describes mechanical methods for controlling weeds in no-herbicide arable crop systems. The aim is to provide information and recommendations that can be used to design customised weed management regimes in such systems. The target audience is organic farmers, farmers seeking to reduce their herbicide usage, and their agricultural advisors. However, this document may also be of interest to researchers, academics, or students studying sustainable agriculture.

The guide is composed of two parts. The first part discusses non-chemical methods for controlling weeds and the main tools used in mechanical weed control.

> First of all, it is crucial to state that prevention is the key to non-chemical weed control in arable crop systems. Preventive strategies should be complemented by, not replaced by, mechanical strategies, which are not very effective on their own. In other words, weed control should make use of the crop system's inherent characteristics before resorting to annual management techniques, such as tillage during the fallow period or mechanical weed control during the crop season.

The second part of the guide is descriptive in nature. Organised by crop type, it provides examples of how mechanical weed control methods can be applied in no-herbicide arable crop systems.

> The scenarios described should not be taken as representative; they are for illustrative purposes only. They were collected as part of CASDAR Programme no. 8135, during a project entitled "Optimising and Promoting Mechanical Weed Control" (2009–2011).

It is important to underscore here that non-chemical methods for managing weeds involve two key principles.

- First, it is important to regularly **monitor** the state of one's field and to **be familiar with common weed species** (identity and biology). This is the foundation for any weed control regime.
- Second, the goal is to **manage** weeds, not eliminate them. Weeds should therefore be **tolerated**: they can exist in fields without impacting current crops or future crops. There are even some advantages to leaving weed species in place because they contribute to biodiversity and provide habitat for beneficial insects.

For more information

For more information, the research programme's findings are available on ITAB's website: http://www.itab.asso.fr/programmes/desherbage.php

In particular, you can download the complementary guide "Understanding and managing weeds in arable crops without herbicides" (2012).

The references for the texts cited in this guide are available in the bibliography.

Mechanical weed control: general recommendations

PREVENTIVE MEASURES FOR CONTROLLING WEEDS

The preventive measures described in this section are based on rotation design (species and sequence choice), sowing methods (date, depth, and rate), and fallow-period tillage (which aims to bury weed seeds deep enough to limit germination or to provoke seedling emergence to allow subsequent weed removal).

ROTATION DESIGN

A crop rotation is **the type and sequence of crops used in a given field**. The goal of any rotation is to preserve or improve soil fertility and to protect crops (i.e., from diseases, pests, and weeds), all while ensuring that farmers can make a living. When designing a crop rotation, farmers must trade-off between different objectives, such as managing soil fertility, limiting crop risk, and ensuring farm profitability. Other factors, such as the availability of labour, also come into play.

Designing rotations to control weeds involves the following strategies:

- employing "cleaning" head crops (e.g., grasslands, lucerne)
- alternating crops with contrasting features, thus breaking weed cycles and preventing selection for certain species (for example, a sequence of winter grains will favour the development of autumn grasses such as black-grass or bromegrass)
- employing crops that produce good cover and thus suppress weeds via competition for light, water, and nutrients (or via allelopathy, in some cases)
- employing row crops, which can be weeded with a row cultivator (better mechanical weed control)

Choosing cleaning head crops

In **mixed crop-livestock systems**, long-term temporary grasslands (4–7 years) generally serve as cleaning head crops. Because livestock graze selectively, avoiding certain weeds (e.g., dock, sorrel, and thistle), it is necessary to alternate between cutting and grazing such fields. Cutting is one of the best tools for controlling perennial weeds, especially thistle.

In **specialised cropping systems**, planting lucerne or a temporary grassland (2–4 years) can help control weeds. The competitive pressure exerted by lucerne or the grassland species limits weed development, while repeated cutting eventually weakens the weeds' rhizomes, prevents bolting, and diminishes prevalence in future crops.

Alternating different crop types

Within the rotation, it is important to alternate different types of crops to interrupt the cycle of weeds and avoid selecting for species with exponential growth. There are four crop sowing periods: autumn (e.g., winter rapeseed), winter (e.g., winter grains, winter protein crops), early spring (e.g., spring grains, spring protein crops), and late spring to early summer (e.g., maize, sorghum, sunflower, soybean, hemp).

Rotations should be slightly weighted towards autumn/winter crops because spring/summer weeds, especially the dicots, are harder to manage over the longer term; for example, they produce large numbers of seeds that remain highly viable in the seed bank. That said, this advice does not apply if certain problematic winter weeds are present.

Promoting vegetative cover

> ***Using competitively dominant crop species and varieties***

Certain crops have morphological traits that allow them to outcompete weeds. Plant growth form (erect or bushy), height, developmental vigour, or degree of cover (i.e., shade-casting ability) can be exploited as part of weed management regimes. For example, because it provides more extensive cover and grows taller, triticale is better than common wheat at outcompeting weeds. Crops can be ranked according to their competitive abilities under the pedoclimatic conditions found in the Ile-de-France region (Fig. 1). Other crops, such as oat, rye, sorghum, and buckwheat, display allelopathic activity, which is when plants directly or indirectly have positive or negative effects on other plants via the release of chemical compounds into the environment *(Rice, 1984)*.

Within species, certain varieties may be more competitive than others. A study examined how well different common wheat varieties competed against weeds *(2007–2010; financial support from the Fonds de Soutien à l'Obtention Végétale; more details are available at http://www.itab.asso.fr/programmes/FSOV.php)*. It found that varietal variability existed in weed tolerance (treatment with ryegrass as the weed vs. control in which herbicides were used). Losses in yield ranged from 20 to 40% for varieties providing the greatest cover (Pegassos, LD76) and the least cover (Glasgow, Sankara), respectively. The study also looked at the ability of different wheat varieties to suppress weeds (i.e., reduce their biomass). In trials carried out under natural conditions of weed infestation in an organic agricultural system, the Renan variety reduced weed biomass 40% more than did the Caphorn variety (a short plant that provides little cover). Researchers found that the competitiveness of common wheat varieties was determined first by plant height and second by the degree of cover and foliage distribution. The trials carried out in the organic system also underscored the importance of wheat seedling emergence, which is the basis for later crop, and cover, development.

Variety competitiveness is a key selection criterion in organic systems or low-herbicide systems.

> *Combining crops to create mixed cover*

Another approach is to combine different crop species that will outcompete weeds via the creation of more extensive vegetative cover. The entire crop association can be harvested (e.g., grains associated with field peas or forage peas) or the partner crop may simply be exploited for its services *in situ* (e.g., grains associated with small-seeded legumes).

> *Fallow-period cover crops (intermediate crops)*

Regardless of whether they are undersown in the spring or sown post harvest in the late summer, intermediate crops can help with several primary and secondary

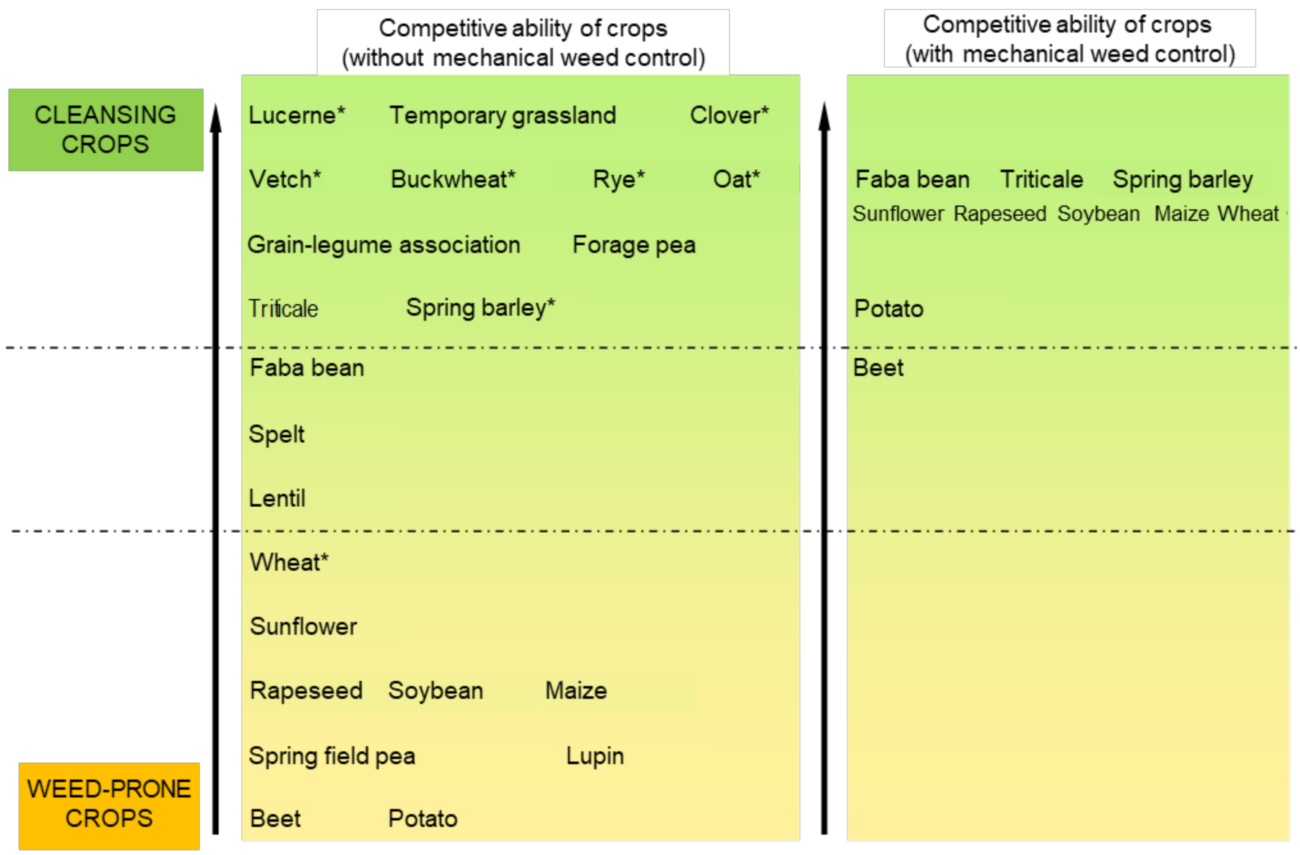


Figure 1: Crops ranked according to their competitive dominance over weeds (in systems with and without mechanical weed control). Ranks were determined in the ***Ile-de-France*** *region (source: Seine and Marne Chamber of Agriculture) and may not be the same in other regions.*
**Crops known to display varying degrees of allelopathic activity*

management objectives: supplying green manure (one or several legumes can be used); taking up nitrates during the autumn leaching period; producing relay forage; and, of course, controlling weeds.

Planting cover crops during the fallow period has a clear negative effect on weeds: the extensive vegetative cover prevents weed seedling development during this part of the crop cycle. That said, the use of cover crops must be carefully weighed because it limits the ability to employ the stale seedbed technique, a crucial weed control strategy when the potential for weed infestation is great. It is also important to carefully choose one's cover crop species, to limit the risk of regrowth. Indeed, properly terminating intermediate crops is crucial in no-herbicide systems.

At present, little is known about how to evaluate the functional efficacy of fallow-period cover crops in providing weed control in such systems. However, as more and more research is carried out in organic systems, a base of knowledge is building (see Munier Jolain et al. [2005] in Valantin Morison et al. [2008] for some initial results).

Regardless of the situation, it is essential to think about weed control within fields from the perspective of the rotation, and not that of the annual crop cycle. Some organic farmers include two years of lucerne in their rotations even though they gain no direct economic benefits (e.g., no sales of roughage or dehydrated hay). The associated costs are spread across the whole rotation, which benefits overall from the crop's initial presence (weed suppression and fixation of atmospheric nitrogen).

Findings from the RotAB programme

The RotAB programme carried out research on rotations in organic arable crop systems (CASDAR project 2008-2010; see http://www.itab.asso.fr/programmes/rotation.php for a description of the results). Its findings underscore that perennial forage legumes play a crucial role as head crops. Multispecies grasslands serve this function in mixed crop-livestock systems, whereas lucerne and clover do the same in specialised cropping systems (i.e., without livestock). These species significantly enhance soil fertility and suppress weeds. For example, lucerne that is left in place two or three years does a good job of controlling weeds, including creeping thistle. The grain that follows requires little in the way of mechanical weed control, in contrast with what would be needed if the preceding crop were faba bean. There are ways to derive an economic advantage from the lucerne (production of roughage in regions with livestock farming, production of dehydrated hay), which facilitate its use.

These benefits are not available in specialised cropping systems, which do not consistently exploit perennial forage species as head crops. On such farms, weed control relies on alternating diverse varieties of crops and including a large percentage of row crops, facilitating the use of the row cultivator. Specialised cropping systems (e.g., in which soybean, maize, or sunflower are grown) are especially common in the southern half of France, where mild winter conditions allow early, more frequent mechanical weed control. Lucerne is only employed when crop alternation and usage of the row cultivator do not sufficiently control weeds.

The RotAB research also showed that, in such systems, the greater availability of row cultivators in general and of higher-quality row cultivators in particular (e.g., with the ability to handle narrower row spacing) has led to an increase in the proportion of wheat weeded with these tools.

Fallow-period tillage

Like rotation design, tillage during the fallow period is a crucial part of weed control in no-herbicide systems.

Each weed, whether annual or perennial, has unique germination requirements and features: optimal depth, soil moisture, length of dormancy, cues prompting emergence, and annual rate of seed loss (i.e., loss in seed viability per year). Tillage can either be used to encourage weed emergence (with the goal of subsequent removal) or to prevent emergence altogether. This work can take different forms: stubble ploughing, ordinary ploughing, and stale seedbed preparation.

Stubble ploughing

Stubble ploughing should take place as soon as possible after the harvest and definitely before the weeds set seed. It should also be performed after each rainfall event. It accomplishes the following tasks:

- destroys preceding crop regrowth
- destroys weed seedlings that have emerged and/or developed post harvest
- encourages the emergence of other weeds that will be removed by a later pass with a mechanised tool
- limits perennial weeds by uprooting and drying out their rhizomes (e.g., using a tine-based tool on dock/ sorrel/couch grass) or by weakening their rhizomes (e.g., using a tine-based tool + winged sweeps on thistle)

To effectively weaken the rhizomes of perennial weeds, it is better to use tine-based tools than disc-based tools. The latter can promote weed regrowth by chopping up the single original rhizome into numerous propagules.

Stubble ploughing with a tine harrow

However, tine-based tools are not without risk: they can disseminate weeds by dragging them from one part of the field to another. When dealing with thistle, bindweed, Johnson grass, common horsetail, and other perennial weeds, it is important to act only when conditions are warm and very dry, preferably when growth is root focused (after late June), regardless of the method used (i.e., stubble ploughing, ordinary ploughing, or soil decompaction). To control these weeds, which have stolons, rhizomes, and deep tubers, tines should be used in tandem with winged sweeps covering a 10-cm cutting diameter, for the slicing action to be complementary. The working depth will depend on tractor power; power requirements are at least 1 hp/cm per tine.

Ordinary ploughing

In no-herbicide systems in general and in organic systems in particular, ordinary ploughing is another major technique for controlling both annual and perennial weeds. However, it can only be used when the soil is not too saturated with water. Ordinary ploughing controls weeds by disrupting their root systems at greater depths (~20 cm). It also turns over the soil, taking any weed seeds present at the surface and burying them until at least the following crop year, when the field is ploughed again. Many will die because conditions at such depths are unsuitable for germination. Others, however, will go dormant until they resurface and can then germinate. **It is therefore important to know the identity and biology of the weed species that may be present in the field**. For instance, it is helpful to know germination depth and type, chilling requirements, temperature requirements, light requirements, and the duration of seed viability.

- Although most weed seeds germinate within the top 3 cm of soil, certain species, like wild oat, can germinate at depths of over 25 cm. Consequently, ordinary ploughing by itself will not suffice to control wild oat in a field where it is already present.
- It is especially important to know the annual loss in viability for weed seeds. For example, bromegrass seeds have a very high annual loss of viability; if buried, the seed bank can be almost entirely eliminated within a year. In contrast, burying meadowgrass or scarlet pimpernel seeds, which have a very low loss of viability, only results in seed bank reductions of 10–30% over the same time period. Many spring dicots (e.g., amaranth, fat hen, nightshade, knotweed, thorn apple, cocklebur) display

Ploughing frozen soil

little loss of annual viability and will thus be relatively unaffected by ordinary ploughing; they could emerge even several years after being buried.

However, it can be useful to bring weed seeds back up to the surface to encourage them to emerge so that they can then be removed (weed flushing, which is similar to the effect of stubble ploughing).

Stale seedbed preparation

The stale seedbed technique can help reduce the number of weed seeds found near the soil surface. It involves preparing the soil as if one were sowing a crop. However, the goal is to encourage weed seeds to germinate so as to facilitate their removal. The technique uses very light tillage (<3–4 cm), carried out with a tine harrow or a rotary harrow, so as not to bring up any deeply buried seeds. A Dansih cultivator or a grass harrow can also be used to terminate weeds while limiting tillage depth.

In the spring, when conditions are more favourable to the use of mechanical tools, successive stale seedbeds can be established, at intervals of 8–10 days. However, it is important to reduce tillage depth each time, so as not to bring back up any previously buried seeds. Also, the last stale seedbed should be created well before the crop is sown so that weed and crop seedlings are not competing.

It can be problematic to use the stale seedbed technique in certain soil types (e.g., silty soils). Fine soil texture and the absence of clods can lead to compaction. Overall, it is important to properly implement the technique at the right moment and over a very short period of time. The soil should always be well drained, and tractors that will not damage soil structure should be used.

Sowing

Sowing date

A significant part of weed control is choosing the right time to sow. Consequently, in organic agricultural systems, the sowing of autumn grains is delayed to limit weed growth before the winter. Similarly, sowing in the spring should occur when the soil has warmed up and after several stale seedbeds have been created. This approach will allow the crop to get a good start and have a competitive advantage over weeds. However, it is always better to seed too early under good conditions than to seed late under poor conditions. A crop's success is greatly determined by its degree of development: crops that are further along will have an easier time outcompeting weeds.

Sowing rate

Recommended sowing rates are generally higher in organic agricultural systems (by 10–15%). The idea is two-fold: 1) to compensate for plant losses due to mechanical weed control and the absence of herbicides (seedling losses) and 2) to promote faster crop growth and more extensive vegetative cover. However, when sowing occurs early, higher sowing rates can sometimes create conditions that increase plant health risks. For example, rapeseed may be more vulnerable to pests if nutrient levels are low. It is therefore important to strike the right balance.

Sowing depth

Sowing depth needs to be consistent for crop seedling emergence to be homogeneous. If seedling emergence is homogeneous, further crop development will also be homogeneous, which will make mechanical weed control much easier.

For all crop types, normal sowing depth should be increased by 1 cm so that a pass can be made with a tine harrow or a rotary hoe, eliminating weed seedlings (that may have emerged post sowing or post crop emergence) without hurting the crop's germinated seeds or seedlings.

Sowing tools

It is better to use a disc drill than a tine seeder or a coulter drill. The disc drill disturb the soil surface less and thus brings up fewer of the buried weed seeds.

In certain situations, wider row spacing will make it possible to exclusively work the row and prevent weeds from germinating in the row middle. A contrasting result is seen with narrower row spacing, where almost the entire sowing width is worked. It is also important to note that, for winter crops, combining tillage and sowing may promote weed emergence. Direct sowing can sometimes be useful when sowing is late and there is no additional soil preparation.

Limiting the size of the weed seed bank

Preventing weed seeds from arriving in one's fields is an important weed control strategy in no-herbicide arable crop systems. It involves the following tasks:

- preventing weeds from going to seed within fields
- regularly cutting or shredding vegetation along field edges (e.g., grass strips and ditches) to prevent nearby weeds from going to seed and contaminating the field
- composting the material produced (even if just for a short period: 8–10 days); the temperatures in the pile (≥55°C) will reduce weed seed viability
- cleaning and sorting farm-saved seeds to avoid re-contaminating fields with weed seeds collected during the previous harvest
- cleaning farm equipment (e.g., tillage equipment and combine harvesters [which can be equipped with a chaff-collection device]) to prevent accidental field contamination

Mayweed, ryegrass, and common poppy in a field of wheat

MECHANICALLY MANAGING WEEDS DURING THE CROP SEASON

The previous section described the first component of weed control: prevention. This section describes the second component: mechanical weed management during the crop season.

Mechanical weed control has two goals:

- destroying weeds to prevent them from significantly competing with crops (direct effects)
- stopping weeds from bolting to prevent future infestations in the field and to limit deposits in the weed seed bank (indirect effects)

MECHANICAL WEED CONTROL TOOLS

Tine harrow

Tine harrow

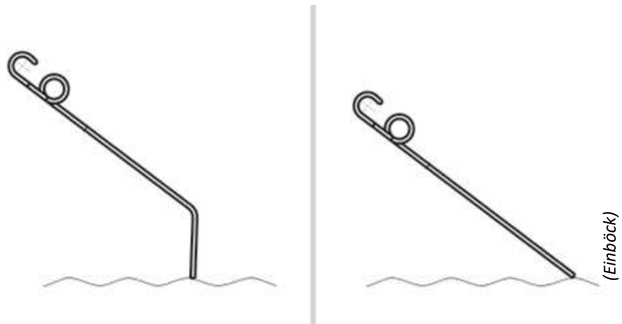


Figure 2: Two tine types

> ***Mode of action***

The tine harrow works the top two centimetres of the soil (or up to 3–4 cm during pre-emergence); its action is independent of the crop rows, and it thus control weeds across the field's entire surface. As the harrow moves forward, the flexible tines vibrate and uproot weeds as they encounter them. Tines are separated by 2–3 cm, and they can be curved or straight (Fig. 2). Curved tines more aggressively rip out weeds, while straight tines are better adapted to very rocky soils. The harrow is composed of independent sections, to which the tines are attached. This design allows the harrow to maintain constant pressure relative to the ground and to respond to surface heterogeneity. Tine diameter and length will depend on the level of aggressiveness desired.

> ***Adjustments and aggressiveness***

The aggressiveness of the tine harrow is determined by tine angle and vibration speed, which are affected by harrow speed. It can be tricky to find the right settings because it is necessary to strike the proper balance between selectivity and weed removal. Harrowing depth is regulated by the gauge wheels. It should not be too great or weed seeds will be brought back up.

> ***Effect of soil conditions on efficacy and selectivity***

Like other mechanical weed control tools, the tine harrow works most effectively on soils that are well drained, level, and packed. It is a good choice when soils are rocky because its efficacy is unaffected by terrain roughness. However, it cannot be used on compacted soils, which the tines cannot penetrate. Cloddy soils are also problematic—crop seedlings risk being buried under soil clods. Finally, if there is too much plant debris, the tine harrow will tend to rake it up.

> ***Weed control efficacy***

The tine harrow does little to control perennial weeds. However, it can weaken field bindweed and hedge bindweed if several passes are made. It only really works well on young weeds (50–70% effective; ACTA, 2011). The weeds must still be in the germination stage (e.g., "white thread" stage) or the cotyledon stage. They can have no more than 2–3 leaves at most.

> ***Degree of selectivity***

The tine harrow can be used with all types of crops, but not at all crop stages. Crop growth stage is one of the factors that determines when mechanical weed control should occur. The crop in place should not be put at risk, which means passes should be made when the crop is less vulnerable to the tool's work (e.g., tiller stage for grains, 2- to 4-leaf stage for other crop types). Nonetheless, sowing rate should be increased by 10% to account for plant losses associated with the tool's use. Early on in crop development (during pre-emergence and once the first leaves have appeared), the rotary hoe and the tine harrow will display greater selectivity (respectively) than the row cultivator. Later on, the tine harrow will only be effective in removing new weed growth.

Rotary hoe

Close-up of a rotary hoe (in soybean)

Soil and weeds being flung up by a rotary hoe

> ***Mode of action***

The rotary hoe generally works the top two centimetres of the soil; its action is independent of the crop rows, and it thus control weeds across the field's entire surface. It is equipped with wheels edged with finger-like prongs. These prongs dig up, dislodge, and rip up weeds, which are then flung away. The wheels occur in groups of two or four (all on the same spring-loaded arm), or by themselves (one per arm) to better maintain constant pressure relative to the ground.

> ***Adjustments and aggressiveness***

The rotary hoe requires very few adjustments. Its degree of aggressiveness is determined by hoeing depth and speed. The hoe must be moving at more than 10 km/h (optimal speed is 18 km/h) to properly dislodge and fling up weeds and clods. Hoeing depth can be regulated by using gauge wheels, a compression spring, or depth wheels. It can also be regulated by placing weights (up to 300–400 kg) on the frame.

> ***Effect of soil conditions on efficacy and selectivity***

As in the case of the tine harrow, the soil must be relatively well drained, level, and packed. It also must not be cloddy. In contrast to the tine harrow, the rotary hoe can be used on compacted soils. It also does a better job of dealing with plant debris. However, it is less effective on loose or rocky soils (can fling up rocks and gravel). The rotary hoe can be used on somewhat wet soils (it can be employed sooner than the tine harrow after rainfall), but the soil should be allowed to dry somewhat to ensure effective weed control (i.e., prevent cut weeds from re-establishing themselves).

> *Weed control efficacy*

Some constraints are the same for the rotary hoe as for the tine harrow: weeds must be in the germination stage (i.e., "white thread" stage). However, the rotary hoe is less aggressive than the tine harrow and does not effectively eliminate weeds that have reached the 1-leaf stage. For weed control to be effective, the rotary hoe should be used at the start of the crop cycle. Care must be taken, though, not to harm the crop if the hoe is employed between emergence and the 2- to 3-leaf stage.

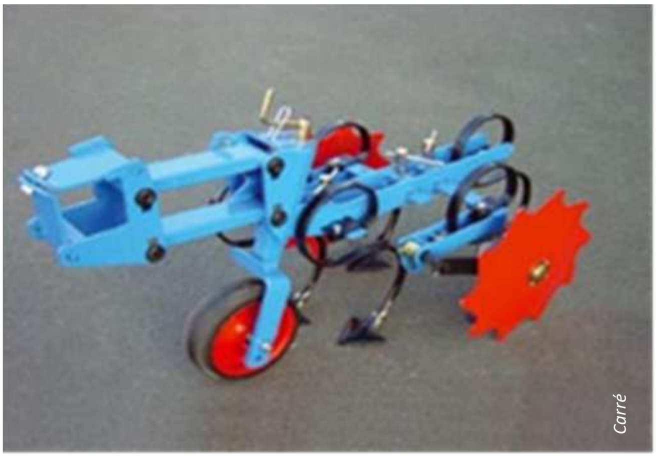
> *Degree of selectivity*

The rotary hoe can be used with all crop types during pre-emergence or during the 2- to 3-leaf stage. In rapeseed, the rotary hoe can be used during all stages of crop development. However, its action is most effective during the month following sowing. In maize, the rotary hoe can be used between emergence and the 3-leaf stage, provided that sowing depth is sufficiently great (4–5 cm).

To ensure selectivity, hoeing depth must be controlled. Action needs to be focused on the upper soil layer, from which weeds will emerge, instead of on deeper soil layers, which contain crop seeds or roots.

Row cultivator

Kress© finger weeder in action



Example of a five-member row cultivator tool gang

> *Mode of action*

The sweeps of the row cultivator cut or dislodge roots and can bury young weeds by moving soil onto the row. In contrast to tine harrows and rotary hoes, row cultivators do not operate at the whole-field level. Their work is focused on the row middle. The width worked (broader vs. narrower) depends on guidance system precision. The row cultivator comprises different tool gangs (one per row middle) that are all attached to the main toolbar. Each gang functions independently and can have its own working width. A given tool gang is made up of 1–5 members; the sweep type will determine what happens to the soil and weeds. Increasing the number of working pieces can result in heterogeneous weed control among row middles.

> *Adjustments and aggressiveness*

Row cultivator aggressiveness is determined by the rigidity of the shanks to which the sweeps are attached. More rigid shanks result in greater soil penetration. There are different types of shanks: rigid shanks (like in beet hoes); mixed and semi-rigid shanks (C-shaped; the most common); and vibrating S-tines. The orientation of the sweep also determines row cultivator aggressiveness. If the sweep is parallel to the ground, it will slice the soil surface. If the sweep is angled more vertically, it will dig deeper into the soil. More soil will be turned up, and there may be a positive effect on compacted layers. However, there is also a greater risk of bringing up weed seeds.

Finally, the action and aggressiveness of the row cultivator are also affected by sweep type:

- **Double points** are straight, which means they more easily penetrate the earth and work the soil more deeply. Because they are straight, they do not cover over the work done by other sweeps. However, they often prepare the soil so that the sweeps behind them, such as duckfoot sweeps or flat, conventional sweeps, are more effective.

- **Duckfoot sweeps** are triangular in shape. They work at a depth of approximately 5 cm and penetrate the soil well, as long as they are not flat. These sweeps can create ridges and thus bury weeds in the row. However, if the crop plants are at a vulnerable stage and soil displacement is undesirable, there are half sweeps that shave close to the row without creating ridges or burying weeds. Triangular sweeps can be flat (and thus parallel to the ground). In such cases, they function similarly to flat sweeps.

- **Flat sweeps** are oriented parallel to the ground. They shave the entire row middle. However, they must be employed with care (front mounting or exploiting the tool holder) or a guidance system must be used. Beet sweeps with *Lelièvre* blades have a unique form of action: they are half-sweeps, which means they can get closer to the row.

- Depending on the situation, the shank + sweep gangs can be replaced by **spider gangs**. Spiders are wheels of cutting teeth that rip out weeds and bury them with soil. Just like the rotary hoe, this type of rolling cultivator breaks up compacted soil and can be used to build up ridges.

> ***Effect of soil conditions on efficacy and selectivity***

For row cultivators to be effective, soils must be well drained (but not too dry), level, and relatively smooth.

> ***Weed control efficacy***

In contrast to the tine harrow and the rotary hoe, the row cultivator is highly effective (70–100%) at controlling more developed weeds (up to the 3- to 6-leaf stage). It can therefore be used later in the crop cycle (starting at the tiller stage for grains). However, the row cultivator does not deal well with perennials. Its shaving action can generate propagules from the rhizomes. One of the row cultivator's major limitations is that it can only effectively control weeds in the row middle. To deal with weeds growing on the row, it is necessary to get right up next to the crop plants. This task can sometimes be accomplished using discs or a finger weeder (e.g., Kress©). In all cases, it is crucial to find a compromise in which the row is sufficiently covered (5 cm of earth) without hurting the crop in place.

> ***Degree of selectivity***

As its name implies, the row cultivator should only be used with row crops, especially crops such as maize, sorghum, sunflower, soybean, lupin, faba bean, and rapeseed. Although wider row spacing is desirable and enhances selectivity, it is possible to use row cultivators to hoe grains grown in rows when row spacing is around 17.5 cm. However, a guidance system and the proper sweeps must be used.

Row cultivators display greater selectivity because they only work the row middle. If a guidance system is used (camera, sensor [e.g., photoelectric], or GPS based), weed control becomes more precise and crop plants are less likely to be damaged by cultivator gangs. However, to attain the right level of selectivity, crop plants must be relatively well developed and thus less vulnerable to the row cultivator's action. For extra reassurance, the row cultivator can be equipped with shields for protecting crop plants.

More information can be found on the ARVALIS—Institut du Végétal website:

http://www.arvalis-infos.fr/view-9365-arvarticle.html

Optimal conditions for different mechanical weed control tools

Different factors determine when the moment is right for implementing mechanical weed control. These include **crop growth stage**, **weed growth stage,** and **climatic conditions** before and after intervention.

Mechanical weed control should not hurt the crop in place. Consequently, it should only be used when crop plants are at a stage where they are not vulnerable to tool action. Early on in crop growth, it is better to use the rotary hoe (first) or the tine harrow (second). They will display greater selectivity than the row cultivator. Weeds should be in the germination stage (i.e., "white thread" stage). If the tine harrow is used, weeds can be at the 1-leaf stage; the tine harrow is more aggressive than the rotary hoe (Fig. 3). At later stages of crop growth, the row cultivator will more effectively deal with more developed weeds. It is important to note that mechanical weed control is not an effective means of fighting perennial weeds. Consequently, any weed control regime must implement preventive measures during the entire rotation.

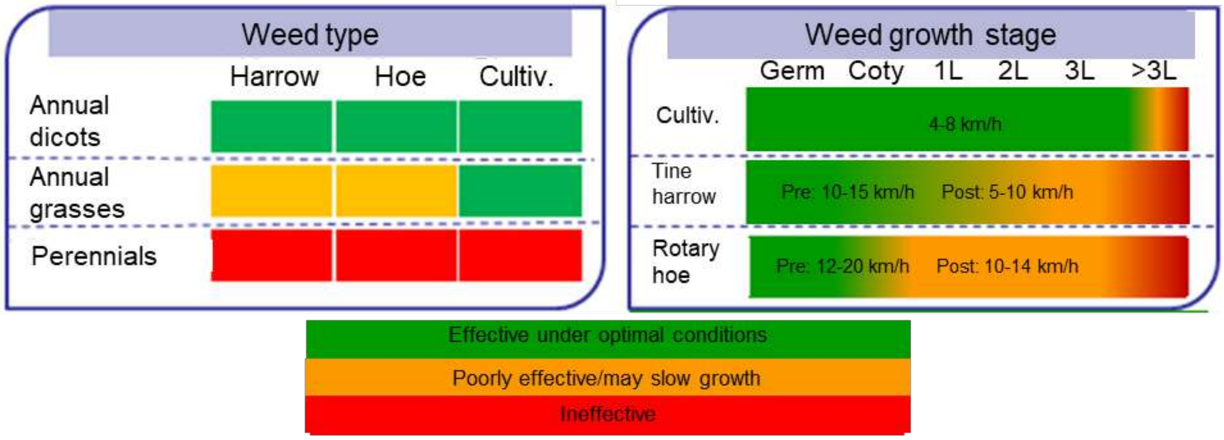


Figure 3: Relationship between tool effectiveness and weed characteristics

The feasibility and efficacy of a given tool will depend on how well the soil is drained (Fig. 4) and on climatic conditions in the days following its use. Consequently, for conditions to be right for mechanical weed control, several criteria must be met. First, the soil surface cannot not be frozen or too wet for equipment to pass. Second, there should be little to no rain the day of the operation and in the four days that follow (or the two days that follow if evapotranspiration >0.5 mm) to prevent cut weeds from re-establishing themselves.

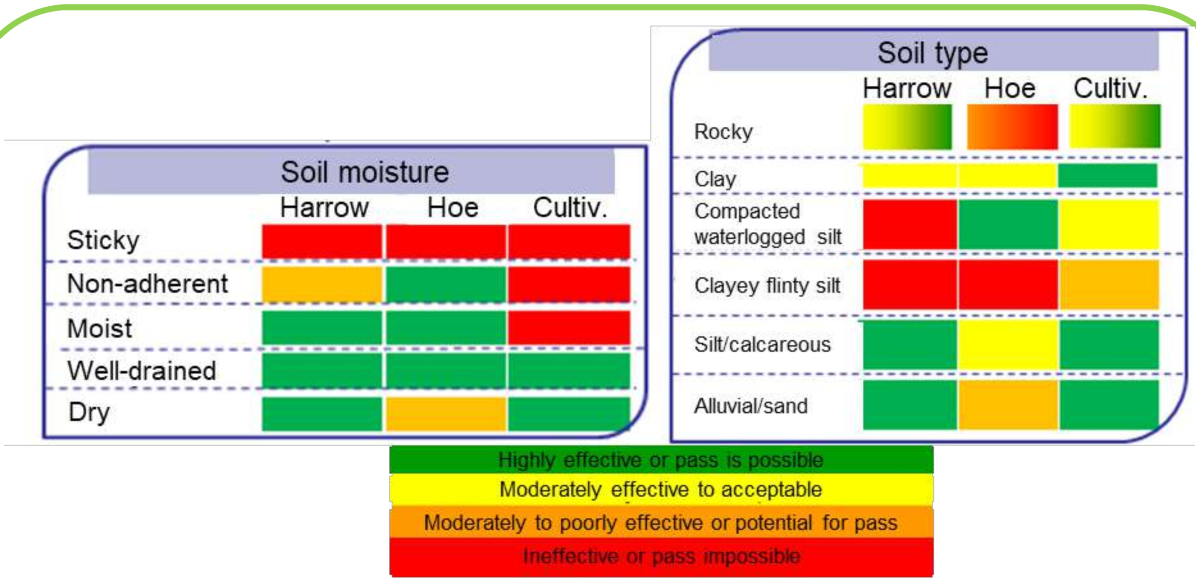


Figure 4: Relationship between tool effectiveness and soil conditions

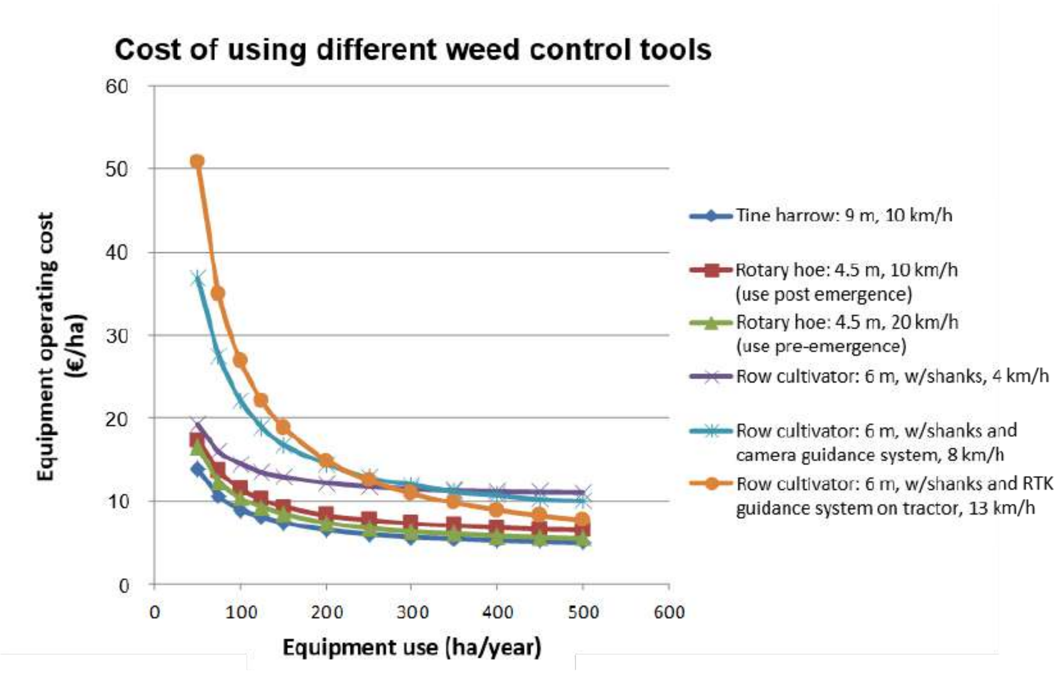
For weed control to be effective, certain criteria must be respected: the results below (Fig. 5) come from experiments on grains and maize carried by the ARVALIS—Institut du Végétal. These findings were confirmed by further research by CETIOM (in 2011).

TINE HARROW/ROTARY HOE	ROW CULTIVATOR
65% efficient under optimal conditions (±11%)	70% efficient under optimal conditions (±10%)
36% efficient on average (±30%)	46% efficient on average (±30%)
14% efficient under poor conditions (±20%)	17% efficient under poor conditions (±16%)
IMPORTANT FACTORS: Soil type and conditions, weed growth stage	IMPORTANT FACTORS: Number of days w/out rain, PET

Figure 5: Importance of conducting weed control under optimal conditions

Technical, economic, and environmental indicators

This figure can be used to estimate the cost of mechanical weed control depending on equipment characteristics, usage, and hectares covered.



Assumptions: Tractor—€52,000, 100 hp, and used 400 h/year; tine harrow—€7,000; rotary hoe—€8,700; row cultivator—€6,700; row cultivator with camera—€21,700; tractor with RTK guidance system: initial investment of €18,000 + €1,200 per year for the service contract

Organised by crop type, the second part of this guide provides examples of different mechanical weed control regimes. This information was provided by farmers who participated in surveys aimed at understanding current weed control strategies; the surveys were conducted as part of the CASDAR project.

For each regime, technical, economic, and environmental indicators were calculated; Systerre software, developed by the ARVALIS—Institut du Végétal, was used. The tables below provide median indicator values for different tools and crop types (based on one pass), which were calculated using data collected during the surveys.

	Fuel consumption (l/ha)	Primary energy consumption (MJ/ha)	GHG emissions (kg CO_2/ha)	Equipment operating costs (€/ha)	Working speed (ha/h)	Working time (h/ha)
	Median values for a single pass (calculated based on data from 31 farmers)					
TINE HARROW	2.5	117	8	14.3	4.5	0.2
ROTARY HOE	3.5	161	11	19.5	3.4	0.3
ROW CULTIVATOR	6.6	302	20	19.5	2	0.5

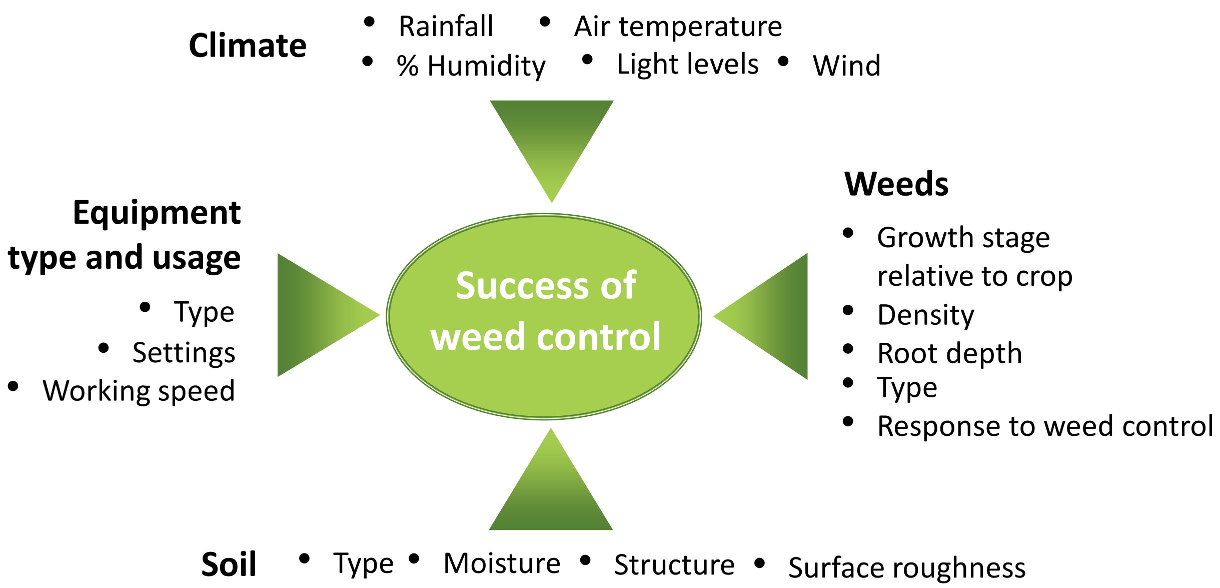
Values of technical, economic, and environmental indicators for three mechanical weed control tools
Important note**: These values were calculated based on data collected from a subset of 31 farmers. They were therefore influenced by the specific equipment and infrastructure present on those farms. Consequently,* ***they are not representative and should be used for informational purposes only.

	Fuel consumption (l/ha)	Equipment operating costs (€/ha)	Total working time (h/ha)	Number of total passes
	Median values per crop for weed control regimes with fallow-period tillage and mechanical weed control (based on survey data from 31 farmers)			
Winter grains (n=19)	45	150	2.5	6.5
Spring grains (n=3)	20	120	1.6	4.0
Winter rapeseed (n=3)	35	150	2.8	7.0
Sunflower (n=4)	70	170	4.1	8.5
Maize (n=7)	65	380	3.9	8.0
Winter faba bean (n=5)	50	160	2.4	6.5
Potatoes (n=3)	75	410	4.8	8.5

Median values of the technical, economic, and environmental indicators for the crop-specific weed control regimes employed by the farmers surveyed
***Important note**: These values were calculated based on data collected from a subset of 31 farmers. They were therefore influenced by the specific equipment and infrastructure present on their farms. Consequently, they are not representative and should be used for informational purposes only. Certain values may seem higher than normal because some farmers were highly equipped and there was variability in the survey results.*

Remember:

Many factors will determine whether weed control is successful or not



Source: Christiane Schaub, Bas-Rhin Chamber of Agriculture, citation from the ITAB 2005 guide

A farmer's experience...

An organic grain and meat poultry farm in the department of Sarthe (72)

This example underscores the importance of preventive weed control; it also illustrates the benefits afforded by mechanical tools, when used at strategic moments.

Farm description

> ***Grains and meat poultry***

> ***Usable farm area: 106 ha***

> ***Organic status obtained 10 years ago***

The fallow period

"*The only time I can control weeds is during the fallow period [...].*" The key components of Philippe's system for managing weeds during the **fallow period** are as follows:

- **early ploughing** to remove perennial weeds as soon as possible and to promote the rapid emergence of weed seedlings
- **using the stale seedbed technique** to flush and eliminate weeds before crops are planted, which limits pressure by annual weeds
- **pulling up the rhizomes** or roots of perennial weeds during the summer
- working at a **reasonable depth (10–18 cm)** to stimulate the activity of soil micro-organisms
- **working quickly** and saving fuel

Philippe replaced his traditional plough with a **stubble plough**, which better meets his needs.

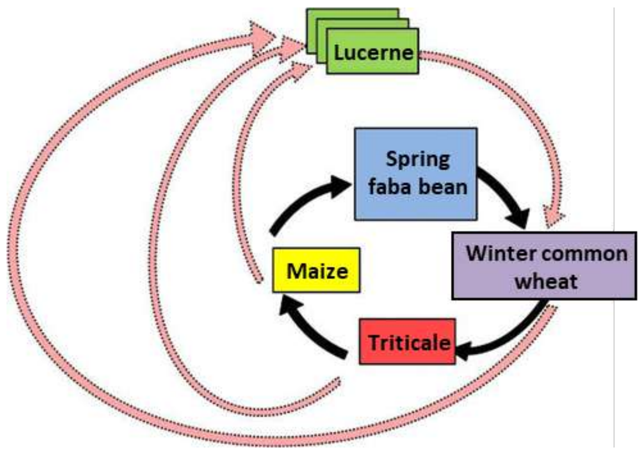
A weed control regime based on agricultural strategies and limited mechanical tool use

Constraints and objectives

"I had two initial constraints: my soils drain slowly, and I don't have much time to spend in the field when I am managing my poultry flocks." Given these limitations, Philippe has defined the following objectives:

- keeping his fields clear of weeds over the long term
- limiting the amount of time spent in the field when his other farming activities are at their busiest, notably in November, April, and July
- always working with well-drained soils
- limiting the time and energy invested

"When I leave the field after sowing, I have no intention of returning until the harvest."



The crop rotation

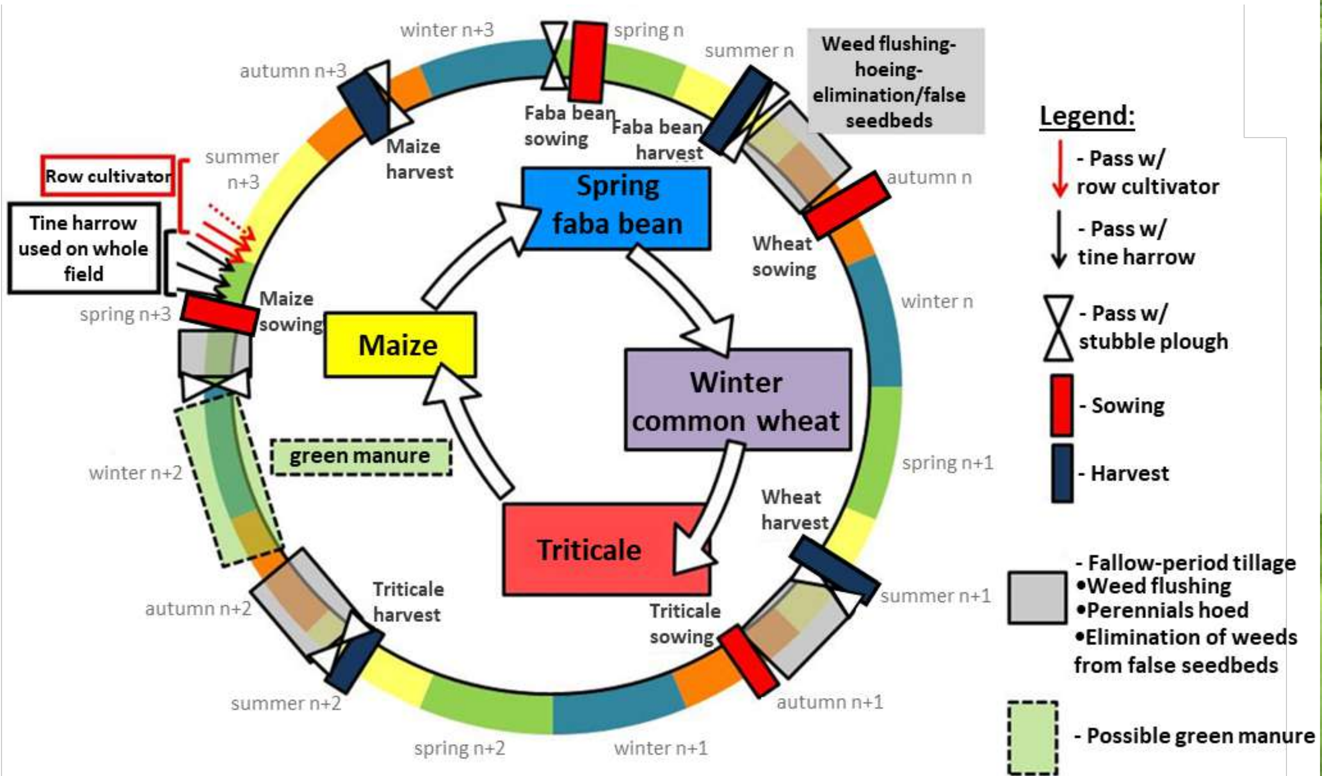
The rotation includes **lucerne**. Repeated cutting, three years without tillage, and competitive pressure—all three features help lucerne act as a cleansing crop. Lucerne also fixes atmospheric nitrogen and improves soil structure.

In the rest of the rotation, **two spring crops are alternated with two winter crops** to deal with soil horizon inversion and the presence of weed seeds.

Ultimately, mechanical weed control is only used in the maize. Delayed sowing means **weeds can be flushed** out of the seed bank several times. "*I considered letting the maize go because its yield was unpredictable. However, as a result of the passes with the tine harrow and then the row cultivator, it can actually act as a cleansing crop. I have decided to keep it.*"

Philippe sows grains and faba bean **using very narrow row spacing (3.5 cm)**. He uses a rather high sowing rate (grains: 350 seeds/m², maize: 85,000 seeds/ha). The goal is to promote weed suppression via homogeneous seedling emergence and plant cover.

However, Philippe does not choose his crop varieties based on the cover they produce; he feels that this trait is of negligible importance within his broader weed control regime. In the case of wheat, he chooses varieties displaying greater milling quality. More generally, he prefers varieties with **good seed vigour and rapid emergence**, especially for the maize.



Summary of Philippe's weed control regime, where mechanical tools play a limited but crucial role

MECHANICAL WEED CONTROL: CROP-SPECIFIC RECOMMENDATIONS

Descriptive sheet 1:

Mechanical weed control of winter common wheat (and other winter grains)

Background—Challenges

In most regions of France, black-grass, ryegrass, and bromegrass are the most common and most challenging weeds in conventionally grown wheat. In organically grown wheat, there are a wider variety of troublesome weeds. Problem groups include grasses (wild oat, ryegrass, and black-grass); perennials (thistle, dock, sorrel, and hedge bindweed); and annual dicots (vetch, charlock, wild radish, turnip weed, bristly oxtongue, and cleavers).

When controlling weeds in wheat without using herbicides, there are several criteria to consider that will determine the best agricultural strategies and mechanical approaches to use. In particular, weed type and infestation level come into play.

Preventive weed control measures

Different **agricultural strategies** can be used to control weeds. Below, we describe them in order of efficacy.

Field selection and crop sequence

When a crop is preceded by temporary grassland or lucerne, weed pressure will be significantly lower (except in the case of dock, sorrel, or wild oat). Alternating winter wheat with spring or summer crops can also reduce the pressure exerted by fall-germinating weeds (e.g., black-grass, bromegrass, ryegrass, canary-grass, common poppy, cleavers, cranesbill, speedwell, and field pansy).

Tillage

Because it buries seeds, ploughing is a method for fighting grasses (e.g., wild oat, bromegrass, black-grass, ryegrass, canary-grass, and annual meadow-grass) that takes advantage of their rather high annual loss in viability. Ploughing can also be used to control certain dicots, like cleavers. By alternating ploughing and low-level soil preparation, it is possible to prevent certain buried seeds from being brought back up and/or to force certain seeds to germinate (allowing the seedlings to be eliminated).

Ploughing and wild oat

According to HA Roberts, wild oat that emerges in the winter comes from deeply buried seeds (>25 cm) of the species *Avena ludiviciae*, while wild oat that emerges in the spring comes from shallowly buried seeds (~10 cm) of the species *Avena fatua*. Consequently, ploughing limits the spring emergence of *Avena fatua* seedlings.

Stale seedbed technique

The stale seedbed technique (and stubble ploughing) can be useful in winter grains, especially for dealing with black-grass, ryegrass, bromegrass, or autumn dicots (e.g., wild radish, mustard, cranesbill). To enhance the technique's efficacy, the date of wheat sowing can be pushed back, as long as the delay does not slow seedling growth. As a general rule, it is better to sow earlier under good conditions than later under bad conditions.

Using competitively dominant species and varieties

Some wheat varieties, such as Renan, Togano, or Pireneo, produce more cover, giving them a competitive advantage over weeds. Surveys conducted as part of the CASDAR project revealed that 40% of organic farmers exploit the competitive abilities of their crops.

Over the last 50 years, plant breeding efforts have generated varieties that are shorter and that provide less cover. At present, new breeding programs are focused on other traits that are more relevant for sustainable agriculture in general and organic agriculture in particular. Although advances have been made, it will still be several years before diverse weed-dominating wheat varieties become available.

Because different varieties have different growth cycles, it is also important to account for the types of weeds present: certain varieties produce more cover early on before becoming erect and thus less competitive, while others produce more cover later on.

Wheat varieties producing different levels of cover

Weed control during the crop season

One positive aspect of mechanical weed control in wheat is that intervention can occur at several crop stages—from pre-emergence all the way to the 2-node stage (excluding the period between emergence and the 1-leaf stage). During pre-emergence, the tine harrow and the rotary hoe effectively control germinating weeds. The tine harrow can manage 1-leaf-stage weeds, which means it can successfully replace herbicides during autumn weed control, if weather permits. From the 2-node stage to heading, the row cultivator is very effective. However, if the height of the tine harrow is adjusted for the height of the vegetation, then it can deal well with cleavers, dragging them to the edge of the field.

Tine harrow with a front-mounted row cultivator

Another positive aspect of mechanical weed control in wheat is that all available tool types can be used. The tine harrow and rotary hoe operate at the whole-field level and thus match up well with classical wheat sowing methods. However, a row cultivator can also be used as long as the spacing of the sweep fits with that used by the seed drill. Nonetheless, even if proper spacing is employed, cultivator use can diminish yield under certain circumstances. Issues may arise if the wheat is at a later growth stage and root systems are disturbed (e.g., roots are ripped apart because of a rough pass on dry soil or because a pass takes place too close to a rainfall event, disrupting root function).

Maximising the efficacy of mechanical weed control tools

The efficacy of mechanical weed control depends on several factors: tool settings, weed type and growth stage, soil type, soil conditions at the time of the pass, and weather conditions post intervention.

The next three pages describe how to optimally use the tine harrow, rotary hoe, and row cultivator to control weeds in winter wheat and other winter grains.

TINE HARROW

During the pre-emergence period, the tine harrow should only be used when soil and weather conditions have been favourable in the 4–6 days after sowing, before the coleoptile exceeds 0.5–1 cm (otherwise, there will be a risk of breakage). The working depth should be more shallow than in the post-emergence period, so as not to disturb the planted wheat seeds. Starting at the 3-leaf stage, the right balance must be struck between aggressiveness and selectivity by adjusting tine angle and working speed.

<table>
<tr><th>Winter grain growth stage</th><th>Post-sowing/
Pre-emergence</th><th>Emergence to 1 leaf</th><th>2–3 leaves</th><th>Tillering</th><th>Early stem elongation
Pseudo-stem erection
(Zadoks 30)</th><th>2 nodes
Heading</th></tr>
<tr><td>Weed growth stage</td><td>germination/
"white thread"</td><td rowspan="3">not recommended</td><td colspan="3">early growth to 2–3 leaves, max</td><td>cleavers and vetch developed</td></tr>
<tr><td>Working speed</td><td>8–12 km/h</td><td>4 km/h</td><td colspan="2">6–8 km/h</td><td>8–10 km/h</td></tr>
<tr><td>Aggressiveness
Tine angle</td><td>low to intermediate</td><td>low</td><td colspan="2">intermediate to high</td><td>intermediate</td></tr>
<tr><td>Crop loss</td><td>none</td><td>high</td><td>low</td><td colspan="2">none</td><td>none</td></tr>
</table>

Source: CASDAR project on mechanical weed control, joint report, guide CDA89

Recommendations

- Slightly increase the wheat sowing rate (by 10–15%) to compensate for potential plant losses
- Test the effects of different adjustments to the tine harrow over a few dozen metres (e.g., section or component angle); also explore the impact of working speed. Then determine which settings provide the greatest selectivity and weed control.
- During tillering, if penetration is poor, consider either doing a second pass at a different angle to the first (perpendicular or other) or making one or two preliminary passes with the rotary hoe as soon as the wheat reaches the 2- to 3-leaf stage
- If weed pressure is high during wheat tillering, start with a first pass. The next day, once the wind and sun have had an effect, do a second pass in the opposite direction ("backwards"). Doing so will remove any remaining weeds while simultaneously straightening up the crop plants.

Rotary hoe

In wheat, the conditions associated with optimal rotary hoe use are similar to those associated with optimal tine harrow use. The working depth, pressure applied to the soil, and working speed should be adjusted. During pre-emergence, soil preparation should remain rather light, especially in fluffy or very loose soil, so as not to expose the wheat seeds. Compared to the tine harrow, the rotary hoe presents less of a risk to crop plants. Consequently, sowing rate can be increased by just 5%.

Winter grain growth stage	Post-sowing/ Pre-emergence	Emergence to 1 leaf	2–3 leaves	Tillering	Early stem elongation Pseudo-stem erection (Zadoks 30)	2 nodes Heading
Weed growth stage	germination/ "white thread"	not recommended	early growth to 2–3 leaves, max			unsuitable
Working speed	12–15 km/h		15–20 km/h			
Working depth	shallow		shallow	intermediate to deep		
Crop loss	none	high	low	none		

Source: CASDAR project on mechanical weed control, joint report, guide CDA89

Recommendations

- The rotary hoe can be used in compacted soils to break up crusts, rip out young weeds, and improve grain seedling growth. It also prepares the soil for the tine harrow, which will subsequently be able to penetrate deeper and work more effectively.

Row cultivator

In contrast to the tine harrow and the rotary hoe, the row cultivator can be used later in the crop cycle and can remove more developed weeds.

For farmers who rely on row cultivators to weed their grains, one strategy is to plant their seeds in twin rows separated by 8 or 10 cm; pairs of rows are then separated by 20 or 30 cm. ARVALIS experiments (2009 and 2010) have suggested that, compared to normal spacing in organic systems, increased spacing can cause a 6–15% loss in yield. However, this pattern was not seen in the same experiment conducted in 2011. Certain high-precision guidance systems (camera based or RTK) could theoretically reduce row spacing down to 15 cm; however, further testing is needed. When row spacing is wider, then manual, wand-based, or optical-sensor-based (e.g., Précizo) guidance systems are sufficient.

Winter grain growth stage	Post-sowing/ Pre-emergence	Emergence to 1 leaf	2–3 leaves	Tillering	Early stem elongation Pseudo-stem erection (Zadoks 30)	2 nodes Heading
Working speed	not recommended			2–5 km/h		
+ camera-based guidance system				up to 14 km/h		
Crop spacing				>20 cm		
+ camera-based guidance system				<20 cm		
Crop loss	high			low		

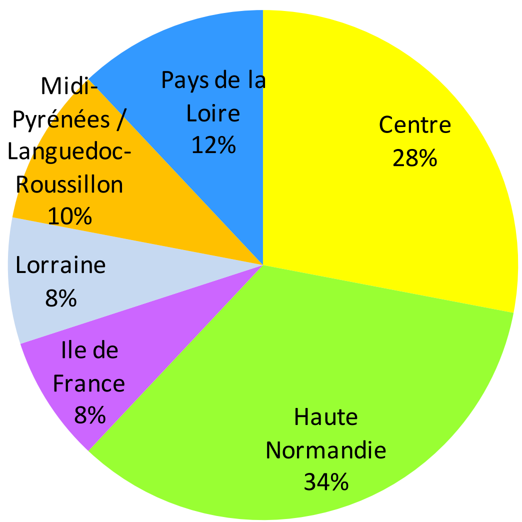
Source: CASDAR project on mechanical weed control, joint report, guide CDA89

Recommendations

- Plan ahead for weed control: adapt row spacing at sowing to correspond to cultivator spacing
- One to two days after the cultivator pass, go through with the tine harrow to break up clods; straighten up crop plants; and prevent cut weeds from re-establishing themselves
- Based on the equipment used, adapt the cultivator's working depth to prevent damage to crop plants

Diverse strategies for mechanically controlling weeds in organic agricultural systems

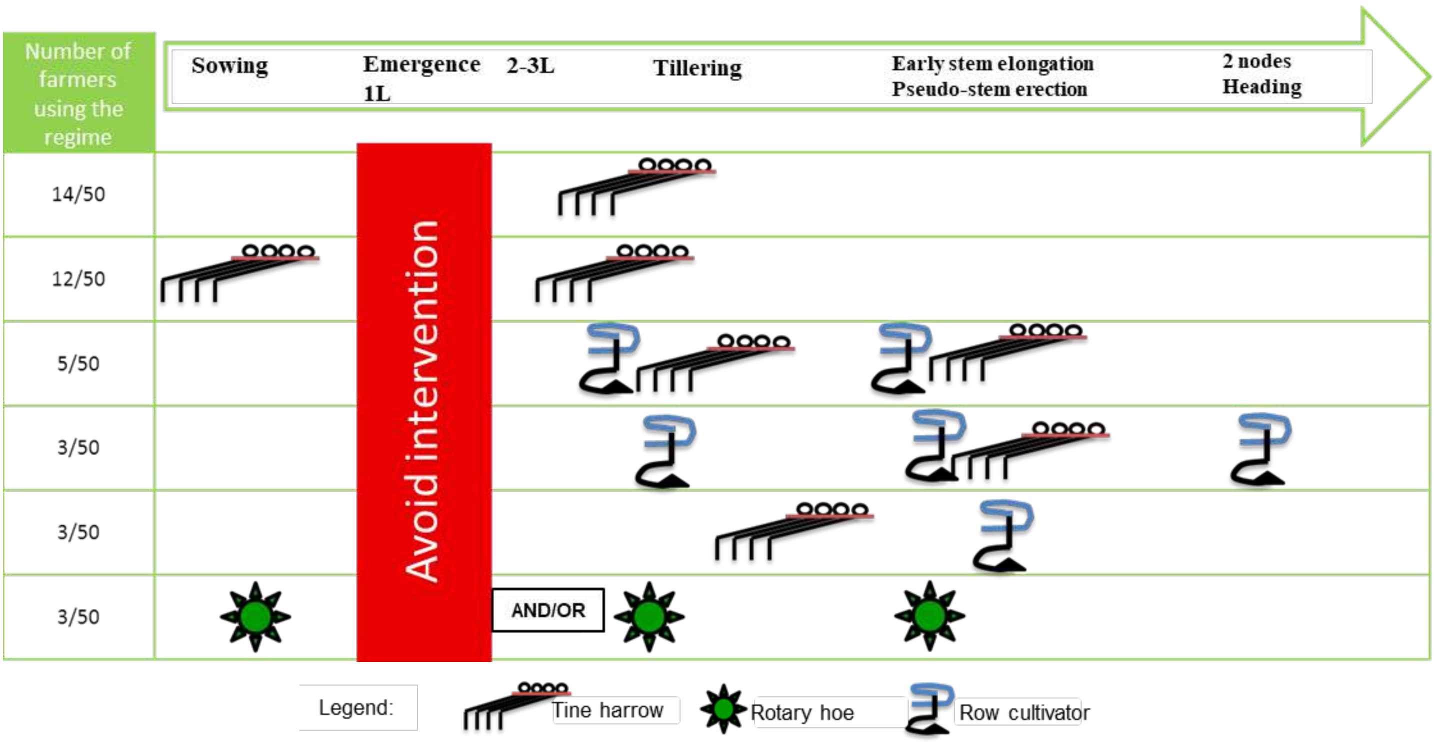
As part of the CASDAR project on mechanical weed control, 50 farmers from across France were asked about their 2009 weed control regimes. The regional distribution of those surveyed is presented in the pie chart below.



Many different regimes were used, and regime type was strongly dependent on equipment availability and the ability to act at the opportune moment. In organic agricultural systems, the tine harrow is often used on its own (one to several passes) or in association with the row cultivator (see graphic summary of the regimes below). Sometimes the rotary hoe is also employed.

Important note:

The weed control regimes summarised in the graphic below, as well as those described in the farmer case studies, were those used in 2009 by the farmers (n=19) who participated in the CASDAR surveys. Consequently, they should not be taken as fixed recommendations but rather as descriptions of real approaches used under certain pedoclimatic conditions. They reflect a range of strategies that arose in different contexts (based on soil type, climate, available equipment, etc.).



Case study...

Winter common wheat grown by an organic grain farmer in the Ile-de-France region

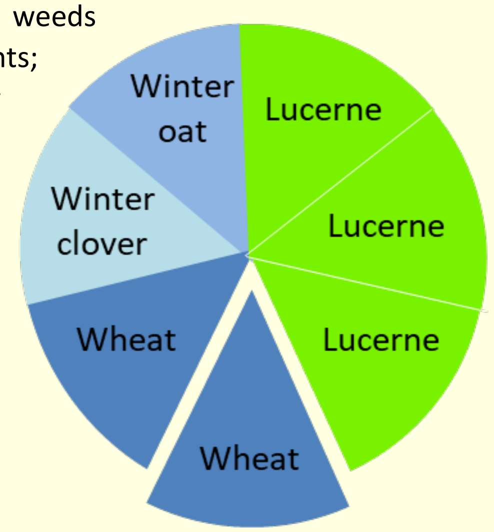
Farm description

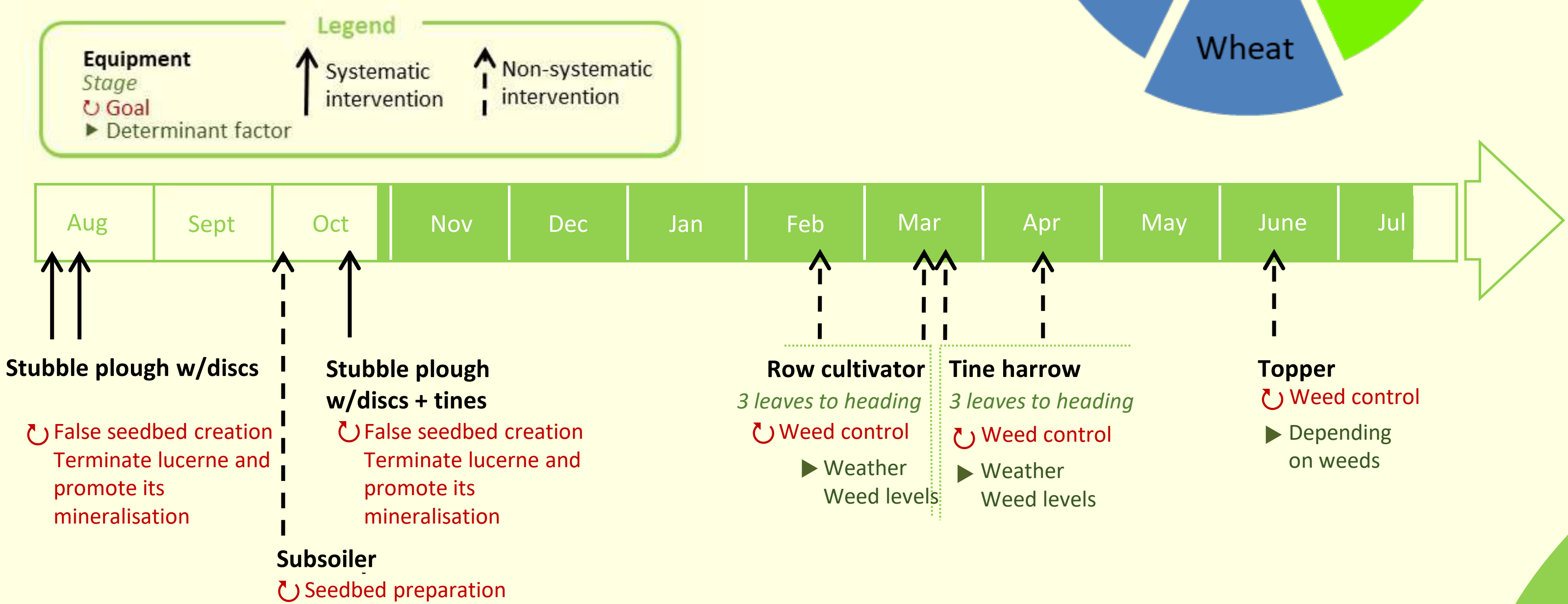
- ***Grains***
- ***Usable farm area: 162 ha***
- ***Main soil type(s): compacted silt, clayey silt***
- ***Organic status obtained 8 years ago***
- ***Equipment: 3.7 hp/ha Tine harrow—12 m (250 ha/ year), Grain row cultivator—16 rows (6 m) with camera-based guidance system (150 ha/year)***

The schematic below depicts the weed management regime for an **unploughed** field of wheat under **cold soil conditions**. The field is considered to be **rather weed infested** (black-grass, ryegrass, bent-grass, wild oat, cleavers, thistle) but in a stable state.

Why this crop rotation?

Rotation composition is a tool for managing weeds while simultaneously ensuring sufficient nitrogen levels and thus crop yields. **Lucerne**, in particular, reduces thistle pressure and increases soil nitrogen, with the help of clover (or faba bean). In this system, it is possible for **a wheat to follow a wheat** because a lucerne has come before. There are two key results: the risk of wheat diseases is greatly reduced and the second wheat benefits from the increased supply of nitrogen. **Oat (or buckwheat)** exerts strong competitive pressure on weeds and has low nitrogen requirements; it is a good solution for safely finishing off the rotation. From an economic perspective, the hay can be sold as forage and the two wheats bring in good revenue.





Why this particular weed control regime?

The field is only occasionally ploughed. **The soil is decompacted** to allow the proper termination of the lucerne. Two-fold **stubble ploughing** (with discs and tines) destroys the lucerne, promoting its decomposition and encouraging nitrogen mineralisation. This process also ensures that the first wheat in the rotation becomes properly established.

Mechanical weed control exploits **the complementarity of the tine harrow and the row cultivator**; the farmer does two alternating passes with each. The topper finishes off the work, taking care of thistles in particular. Wild oat may also be removed, although mechanical weed control often takes place too late to have a significant effect.

Economic and environmental indicators

	Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
Results for the farm's weed control regime	25	70	1.1
Median results for other farms growing winter grains (n=19)	45	150	2.5

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

Summary

+

- ***Time saving***
- ***Good organisation (systematic passes)***
- ***Equipment adjusted accordingly***
- ***Low operating costs***
- ***Use of ploughing depends on the crop, crop-specific weed management needs, and weed type***

-

- ***Lack of ploughing can be risky***
- ***Equipment works too deeply (5–10 cm with disks and tines) and reduces pass efficacy***
- ***Cover crops must be carefully considered, given the numerous passes made with the tools***

Case study...

Winter common wheat grown by an organic grain farmer in the Centre region

Farm description

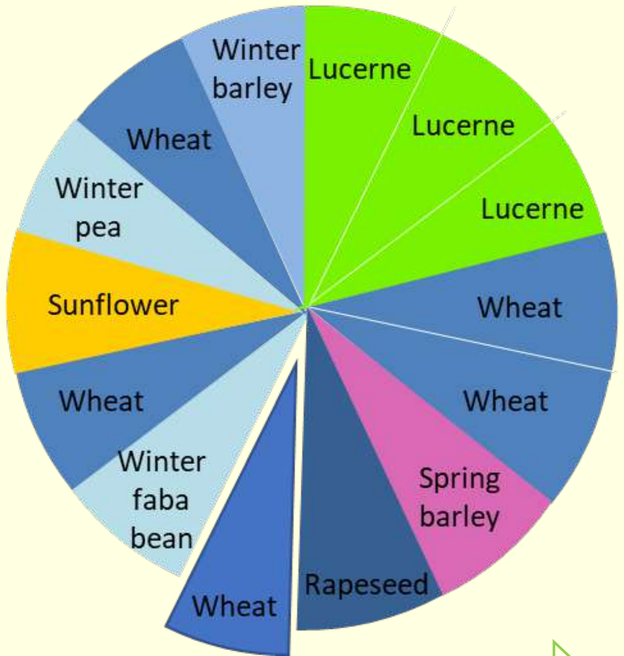
> *Grains*
> *Usable farm area: 153 ha*
> *Main soil type(s): silts, sands, and gravels*
> *Working towards organic status since 1999; full conversion expected by 2012*
> *Equipment: 2.3 hp/ha*
> *Tine harrow—9 m,*
> *2 Grain row cultivators—4 m, Rotary hoe—6 m,*
> *Topper—6 m*

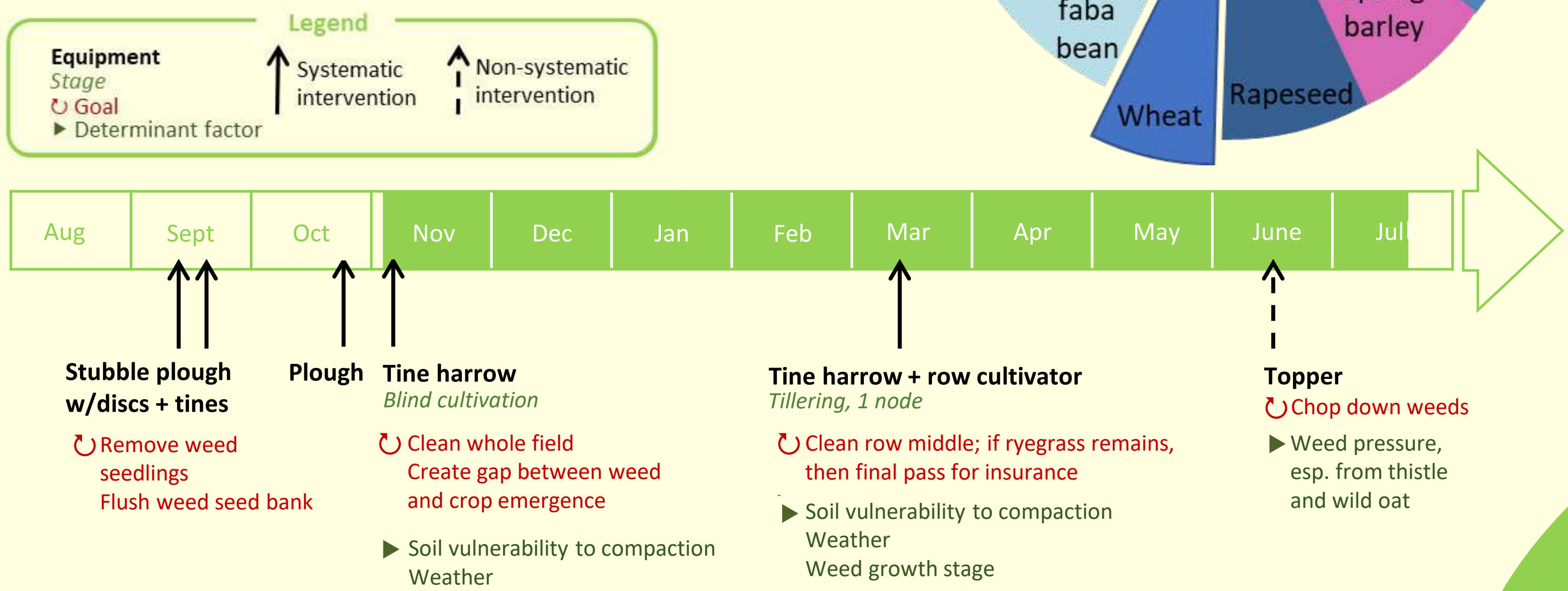
In this case study, the field is considered to be **fairly weed free**.

Why this crop rotation?

This farm has rather heterogeneous soils. The rotation is used on shallow soils, which is why there is a small proportion of spring crops. It begins with a lucerne, a crucial crop that controls perennial weeds, improves soil structure, and supplies nitrogen. The rotation is rather long (14 years) but can be shortened if weed levels climb too high. In such a case, it is reinitiated, starting with the lucerne. **Weed control is the farmer's top priority**.

Soil **fertility** is maintained by alternating, to the greatest degree possible, more-nitrogen-demanding crops and less-nitrogen-demanding crops, with legumes serving as intermediate crops. Diverse types of organic fertiliser (plant-based compost, horse manure, and poultry droppings) are added regularly.





Why this particular weed control regime?

Systematic **ploughing** is used to control weeds although the farmer is currently considering a no-till system. In this field, wheat is sown in twin rows (8.5 cm) with row spacing of 28 cm. **Ryegrass and black-grass** are the main weeds found in the wheat. They are managed using tillage and mechanical weed control during the crop season. Blind cultivation is carried out with the tine harrow in the week after sowing, if conditions allow, and again in the spring. Then, two passes are done with the row cultivator and the tine harrow in succession. The last pass is done just to be **safe**. Weed infestation levels, soil vulnerability to compaction, and weather conditions will determine when interventions take place.

Economic and environmental indicators

	Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
Results for the farm's weed	70	160	4.6
Median results for other farms growing winter grains (n=19)	45	150	2.5

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

Summary

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> *Managing weeds and ensuring system safety: keeping fields clear over the longer term*
> *Full suite of equipment means farmer can adapt the regime to climatic conditions and weed pressure*
> *Significant effect of lucerne*
> *Spring lentil can be grown instead of winter faba bean*

-

> *Many passes = high fuel consumption and long working hours*
> *Thought must be given to fallow period management*
> *Spring crops are needed to deal with the ryegrass and black-grass; however, they are hard to use because of pedoclimatic conditions*

Case study...

Winter common wheat grown by an organic sheep farmer in the Midi-Pyrénées region

Farm description

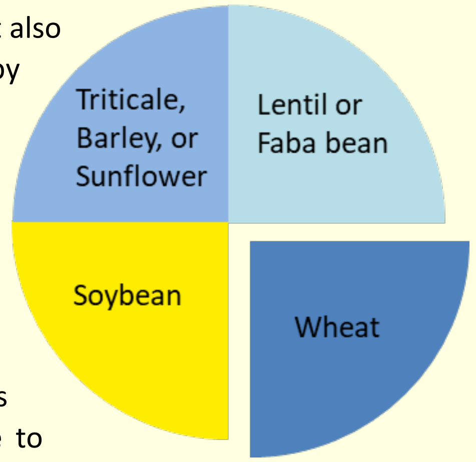
- *Mixed cropping and sheep production (2 labour units)*
- *Usable farm area: 180 ha (120 ha are irrigated)*
- *Main soil type(s): calcareous clay*
- *Organic status obtained 7 years ago*
- *Equipment: 3.7 hp/ha Tine harrow—12 m*

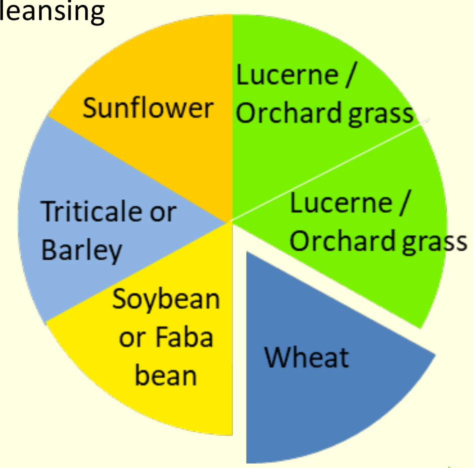
The schematic below depicts the weed management regime for an **irrigated, unploughed** field of wheat. This field is considered to be **minimally infested** by weeds (wild oat, thistle, speedwell, cleavers, ryegrass, mustard).

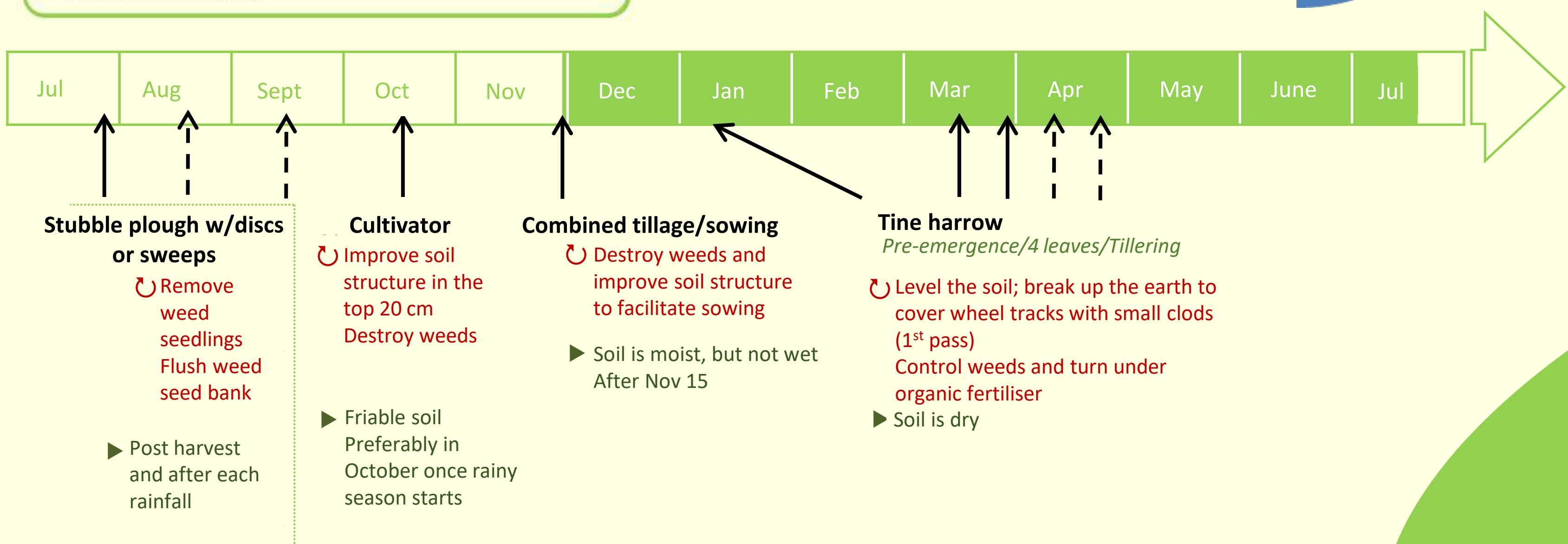
Why this crop rotation?

This farm comprises steep and flat terrain. It also uses irrigation. Soil **fertility** is maintained by employing organic fertiliser—manure from the sheep flock (established in 2006); planting 30 ha of grasslands composed largely of legumes; incorporating legume crops into the rotation; adding 800 T of composted manure before the sunflower; and adding 1–1.5 T of bone powder as fertiliser to the grains. The grains systematically precede or follow a **legume** to benefit from its fertility-enhancing and cleansing effects (reversed crop cycle or row crop).

Triticale is grown when there are annual weeds (e.g., wild oat, ryegrass, mustard, cleavers, or speedwell) that may hamper grain growth.







Why this particular weed control regime?

For the last 15 years, this farm has replaced ploughing with **deep, tine-based tillage** before the summer crops. The main goal is to maintain levels of organic matter and to promote the activity of micro-organisms at the soil surface. Both enhance soil fertility while limiting erosion on the farm's very steep slopes. Although the soil is loosened (without using winged sweeps), perennial weeds (e.g., thistle) remain in fields that are not planted with lucerne. **Mechanical tool use follows a pre-established order**. The factors that determine when passes can occur are soil moisture, post-intervention weather, wheat growth stage, weed density, and weed growth stage. With the **tine harrow**, it is possible to control winter weeds that did not emerge during the fallow period (mustards, various knotweeds, grasses). However, because the harrow is only used once the seedlings have reached the 4-leaf stage, and are sometimes well rooted, there is room for improvement in the regime.

Economic and environmental indicators

	Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
Results for the farm's weed	50	150	1.7
Median results for other farms growing winter grains (n=19)	45	150	2.5

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

Summary

+

- *Alternation of different crop types*
- *No ploughing despite vulnerability of irrigated crops to summer infestations*
- *Relatively weed-free fields despite lack of manual intervention*
- *Operating costs = average for survey group*

-

- *Recurrent infestations of thistle and wild oat in fields that do not experience lucerne*
- *Absence of rotary hoe, which can be used starting at the 2-leaf stage*
- *Farmers not always available when soil conditions are favourable*

Case study... Winter common wheat grown by an organic livestock farmer in the Lorraine region

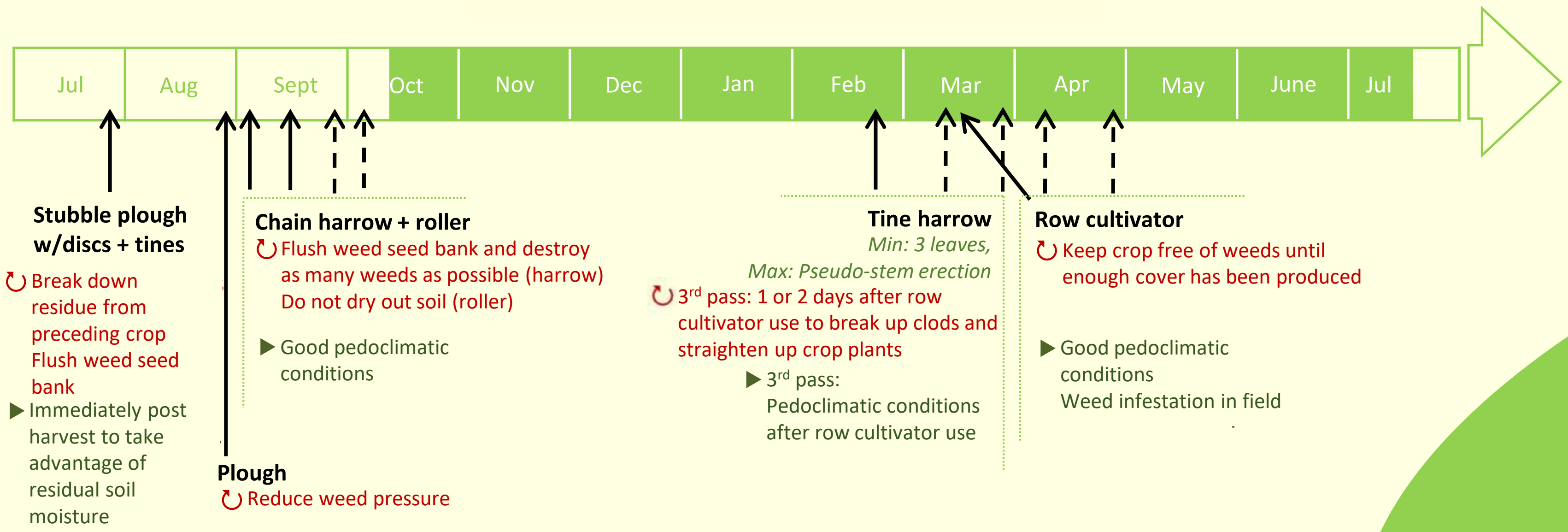
Farm description

- *Mixed cropping and poultry production*
- *Usable farm area: 75 ha*
- *Main soil type(s): shallow and rocky calcareous clay*
- *Organic status obtained 5 years ago*
- *Equipment: 2.1 hp/ha Tine harrow—12 m (100 ha/ year), Grain row cultivator—16 rows (6 m; 30 cm spacing) with camera-based guidance system (275 ha/year) from agricultural equipment co-operative (CUMA)*

The schematic below depicts the weed management regime for a field of wheat during a **short rotation**. The field is considered to be **rather weed infested**.

Why this crop rotation?

There are two basic rules on this farm: winter and spring crops should be systematically **alternated**, and a **cover crop should be planted during the long fallow period**. Also, the crops in the rotation must **correspond to the needs of the farm's livestock system**.



Why this particular weed control regime?

Because of climatic conditions, the farmer must carefully consider how to best combine different soil preparation practices. For instance, in wet years, the stale seedbed technique is implemented several times and the wheat is sown late; in dry years, the technique is used less and the wheat is sown early, allowing it to grow as much as possible before the winter. When conditions are dry, mechanical weed control usually takes place in the spring.

The row cultivator is used almost exclusively in the spring, except in the most infested fields. When climatic conditions allow it, passes with the tine harrow are systematically carried out in the two days following row cultivator use.

Economic and environmental indicators

	Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
Results for the farm's weed	30	190	2.5
Median results for other farms growing winter grains (n=19)	45	150	2.5

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

Summary

+

- *Rotation adapted to livestock farming*
- *Alternation of winter and spring crops*
- *Spring naked oat is a good preceding crop for controlling weeds*
- *High-precision guidance system allows the row cultivator to have a good working speed (2 ha/h)*

-

- *Short rotation*
- *Frequent interventions during the fallow period and crop season, but working time is optimised*

Case study...

Mixed grains grown by an organic dairy farmer in the Brittany region

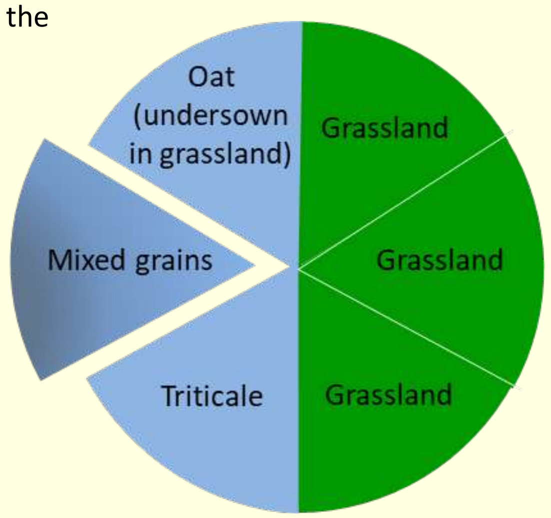
Farm description

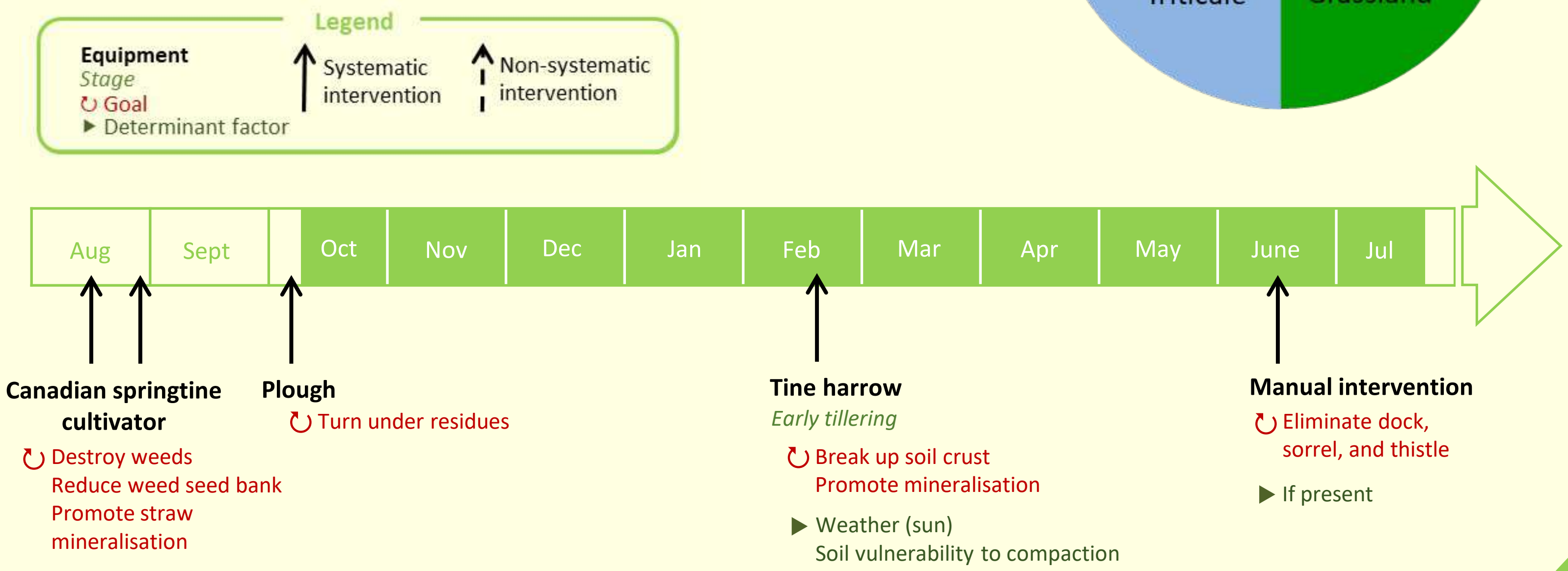
- *Dairy*
- *Usable farm area: 48 ha*
- *Main soil type(s): sandy silt*
- *Organic status obtained 16 years ago*
- *Equipment: 2.9 hp/ha Tine harrow—9 m (15–20 ha/year)*

In this case study, the field of mixed winter grains, which was **ploughed**, is considered to be **fairly weed free** (some vetch, dock, sorrel, thistle, and wild radish).

Why this crop rotation?

This is a rotation that is commonly found in systems with grazed grasslands. On livestock farms, **long-term multispecies grasslands** are of critical importance. They serve as the basis for the forage system, increase soil nitrogen, and dilute the weed pool. In the rotation, the grassland is followed by a single grain crop, which will take advantage of the nitrogen supply and weed-free conditions. Then, a grain-legume association will be used to provide soil cover and suppress weeds. The next step is to simultaneously sow oat, for cover, and a mixed grassland. In the spring, the oat is harvested as hay, but the grassland is left in place. This approach allows the grassland to become properly established and limits the number of passes made.





Why this particular weed control regime?

In this regime, **stubble ploughing and ordinary ploughing** are systemically paired to destroy weeds, turn under residues, and obtain the most level seedbed possible, which is key to successful mechanical weed control. The tine harrow is used coming out of the winter, when the mixed-grain crop does not completely cover the soil. There is no need for a second pass because of the cover generated by the mixture. Manual weed control is carried out on any perennial weeds (dock, sorrel, and thistle) that the tine harrow cannot eliminate.

Economic and environmental indicators

	Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
Results for the farm's weed control regime	45	140	3.4
Median results for other farms growing winter grains (n=19)	45	150	2.5

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

Summary

+

- *Good organisation (regime is informed by past experience)*
- *Operating costs are lower than average*
- *Rotation composition limits the need for mechanical weed control (longer-term grassland, weed-suppressing mixed-grain crop, undersown grassland)*

-

- *Significant time invested in manual weed control (farmer wants weed-free field)*

DESCRIPTIVE SHEET 2:

MECHANICAL WEED CONTROL OF WINTER AND SPRING FABA BEAN

BACKGROUND—CHALLENGES

Effective weed control is essential to the successful production of faba bean. However, weed management begins well before the crop is even sown. Several preventive measures must be taken, each as important as mechanical weed control. These measures involve rotation design (including faba bean's place therein), sowing methods, establishment techniques, and row spacing.

Winter faba bean is generally sown rather late and rather deep. It emerges and develops very slowly. In the end, from a vegetative perspective, it differs by just 15–21 days from spring faba bean. Because weed control strategies are very similar for both crops, they will be described together here.

The decision of whether to plant winter faba bean or spring faba bean will largely hinge on soil type (drying ability) and climate-related risks (i.e., freezing temperatures for winter faba bean and hot temperatures during flowering for spring faba bean). For both crops, weed pressure is concentrated towards the end of the crop cycle.

Full-grown faba bean

PREVENTIVE WEED CONTROL MEASURES

Field selection and crop sequence

In general, the faba bean occurs mid rotation, after two years of grains (common wheat or a secondary grain), maize, or sunflower. The exact order is determined for each field, based on its history and "experience" with weeds. If grasses are ubiquitous (e.g., ryegrass or wild oat), then it is better to use a rotation that includes spring crops. If dicots dominate the weed community, then faba bean can be included in a rotation with other winter crops.

See the figure on the following page for clarification.

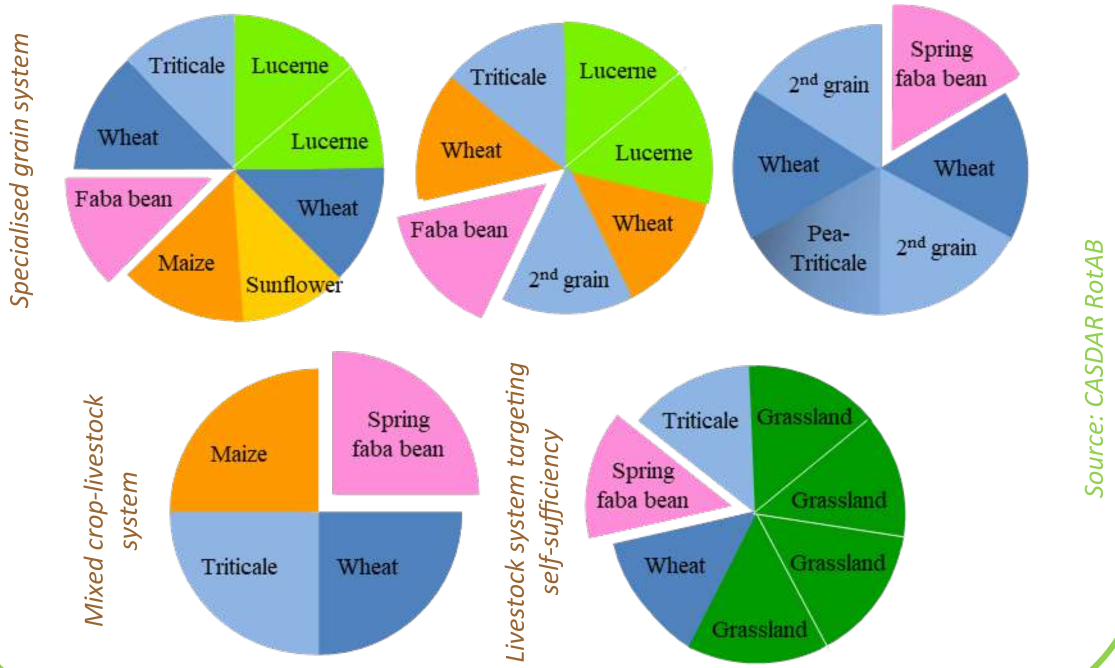
Preparing to sow

> ***Stale seedbeds and fallow-period tillage***

The fallow period between a grain (common wheat, triticale, or spring barley) and a faba bean leaves enough time to implement the stale seedbed technique and flush weed seeds, especially if there is no ploughing. Throughout this period, tillage can weaken perennials and drain the weed seed bank. For example, the optimal period for black-grass germination is in September and early October. Consequently, if the stale seedbed technique is used in late August, it will do little to diminish levels of this weed.

Examples of rotations with faba bean

Unless otherwise specified, a rotation can include either winter or spring faba bean



In certain regions, legislation requires that cover crops be planted before the spring cash crop. For example, after stubble ploughing, a mustard could be planted until mid-September or, if the field is already weed free, a brassica/grass mixture could be planted post harvest. It will then be necessary to shred the cover and plough the soil.

Faba bean is harvested in July-August (depending on the region). This means that tillage can be an effective tool in eliminating germinating weeds during the fallow period, in preparation for the following crops.

> ***Sowing***

It is better to sow faba bean **rather deeply** (6–8 cm for winter faba bean if possible and at least 5 cm for spring faba bean). The goal is to protect seeds from birds and (potential) freezing temperatures. This greater sowing depth is an advantage when mechanical weed control is used.

As compared to winter faba bean, spring faba bean prefers deeper, well-drained **soils** with good water reserves: it has a low tolerance for high temperatures and drought during flowering and grain ripening.

The faba bean is fine with **wider row spacing,** a requisite for row cultivator use (>20 cm). The weed control strategy will therefore dictate row spacing:

- It should be between 20 and 40 cm if the row cultivator will be used; watch out—faba bean is slow to generate cover, so the risk of weeds developing is greater.
- It should be 17 cm (use of grain seed drill) if the row cultivator will not be used.

Although the **sowing rate** can be adjusted to help limit weeds, overly high crop densities are problematic. They will not necessarily prevent later weed infestations, and the high biomass levels are harmful to grain production and can often lead to lodging. Light sowing will reduce disease risks, and precise sowing will help reduce waste (see the table on the following page).

> ***Sowing date***

For winter faba bean, late establishment—in November—means that sowing takes place during a period when weed emergence is less pronounced.

For spring faba bean, sowing should take place as early as possible when soils are in good condition and well drained—from mid-February to mid-March—even if the upper soil layer is still frozen. Soils must not be compacted. They do not need to have fine texture either.

Sowing rate (seeds/m²) based on drill and soil type

Soil type	Type of seed drill	
	Precision	Classic
Silty	25–30 (SFB) *20–25 (WFB)*	30–35 (SFB) *25–30 (WFB)*
Clayey	35–40 (SFB) *20–25 (WFB)*	45–50 (SFB) *25–30 (WFB)*

(SFB: spring faba bean;
WFB: winter faba bean)

(Based on the official 2004 faba bean description sheet for CA77 and CA IdF)

These sowing rates are for informative purposes only and will depend on local conditions and sowing equipment. It is important to note that sowing rates should be higher for compacted silty soils if winters are rainy and springs are wet. Other details are available in the faba bean description sheet, which can be downloaded from ITAB's website: http://www.itab.asso.fr/publications/fichestechniques.php

Weed control during the crop season

Maximising the efficacy of mechanical weed control tools

Pedoclimatic conditions dictate how mechanical weed control tools can be used. Under the same climatic conditions, tool use may be difficult to impossible on compacted or waterlogged silty soils (especially from December to March), while it can be very effective on calcareous clay soils, which drain rapidly, thus increasing the number of days on which weed management can take place.

The next two pages describe how to optimally use the tine harrow, rotary hoe, and row cultivator to control weeds in faba bean.

Tine harrow in faba bean field

Tine harrow

The tine harrow can be used for blind cultivation, from right after sowing to the 8-leaf stage. However, it is best to avoid any intervention between emergence and the 2-leaf stage. The faba bean does not mind being partially buried. The tine harrow is most effective when weeds are not very well developed.

Faba bean growth stage	Post-sowing/ Pre-emergence	Emergence to 1 leaf	2–4 leaves	4–8 leaves
Weed growth stage	germination/ "white thread" (optimum)	strongly discouraged	cotyledon, 2 leaves max	
Working speed	7–8 km/h		3–4 km/h	up to 10 km/h when crop reaches 10 cm
Tine aggressiveness	intermediate		low	high
Crop loss	none	high	none to low	

Rotary hoe

The rotary hoe displays a high degree of selectivity when used in faba bean. It can be employed for blind cultivation (if seeds are buried deep enough), and it is easy to adjust. However, in faba bean, its use is strongly discouraged between cotyledon emergence (folded scale leaves visible) and the 2-leaf stage as well as past the 8-leaf stage. It is also important to intervene when weeds are young.

Faba bean growth stage	Post-sowing/ Pre-emergence	Emergence to 1 leaf	2–4 leaves	4–8 leaves
Weed growth stage	germination/ "white thread" (optimum)	strongly discouraged	"white thread" (optimum) effective until 2-leaf stage	
Working speed	15 km/h		12–20 km/h	
Working depth	shallow		intermediate	deep
Crop loss	none	high	none to low	low (after 8-leaf stage, risk of stem breakage)

Row cultivator

The row cultivator can remove well-developed weeds and limit the growth of certain perennials, but it cannot necessarily deal with weeds in the row itself. That said, it is possible to use a sweep (duckfoot or winged, depending on spacing) during the last pass to throw dirt against the row and bury weeds. Another possibility is to employ a finger weeder (e.g., Kress©; speed: 3–6 km/h). To use the row cultivator in faba bean, it is important to properly space rows at sowing, so that there is enough room for the wheels to pass. However, the cultivator should not be used once any flowers have appeared or when crop height exceeds tractor clearance.

Faba bean growth stage	Post-sowing/ Pre-emergence	Emergence to 2 leaves	2–4 leaves	4–8 leaves
Working speed	use is discouraged		3 km/h	5 km/h
Component choice			use shields or Lelièvre blades to avoid burying crop	throw dirt on the row during the last pass by raising the shields (or via sweep action, where appropriate)
Guidance system			GPS, camera, tracking devices—all improve work accuracy and precision	
Cultivator/tractor configuration			Front mounted: improves comfort Tool holder: improves precision Rear mounted: traditional; reduced precision	
Crop loss	very high		none to low (occurs if plants buried)	none

Case study...

Spring faba bean grown by an organic grain farmer in the Brittany region

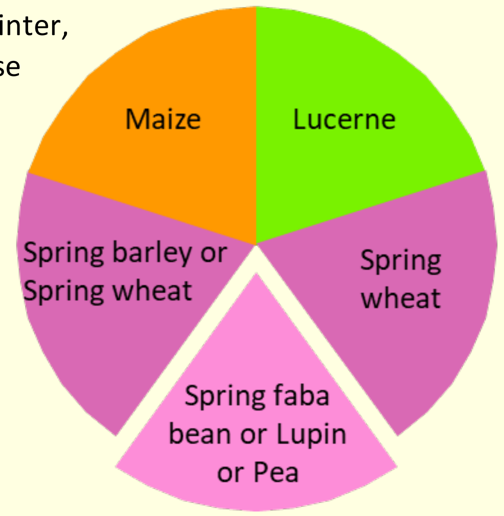
Farm description

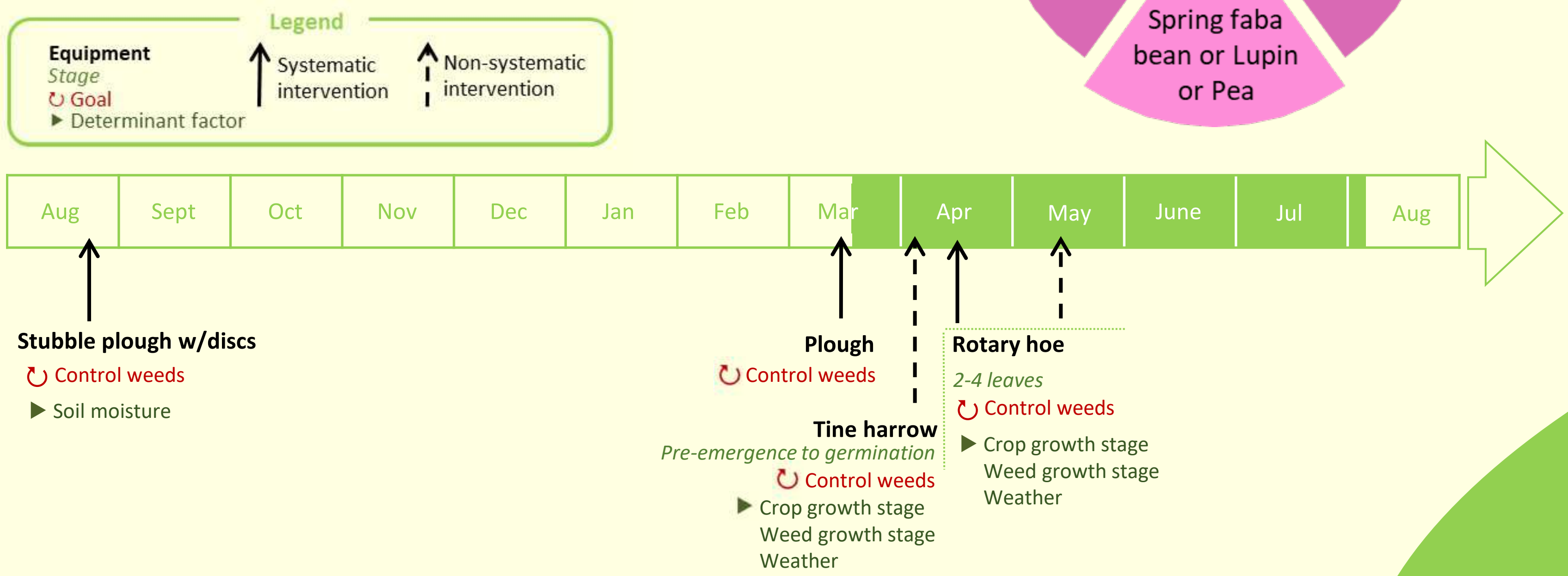
- ***Grains***
- ***Usable farm area: 40 ha***
- ***Organic status obtained 10 years ago***
- ***Main soil type(s): waterlogged, light, and fast drying***
- ***Equipment: 6.2 hp/ha Tine harrow—9 m (40 ha/year), Rotary hoe—5 m (40 ha/year)***

The faba bean occupies a **somewhat risky** position (follows a wheat) in a rotation that is also somewhat risky (rather short in duration—5 years—with 1 year of lucerne, composed of just spring crops and maize). **Ploughing** systematically occurs before the faba bean is planted. The field is considered to be **rather weed infested but in a stable state**. The main weeds are knotweed, wild radish, common fumitory, and fat hen.

Why this crop rotation?

This rotation only comprises **spring crops**; given the farm's pedoclimatic conditions, this crop type is the easiest in which to mechanically control weeds. Using **lucerne** as a head crop has a cleansing effect on the rotation, especially with regards to thistle and sow thistle. **Faba bean** is planted in the middle of the rotation as a nitrogen booster, which will allow one or two years of grains to follow. The farmer regularly plants **cover crops** to cover the soil in the winter, improve soil structure, and increase soil fertility. These cover crops are terminated in the spring, before the spring cash crops are planted.





Why this particular weed control regime?

The farmer owns a rotary hoe, tine harrow, and row cultivator. He carries out weed control **as needed**, depending on the year's conditions and the field's level of weed infestation. Both the faba bean and the grains are sown using a **row spacing of 25 cm**, which leaves sufficient room for the row cultivator and allows the tine harrow to work more aggressively. The **sowing rate is the typical one**, which means plant density in the row is higher and weeds are crowded out.

Economic and environmental indicators

	Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
Results for the farm's weed control regime	25	160	1.9
Median results for other farms growing faba bean (n=5)	50	160	2.4

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

Summary

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- ***25-cm row spacing allows room for the row cultivator (if needed)***
- ***Full suite of equipment means farmer can adapt the regime to climatic conditions and weed pressure***
- ***Cover crops are part of the rotation***

-

- ***Difficult to keep weeds out of the faba bean***
- ***Little organic matter available***

Case study...

Spring faba bean grown by an organic grain farmer in the Brittany region

Farm description

> *Grains*

> *Usable farm area: 39 ha*

> *Main soil type(s): silts, granitic soil*

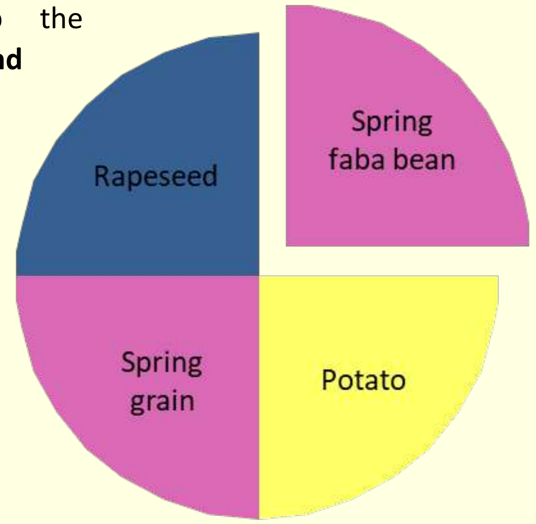
> *Organic status obtained over 19 years ago*

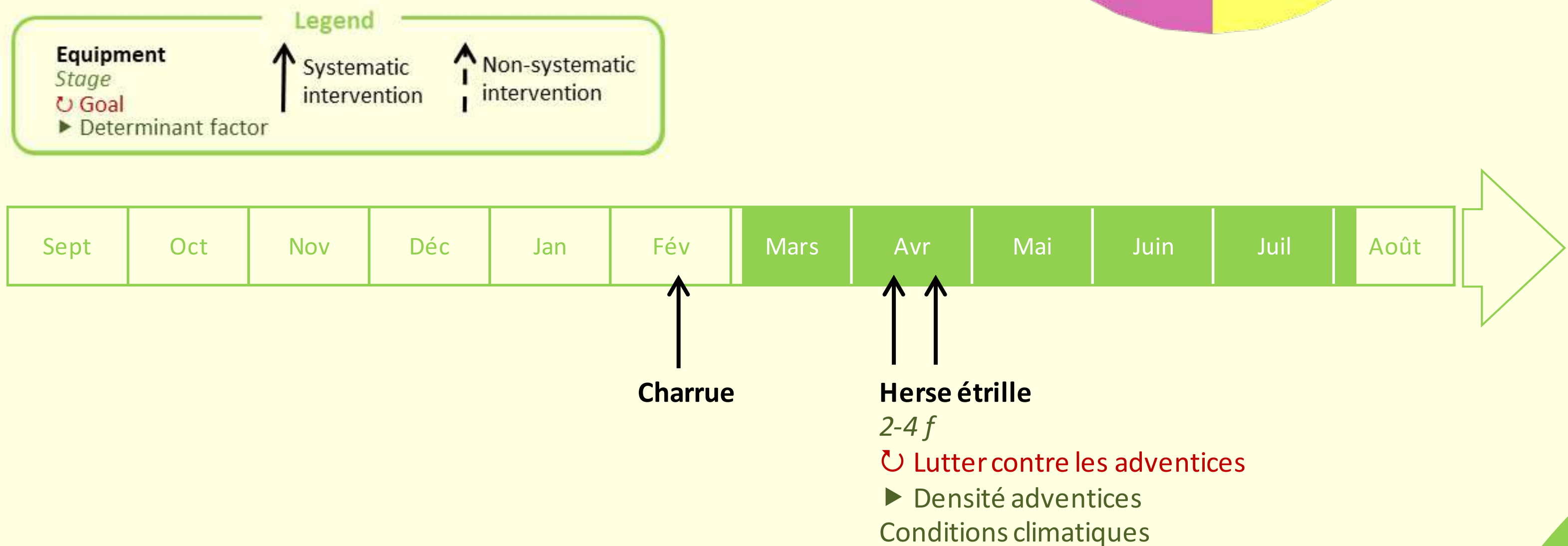
> *Equipment: 5.5 hp/ha Tine harrow—6 m (40 ha/year), Row cultivator—3 m (30 ha/ year)*

In this case study, faba bean is planted in granitic soil. It has a somewhat risky place (preceding crop: winter rapeseed) in a rather risky rotation (four years long, no perennials, just one winter crop). **Ploughing** systematically occurs before the faba bean is planted. The field is considered to be **rather weed infested**.

Why this crop rotation?

There are no livestock on this farm; the rotation seeks to improve soil fertility. The faba bean will **release nitrogen** to the following cash crop: the potato. Indeed, the main goal of the rotation is to **increase potato yield**. Incorporating a protein crop into the rotation helps break up the **sequence of grains and potatoes** (grown for plant production).





Why this particular weed control regime?

The weed control regime includes **two passes (at most) with the tine harrow**. The farmer does not have a rotary hoe. It could be helpful in this cropping system, but he cannot afford it on his own.

Strategies involving **cover crops**, which suppress weeds and improve soil fertility, were greatly developed in 2011. The farmer plans to undersow white clover as a cover crop in the faba bean (always a monoculture), which will be planted in 2012. The clover will be sown during the pass with the tine harrow at a sowing rate of 4.5 kg/ha. The goal is to limit weed growth and generate soil cover that will last through the harvest of the faba bean.

Economic and environmental indicators

	Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
Results for the farm's weed control regime	30	90	2.4
Median results for other farms growing faba bean (n=5)	50	160	2.4

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

The passes with the **tine harrow** consume a lot of fuel because the **working speed is very low** (small tool wdith: 6 m). However, the indicators all have low values because **the number of passes is very low**.

Summary

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> ***Available equipment especially suited to tillage***

> ***Use of fallow-period cover crops***

-

> ***Short rotation; the farmer wants to find 5 ha of land to improve the rotation***

> ***No rotary hoe at present, but farmer plans to acquire one, which would enhance the mechanical weed control regime***

Case study...

Winter faba bean grown by an organic grain farmer in the Centre region

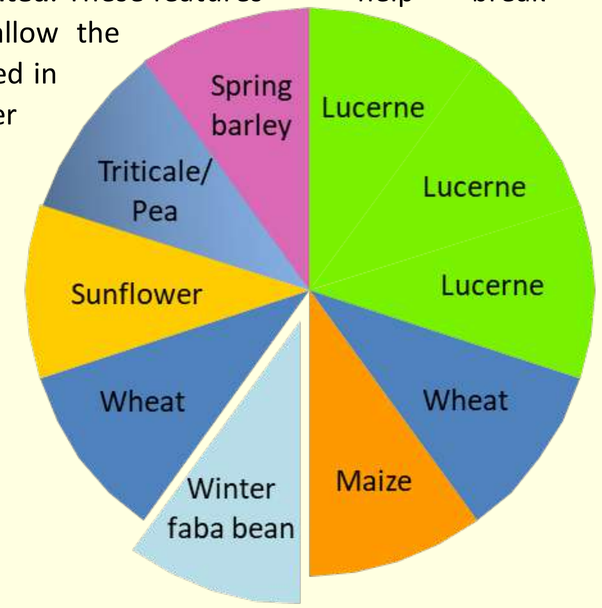
Farm description

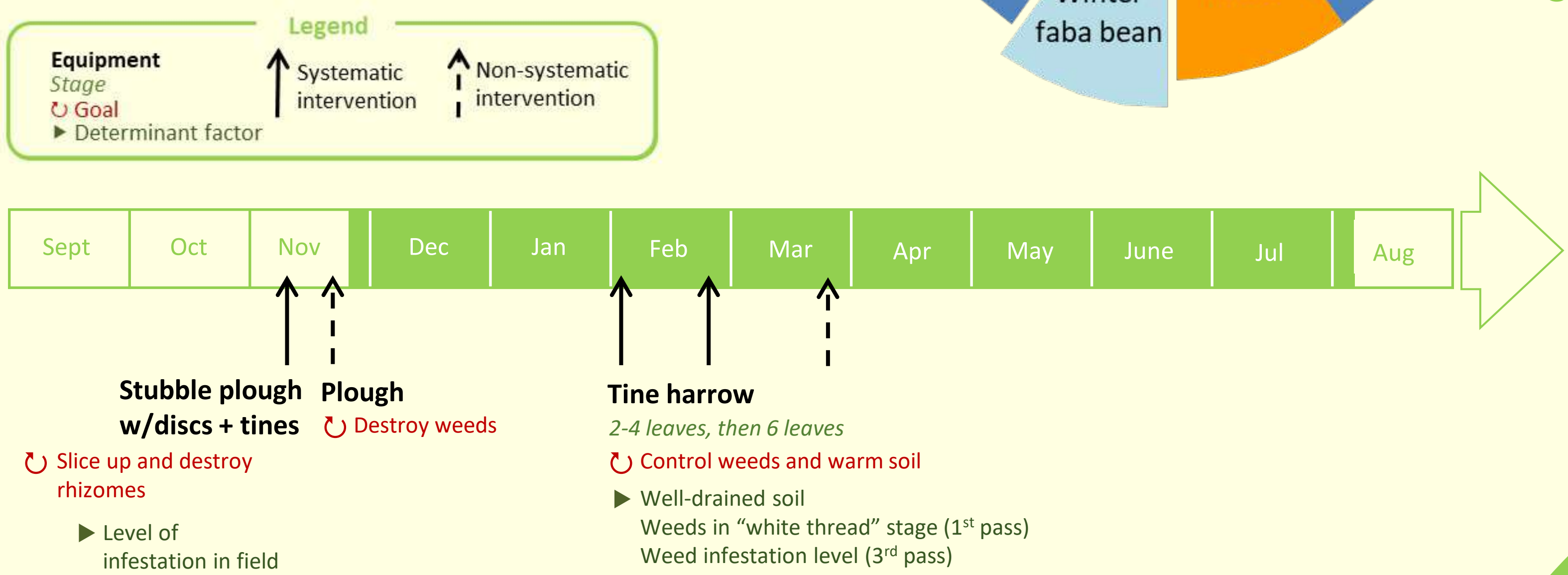
- > ***Grains***
- > ***Usable farm area: 90 ha***
- > ***Main soil type(s): deep calcareous clay***
- > ***Organic status obtained 9 years ago***
- > ***Equipment: 3.1 hp/ha Tine harrow—12 m (160 ha/year), Row cultivator (only used for spring crops)***

The rotation is rather long and includes two or three years of lucerne. The faba bean occurs mid-rotation and is planted using the grain seed drill (excluding later use of the row cultivator). The field is considered to be **moderately weed free**, although there are significant amounts of **wild oat**.

Why this crop rotation?

Lucerne, undersown in spring barley, helps cleanse fields. Furthermore, **rotation length is long** (10 years), and **winter and spring crops are alternated**. These features help break the weed cycle and allow the row cultivator to be used in spring crops with wider spacing (i.e., sunflower and maize). The **faba bean**, which occurs mid-rotation, increases soil nitrogen levels.





Why this particular weed control regime?

The farmer plants faba bean using a grain seed drill (spacing: 17.5 cm). This technique precludes the use of the row cultivator, but **combined sowing and tilling** using a tool with reinforced tines helps bury the faba bean seeds rather deep (8–10 cm). It also facilitates blind cultivation before the crop emerges. Winter crops (including winter faba bean) are weeded using blind cultivation with the **tine harrow**, when weather conditions permit. Early passes (blind cultivation or when weeds are at the 1-leaf stage) are the most effective.

In 2010, the farmer had to plough up several hectares of faba bean because **wild oat** had suffocated the crop, despite the two consecutive passes made with the tine harrow.

Economic and environmental indicators

	Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
Results for the farm's weed control regime	35	80	2.2
Median results for other farms growing faba bean (n=5)	50	160	2.4

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

The tine harrow (width: 12 m) has a good working speed. Costs could be reduced even further by sharing equipment, but this could decrease the farmer's ability to react quickly when needed; conditions that are favourable to tine harrow use do not last long.

Summary

+

- > ***Well-drained calcareous clay soils***
- > ***Easy to implement mechanical weed control in the autumn***
- > ***Autumn sowing can theoretically be delayed without affecting yield***
- > ***Lucerne is the best tool for controlling wild oat***

-

- > ***Row cultivator cannot be used with the faba bean given current farm equipment***
- > ***Faba bean does not compete well with weeds***
- > ***Faba bean yield is low in light calcareous clay soils with low water reserves***
- > ***Wild oat can germinate at any time of year***

DESCRIPTIVE SHEET 3:

MECHANICAL WEED CONTROL IN LINSEED

BACKGROUND—CHALLENGES

Controlling weeds is an important part of successfully growing linseed, which produces little cover at early growth stages (until it reaches 30 cm). Consequently, weeds may compete with the crop (whether it is a seed or fibre [flax] variety) and thus reduce yield. For seed varieties, weeds can interfere with the harvest and reduce yield quality (seed purity and moisture levels). For flax varieties, weeds make it harder to pull up the mature plants and carry out retting. If they infest the swaths, scutching will be more difficult: the weeds will get mixed up with the flax and lower the quality of the final product.

However, mechanical weed control must proceed with care because linseed is a delicate crop. It is sown using traditional row spacing (narrow); in organic systems, the tine harrow is the most common weed control tool. However, given the importance of producing high-quality flax, more and more organic farmers are using row cultivators. The rotary hoe is also being employed with increasing frequency.

In this crop, the major weeds are knotweed, fat hen, charlock, wild oat, dock, sorrel, thistle, bindweed, mayweed, scarlet pimpernel, and speedwell.

Black bindweed and common poppy in the row middle of a linseed crop (seed variety)

PREVENTIVE WEED CONTROL MEASURES

Weed control regimes should be based first and foremost on prevention, which involves using weed-free fields; placing linseed at the head of the rotation (after a small-grain crop); ploughing (recommended); using the stale seedbed technique (as long as it does not destroy true seedbed structure); and sowing at a high rate. Emergence must be fast and homogeneous. Sowing can be delayed (from March 15 to April 15) to take advantage of warmer soils, which will speed up emergence and give the linseed a competitive advantage over weeds. Furthermore, scheduling of mechanical weed control becomes more flexible.

Flax varieties must be planted in very clean fields. Linseed has low nitrogen requirements. It is for this reason that it should be placed at the head of the rotation, after a sequence of temporary grassland (lucerne or mixed) and wheat, or, if that is not possible, after an annual protein crop. For a given field, at least seven years should elapse between linseed crops.

Linseed requires good-quality soil. Flax varieties should be grown in rather deep clayey to compacted silty soils. Calcium levels should not be at saturation. It is better to stubble plough several times after the previous harvest to thoroughly flush out the weed seed bank, breakdown residues, and reduce the presence of pests. After regular

Linseed field (seed variety) hoed by row cultivator

ploughing, clods should average less than 5 cm over 15 cm and display a certain minimum level of fine soil. A seedbed 5 cm thick is sufficient, but the goal is to obtain 60% fine soil. The small clods will protect the seeds from compaction and promote the efficacy of mechanical weed control tools during the crop cycle (i.e., the tine harrow). The stale seedbed technique can be used, but the soil should not be broken up too much. An excessively fine seedbed will increase the risk of crust formation and compaction, phenomena to which linseed is very sensitive.

Seedling density must be great enough to create decent soil cover. For flax varieties, the desired density is 1,600 –2,000 plants/m². For seed varieties, 800–1,000 plants/m² is sufficient.

Weed control during the crop season

Maximising the efficacy of mechanical weed control tools

The following page describes how to optimally use the tine harrow, rotary hoe, and row cultivator to control weeds in linseed.

Tine harrow mounted on a seed drill in a linseed field

Tine harrow

The tine harrow can be effective when the crop plant reaches 5 cm, as long as the weeds are not too developed. Given how fragile linseed is, tool speed and aggressiveness should be limited. The tine harrow should not be used once the crop exceeds 10 cm because plant fibres could be affected. It is not possible to mechanically control weeds post sowing or pre-emergence because linseed is planted at a very shallow depth (1–2 cm). Plant loss and non-homogeneous emergence could result.

Linseed growth stage	Post-sowing/ Pre-emergence	Emergence to 5 cm	5–10 cm	10–25 cm
Weed growth stage	use not recommended		young	use not recommended
Working speed			about 6 km/h	
Tine aggressiveness			intermediate	
Crop loss	high		low	high

Rotary hoe

Farmers are just starting to use the rotary hoe in linseed, so information is sparse. The table below summarises what little is know.

Linseed growth stage	Post-sowing/ Pre-emergence	Emergence to 5 cm	5–7 cm	7–10 cm	10–25 cm
Weed growth stage	use not recommended		young		use not recommended
Working speed			10 km/h	12 km/h	
Crop loss	high		low		high

Row cultivator

The row cultivator can be used when the crop reaches 6–8 cm and until it exceeds 25 cm. It is possible to go in earlier (starting at 4 cm) as long as a guidance system is used (GPS or camera) and equipment speed is very slow, so as not to bury the linseed.

Linseed growth stage	Post-sowing/ Pre-emergence	Emergence to 4 cm	4–7 cm	7–10 cm	10–25 cm
Weed growth stage	use not recommended			even for well-developed weeds	
Working speed			2–3 km/h; only using a guidance system	3–5 km/h	up to 8 km/h if guidance system used
Crop loss	high		low; only using a guidance system	low; use of twin rows can help limit losses	

Diverse strategies for mechanically controlling weeds in organic agricultural systems

To control weeds in linseed, the three tools—the tine harrow, rotary hoe, and row cultivator—can be used on their own or together. The CASDAR surveys found that most farmers ploughed before planting linseed.

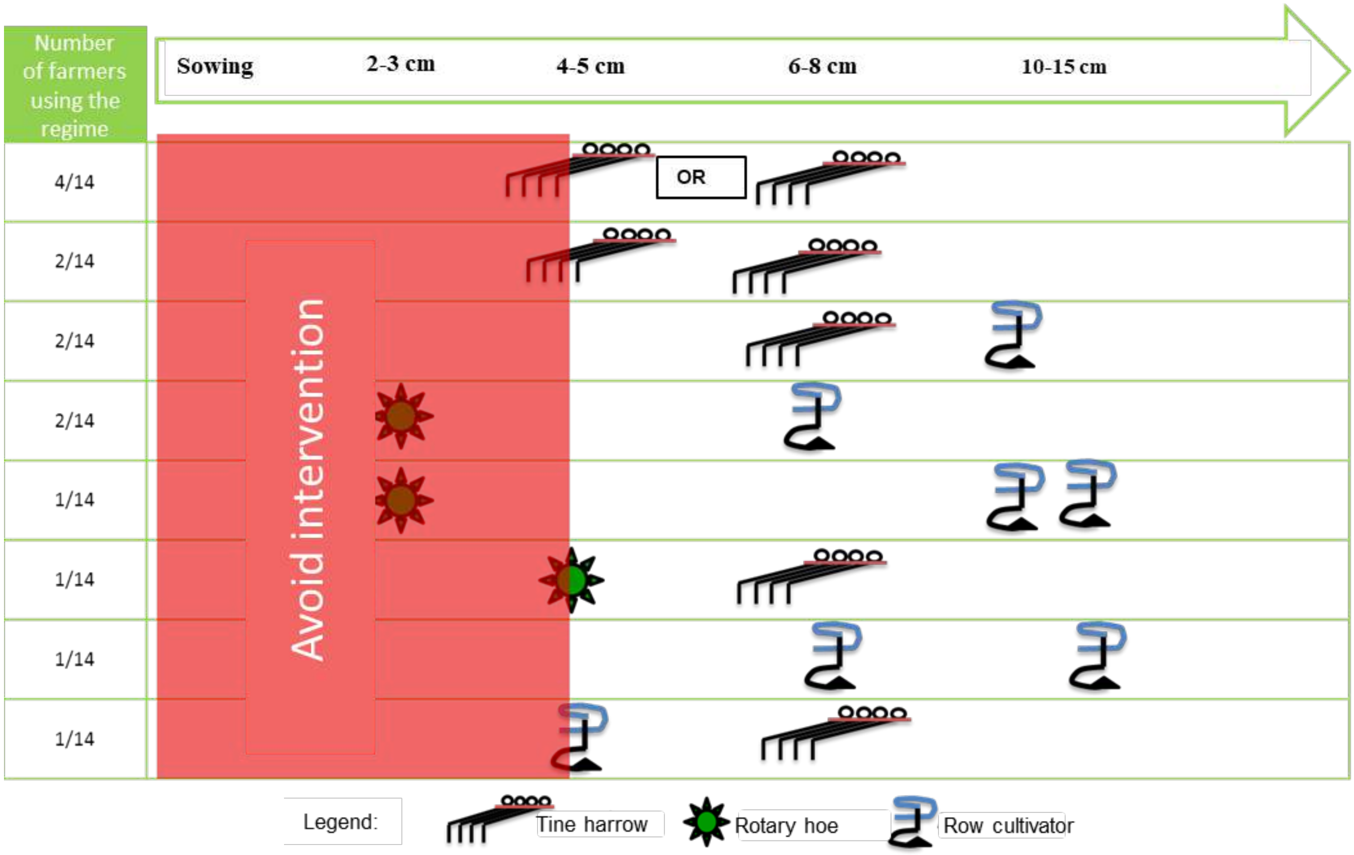
Important note:

The weed control regimes summarised in the graphic below, as well as those described in the farmer case studies, were those used in 2009 by the farmers (n=14) who participated in the CASDAR surveys. Consequently, they should not be taken as fixed recommendations but rather as descriptions of real approaches used under certain pedoclimatic conditions. They reflect a range of strategies that arose in different contexts (based on soil type, climate type, available equipment, etc.).

Study conducted in 2009/2010 on 14 fields

> 8 in the Haute-Normandie region, 5 in the Ile-de-France region, and 1 in the Centre region

> 3 dedicated to seed varieties and 11 dedicated to flax varieties



Case study...

Flax grown by an organic grain farmer in the Haute-Normandie region

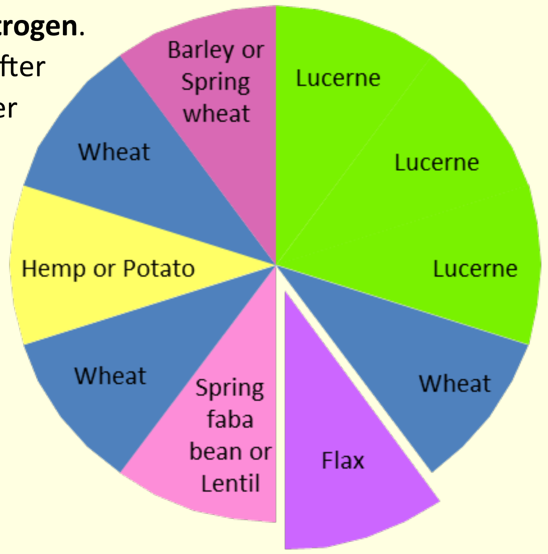
Farm description

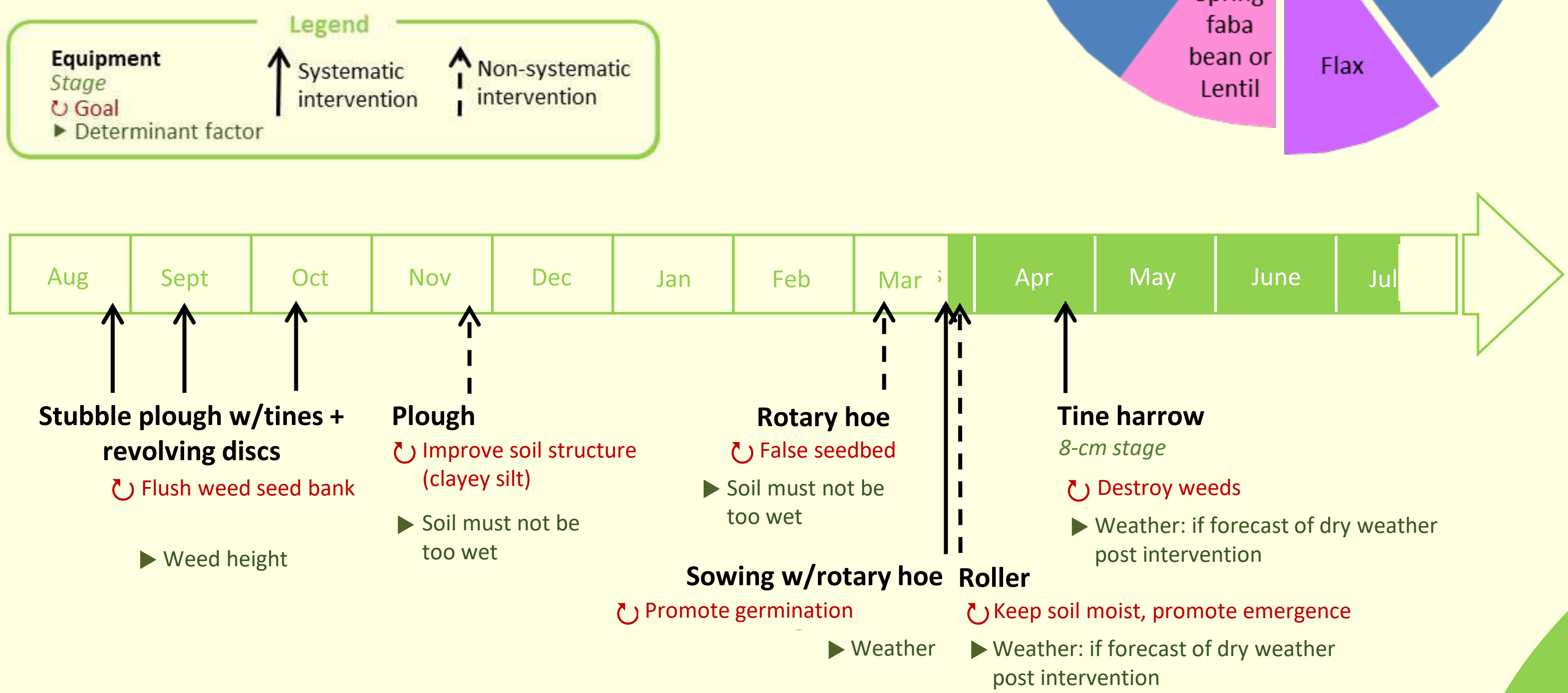
- *Grains*
- *Usable farm area: 150 ha*
- *Organic status obtained 9 years ago*
- *Main soil type(s): flinty clayey silt*
- *Equipment: 150 hp Tine harrow—9 m (~100 ha/year), Rotary hoe—6 m (~100 ha/year)*

The rotation lasts 9–10 years and starts with 2–3 years of lucerne, which is undersown in the preceding grain crop. The flax comes **after the lucerne-wheat sequence**, in fields with the least flinty soils. In this case study, the field is considered to be **fairly weed free**. The weeds present, at low levels, are knotgrass, black bindweed, wild oat, thistle, dock, and sorrel.

Why this crop rotation?

The **lucerne** increases soil nitrogen levels and removes a large percentage of the weeds already present in the soil, either as seeds or as rhizomes (i.e., thistle). Because the lucerne is undersown in a grain, the soil goes longer without being worked and thus a greater percentage of weed seeds die. The flax comes after the lucerne-wheat sequence because it requires **relatively little nitrogen**. Because the flax occurs soon after the lucerne, the field stays rather clear of weeds. Flax plays a useful role in this rotation because **it improves soil structure**.





Why this particular weed control regime?

Stubble ploughing can remove a large percentage of the seeds that fall to the ground during the previous harvest. It acts to generate **stale seedbeds** before the flax is planted, if there is no ploughing. If not, it is especially helpful for the following crops. Because of the clayey soils, **ploughing** is carried out in the winter. A pass is done with the rotary hoe 2–3 weeks before sowing to create the **stale seedbeds** and thus flush some of the weed seeds present in the soil. A roller can be used just after sowing to keep the soil moist and promote flax emergence, provided that no rain is forecast for the days after. A pass can be made with the **tine harrow** in late April, when the flax is at about 8 cm, to pull up any weeds. This work is effective as long as there is no rain for several days after the pass, which will result in weed death.

Economic and environmental indicators

Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
30	110	1.6

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

Summary

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- ***Flax is well positioned within the rotation, allowing alternation of spring and autumn crops***
- ***Minimal mechanical weed control equals lower time investment and cost***
- ***Long-term management strategy (three instances of stubble ploughing)***

-

- ***Row cultivator cannot be used for later weed removal because the flax is sown with 15-cm row spacing and wide-band coulters (6 cm)***
- ***Flax gets infested by knotgrass during the retting period (it is better to turn the flax over sooner)***

Case study...

Linseed grown by an organic grain farmer in the Haute-Normandie region

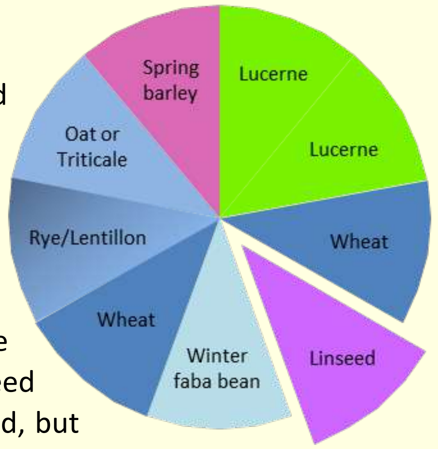
Farm description

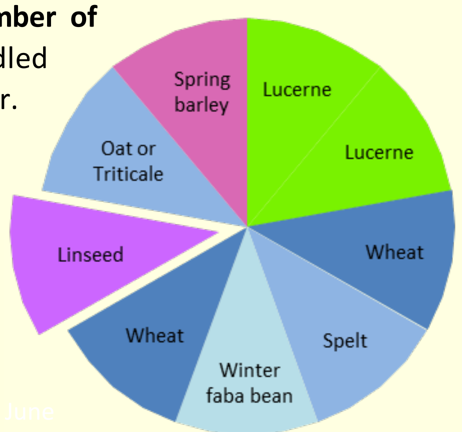
- ***Grains***
- ***Usable farm area: 116 ha***
- ***Main soil type(s): heterogeneous clayey silt***
- ***Organic status obtained 15 years ago***
- ***Equipment: 150 hp Tine harrow—12 m (~130 ha/year), Row cultivator—4 m (~100 ha/year)***

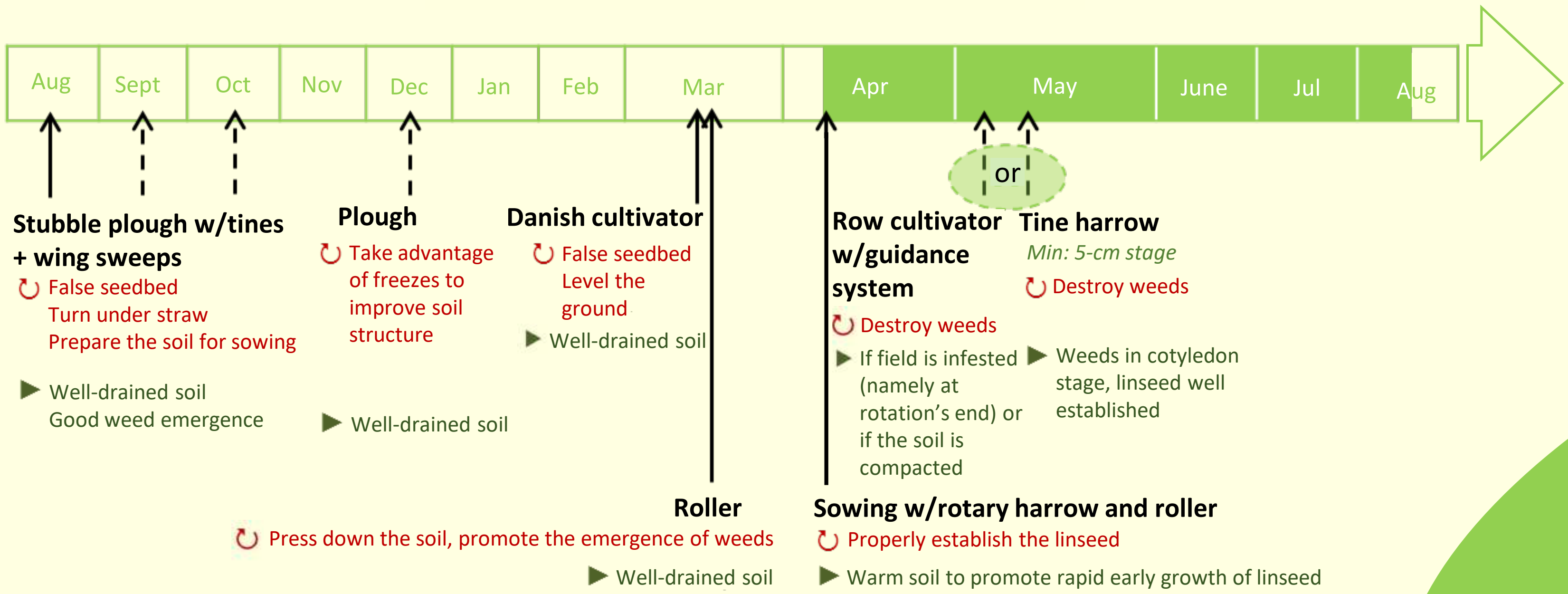
In this rotation, the linseed comes **after the lucerne-wheat sequence or the faba bean-wheat sequence**. The linseed crops are considered to be **rather weed infested**, especially the end-of-rotation linseed. The main weed is fat hen; there is also some black bindweed, which has a minor impact.

Why this crop rotation?

The **lucerne** increases soil nitrogen levels and removes a large percentage of weed seeds and rhizomes. Because the lucerne is undersown in a grain, the soil goes longer without being worked and thus a greater percentage of weed seeds die. The linseed following the lucerne-wheat sequence benefits from weed-free conditions. Weed management is more difficult towards the end, but the rotation's **crop diversity** and **small number of spring crops** mean that weeds can be handled fairly well with the row cultivator. Furthermore, the linseed's placement makes sense because of its low nitrogen requirements.







Why this particular weed control regime?

Stubble ploughing eliminates some of the seeds that fall to the ground during the previous harvest. In particular, it helps **preventively** control weeds in the crops that follow the linseed. One to three instances of stubble ploughing are carried out, depending on weather conditions and weed infestation levels in the field.

The soil is ploughed, and then a Danish cultivator and a roller are used—the earth is well worked, and a **stale seedbed** is created. The linseed is planted using a rotary hoe and a roller around March 10. Warmer soil temperatures mean that the **linseed will develop rapidly**, which is essential if the crop is to effectively compete with weeds. A pass with the tine harrow is carried out in early May, ripping up the weeds present. For the linseed planted towards the end of the rotation, when the field is more weed infested, the row cultivator is used instead of the tine harrow.

Economic and environmental indicators

Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
65	170	3.4

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

Summary

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- ***Good placement of linseed (after lucerne-wheat sequence)***
- ***In more infested fields (end-of-rotation linseed), the row cultivator can play catch up because linseed is planted in twin rows with 20-cm row spacing***
- ***Camera recently purchased to facilitate row cultivator use and permit early passes (3-cm stage)***

-

- ***The tine harrow must be used with care in linseed: the crop does not produce tillers, so lost plants cannot be replaced***
- ***Hard to define the right moment to act: weeds must be young but crop development must be sufficient***
- ***It is tricky to use the row cultivator without a guidance system***

DESCRIPTIVE SHEET 4:

MECHANICAL WEED CONTROL IN MAIZE

BACKGROUND—CHALLENGES

Growing maize requires a good weed control regime. Maize is most sensitive to weeds the first six weeks after sowing. Certain perennials and annuals present a particular challenge: bindweed, Johnson grass, sunflower regrowth, knotweed, nightshade, amaranth, fat hen, common cocklebur, thorn apple, common ragweed, barnyardgrass, foxtail grass, and crabgrass. Maize can also be infested by creeping thistle, which is a general weed that can affect all of a farm's crops. To control some of these weeds, additional manual intervention may be required. This is especially the case in organic systems, where herbicides cannot be used as a complementary form of weed management.

PREVENTIVE WEED CONTROL MEASURES

Field selection and crop sequence

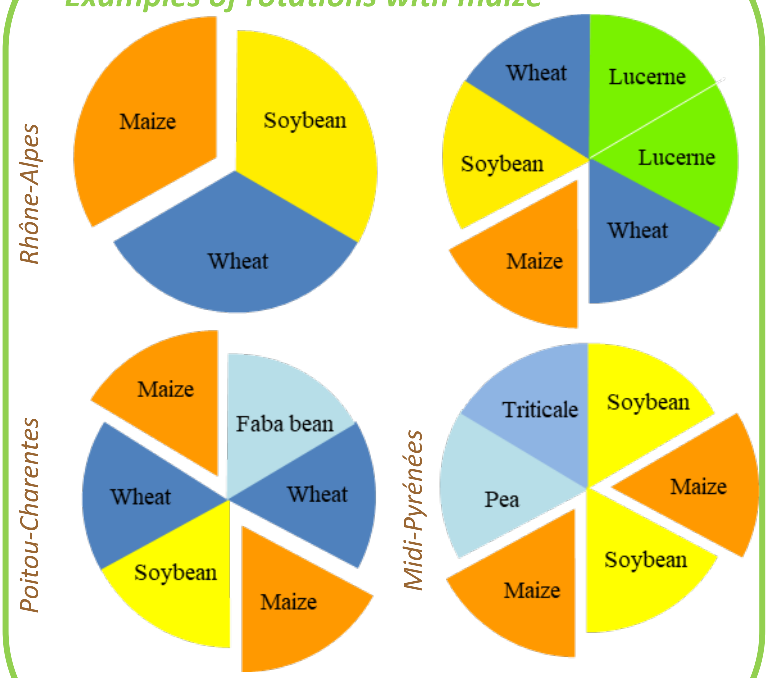
Because mechanical weed control should be more of a last resort, it is best to preventively reduce the weed seed bank in fields. This can be accomplished within the rotation by alternating diverse crop types and by tilling appropriately.

In general, it is easy to incorporate maize into different types of rotations:

- those of differing length (one year of every three or one year of every six)
- those with grains (wheat, barley, rye, and triticale)
- those with other spring crops (soybean, sunflower, and rice)
- or those with legumes (e.g., pea, lentil, faba bean, and lucerne)

Examples of rotations with maize that are used in France are illustrated in the figure to the right.

Examples of rotations with maize



Source: CETIOM, CASDAR RotAB

Preparing to sow

> ***Tillage***

Stubble ploughing is an effective method for flushing weeds from the seed bank during the fallow period. The presence of perennials (Johnson grass, thistle, bindweed, dock, and sorrel) may require deeper work during the dry period, exploiting shanks with flat sweeps that can thoroughly slice up rhizomes and other storage organs.

Ploughing is highly effective on weeds that are vulnerable to soil turn-over, which are namely grasses like barnyardgrass, foxtail grass, and crabgrass. For dicots that emerge in the spring (e.g., amaranth, fat hen, nightshade, knotweed, thorn apple, and common cocklebur), ploughing has more variable effects.

In well-structured soils (e.g., calcareous clay soils, silty clay soils, and high-clay soils), the no-till approach is a good option because weed infestation levels are lower than in compacted silty soil. In such cases, tools with large tines can be used to loosen the soil in the autumn to promote maize root growth.

> ***Stale seedbed technique***

Seventy-five percent of farmers growing maize use the stale seedbed technique and destroy emerging weeds in April using tools such as Danish cultivator, grass harrows, stubble ploughs, or tine harrows (2009 CETIOM & CASDAR projects on mechanical weed control). The ability to prepare stale seedbeds depends on the farm's work schedule, equipment, and, especially, pedoclimatic conditions:

- In clay soils, light soil preparation should begin early to increase the efficacy of the technique.
- In certain sensitive soils (the silty ones especially), it may be challenging to prepare stale seedbeds; it is important to properly implement the technique, and soils must always be well drained.

> ***Sowing date***

In the 2009 surveys, more than 50% of farmers said that they delay sowing maize to eliminate the weeds emerging from the stale seedbed and to take advantage of warmer soil temperatures, which help ensure vigorous and homogeneous crop seedling emergence. These farmers are located in southwestern France. There, the sowing period lasts from April 15 to May 30; the median sowing date is May 15.

Weed control during the crop season

The four to six weeks following planting are a critical period in the crop cycle because maize produces little cover during early growth.

One key strategy is to do one or two passes with the tine harrow before the maize emerges (i.e., blind cultivation) and then, just after emergence, to break up the soil crust with the rotary hoe. This technique allows the soil to warm up properly and rips up emerging weeds. When the maize reaches the 4- to 5-leaf stage, the tine harrow can once again be used to pull out young weeds. The row cultivator can be employed one, two, or three times starting at the 3- to 4-leaf stage, or even earlier if it is equipped with shields (discs or panels), Lelièvre blades, or flat sweeps. Its use can continue until maize height exceeds tractor clearance.

Maximising the efficacy of mechanical weed control tools

Mechanical weed control must be scheduled so that it eliminates a maximum number of weeds without harming the maize. Passes should only be done when weather conditions are favourable (i.e., dry weather in the days following the intervention).

The following pages describe how to optimally use the tine harrow, rotary hoe, and row cultivator to control weeds in maize.

Tine harrow

The tine harrow is very useful because it can be used to carry out blind cultivation in the three days after sowing. Furthermore, it acts on the crop row, which is inaccessible to the row cultivator.

Certain adjustments must be made (tine angle, working depth, working speed), and different settings should be used to deal with different maize and weed growth stages as well as with different fields.

Maize growth stage	Post-sowing/ Pre-emergence	Post-sowing/ Germination	3–4 leaves	4–6 leaves
Weed growth stage	germination/"white thread"		seedlings	seedlings
Working speed	8–12 km/h		3 km/h	4–5 km/h
Tine aggressiveness	intermediate to high	intermediate	low	low to intermediate
Crop loss	none	none to intermediate	low to high, depending on root development	tear damage to leaves

Recommendations

- It is important to note that, before the maize reaches the 4-leaf stage, there is a risk of ripping up the crop plants. It is recommended that farmers use a tine harrow with a low level of aggressiveness.

ROTARY HOE

The rotary hoe acts along its entire width and removes very young weeds. To use this tool effectively, it is important to take action as early as possible, as soon as the weeds reach the germination ("white thread") stage. The rotary hoe can deal with a wide range of soils, including compacted soils.

Maize growth stage	Post-sowing/ Pre-emergence	Post-sowing/ Germination	Coleoptile	1 leaf	3 leaves	4–5 leaves	6–7 leaves
Weed growth stage	germination/"white thread"			germination/"white thread", cotyledon, 1–2 leaves			
Working speed	15–20 km/h		10 km/h	10 km/h max	12–15 km/h	15–20 km/h	15–20 km/h
Crop loss	none		intermediate to high	intermediate	low	very low	tassel breakage

ROW CULTIVATOR

The row cultivator is the best tool for finishing off the last weeds before the maize covers over the row middle.

Maize growth stage	Post-sowing/ Pre-emergence	Post-sowing/ Germination	Coleoptile	1 leaf	2 leaves	3 leaves	4–5 leaves	6–7 leaves	8–11 leaves
Weed growth stage	unsuitable			"white thread"	Seedlings, up to 3–4 leaves				
Working speed				3 km/h	3 km/h	5 km/h	6 km/h	7–8 km/h	8–10 km/h
Crop loss	high			intermediate to high	low if properly equipped			low	low; ridge creation is useful

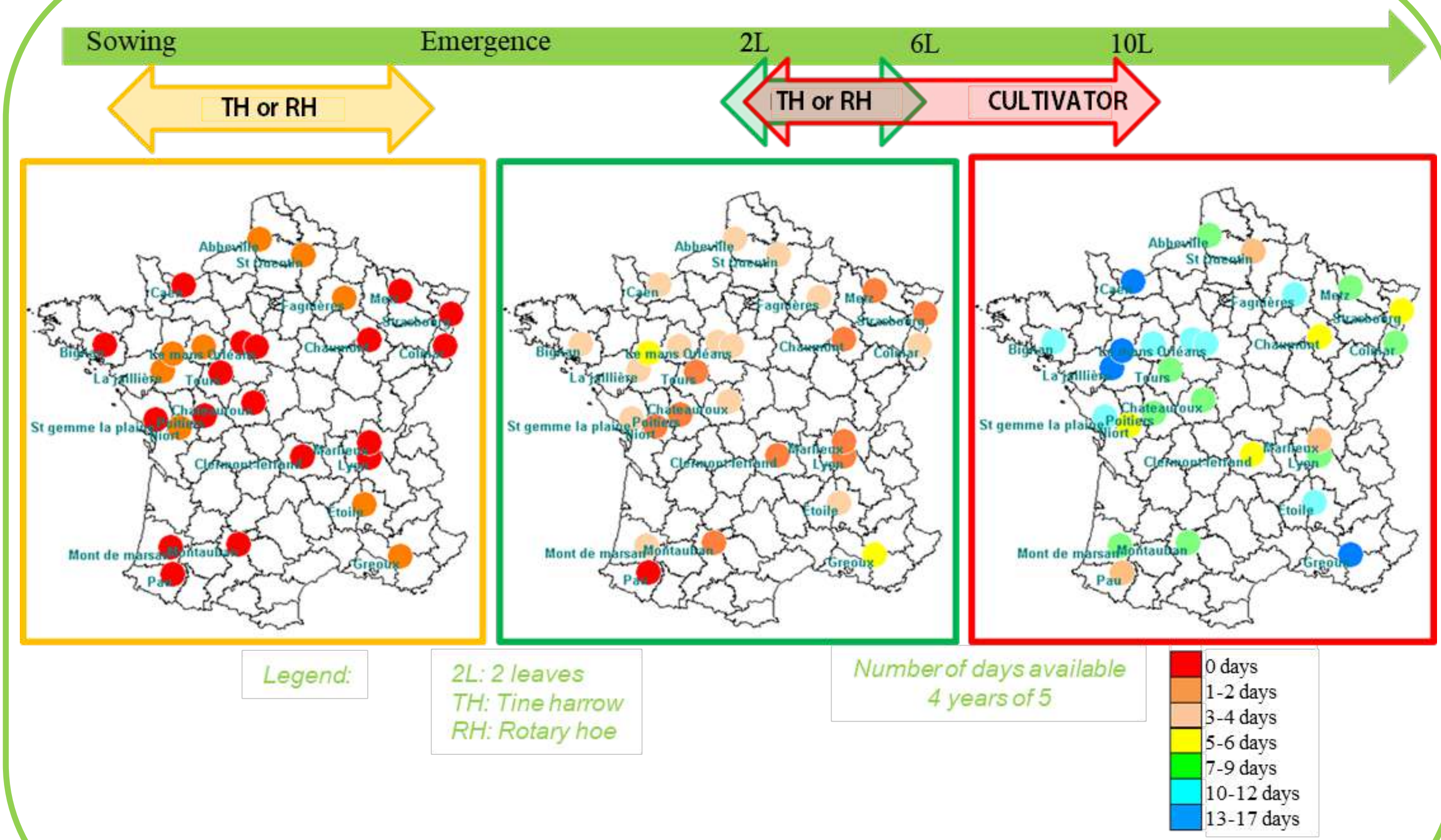
Recommendations

- It is important to make sure that the spacing used by the seed drill, cultivator, and combine harvester is the same
- Equipping the cultivator with a finger weeder will improve the level of weed control on the row. However, a high-precision guidance system (electronic) must be used.
- The rotating fingers (as compared to sweeps) can get closer to the maize and more aggressively remove weeds while posing less of a risk to the crop plants.

SUGGESTIONS FOR USING WEED CONTROL TOOLS IN MAIZE

The ARVALIS—Institut du végétal carried out a study using Jdispo software to determine the number of days in the year that mechanical weed control tools could be used. There were two assumptions: 1) the tine harrow and rotary hoe would be employed during pre-emergence and between the 2- and 6-leaf stage and 2) the row cultivator would be used between the 2- and 10 -leaf stage.

The figure below shows the number of days weed control tools can be used at least four years out of five under the different pedoclimatic conditions found in France. These estimates were obtained using the windows of time during which the maize is at a growth stage where tools cannot do it harm.



Source: ARVALIS —Institut du végétal

...Sheet 4: Maize...

Case study...

Irrigated maize grown by an organic grain farmer in the hilly part of the Gers region

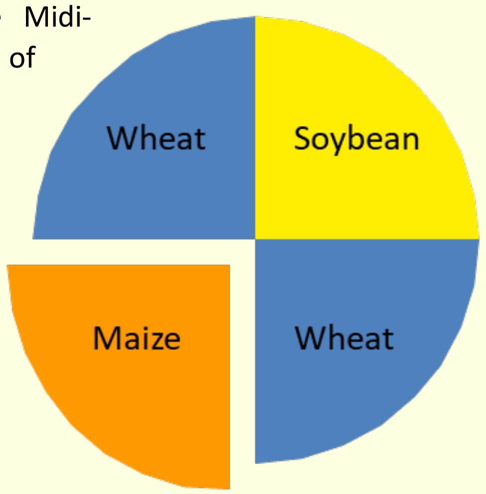
Farm description

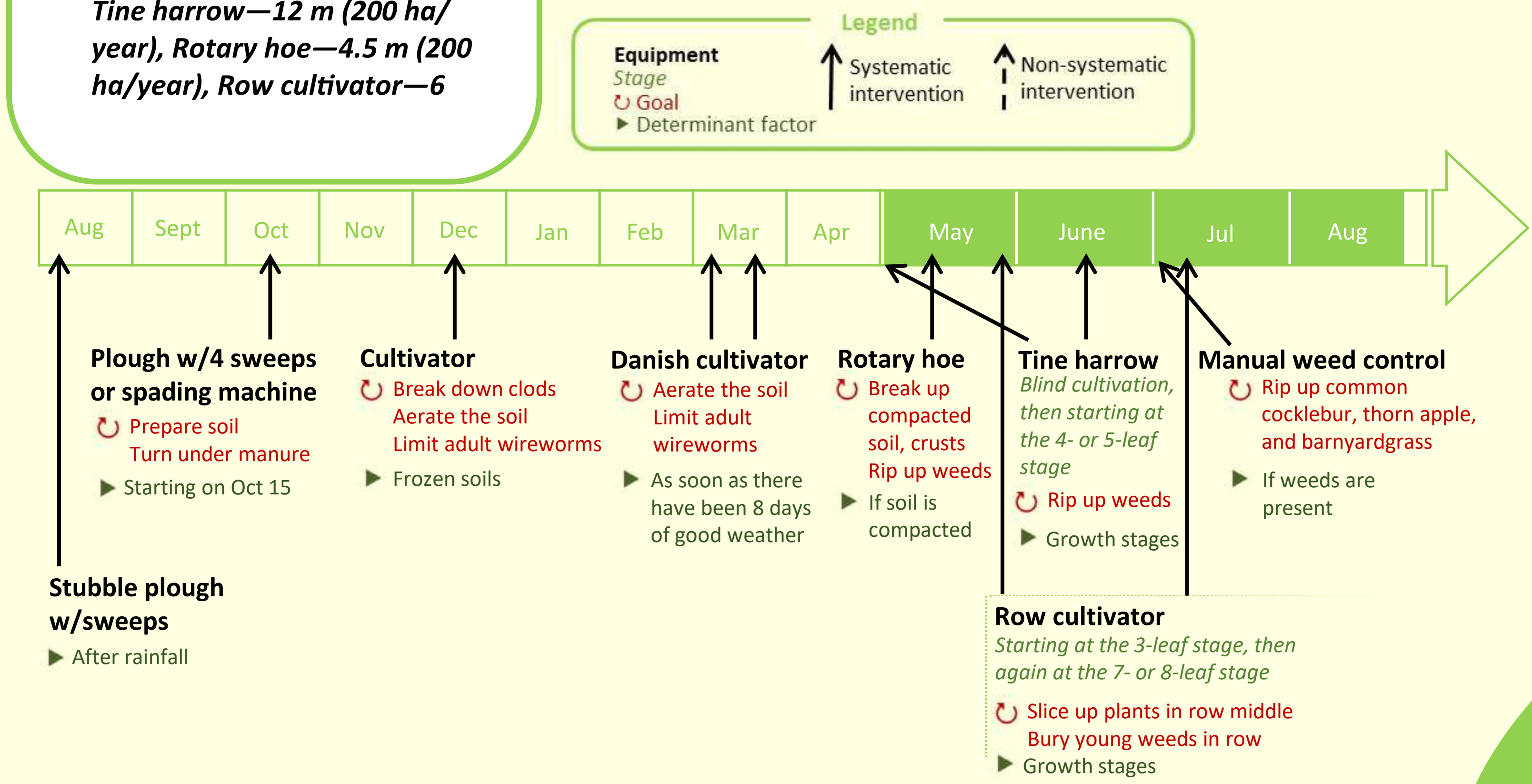
- > ***Grains***
- > ***Usable farm area: 100 ha***
- > ***Main soil type(s): steep, deep calcareous clay soils typical of Gascony***
- > ***Organic status obtained 6 years ago***
- > ***Hose-reel/traveling gun system used to irrigate 30 ha***
- > ***Equipment: 2.35 hp/ha Tine harrow—12 m (200 ha/year), Rotary hoe—4.5 m (200 ha/year), Row cultivator—6***

The maize follows a wheat, which is ploughed in October. In this case study, the field is considered to be **fairly weed free**. The most common weed is **thistle**, but barnyardgrass also occurs. Some thorn apple plants are removed manually.

Why this crop rotation?

This rotation is **typical** of the Midi-Pyrénées region. To limit the risk of weed infestation, the farmer not only ploughs but also consistently **alternates summer row crops with winter crops**.





Why this particular weed control regime?

The farmers plough half of the usable farm area. Soil fertility is a matter of good soil structure, requiring the right work at the right time. Given the high clay content of the soil (28%), **autumn ploughing** generates good soil structure by the spring. After sowing, the **tine harrow** is used to carry out early weed control. Then, the **rotary hoe** loosens up the compacted soils. Finally, the **row cultivator** is employed to more aggressively remove weeds. The combination of the three tools ensures good weed management, but this sometimes comes at the cost of crop density. A **general weed control regime is defined ahead of time** and is then adapted to each field based on the state of the land, crop growth stage, and weed growth stage. These farmers follow traditional guidelines for cropping systems in southwestern France, both in terms of weed control timing and tool choice. Weeds are not seen as disrupting the system—maize is a crop that grows rapidly and generates good cover, which means it exerts strong competitive pressure on weeds.

Economic and environmental indicators for this regime

	Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
Results for the farm's weed control regime	65	200	4.3
Median results for other farms growing maize (n=7)	65	380	3.9

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

A **large number of passes are made** (six in all), resulting in good weed control. The values of the economic and technical indicators are good as well, thanks to a good management system that is informed by seven years of organic farming.

Summary

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- > ***Crop alternation (summer/winter)***
- > ***Good organisation (regime refined through experience)***
- > ***Manual weed control to actively target weeds***
- > ***Complete and appropriate suite of equipment***

-

- > ***Many instances of weed control despite ploughing***

Case study...

Irrigated maize grown by an organic grain farmer in the Midi-Pyrénées region

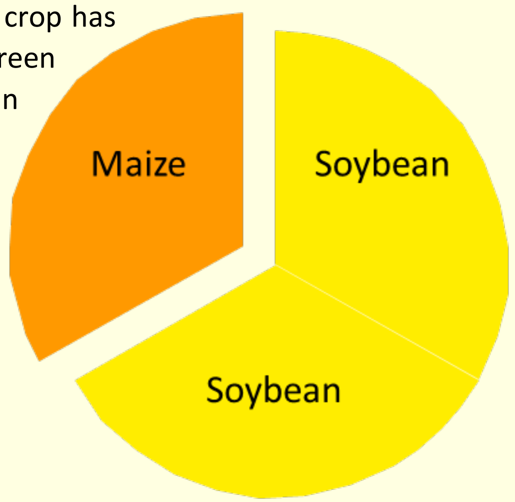
Farm description

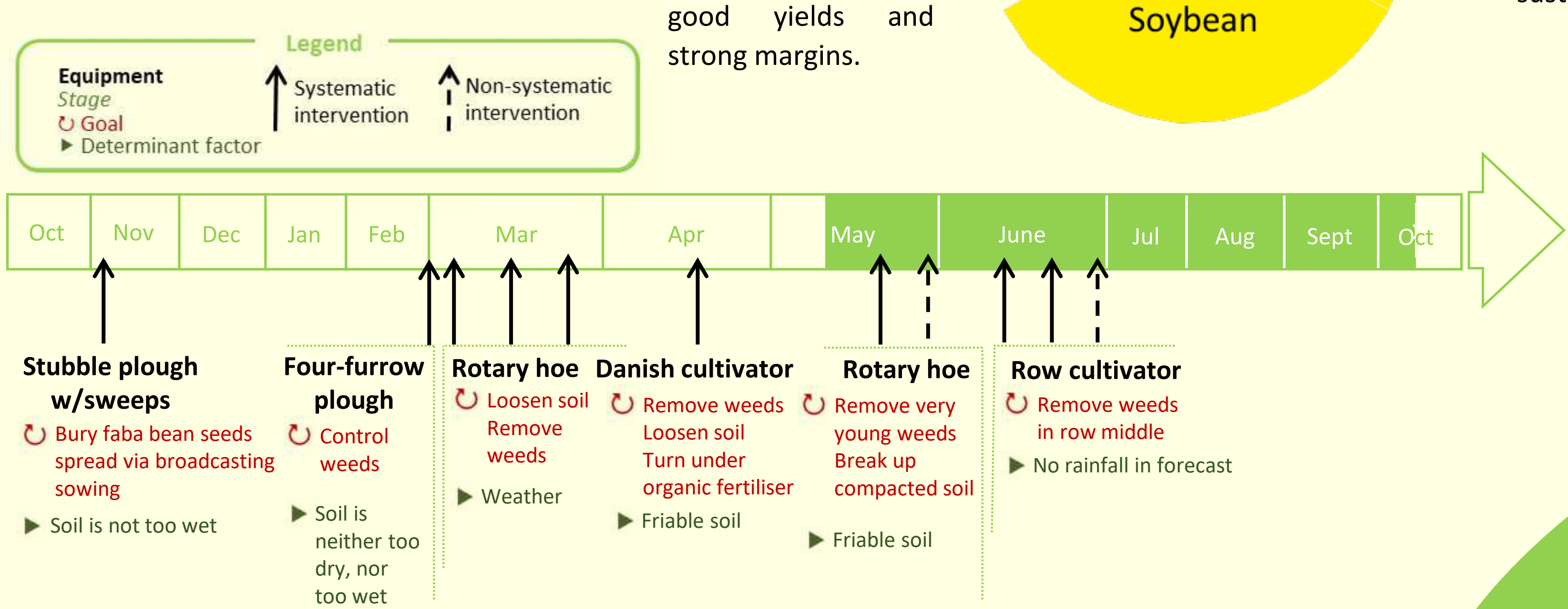
- *Grain (1.5 labour units)*
- *Usable farm area: 71 ha (irrigated)*
- *Main soil type(s): alluvial soils (Adour river basin), high in clay and silt*
- *Organic status obtained 10 years ago*
- *Equipment: 3 hp/ha Rotary hoe—4.5 m (140 ha/year), Row cultivator—6 rows (4.5 m, 280 ha/year)*

In this example, **irrigated maize** follows two soybean crops. In the spring, all the fields covered with faba bean are subject to shredding, stubble ploughing, and ordinary ploughing. The field is considered to be **fairly weed free**. The most common weeds are knotweeds, thorn apple, amaranth, bindweeds, fat hen, and **barnyardgrass**.

Why this crop rotation?

This grain farm is located in a valley and experiences **flooding** from the nearby river (50% of surface area). Its lands are fully irrigated. For this reason, winter crops, which are less productive, are no longer planted. This farm has an irrigated maize-soybean-soybean sequence, which is very **atypical for the region**. Winter faba bean is systematically planted across the farm in the winter, as soon as the preceding cash crop has been harvested. It acts as green manure that protects the soil in the winter, limits evapotranspiration in the spring, and increases soil nitrogen. The soybean (35 q/ha) and the maize (80 q/ha) have good yields and strong margins.





Why this particular weed control regime?

On this farm, soil fertility is crucial. This task involves **maintaining excellent soil structure**, which is achieved via deep ploughing. Even though the maize receives just a small amount of fertiliser (80–100 nitrogen units), the production level is excellent for an organic system on clayey silt soils. From the perspective of prevention, it is a good choice to use ploughing in a system with limited weed infestation. After ploughing, working the soil with the rotary hoe helps flush weeds via stale seedbeds and bury weed seeds. **Weed control is intensive before and after sowing** to compensate for the fact that the rotation does not **alternate** different types of crops. The farmers do not tolerate any weeds. They control weeds systematically—preventive measures are taken and weeds are actively targeted. After five years of interventions (often manual), weeds are under control on the farm, but they are still seen as potential disruptive forces.

Economic and environmental indicators

	Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
Results for the farm's weed control regime	65	250	3.9
Median results for other farms growing maize (n=7)	65	380	3.9

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

The amount of ploughing results in high fuel costs because of the low working speed (0.8 ha/h), the powerful tractor used (160 hp), and the working depth (>20 cm). However, the current system is sustainable and effective (has the best gross margin for cash crops in the whole department).

Summary

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- ***Regime tightly controls weed infestation risk: systematic passes; manual interventions; and appropriate equipment***
- ***Legumes used as winter cover crops supply nitrogen and thus compensate for low fertilisation levels***
- ***Excellent technical and economic performance***

-

- ***Rotation does not alternate different crop types***
- ***Several passes made with mechanical tools in the spring to finely work the soil because cover crops sometimes remain until late***
- ***Barnyardgrass shows up some years in very wet areas of the maize***

Descriptive sheet 5:

Mechanical weed control of spring barley

Background—Challenges

Spring barley is useful as a forage crop and is produced for the brewing industry (limited commercial possibilities, under contract only).

Malting barley must meet high standards. Seed quality is related to size and germination ability. To properly grow a malting barley, it is important to choose the right variety, supply the crop with the proper amount of nitrogen (not too much), and control weeds (which affect size).

There are no quality standards for **forage barley**. The goal is therefore to maximise yield. Variety choice remains important—a highly productive variety should be used. Although managing nitrogen levels is less challenging than controlling weeds, the two must be considered together because weed infestations can strongly harm crop development.

In both types of production systems, **well-established** spring barley can develop quickly and compete effectively with weeds. However, in certain cases, spring barley has been observed to have a hard time taking off. Its seedling densities are too low to control weeds, reducing yield and quality.

> ***The successful production of spring barley, especially malting barley, depends on soil type and tillage quality.***

Winter barley/Spring barley

Winter barley is very different from spring barley. If winter barley is sown early enough in the autumn, then it generally creates good soil cover and keeps the field relatively weed free.

Preventive weed control measures

Prevention is the key to effective weed control. Preventive measures exploit crop location within the rotation, fallow-period tillage, sowing method and date, and the use of crop mixtures.

Field selection and crop sequence

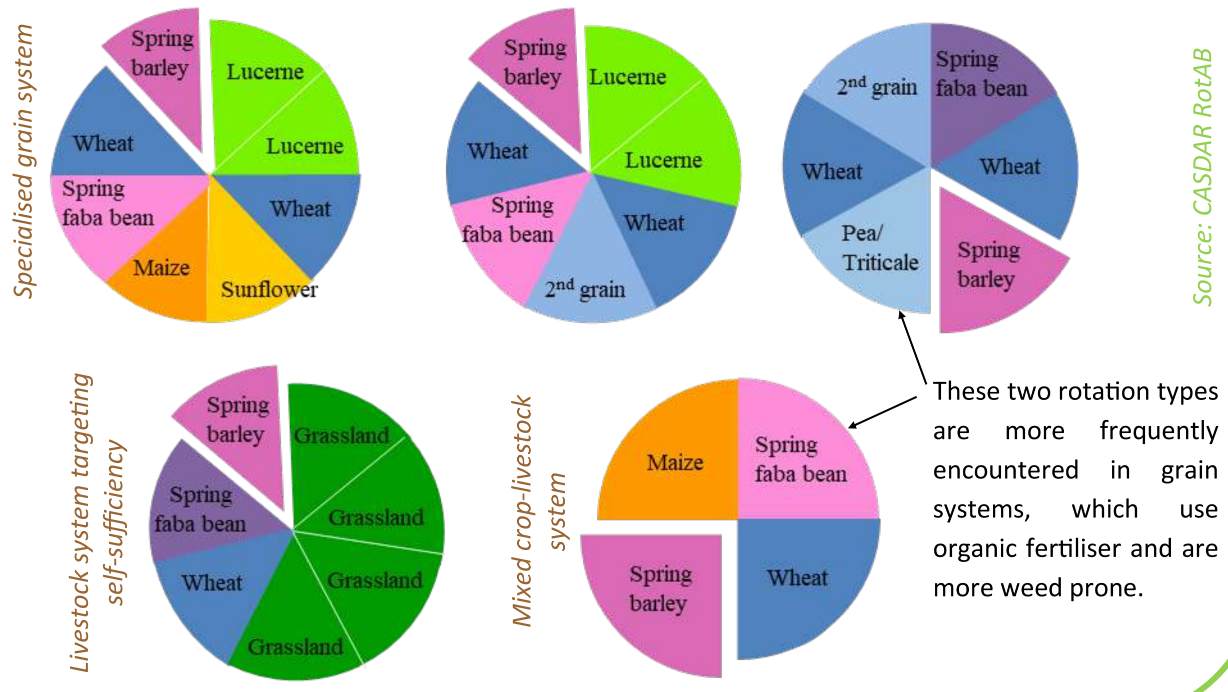
Spring barley generally follows wheat. It may even be the third small-grain crop. Depending on the type of barley being grown (malting or forage), the crop's place within the rotation may be adjusted as a function of soil nitrogen levels.

Malting barley has average nitrogen requirements, so it is a good end-of-rotation crop that often precedes an undersown legume (lucerne, clover).

Forage barley can either come at the beginning of the rotation, after a lucerne-wheat sequence, or in the middle/at the end, after a legume (or even after a sunflower in well-structured, unploughed soil).

See the figure on the following page for clarification.

Examples of rotations with spring barley



Preparing to sow

> ***The fallow period***

The fallow period between a grain (e.g., common wheat, spelt, triticale) or a row crop (e.g., sunflower, rapeseed) and spring barley allows enough time for farmers to carry out **stubble ploughing or the stale seedbed technique**. They can thus flush weeds, especially in no-till systems. However, care should be taken not to create an excessively fine seedbed, which could increase the risk of crust formation and compaction, phenomena to which spring barley is very vulnerable.

A **cover crop** could also be planted to provide soil cover and thus exert competitive pressure on autumn weeds. For example, after stubble ploughing, mustard or crimson clover can be planted until mid-September. If the field is weed free, clover/brassica/grass mixtures can be planted after the preceding crop has been harvested.

Spring barley is harvested in August (depending on the region). This means that tillage can be an effective tool for eliminating germinating weeds during the fallow period, in preparation for the following crops.

Spring barley must be planted in a field with **good soil structure**.

- Soils that are waterlogged (establishment will be poor) or too dry (poor final quality, unless irrigated) are to be avoided.
- Avoid any conditions that could hamper proper root development: do not till under bad conditions and make sure levels of green manure are significantly reduced before ploughing (terminate the plants and incorporate them into the soil at least one month before ploughing or before sowing spring barley).
- Make sure porosity is good in the top 10–15 cm of the soil.

Ploughing is strongly recommended in weed-infested fields. In weed-free fields, light tillage (repeated stubble ploughing) may be enough if soil structure is good. If not, deeper work may have to be done.

The seedbed should be rather fine to ensure that emergence is rapid (be careful, though, to avoid compaction). Light repeated ploughing should ultimately result in clods of less than 5 cm (on average). A seedbed 5 cm thick is sufficient, but the goal is to obtain 50% fine soil. The small clods will protect the seeds from compaction.

> ***Sowing***

As previously mentioned, weed control is easier when the crop is **well established**. To enhance seedling establishment:

- Sow as early as possible in the spring when soils are well drained and in good condition, even if the surface layer is frozen; sowing too late, especially in drying soils, increases the risk of poor establishment.
- Avoid sowing just before it rains if soils are compacted; the soil will seal up, thus asphyxiating the seeds and interfering with germination (resulting in plant loss) and crop growth.
- In cloddy soils (clayey silt to silty clay and calcareous clay), it might be necessary to use a roller to flatten the earth after a dry winter and/or a winter of freezing temperatures.
- Do not seed too deeply in compacted soils (2–3 cm, max); in contrast, if the soil is slightly too friable, then sowing depth should be a bit greater (3–5 cm). Deeper seeds will be better protected when mechanical weed control is used, especially in fields where there is a possibility of weed infestation.

Row spacing will depend on the specific tool utilised:

- It should be 17–28 cm if the row cultivator will be employed (or as little as 15 cm if the cultivator has a camera-based guidance system).
- It should be 12–17 cm (sowing via grain seed drill) if the tine harrow and rotary hoe but not the row cultivator will be used.

The **sowing rate** should be around 120–130 kg/ha, or 250 seeds/m^2. Although the sowing rate does play a role in weed control, the crop's real competitive advantage is dictated by the quality of its establishment, tillering, and growth. In other words, a dense population of skinny crop plants without tillers will lose out to the weeds.

Spring barley—tillering stage

Weed control during the crop season

To control weeds in spring barley, four tools can be used: the tine harrow, rotary hoe, row cultivator, and header.

Maximising the efficacy of mechanical weed control tools

Pedoclimatic conditions dictate how mechanical weed control tools can be used. Under the same climatic conditions, tool use may be impossible on compacted or waterlogged silty soils (when March and April are rainy), while it can be very effective on calcareous clay soils, which drain rapidly, thus increasing the number of days available for weed control.

> ***Spring barley is vulnerable early on in the crop cycle, so mechanical weed control should proceed with great care.***

The next two pages describe how to optimally use the tine harrow, rotary hoe, and row cultivator to control weeds in spring barley.

TINE HARROW

The tine harrow is an effective tool for removing weeds at the "white thread" stage. Depending on harrow aggressiveness and seed depth, it is also possible to eliminate some of the young weeds.

The tine harrow can be used during pre-emergence and then again when the crop is at the 3- to 4-leaf stage. However, spring barley seeds are very fragile. Consequently, weed removal during pre-emergence must be implemented with extreme care; the right equipment settings must be used, soils should be in good condition, and seeds need to have been buried sufficiently deep.

Spring barley growth stage	Post-seeding/ Pre-emergence	Emergence to 2 leaves	3–4 leaves	Tillering	Early stem elongation Pseudo-stem erection (Zadoks 30)	2 nodes Heading
Weed growth stage	germination/ "white thread" (optimum)	strongly discouraged	cotyledon to 2 leaves max			cleavers developed
Working speed	8–10 km/h		3–4 km/h	6–8 km/h	6–8 km/h	8–10 km/h
Aggressiveness Tine angle	low; deeper seeds		low	intermediate aggressiveness (also depends on soil)		high
Crop loss	low	high	low	possible	none	none

Recommendations

- A sowing depth of 4–5 cm will reduce the risk that barley seeds will be brought up during pre-emergence passes. However, this recommendation is not universal. For instance, it does not apply to compacted silty soils if it rains just after sowing.
- Increase the sowing rate by 10–15% to compensate for the losses that will result from tine harrow use prior to the tillering stage

Rotary hoe

Like the tine harrow, the rotary hoe should be used with care. It is easy to adjust, and it can be employed between the crop's 3-leaf and 2-node stage. It eliminates young weeds, but it can also aerate and prepare the soil (especially compacted soil) for the tine harrow, thus promoting crop growth. As in the case of the tine harrow, it is better to use a greater sowing rate and depth than normal.

Spring barley growth stage	Post-seeding/ Pre-emergence	Emergence to 2 leaves	3–4 leaves	Tillering	Early stem elongation Pseudo-stem erection (Zadoks 30)	2 nodes Heading
Weed growth stage	strongly discouraged		cotyledon to 2 leaves max			not useful
Working speed			12–18 km/h			
Working depth			shallow	intermediate to deep		
Crop loss	high		low	possible	none	

Row cultivator

It is possible to start using the row cultivator when the crop reaches the 3- to 4-leaf stage, provided that the barley is well developed. Row spacing must be rather wide (20–40 cm), which creates an ideal area for weed growth, especially pre-tillering. The use of a camera-based guidance system can decrease row spacing to 15–20 cm (among other benefits). The row cultivator can also help fight perennials in the row middle.

Spring barley growth stage	Post-seeding/ Pre-emergence	Emergence to 2 leaves	3–4 leaves	Tillering	Early stem elongation Pseudo-stem erection (Zadoks 30)	2 nodes Heading
Weed growth stage	use is discouraged					cleavers developed
Working speed			3–4 km/h	6–8 km/h		8–10 km/h
+ camera-based guidance system			7–8 km/h	10–14 km/h		15 km/h
Component choice			use shields or Lelièvre blades to avoid burying the crop			shields raised
Guidance system			GPS, camera, tracking devices—all improve work accuracy and precision			
Cultivator/ tractor configuration			front mounted: improves comfort tool holder: improves precision rear mounted: traditional; reduced precision			
Crop loss	very high		low (intermediate if crop is buried)	possible	none	

Case study...

Spring barley grown by an organic grain farmer in southern Ile de France

Farm description

- *Grains*
- *Usable farm area: 200 ha*
- *Main soil type(s): clayey silts—shallow (rocky) to semi-shallow*
- *Organic status obtained 10 years ago*
- *Equipment: 1.5 hp/ha (excluding the combine harvester)*
  Tine harrow—12 m (300 ha/year)

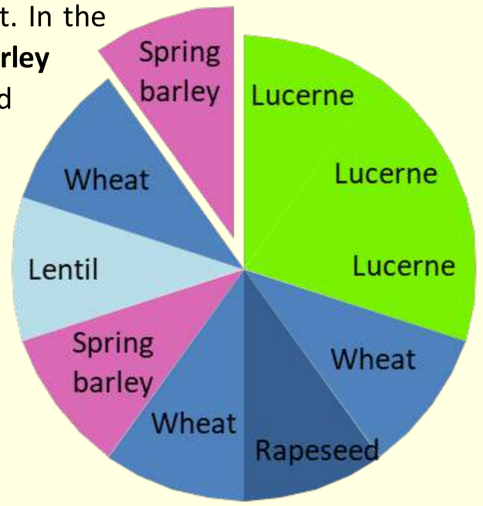
The field is composed of shallow to semi-shallow clayey silt; it is considered to be **moderately weed free**. The main weeds are common poppy, wild oat, and, to a lesser degree, cleavers. The spring barley occurs at the end of the rotation; given the higher weed levels, there is autumn ploughing.

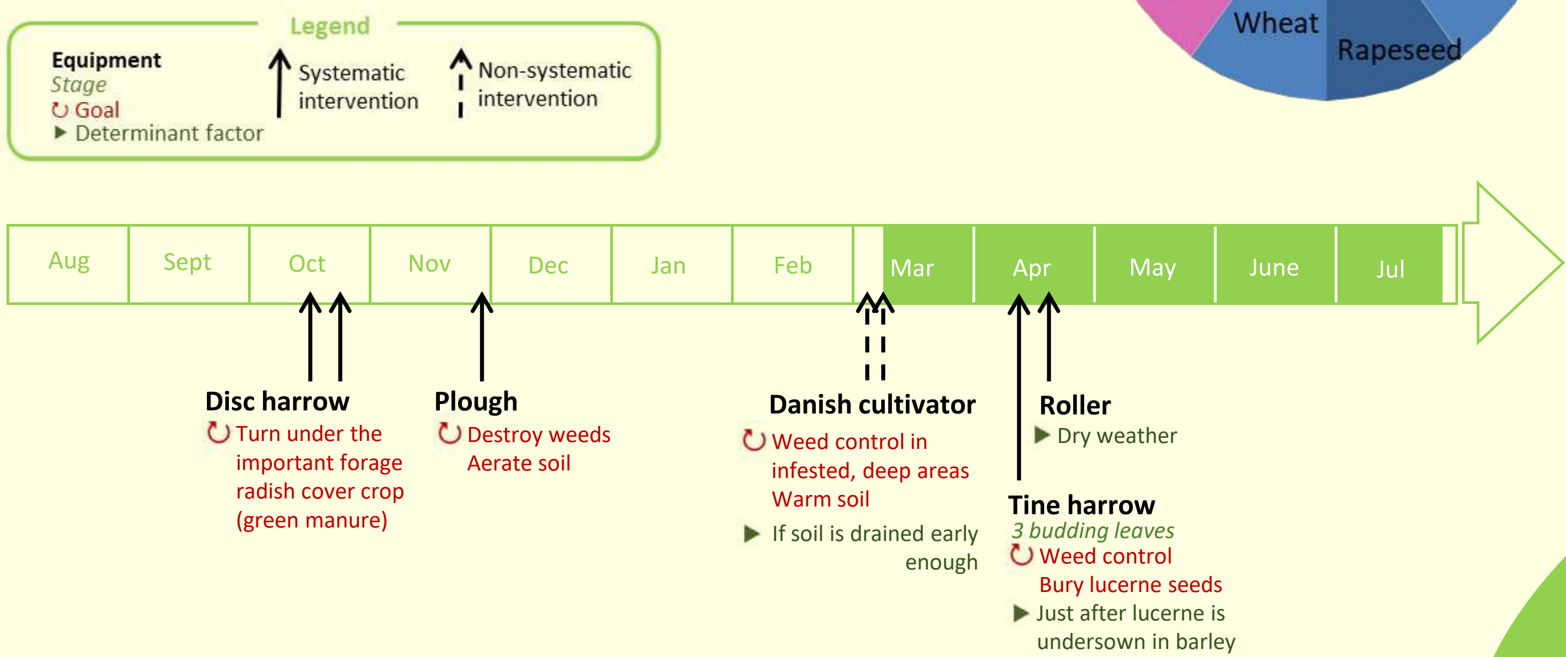
Why this crop rotation?

Given the soil types and rainfall levels (640 mm/year), crops **with low water requirements** are used (no maize).

Furthermore, because the farmer is on his own, he tries to **limit periods when the workload gets excessive**. This is the reason he keeps the lucerne in place for three years and avoids ploughing at the rotation's beginning, after the lucerne.

The spring barley comes after the **legume-wheat sequence**, so that it benefits from the nitrogen boost. In the spring, **lucerne** is **undersown in the barley** to take advantage of the moist soil and to reduce sowing costs as much as possible. In this soil type, in contrast to wheat, spring barley does not suppress lucerne.





Why this particular weed control regime?

Ploughing aims to periodically loosen the soil during the rotation and to better control weed levels, which increase by rotation's end.

Soil preparation can be reinitiated in late February-early March: one or two passes can be done with a Danish cultivator if the soil drains early enough. This process can warm the soil and limit weeds if infestation has occurred over the winter. Additionally, it is likely to rain more, which will replenish groundwater levels.

If sowing is delayed (late March), the farmer uses the Danish cultivator on highly infested parts of the field, to avoid drying out the soil.

The **tine harrow** is used to lightly bury lucerne seeds and to limit weed levels. Consequently, the pass should take place as early as possible: as soon as the soil is in good shape and no longer vulnerable to compaction and the crop can handle it. A second pass is unnecessary and can hurt the barley by killing plants and reducing vigour (i.e., damaged root systems).

Summary

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- *Lucerne is planted under good conditions and at a low cost*
- *Cover crop limits weed infestation*

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- *Lucerne seedling emergence will be poor if conditions are dry after the cover is undersown*
- *Impossible to remove perennial weeds in particular after the cover crop has emerged*

Descriptive sheet 6:

Mechanical weed control in soybean

Background—Challenges

In soybean, the critical period for weed control is the first two months after sowing. Certain species present a particular threat: bindweed, common ragweed, Johnson grass, common cocklebur, sunflower regrowth, knotweed, nightshade, amaranth, fat hen, thorn apple, barnyardgrass, and foxtail grass. Creeping thistle can easily infest soybean, but it is a general weed that affects several of a farm's crops.

If the soybean is intended for human consumption, certain weeds must be fully controlled, which may require complementary manual intervention. Nightshade is toxic to humans, cocklebur berries stain soybeans during the harvest, and thorn apple presents both problems.

Preventive weed control measures

Because mechanical weed control is not 100% effective, it is better to take preventive measures, such as planting soybean in fields at low risk of infestation by the weeds of summer crops.

Field selection and crop sequence

Within the rotation, prevention involves utilising diverse crop types (e.g., winter/summer/spring, annual/perennial).

In general, it is easy to incorporate soybean into different types of rotations:

- those of differing length (one year of every three or one year of every six)
- those with grains (wheat, barley, rye, triticale, maize, and rice)
- those with legumes (e.g., pea, lentil, faba bean, and lucerne)
- those with sunflower

Under certain conditions (relatively weed-free field, adapted weed control methods), soybean can be grown two years in a row in the same field.

See the figure on the following page for clarification.

Preparing to sow

> ***Stubble ploughing***

Stubble ploughing should be carried out as soon as possible after the harvest and, in all cases, before

Soybean—hoed and earthed up

summer weeds set seed. The goal is to destroy any weeds that have developed and limit deposits in the weed seed bank. To maintain the results of the ploughing, it is important to lightly work the soil after each summer rainfall event, using a tool with independent discs, a tool with sweeps, or any other appropriate piece of equipment. Soils should be flattened to encourage the emergence of summer and autumn weeds from the upper soil layer; the weeds can then be cleared.

The presence of perennials (Johnson grass, thistle, bindweed, dock, sorrel, and Bermuda grass) may require deeper work during the hot, dry period; a tool equipped with flat sweeps can thoroughly slice up rhizomes and other storage organs.

> ***Ordinary ploughing or false ploughing***

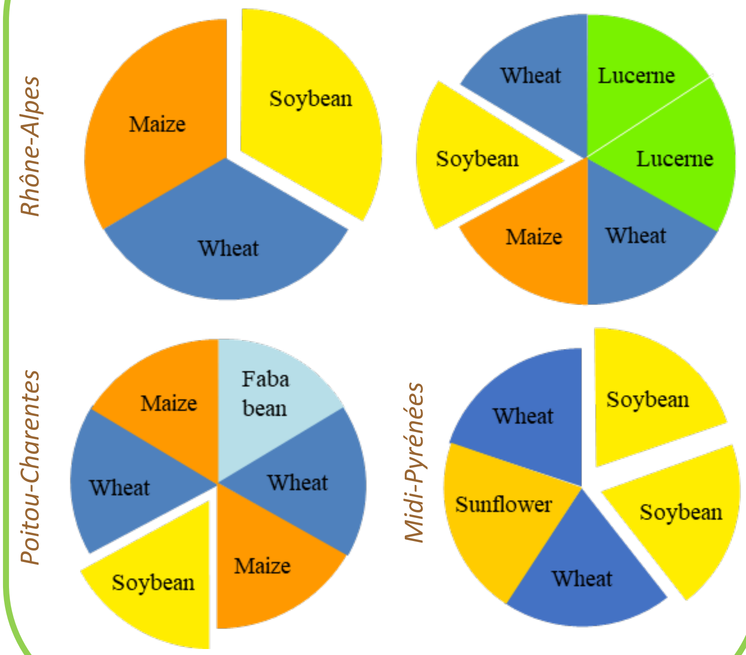
Ploughing efficacy is determined by ploughing frequency (every two to four years, ideally) and the size of the weed seed bank. Bromegrass, black-grass, ryegrass, foxtail, and crabgrass can be eliminated relatively well via ploughing because they have a high annual loss of viability. This is not the case for most of the dicots found in soybean (e.g., amaranth, fat hen, nightshade, knotweed, thorn apple, and common cocklebur).

> ***Stale seedbed technique***

Around 75% of soybean farmers prepare stale seedbeds and destroy emerging weeds in April using tools such as Danish cultivators, grass harrows, stubble ploughs, or tine harrows (2009 CETIOM & CASDAR projects on mechanical weed control).

In clay soils, it is best to begin light soil preparation early to increase the efficacy of the stale seedbed technique. In vulnerable silty soils, the use of the technique in the spring tends to degrade soil structure. It is therefore important to implement weed control at the last possible moment using a tool with fixed teeth.

Examples of rotations with soybean



Source: CETIOM, CASDAR RotAB

> ***Sowing date***

In the 2009 surveys, more than 50% of farmers said that they delay sowing soybean to eliminate the weeds emerging from the stale seedbed and to take advantage of warmer soil temperatures, which help ensure vigorous and homogeneous crop seedling emergence. These farmers are in southwestern France (n=18). There, the sowing period lasts from April 15 to May 30; the median sowing date is May 15 (CETIOM & CASDAR projects on mechanical weed control).

Hoed soybean

Weed control during the crop season

The four to eight weeks following sowing are a critical period in the crop cycle because soybean produces little cover during early growth. The tine harrow, rotary hoe, and row cultivator not only remove weeds but also promote soybean development, especially when pedoclimatic conditions are unfavourable (compacted soil, low temperatures).

Weed control regimes that combine the use of different mechanical tools function even better when the work is carried out early and in a preventive fashion. To clear out weeds initially, tools that operate at the whole-field level (the tine harrow and rotary hoe) should be used. The row cultivator can be employed for follow-up weed control once the crop is well established; this tool is used on 95% of the soybean break, according to a 2007 CETIOM study.

Using a combination of different tools (tine harrow, rotary hoe, and row cultivator) improves weed control efficacy. Effective passes with the tine harrow or rotary hoe during pre-emergence and early emergence help generate a delay between weed growth and soybean growth.

Maximising the efficacy of mechanical weed control tools

Mechanical weed control must be scheduled so that it eliminates a maximum number of weeds without harming the soybean. Passes should only be done when pedoclimatic conditions are favourable (i.e., dry weather in the days following the intervention).

The next two pages describe how to optimally use the tine harrow, rotary hoe, and row cultivator to control weeds in soybean.

Tine harrow

The tine harrow yields good results on calcareous clay soils and silty soils that are not compacted, if they are well drained and drying. In contrast, in compacted silty soils, the tine harrow is only effective after one or two passes have been made with the rotary hoe (except in the case of post-seeding/pre-emergence blind cultivation).

<table>
<tr><th>Soybean growth stage</th><th>Post-sowing/ Pre-emergence</th><th>Post-sowing/ Germination</th><th>Scale leaves visible</th><th>Cotyledon</th><th>1st single leaf set</th><th>1st trifoliate leaf</th><th>10–20 cm</th><th>20–50 cm</th></tr>
<tr><td>Weed growth stage</td><td colspan="2">germination</td><td rowspan="3">strongly discouraged</td><td colspan="4">between germination and 2–3 leaves</td><td rowspan="3">strongly discouraged</td></tr>
<tr><td>Working speed</td><td colspan="2">8–12 km/h</td><td>2 km/h</td><td>3 km/h</td><td>4–5 km/h</td><td>6–7 km/h</td></tr>
<tr><td>Tine aggressiveness</td><td>intermediate to high</td><td>intermediate</td><td>low</td><td>low to intermediate</td><td>intermediate</td><td>high</td></tr>
<tr><td>Crop loss</td><td>none</td><td>none to intermediate</td><td>high</td><td>intermediate</td><td>low</td><td>fairly low</td><td>none</td><td>high</td></tr>
</table>

Recommendations

- Adjust harrow settings on a field-by-field basis
- For greater ease of use, there are ways to hydraulically regulate tine aggressiveness

Rotary hoe

The rotary hoe is a crucial tool when dealing with silty soils—it prepares the earth for the tine harrow, making the latter's work more effective. However, it is also helpful in many other soil types. It remains the only tool that can be used during very early crop development.

It is possible to do a pass when the crop's folded scale leaves are visible. However, the speed must be just right to destroy weeds but leave the young soybean unharmed.

Soybean growth stage	Post-sowing/ Pre-emergence	Post-sowing/ Germination	Scale leaves visible	Cotyledon	1st single leaf set	1st trifoliate leaf	10–20 cm	20–50 cm
Weed growth stage	germination			germination, cotyledon, 1–2 leaves				unsuitable
Working speed	15–20 km/h		<10 km/h	10 km/h max	12–15 km/h	15–20 km/h	15–20 km/h	
Crop loss	none	none	intermediate to high	low to intermediate	very low	none	none	

Row cultivator

The row cultivator is the best tool for finishing off the last weeds before the soybean covers over the row middle.

Soybean growth stage	Post-sowing/ Pre-emergence	Post-sowing/ Germination	Scale leaves visible	Cotyledon	1st single leaf set	1st trifoliate leaf	10–20 cm	20–50 cm	50–70 cm
Weed growth stage	discouraged				germination to 3–4 leaves				
Working speed					3 km/h	5 km/h	6 km/h	7–8 km/h	8–10 km/h
Crop loss	high				none with shield	none with shield	none	none	ridge creation is useful

Diverse strategies for mechanically controlling weeds in organic agricultural systems

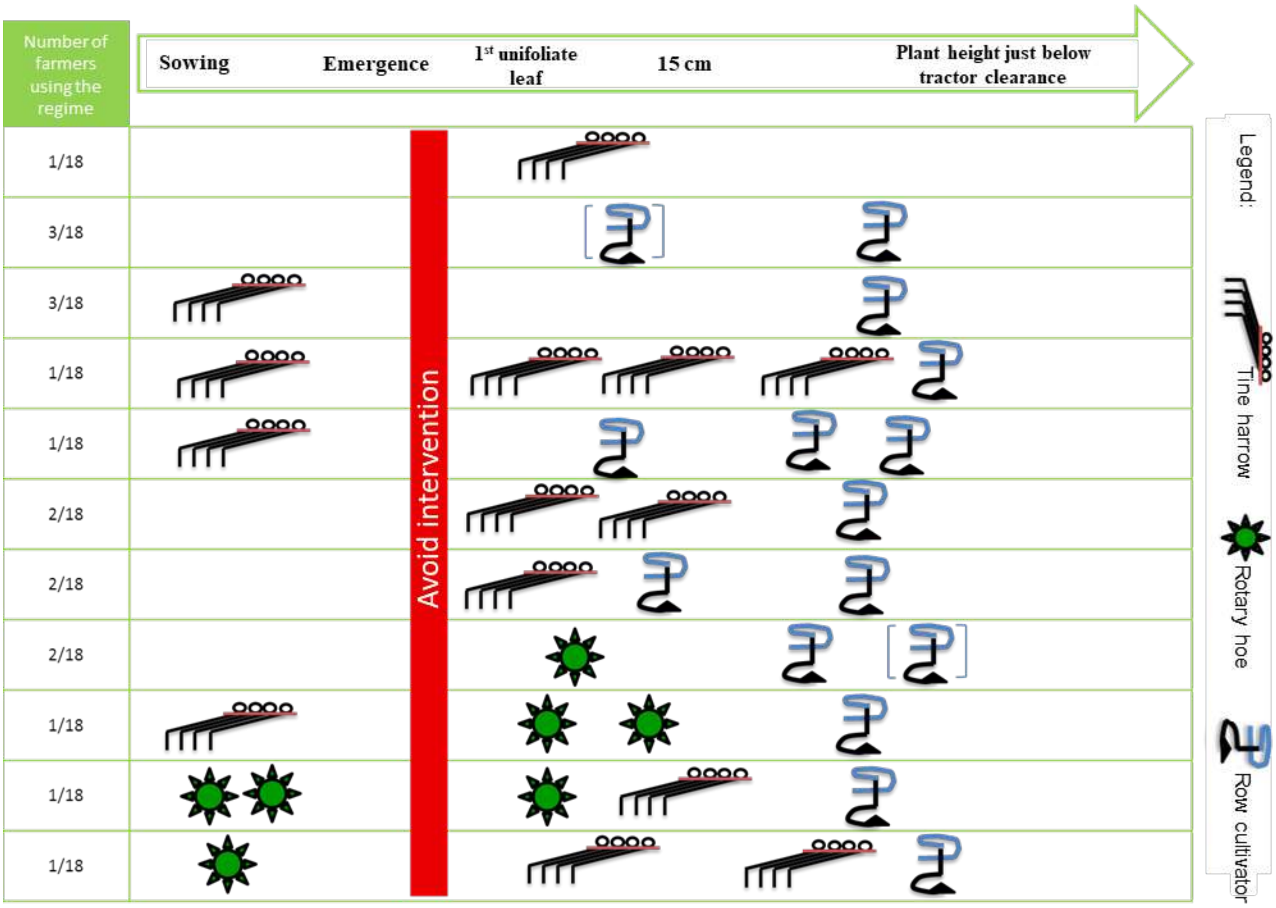
Weed control regimes carry out three interventions, on average. **Seventy-seven percent of farmers use a combination of 2–3 tools to mechanically control weeds.** The most common combination is the tine harrow and row cultivator. Nearly 50% of farmers initiate weed control in soybean using blind cultivation during pre-emergence, 3–4 days after seeding. Generally, the tine harrow rather than the rotary hoe is used. In the month following crop emergence, one or two passes are made at the whole-field level (notably with the tine harrow, although the rotary hoe is being used more and more in calcareous silty soils). This strategy does a good job of controlling weed seedlings. The row cultivator is the main tool used from the time the crop reaches 12 cm to the time when it exceeds tractor clearance.

Study conducted in 2009/2010 on 18 fields in southern France

- ***Clay soils (calcareous [terreforts calcaires] or non calcareous), silty soils (boulbènes), or sandy soils (sables de Landes)***
- ***Mean usable farm area = 111 ha***
- ***Farms that obtained organic status over 10 years ago***
- ***Soybean is most often irrigated. It is included both in long, diverse rotations (e.g., with wheat, barley, maize, rice, faba bean, chickpea, lentil, sunflower, or lucerne) and in short rotations.***
- ***Observed yields (several-year mean): 27–40 q/ha***

Important note:

The weed control regimes summarised in the graphic below, as well as those described in the farmer case studies, were those used in 2009 by the farmers (n=18) who participated in the CASDAR surveys. Consequently, they should not be taken as fixed recommendations but rather as descriptions of real approaches used under certain pedoclimatic conditions.



Case study...

Non-irrigated soybean grown by an organic farmer in the Midi-Pyrénées region

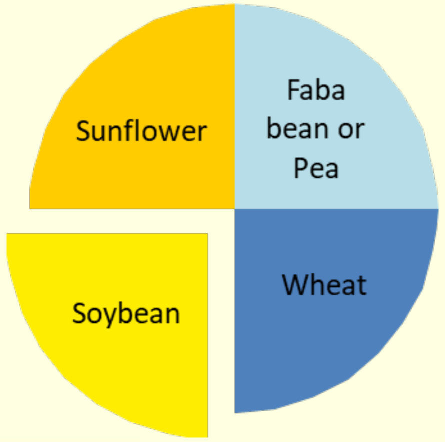
Farm description

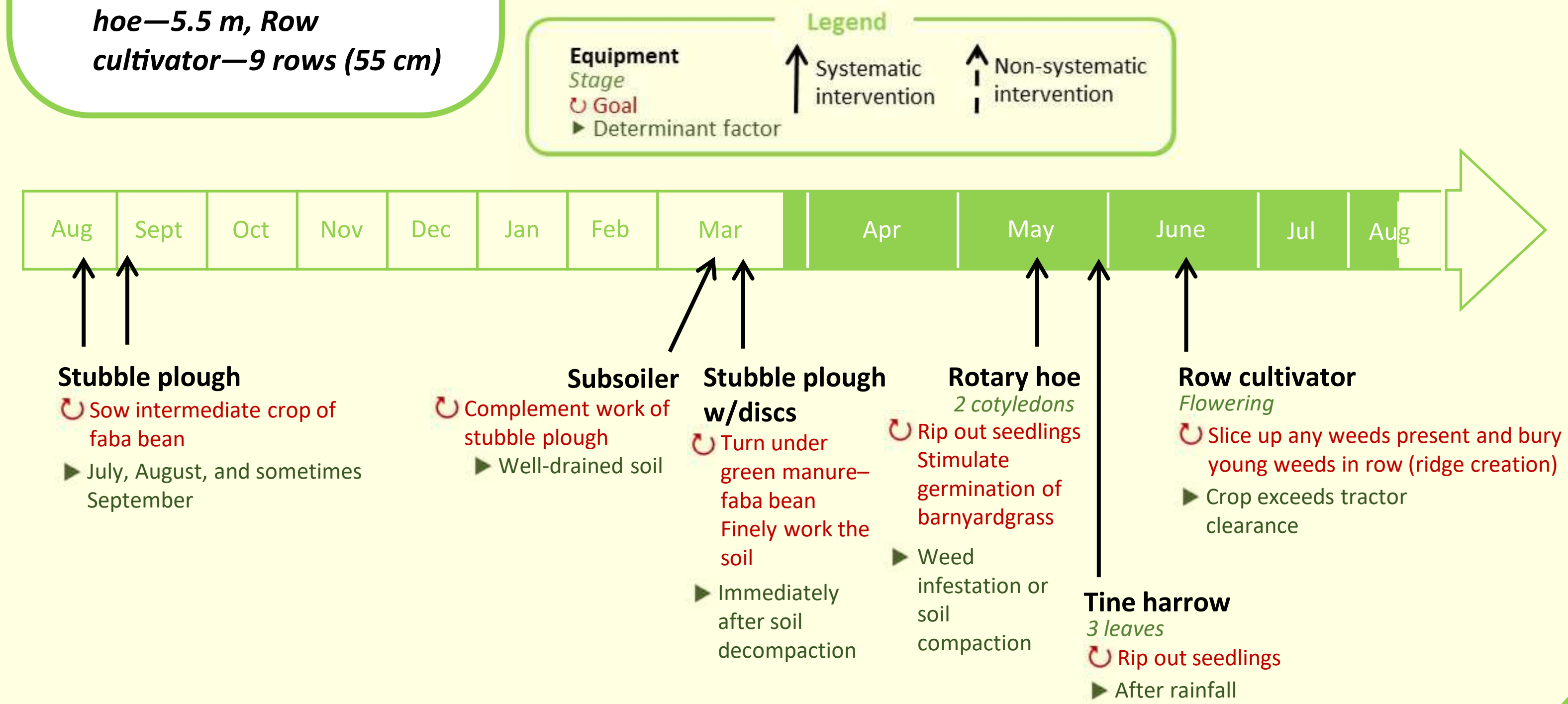
- *Mixed cropping-livestock system (15 LUs on 15 ha of natural grassland)*
- *Usable farm area: 145 ha*
- *Main soil type(s): steep, calcareous clay soil typical of Gascony*
- *Organic status obtained 6 years ago*
- *Equipment: 2.4 hp/ha Tine harrow—12 m, Rotary hoe—5.5 m, Row cultivator—9 rows (55 cm)*

The schematic below depicts the weed management regime for a field of soybean during a **short rotation**. The soybean **follows a wheat**, and there is **no ploughing**. In this case study, the field is considered to be **fairly weed free**. The main weeds are barnyardgrass, thorn apple, nightshade, and thistle.

Why this crop rotation?

This rotation is **typical** of the region. To limit the risk of weed infestation in this no-till system, crops are **alternated** throughout the rotation (two summer row crops/two winter non-row crops). A winter faba bean is sown as a **winter cover crop** before each spring cash crop, to boost soil nitrogen. Grasslands are planted on less fertile farmland that is poorly spatially organised.





Why this particular weed control regime?

On this no-till farm, **soil fertility** is crucial and relies on the maintenance of excellent soil structure. This is the reason why **tools with deep-penetrating tines are employed after the use of green manure**. Post sowing, the tine harrow is the most frequently used tool; it is employed before or after the rotary hoe. It allows **weeds to be controlled early**, sometimes to the detriment of crop density. The row cultivator finishes off the work in the row middle. The farmers have high weed control standards. They control weeds **systematically**—preventive measures are taken and weeds are actively targeted. The timing and tools are established ahead of time and are then adjusted depending on the state of the land, crop growth stage, and weed growth stage. The weeds do not interfere with crop growth, especially that of soybean, which generates extensive cover and grows fast, as soon as it reaches the 6-leaf-pair stage. The decision to go **no-till** was carefully thought out. However, the lack of tillage means that occasional recurrent weed infestations must be handled manually. In general, this type of intervention is limited.

Economic and environmental indicators

Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
65	200	3.0

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

Summary

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- *Weeds are managed by alternating crops; making systematic passes with mechanical tools; manually removing weeds; and making appropriate adjustments to the three tools*
- *Legumes are planted during the fallow period*

-

- *No-till system increases weed infestation risk*
- *Several passes are made with mechanical tools in the spring because green manure is planted in the fallow period before the cash crop*
- *Diminished yields because of lower crop density and low soil nitrogen, despite the fields being clear of weeds*

Case study...

Soybean grown by an organic grain farmer in the Midi-Pyrénées region

Farm description

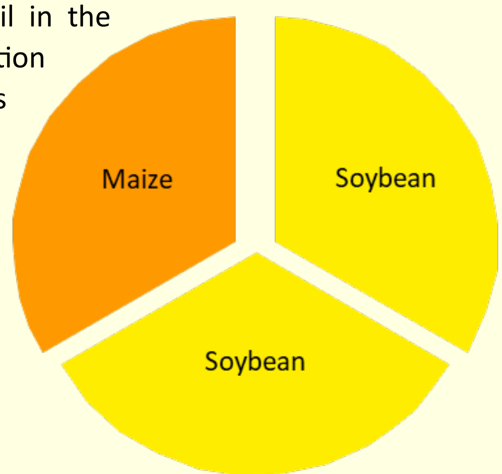
- *Grains*
- *Usable farm area: 71 ha (irrigated)*
- *Main soil type(s): alluvial soils (Adour river basin), high in clay and silt*
- *Organic status obtained 8 years ago*
- *Equipment: 3 hp/ha Rotary hoe—4.5 m (140 ha/year), Row cultivator—6 rows (4.5 m, 280 ha/year)*

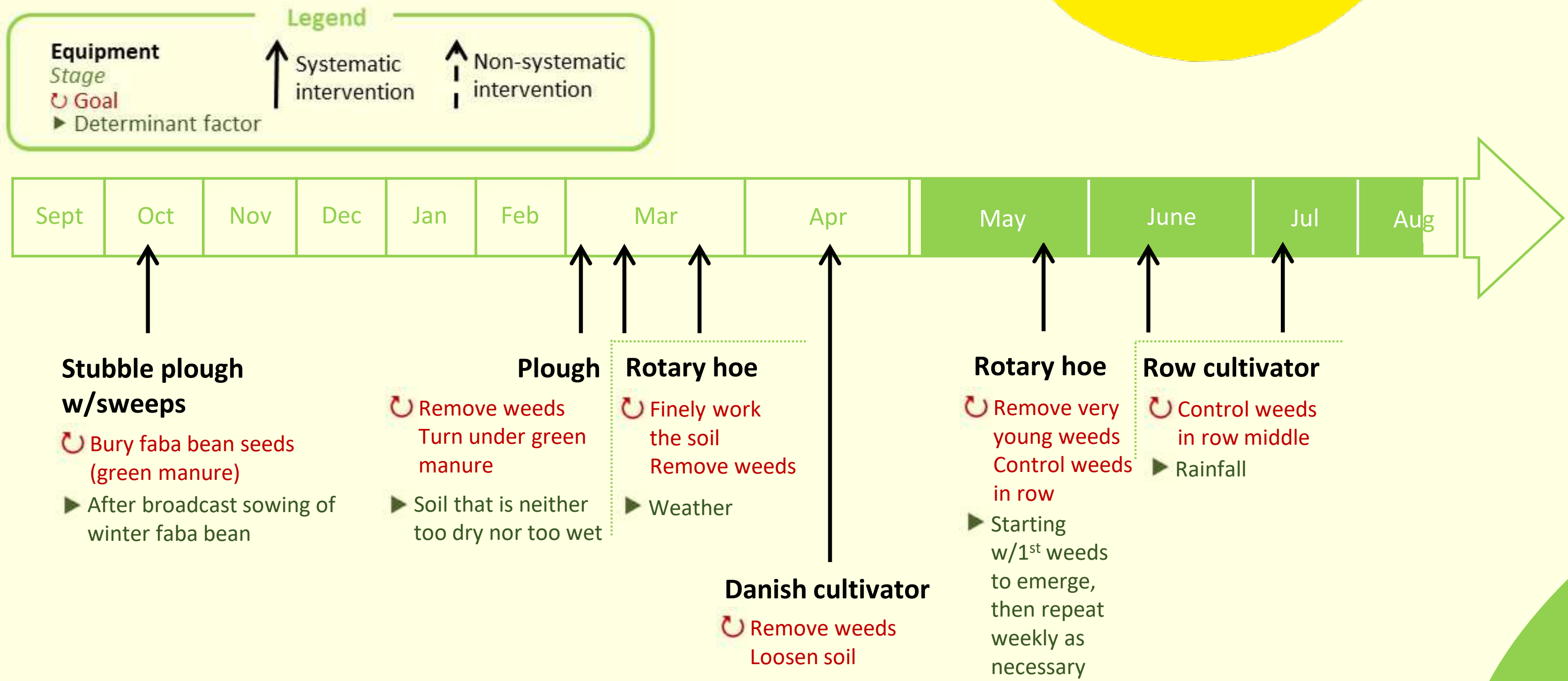
The schematic below depicts the weed management regime for a field of soybean during a **short rotation** of irrigated spring crops. The field is considered to be **fairly weed free**. The most common weeds are knotweed, thorn apple, amaranth, bindweed, and fat hen.

Why this crop rotation?

As is often the case in a region where **lands are flooded**, the rotation—based on **summer crops**—lasts three years. The soybean (35 q/ha) and the maize (80 q/ha) have good yields and strong margins.

Winter faba bean is systematically planted as a **winter cover crop** across the farm, as soon as the preceding cash crop has been harvested. It protects the soil in the winter, limits evapotranspiration in the spring, and increases soil nitrogen. The seeds are buried using a stubble plough with sweeps. In the spring, the faba bean is shredded and the field parcels are ploughed (eight days later).





Why this particular weed control regime?

From the perspective of prevention, it is a good choice to use **spring ploughing** in a system with limited weed infestation. It makes it possible to control weeds from the previous year's infestations and to compensate for the **lack of alternation** between spring and winter crops. The rotary hoe is used several times to refine soil texture, which has the benefit of creating false seedbeds. The deep ploughing also improves soil structure.

The farmers control weeds **systematically**—preventive measures are taken and weeds are actively targeted. Timing is determined by crop and weed growth stages. Indeed, weed control standards are high. After the three-year non-alternating rotation and after five years of **interventions (often manual)**, weed levels are under control but remain under surveillance.

Economic and environmental indicators

Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
65	250	3.9

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

The amount of ploughing results in high fuel costs because of the low working speed (0.8 ha/h), the powerful tractor used (160 hp), and the significant working depth (>20 cm). Furthermore, the large quantities of fuel and the use of the plough on just 72 ha of land increase operating costs.

Summary

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- *Regime tightly controls weed infestation risk: systematic passes; manual interventions; and appropriate equipment*
- *Legumes used as winter cover crops supply nitrogen and thus compensate for low levels of fertilisation*
- *Excellent technical and economic performance*

-

- *Rotation does not alternate different crop types*
- *Several passes are made with mechanical tools in the spring to finely work the soil because cover crops sometimes remain until March 15*

Descriptive Sheet 7

Mechanical weed control in sunflower

Background—Challenges

In sunflower, the 3–5 weeks that follow sowing are particularly important for weed control because young sunflower plants produce little cover.

Yield losses can be high when weed pressure is high. Notable problem species are perennials—creeping thistle, couch grass, and bindweed—or annuals—thorn apple, cocklebur, amaranth, fat hen, barnyardgrass, foxtail grass, and crabgrass.

As previously mentioned, mechanical weed control (whether in conventional or organic systems) will be easier if preventive agricultural strategies are deployed throughout the rotation. This remains true for sunflower.

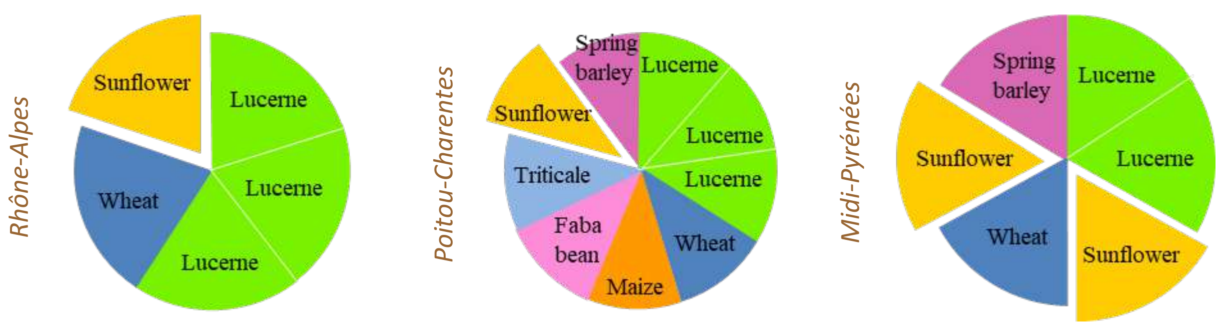
Preventive weed control measures

Field selection and crop sequence

Within the rotation, prevention involves alternating crop types that differ from sunflower (winter/spring). This is the most effective and least expensive method for controlling weeds in sunflower fields.

In organic systems, sunflower can be included in different types of rotations, including those with grains (e.g., wheat, triticale, barley, maize, and sorghum) or those with legumes (e.g., soybean, pea, lentil, faba bean, and lucerne), regardless if they are autumn or summer crops. Non-irrigated systems are the most common, although some irrigated systems are observed as well.

Examples of rotations with sunflower



Source: CETIOM, CASDAR RotAB

Sheet 7: Sunflower...

Preparing to sow

> ***Tillage (stubble or ordinary ploughing)***

As is the case in all spring crops, stubble ploughing and ordinary ploughing are two techniques for controlling weeds even before sunflower is planted. To limit the risk of pollen-related allergic reactions, it is crucial to stubble plough in the summer if ragweed is present.

> ***Stale seedbed technique***

Around 75% of sunflower farmers prepare stale seedbeds and destroy emerging weeds in April using tools such as Danish cultivators, grass harrows, stubble ploughs, or tine harrows (2009 CETIOM & CASDAR projects on mechanical weed control).

The success of the stale seedbed technique is tightly linked to pedoclimatic conditions. In certain types of soils (especially silty soils), it can be challenging to set up stale seedbeds. If numerous passes are made, clods may be eliminated and overly fine soil structure may result, which can lead to compaction. It is therefore crucial to implement mechanical weed control when soils are well drained and using tools with non-vibrating teeth.

> ***Sowing date***

In the 2009 surveys, more than 50% of farmers said they delay sowing sunflower to use the stale seedbed technique one or two times beforehand, which ensures vigorous and homogeneous crop seedling emergence.

If sunflower growth is homogeneous within the field, passes can be made with mechanical weed control tools in the weeks following sowing.

These farmers are located in southwestern France (n=22). There, the sowing period lasts from April 15 to May 30; the median sowing date is May 5 (CETIOM & CASDAR projects on mechanical weed control).

Weed control during the crop season

The tine harrow, rotary hoe, and row cultivator do not only remove weeds; they also promote sunflower development, especially when pedoclimatic conditions are unfavourable.

Weed control regimes that combine the use of different mechanical tools function even better when the work is carried out early and under good conditions. To clear out weeds initially, tools that operate at the whole-field level (the tine harrow, rotary hoe) should be used. Fifty percent of organic farmers use the tine harrow to control weeds in sunflower. As soon as the crop seedlings emerge, only the rotary hoe can be used, especially in compacted soils or when soil crusts are present. The row cultivator can be used for effective follow-up weed control; this tool is used on 91% of the sunflower break, according to a 2011 CETIOM study.

Maximising the efficacy of mechanical weed control tools

Mechanical weed control must be scheduled so that it eliminates a maximum number of weeds without harming the sunflower. Passes should only be done when weather conditions are favourable (i.e., dry weather in the days following the intervention).

The next two pages describe how to optimally use the tine harrow, rotary hoe, and row cultivator to control weeds in sunflower.

Blind cultivation with a tine harrow in a sunflower field

Tine harrow

Although the tine harrow is frequently used in sunflower, farmers should proceed with care during post emergence: moderate speeds should be adopted when temperatures are higher. Ideally, passes should take place pre-emergence (blind cultivation) or, if necessary, during the 1- to 2-leaf stage (3–5 km/h max).

Sunflower growth stage	Post-sowing/ Pre-emergence	Post-sowing/ Germination	Scale leaves visible	Cotyledon	BBCH 12: one pair of leaves	BBCH 14: h<20 cm	20 cm < h < 40 cm
Weed growth stage	"white thread"		strongly discouraged		germination to 2-3 leaves		
Working speed	8–10 km/h				2–4 km/h	5 km/h	5 km/h
Tine aggressiveness	high	intermediate to high			low	low to intermediate	intermediate
Crop loss	none to intermediate	none to intermediate	high		intermediate to great	intermediate	intermediat e to great

Recommendations

- It is important to adjust harrow settings on a field-by-field basis
- If the tine harrow is used post emergence, passes should take place during the warmest part of the day so as not to harm the crop; it is even better if the plants have attained a height of 15–20 cm

Rotary hoe

The rotary hoe acts along its entire length and eliminates very young weeds by ripping out and projecting the clods in which they are growing.

Sunflower growth stage	Post-sowing/ Pre-emergence	Germination/ Pre-emergence	Scale leaves visible	Cotyledon	BBCH 12: one pair of leaves	BBCH 14: h<20 cm	20 cm < h < 40 cm
Weed growth stage	"white thread"		discouraged	"white thread", cotyledon, 1 leaf			discouraged
Working speed	15 km/h			8–10 km/h	10–12 km/h	12–15 km/h	
Crop loss	none to intermediate	none to intermediate	high	intermediate	none to intermediate	intermediate	high

Row cultivator

The row cultivator is clearly a key part of weed control in sunflower. It is the best tool for finishing off the last weeds before the sunflower covers the row middle. If shields are used, the row cultivator can be employed as soon as the crop's first pair of leaves appears. Depending on the level of weed infestation, one or two interventions should take place 25–45 days after planting. Ridging helps keep weeds on the row to a minimum, especially in cases where the tine harrow or rotary hoe have not been used beforehand.

Sunflower growth stage	Post-sowing/ Pre-emergence	Post-sowing/ Germination	Scale leaves visible	Cotyledon	BBCH 12: one pair of leaves	BBCH 14: h<20 cm	BBCH 16–18: 20 cm < h < 40 cm	20 cm < h < 40 cm
Weed growth stage	unsuitable				cotyledon to 3- or 4-leaf stage			
Working speed					3–4 km/h	5 km/h	6 km/h	8–9 km/h
Crop loss					low if properly equipped	none	none	ridge creation useful

Diverse strategies for mechanically controlling weeds in organic agricultural systems

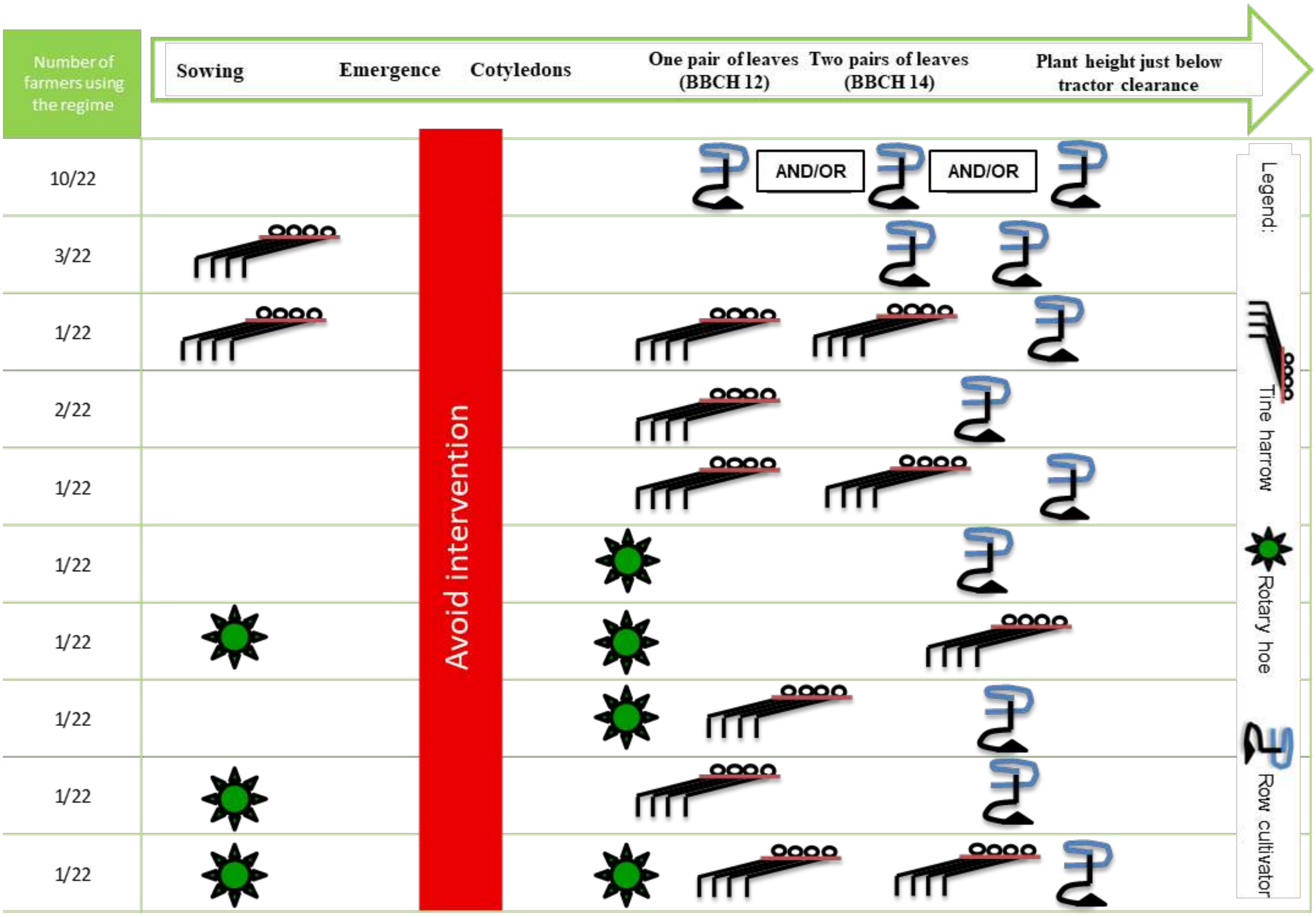
Study conducted in 2009/2010 on 21 organically farmed fields primarily located in southern France

- ***Clay soils or clayey silt soils (terreforts, calcareous clay or non calcareous clayey silt), silty soils (boulbènes), or sandy soils (sables de Landes)***
- ***Mean usable farm area: 134 ha***
- ***Farms that obtained organic status over 10 years ago***
- ***Sunflower included in rather long rotations; occurrence every 5–6 years in the same field***
- ***Sunflower mainly farmed without irrigation***
- ***Variable yield: 10–30 q/ha, with a mean of about 20 q/ha***

In the 2009 surveys, farmers carried out 2.4 interventions on average. Slightly over 50% of farmers use a combination of 2–3 tools to mechanically control weeds in sunflower. The most common combination is the tine harrow and row cultivator. Half of organic farmers only use the row cultivator to control weeds in sunflower. Infrequently employed in 2009, the rotary hoe is more and more common on farms.

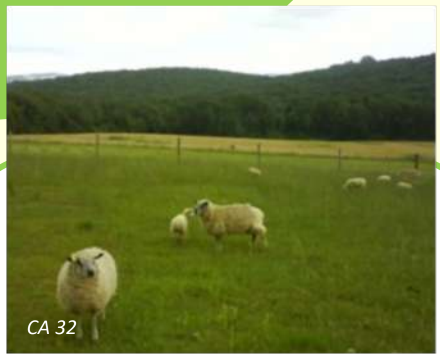
Important note:

The weed control regimes summarised in the graphic below, as well as those described in the farmer case studies, were those used in 2009 by the farmers (n=22) who participated in the CASDAR surveys. Consequently, they should not be taken as fixed recommendations but rather as descriptions of real approaches used under certain pedoclimatic conditions. They reflect a range of strategies that arose in different contexts (based on soil type, climate type, available equipment, etc.).



Case study...

Sunflower grown by an organic sheep farmer in the Midi-Pyrénées region



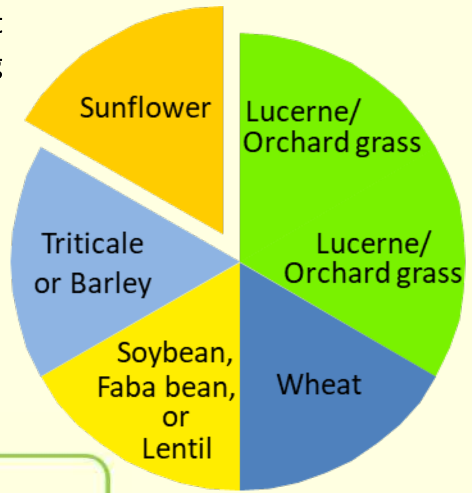
Farm description

- *Mixed cropping and sheep production (70 LUs)*
- *Usable farm area: 185 ha (100 ha—irrigated)*
- *Main soil type(s): calcareous clay*
- *Organic status obtained 8 years ago*
- *Equipment: 2.5 hp/ha 2 Tine harrows—12 m and 4.5 m), Row cultivator—7 rows (60 cm); the 4.5-m tine harrow is associated with the front-mounted row cultivator*

In this case study, the sunflower **comes after a grain** and the field is considered to be **relatively weed infested**. The main weeds are those common in this area and production system: knotweed, fat hen, amaranth, common cocklebur, thorn apple, and creeping thistle.

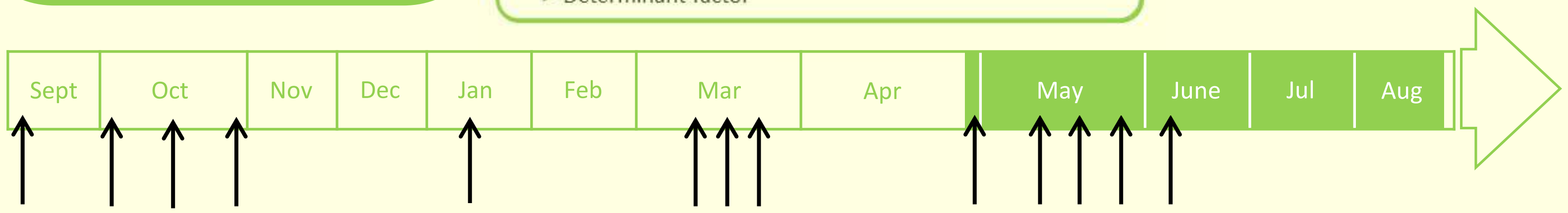
Why this crop rotation?

This rotation is **typical** of the region. It lasts six years and includes a legume grassland, winter crops (60%), and pulse legumes. This grain farm used to grow legume field crops before going organic. It became a mixed crop-livestock farm when the farmer's son joined the operation. The **legume grasslands** help manage weeds and maintain the fertility of the farm's steep, irrigated soils. To limit the weed infestation risks arising from **the no-till system**, **summer and winter crops** are consistently alternated and rotation length is long.



Legend

- **Equipment**
- *Stage*
- Goal
- ▶ Determinant factor
- ↑ Systematic intervention
- ↑ Non-systematic intervention



Stubble plough w/discs then w/sweeps
Remove emergent weeds
Flush weed seed bank
▶ After harvest, then after each rainfall

Subsoiler
Aerate and break up soil
Slice up perennial roots; let them dry out
▶ Hot temperatures (35°C in summer)

Cultivator
Bring up structural elements to expose them to freezing temperatures
Destroy weeds
▶ Soil is frozen and not vulnerable to compaction

Danish cultivator
Manage wild oat and spring dicots

Tine harrow
Just after sowing, then at the 2- to 3-cm stage
Level and break up soil
Cover wheel tracks with small clods
Control weeds
▶ Growth stage

Front-mounted row cultivator
Hoe and slice up weeds
Then throw dirt on the row to suffocate young weeds
▶ Starting at the 2-leaf-pair stage on non-moist soil and before a period of nice weather

Why this particular weed control regime?

On this no-till farm, the challenge is **maintaining soil fertility**. Consequently, **tools with deep-penetrating tines are used** before summer crops, and 700 T of **organic fertiliser** (horse manure; from an outside source) is spread. The usual factors guide weed control decisions (timing and tools). There is no pre-established acceptable level of weed infestation. Instead, the state of the land, crop growth stage, and weed growth stage are what drive mechanical tool use. More than three passes are made with the **tine harrow**, which allows early weed control and the incorporation of powder nitrogen fertiliser. The **row cultivator** finishes off the work in the row middle. The choice has been made not to manually manage recurrent weed infestations resulting from the no-till system.

Economic and environmental indicators

Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
140	370	5.2

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

The no-till system means that intervention frequency is high, which increases energy costs and lengthens working hours for the two farmers, whose usable farm area is of average size. Soil decompaction is a significant part of the regime but ensures good perennial weed control.

Summary

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- *Weed infestation risk is limited by lucerne and crop alternation*
- *Systematic passes*
- *Adapted equipment*
- *Thistle under control thanks to grasslands and soil decompaction*
- *No manual weed control*

-

- *No-till system entails risks (reduced by several pre-sowing passes with the tools set to an intermediate working depth)*
- *Weed presence limits farm technical performance*

Case study...

Sunflower grown by an organic grain farmer in the Centre region

Farm description

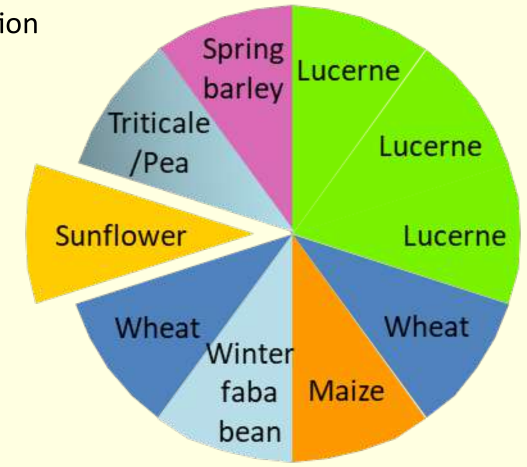
- > ***Grains***
- > ***Usable farm area: 100 ha***
- > ***Main soil type(s): calcareous clay***
- > ***Organic status obtained 10 years ago***
- > ***Equipment: 3.1 hp/ha Tine harrow—12 m (160 ha/year), Row cultivator—4 m***

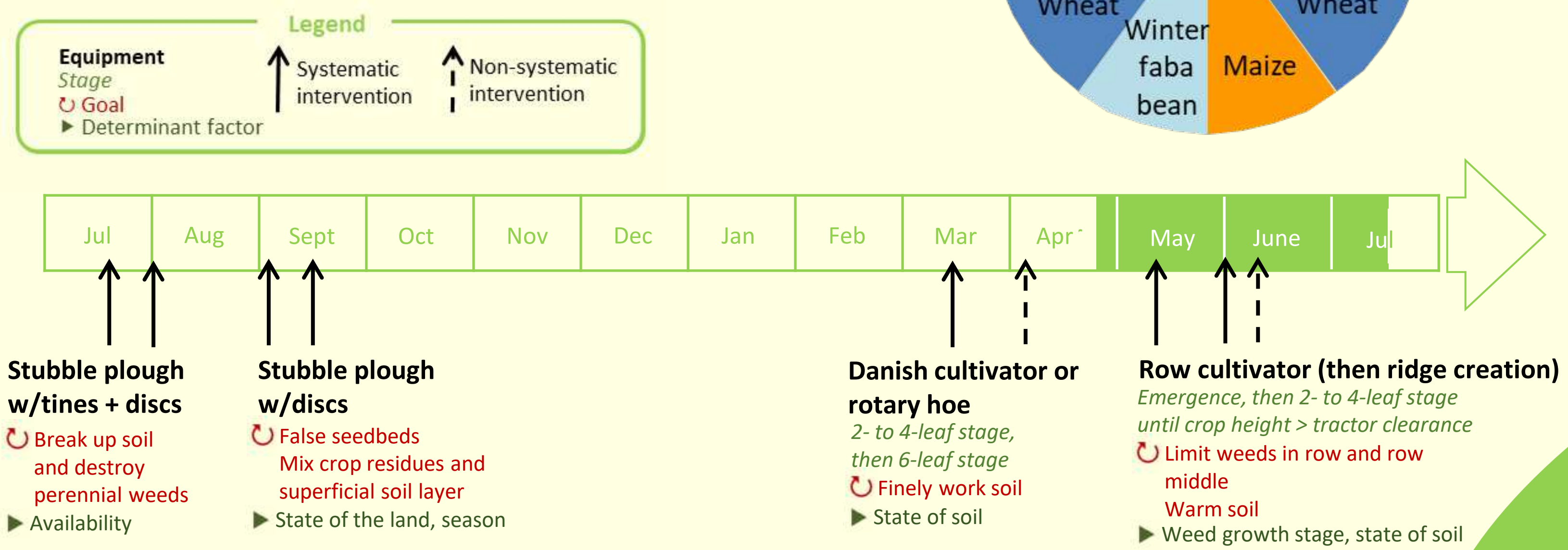
In this case study, the sunflower **follows a wheat**, and there is no ploughing. The field is considered to be **rather weed infested**. **Wild oat** is a major problem in the sunflower, as well as in the rotation's other crops.

Why this crop rotation?

Sunflower is a **traditional** crop in this region. It requires little nitrogen and works well in organic crop rotations. Sunflower plays an important role in both long supply chains and short supply chains (i.e., **oil production**). Here, it follows a winter grain, and the long fallow period is helpful for flushing the weed seed bank and fighting perennials.

Furthermore, the **rotation's length (10 years)** and inclusion of **lucerne** help limit wild oat, a recurrent weed in this type of calcareous clay soil. A key part of the farmer's weed control regime is **alternating spring and autumn crops**. Some modifications may be made at the beginning of the rotation (just after the lucerne).





Why this particular weed control regime?

The **row cultivator** is used in the sunflower (at least twice). Tillage during the fallow period helps flush weeds from the seed bank. **Lucerne** undersown in spring barley is productive as soon as the next spring and does a good job of suppressing **wild oat**. To fight this weed, it is also important to delay sowing until the soil is warm enough. Under such conditions, sunflower is better able to deal with emerging weeds.

Economic and environmental indicators

Fuel consumption (l/ha)	Operating costs (€/ha)	Working time (h/ha)
60	150	4.3

These values were influenced by the farm's specific equipment and infrastructure. Consequently, they are not representative and should be used for informational purposes only. They take into account fallow-period tillage and mechanical weed control during the crop season.

Row cultivation is inexpensive because the working speed is optimal. Also, the farmer uses a low-power tractor that has long since been paid off. In contrast, stubble ploughing incurs energy costs that are higher than average for the farmers surveyed. Intervention frequency seems optimal. Weed control during the fallow period seeks to deal with the weed seed bank and prepare the soil for sunflower sowing. Mechanical weed control during the crop season is handled exclusively by the row cultivator.

Summary

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- > ***Long rotation***
- > ***Alternation of spring and winter crops***
- > ***Mechanical weed control is easy thanks to the well-drained soils***
- > ***Several spring crops***
- > ***Lucerne has a cleansing effect on field parcels***

-

- > ***No-till system results in weed infestation risks***
- > ***Staggered emergence of wild oat in the rotation's crops, including in the sunflower***
- > ***Row cultivator is old and less efficient***

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