



Integrated Weed Management: PRActical Implementation and Solutions for Europe

# EXPERIMENTAL TRIALS IN EUROPE

## 2018 EDITION



This project has received funding from the European Union's Horizon 2020 research and innovation programme under agreement no. 727321

IWMPRAISE - H2020-SFS-2016-2017/H2020-SFS-2016-2



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# EXPERIMENTAL TRIALS IN EUROPE

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# The IWMPRAISE project

Integrated Weed Management: PRActical Implementation and Solutions for Europe

## Participating Countries

Denmark  
France  
Italy  
Slovenia

Spain  
Switzerland  
The Netherlands  
United Kingdom

## Partners





### **Integrated weed management is the future**

Integrated weed management (IWM) is the way forward for sustainable and resilient agriculture. IWM PRAISE is a Horizon 2020 project that will support and promote the implementation of IWM in Europe. This five-year project began in June 2017 and will run until May 2022. It is coordinated by professor Per Kudsk, Department of Agroecology, Aarhus University, Denmark.

The project has been granted 6.6m Euro and aims to support and promote integrated weed management (IWM) in Europe. Weed management in Europe will become more environmentally friendly if the concept of integrated weed management takes better hold on European farms.

the case studies that the project deals with.

The four scenarios that the project will focus on are:

- Annually drilled crops in narrow rows (e.g. small grain cereals, oilseed rape)
- Annually drilled crops in wide rows (e.g. maize, sunflowers, field vegetables)
- Perennial herbaceous crops (e.g. grasslands, alfalfa, red clover)
- Perennial woody crops (e.g. pome fruits, citrus fruits, olives)

### **Overcoming barriers and spreading the word**

The project will review current socio-economic and agronomic barriers to the uptake of IWM in Europe and develop and optimize novel alternative weed



The IWM PRAISE workgroup

The project aims to demonstrate that IWM supports more sustainable cropping systems that are resilient to external impacts and do not jeopardise profitability or the steady supply of food, feed and biomaterials. The project consortium consists of 37 partners from eight different European countries and includes 11 leading universities and research institutes within the area of weed management, 14 SMEs and industrial partners, and 12 advisory services and end user organisations.

### **Focus on four scenarios**

The project will develop, test and assess management strategies delivered across whole cropping systems for four contrasting management scenarios representing typical crops in Europe. By adopting this categorical approach, it will be possible to establish principles and develop IWM strategies that can be applied beyond

control methods. On this basis, the project will create a toolbox of validated IWM tools. The project will also design, demonstrate and assess the performance and environmental and economic sustainability of context-specific IWM strategies for the various management scenarios that address the needs and concerns of end users and the public at large.

A final output of the project will be to make the results available to end users via online information, farmer field days, educational programmes, dissemination tools and knowledge exchange with rural development operational groups dealing with IWM issues.

# SPAIN

The olive (*Olea europaea* L.) is one of the major perennial woody crop plants, occupying over 10 million hectares worldwide. In addition, these woody fruit trees play a very important role in the Mediterranean Basin economy and most of global production comes from Southern Europe. In fact, Spain is the country with the largest olive-growing area in the world (2.6 million hectares of olive groves). The effective management of annual and perennial weed species in this crop is essential since weeds reduce tree growth and yields by competing for nutrients, light, rooting space and water, this latter being the most limiting factor in rain-fed areas of Southern Europe. Weed infestation may also increase the likelihood of pests and diseases and can interfere with cultural practices and harvest. For all these reasons and given the economic and agronomic importance of the olive crop, Spain participates in the IWM PRAISE project within the group of perennial woody crops, which constitutes Work Package 6 (WP6), in an attempt to improve the integrated weed-management systems carried out by farmers.





According to the IWM PRAISE goals, the study of perennial woody crops in Spain aims at developing, testing and assessing sustainable and cost-effective IWM strategies for olive orchards to reduce the dependence on chemical weed-control without jeopardizing profitability or the steady supply of food, feed and biomaterials. To achieve this goal, three main tasks have to be carried out:

1. design IWM strategies within the Spanish national clusters;
2. validate IWM strategies by conducting field trials in Spain;
3. evaluate IWM strategies, disseminate results, and feed information and data into the project database.

Spain has olive groves scattered over almost the entire country, but the highest concentration is in Andalusia (1,601,295 ha), the southernmost region of Spain, with the main concentrations being in the provinces of Jaen (586,173 ha) and Cordoba (351,735 ha). Nevertheless, in regions of northern Spain, such as Navarra, olive groves have undergone enormous expansion in recent years and currently there are 5,921 ha. Given the broad geographical area that olive crops cover, soil- and weed-management decisions are significantly influenced by location, climatic conditions, soil, topography and grower preferences. However, olive groves in Córdoba and Navarra undergo similar weed-management strategies despite their geographical distance and different weather conditions. The most-used soil-management technique in olive groves continues to be traditional tillage and reduced tillage, so it is necessary to increase the use of other IWM strategies, such as the use of spontaneous grass cover crops or no tillage with chemical control.

A brief overview of IWM strategies in olive orchards shows that two very distinctive areas have to be singled out: soil beneath the olive trees, where it is necessary to facilitate harvesting; and along the lanes (intra-row and inter-row spacing), where soil compaction and susceptibility to greater runoff and erosion will influence system choice. Moreover, growers have different soil- and weed-management tools available to achieve control objectives. The best strategy for employing these tools, however, will vary between years and farms, according to local conditions. Nevertheless, tillage operations continue to be the most-used soil management system along the lanes, followed by no tillage with chemical control, with pre-emergence herbicides and glyphosate being applied beneath the olive trees and along the lanes, although there are serious problems with resistant species, such as annual ryegrass (*Lolium rigidum*) or

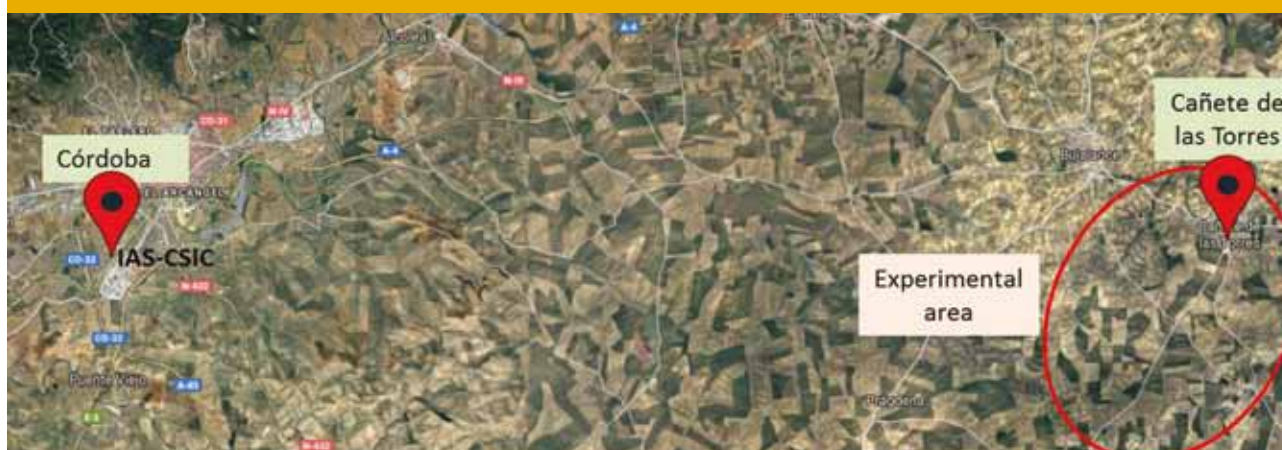
horseweed (*Conyza canadensis*). A combination of both management techniques is also used, although it depends on plantation type and olive-tree spacing. Due to the water constraints existing in Spain, covered soil is also commonly used to conserve water. Plant-residue mulches are used in inter-row and intra-row spacing, above all pruning wood-residues generated on the farm because they also ensure weed control due to the physical barrier formed. Living cover crops are highly recommended for inter-row management because they reduce erosion and improve soil water-content and fertility. They consist of spontaneous flora (weeds) growing on the farm, especially grasses and crucifers, and cultivated species such as grasses, legumes and crucifers. In this regard, natural grasses are the most common spontaneous cover crops in the olive orchards of southern Spain, while natural crucifers are the most significant in northern Spain. Under these circumstances and in an attempt to achieve the Work Package 6 goals, the IWM strategies implemented for on-farm experiments in the perennial woody crops of Spain have to be adapted to the realities of Spanish farmers. The field study will start in the second half of 2018 and field trials will be conducted during three growing seasons (2018/2019, 2019/2020 and 2020/2021) at two different locations with typical Mediterranean climate: the south of Spain (Cañete de las Torres, Córdoba) and the north of Spain (Pamplona, Navarra). Experimental farms will belong to farmers collaborating with the Navarre Institute of Transfer and Innovation in Agri-food Sector (INTIA) in Pamplona, and farmers who are members of the Virgen del Campo olive-growing cooperative in Cañete de las Torres (Córdoba). A detailed summary of each area, plus experimental design and assessments types, has been provided in the next two sections.

# EXPERIMENTAL TRIALS IN SOUTHERN SPAIN



*The Institute for Sustainable Agriculture in Córdoba, a center of the Spanish National Research Council (IAS-CSIC), has established a collaboration with the Virgen del Campo olive-growing cooperative for the next three years. This cooperative is located in the town of Cañete de las Torres, 60 km from Córdoba, and it has more than 800 members. One of its main economic activities is olive-grove cultivation (Picual olive cultivar with farm*

*size averaging 4-6 ha), which is mostly based on soil management by tillage or spontaneous grass cover crops. The experimental farms belong to members of the olive-growing cooperative and are located in Cañete de las Torres.*



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Cañete del las Torres – 14660 Córdoba – Spain  
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### Objectives

The main objective of the field trials is to evaluate the influence of different soil-management strategies commonly used in olive groves on weeds, soil, and crop yields and quality. Given the interest shown by farmers, the effects of cover crops will be compared with those of conventional tillage.

### Materials and methods

Integrated weed-management (IWM) strategies will be studied in two different fields with Vertisol clay soils spread over a maximum distance of 8 km from the cooperative.

## GCC – GRASS COVER CROPS

These olive groves have a mixture of natural brome grasses (*Bromus* spp.) growing as spontaneous cover crops. The IWM technique includes inter-row cover crops with pruning wood-residues in a crossed pattern to the direction of the tree rows. Moreover, herbicide application beneath the olive trees is used to keep this area completely bare of vegetation. Intra-row weeds are controlled during the autumn by pre-emergence and post-emergence herbicides composed of glyphosate 36% + oxyfluorfen 24% at a rate of 2 l/ha. In addition, intra-row and inter-row cover-crop management includes control of broadleaf weeds by patch spraying (a mixture of fluroxypyr and MCPA). This cover crop does not need to be killed in early spring by chemical means or mechanical mowing because it dries naturally in late April-early May. After the cover crops have dried, self-seeding is carried out by mechanical mowing.



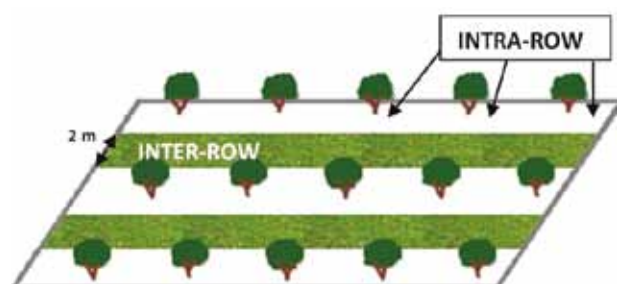
**Figure 2** - Field area with GCC strategy



**Figure 1** - Map of the field trial area

## CT – CONVENTIONAL TILLAGE

These olive groves use inter-row and intra-row conventional tillage management, incorporation of pruning wood-residues along inter-row spacing during the winter, and herbicide application beneath the olive trees. The strategy includes five different tillage operations per year with vibro-cultivator and rotary cultivator operations at 10-15 cm depth. The area beneath the trees is controlled by oxyfluorfen 24% at a rate of 2 l/ha in autumn, and post-emergence grass herbicides in summer.



**Figure 3** - Inter-row and intra-row sampling area in each block with cover crop strategy

### Experimental design

The different IWM strategies will be evaluated in a randomized complete block design with four replications per field. Each plot is 16 m × 40 m (640 m<sup>2</sup>) and corresponds to the distance between five trees, uniformly distributed along the farm and located in a crossed pattern to the slope direction.

In each block, two different sampling areas will be evaluated: an inter-row spacing of 2 m wide where the cover crop or the tilled soil will be, and an intra-row spacing of 2 m wide along the olive tree lanes where the pruning wood-residues will be. The space between the trees is 8 × 8 m and the total sampling area in each farm spans 5,120 m<sup>2</sup>.

## ASSESSMENTS

### Weeds in the inter-row and intra-row spacing

Weeds will be evaluated at two different times: January-February, before the various weed-control methods (herbicides and tillage respectively) are applied, and February-April, 21 days after the control methods are applied.

Plant density, ground cover, height and biomass production will be evaluated. Plant density will be estimated by counting each weed species in four randomly selected 0.5 m<sup>2</sup> areas of each sampling area per plot. Plant-ground coverage will be determined visually in each selected 0.5 m<sup>2</sup> area based on the

Barralis scale. Plant height will be calculated as the modal height. Weed above-ground fresh biomass will be evaluated by measuring the fresh weight of the above-ground parts of the plants, collected in four randomly selected 0.5 m<sup>2</sup> areas of each sampling area per plot. Additionally, the phenological development stages of the plants will be monitored based on the BBCH scale. The weight after drying for 48 h in a forced-air oven at 70°C will be determined.

### Cover crops in the inter-row spacing

Ground cover, height and phenological growth stages of GCC will be evaluated in the same way as for weeds, but without disturbing the cover crop.

### Olive crop

Olive yield (kg/ha) and quality (fruit size and oil content) will be determined.

### Soil analyses

At the beginning of the experiment, 10 soil samples will be extracted from 0-15 cm depth per farm for the soil's physical characterization (CEC, Ca, Mg, carbonates, active lime, Na, N, P, K, OM and soil texture). Thereafter, soil fertility will be analysed each growing season (N, P, K, OM and organic C).

### Weather data

Weather data will be obtained from the weather station located at El Carpio (Córdoba), less than 20 km from the experimental area (37° 54' 50" N, 04° 30' 14" W).

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# EXPERIMENTAL TRIALS IN NORTHERN SPAIN



*The Navarre Institute of Transfer and Innovation in the Agri-food Sector (INTIA) is a public company created by the Government of Navarra to help improve agricultural viability and sustainability, to keep the rural environment alive while respecting the environment and offering quality food to society. It has signed agreements with many companies and it also has a number of partners comprising more than 48 cooperatives, 11,400 farmers and 1,138 ranchers. Many of these farmers are olive farmers whose groves are distributed in two different areas (average size 1-5 ha per farm): 'La Ribera', where the Empeltre olive cultivar is grown, and 'La zona media' where Arróniz is the most important olive cultivar. However, both areas are commonly managed by tillage or spontaneous cover crops, mainly composed of crucifers, and will be the experimental farms in the north of Spain.*



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### Objectives

The main objective of the field trials is to evaluate the influence of various soil-management strategies commonly used in olive groves on weeds, soil, and crop yields and quality. Given the interest shown by farmers, the effects of cover crops will be compared with conventional tillage.

### Materials and methods

Integrated weed-management (IWM) strategy will be studied in silty clay soils located in the 'La zona media' area.

### CCC – CRUCIFER COVER CROP

These olive groves have a mixture of white mustard (*Sinapis alba*) and other spontaneous species growing as cover crops, composing a multi-species cover crop. The IWM technique includes inter-row cover crops combined with herbicide application in the area beneath the olive trees and the intra-row spacing. Weeds are controlled during the autumn by glyphosate 36% at a rate of 2 l/ha combined with oxyfluorfen 24% (2 l/ha), tribenuron methyl 50% (30–40 g/ha) or diflufenican (0.5–0.75 l/ha). In addition, the management of inter-row cover crops includes weed control by glyphosate 36% at a rate of 2–4 l/ha. This cover crop is killed in spring by mechanical mowing (brush cutter and shredder).

### CT– CONVENTIONAL TILLAGE

These olive groves use inter-row conventional tillage management and herbicide application beneath the olive trees and in the intra-row spacing. The strategy includes 2–3 different tillage operations before spring with vibro-cultivator and rotary cultivator operations at a depth of less than 20 cm, and an additional tillage operation before olive harvest (December) each year. The area beneath the trees and intra-row spacing

are controlled by glyphosate 36% at a rate of 2 l/ha combined with oxyfluorfen 24% (2 l/ha), tribenuron methyl 50% (30–40 g/ha) or diflufenican (0.5–0.75 l/ha).

### Experimental design

The different IWM strategies will be evaluated in a randomized complete block design with four replications per field. Each plot is 14 m × 30 m (420 m<sup>2</sup>) and corresponds to the distance between five trees, uniformly distributed along the farm and located in a crossed pattern to the slope direction. In each block, two different sampling areas will be evaluated: an inter-row spacing of 2 m wide where the cover crop or the tilled soil will be and an intra-row spacing of 2 m wide along the olive tree lanes where the pruning wood-residues will be. The space between trees is 7 × 6 m and the total sampling area in each farm spans 3,360 m<sup>2</sup>.

### ASSESSMENTS

#### Weeds in the inter-row and intra-row spacing

Weeds will be evaluated at two different times: February–March, before the various weed-control methods (herbicides and tillage respectively) are applied, and April–May, 21 days after the control methods are applied.

Plant density, ground cover, height and biomass production will be evaluated. Plant density will be estimated by counting each weed species in four randomly selected 0.5 m<sup>2</sup> areas of each sampling area per plot. Plant-ground coverage will be determined visually in each selected 0.5 m<sup>2</sup> area based on the Barralis scale. Plant height will be calculated as the modal height. Weed above-ground fresh biomass will be evaluated by measuring the fresh weight of the above-ground parts of the plants, collected in four randomly selected 0.5 m<sup>2</sup> areas of each sampling area per plot. Additionally, the phenological development



**Figure 4** - Field area with CCC strategy



stages of plants will be monitored based on the BBCH scale. The weight after drying for 48 h in a forced-air oven at 70°C will be determined.

#### Cover crops in the inter-row spacing

The ground cover, height and phenological growth stages (Lancashire *et al.*, 1991) of CCC will be evaluated in the same way as for weeds, but without disturbing the cover crop.

#### Olive crop

Olive yield (kg/ha) and quality (fruit size and oil content) will be determined.

#### Soil analyses

At the beginning of the experiment, 10 soil samples will be extracted from 0-15 cm depth per farm for the soil's physical characterization (CEC, Ca, Mg, carbonates, active lime, Na, N, P, K, OM and soil texture). Thereafter, soil fertility will be analysed each growing season (N, P, K, OM and organic C).



Figure 5 - Field area with CT strategy

#### Weather data

INTIA has installed 27 weather station, 9 of which are located in 'La zona media', so weather data will be obtained from a distance of less than 10 km.

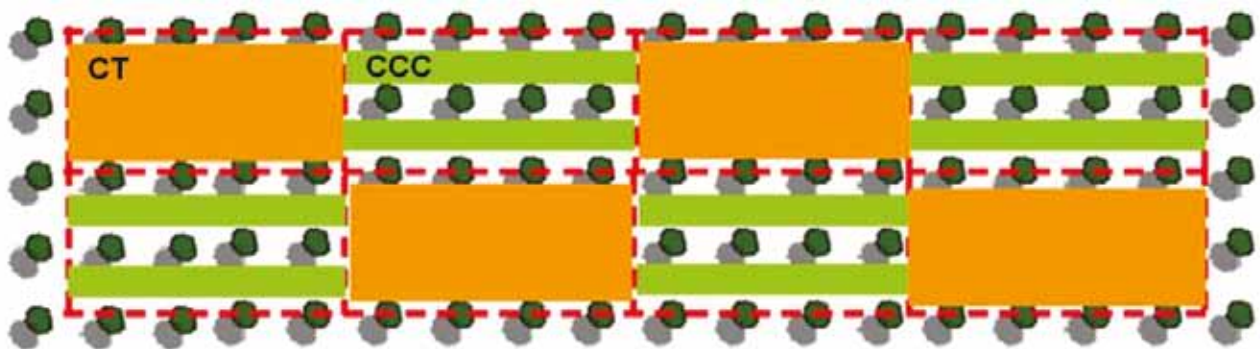
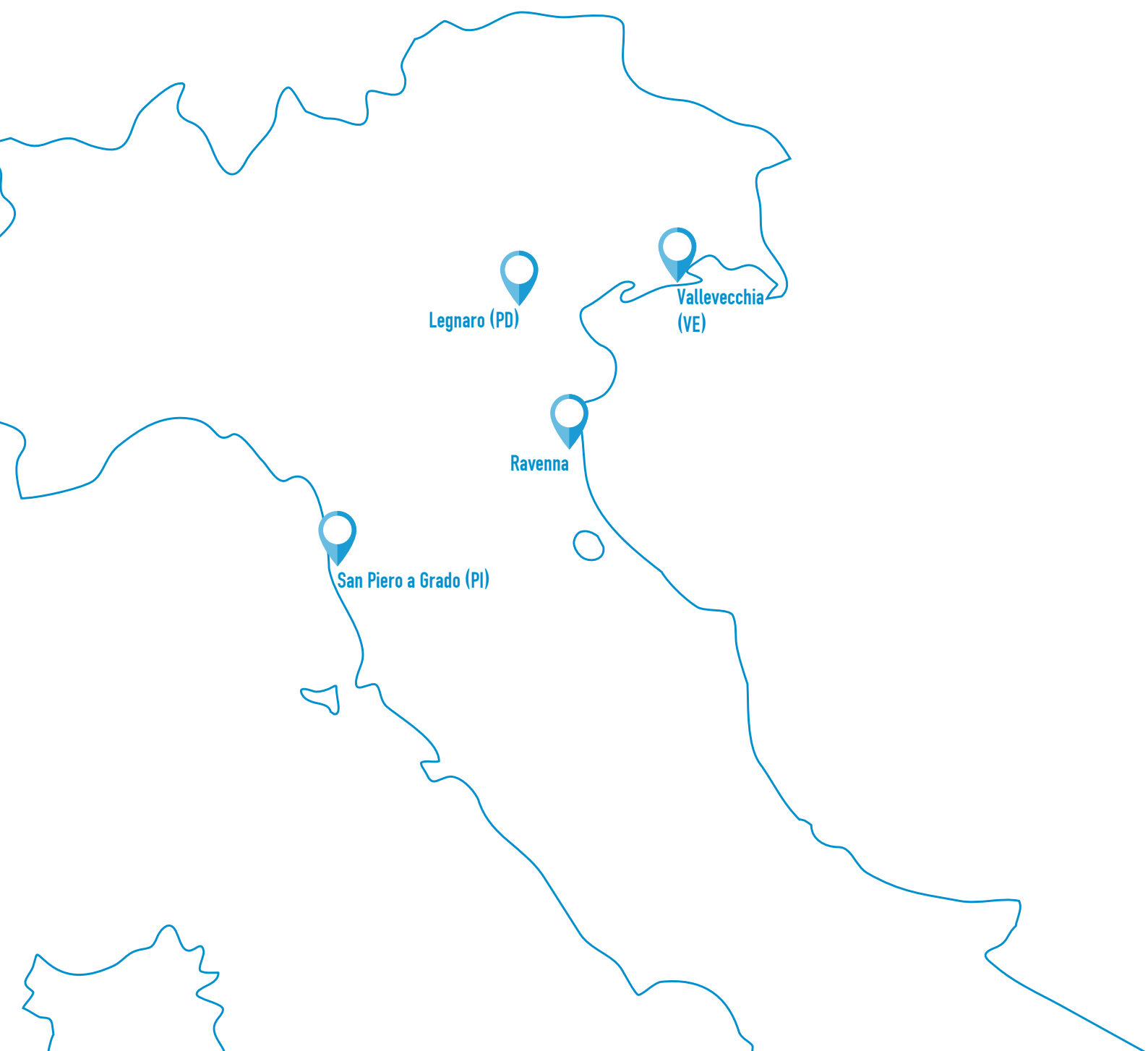


Figure 6 - Experimental design

# ITALY



# EXPERIMENTAL TRIALS AT VALLEVECCHIA FARM

VENETO  
AGRICOLTURA



Consiglio Nazionale delle Ricerche



*Owned by the Veneto Region and managed by Veneto Agricoltura (the regional agency for innovation in the primary sector), Vallevecchia pilot farm is located between the beach towns of Caorle and Bibione, in the Province of Venice, and is the last non-urbanized coastal site in the northern Adriatic area.*

*Among the last land reclamations in Veneto, the area is characterized by major environmental sites: 63 hectares of coastal pine forest, 100 hectares of lowland forests,*

*24 km of hedges, and over 68 hectares of wetlands. Between the sandy shore and the pine forest lies one of the largest shoreline dune systems in the Veneto region; it is annexed to 377 hectares of farmland used for rotated crops (maize, winter-wheat, soybean, canola, sorghum, alfalfa, meadows and vegetables).*

*Vallevecchia was recognized as a Special Protected Area and Site of Community Importance within the European Union's Natura 2000 network.*

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## WP4 – WEED MANAGEMENT ON MAIZE USING PRECISION AGRICULTURE TO MINIMIZE HERBICIDES

Reducing herbicide use and introducing alternative control methods is a key priority in Europe. Mechanical weed-control is usually adopted in the inter-row of wide-row crops such as maize via soil cultivation operations that also aim to incorporate fertilizer. However, common weed management in maize is based on the broadcast application of pre- or post-emergence herbicides, so herbicides are also applied in the inter-row where mechanical control is performed.

Reducing herbicide use is feasible under these conditions as farmers can switch from a broadcast application to a localized (band) application along the crop row where mechanical control is not performed. The extent of reduced herbicide use would be related to the size of the treated area, which can be narrowed using precision agriculture technologies (semi-automatic driving systems in tractors with RTK correction). This approach requires the various farming procedures to be carried out with great care, however precision positioning and auto-steering systems based on RTK/GPS technology are now available for tractors. The currently available systems for herbicide band application are based on sowing machines equipped with nozzles that spray along the crop row (Figure 1). This operation is rather fast and simple, but herbicides may only be applied during crop sowing. Only pre-emergence herbicides, whose efficacy is related to environmental conditions after the application date, can be therefore used, and a subsequent operation

is required to perform inter-row soil cultivation. Combining herbicide band application along the crop row with inter-row soil cultivation in a single operation would represent a significant logistical improvement. Furthermore, this operation could be performed in a wide range of crop stages (from 2 to 6 leaves). This would also allow the use of post-emergence herbicides, thus increasing the range of potentially active ingredients. Herbicide application in this approach, however, could be performed only when soil conditions allow soil cultivation. Precision is also necessary since the operating machine has to maintain a precise course in relation to the crop rows, therefore this option requires precision tractor positioning and auto-steering systems to be combined with a crop-row detection system.

### Objectives

Given that environmental conditions can strongly affect the feasibility and efficacy of mechanical and chemical weeds control tools, a wide range of tools would enable farmers to compensate for erratic weather. Thus, it is crucial to develop low herbicide input alternatives in order to meet this need. This study evaluates the feasibility and efficacy of weed control strategy in maize based on herbicide band application along crop rows combined with mechanical control in the inter-row.

Its specific objectives are to:

- evaluate the efficacy of an existing system for herbicide band application (herbicide application with a sowing machine followed by inter-row soil cultivation);
- evaluate the efficacy of an innovative system for herbicide band application (with a prototype that simultaneously applies herbicide along the crop



**Figure 1** - Sowing machine equipped with nozzles for herbicide band application



**Figure 2** - The Maschio Gaspardo prototype which combines inter-row soil cultivation and herbicide band application along crop rows



- rows and cultivates inter-row soil);
- assess the accuracy and efficacy of this prototype with different application timings or different sprayed band widths along the crop row;
- compare the control efficacy of herbicide band application strategies with traditional herbicide broadcast application strategies (both pre- and post-emergence applications).

### Materials and methods

A prototype of an inter-row cultivator equipped with nozzles for herbicide band application (Figure 2) has been developed by Maschio Gaspardo by integrating three technologies:

- 1) a semi-automatic driving system in tractors with RTK correction that enables high precision and repeatability, i.e. the ability to return precisely ( $\pm 2.5$  cm) to the same run-lines at any later date;
- 2) an imaging camera (Figure 3) that identifies crop rows and enables the equipment's position to be adjusted with a hydraulic side shift, thus allowing the mechanically cultivated inter-row area to be maximized;
- 3) herbicide band application along the crop rows by nozzles positioned on the cultivator structure (Figure 4) and managed by a control unit in order to adjust the volume applied according to tractor speed and size of the band being treated.

The experiment was set up on four adjacent fields and includes four treatments: T1) broadcast application of pre-emergence herbicides (control standard management 1); T2) herbicide band application with the existing system (herbicide application with the sowing machine followed by inter-row soil cultivation); T3) broadcast application of post-emergence herbicides (control standard management 2); and T4) herbicide band application with an innovative system (the Maschio Gaspardo prototype that simultaneously applies herbicide application along the crop rows and cultivates inter-row soil). Inter-row cultivation will be performed for all treatments to control weeds and incorporate fertilizer into the soil. A randomized block design with three replicates was adopted with plot size of  $200 \text{ m} \times 12 \text{ m} = 2,400 \text{ m}^2$ , total experiment size around 5 ha. Additional sub-plots have been included to assess the precision and efficacy of the Maschio Gaspardo prototype with different application timings (2 or 6 leaves for maize) or different band widths (25 or 10 cm) sprayed along the crop row. Maize (hybrid DKC6815) was sown on 2 May 2018 using a tractor equipped with RTK/GPS positioning and an auto-steering system to map crop rows. On the same day, pre-emergence herbicide band application (Lumax 1.2 L/ha: mesotrione 37.5 g/L, S-metolachlor

312.5 g/L, terbutylazina 187.5 g/L, band width treated 25 cm, spray volume 100 L/ha) was performed on T2 plots using a sowing machine equipped with specific nozzles (Fig. 5). The following day broadcast pre-emergence herbicide application (Lumax 3.6 L/ha: mesotrione 37.5 g/L, S-metolachlor 312.5 g/L,



**Figure 3** - Imaging camera that identifies crop rows and enables equipment position to be adjusted



**Figure 4** - Nozzles for herbicide band application along crop rows positioned on the cultivator structure



Figure 5 - Experimental scheme of the WP4 trial

| WP4      |     |         |     |         |     | WP2      |  |
|----------|-----|---------|-----|---------|-----|----------|--|
| TASK 4.2 |     |         |     |         |     | TASK 2.3 |  |
| Field 8  |     | Field 7 |     | Field 6 |     | Field 5  |  |
| T 4      | T 3 | T 1     | T 2 | T 3     | T 4 |          |  |
| T 2      | T 1 | T 3     | T 4 | T 1     | T 2 |          |  |

LEGEND

WP4

- T 1 Broadcast pre-emergence applied with boom sprayers
- T 2 Localized pre-emergence applied with sowing machine
- T 3 Localized post-emergence applied with boom sprayers
- T 4 Localized post-emergence applied with Gaspardo prototype

WP2

Task 2.3 Trials with Gaspardo prototype (different band widths treated along crop row, different application timing)



terbutilazina 187.5 g/L, spray volume 300 L/ha) was carried out on T1 plots with a boom sprayer (Figure 6A). An initial weed assessment was conducted before inter-row cultivation and post-emergence herbicide application to evaluate initial weed density in the untreated plots. The first post-emergence herbicide application with the Maschio Gaspardo prototype is scheduled at the maize 2-leaf stage on some T4 sub-plots and at the maize 6-leaf stage for the remaining T4 sub-plots, if soil conditions are adequate. Broadcast post-emergence herbicide was applied at the maize 6-leaf stage on T3 plots and inter-row soil cultivation was carried out at the same time on all plots apart from T4 plots. A second weed assessment is scheduled one month after post-emergence herbicide application to evaluate the weed-control level obtained with the various treatments, and lastly the yield of each plot is measured at crop harvest.

#### Further developments

Field visits and demonstrations will be organized on this experimental site to promote debate with local farmers and advisors about the results and obstacles to weed control with herbicide band application. The experimental protocol could be modified according to the first-year's results and stakeholder feedback. We will also try to involve private farms in order to set up additional on-farm experiments for next year to test systems for herbicide band application.

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## WP7 – WEED MANAGEMENT IN THE TRANSITION PHASE FROM CONVENTIONAL TO CONSERVATION AGRICULTURE

Conservation Agriculture (CA) is based on tillage reduction, continuous soil cover by crop residues and cover crops, and crop rotation. CA adoption produces major benefits, such as reduced fuel consumption, greenhouse-gas emissions and soil erosion, as well as improved soil fertility, but agronomic practices need to be adapted. Weed management, in particular for sod seeding, is more difficult because reduced soil tillage significantly limits weed mechanical control. CA systems are consequently more dependent on herbicide use, including when cover crops are terminated.

Shifting to CA systems interrupts the cycle due to the tillage operations, as well as to the recurring burial and exhumation of weed seeds. Seeds also accumulate on the top soil layer where they have a higher probability of germinating. Minimizing weed dissemination is therefore crucial for progressively reducing soil seed bank and consequently weed-infestation density, this allowing future control strategies to use less herbicide. Weed management is particularly important during the transition phase since transition results affect the future sustainability of CA systems. Poor weed control would lead to a rapid increase in superficial soil seed bank and consequently to increasingly problematic weed infestations. A rationale chemical control strategy is necessary, but careful cover-crop management also contributes both to controlling weeds and reducing herbicide use. Cover-crop mixtures and sowing



**Figure 6A** - Maize sowing with herbicide band application along crop rows



**Figure 6B** - Nozzle for herbicide band application positioned on the sowing machine

techniques should be adapted to local conditions if good cover-crop establishment and rapid growth is to control weeds. Furthermore, the adoption of effective no-chemical termination (e.g. mechanical) techniques may reduce the environmental impact of CA systems.

### Objectives

This study focuses on establishing weed-control strategies for CA systems and, in particular, for the transition phase. A variety of chemical control options are compared, while various cover-crop species or mixtures are evaluated, and a range of sowing (i.e. undersowing in cereals) or termination techniques (i.e. roller crimper – Figure 7) are tested. The specific objectives of this study are to:

- establish weed control strategies for cropping and intercropping periods to minimize dissemination;
- evaluate cover-crop mixtures and sowing techniques to achieve rapid establishment and high competition against weeds;
- decrease herbicide use for cover-crop termination by adopting mechanical tools (e.g. roller crimpers), or selecting cover crops which are killed by winter frost.

### Materials and methods

This experiment is designed to simulate the transition phase, i.e. the first three years, from arable management to a CA system, by adopting a three-year crop rotation (wheat-maize-soyabean) with cover crops during the intercropping periods. Minimum tillage was performed to prepare the seedbed of the first crop (wheat) while no-till will be adopted from the second year.

The experiment compares three treatments, i.e. three



**Figure 7** - Cover crop termination with roller crimper

different management strategies, characterized by different levels of herbicide use and cover-crop management. Treatment T1 includes high herbicide use, with pre- and post-emergence application for some crops, and use of glyphosate for cover-crop termination. The objective of T1 is to achieve the maximum weed-control level by minimising initial weed dissemination and consequently reducing superficial soil seed bank in order to facilitate weed control and reduce environmental impact in the following years.

Treatment T2 simulates standard local management for CA systems and relies on post-emergence herbicide application for weed control and glyphosate for cover-crop termination. Cover crops are always present during the intercropping periods. Treatment T3 aims to reduce herbicide use by adopting techniques for sowing cover crops (i.e. undersowing in cereals) that increase their ability to compete against weeds, by using non-chemical termination techniques, such as roller crimpers, or by selecting cover crops which are killed by winter frost. Detailed information about the different managements for the three treatments are presented in Figure 8 and Table 1. The field experiment is arranged in three adjacent fields, each divided into 10 m x 500 m strips with a randomized block design and three replicates (replicate plot size: 10 m x 500 m = 5,000 m<sup>2</sup>, total experiment size: about 4.5 ha). After the harvest of the previous crop (soybean) in October 2017, minimum tillage was done on the whole experiment surface and initial fertilization (150 kg/ha of diammonium phosphate 18-46 NP) was performed. Wheat (cv Altamira) was sown on 28 October. The first weed assessment was done in March 2018 to evaluate whether herbicide was needed and to choose a suitable herbicide mixture. Given that weed presence was low (Fig. 9), no herbicide was applied on T3 plots, while Traxos one (clodinafop 30 g/L, pinoxaden 30 g/L, florasulam 7.5 g/L at 0.7 L/ha) was distributed on the other plots. Undersowing of a red clover (*Trifolium pratense*, 20 kg/ha) + white clover (*Trifolium repens*, 5 kg/ha) was performed on 29 March in the cereal plots of Treatment T3 (Fig. 10). A second assessment was done in May to evaluate the level of weed control achieved with the different treatments, as well as cover-crop establishment and growth (Fig. 11). The yield achieved with the three strategies will be compared.

After the wheat is harvested in July, a summer cover crop (sorghum) will be sown in T2 plots, while glyphosate will be applied to T1 plots during the intercropping period until September to kill any weeds. During October 2018, the summer cover



**Figure 8** - Experimental scheme of the WP7 trial

|                     | Treatment 1                      | Treatment 2  | Treatment 3  |
|---------------------|----------------------------------|--|--|
| <b>October 2017</b> | Wheat sowing                     | Wheat sowing   | Wheat sowing   |
| March 2018          |                                  |  | Cover crop undersowing                                       |
| <b>April 2018</b>   | Post-emergence herbicide         | Post-emergence herbicide                               | Post-emergence herbicide (if necessary)                      |
| June 2018           | Wheat harvest                    | Wheat harvest  | Wheat harvest  |
| July 2018           |                                  | Summer cover crop sowing                               |  |
| August 2018         | Glyphosate on stubble            |  |  |
| <b>October 2018</b> | Autumn cover crop sowing         | Summer cover crop termination/Autumn cover crop sowing |  |
| March 2019          | Chemical cover crop termination  | Chemical cover crop termination                        | Mechanical or chemical (if necessary) cover crop termination |
| <b>April 2019</b>   | Maize sowing                     | Maize sowing   | Maize sowing   |
| May 2019            | Pre and Post-emergence herbicide | Post-emergence herbicide                               | Post-emergence herbicide                                     |
| September 2019      | Maize harvest                    | Maize harvest  | Maize harvest  |

**Table 1** - Main operations for the three treatments during 2018-19



crop will be terminated in the T2 plots and then an autumn cover crop will be sown in the T1 and T2 plots. No operations are envisaged for the T3 plots until cover-crop termination in spring 2019 for all plots.

#### Further developments

This experiment will continue for at least three years in order to monitor the evolution during the transition phase and evaluate the mid-term efficacy of the techniques. This experimental site will be used to organize field visits and demonstration activities to promote a fruitful exchange with local farmers and technicians, and the experimental protocol will be progressively adjusted according to results and the feedback from local stakeholders.

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**Figure 9** - Wheat plots in March 2018



**Figure 10** - Cover crop undersowing in wheat plots

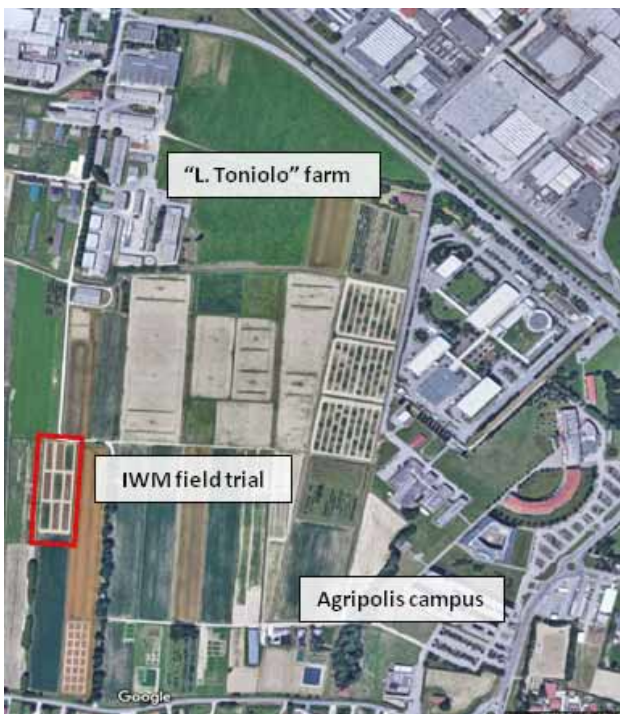


**Figure 11** - Clover cover crops growing beneath wheat canopy

# EXPERIMENTAL TRIALS AT THE “LUCIO TONIOLO” FARM



Consiglio Nazionale delle Ricerche



The University of Padova's "Lucio Toniolo" experimental farm was founded in 1960 and has a main unit of about 65 ha of agricultural land at Legnaro (Padua), plus a second part of 15 ha at Pozzoveggiani (Padua) under organic agriculture management. This farm is both a research station and a commercial farm producing arable crops, dairy and animal products, and organic wine. Given its proximity to the Agripolis campus where the University of Padova's School of Agricultural Sciences and Veterinary Medicine is located, educational and demonstration activities are organized

regularly. This farm is equipped with a range of research facilities, such as greenhouses and barns, and it is characterized by several long-term experiments. It conducts field research on a variety of topics, such as the long-term effect of different cropping systems or managements, mitigation measures (e.g. buffer strips, wetlands, biobeds) to reduce environmental contamination by pesticides or nutrients, turf grass management, crop protection and weed control, organic farming, cover crops, animal husbandry, and food quality.

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## INTEGRATED WEED MANAGEMENT IN WHEAT

Cropping systems in Northern Italy are usually based on spring crops (e.g. maize, soyabean) and wheat is usually cultivated every three or four years. Wheat-yield potential (7-9 t/ha) is higher in this area than in Italy's traditional wheat-producing regions. Weed infestation can therefore cause economically relevant yield losses and weed management strategies normally rely on post-emergence herbicide application in spring. However, since spring crops are the majority of crop rotation, weed communities are not as specialized and hard to manage as in wheat monoculture. Herbicide use can be reduced under these conditions by adopting a combination of mechanical and cultural control tools.

Mechanical tools, such as the false seedbed technique or flexible tine harrow, are very effective for weed management in wheat but environmental conditions, such as soil moisture and weed size at the time of application can strongly affect control efficacy. Low precipitation in autumn may decrease weed-seed germination and consequently make the false seedbed technique ineffective, while prolonged rainy periods in late winter/early spring may prevent the application of flexible tin harrowing.

### Objectives

This study evaluates the feasibility and efficacy of mechanical weed-control tools for wheat in both autumn and spring under the environmental conditions of Northern Italy and compares control

strategies based on 1) chemical control only; 2) integration of chemical and mechanical control; and 3) mechanical control only.

The specific objectives of this study are to:

- Design mechanical weed-control strategies for wheat according to local environmental conditions and considering the limitations due to timing of cropping operations and weather trends.
- Reduce the environmental impact of weed control in wheat by decreasing or avoiding herbicide application thanks to the introduction of effective mechanical control.

### Materials and methods

The experiment is being conducted in a field where soyabean and maize were grown in the two previous years to reproduce the situation of the typical three-year rotation adopted in this area. The experiment involves three weed-management strategies: 1) only chemical control based on spring post-emergence herbicide application (Treatment C); 2) integration of chemical and mechanical control with the false seedbed technique in autumn, plus spring post-emergence herbicide application only if necessary and attempts to minimize herbicide use (Treatment CM); and 3) only mechanical control with the false seedbed technique in autumn, plus flexible tine harrowing at the crop-tillering stage (Treatment M). The same strategy for fertilizer application and crop protection (i.e. fungicide and insecticide application) is adopted for all three treatments. A randomized block design with three replicates was set up (replicate plot size: 40 m x 9 m = 360 m<sup>2</sup>, total experiment size: about 5300 m<sup>2</sup>). See Figure 1. After the maize harvest in September 2017, ploughing and rotatory harrowing were performed on 10 October to prepare the false seedbed on the plots belonging to treatments CM and M. Soil cultivation for seedbed preparation was then performed with rotatory harrowing on the whole field on 25 October and on the same day summer wheat (cv Rubisco) was sown. Weed emergence was monitored during autumn 2017 to evaluate the efficacy of the false seedbed technique. Weed assessment (Figure 2) was conducted in March 2018 to evaluate the need for herbicide application or mechanical weed-control in the treatments. As a major *Veronica persica* infestation had occurred (Figure 3), herbicide application was considered necessary for Treatment CM as well. Various herbicide mixtures were applied on 28 March 2018 on both the C- and CM-treatment plots, while flexible tine harrowing was not performed for M-treatment plots as conditions were deemed to be unsuitable, i.e. excessive soil moisture throughout



Figure 1 - Experimental design of field trial





**Figure 2** - Example of sampling area used for weed assessment

the appropriate period for this operation (wheat tillering). Weed assessment will be repeated at wheat flowering to evaluate the control efficacy of the three treatments, and crop yield will be measured at harvest.

#### Further developments

Given that any proposed strategy based on progressive reduction of herbicide use and substitution with mechanical control should be calibrated according to local environmental conditions and farming practices, promoting and



**Figure 3** - Heavy infestation of *Veronica persica*, the main weed species at this site

maintaining a constant exchange with local farmers and technicians is a key issue. The experimental field will be used as an occasion to spark a debate on weed management with reduced herbicide-use. Field days and other demonstration activities will be organized for this purpose and the list of control tools and strategies for next year's experiment will be amended according to the outcomes of the liaison with local stakeholders. An additional reason for farmer involvement is to look into whether on-farm experiments to test IWM strategies for wheat can be set up from next year.



**Figure 4** - View of the experimental trial at the moment of herbicide application

# EXPERIMENTAL TRIALS AT THE “ENRICO AVANZI” CENTRE FOR AGRO-ENVIRONMENTAL RESEARCH



With its 500-plus ha of agricultural land, the University of Pisa's "E. Avanzi" Centre for Agro-environmental Research (CIRAA) is Italy's largest agricultural experimental centre and one of the largest centres in Europe. CIRAA conducts on-farm research and regularly organizes demonstration activities to involve local stakeholders in new practices and product development. At CIRAA, plot-scale experiments are usually included in the layout of larger scale trials, with fields being used as experimental units. The main research topics at CIRAA are low-external input cropping systems, soil tillage, cover crops, crop protection and weed control, organic farming, agricultural mechanization, animal husbandry, food quality, biomass and bioenergy, and economic and environmental impact. Due to its size, CIRAA is both a

research station and a commercial farm. A considerable portion of its agricultural land is managed for the marketable production of arable crops and field vegetables. These features resulted in CIRAA being formally included by Tuscany's Regional Government among its Centres for Innovation Transfer in Agriculture. CIRAA is located in the Regional Park of "Migliarino - San Rossore - Massaciuccoli" and within the "Selva Pisana" biosphere reserve. CIRAA was founded in 1963 after the Italian Republic donated land to the University of Pisa with the aim of supporting research and teaching within veterinary and agricultural science. The research station is named in memory of Enrico Avanzi, professor in agronomy and dean of the University of Pisa from 1947 to 1959.

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## LTE – LONG TERM EXPERIMENT ON COVER CROPS

This long-term experiment started in 1993 in an attempt to study alternatives to maize monoculture, a widespread cropping system in the Pisa area at that time. The starting-point experiment tested the introduction of cover crops in monoculture as a practice for reducing weed pressure on maize crop and for optimizing the use of external inputs. Two tillage systems were included in the experiment, with 4 different levels of nitrogen fertilization. In 1998, durum wheat (as a case of an autumn-sown crop) was introduced into the system, leading to a two-year rotation. This change was made to match the changes in the local cropping system. For the same reason, sunflowers were introduced as an additional spring-sown cash-crop in 2007. This led to crop rotation being extended to four years (durum wheat, maize, durum wheat, sunflower), with the cover crop being grown before each spring-sown cash-crop. Starting from 2018, maize has been replaced by grain sorghum, considering that in sod seeding and no irrigation conditions it is rather difficult to stabilize maize production.

### Objectives

The aim of this long-term experiment is to determine the combined effect on soil quality, crop yield and weed community dynamics of (i) two management systems (conventional vs. low-input); (ii) four N fertilization levels of the main crop; and (iii) four soil-cover types (*Brassica juncea*, *Trifolium squarrosum*, *Vicia villosa*, and a control).

### Materials and methods

Three constant factors studied in the trials are tillage, nitrogen fertilization, and cover-crop type. The experiment is arranged in a split-strip split-plot design with four replicates (blocks). All factors are crossed.

Tillage comparison is based on two systems: a Conventional System (CS) based on annual ploughing at 30 cm depth, and a Low Input System (LIS) based on no soil inversion operations, i.e. chiselling at 30 cm depth for summer crops and direct sowing for durum wheat.

The four levels of fertilization are arranged as a strip plot. The four levels are always constant in the ranking, but the amount of nitrogen changes according to the need of each cash crop: 0, 60, 120 and 180 kg of nitrogen per hectare for durum wheat; 0, 100, 200 and 300 kg for maize; and 0, 50, 100, 150 kg for sunflowers and grain sorghum. Each fertilization strip comprises the four cover-crop plots: Control (C) (weedy); *Brassica juncea* L. (Bj); *Trifolium squarrosum* L. (Ts); and *Vicia villosa* Roth (Hv). In 2018, the cover crops were changed to: Control (C) (weedy); *Sinapis alba* L. (NL); *Vicia villosa* Roth (HNL) and *Vicia villosa* + *Sinapis alba* mixture (LNL).

Cover crops are sown in autumn and terminated in April, before maize or sunflower is sown. In both systems, disk harrowing is used to devitalize the cover crops. Weed control varies in the two tillage systems. Herbicides are used in CS post-emergence (for sunflower and sorghum) and pre-emergence (for wheat and sorghum, if needed after hoeing). In LIS, hoeing is used for spring crops and herbicides are applied in pre-sowing and early post-emergence for wheat. Active ingredients are chosen considering the dominant weed species.

Based on the varying availability of personnel,



**Figure 1** - Maize grown in spring 2014 clearly showing the previous cover-crop plots

| FIELD 1 |    |    |    | FIELD 2 |    |    |    | FIELD 3 |     |     |     | FIELD 4 |     |     |     | FIELD 5 |     |     |     | FIELD 6 |     |     |     | FIELD 7 |     |     |     | FIELD 8 |     |     |     |
|---------|----|----|----|---------|----|----|----|---------|-----|-----|-----|---------|-----|-----|-----|---------|-----|-----|-----|---------|-----|-----|-----|---------|-----|-----|-----|---------|-----|-----|-----|
| 36      | 37 | 44 | 45 | 52      | 53 | 60 | 61 | 68      | 69  | 76  | 77  | 84      | 85  | 92  | 93  | 104     | 105 | 112 | 113 | 120     | 121 | 128 | 133 | 140     | 141 | 148 | 149 | 156     | 157 | 164 | 165 |
| BJ      | C  | TS | Vv | C       | BJ | TS | Vv | Vv      | BJ  | C   | TS  | BJ      | Vv  | C   | TS  | C       | BJ  | TS  | Vv  | BJ      | C   | TS  | TS  | BJ      | C   | TS  | BJ  | C       | TS  | BJ  | C   |
| 35      | 38 | 43 | 46 | 51      | 54 | 59 | 62 | 67      | 70  | 75  | 78  | 83      | 86  | 91  | 94  | 103     | 106 | 111 | 114 | 119     | 122 | 127 | 132 | 135     | 142 | 145 | 152 | 155     | 162 | 167 | 170 |
| C       | BJ | BJ | TS | TS      | C  | Vv | BJ | C       | TS  | BJ  | Vv  | TS      | BJ  | C   | TS  | Vv      | TS  | C   | BJ  | Vv      | Vv  | BJ  | C   | TS      | TS  | BJ  | C   | TS      | BJ  | C   | TS  |
| 34      | 39 | 42 | 47 | 50      | 55 | 58 | 63 | 66      | 71  | 74  | 79  | 82      | 87  | 90  | 95  | 102     | 107 | 110 | 115 | 118     | 123 | 126 | 131 | 134     | 143 | 146 | 153 | 158     | 161 | 166 | 169 |
| Vv      | TS | Vv | C  | BJ      | Vv | C  | TS | BJ      | Vv  | TS  | C   | Vv      | C   | TS  | BJ  | TS      | C   | BJ  | C   | TS      | TS  | C   | BJ  | C       | TS  | TS  | BJ  | C       | TS  | BJ  | C   |
| 33      | 40 | 41 | 48 | 49      | 56 | 57 | 64 | 65      | 72  | 73  | 80  | 81      | 88  | 89  | 96  | 101     | 108 | 109 | 116 | 117     | 124 | 125 | 130 | 136     | 144 | 147 | 154 | 159     | 163 | 168 | 171 |
| TS      | Vv | C  | BJ | Vv      | TS | BJ | C  | TS      | C   | Vv  | BJ  | C       | TS  | BJ  | Vv  | TS      | C   | BJ  | TS  | C       | BJ  | C   | TS  | TS      | BJ  | C   | TS  | BJ      | C   | TS  | BJ  |
| 4       | 5  | 12 | 13 | 20      | 21 | 28 | 29 | 97      | 104 | 105 | 112 | 113     | 120 | 121 | 128 | 109     | 116 | 117 | 124 | 125     | 130 | 136 | 144 | 147     | 154 | 159 | 163 | 168     | 171 | 174 | 177 |
| Vv      | TS | C  | Vv | BJ      | C  | TS | BJ | C       | BJ  | BJ  | Vv  | Vv      | BJ  | C   | TS  | C       | BJ  | TS  | TS  | C       | BJ  | C   | TS  | TS      | BJ  | C   | TS  | BJ      | C   | TS  | BJ  |
| 3       | 6  | 11 | 14 | 19      | 22 | 27 | 30 | 98      | 103 | 106 | 111 | 114     | 119 | 122 | 127 | 108     | 115 | 110 | 113 | 118     | 121 | 126 | 131 | 134     | 143 | 146 | 153 | 158     | 161 | 166 | 169 |
| BJ      | C  | Vv | BJ | TS      | Vv | C  | TS | Vv      | TS  | TS  | C   | BJ      | Vv  | Vv  | BJ  | C       | BJ  | C   | Vv  | BJ      | C   | TS  | C   | TS      | TS  | BJ  | C   | TS      | BJ  | C   | TS  |
| 2       | 7  | 10 | 15 | 18      | 23 | 26 | 31 | 99      | 102 | 107 | 110 | 115     | 118 | 123 | 126 | 107     | 112 | 117 | 120 | 125     | 130 | 135 | 140 | 145     | 150 | 155 | 160 | 165     | 170 | 175 | 178 |
| TS      | BJ | TS | C  | C       | TS | BJ | Vv | BJ      | C   | Vv  | BJ  | C       | TS  | TS  | C   | BJ      | C   | TS  | TS  | C       | BJ  | C   | TS  | TS      | BJ  | C   | TS  | BJ      | C   | TS  | BJ  |
| 1       | 8  | 9  | 16 | 17      | 24 | 25 | 32 | 100     | 101 | 108 | 109 | 116     | 117 | 124 | 125 | 106     | 111 | 114 | 119 | 122     | 127 | 132 | 137 | 142     | 147 | 152 | 157 | 162     | 167 | 172 | 176 |
| C       | Vv | BJ | TS | Vv      | BJ | Vv | C  | TS      | Vv  | C   | TS  | TS      | C   | BJ  | Vv  | TS      | C   | BJ  | TS  | C       | BJ  | C   | TS  | TS      | BJ  | C   | TS  | BJ      | C   | TS  | BJ  |
| N0      | N1 | N2 | N3 | N2      | N1 | N0 | N3 | N0      | N1  | N2  | N3  | N2      | N1  | N0  | N3  | N0      | N1  | N2  | N3  | N2      | N1  | N0  | N3  | N2      | N1  | N0  | N3  | N2      | N1  | N0  | N3  |
| CS      |    |    |    | LIS     |    |    |    | CS      |     |     |     | LIS     |     |     |     | CS      |     |     |     | LIS     |     |     |     | CS      |     |     |     | LIS     |     |     |     |

| DURUM WHEAT |           | MAIZE |           | SUNFLOWER |           |
|-------------|-----------|-------|-----------|-----------|-----------|
| N0=         | 0 Kg/ha   | N0=   | 0 Kg/ha   | N0=       | 0 Kg/ha   |
| N1=         | 60 Kg/ha  | N1=   | 100 Kg/ha | N1=       | 50 Kg/ha  |
| N2=         | 120 Kg/ha | N2=   | 200 Kg/ha | N2=       | 100 Kg/ha |
| N3=         | 180 Kg/ha | N3=   | 300 Kg/ha | N3=       | 150 Kg/ha |

C= Control (no cover crop)  
 BJ= Brassica juncea  
 TS= Trifolium squarrosus  
 Vv= Vicia villosa

I Block  
 II Block  
 III Block  
 IV Block

Figure 2 - The experimental scheme of the LTE COVER CROP trial



Figure 3 - Brassica Juncea L.



Figure 4 - Trifolium squarrosus L.





**Figure 5** - *Vicia Villosa* Roth

various intensities of sampling were performed from 1993 up to the current growing season. Data collected in most seasons included above-ground biomass of cash crops at harvest; above-ground biomass of cover crops and weeds at the devitalization phase; and weed density at the early stage of cash crops. From 2008, weed cover at the full development of cash crops was included in the sampling calendar.

## RESULTS

### Soil fertility

The two main parameters assessed to estimate soil fertility (soil organic carbon and total nitrogen) measured in the 0-30 cm layer from 1993 to 2008 clearly show a positive accumulation trend when reduced tillage is applied (+17.3% and +10.4% respectively in the first 15 years). Similarly, a significant increase was registered when fixing nitrogen cover crops were applied (the mean for the two nitrogen fixing cover-crop types is a 13.3% and 4.4% increase for organic carbon and total nitrogen respectively in 15 years). Non-nitrogen fixing cover crops did not show any difference from the control when no cover crop was applied (Mazzoncini et al., 2011). Regarding soil biological fertility, the positive effect of reduced tillage on soil respiration and microbial biomass resulted in a 44% and 71% increase respectively when compared with conventional tillage systems. Another indicator of



**Figure 6** – Control plot

soil health used was the abundance and diversity of micro-artopods. Both indicators had higher values in reduced tillage compared with conventional tillage systems (Sapkota et al., 2012).

### Weed control

Weed-composition measurements from 2012 to 2015 revealed that cover-crop type strongly influenced weed-community composition during the cover-crop growth cycle. This effect was not clearly detectable in summer and winter cash crops. The low-input system favoured the growth of mainly perennial weeds. In this system, total weed biomass increased when compared with a conventional tillage system. This suggests that some adjustments in cover-crop management under a low-input system may be needed to prevent potentially troublesome weed shifts which might offset the benefits attained by reduced tillage systems on other production-related agroecosystem services (Carlesi et al. 2015).

### List of publications for further reading

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## LEGUME AND DURUM WHEAT RELAY INTERCROPS

GPS coordinates: 43°40'11.7"N 10°18'49.2"E

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Nitrogen deficiency and weed infestation are two major factors determining yield and grain-protein content losses in cereal production, especially in organic farming. Durum-wheat based cropping systems are common in Italy. Durum wheat is a major agricultural commodity because of the importance of the pasta industry and it is the most cultivated small grain cereal in Italy.

Legumes can be used in durum-wheat based crop rotations to optimize nitrogen availability and weed control. At crop rotation level, we study the weed-control and soil-fertility potential of durum wheat-legume relay intercrops. Wheat-legume relay intercrops are a sustainable and innovating tool when appropriate legume types are used. It is essential, however, to select the best-performing legumes, i.e. ones with morphological and phenological traits suitable for intercropping, if this system is to be successful. Legumes selected for sole stand grain production or as forage may not meet the specific requirements for being grown as intercrops. The legume ideotype for relay intercropping should have high early vigour so that it germinates below the wheat stand; be prostrate to cover the soil and control weed growth; and not accumulate too much biomass to avoid over-competition with the crop during the wheat-growing season.

## Objectives

Our study includes several legume types (annual, self-reseeding and perennial species) and aims to select the best-performing legumes for relay intercropping with durum wheat for our local pedo-climatic conditions. Legume development, weed control, N availability, grain yield and grain quality are monitored in wheat and in the following cash-crops.

We study the effect of wheat-legume intercrops at rotation level. In this context, self-reseeding legume species may be an interesting solution because they will be able to germinate in the autumn after the wheat harvest and cover the soil as living mulch until the following crop is sown (Table 1). In order to test solutions for different types of farms, we have also included annual (for grain or forage production) and perennial legumes in the experiment.





## Materials and methods

In order to reproduce a typical crop rotation in the Pisa plain area, we are managing two adjacent fields (A and B, Figure 7) to evaluate the effect of legumes on



**Figure 7** - Location of experimental fields at the University of Pisa's Centre for Agro-Environmental Research (CIRAA) in San Piero a Grado (Pisa)



| RELAY INTERCROPPING   |  | Hypothesis   |
|---|--|--|
| Pulses  | Solution oriented to farms producing pulses<br> | Weed control: <b>LOW</b><br>Soil cover: <b>LOW</b><br>Soil fertility: <b>LOW</b><br>SYSTEM PRODUCTIVITY: <b>HIGH</b>                           |
| Annual  | Solution oriented to field crops farms<br>      | Weed control: <b>MEDIUM-HIGH</b><br>Soil cover: <b>MEDIUM-HIGH</b><br>Soil fertility: <b>MEDIUM-HIGH</b><br>SYSTEM PRODUCTIVITY: <b>MEDIUM</b> |
| Self-seeding  | Solution oriented to field crops farms<br>     | Weed control: <b>HIGH</b><br>Soil cover: <b>HIGH</b><br>Soil fertility: <b>HIGH</b><br>SYSTEM PRODUCTIVITY: <b>MEDIUM</b>                      |
| Perennial   | Solution oriented to farms with grassland<br> | Weed control: <b>HIGH</b><br>Soil cover: <b>HIGH</b><br>Soil fertility: <b>HIGH</b><br>SYSTEM PRODUCTIVITY: <b>HIGH</b>                        |
| Durum wheat cv: MINOSSE, resistant to lodging<br>Wheat sowing: 250 kg/ha<br>Inter-row distance: 18 cm |  | Durum-wheat sowing date: 22/11/2017<br>Legume-sowing date: 28/02/2018  |

**Table 1** - Description of relay intercropping experiment

following cash crops and to replicate the trial for two consecutive wheat-growing seasons. Soil conditions for the four blocks in each field are presented in Table 2. During the 2017/2018 season, we are performing the relay intercropping of wheat and legumes in Field A. The following cash-crop in Field A will be sorghum. During 2018/2019, we will perform the relay intercropping in Field B with millet as the preceding crop and sorghum as the following crop. We are testing 30 legume types (Table 3) in a randomized block design experiment with four replications. After seed-bed preparation (ploughing at 20 cm depth followed by rotative harrowing), we sowed durum wheat (the MINOSSE variety provided by IWM PRAISE partner ISEA) with an inter-row distance of 18 cm in November 2017. We then sowed legumes in between the rows of wheat in February 2018, before the wheat-stem elongation phase (Figure 8).

During the current growing season, assessment will be performed both on wheat and on cover crops in order



**Figure 8** - Durum wheat (cv. MINOSSE) and lentil (cv. Elsa) relay intercrop on 29/03/2028. (Picture by Federico Leoni)

| Block | pH   | total N <sup>(1)</sup><br>mg kg <sup>-1</sup> | organic<br>matter <sup>(2)</sup><br>% | p <sup>(3)</sup><br>ppm | clay<br>% | silt<br>% | sand<br>% |
|-------|------|---|---------------------------------------|-------------------------|-----------|-----------|-----------|
| 1A    | 7.87 | 1.18  | 1.82                                  | 11.5                    | 23.5      | 24.0      | 52.4      |
| 2A    | 8.13 | 1.23  | 1.75                                  | 10.5                    | 26.0      | 27.6      | 46.4      |
| 3A    | 7.99 | 1.34  | 1.99                                  | 8.4                     | 23.3      | 31.0      | 45.7      |
| 4A    | 8.02 | 1.07  | 1.54                                  | 10.2                    | 20.2      | 21.7      | 58.1      |
| 1B    | 8.02 | 1.32  | 1.95                                  | 11.3                    | 26.3      | 37.2      | 36.5      |
| 2B    | 8.01 | 1.37  | 2.02                                  | 9.4                     | 29.0      | 29.0      | 42.0      |
| 3B    | 7.99 | 1.50  | 2.27                                  | 10.5                    | 37.3      | 30.5      | 32.2      |
| 4B    | 7.97 | 1.09  | 1.54                                  | 7.9                     | 9.2       | 42.3      | 48.5      |

1) Kjeldahl method, (2) Walkley-Black method; (3) Olsen method

**Table 2** - Soil properties of the experimental fields

to collect data on:

- i) **Legume** germination and emergence, phenological phases, biomass, weed population (density and species) and soil cover;
- ii) **Wheat** yield, grain quality, N fertilization.

### Further developments

We are working to provide sustainable solutions as an alternative or complement to herbicides in order to minimize their use in cropping systems. We are doing this in collaboration with local farmers. The experimental field will be used as an open-air catalogue from which to select high-potential intercropping solutions for local farms. Farmers will participate in organized field activities to share challenges and opportunities for including relay intercropping in local cropping systems with a practical example being provided by our experimental field. From this exchange, we foresee some of the legume-wheat combinations being tested directly on-farm from next year.

## ADAPTATION OF THE DONDI CUT-ROLLER AS AN EFFECTIVE ROLLER CRIMPER

Cover crops are recognized as smart tools for arable farms for preventing weed infestation in a sustainable way, while also providing a number of other important agroecosystem services for crop rotation. Cover crops, however, are not widely adopted by farmers, mainly due to their cultivation costs and to the technical/operational skills needed for their management. New possibilities for the adaptation of existing farm machinery are thus to be explored to optimise: i) sowing or under-sowing, and non-

chemical termination of cover crops, one reason being uncertainty about the use of glyphosate as a direct chemical tool for cover-crop termination in the future; ii) the agronomical management of living and dead mulches and of green manures; iii) the sowing or planting of the following crop within a cropping system. Planting and direct drilling are particularly important in no-till systems where the mulch-layer may hinder these operations.

### Objectives

The main objective of this on-station trial is to test the effectiveness of the "cut-roller" when used as a roller-crimper for the mechanical termination of some of the most common winter cover crops for arable-cropping systems. The cut-roller is produced by DONDI S.p.A. and marketed as a tool for crop-residue management (Figure 9). Besides the fine-tuning of working parameters and blade type, special focus will be on weed suppression and soil compaction effects.

### Materials and methods

A field trial was started in autumn 2017 (Figure 10) and will be replicated for three seasons at the University of Pisa's Centre for Agro-Environmental Research (CIRAA) in San Piero a Grado (Pisa, Tuscany). Three cover crops were drilled in October 2017 in three different fields sized 30 m x 260 m each. The cover crops were rye (*Secale cereale* L.), hairy vetch (*Vicia villosa* Roth.), and a rye-hairy vetch mixture. The sowing rates were 180, 120 and 90:60 kg/ha respectively for rye in the pure stand, vetch in the pure stand, and rye and vetch in the mixture. The inter-row space was 15 cm. Each field was split into six strips 3 m wide and 260 m long. In each strip, a combination of blade type (sharpened vs non-sharpened) and working speed (5, 10, 15 km

| Life cycle     | Genus and species                                 | Cultivar       |
|----------------|---|----------------|
| Pulses         | <i>Cicer arietinum</i>                            | Pascià         |
|                | <i>Lens culinaris</i>                             | Elsa           |
| Annual         | <i>Trifolium alexandrinum</i>                     | Leila          |
|                | <i>Trifolium incarnatum</i>                       | Kardinal       |
|                | <i>Trifolium resupinatum</i>                      | Lighting       |
|                | <i>Trifolium resupinatum</i>                      | Laser          |
|                | <i>Vicia villosa</i>                              | Capello        |
| Self-reseeding | <i>Medicago lupulina</i>                          | Nd             |
|                | <i>Medicago polymorpha</i>                        | Scimitar       |
|                | <i>Medicago rotata</i>                            | Highlander     |
|                | <i>Medicago truncatula</i>                        | Paraggio       |
|                | <i>Medicago scutellata</i>                        | Sava           |
|                | <i>Trifolium subterraneum sub. brachycalcinum</i> | Ep 30 brachy A |
|                | <i>Trifolium subterraneum sub. brachycalcinum</i> | Antas          |
|                | <i>Trifolium subterraneum sub. brachycalcinum</i> | Mintaro        |
|                | <i>Trifolium subterraneum sub. yanninico</i>      | Monti          |
|                | <i>Trifolium subterraneum sub. subterraneum</i>   | Ep 118 sub J   |
|                | <i>Trifolium michelianum</i>                      | Paradana       |
|                | <i>Ornithopus sativus</i>                         | Enema          |
| Perennial      | <i>Hedysarum coronarium</i>                       | Carmen         |
|                | <i>Medicago x varia</i>                           | Camporeggio    |
|                | <i>Medicago sativa</i>                            | Gamma          |
|                | <i>Trifolium repens</i>                           | Companion      |

**Table 3** - List of legumes used in the experiment



**Figure 9** - DOND cut-roller, original version (Picture by Christian Frasconi)



**Figure 10** - Experimental field at CIRAA (43°39'30.64"N, 10°18'08.85" E) (Pictures ©2017 Google)

hr-1) will be tested at cover-crop termination (i.e. in April) and establishment of a dead mulch for the sod-seeding of the following spring crop of grain sorghum (*Sorghum bicolor* (L.) Moench.) (Figure 11). Each year, the following parameters will be assessed:

- Biomass and soil cover produced by cover crops at different stages, including the termination stage;
- Weed abundance and composition in cover crops at different stages, including the termination stage;
- Number of crimps per stem produced by the cut-roller on cover crop plants;
- Killing rate of cover crops;
- Mulch thickness;
- Mulch persistence in the following spring crop of sorghum;
- Weed suppression in the sorghum crop;

- Effects on sorghum growth and yield;
- Soil compaction;
- Energy consumption and economic issues.

GPS coordinates: 43°39'34.72"N 10°18'06.26"E

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## SMOCA LTE – CONSERVATIVE MANAGEMENT OF ORGANIC FIELD VEGETABLES

The production of organic vegetables is an increasingly important market sector. Organic management of vegetable cropping systems, normally characterized by intensive techniques (e.g. frequent soil cultivation, high rates of mineral fertilization and pesticide application) can lead to more sustainable vegetable production. Nevertheless, major concerns have been raised over agro-environmental drawbacks linked to the organic management of vegetable systems. Intensive mechanical weed control, narrow windows in crop rotations for green manures, and high rates of organic fertilizer application may lead in the end to depletion of soil fertility, high demand for fossil fuels, and low economic return for farmers. One solution for this problem may be the application of conservation agriculture techniques to organic field vegetable systems. The combination of organic farming and conservation agriculture techniques is normally considered unfeasible due to limitations, mainly the strong dependence of conservation cropping systems on chemical weed control and on the use of mineral fertilizers, which

are considered essential for supporting acceptable levels of crop productions.

Cultural preventive methods of weed control, including cover cropping and intercropping, are thus crucial for the viable management of conservative organic cropping systems. Cover crops introduced as living or dead mulch in crop rotation are versatile tools for achieving effective weed control, but also have additional benefits as they provide important agroecosystem services, such as supplying crops with nutrients (if using catch crops or N<sub>2</sub>-fixing crops) and improving soil fertility.

In order to apply reduced tillage to organic and integrated vegetable production, it is therefore indispensable to have specific versatile and efficient machines for the management of non-chemical cover-crops and weed control.

### Objectives

The main objective is to test the agro-environmental performance of combining conservation agriculture (i.e. no-till or strip tillage, permanent soil cover with living mulch) and organic farming practices (i.e. non-chemical weed control, organic fertilization and crop protection) in the production of field vegetables. This involved comparing three different cropping systems based on the same three-year crop sequence (processing tomato-chicory-melon-faba bean-fennel), but with a decreasing level of soil disturbance, to establish crop performance, economic viability, soil fertility, plus weed abundance and composition.

### Materials and methods

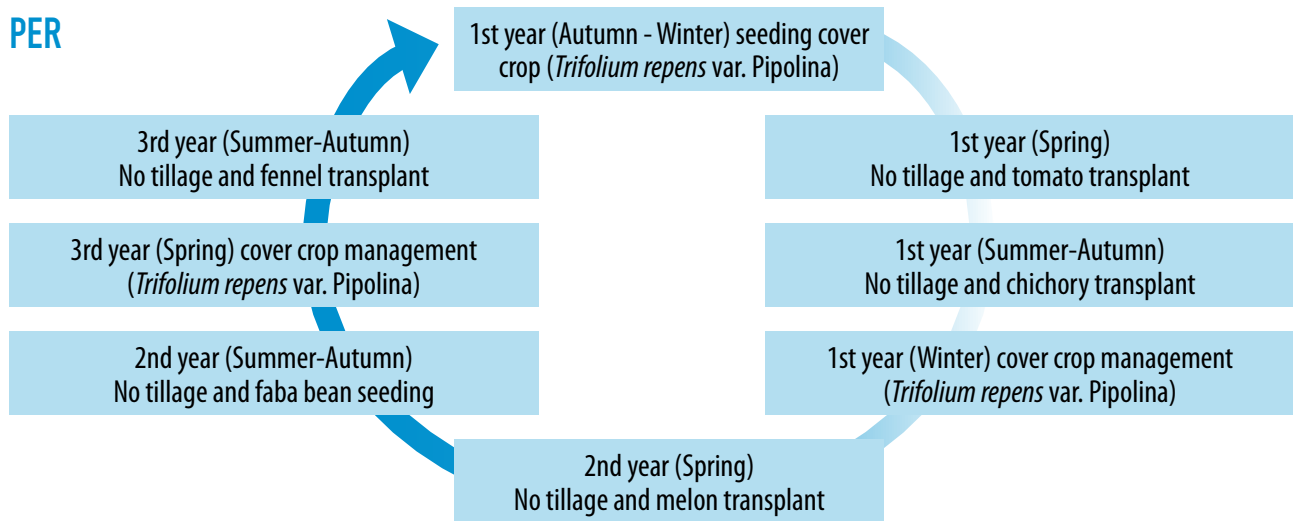
The experimental field is located at the University of Pisa's Centre for Agro-Environmental Research (CIRAA) in San Piero a Grado (Pisa, Tuscany). Three different cropping systems (ORG, RED, PER) were established there in winter 2017-18, and they will be compared with a system approach for three years. ORG is mainly based on standard organic practices, such as annual soil tillage, green manures



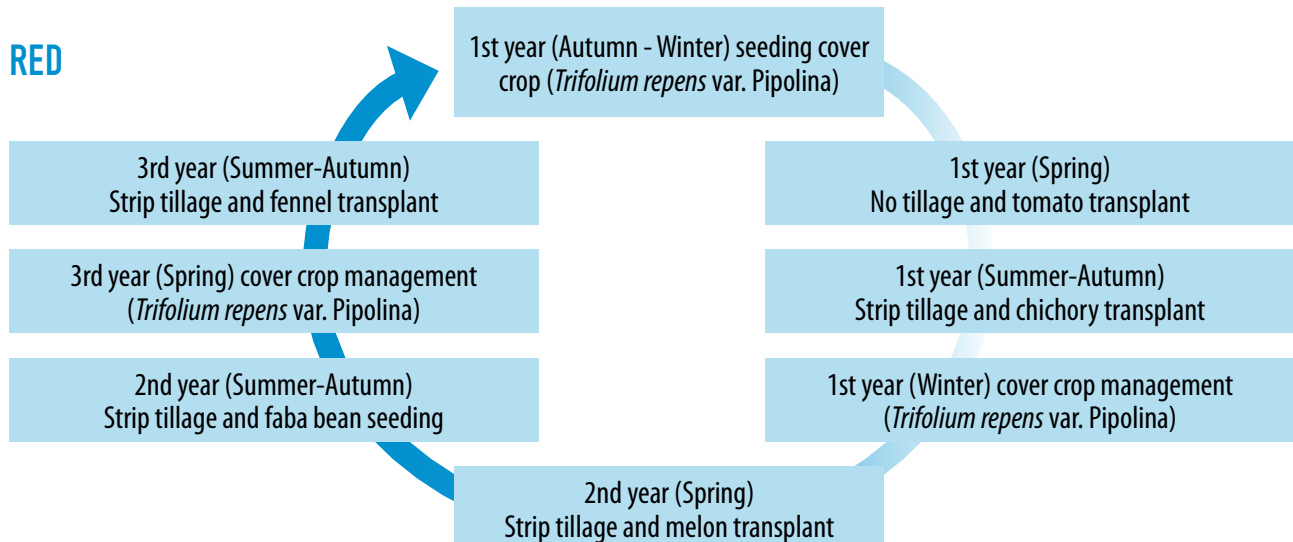
**Figure 11** - Description of the cropping system



## PER



## RED



## ORG

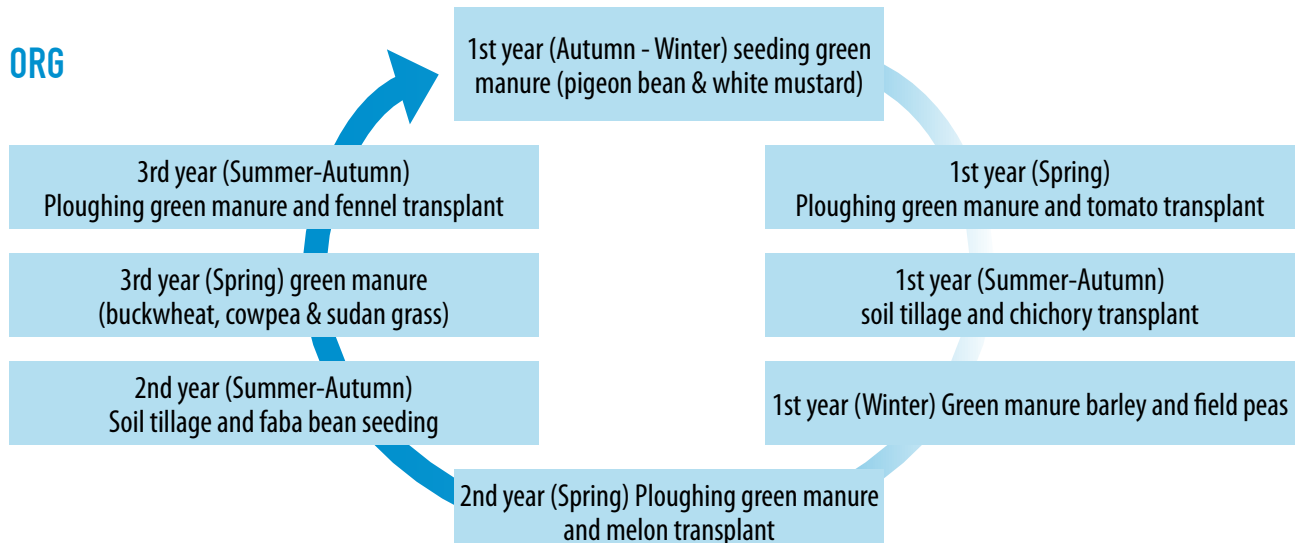


Figure 12 - Description of the three cropping systems

incorporated into the soil, organic fertilization, as well as mechanical and thermal weed control. RED is based on permanent soil cover with a perennial cover crop (a dwarf variety of white clover), strip-tillage performed along seed furrows, and reduced use of organic fertilizers. PER, which is established on plots managed under no-till for the previous three years, is based on permanent soil cover with white clover and no-till transplanting of vegetables, whilst fertilization is reduced to a minimum level and will also involve the use of mycorrhizal formulations.

The experimental design is a randomized complete block (RCB) with three replications with a total of 18 plots each sized 3 m wide and 21 m long. The field is split into two parts hosting the two different segments of crop sequence in order to halve the time needed to replicate the crop sequence twice. Each year, the following parameters will be assessed:

- Biomass and soil cover produced by cover crops and cash crops (i.e. yield and residues) at maturity;
- Nutrient uptake of cash crops and cover crops;
- Crop root colonization by AMF;
- N<sub>2</sub>-fixation by legume plants;
- Weed abundance and composition in cover crops and cash crops;
- Soil chemical, physical and biological fertility parameters;
- Rheological quality of crop produce;
- Energy consumption and monetary cost of each field operation.

GPS coordinates: 43°40'18.47"N 10°20'40.25"E

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## COMPARISON BETWEEN DIFFERENT PRODUCTION SYSTEMS OF PROCESSING TOMATO IN ORGANIC AGRICULTURE. THE EFFECTS OF TILLAGE AND COVER CROPS

### Objectives

To evaluate the agro-ecological effects of two cover crop management systems (no-till/dead mulch with direct transplantation of tomato, and conventional tillage with soil incorporation of cover crops as green manures), in organic production systems of

processing tomato.

Three cover crops (i. rye- *Secale cereale* L., ii. squarrose clover - *Trifolium squarrosum* L.- and iii. a mixture of both), managed in no-till or in conventional tillage, are compared in terms of weed presence, soil fertility, nutrients cycle, yield production and tomato quality.

### Hypotheses

**H1:** The use of winter cover crops can improve soil fertility and consequently the production, both in terms of quantity and quality.

**H2:** Cover crops can contribute to weed management, as living mulch in winter and through their allelopathic activity following their devitalization in spring-summer.

**H3:** Reduction in tillage intensity before transplantation can result in higher soil fertility compared to conventionally-tilled systems.

**H4:** A mixture of legume and cereal cover crops, both as dead mulch and green manure, is a compromise, as it results in the higher biomass needed to improve soil fertility and weed management (mainly in the case of dead mulch), and helps to nourish the tomatoes.

### Experimental design

Eight different growing systems were compared during the 2017-18 season, on an experimental field at CIRAA. The experiment is in its first year of evaluation and is based on the results of two previous years. For no-till/dead mulch systems (NT-rye, NT-clover, NT-mix), cover crops are terminated by roller crimper and then flamed, and tomato plants are directly transplanted on the devitalized mulch. For conventionally-tilled systems, cover crops



**Figure 13** - Experimental field at CIRAA (43°40'18.47"N 10°20'40.25"E) (Pictures©2017 Google)

are incorporated into the soil as green manures by a rotary hoe (CT-rye, CT-clover, CT-mix). All the growing systems are managed according to the standards of organic agriculture, with a small quantity of organic fertilizers supplied in fertigation during tomato growth. The growing systems are compared to two control systems: one without preceding cover crop before tillage and one left undisturbed and covered with natural vegetation. The experimental design is a split-split plot design with three replications.

#### Parameters measured in each of the growing systems evaluated

- Biomass and soil cover of cover crops before transplantation
- Nutrient uptakes of cover crops and tomato plants
- Composition, abundance and characteristics of weed flora present in cover crops and tomato during the growing season
- Dead mulch characteristics (thickness, light interception, decomposition)
- Physical, chemical and biological indicators of soil fertility (nitrates, moisture content, compaction, structure...)
- Tomato production in terms of fruit yield and residues
- Nutraceutical properties of tomato fruits

#### Contact:

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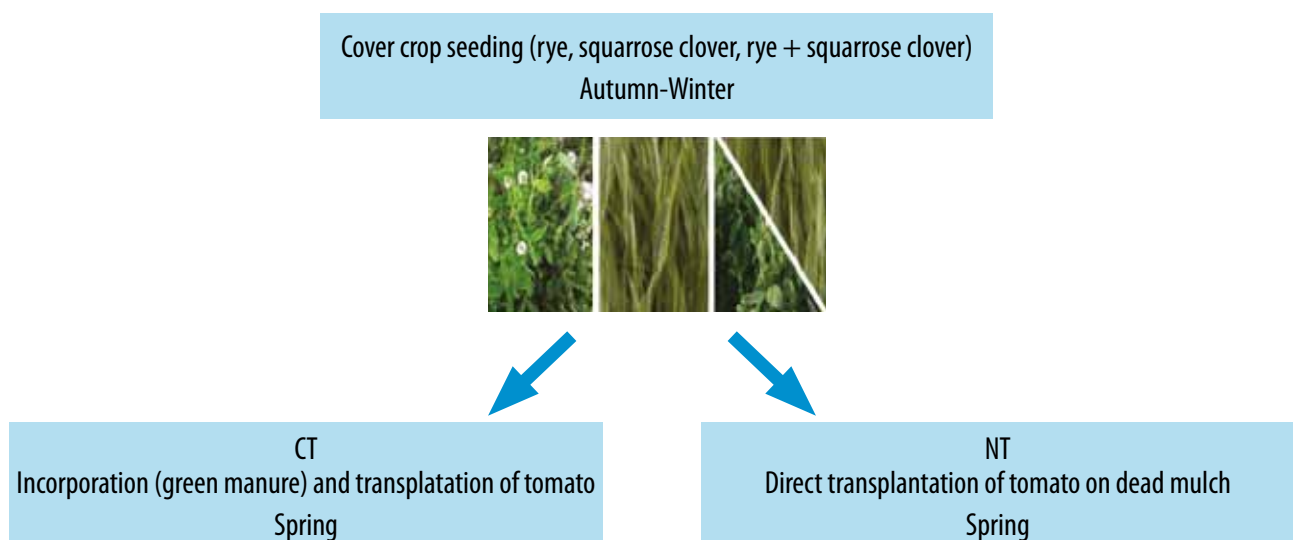
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**Figures 14A and 14B** - Tomato plants transplanted on dead mulch of squarrose clover (A) and rye (B)



**Figure 15** - Experimental scheme

# EXPERIMENTAL TRIALS AT HORTA SRL

HORT@  
— From research to field —



**Figure 1** - Aerial view of experimental plots

*The experimental trials are conducted by Horta srl on Cà Bosco farm. The farm covers 220 ha and is divided in three 70 ha blocks. It has one area under integrated management and one under organic management. The farm applies three- or four-year rotations and its main crops are durum wheat, bread wheat, maize, sugar beet, peas and soy. Soil texture is mainly loam, with a tendency to silt-loam. The farm is irrigated*



**Figure 2** - The main building

*by means of two pivots, of which one is set up as a hippodrome. An underground drainage system serves the entire farm. Horta manages about 20 ha of the farm, where it carries out its experimental trials on plots. The main experimental work is on small-grain cereals, maize and tomatoes. For small-grain cereals, the main experimental activities are the study of fungicide efficacy, crop fertilization and sowing density.*

**Address:**

Horta srl – Az. Agr. Ca' Bosco

Via S. Alberto 327

48123 Ravenna – Italy

GPS coordinates: 44°28'56.6"N 12°10'38.0"E

**For further information and guided visits**

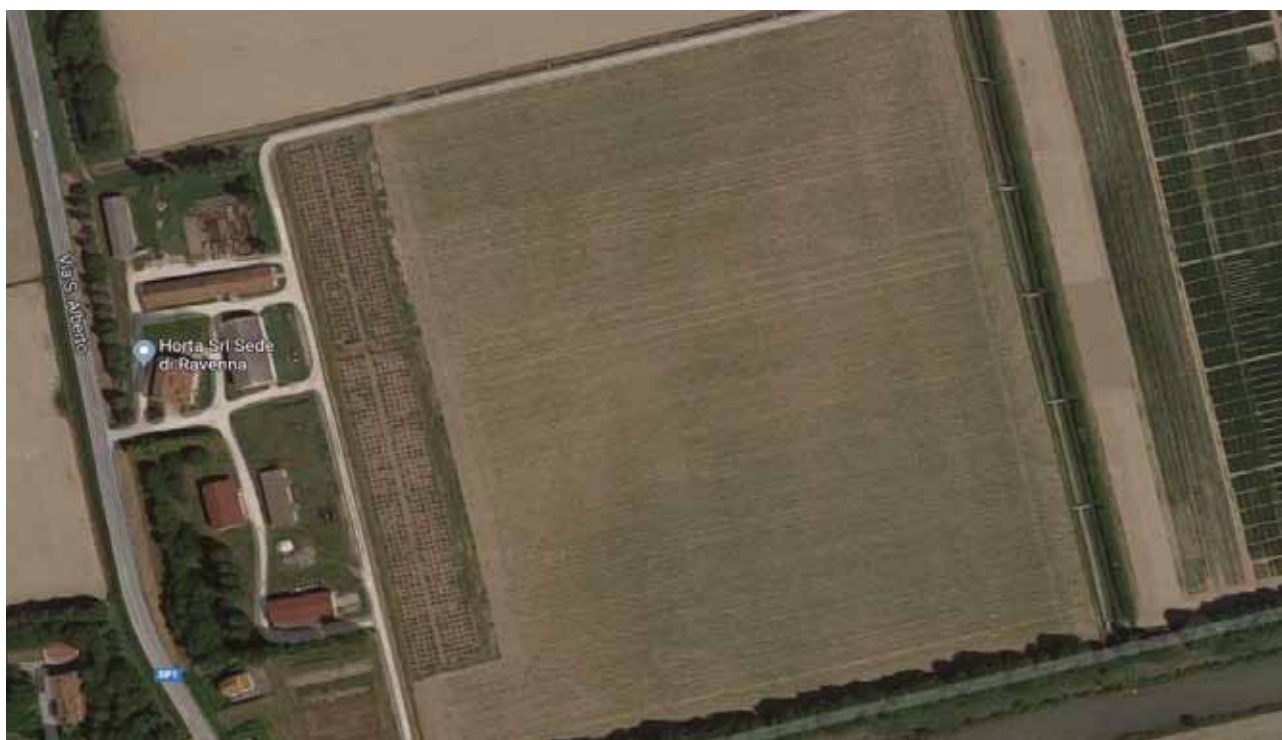
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**Figure 3** - The experimental site

## LEGUME AND DURUM WHEAT RELAY INTERCROPS

Background and objectives are the same of the similar experimental trial held at CIRAA.

### Materials and methods

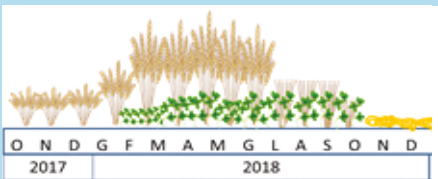
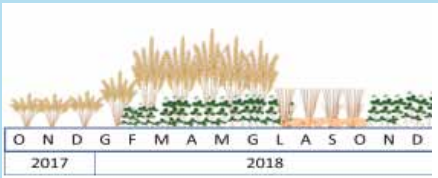
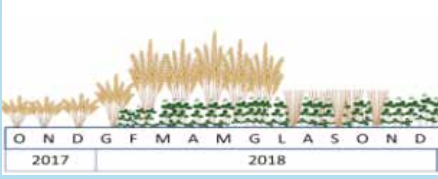
Twenty legume types (Table 2) will be tested in a randomized block design experiment with four replications. After the seed bed was prepared, the Minosse variety of durum wheat was sown in November 2017, with inter-row distance of 18 cm. The wheat was provided by IWMPPRAISE partner ISEA. Legume species were then sown in between wheat rows in February 2018, before the wheat stem elongation phase (Figures 4-6).



**Figure 4** - Sowing of cover crops in wheat.  
(Photo by Matteo Ruggeri)



**Figure 5** - Cover crop seeded in rows in the wheat inter-rows.  
(Photo by Matteo Ruggeri)

| RELAY INTERCROPPING   |   | Hypothesis  |
|---|---|---|
| Annual  | Solution oriented to field crops farms<br>     | Weed control: <b>MEDIUM-HIGH</b><br>Soil cover: <b>MEDIUM-HIGH</b><br>Soil fertility: <b>MEDIUM-HIGH</b><br>SYSTEM PRODUCTIVITY: <b>MEDIUM-HIGH</b> |
| Self-reseeding  | Solution oriented to field crops farms<br>     | Weed control: <b>HIGH</b><br>Soil cover: <b>HIGH</b><br>Soil fertility: <b>HIGH</b><br>SYSTEM PRODUCTIVITY: <b>MEDIUM</b>                           |
| Perennial   | Solution oriented to farms with grassland<br> | Weed control: <b>HIGH</b><br>Soil cover: <b>HIGH</b><br>Soil fertility: <b>HIGH</b><br>SYSTEM PRODUCTIVITY: <b>HIGH</b>                             |
| Durum wheat cv: MINOSSE, resistant to lodging<br>Wheat sowing: 220 kg/ha<br>Inter-row distance: 18 cm |   | Durum-wheat sowing date: 02/11/2017<br>Legume-sowing date: 01/02/2018   |

**Table 1** - Relay intercropping experiment description

Cover crops were sown broadcast and harrowing was performed after sowing. Three legume species were also sown in rows in the wheat inter-row. The soil characteristics of the experimental plot are detailed in Table 3.

During the current growing season, assessment will be performed both on the wheat and cover crops in order to collect data on:

- **Cover-crop** germination and emergence, phenological phases, biomass, weed population (density and species), soil cover;
- **Wheat** yield, grain quality, N fertilization.

#### Further developments

The experiment will provide farmers with a list of tested cover crops, with indicators of their performance in terms of weed suppression, soil coverage, plus quality and quantity of wheat production. Due to a major fall in temperature after sowing, the species' cold tolerance will also be evaluated.



**Figure 6** - Detail of the experimental plot after harrowing.  
(Photo by Matteo Ruggeri)

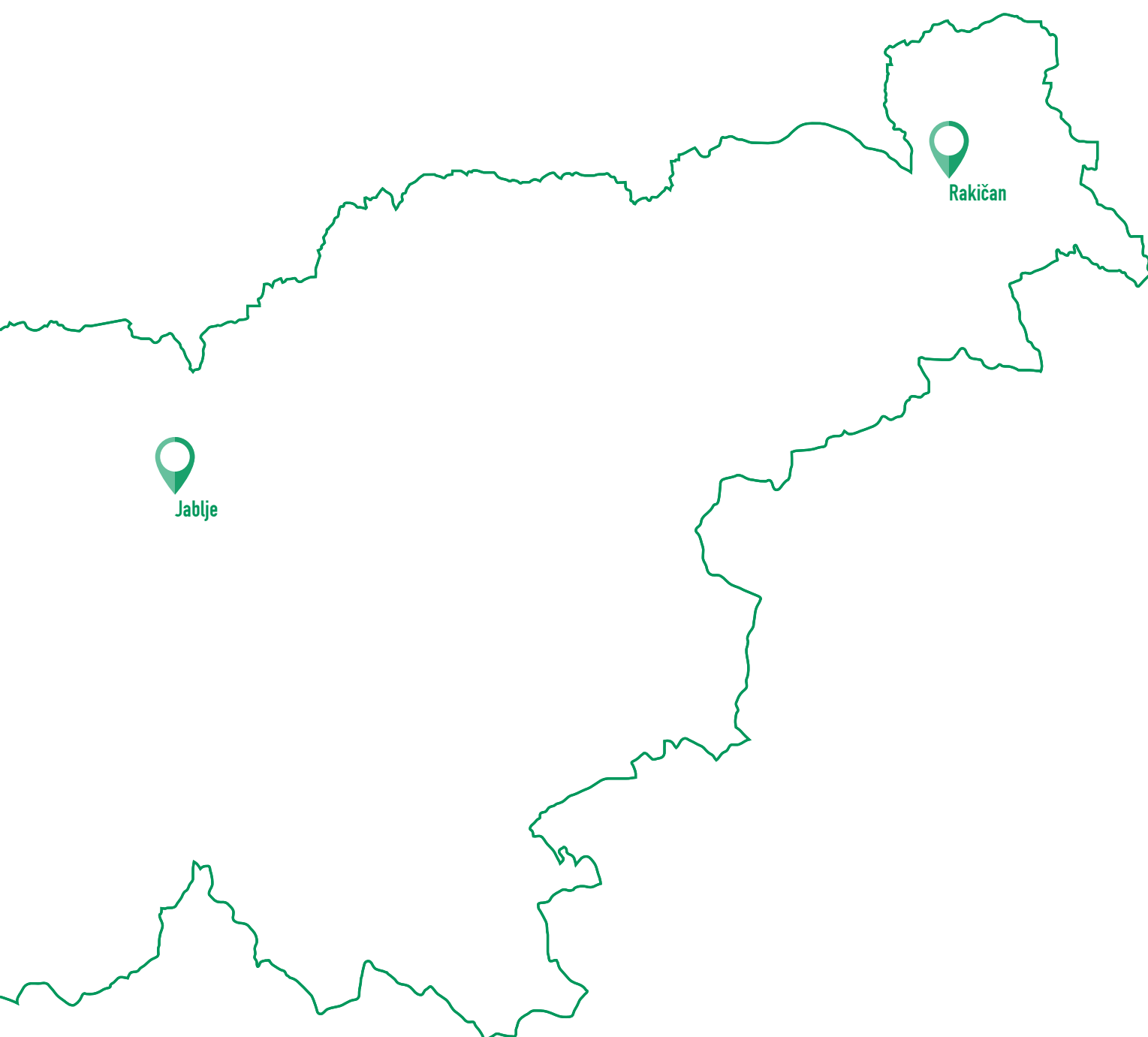
| Life cycle     | Genus and species                                 | Cultivar   |
|----------------|---|------------|
| Annual         | <i>Lathyrus sativus</i>                           | -          |
|                | <i>Trifolium alexandrinum</i>                     | Leila      |
|                | <i>Trifolium incarnatum</i>                       | Kardinal   |
|                | <i>Trifolium resupinatum</i>                      | Lighting   |
|                | <i>Vicia pannonica</i>                            | Detenika   |
|                | <i>Vicia sativa</i>                               | Alexandros |
|                | <i>Vicia villosa</i>                              | Capello    |
| Self-reseeding | <i>Medicago lupulina</i>                          | -          |
|                | <i>Medicago polymorpha</i>                        | Scimitar   |
|                | <i>Medicago rotata</i>                            | Highlander |
|                | <i>Medicago truncatula</i>                        | Paraggio   |
|                | <i>Medicago truncatula</i>                        | Sephi      |
|                | <i>Medicago scutellata</i>                        | Sava       |
|                | <i>Ornithopus sativus</i>                         | Enema      |
|                | <i>Trifolium michelianum</i>                      | Paradana   |
|                | <i>Trifolium subterraneum sub. brachycalcinum</i> | Mintaro    |
|                | <i>Trifolium subterraneum sub. yanninico</i>      | Monti      |
| Perennial      | <i>Hedysarum coronarium</i>                       | Carmen     |
|                | <i>Medicago sativa</i>                            | Gamma      |
|                | <i>Trifolium repens</i>                           | Companion  |

**Table 2** - List of legumes used in the experiment

| Year of analysis | pH  | total N<br>‰ | organic matter<br>% | P205<br>ppm | clay<br>% | silt<br>% | sand<br>% |
|------------------|-----|--------------|---------------------|-------------|-----------|-----------|-----------|
| 2018             | 8.2 | 1.17         | 1.37                | 19          | 35        | 60        | 5         |

**Table 3** - Soil properties of the experimental field

# SLOVENIA





# EXPERIMENTAL TRIALS IN JABLJE



*The Infrastructure Centre Jablje (IC Jablje) recently joined the Agriculture Institute of Slovenia (AIS), although expert and research activities have been conducted there for many decades. With the merger, the AIS consolidated its reputation as Slovenia's main scientific research and expert institution in the field of agriculture and it is successfully implementing and transferring new scientific findings into agricultural practice. The IC Jablje is located in the centre of Slovenia, close to the capital Ljubljana, and it operates on approximately 410 ha of arable land. Crop production is based on conventional management practices, with large restrictions on water-protected areas and minor organic production in the transition phase. The farm has a range of soil types, ranging from light sandy-loam to heavy clay-loam, and a continental climate with more than 1000 mm of average annual precipitation. The farm also owns facilities for indoor experiments (400 m<sup>2</sup> of controlled-environment glasshouses and 1500 m<sup>2</sup> of greenhouses). The majority of the property is used for commercial seed production and breeding of their own grass, clover, buckwheat and cereal varieties. Its flat agricultural*

*land with continental climate is a great representative site for central Slovenia's main commercial field conditions (including soil conditions, precipitation and temperature fluctuation), therefore it also serves as a demonstration site and knowledge-transfer centre for end-users: experts, farmers and students. The farm has an experienced research team and works in collaboration with the advisory service, organising joint workshops and education courses on integrated weed management.*



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## WP3 – WINTER WHEAT TRIAL

### Objectives

The aim of the experiment is to incorporate, test and demonstrate a range of weed-management tools and strategies in winter-wheat production. Tools and strategies, including delayed sowing and blind harrowing, will be tested to reduce weed germination and development in the crop-establishment phase. Furthermore, mechanical weeding in various crop-development stages will also be included and compared with standard strategies, such as autumn and spring broadcast herbicide application.

### Materials and methods

A field trial with five strategies was established in autumn 2017 at the AIS research station IC Jابلje for demonstration purposes with winter-wheat variety Vulkan. The experiment is arranged in long, 24 m wide strips, where two standard strategies will be

compared with three alternative strategies. Standard strategies include spring and autumn broadcast herbicide application, which represent common weed-management practice. One of the alternative strategies implemented autumn harrowing, which is not commonly used in central Slovenia due to its humid conditions. The other two alternative strategies apply delayed sowing and blind harrowing, in a bid to reduce weed germination and establishment in the early crop-development phase, while herbicides will be used in the spring according to weed infestation.

### Further development

Field trials will be repeated in the next two seasons at the IC Jابلje research station. The design will include two standard approaches and three alternative strategies, which will be adapted according to the stakeholders' response to this year's results and to their experiences. Focus will be on more efficient use of mechanical tools in the autumn and targeted use of herbicides in the spring.

West

| Strategy  | Standard 1         | Strategy 5                 | Strategy 4                 | Strategy 3            | Standard 2         |
|---|--------------------|----------------------------|----------------------------|-----------------------|--------------------|
| Soil tillage  | Spring ploughing   | Spring ploughing           | Spring ploughing           | Spring ploughing      | Spring ploughing   |
| False seed bed  | /                  | Tine harrowing             | /                          | /                     | /                  |
| Sowing time   | Optimal            | Delayed 10 days            | Delayed 10 days            | Optimal               | Optimal            |
| Herbicides broadcast application  | Spring application | Reduced spring application | Reduced spring application | Spring application    | Autumn application |
| Mechanical weeding  | -                  | Spring tine harrowing      | Spring tine harrowing      | Autumn tine harrowing | /                  |
| <div style="display: flex; justify-content: space-around; align-items: center;"> <span>← 24 m</span> <span>← 24 m</span> <span>← 24 m</span> <span>← 24 m</span> <span>← 24 m</span> </div> |                    |                            |                            |                       |                    |
| Field road (East)   |                    |                            |                            |                       |                    |

**Table 1** - WP3 trial layout



**Figure 1** - Autumn harrowing in wheat plots 5 weeks after sowing

## WP4 – MAIZE TRIAL

### Objectives

The objective of the trial is to test various integrated weed-management strategies in maize production. Strategies will be demonstrated in real field-conditions and designed to reduce reliance on herbicides. To achieve this goal, herbicide use will be partially replaced with use of mechanical tools and band spraying.

### Materials and methods

The field experiment on maize was established at the end of April 2018 at the AIS's IC Jابلje research station. The demonstration trial is arranged in long, 12 wide strips and consists of three alternative weed-

management strategies which will be compared with standard early post-broadcast herbicide application. In two alternative strategies, reduced doses of herbicide and band application will be combined with a highly precise camera-guided finger weeder, while mechanical tools only will be used to control weeds in the third strategy.

### Further development

In the upcoming season, the basis of weed-management tools and strategies will remain the same. However, additional tools and strategies, such as cover crops and blind harrowing, may be included in the future, based on end-user response and suggestions.

| North  |  |  |   |                                      |
|--|--|--|---|--------------------------------------|
| Strategy   | Standard 4                                 | Strategy 3                                 | Strategy 2                              | Strategy 1                           |
| Lavorazione del terreno  | Spring ploughing                           | Spring ploughing                           | Spring ploughing                        | Spring ploughing                     |
| Herbicides   | /  | Band spraying<br>Recommended dose          | Band application<br>Dose reduced by 40% | Band application<br>Recommended dose |
| Mechanical weeding   | Finger weeder EC 14<br>Finger weeder EC 18 | Finger weeder EC 16<br>Finger weeder EC 18 | /<br>Finger weeder EC 18                | /<br>/                               |
| <div> <div></div> <div>12 m</div> <div></div> <div>12 m</div> <div></div> <div>12 m</div> <div></div> <div>12 m</div> <div></div> </div> |  |  |   |                                      |
| Field road (South)   |  |  |   |                                      |

**Table 2 – WP4 trial layout**



**Figure 2 – Mechanical weeding with camera guided finger weeder in maize plots**



# EXPERIMENTAL TRIALS IN RAKICAN



*Biotehniška šola Rakičan (BSR) is a public agricultural high school in the Panonian lowland. Besides running basic, principally agricultural education programs for approximately 120 pupils, the school performs various research activities mainly focused on arable production with variety testing and the implementation of new technology and management into practice. BSR also provides certified adult training for crop production, animal husbandry, fruit and wine production, agricultural businesses, and other fields of agronomy. The school owns around 18 ha of arable land with*

*a high quality silty-loam soil and warm continental climate, providing excellent conditions for outdoor experiments. BSR also carries out greenhouse trials, where pupils and students perform their research. The BSR's skilled staff regularly conduct demonstration trials and education courses. In recent years, BSR has been recognized as a regional education and knowledge-transfer centre.*

*Its collaboration with the advisory service is well-recognized, since it hosts experiments, as well as traditional wheat and maize field days.*

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## WP3 – WINTER WHEAT TRIAL

### Objectives

The purpose of the demonstration trial is to test alternative weed-management approaches whereby mechanical tools will be incorporated in weed-control strategies in a bid to reduce herbicide use in winter-wheat production. Besides mechanical weeding, measures to prevent weed germination and reduce weed establishment in the early crop-development phase will also be implemented.

### Materials and methods

The field trial at the Biotechnical School Rakičan was established in autumn 2017 when two alternative strategies and one standard weed-management practice were implemented. The experiment is arranged in long, 15 m wide strips, where standard weed-control strategies entail spring broadcast herbicide application. In one of the alternative strategies, autumn and spring tine harrowing were combined with reduced herbicide use in the spring. In the second alternative approach, delayed sowing and spring tine harrowing were utilized, with herbicides being used in the spring as needed.

### Further development

In the next two years, the experiment will be repeated with similar strategies and tools, with focus being placed on more efficient use of mechanical tools. The final design will be adapted in collaboration with other stakeholders and end users.

## WP4 – MAIZE TRIAL

### Objectives

The objective of the demonstration trial is to include mechanical measures in weed-management strategies in maize production where commonly only herbicides are used for weed control.

Strategies will be demonstrated in real field-conditions and designed to reduce reliance on herbicides. To achieve this goal, herbicide use will be partially replaced with use of mechanical tools and band spraying.

### Materials and methods

The field experiment on maize was established at the beginning of April 2018 at the Biotechnical School Rakičan. The demonstration trial is arranged in long, 12 wide strips and consists of three alternative weed-management strategies, which will be compared with standard early post-broadcast herbicide application. As an alternative strategy, an inter-row weeder will be adapted for band spraying. The second alternative strategy sees late post-herbicide application compared with the standard strategy.

### Further development

In the upcoming season, field trials on maize will be repeated and the main weed-management tools and strategies will remain similar. However, additional tools and strategies, such as cover crops and blind harrowing, may be included in the future, based on end-user response and suggestions.

| North  |                    |                                  |                            |
|--|--------------------|----------------------------------|----------------------------|
| Strategy   | Standard 1         | Strategy 2                       | Strategy 3                 |
| Soil tillage   | Ploughed           | Ploughed                         | Ploughed                   |
| False seed bed   | /                  | /                                | Tine harrowing             |
| Sowing time  | Optimal            | Optimal                          | Delayed 10 days            |
| Herbicides broadcast application   | Spring application | Reduced spring application       | Reduced spring application |
| Mechanical weeding   | /                  | Autumn and spring tine harrowing | Spring tine harrowing      |
| <div> <div style="width: 25%;"></div> <div style="width: 25%;"></div> <div style="width: 25%;"></div> <div style="width: 25%;"></div> </div> |                    |                                  |                            |
| 15 m   |                    |                                  |                            |
| (South)  |                    |                                  |                            |

**Table 1 - WP3 trial layout**

| North  |   |  |  |
|--|---|--|--|
| Strategy   | Standard 1  | Strategy 2                                     | Strategy 3                                       |
| Soil tillage   | Autumn ploughing                                  | Autumn ploughing                               | Autumn ploughing                                 |
| Herbicides   | Broadcast application recommended dose early post | Band spraying with recommended dose            | Broadcast application recommended dose late post |
| Mechanical weeding   | /   | Between rows in combination with band sprayers | /  |
| <div> <div style="width: 25%;"></div> <div style="width: 25%;"></div> <div style="width: 25%;"></div> <div style="width: 25%;"></div> </div> |   |  |  |
| 12 m   |   |  |  |
| (South)  |   |  |  |

**Table 2 - WP4 trial layout**

# SWITZERLAND

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# EXPERIMENTAL TRIALS MANAGED BY AGROSCOPE AND AGFF



*Agroscope is the Swiss center of excellence for agricultural research and is affiliated with the country's Federal Office for Agriculture (FOAG). Agroscope makes an important contribution to sustainable agriculture and the food sector, as well as to maintaining the environment, thereby contributing to an improved quality of life. Agroscope engages in research along the entire value chain of the agriculture and food sector. Its goals are to uphold a competitive and multifunctional agricultural sector, high-quality food for a healthy diet, and good environmental standards.*

*As grasslands account for about 75% of Switzerland's agriculturally utilized area, they are of outstanding importance for the Swiss agricultural sector and the environment. Agroscope's Grassland Systems and Forage Production research group focuses on agricultural ecology and grassland management covering both the conventional and organic sectors. The group's mission is to contribute to the development of site-adapted, sustainable and multifunctional grassland production systems for a wide range of*

*management intensities and site conditions, from highly productive sites in the lowlands to marginal sites in the Alps.*

*The Swiss Grassland Society (Arbeitsgemeinschaft zur Förderung des Futterbaues AGFF) is governed by a joint body of farmers, advisors, and representatives of industry partners, associations and agricultural research institutes. Its main activity consists of establishing close ties between all interested partners to achieve high quality forage and sustainable, site adapted management of grassland. This setting facilitates the rapid and effective exchange of ideas and research results between practitioners and researchers. AGFF is a nationally recognized organization for all technical aspects of grasslands and grassland production systems. AGFF grassland management tools and fact sheets are widely disseminated, being used by advisory services and all Swiss agricultural schools for the training of future farmers.*

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## INTEGRATED WEED MANAGEMENT IN PERMANENT GRASSLANDS

*Rumex obtusifolius* is a major weed infesting grasslands. Currently, the standard control method is herbicide in conventional farming systems and hand-removal in organic farming systems (Grossrieder & Keary, 2004). Reviews pointed out the potential of *Sesiidae* moths for the biological control of the dock species in Europe (Grossrieder & Keary, 2004, Hatcher et al., 2008). The potential of two *Sesiidae* spp (*Pyropteron doryliforme* and *Pyropteron chrysidiforme*) is particularly promising due to their ability to feed on roots during the larval stage (Scott & Sagliocco, 1991 a, b). In Australia, invasive *Rumex* species of European origin were successfully controlled using *Pyropteron doryliforme*. By introducing a specialist natural enemy from the native range, a natural equilibrium between the root boring insect and the weed species was installed, thereby significantly reducing the abundance of *Rumex*.

In 2008, the Centre for Agriculture and Biosciences International (CABI) launched a biological control project in Switzerland to target *Rumex obtusifolius*, the most problematic *Rumex* species in Swiss grassland. As both the target weed and its natural enemy are native to Europe, a classical biological control approach, as described above for Australia, is not feasible. Thus, we chose an inundative approach, i.e. targeted mass-releases of the native biological agent as a bioherbicide over a short duration to reduce dock densities. In our project, we first selected *P. chrysidiforme* as the biological control agent, as it is native to Switzerland and Western Europe. In contrast, *P. doryliforme* is native to Southern Europe and Northern Africa (Spatenka et al., 1999). Initially, *P. chrysidiforme* was found to have a successful impact on dock survival and performance in a pot experiment (U. Schaffner, results not published). Under field conditions, however, this effect was not observed, largely due to a low larval infestation level (Hahn et al., 2016). The impact and mortality on docks was different among the Swiss (Hahn et al., 2016) and the Australian (Spafford et al., 2008) biological control projects, each of which involved different *Pyropteron* species (*P. doryliforme* in Australia and *P. chrysidiforme* in Switzerland) and different weed species (mainly *R. pulcher* in Australia and *R. obtusifolius* in Switzerland).

### Objectives

In the new IWMPRAISE project, we will explore whether the two sister species (*P. chrysidiforme* and *P. doryliforme*) have a different infestation and impact potential on docks and whether a combination of

both *Pyropteron* species increases this impact. We will also test whether our target weed (*R. obtusifolius*) differs in terms of larval attack rate and impact from the target weed in Australia (*R. pulcher*).

### Materials and methods

We are currently conducting a multifactorial pot experiment in the Agroscope garden in Reckenholz to evaluate the infestation and impact potential of the two biological control candidates *Pyropteron doryliforme* and *Pyropteron chrysidiforme*, both alone or combined, on the two *Rumex* species: *R. obtusifolius* and *R. pulcher*. The experiment includes three treatments with biological agents: (1) *P. chrysidiforme*, (2) *P. doryliforme* and (3) *P. chrysidiforme* & *P. doryliforme*, plus an (4) untreated control. *Pyropteron chrysidiforme* individuals were provided by CABI Delémont from a rearing started in 2010. Late-instar larvae of *Pyropteron doryliforme* were collected in April in Southern Spain to set up a rearing at CABI Delémont (Figure 1). Emerging adults (mid-May to mid-July) were mated in cages and the females then transferred into plastic cylinders for oviposition. Eggs were collected weekly and transported to Agroscope Reckenholz to infest plants in the garden experiment. Eggs from at least two different females (30 eggs in total) were glued onto wooden toothpicks.

Field-collected one-year-old-plus *R. obtusifolius* plants and younger seed-reared *R. obtusifolius* and *R. pulcher* plants were planted in pots (volume 5.5l, ø 19.5cm,



**Figure 1** - Roots infested with *P. doryliforme* from field collection in Spain





**Figure 2** - Garden experiment



**Figure 3** - Egg sticks ready for inoculation



**Figure 4** - *R. pulcher* infested

height 25.5cm) containing a mixture of soil, sand, vermiculite and long-term fertilizer. The experimental design was arranged in a randomized block design with 15 replicates (Figure 2), resulting in 360 plants (3 plant types x 4 *Pyropteron* treatments x 2 harvesting times x 15 replicates).

In June 2018, the *Pyropteron* treatments were applied by inserting one toothpick per plant into the soil near the plant base after cutting the aboveground biomass at 6-7cm (Figure 3 and 4). The plants and egg sticks were protected from rainfall for two weeks after inoculation. The parameters recorded during dissection were aboveground biomass, belowground biomass, number of roots, number of feeding marks, number of larvae alive & dead, weight & length of larvae, place of larva on root, and plant performance (Figure 5). Recording will continue until autumn 2018 to assess infestation and until spring 2019 to assess impact on *Rumex* performance.



**Figure 5** - Larval infestation and impact on *R. obtusifolius* taproot under the *P. chrysidiiforme* & *P. doryliiforme* combination treatment in autumn 2018



### Further development

The next step will be to test the infestation and impact rate of the most successful species along a temperature and rainfall gradient in pot and field experiments.

### Literature

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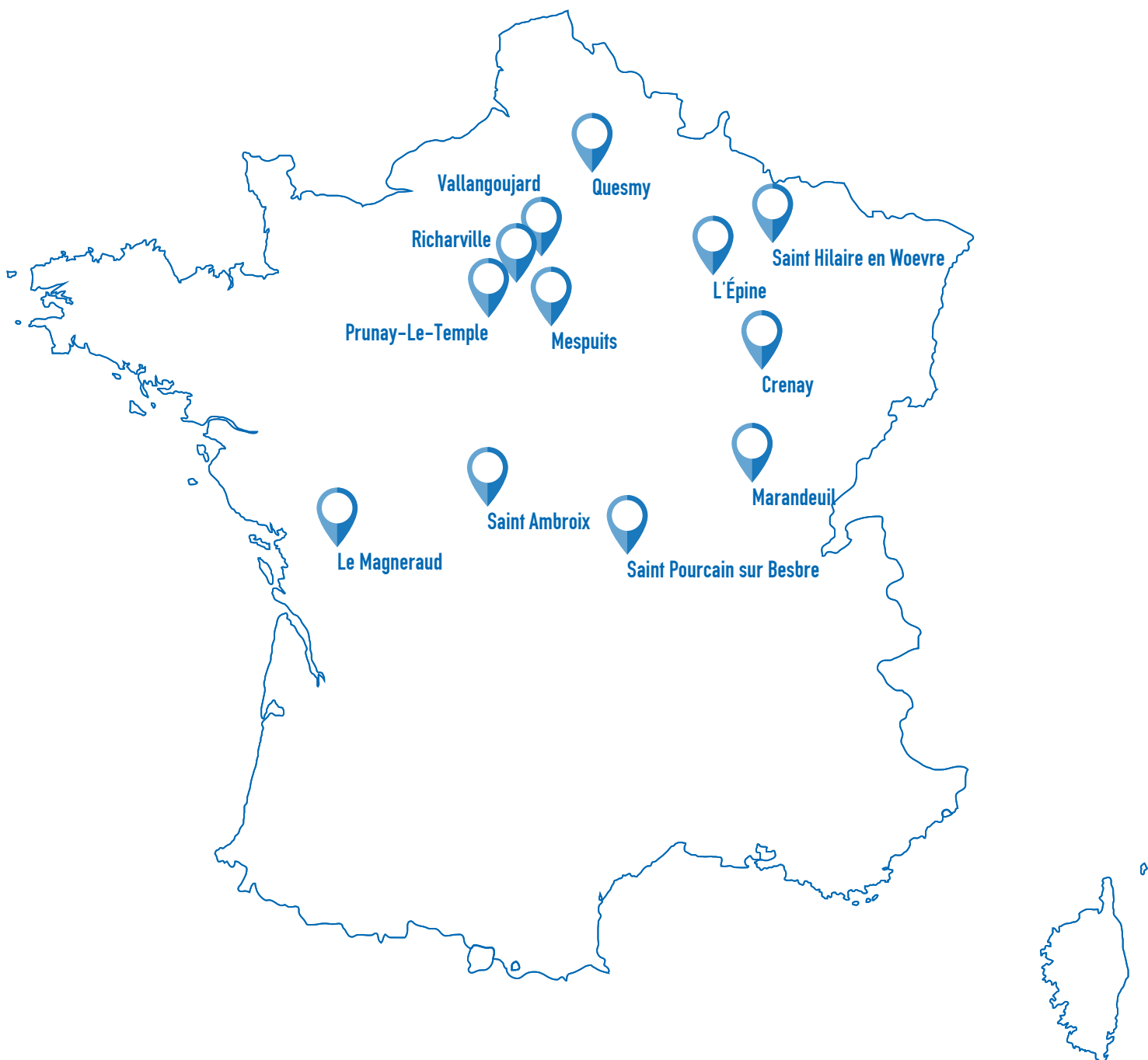
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# FRANCE





# EXPERIMENTAL TRIALS MANAGED BY THE ILE-DE-FRANCE CHAMBER OF AGRICULTURE



Ile-de-France, the nation's capital region, is also a major agricultural area. Agriculture accounts for 48% of its land. The region's exceptional natural conditions have led to productive, high-performance agriculture. However, major urbanization on the one hand and the nature of agricultural activity on the other exert serious pressure on the quality of its water, soil, air and natural habitats.

As it has a substantial population that needs to be

fed, restoring water quality is a priority. Many of the region's farmers are aware that it is crucial to develop economically and ecologically performing strategies if their farms are to survive.

The reduction of herbicide use in weed management is a part of this new process. Considering the increasing resistance of weeds to authorized pesticides, it is more important than ever to find mechanical and agronomical alternatives.

## WP3 – EXPERIMENTAL TRIAL OF WEED MANAGEMENT ON WHEAT



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## Objectives

The Ile-de-France Chamber of Agriculture supports farmers who are searching for alternative solutions to herbicides. These solutions were implemented in three Ile-de-France exploitations in order to compare their efficiency. The other goal of this trial is to introduce demonstration fields so that farmers can see the results of various weeding strategies. In June, between 200 and 400 farmers came to visit the trial sites. This event was an opportunity for them to compare experiences.

## Materials and methods

The following chart sums up the various weed management strategies that are due to be tested next autumn. The final protocol will be chosen in cooperation with the participating farmers. It will be identical on all three sites so that the results can be reproduced.

The main criteria for deciding the location of a trial within a plot will be weed-infestation level. The more infested the site, the more visible the results of weeding methods will be at the end of the test. Several

strategies are tested and combined: soil tillage, false seedbed technique, direct seeding, covered seeding and sowing-date variation.

Black grass and ryegrass are the two species studied because they are the weeds that cause the most

damage to the region's cereals. The plants will be counted at the beginning of winter (November), at the end of winter (January - February), and in June. Wheat yield will be evaluated at the end of the trial.

|             | 1   |                              | 2   |                              | 3   |                              | 4                                      |                              | 5   |                              |
|-------------|---|------------------------------|---|------------------------------|---|------------------------------|--|------------------------------|---|------------------------------|
|             | Ploughing                                     |                              | Pseudo ploughing                              |                              | Pseudo ploughing without rotary harrow          |                              | Direct sowing without vegetative cover |                              | Direct sowing with vegetative cover                                   |                              |
| Steps       | Summer labor                                  |                              | Post harvest: 15–20 cm deep tillage           |                              | Post harvest: 15–20 cm deep tillage             |                              |  |                              | Post harvest sowing of the vegetative cover (oat and pigeon bean mix) |                              |
|             | False seed-bed with superficial rotary harrow |                              | False seed-bed with superficial rotary harrow |                              | False seed-bed with superficial rotary harrow   |                              |  |                              |   |                              |
|             | Rotary harrow and drill combined sowing       |                              | Rotary harrow and drill combined sowing       |                              | Rotary harrow free sowing (tillage free sowing) |                              | Direct sowing with adapted drill       |                              | Direct sowing with adapted drill                                      |                              |
| Sowing date | Mid-October sowing                            | Late sowing in mid-November* | Mid-October sowing                            | Late sowing in mid-November* | Mid-October sowing                              | Late sowing in mid-November* | Mid-October sowing                     | Late sowing in mid-November* | Mid-October sowing  | Late sowing in mid-November* |

\* at least 3 weeks after the first sowing, adapt to the ongoing year conditions  
Each modality is compared with an untreated control

**Table 1** - WP3 trial layout

## WP4 – EXPERIMENTAL TRIAL OF WEED MANAGEMENT ON BEETS



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|                   |                |  |   |  |   |
|-------------------|----------------|--|---|--|---|
| 6 meters          | 6 meters       | 6 meters                                       | 6 meters  | 6 meters   | 6 meters  |
| Untreated control | Tilled control | Local practices<br>3 applications of herbicide | Local practices + hoeing<br>3 applications of herbicide | Reduced chemical treatment + hoeing<br>2 applications of herbicide | Reduced chemical treatment + harrow<br>2 applications of herbicide and 2 mechanical weeding steps |

**Table 2** - WP3 trial layout



**Figure 1** - Sugar beet sowing machine

### Objectives

The Ile-de-France Chamber of Agriculture helps volunteering farmers to find alternative solutions to herbicides in the fight against weeds. A study was launched in March 2017 in Richarville's experimental site. Its goal is to evaluate and prove that chemical and physical treatments are complementary. The final goal

is to reduce the frequency - and then the quantity - of pesticides used by farmers without compromising beet yield.

In June 2018, hundreds of farmers will visit this trial site (there were 350 last year). This event will give them the opportunity to discuss the issue with other farmers.

### Materials and methods

The beet crop-itinerary sees local farmers usually apply herbicides three times. The on-going trials between zero and the third application of chemical treatment may or may not be combined with mechanical means, i.e. rotary hoe or harrow. The following chart shows the organization of the fields undergoing the different methods during the Richarville trial.

Beets were seeded on 13 March 2018, and the weed plants were counted one month later. A global analysis of the efficiency of each tested method was conducted between June and July. An "acceptability score" from 1 to 10 will be given in accordance with the crops' appearance.

# EXPERIMENTAL TRIALS MANAGED BY ARVALIS



Arvalis - Institut du végétal is an applied agricultural research organization dedicated to arable crops: cereals, maize, sorghum, potatoes, fodder crops, flax and tobacco. Research and development is the first field of activity of the Institute and represents 50% of its resources. Arvalis conducts annually an average of 1,700 tests experiments on 26 experimental stations. Its studies focus on agronomy, plant knowledge, modelling, biotechnology, crop management and protection, agri-environmental schemes, precision farming, agricultural machinery, digital applications, harvesting and storage, economy, and agricultural markets.

Arvalis in 2018 implemented two protocols on IWM for winter wheat in various parts of France:

- 1) Evaluation of the introduction of mechanical weeding in winter wheat, combined with herbicide use;
- 2) Impact of the drilling date for winter wheat on the herbicide strategy in autumn.

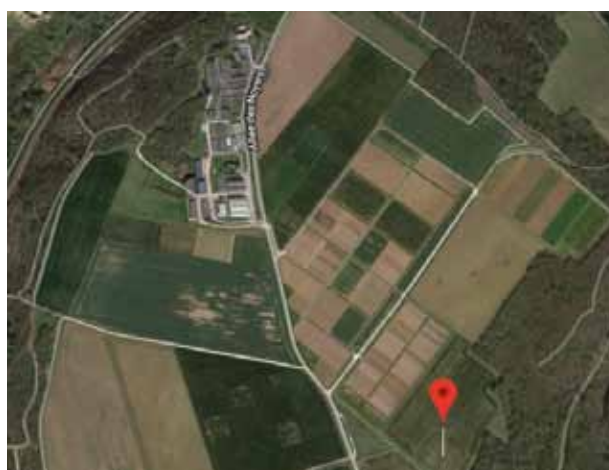
|   |   |
|---|---|
| 1 | CONTROL   |
| 2 | HOEING in Spring  |
| 3 | DAIKO+FOSBURI+H 2.25L+0.6L 1-2 leaves                                     |
| 4 | DAIKO+FOSBURI+H 2.25L+0.6L 1-2 leaves + HOEING (1 pass)                   |
| 5 | DAIKO+FOSBURI+H 2.25L+0.6L 1-2 leaves + HOEING (multi-pass)               |
| 6 | TROOPER 2.5L Pre em / DEFI+CARAT 3L+0.6L 1-2 leaves                       |
| 7 | TROOPER 2.5L Pre em / DEFI+CARAT 3L+0.6L 1-2 leaves + HOEING (1 pass)     |
| 8 | TROOPER 2.5L Pre em / DEFI+CARAT 3L+0.6L 1-2 leaves + HOEING (multi-pass) |

Rye grass densities: about 200 plants/m<sup>2</sup> (counts in December)

**Table 1** - Methods tested in Boigneville trial in 2017-2018



**Figure 2** – Hoeing machine for rye-grass management in wheat trials



**Figure 3** – Location of the trial in Boigneville (48°19'26.4N 2°23'11.4"E)





**Figure 4** – Winter wheat in autumn on a “drilling date” trial

## EVALUATION OF THE INTRODUCTION OF MECHANICAL WEEDING IN WINTER WHEAT COMBINED WITH HERBICIDE USE

### Objectives

Evaluate interest in a combined strategy (herbicides in autumn and hoeing in spring) for winter wheat on resistant rye grass. The objectives of the trial are to evaluate:

- 1) the effectiveness of hoeing (one pass or multipass) in spring, in addition to one or two autumn treatments;
- 2) whether hoeing in spring reduces the number of applications in autumn, in the presence of resistant rye grass;
- 3) whether hoeing affects yield.

### Materials and methods

The trial is a three repeat block test. Wheat (FRUCTIDOR) was sown on 20 October 2017, with a row spacing of 15 cm. A hoeing machine was equipped with a camera-type guidance system. The elementary plots have a minimum gross area of 20 m<sup>2</sup>, with their width being the same as the hoeing machine's. An area was provided for alignment and to allow the automatic guidance system to secure the position of the hoeing machine before it entered the trial area.

Hoeing is performed whenever infestations of rye grass occur and when conditions are suitable. As indicated in EPPO 093, controls are nested between plots so as to have a representation of the infestation and its potential heterogeneity. At least one randomized control is planned per block for the harvest.

## IMPACT OF THE DRILLING DATE FOR WINTER WHEAT ON THE HERBICIDE STRATEGY IN AUTUMN

### Objectives

Evaluate the impact of delaying the sowing date on weed development and its consequences on winter wheat (positioning and doses of autumn herbicides, yield). The objectives of these trials are to:

- 1) decide whether early seeding is preferable, with pre-emergence and post-emergence options, or whether the seeding date should be delayed and a more random herbicide strategy with lower rates be used in autumn (feasibility) to control weeds;
- 2) understand the most cost-effective strategy. Six trials will be set up on this theme. Another three will be set up on superficial soils to test very early drillings. Their objective is to maximize cereal development in order to limit weeds.

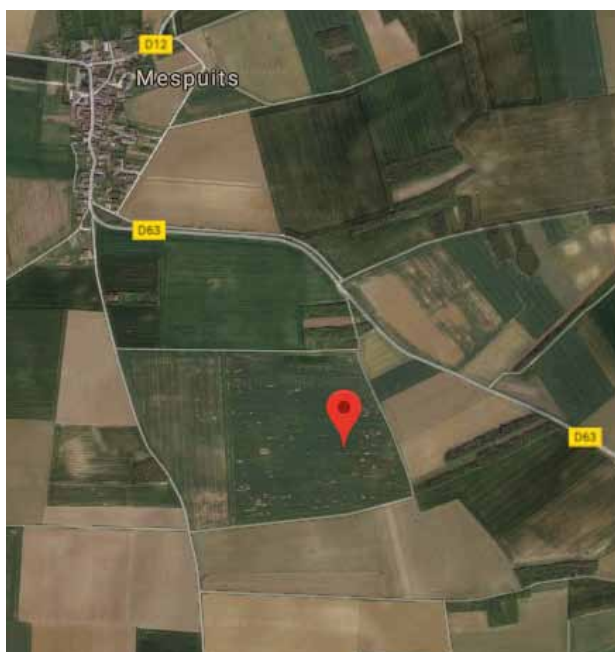
### Materials and methods

The trials are in three blocks. The elementary plots have a minimum gross area of 20 m<sup>2</sup>. Three drilling dates are studied in each of the trials and adapted to local conditions. The dates are “early”, “normal” (i.e. according to local practices) and “late”. The variety can also be adapted to the sowing date in the event of very late sowing. Each drilling date is about 20 days apart. Blackgrass is an issue in five trials and rye grass in one. Three trials have also been implemented, with equivalent herbicide methods but with more contrasting drilling dates: “ultra” early (early September), “early” (early October) and “normal” (2nd fortnight of October).

| Modalities | Drilling date | Doses               |   |   |
|------------|---------------|---------------------|---|---|
|            |               | Pre-emergence       | post-emergence                                  | end of winter                                       |
| M01        | 1/10          | Defi 2L + Flight 3L | /   | /   |
| M02        | 1/10          | /                   | Daiko 2.25L + Fosburi 0.6L + Actirob B 1L       | /   |
| M03        | 1/10          | Defi 2L + Flight 3L | Daiko 2.25L + Fosburi 0.6L + Huile Actirob B 1L | /   |
| M04        | 1/10          | /                   | /   | Atlantis Pro 1.5L<br>+ Actirob B 1L<br>+ Actimum 1L |
| M05        | 1/10          | /                   | Daiko 2.25L + Fosburi 0.6L + Actirob B 1L       | Atlantis Pro 1.5L<br>+ Actirob B 1L<br>+ Actimum 1L |
| M06        | 1/10          | Defi 2L + Flight 3L | Daiko 2.25L + Fosburi 0.6L + Actirob B 1L       | Atlantis Pro 1.5L<br>+ Actirob B 1L<br>+ Actimum 1L |
| M07        | 1/10          | Untreated control   |   |   |
| M08        | 20/10         | Defi 2L + Flight 3L | /   | /   |
| M09        | 20/10         | /                   | Daiko 2.25L + Fosburi 0.6L + Actirob B 1L       | /   |
| M10        | 20/10         | Defi 2L + Flight 3L | Daiko 2.25L + Fosburi 0.6L + Huile Actirob B 1L | /   |
| M11        | 20/10         | /                   | /   | Atlantis Pro 1.5L<br>+ Actirob B 1L<br>+ Actimum 1L |
| M12        | 20/10         | /                   | Daiko 2.25L + Fosburi 0.6L + Actirob B 1L       | Atlantis Pro 1.5L<br>+ Actirob B 1L<br>+ Actimum 1L |
| M13        | 20/10         | Defi 2L + Flight 3L | Daiko 2.25L + Fosburi 0.6L + Actirob B 1L       | Atlantis Pro 1.5L<br>+ Actirob B 1L<br>+ Actimum 1L |
| M14        | 20/10         | Untreated control   |   |   |
| M15        | 10/11         | Defi 2L + Flight 3L | /   | /   |
| M16        | 10/11         | /                   | Daiko 2.25L + Fosburi 0.6L + Actirob B 1L       | /   |
| M17        | 10/11         | Defi 2L + Flight 3L | Daiko 2.25L + Fosburi 0.6L + Huile Actirob B 1L | /   |
| M18        | 10/11         | /                   | /   | Atlantis Pro 1.5L<br>+ Actirob B 1L<br>+ Actimum 1L |
| M19        | 10/11         | /                   | Daiko 2.25L + Fosburi 0.6L + Actirob B 1L       | Atlantis Pro 1.5L<br>+ Actirob B 1L<br>+ Actimum 1L |
| M20        | 10/11         | Defi 2L + Flight 3L | Daiko 2.25L + Fosburi 0.6L + Actirob B 1L       | Atlantis Pro 1.5L<br>+ Actirob B 1L<br>+ Actimum 1L |
| M21        | 10/11         | Untreated control   |   |   |

Sowing dates and herbicides tested may vary depending on the location

**Table 2** - Methods tested in Saint Ambroix on blackgrass

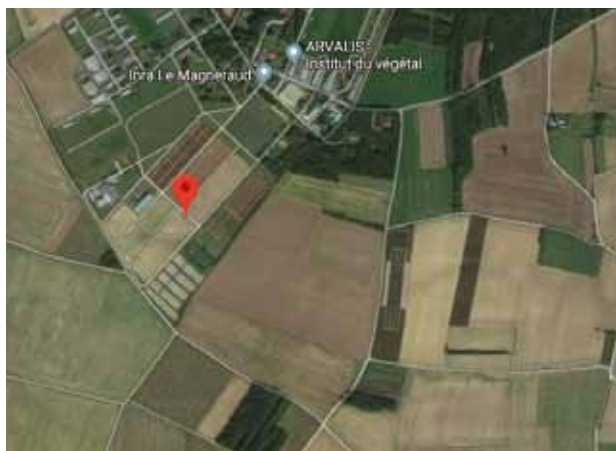


**Figures 5 and 6** - Blackgrass trials in Mespuits ( $48^{\circ}20'53.3\text{N } 2^{\circ}16'46.8\text{E}$ ) and Saint Ambroix ( $46^{\circ}55'43.7\text{N } 2^{\circ}07'40.1\text{E}$ )



**Figures 7 and 8** - Blackgrass trials in Saint Pourçain sur Besbre ( $46^{\circ}29'11.0\text{N } 3^{\circ}37'37.6\text{E}$ ) and L'Épine ( $48^{\circ}57'49.0\text{N } 4^{\circ}27'02.9\text{E}$ )

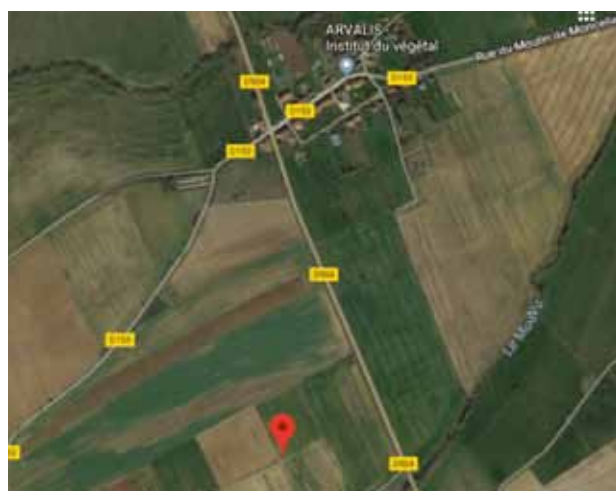




**Figures 9 and 10** - Blackgrass trials in Le Magneraud (46°08'48.4"N 0°41'40.2"W) and Quesmy (49°38'08.8"N 3°03'21.8"E)



**Figures 11 and 12** - "Early variant" trials on blackgrass – trial in Crenay (52) (48°01'0.41"N 5°09'42.8"E) and Marandeuil (21) (47°20'40.2"N 5°20'25.7"E)



**Figure 13** - Blackgrass trial "early variant" protocol, in Saint Hilaire en Woevre (55) (49°04'21.1"N 5°42'10.6"E)



# EXPERIMENTAL TRIALS MANAGED BY THE CENTRE-VAL DE LOIRE CHAMBER OF AGRICULTURE



## WP3 and WP4 – trial programme for 2018-2019

The Centre-Val de Loire Chamber of Agriculture has implemented 11 separate protocols in different sites

around the region for annual narrow-row crops and annual row crops.



### CHER

- 1 - **Common wheat:** combination of mechanical weeding and herbicides
- 2 - **Common wheat:** impact of rotation on weeds (five year trial)
- 3 - **Barley:** impact of sowing date on weeding
- 4 - **Maize:** localized weeding (thistle)



### INDRE ET LOIRE

- 1 - **Common wheat:** impact of different sowing dates on weeding



### LOIRET

- 1 - **Maize:** localized weeding with drone (thistle)
- 2 - **Sugar beet:** localized weeding with drone (thistle)
- 3 - **Sugar beet:** weeding robot
- 4 - **Onion:** weeding robot
- 5 - **Barley:** weeding test when associated with clover
- 6 - **Common wheat:** combination of herbicides and sowing date

# UNITED KINGDOM

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# EXPERIMENTAL TRIALS MANAGED BY ROTHAMSTED RESEARCH

## Harpenden and Brooms Barn sites



*Rothamsted Research is the largest agricultural research centre in the UK and the longest running agricultural research station in the world, providing cutting-edge science and innovation for 175 years. The main campus is located in the town of Harpenden approximately 50 km north of central London which includes a 330 ha research farm growing arable crops typical of the region; mainly winter wheat, oilseed rape, spring barley, oats and field beans. Rothamsted is famous for its long-term experiments established in the mid 1800's by its founder Sir John Bennet Lawes; the oldest of which is the Broadbalk winter wheat fertiliser experiment started in 1843.*

*Rothamsted takes a multi-actor approach and integrates advanced lab-based science with applied*

*areas of science, such as agronomy and agro-ecology, to implement new enabling technologies to improve agricultural practice. Our strength therefore lies in an integrated, multidisciplinary approach to plant and soil science with the aim of developing sustainable, resource-efficient primary production systems. We work closely with farmers and have a number of formal farmer networks that facilitate knowledge exchange. A long-term experiment on the impact of crop rotation and reduced tillage on weed populations is included in the IWM PRAISE project and has been established at the Harpenden site and an additional 77 ha farm in the South East, Brooms Barn (that is in the sugar beet growing region of the UK).*

### Address:

**Rothamsted Research  
West Common  
Harpenden  
Hertfordshire AL5 2JQ  
United Kingdom**

### GPS Coordinates:

**Harpenden 51°48'35.172"N 0°21'14.04"W  
Brooms Barn 52°15'41.796"N 0°34'1.596"E**

### Contact:

**Jonathan Storkey  
email: [jonathan.storkey@rothamsted.ac.uk](mailto:jonathan.storkey@rothamsted.ac.uk)  
phone: +44 1582 938550**

## WP7 – EFFECT OF CROPPING DIVERSITY AND REDUCED TILLAGE ON WEED COMMUNITY DYNAMICS AND COMPETITION

### Objectives

The experiment has been set up as a platform for integrating data on different components of the cropping system in terms of their response to contrasting management. The two top level treatments, increasing cropping diversity and ploughing vs. minimal tillage, have been chosen because they will have the biggest impact on a range of agronomic and environmental metrics. In terms of the IWMPrise goals, we aim to quantify and model the response of weed floras (and their impact on yield and biodiversity) alongside other measurements including soil carbon and soil biology. Ultimately, we aim to quantify the trade-offs and synergies between agronomic, environmental and economic sustainability of the system.



**Figure 1** - Harpenden location (Fields: 'Great Harpenden' and 'Little Hoos') 51°48'38.567"N 0°22'13.328"W

### Materials and methods

The experiment is trialling three contrasting crop rotations (3 year, 5 year and 7 year) incorporating a gradient of crop diversity. At the Harpenden site, sugar beet is replaced with spring linseed. In addition, the 5 year and 7 year rotations also include over winter cover crops. Each phase of every rotation is present every year either in an annually ploughed or minimum tillage system. For the latter, we aim for zero soil disturbance but have the flexibility for occasional non-inversion minimum tillage when soil becomes compacted or capped. We call this treatment 'adaptive tillage'. Finally, the main rotation x tillage plots are split with half the plots receiving additional organic material as green compost. All plots are replicated twice. The experiment began at Brooms Barn in September 2017 and at Harpenden in September 2018.



**Figure 2** - Brooms Barn location (Field: 'Brome Pin') 52°15'46.483N 0°33'53.276"E

#### Radical rotation (*Environmental*)

|                    |               |                               |                               |              |                    |                         |
|--------------------|---------------|-------------------------------|-------------------------------|--------------|--------------------|-------------------------|
| Winter wheat       | Spring cereal | Grass / clover or Lucerne ley | Grass / clover or Lucerne ley | Winter wheat | Sugar beet         | Spring legume (soybean) |
| - Cover cropping - |               |                               |                               |              | - Cover cropping - |                         |

#### Winter wheat based, best practice (*Agronomic*)

|                    |               |                    |               |                     |
|--------------------|---------------|--------------------|---------------|---------------------|
| Winter wheat       | Spring legume | Winter wheat       | Spring cereal | Winter oilseed rape |
| - Cover cropping - |               | - Cover cropping - |               |                     |

#### Business as usual (*Economic*)

|                     |                     |                    |
|---------------------|---------------------|--------------------|
| Second winter wheat | Winter oilseed rape | First winter wheat |
|---------------------|---------------------|--------------------|

**Table 1** - Three contrasting rotations trialled in the WP7 experiment at Rothamsted. The rotations have either been designed to optimise short term economic gain, agronomic best practice or deliver environmental goods and services.



The weed seedbank was sampled on all sub-plots before the treatments were imposed giving a baseline of the local weed species pool. In addition, baseline measurements of soil physical, biological and chemical properties were taken. In future years, herbicides will be excluded from areas on the plots to quantify the effect of the different treatments on weed community dynamics and competition. Yields are routinely recorded on all plots along with all management data and agro-chemical inputs.



Figure 3 - Aerial view of WP7 trial at Brooms Barn

Initial results

The analysis of the weed seedbank data identified 21 species (in addition to volunteer oats and oilseed

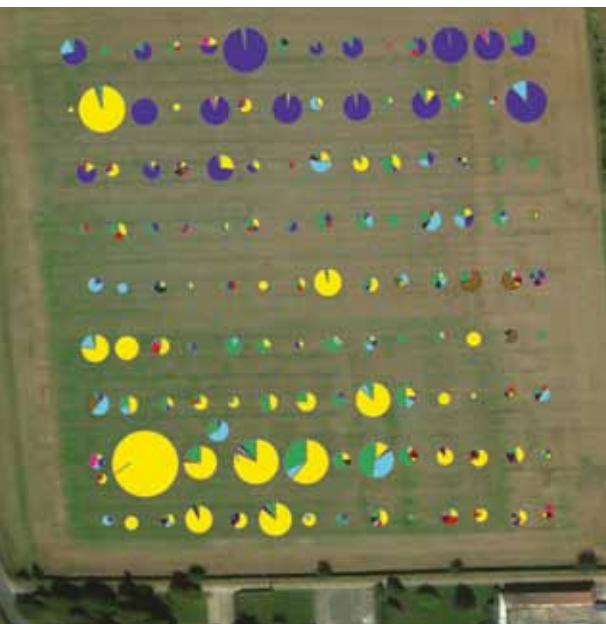


Figure 5 - Brooms Barn weeds



Figure 4 - In zero tillage plots, crops are being sown using a 'Weaving' direct drill

rape) with clear spatial patterns in the background weed flora that will need to be taken into account when analysing the effect of the different treatments.



## North Wyke site



Rothamsted Research North Wyke is located near Oakhampton in South West UK in a region of beef and lamb production. The 350 ha grassland farm is home to the 'North Wyke Farm Platform' (NWFP) which contrasts three farming systems in farmlets, each consisting of five component catchments comprising approx. 21 ha in total per farmlet. Each farmlet is managed using alternative approaches to livestock production from grassland and measurements on water, air and soil are also recorded. Much of this data has a high (15 min) temporal resolution, such as water flow and water chemistry data measured at a flume for each of the 15 catchments, which can comprise either single or multiple fields. As a UK government funded National Capability, the data collected are made publicly available. The main 'treatments' on the platform are:

1. permanent pasture: improvement through use of inorganic fertilisers;

2. increased use of legumes: replacing nitrogen fertilisers with biological fixation using sown legume and grass mixtures;

3. planned reseedling: regular renewal, providing opportunities for introducing innovative varieties with desirable traits. Currently, high sugar grasses and deep rooting grasses are studied.

IWMPRAISE is utilising the Farm Platform in WP5 (herbaceous, perennial crops) by taking additional vegetation samples to quantify the effect of the different management treatments on the proportion of unsown or undesirable species in the pastures. In addition, a new manipulative experiment on the effect of different establishment methods on weeds in newly sown pastures started in autumn 2018 on the North Wyke Farm (but outside the NWFP).

### Address:

Rothamsted Research  
North Wyke  
Okehampton  
Devon EX20 2SB  
United Kingdom

### GPS Coordinates:

50°46'9.757"N 3°54'4.719"W

### Contact:

Jonathan Storkey  
email: [jonathan.storkey@rothamsted.ac.uk](mailto:jonathan.storkey@rothamsted.ac.uk)  
phone: +44 1582 938550

## WP5 – EFFECT OF METHOD OF SEED BED PREPARATION, SEED RATE AND SEED MIX DIVERSITY ON WEED PRESSURE IN NEWLY ESTABLISHED PASTURES

### Objectives

The trial has been set up as a multi-factorial, replicated experiment to investigate the effects of seed bed preparation, seed mix diversity and sowing rates on the diversity and abundance of unsown species. While these species can be perceived as weeds, the experiments will be part of a wider suite of measurements on the yield, nutritional value and silage quality of the resulting established pastures. Complementary pot experiments will quantify the potential contribution of unsown species to animal nutrition allowing their relative undesirability to be assessed.

### Materials and methods

Experiment design:

Factors:

- Seed bed preparation 3 levels: Ploughed, Minimal Cultivation Power Harrow, Minimal Cultivation Disc Harrow. All areas to be sprayed with glyphosate.
- Seed mix (increasing diversity) 4 levels: 2 (binary 'control' PRG & white clover), 6, 12, 18 species (Grass, Legume & Forb seed mixes).
- Sowing rates 2 levels: conventional and conventional plus 50%



**Figure 6** - Location (Rowden Moor East): 50°46'49.562"N 3°55'13.144"W

Three reps, 24 treatments, randomised split plot design:  
3 x 3 x 4 x 2 = 72 plots

Plot size: 3 x 8m (sampling area 7 x 2m)

Seed mixes: Three seed mixes (G=Grass, L=Legume, F=Forb) with increasing diversity. Each seed mix to contain grass, legume (improve Nitrogen Use Efficiency as no N fertiliser required) and non-legume forb species. All seed mixes contain species with different functional traits and are multi-functional to provide good yield, forage quality (including silage quality) and ecosystem services.

|   |  |                                   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                       |  |  |  |  |  |     |  |                      |  |                 |  |
|---|--|-----------------------------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|---------------------------------------|--|--|--|--|--|-----|--|----------------------|--|-----------------|--|
| Rowden Moor West gate way<br>152m                 |  |                                   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                       |  |  |  |  |  | 20m |  | 104m                 |  |                 |  |
|   |  |                                   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                       |  |  |  |  |  | 20m |  |                      |  |                 |  |
| Rep 1   |  | PC+ B B+ HD+ A A+ PC HD           |  |  |  |  |  |  |  | HD+ A+ PC+ PC B+ HD B A                    |  |  |  |  |  |  |  | B A+ A B+ PC+ HD+ HD PC               |  |  |  |  |  |     |  | 8m                   |  |                 |  |
| Plot Number                                       |  | 1 2 3 4 5 6 7 8                   |  |  |  |  |  |  |  | 9 10 11 12 13 14 15 16                     |  |  |  |  |  |  |  | 17 18 19 20 21 22 23 24               |  |  |  |  |  |     |  | 20m                  |  |                 |  |
| Rep 2   |  | A PC+ B+ HD+ B HD PC A+           |  |  |  |  |  |  |  | B HD A PC+ A+ HD+ PC B+                    |  |  |  |  |  |  |  | B B+ PC+ PC A HD A+ HD+               |  |  |  |  |  |     |  | 8m                   |  |                 |  |
| Plot Number                                       |  | 25 26 27 28 29 30 31 32           |  |  |  |  |  |  |  | 33 34 35 36 37 38 39 40                    |  |  |  |  |  |  |  | 41 42 43 44 45 46 47 48               |  |  |  |  |  |     |  | 20m                  |  |                 |  |
| Rep 3   |  | PC B B+ PC+ HD HD+ A A+           |  |  |  |  |  |  |  | B+ PC A+ HD+ A B HD PC+                    |  |  |  |  |  |  |  | A PC HD A+ PC+ HD+ B B+               |  |  |  |  |  |     |  | 8m                   |  |                 |  |
| Plot Number                                       |  | 49 50 51 52 53 54 55 56           |  |  |  |  |  |  |  | 57 58 59 60 61 62 63 64                    |  |  |  |  |  |  |  | 65 66 67 68 69 70 71 72               |  |  |  |  |  |     |  | 20m                  |  |                 |  |
| Each plot 3m x 8m (sample area 2m x 7m)           |  |                                   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                       |  |  |  |  |  |     |  |                      |  |                 |  |
| Treatments:                                       |  | Seed bed prep                     |  |  |  |  |  |  |  | Seed mix                                   |  |  |  |  |  |  |  | Sowing rate                           |  |  |  |  |  |     |  | Rowden plot gate way |  | Okehampton Road |  |
| All seed beds sprayed before seed bed cultivation |  | Minimal cultivation: Power harrow |  |  |  |  |  |  |  | PC PRG & white clover                      |  |  |  |  |  |  |  | PC Conventional sowing rate           |  |  |  |  |  |     |  |                      |  |                 |  |
|   |  | Minimal cultivation: Disc harrow  |  |  |  |  |  |  |  | A Optimal mix A (lower diversity - 6 sp)   |  |  |  |  |  |  |  | PC+ Conventional sowing rate plus 50% |  |  |  |  |  |     |  |                      |  |                 |  |
|   |  | Ploughed                          |  |  |  |  |  |  |  | B Optimal mix B (higher diversity - 12 sp) |  |  |  |  |  |  |  |                                       |  |  |  |  |  |     |  |                      |  |                 |  |
|   |  |                                   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                       |  |  |  |  |  |     |  |                      |  |                 |  |
|   |  |                                   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |                                       |  |  |  |  |  |     |  |                      |  |                 |  |

**Table 2** - Plan of WP5 Trial at Rothamsted North Wyke



1. Control (2 species) 1G:1L - PRG & white clover (same as Duchy)
2. Intermediate mix A (6 species): 2G:2L:2F  
G: PRG, Timothy  
L: white clover, birdsfoot trefoil  
F: chicory, ribwort plantain
3. Intermediate mix B (12 species) 4G:4L:4F  
G: PRG, Timothy, Cocksfoot, Festulolium  
L: white clover, birdsfoot trefoil, red clover, lucerne  
F: chicory, ribwort plantain, yarrow, burnet
4. High diversity mix (18 species) 6G: 6L: 6F  
L: Red clover, White clover, Alsike clover, Lucerne, Sainfoin, Birdsfoot trefoil

G: Festulolium, Perennial ryegrass, Timothy, Cocksfoot, Meadow fescue, Meadow foxtail  
F: Ribwort Plantain (Tonic), Chicory, Burnet (S.minor), Yarrow, Selfheal, Sheeps parsley

### Measurements

Baseline seedbank samples and soil physical and chemical samples have been taken across the whole site before the establishment of the treatments. Vegetation assessments will be done in the autumn of 2018 followed by relative biomass and nutritional quality of the swards assessed for the first time in spring 2019.



**Figure 7** - Baseline seedbank samples from WP5 trial at Rothamsted North Wyke





# THE NETHERLANDS

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# EXPERIMENTAL TRIALS MANAGED BY WAGENINGEN UNIVERSITY & RESEARCH



*With its 700-plus hectares of agricultural land, Wageningen University and Research's experimental farm in Lelystad is the Netherlands' largest experimental centre for arable cropping systems. Wageningen Research's Field Crops department manages the farm and conducts on-farm research at this site. The department organizes field days where new crop varieties, equipment and practices are demonstrated to both national and international stakeholders. Its research focuses on all aspects of arable and vegetable field crops. Its overall goal is to design arable production*

*systems for both conventional and organic agriculture that meet production, environmental and societal goals. The main research topics are the introduction of new crops and varieties, economic and environmental impact, crop protection and weed management, soil management and health, and precision agriculture. A large part of the experimental farm is managed for the marketable production of arable crops and field vegetables. Its main crops are a reflection of the major Dutch arable crops: potatoes, sugarbeet, onions, carrots and cereals.*

**Address:****WUR Experimental Farm****Edelhertweg 1****8219 PH Lelystad – The Netherlands****GPS coordinates: 52°32'23.7"N 5°33'44.9"E****tel. +31 320 291111****Contact for visits of trial 1:****Joop Esselink****e-mail: [joop.esselink@wue.nl](mailto:joop.esselink@wue.nl)****tel. +31 320 291439****Contact for visits of trial 2:****Hilfred Huiting****e-mail: [hilfred.huiting@wur.nl](mailto:hilfred.huiting@wur.nl)****tel. +31 320 291339**

Two experiments are in place for the IWM PRAISE project:

1. Annual row crops - arable & vegetable crops
2. Annual row crops - maize

Integrated Weed Management (IWM) focuses on the management of weed populations on a timescale that extends the current growth season by impacting weeds in different stages of their life-cycle in one of the following ways:

- reducing seed rain;
- preventing establishment of weed seedlings;
- preventing seedlings from maturing.

Integrated Weed Management systems ideally combine several control tactics to impact weed life-cycle and, as a result, reduce crop-yield losses. However, the choice for farmers (and researchers) is which tactics to combine in order to ensure an efficient weed-management system is put in place. Each tactic may be successful for managing weeds on its own, but its effectiveness may vary when combined with others. We established a framework for Integrated Weed Management that can be applied to a range of cropping systems. It distinguishes between five classes, or pillars, of integrated weed management so that an informed decision can be made on what tactics to combine on a timescale that extends the current growth season. Successful IWM strategies will combine tactics from all or most of these five classes. This is the basis for our experiments.

- I. Diverse cropping systems
  - a. Diverse systems increase or equal crop yields or

profitability compared with conventional systems.

II. Suppressive/tolerant varieties

- a. Selecting weed-suppressive (or weed-tolerant) crops.
- i. Suppressive varieties will reduce weed-seed production, while tolerant varieties will maintain high yield levels under weed pressure but will not necessarily reduce weed pressure and may therefore lead to potentially higher weed-population levels.

III. Crop management, enhancing crop growth (nutrient placement, sowing depth, transplanting, tillage systems).

IV. Targeted control tactics to disturb weed life-cycles (e.g. flame weeding, biocontrol, targeted herbicide application, site specific).

V. Monitoring & evaluation (e.g. innovative sensing technologies and decision-support systems - DSS).

## ANNUAL ROW CROPS: ARABLE & VEGETABLE CROPS

In this experiment, we test the effects of two management strategies: a conventional four-year rotation based on targeted control with herbicides, and a diversified system using an eight-year rotation with optimal variety choice, targeted crop management, variable targeted control, and state-of-the-art monitoring and evaluation systems. The experiment has three replicates.

| Wageningen | year               | 2018         | 2019         | 2020         | 2021         | 2022         | 2023         | 2024         | 2025         |
|------------|--------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Plot       | length of rotation |              |              |              |              |              |              |              |              |
| 1          | 4                  | summerwheat  | potato       | seed onion   | sugarbeet    | summerwheat  | potato       | seed onion   | sugarbeet    |
| 2          | 4                  | seed onion   | sugarbeet    | summerwheat  | potato       | seed onion   | sugarbeet    | summerwheat  | potato       |
| 3          | 8                  | summerwheat  | potato       | grass clover | cabbage      | carrot       | potato1      | seed onion   | sugarbeet    |
| 4          | 8                  | grass clover | cabbage      | carrot       | potato1      | seed onion   | sugarbeet    | summerwheat  | potato       |
| 5          | 8                  | carrot       | potato1      | seed onion   | sugarbeet    | summerwheat  | potato       | grass clover | cabbage      |
| 6          | 8                  | seed onion   | sugarbeet    | summerwheat  | potato       | grass clover | cabbage      | carrot       | potato1      |
| 7          | 8                  | potato       | grass clover | cabbage      | carrot       | potato1      | seed onion   | sugarbeet    | summerwheat  |
| 8          | 8                  | cabbage      | carrot       | potato1      | seed onion   | sugarbeet    | summerwheat  | potato       | grass clover |
| 9          | 4                  | potato       | seed onion   | sugarbeet    | summerwheat  | potato       | seed onion   | sugarbeet    | summerwheat  |
| 10         | 4                  | sugarbeet    | summerwheat  | potato       | seed onion   | sugarbeet    | summerwheat  | potato       | seed onion   |
| 11         | 8                  | potato1      | seed onion   | sugarbeet    | summerwheat  | potato       | grass clover | cabbage      | carrot       |
| 12         | 8                  | sugarbeet    | summerwheat  | potato       | grass clover | cabbage      | carrot       | potato1      | seed onion   |

**Table 1** - Plots and cropping sequence





**Figure 1** - Location of experiment at the farm

#### LEGEND

|               |                                  |               |                         |
|---------------|----------------------------------|---------------|-------------------------|
| <b>Aa1 8-</b> | potato 8 year conventional       | <b>Aa1 8+</b> | potato 8 year iwm       |
| <b>Aa4-</b>   | potato 4 year conventional       | <b>Aa4+</b>   | potato 4 year iwm       |
| <b>Aa5 8-</b> | potato 8 year conventional       | <b>Aa5 8+</b> | potato 8 year iwm       |
| <b>Gk8-</b>   | grass clover 8 year conventional | <b>Gk8+</b>   | grass clover 8 year iwm |
| <b>Gr4-</b>   | summer wheat 4 year conventional | <b>Gr4+</b>   | summer wheat 4 year iwm |
| <b>Gr8-</b>   | summer wheat 8 year conventional | <b>Gr8+</b>   | summer wheat 8 year iwm |
| <b>Pn8-</b>   | carrot 8 year conventional       | <b>Pn8+</b>   | carrot 8 year iwm       |
| <b>Sb4-</b>   | sugarbeet 4 year conventional    | <b>Sb4+</b>   | sugarbeet 4 year iwm    |
| <b>Sb8-</b>   | sugarbeet 8 year conventional    | <b>Sb8+</b>   | sugarbeet 8 year iwm    |
| <b>Sk8-</b>   | cabbage 8 year conventional      | <b>Sk8+</b>   | cabbage 8 year iwm      |
| <b>Ui4-</b>   | onion 4 year conventional        | <b>Ui4-</b>   | onion 4 year iwm        |
| <b>Ui8-</b>   | onion 8 year conventional        | <b>Ui8-</b>   | onion 8 year iwm        |

## ANNUAL ROW CROPS: MAIZE AFTER MAIZE CROPPING SYSTEMS

In this experiment, we investigate the effects of four tillage systems on the weed population in a maize

monoculture. We test two varieties of maize: normal and short season. Two weed-management strategies are used: a herbicide-based system and a mechanical-control based one. The experiment has three replicates and covers 48 plots in total.

| I             |               |               |               | II            |               |               |               | III           |               |               |               |
|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| A             | D             | E             | C             | A             | D             | E             | C             | A             | D             | E             | C             |
| 19<br>M2 - I  | 30<br>M2 - I  | 50<br>M2 - II | 57<br>M1 - II | 19<br>M2 - I  | 30<br>M2 - I  | 50<br>M2 - II | 57<br>M1 - II | 19<br>M2 - I  | 30<br>M2 - I  | 50<br>M2 - II | 57<br>M1 - II |
| 18<br>M2 - II | 28<br>M2 - II | 49<br>M2 - I  | 56<br>M1 - I  | 18<br>M2 - II | 28<br>M2 - II | 49<br>M2 - I  | 56<br>M1 - I  | 18<br>M2 - II | 28<br>M2 - II | 49<br>M2 - I  | 56<br>M1 - I  |
| 15<br>M1 - II | 23<br>M1 - II | 44<br>M1 - I  | 53<br>M2 - I  | 15<br>M1 - II | 23<br>M1 - II | 44<br>M1 - I  | 53<br>M2 - I  | 15<br>M1 - II | 23<br>M1 - II | 44<br>M1 - I  | 53<br>M2 - I  |
| 11<br>M1 - I  | 21<br>M1 - I  | 43<br>M1 - II | 51<br>M2 - II | 11<br>M1 - I  | 21<br>M1 - I  | 43<br>M1 - II | 51<br>M2 - II | 11<br>M1 - I  | 21<br>M1 - I  | 43<br>M1 - II | 51<br>M2 - II |

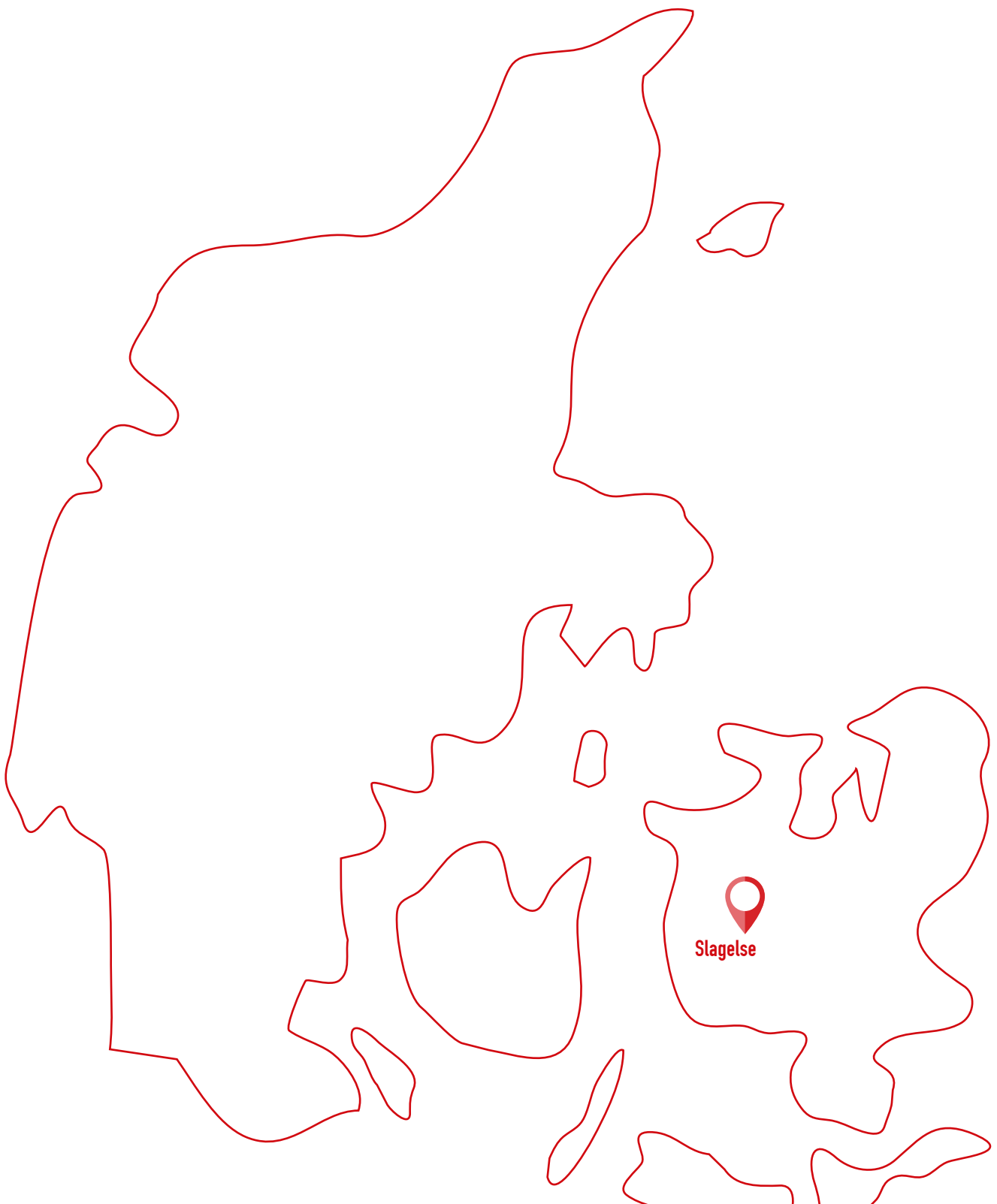
**Table 2** - Maize trial layout

| Code | Description               |                          |                       |                             |
|------|---------------------------|--------------------------|-----------------------|-----------------------------|
|      | Main cultivation          | Sowing bed preparation   | Sowing method         | Remarks                     |
| A    | Plough Spring 25 cm       | Rotary harrow            | Standard sowing       | -                           |
| C    | Deep tine cultivation     | Rotary cultivator        | Standard sowing       | -                           |
| D    | Strip rotary cultivation  | Strip rotary cultivation | Strip sowing          | -                           |
| E    | Deep tine cultivation     | None (direct sowing)     | Direct sowing         | -                           |
|      | Cultivar type             | Cultivar                 | Sowing time           | Harvest time                |
| M1   | Normal cultivation length | P8057 (Pioneer)          | Normal (1st week May) | Normal (end Sep. early Oct) |
| M2   | Short season maize        | Joy (DSV)                | Late (4th week May)   | Normal (end Sep. early Oct) |
|      | Weed control              |                          |                       |                             |
| I    |                           | Conventional             | No cover crop         |                             |
| II   |                           |                          | Mechanical            | No cover crop               |



# DENMARK

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# EXPERIMENTAL TRIALS MANAGED BY AARHUS UNIVERSITY



*The Department of Agroecology at Denmark's Aarhus University is located south of Slagelse on the island of Sjælland. It carries out research into "agroecology", namely the interaction between plants, animals, humans and the environment within agroecosystems for the production of food, feed, energy and bio-based products. The department contributes to sustainable production and growth via research, consultation and teaching. Its experimental area covers approximately 200 ha and is primarily farmed conventionally, although some fields are devoted to organic trials. The soil is a sandy loam with limited organic matter. The weed populations are mainly broadleaved with some grassweeds, such as perennial ryegrass (*Lolium*), blackgrass (*Alopecurus*), silky bent grass (*Apera spica-venti*) and annual meadow grass (*Poa annua*).*



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Arable farming in Denmark is among the most intensive in the world, as its agricultural area accounts for approximately 61% of the entire country. In recent years, large structural changes have taken place, with the number of farms decreasing and more and more hectares being managed by one farm manager. In 2015, the average size per holding was 72 ha, but the average farmed unit was considerably larger due to the common leasing of land. Furthermore, farms are heavily specialized, with the following farm types being dominant:

- farms rearing pigs and a focus on rotations with cereals and oilseed rape;
- farms with dairy production and a focus on grass/clover, maize, fodder beets, and cereals with undersown grass/clover;
- farms not rearing animals, but specialized in crop production, e.g. economic focus on grass seeds, potatoes, sugar-beet or specialty seed production.

It should, however, be noted that several different combinations of the above exist. Dairy production is concentrated in western Denmark (Jutland), while sugar-beet production takes place almost entirely in southern Zealand and the southern isles, Lolland and Falster. Grass-seed is grown all over Denmark, but production of “fine grasses” is concentrated on Zealand.

For 2014-2018, the average agricultural area in Denmark was 2.63 million hectares, and the major crops were:

| Crop / Group                    | x1000 hectares | % of agricultural area |
|---------------------------------|----------------|------------------------|
| Winter wheat                    | 559            | 21                     |
| Winter cereals total            | 789            | 30                     |
| Spring barley                   | 570            | 22                     |
| Spring cereals total            | 656            | 25                     |
| Cereals total                   | 1445           | 55                     |
| Winter oilseed rape             | 168            | 6                      |
| Maize for silage                | 178            | 7                      |
| Potatoes                        | 46             | 2                      |
| Sugar-beet                      | 33             | 1                      |
| Grass and clover for seed prod. | 81             | 3                      |
| Grassland in rotation           | 276            | 11                     |
| Permanent pasture/grassland     | 225            | 9                      |
| Total agricultural area         | 2629           | 100                    |

**Table 1 - Major crops in Denmark**

The challenges for traditional chemical weed management in Denmark include:

- a strong focus on groundwater protection leading to one of the world's strictest registration regimes;
- the relatively low number of available active ingredients;
- the restrictions on use rates for many crops;
- Danish pesticide taxes, which are the highest in the world.

Danish arable farmers depend heavily on herbicides belonging to a few modes of action. Herbicide resistance, however, is an increasing concern and one of the main reasons that farmers become interested in IPM, and IWM in particular.

The use of IWM in cereal production is currently focusing on diversifying crop rotations (a challenge, given that most farms are very specialized), careful choice of sowing time for cereals, increased seed rates, competitive cultivars, stale seed beds etc. Mechanical weed management in cereals is an interesting option for the future, but is currently only used on organic farms or on rented public lands where restrictions for pesticide use apply.

About 85-90% of Denmark's agricultural land is ploughed annually, but many farms show interest in adopting reduced tillage regimes, including conservation agriculture. Due to action plans to reduce the amount of nitrogen leaching into drainage water and ground water, undersown catch crops are grown on a significant part of the area, and there is a ban on any cultivation in early autumn where spring sown crops are going to be grown next year.

The WP3 demonstration trial in winter wheat addresses some of these focus areas.

For crops grown in wider rows, mechanical weed management (inter-row hoeing) is already used to a large extent in maize (primarily grown for silage) and to some extent in potatoes. In these regimes, mechanical methods are often used in combination with one or two blanket applications of herbicides (or banded herbicide application) and in maize they are widely combined with use of undersown catch crops. For sugar-beet, there is currently renewed interest in inter-row hoeing combined with banded application of herbicides, as there are restrictions on the total dose per season of all registered active ingredients. The WP4 demonstration trial was designed to address some of these challenges.

## WP3 – EXPERIMENTAL TRIALS ON WINTER WHEAT

### Objectives

The main objective is to combine management practices with strategies for winter-wheat cropping, which is designed to limit the germination of weeds and inhibit emergence and growth, thus contributing to a reduced dependence on herbicides. To demonstrate the effect of soil tillage, the trial comprises both no-till and ploughed strategies. The focus is on combinations of sowing time and direct management practices.

### Materials and methods

A one-year trial was established at Aarhus University in Flakkebjerg for demonstration purposes. It includes strategies with no-till and others with conventional

ploughing, as well as various levels of herbicide application combined with mechanical weeding. The aim is to lower herbicide application to a minimum by optimizing crop establishment and growing conditions.

Five alternative strategies were established and arranged in wide strips, with a standard strategy in the middle for comparison; two of the strategies were no-till, and three were ploughed conventionally. The management practices, which varied in each strategy, include soil preparation, sowing time, row width depending on weeding strategy, herbicide application, and mechanical weeding. In order to facilitate mechanical weeding in Strategy 4 and Strategy 6, the crop was sown in wider rows. The no-till strategies were sown in wider rows as well due to the sowing equipment used. Fertilizer application and variety selection was the same across all strategies. Fertilizer was broadcast, and the winter-wheat variety

|                    | Strategy 5<br>6 m   | Strategy 3<br>6 m   | Strategy 1<br>5 m   | Strategy 2<br>5 m  | Strategy 4<br>5 m   | Strategy 6<br>5 m                                 |
|--------------------|---|---|---|--|---|---|
|                    | No-till direct sowing<br>Higher risk  | No-till direct sowing<br>Moderate risk  | Reference/standard  | Ploughing<br>similar to standard                                     | Ploughing<br>Higher risk  | Ploughing<br>No herbicides                        |
| Soil tillage       | Straw harrow<br>Direct drilling   | Straw harrow<br>Direct drilling   | Ploughed  | Ploughed same timing as<br>Strategy 1                                | Ploughed same timing<br>as Strategy 1                               | Ploughed same timing<br>as Strategy 1             |
| Sowing time        | Late sowing<br>normal + 20 days   | Late sowing<br>normal + 20 days   | Normal sowing time<br>(planned 15.–20. sept.)<br>Real 28. sept.   | Late sowing<br>normal + 20 days                                      | Late sowing<br>normal + 20 days                                     | Late sowing<br>normal + 20 days                   |
| Seeding density    | Higher than standard<br>due to later sowing   | Higher than standard<br>due to later sowing   | Reference/standard  | Higher than standard<br>due to later sowing                          | Higher than standard<br>due to later sowing                         | Higher than standard<br>due to late sowing        |
| Row width          | Wide rows<br>18 cm<br>Horsch  | Wide rows<br>18 cm<br>Horsch  | Standard row<br>12 cm   | Standard row<br>12 cm  | Wide rows<br>20 cm<br>Kongsilde sowing<br>machine                   | Wide rows<br>20 cm<br>Kongsilde sowing<br>machine |
| Herbicides         | Glyphosate before<br>sowing, same timing<br>in str. 3+5<br><br>Need-based herbicide<br>application spring | Glyphosate before<br>sowing, same timing<br>in str. 3+5<br><br>No herbicide<br>application spring | Standard herbicide<br>application autumn<br><br>Need-based spring | Standard herbicide<br>application autumn<br><br>No herbicides spring | Reduced herbicide<br>application autumn<br><br>No herbicides spring |   |
| Mechanical weeding | -   | -   | -   | -  | Row cultivation<br>in spring  | Row cultivation<br>in spring<br>Tine harrow       |

Straw chopped and left in field before trial was established

Ploughing in the same direction as the strategy strips to avoid driving in the no-till strips

Seeding density and row width is the same in all strategies

Standard fungicides application and insecticides as needed

Standard fertilizer in all strategies

**Table 2 - WP3 experimental layout**



**Figure 1** - Plots of WP3 trials

Sheriff was chosen as it is disease-tolerant with good competitive characteristics and potentially high yield. In no-till strategies, glyphosate was applied prior to sowing and no other autumn application of herbicides was carried out. Herbicide application for ploughed strategies included autumn application (prosulfocarb, diflufenican and pendimethalin in autumn 2017) combined with need-based spring application, or no spring application. In Strategy 4 and Strategy 6, mechanical weeding is planned for spring treatment.

### Results

The trials were established in autumn 2017 under difficult conditions due to repeatedly intense rain. Three sowing dates were initially planned, with a delay of 10 and 20 days respectively. The weather conditions resulted in the standard sowing date being postponed for 10-15 days, and the first sowing was conducted on 28 September. Delayed sowing was then conducted approximately 20 days later, as stated in the table. This resulted in smaller differences between the strategies than planned. Sowing was fairly successful, however the no-till strategies suffered from sub-optimal soil conditions and the establishment of the crop appeared somewhat scattered in late autumn. In spring 2018, weather conditions were cold with some bare frost on the area.

### Further development

Next season's trial will again focus on sowing time combined with different levels of herbicide application and mechanical weeding; it is hoped that the sowing dates can be successfully differentiated in accordance with the plan. Other practices are being considered for the following year's demonstration trials, including camera-guided weeding, preceding cover crops, and weed management in preceding stubble. The strategies will be based on this year's trial, experiences from other trials, and the analysis of stakeholder interest from



**Figure 2** - Direct sowing in stubbles with Horsch sowing machine 18 cm rows

Work Package 1 of this project, whereby farmers are interviewed about their practices and visions for weed management.

## WP4 - EXPERIMENTAL TRIALS ON SUGAR BEET

### Objectives

The main objective is to combine management practices with strategies for sugar-beet cropping, which is designed to limit the germination of weeds and inhibit emergence and growth. Various combinations of mechanical weeding and herbicide application are demonstrated, including band spraying. Furthermore, an ALS-tolerant sugar-beet variety is included in a strategy with band spraying.

### Materials and methods

A one-year trial will be established in spring 2018 at the Aarhus University research station in Flakkebjerg for demonstration purposes. In sugar beet, several herbicide applications with herbicide mixtures are the standard weed management. Between-row harrowing is, however, commonly used by many farmers. In order to lower the herbicide application to a minimum, further inclusion of mechanical weeding is necessary.

Three alternative strategies were established and arranged in wide strips with a standard strategy for comparison; two involved reduced herbicide application and one ALS-tolerant sugar beets. The management practices, which vary for each strategy, include band spraying, weed harrowing between rows, and false seedbed plus flaming before sowing.

### Further development

Next season's trial will again focus on band spraying combined with various levels of herbicide



application and mechanical weeding. Furthermore, pattern-seeding allowing for weed harrowing in two directions is being considered. Inter-row flaming tools may be included in the coming seasons, depending on how they develop. The strategies will be based on the first year's trial, experiences from other trials, and the analysis of stakeholder interest from Work Package 1 of this project, whereby farmers are interviewed about their practices and visions for weed management.



**Figure 3** - Plots of WP4 trials

|                    | Strategy 1<br>6 m                               | Strategy 2<br>6 m  | Strategy 3<br>6 m  | Strategy 4<br>6 m  |
|--------------------|---|--|--|--|
|                    | Reference/standard                              | Band spraying High + weed harrow                                       | Band spraying Low + weed harrow  | Conviso SMART  |
| Soil tillage       | Ploughed  | Ploughed   | Ploughed, False seed bed + flaming.                                    | Ploughed   |
| Sowing time        | Normal sowing time                              | Normal sowing time   | Sowing delayed   | Normal sowing time   |
| Variety            | Fairway, Maribo Seed                            | Fairway, Maribo Seed   | Fairway, Maribo Seed   | CONVISO® SMART ALS-tolerant  |
| Herbicides         | Standard herbicide application 3-4 applications | Band spraying with conventional sugar beet herbicides 3-4 applications | Band spraying with conventional sugar beet herbicides 1-2 applications | CONVISO One band spraying adjusted to 1 l/ha in row corresponding to approx. 0.2 l/ha on field average |
| Mechanical weeding | -   | Between row harrowing  | Between row harrowing and in-row finger wheel                          | -  |

Straw chopped and left in field before trial was established

Ploughing in the same direction as the strategy strips to avoid driving in the no-till strips

Seeding density and row width is the same in all strategies

Standard fungicides application and insecticides as needed

Standard fertilizer in all strategies

**Table 3** - WP4 experimental layout

