Integrated Weed Management: PRActical Implementation and Solutions for Europe

# EXPERIMENTAL TRIALS IN EUROPE

## 2020 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

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

***Authors:***
Irache Garnica (INTIA - Instituto Navarro de Tecnologias e Infrastructuras Agroalimentarias)
Juan Antonio Lezaun (INTIA - Instituto Navarro de Tecnologias e Infrastructuras Agroalimentarias)
José Luis González-Andújar (CSIC - Instituto de Agricultura Sostenible)
Verónica Pedraza Jimenez (CSIC - Instituto de Agricultura Sostenible)
Daniele Antichi (Centre for Agri-environmental Research "Enrico Avanzi", University of Pisa)
Christian Frasconi (Centre for Agri-environmental Research "Enrico Avanzi", University of Pisa)
Stefano Carlesi (Institute of Life Sciences - Scuola Superiore Sant'Anna, Pisa)
Mariateresa Lazzaro (Institute of Life Sciences - Scuola Superiore Sant'Anna, Pisa)
Federico Leoni (Institute of Life Sciences - Scuola Superiore Sant'Anna, Pisa)
Anna Camilla Moonen (Institute of Life Sciences - Scuola Superiore Sant'Anna, Pisa)
Dylan Warren Raffa (Institute of Life Sciences - Scuola Superiore Sant'Anna, Pisa)
Valentina Mastretta (Horta srl)
Matteo Ruggeri (Horta srl)
Donato Loddo (Institute for Sustainable Plant Protection - National Research Council of Italy)
Robert Leskovšek (AIS - Agricultural Institute of Slovenia)
Andrej Vončina (AIS - Agricultural Institute of Slovenia)
Julie Klötzli (Agroscope)
Andreas Lüscher (Agroscope)
Urs Schaffner (Agroscope)
Matthias Suter (Agroscope)
Ludovic Bonin (ARVALIS - Institut du végétal)
Anne Brunet (Chambre régionale d'agriculture Centre-Val de Loire)
Dominique Tozza (Chambre régionale d'agriculture d'Ile de France)
Daniel Hewitt (NIAB)
Julien Lecourt (NIAB)
Andrew Dawson (Wageningen University & Research)
Hilfred Huiting (Wageningen University & Research)
Marleen Riemens (Wageningen University & Research)
Sjoerd Rombout (Wageningen University & Research)
Bo Melander (Department of Agroecology - Aarhus University)
Mette Sønderskov (Department of Agroecology - Aarhus University)
Jens Erik Jensen (SEGES Landbrug & Fødevarer F.m.b.A.)

***Graphic layout:***
Danilo Calderaro (JDW)

***Editors:***
Antonio De Zanche (Veneto Agricoltura)
Francesca Chiarini (Veneto Agricoltura)

***Language consultant:***
Andrew Bailey

***Publisher:***
Veneto Agricoltura - Agenzia veneta per l'innovazione nel settore primario
Sezione Ricerca e Gestioni Agro-Forestali, Direttore Giustino Mezzalira
Settore Ricerca Agraria, Dirigente Lorenzo Furlan
Viale dell'Università, 14 - 35020 Legnaro (PD) - Italy
tel. +39 049 8293711 - fax +39 049 8293815
e-mail: info@venetoagricoltura.org
www.venetoagricoltura.org

# EXPERIMENTAL TRIALS IN EUROPE

## 2020 EDITION

IWMPRAISE

# CONTENTS

# The IWMPRAISE project

Integrated Weed Management: PRActical Implementation and Solutions for Europe

## Participating Countries

| | |
|---|---|
| Denmark | Spain |
| France | Switzerland |
| Italy | The Netherlands |
| Slovenia | United Kingdom |

## Partners

**Integrated weed management is the future**

Integrated weed management (IWM) is the way forward for sustainable and resilient agriculture. IWMPRAISE 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 € 6.6 M and aims to support and promote 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.

By adopting this categorical approach, it will be possible to establish principles and develop IWM strategies that can be applied beyond 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).

The IWMPRAISE workgroup

The project aims to demonstrate that IWM supports more sustainable cropping systems that are resilient to external impacts and do not jeopardize 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.

**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 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

# EXPERIMENTAL TRIALS IN SOUTHERN SPAIN


*The Institute for Sustainable Agriculture in Córdoba, a centre 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.*


**Address:**
**Cooperative "Virgen del Campo"**
**2, Molino Street**
**Cañete del las Torres - 14660 Córdoba - Spain**
**GPS coordinates: 37°52'02.4"N 4°19'17"W**

**For further information and guided visits please contact:**
**José Luis González and Verónica Pedraza**
**e-mail: vpedraza@ias.csic.es**
**tel. +34 957 49 92 55**

# 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, and 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.*


**Address:**
22, Serapio Huici Ave. (Edificio de Peritos)
Villava - 31620 Navarra - Spain
GPS coordinates: 42°49'43.7"N 1°36'46.2"W

**For further information and guided visits please contact:**
Juan Antonio Lezaun and Irache Garnica
e-mail: igarnica@intiasa.es
tel. +34 948 01 30 40

Spain is the country with the largest olive growing area in the world (2.5 million ha) (MAPA, 2017a). Andalusia, the southernmost region of Spain, has the largest extension with 1,596,717 ha, mainly concentrated in the provinces of Jaén (582,497 ha) and Córdoba (351,692 ha) (CAPDR, 2017). Nevertheless, regions of northern Spain, such as Navarra, have seen their olive grove areas undergo great expansion in recent years and currently they have 8,446 ha (MAPA, 2017a).

Given the broad geographical area that olive orchards cover, soil and weed management decisions are significantly influenced by location, climatic conditions, soil, topography and grower preferences (Huqi *et al.*, 2009). However, olive groves in Córdoba and Navarra carry out similar weed management strategies despite their geographical distance and different weather conditions.

Soil management techniques in olive groves have always aimed to promote high profitability and quality production, and weed control is of key importance to prevent weeds competing with olive trees for water and other mineral resources (Saavedra *et al.*, 2015). The most-used soil management systems are tillage, spontaneous cover crops and no-tillage with application of herbicides (MAPA, 2017b). Moreover, a combination of these practices is often used on farms, since most of the olive orchards have two distinct areas: soil beneath the olive trees, which facilitates harvesting, and soil along the lanes (intra-row and inter-row spacing), where soil compaction and susceptibility to greater runoff and erosion will influence the system chosen (CAP, 2006). Tillage continues to be the most-used soil management system in inter-row spacing, although this practice causes the greatest soil loss (Gomez *et al.*, 2009). However, adoption of conservation agriculture (CA) minimizes the disruption of the soil's structure, composition and natural biodiversity, thereby reducing erosion and degradation, as well as fuel consumption (Holland, 2004). CA is based on tillage reduction, continuous soil cover by crop residues, and cover crops in perennial woody crops (Abu-Irmaileh and Abu-Rayyan, 2004). Reduced tillage involves ploughless tillage at 10-15 cm depth, and no tillage occurs with no soil movement in the inter-row and intra-row spacing, both of them using chemical weed control and leaving pruning wood residues on the soil surface after harvesting (minimum 30% soil cover). Cover crops protect soil against erosion by wind and water (Alcántara *et al.*, 2011), facilitate water infiltration and water accumulation (Cucci *et al.*, 2016). Consequently, they can improve soil structure, soil organic matter (Kuo *et al.*, 1997) and soil nitrogen (Perdigao *et al.*, 2012). However, they need to be adapted to local farm conditions and their successful establishment in olive orchards requires careful management and control, to reduce not only the likelihood of pests and diseases appearing (Martinelli *et al.*, 2017) but also to control weeds by reducing herbicide use (Abu-Irmaileh and Abu-Rayyan, 2004).

Application of integrated weed management (IWM) in olive orchards is designed to reduce negative impacts on soil and production while maintaining beneficial flora at an affordable and manageable threshold (Huqi *et al.*, 2009). Therefore, a proper IWM should not only take into account the efficacy of weed control, but also how these practices affect the weed population, the crop and the agro-ecosystem (Fracchiolla *et al.*, 2016). According to the IWMPRAISE goals, the study of perennial woody crops in Spain aims to develop, test and assess sustainable and cost-effective IWM strategies for olive orchards in order to reduce their dependence on chemical weed control without jeopardizing profitability or the steady supply of food, feed and biomaterials. The specific objectives are to evaluate the effects of different IWM practices on 1) the installation and development of weeds; 2) the soil; and 3) crop yields and quality.

## Materials and methods

During the 2018/2019 and 2019/2020 growing seasons, two IWM strategies commonly used by farmers were evaluated, both using inter-row and intra-row spacing as sampling areas. Strategy 1 includes 'tillage' combined with pruning wood residues in both sampling areas of southern Spain and 'no tillage with chemical control' in both areas of northern Spain (Figure 1.a and 1.c respectively). Strategy 2 in both locations includes 'no tillage with chemical control' in the intra-row spacing and 'cover crops' in the inter-row spacing during the first year (Figure 1.b and 1.d respectively). The cover crops comprise spontaneous grass species (*Bromus spp.*, mainly *Bromus madritensis*) in an inter-row spacing 2 m wide in southern Spain. Killing methods are not necessary because the cover crop dries naturally in late April-early May each year. In northern Spain, the sown cover crop is composed of spontaneous species and white mustard (*Sinapis alba*) and it is killed by mechanical mowing in May.

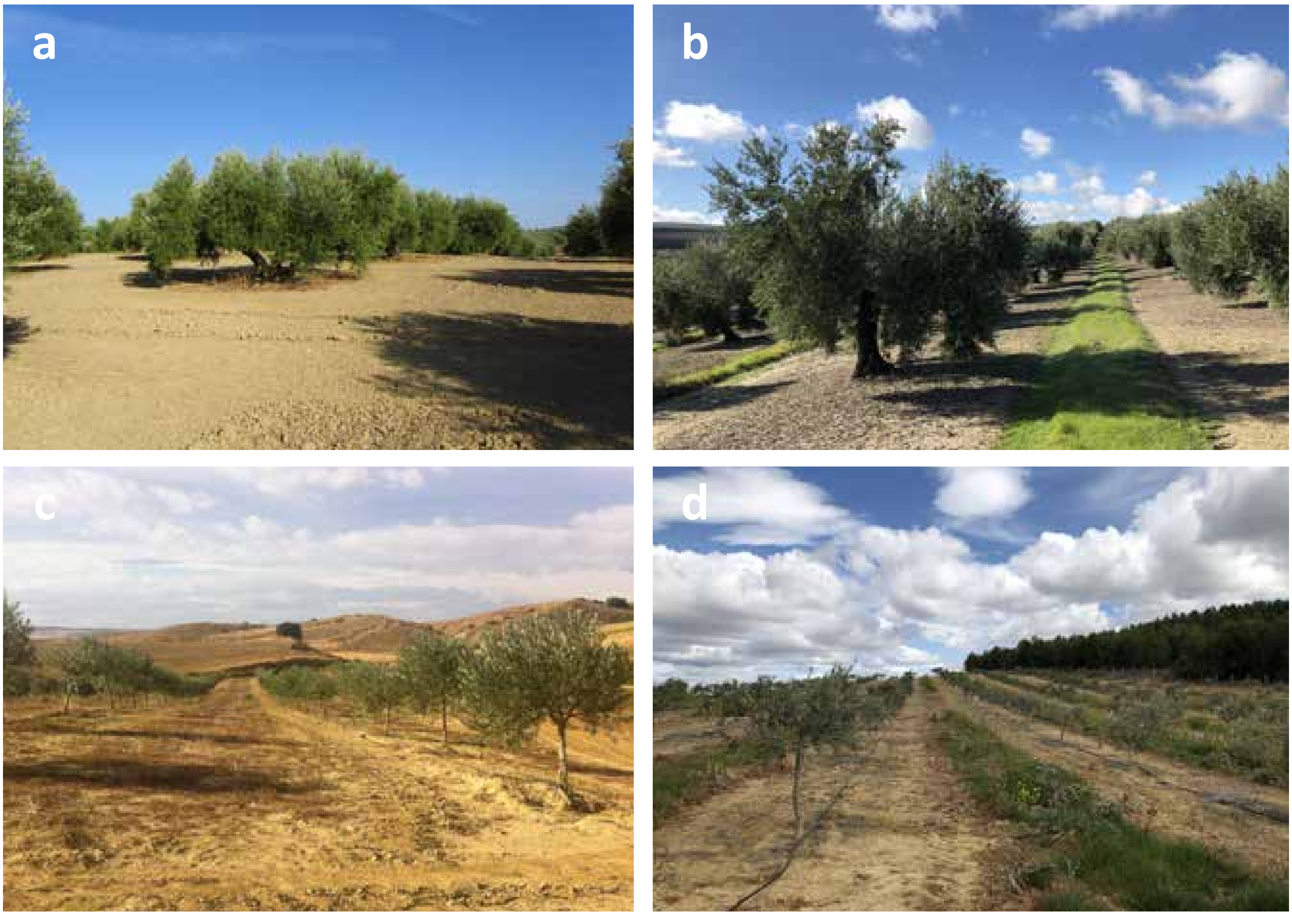



Figure 1.a, 1.b, 1.c and 1.d - Tillage (a) and spontaneous grass cover crops (b) in southern Spain; no tillage with chemical control (c) and crucifer cover crops (d) in northern Spain

### Experimental design

The treatments were evaluated from September to April at both locations in a randomized complete block design with four replications per strategy. Two different fields with silty-loam and clay soils were selected for each IWM strategy in southern Spain and one field with silty clay loam soils in northern Spain. The total sampling area is 8,448 $m^2$ in the south (2,112 $m^2$ per field) and 3,432 $m^2$ in the north of Spain. A detailed description of each strategy is shown in Table 1.

### Assessments

Weeds are evaluated at two different moments: December-February, before applying the two weed control methods and February-April, 3-4 weeks after applying the control methods (hereafter 'pre-control' and 'post-control' respectively). The main assessments include:

- **Weed data collected in the inter-row and intra-row spacing: plant density, ground cover, height, biomass production and phenological growth stage.** Additionally, the weed species diversity during the growing season 2018/2019 was calculated from plant density data in southern Spain using the indices: species richness (S), the exponent of the Shannon-Wiener index (expH') and Pielou eveness index (J').
- **Cover crops in the inter-row spacing:** ground cover, height and phenological growth stage.
- **Olive yield** (kg/ha) **and quality** (oil content, fruit moisture, fat content and acidity).
- **Soil analyses:** eight soil fertility samples (N, P, K, OM and organic C) per field are extracted from 0-30 cm depth during autumn in southern Spain (four soil samples in the north), each of which consisted of two sub-samples from two positions located in a fixed pattern across each sampling area and block.
- **Weather data:** weather data are obtained from Weather Stations located from a distance less than 20 km and 10 km from the experimental area in southern and northern Spain respectively.

| | | South of Spain (CSIC) | | North of Spain (INTIA) | |
|---|---|---|---|---|---|
| | | Strategy 1 | Strategy 2 | Strategy 1 | Strategy 2 |
| **Treatments (2 sampling areas)** | **Inter-row spacing** | TILLAGE + Pruning wood residues | Grass cover crops (*Bromus* spp) | NO TILLAGE with chemical control | Crucifer cover crops (*Sinapis alba*) and spontaneous species |
| | **Intra-row spacing** | | No tillage with chemical control + Pruning wood residues | | No tillage with chemical control |
| **Field trials details** | **Collaboration** | Farmers of the cooperative 'Virgen del Campo' in Cañete de las Torres (Córdoba) | | Farmers collaborating with INTIA (Larraga, Navarra) | |
| | **Plot size** | Distance between 5 trees: 528 (11×48) $m^2$ | | Distance between 6 trees: 429 (13×33) $m^2$ | |
| | **Planting pattern** | 10 × 10 m | | 6.5 × 5.5 m | |

**Table 1** - Field trial details in southern and northern Spain

**First-year study in southern Spain (CSIC field trials)**

**Composition of weed flora** in the inter-row and intra-row spacing during the pre-control surveys identified 20-21 weed species in fields with Strategy 1 (hereafter Tillage 'TL') and 29 species in Strategy 2 (hereafter Cover Crops 'CC'), representing 13-14 botanical families where the most abundant families were *Asteraceae* and *Poaceae*. A clear effect of Strategy CC on weed species diversity was observed during the 2018/2019 growing season, as it showed greater richness (Figure 2.a) and more diverse flora than TL (Figure 2.b). Moreover, the Pielou index (J') values (close to zero) were lower in TL fields than in CC ones, with TL showing the least evenness between the species and the presence of a dominant species (Figure 2.c). After weed control, only grass

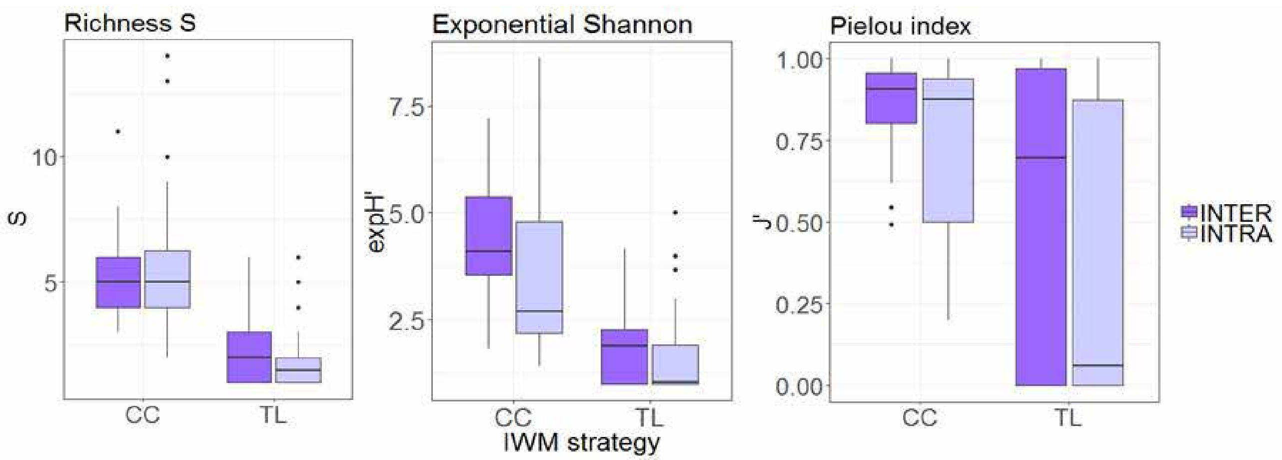



**Figure 2** - Effect of the Strategy Tillage (TL) and Cover Crops (CC) on weed species richness (left), weed diversity (center) and weed species eveness (right)

weeds (*Bromus spp.*) were identified in TL fields, while CC fields showed 21 species. Therefore, weed richness and diversity were low in all the CC fields and practically zero in TL ones (data not shown).

**Plant density** (Figure 3) and **biomass** (Figure 4) in southern Spain showed that there were no significant differences between IWM strategies during the pre-control sampling date. However, plant density and biomass values were observed to be higher in absolute terms in CC than in TL, especially in the intra-row spacing (bare soil), so the observed variations could be due to a large number of interacting processes, each of them being influenced by the weather conditions and the specific factors of each of the four sampled fields.

During the post-control sampling date, scarce weed density and biomass were observed in both IWM strategies and sampling areas, especially in the TL fields (Figures 3 and 4 respectively). It is most likely that this due to the effects of weed control (herbicide applications and tillage operations), but results may also have been influenced by the weather conditions, since the accumulated mean monthly rainfall from January to March 2019 did not exceed 30 mm. The applied post-emergent herbicides reduced weed density from 24-25 to 7-10 pl/m², but resulted in higher weed dry weights than during the pre-control sampling date (5 g/m² vs 2-4 g/m²). In the inter-row spacing, most perennial weeds were effectively controlled by the post-emergence broad-leaf herbicides applied, but annual weeds, such as *Cerastium glomeratum, Galium aparine or Erodium malacoides*, were not effectively controlled and thus dominated this area. In the intra-row spacing, *Bromus madritensis, Malva sylvestris, Erodium malacoides or Lysimachia arvensis*

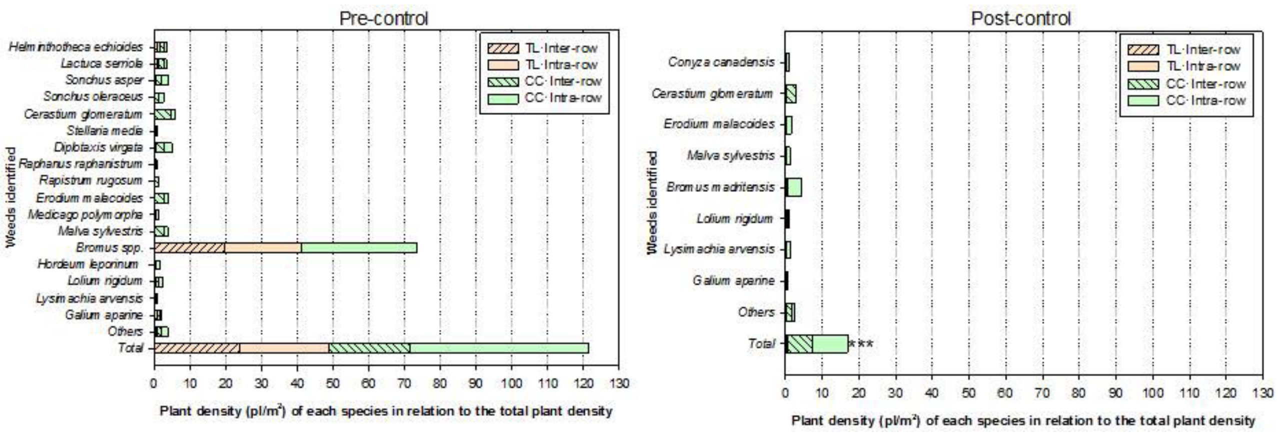



**Figure 3** - Plant density (pl/m²) of each weed species identified in relation to the total plant density in each sampling area using IWM strategies during the pre-control and post-control sampling date. Only significant differences over total plant density are shown (Pearson's Chi-squared test): * p <0.05, ** p <0.01 and *** p <0.001

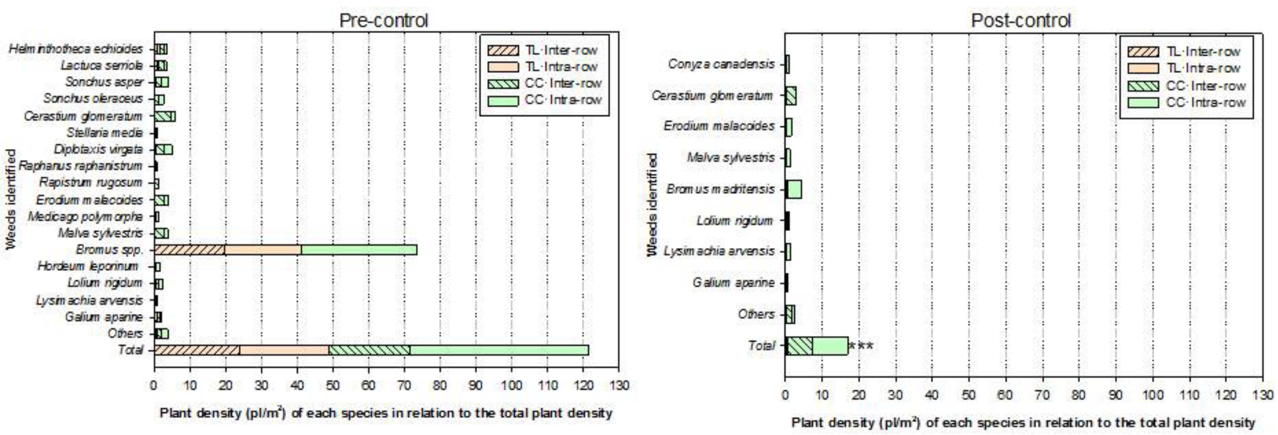



**Figure 4** - Weed dry biomass (g/m²) in each sampling area using IWM strategies at two different sampling dates. Only significant differences are shown (Pearson's Chi-squared test): * p <0.05, ** p <0.01 and *** p <0.001

and *Conyza canadensis* were not eliminated by the application of glyphosate+fluroxypyr or glyphosate respectively.
Despite the weeds and cover crops in CC fields, there were no reductions in **olive yield** (Figure 5) and **quality** (Table 2). According to our results, similar olive yields were obtained in both TL and CC fields (5,695 and 6,293 kg/ha respectively).

Moreover, the different IWM strategies did not induce differences in terms of olive fruit quality in any of the parameters measured. Nevertheless, the variations observed between fields showed that Field CC4 displayed the highest yield (followed by Field TL1), with it also having the greatest fruit oil content, the lowest humidity, and the highest acidity (followed by Field TL3) in absolute terms. Fruit oil content is taken into account when calculating payment to growers, and their values were 21% and 20.5% in TL and CC fields respectively. Fruit moisture showed water content of 47% and 49% respectively, and fat content, which is paramount for knowing when the fruit will ripen since it is not influenced by water content, was around 39-40%. Finally, acidity value is also a key parameter as it provides a reference for oil quality, with it being 0.39% and 0.43% for TL and CC fields respectively.
Soil management techniques can also influence soil, and our results showed that Strategy **CC** displayed higher organic N content than Strategy TL (0.10% vs. 0.08%) (Table 3). Although OM, K, P, total carbonates, active lime and pH were not affected by the farmers' 'IWM strategy', higher OM, K and P values were observed in absolute terms near the soil surface in Strategy CC.

## Conclusions

Results from first-year trials in southern Spain have shown that Strategy CC (Cover Crops+No Tillage with chemical control and pruning residues) displayed a greater weed diversity than Strategy TL (pre-emergence chemical control+tillage), as well as a higher weed density and biomass after the control treatment. Moreover, there were no effects on olive yield and quality values, with the existence of cover crops and olive pruning residues improving soil organic N content. Therefore, our results provide positive indications for the use of this IWM strategy under conditions in southern Spain and form a basis for further research on the optimization of this system. Soil conservation is crucial in semiarid regions where soil cover is not frequent, but necessary for erosion control. Although our study presented no data on soil erosion under the treatment conditions, soil protection

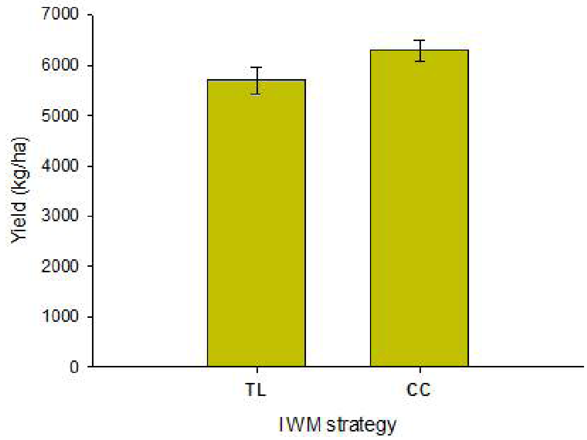



**Figure 5** - Olive yield (kg/ha) in the different IWM strategies. Vertical bars represent standard errors. Only significant differences are shown (Pearson's Chi-squared test): * p <0.05, ** p <0.01 and *** p <0.001

| | TL | CC |
|---|---|---|
| **Fruit oil content** | 21.03 | 20.48 |
| **Fruit moisture** | 46.97 | 48.54 |
| **Fat content** | 39.22 | 39.83 |
| **Acidity** | 0.39 | 0.43 |

**Table 2** - Olive fruit quality parameters evaluated: fruit oil content, fruit moisture, fat content and acidity (%) for the different IWM strategies

| | TL | CC |
|---|---|---|
| **N (%)** | 0.08 | 0.10 |
| **OM (%)** | 1.21 | 1.64 |
| **K (ppm)** | 363 | 415 |
| **P (ppm)** | 5.34 | 5.93 |
| **Total carbonates (%)** | 33.08 | 31.62 |
| **Active lime (%)** | 12.72 | 12.52 |
| **pH** | 8.46 | 8.39 |

**Table 3** - Soil fertility parameters evaluated in the 0-30cm profile: organic nitrogen content 'N' (%), organic matter 'OM' (%), potassium 'K' (ppm), phosphorus 'P' (ppm), total carbonates (%), active lime (%) and pH for the different IWM strategies

was assumed to be based on coverage values, with effective ground cover being ≥ 50%. Moreover, combining non-chemical weed control methods (cover crops and pruning wood residues) with herbicide applications could lead to an improvement in overall long-term orchard biodiversity; not all weeds would be eliminated, but they would be kept at an economical and manageable threshold that does not compromise olive production. Moreover, the results of this study showed that some weed species in the olives groves were tolerant or resistant. This knowledge could be very useful for local farmers, who could change their current herbicides so that they do not use the same active substances (especially glyphosate) every year, thus preventing a shift in the weed flora established. Further verification of these strategies to ascertain agronomic and environmental effects is required during this three-year study so that farmers are able to make better management decisions regarding the use of these techniques.

### First-year study in northern Spain (INTIA field trials)

**Composition of weed flora** during the pre-control surveys identified 19 weed species in the inter-row spacing with Strategy 1 (hereafter No Tillage 'NT') and 16 species in Strategy 2 (hereafter Cover Crops 'CC'), representing 11-9 botanical families (Table 4). **Plant density** (including the *Sinapis alba* sown as cover crop) was 2346 pl/m² in Strategy CC and 1684 pl/m² in Strategy NT (Table 4). Nevertheless, Strategy CC displayed a lower number of species and plant density per species than Strategy NT, except for the *Lolium rigidum* and *Papaver rhoeas* species, which were favoured by the soil management (tillage) used prior to cover crop installation. Thus, tillage operations for cover crop installation can favour the emergence of weed seeds that exist on the soil surface.

During the post-control sampling date, weed flora was studied in the inter-row spacing and the ground coverage of each species assessed. **Ground coverage** in Strategy CC reached 88% and 73% in Strategy NT (Table 5). *Convolvulus arvensis* was the predominant species in both treatments. This species, however, covered 53% of the soil surface in Strategy NT, but only reached 27.75% in Strategy CC, where *Lolium rigidum* was predominant.

Moreover, Strategy CC accumulated higher weed **biomass production** than Strategy NT during pre-

| | | Inter-row | | Intra-row |
|---|---|---|---|---|
| | | **CC** | **NT** | |
| Asteraceae | *Anacyclus clavatus* | 48.75 | 53.75 | 0 |
| Primulaceae | *Anagallis arvensis* | 2.50 | 6.25 | 0 |
| Poaceae | *Bromus sp.* | 36.25 | 66.25 | 0.9 |
| Convolvulaceae | *Convolvulus arvensis* | 6.25 | 1.25 | 0 |
| Cruciferae | *Diplotaxis erucoides* | 5 | 12.50 | 13.4 |
| Onagraceae | *Epilobium brachycarpum* | 0 | 0 | 0.6 |
| Asteraceae | *Filago piramidata* | 0 | 3.75 | 0 |
| Rubiaceae | *Galium parisisense* | 0 | 0 | 0.6 |
| Poaceae | *Hordeum murinum* | 1.25 | 5 | 0.6 |
| Asteraceae | *Lactuca sp.* | 2.50 | 3.75 | 3.1 |
| Poaceae | *Lolium rigidum* | 1707.5 | 995 | 18.4 |
| Papaveraceae | *Papaver rhoeas* | 141.25 | 18.75 | 1.3 |
| Asteraceae | *Picris echioides* | 1.25 | 3.75 | 0 |
| Plantaginaceae | *Plantago lanceolata* | 0 | 8.75 | 0 |
| Polygonaceae | *Polygonum aviculare* | 1.25 | 2.50 | 0.3 |
| Asteraceae | *Scorzonera sp.* | 15 | 191.25 | 14.1 |
| Cruciferae | *Sinapis alba* | 218.75 | 0 | 0 |
| Asteraceae | *Sonchus sp.* | 126.25 | 226.25 | 69.1 |
| Caryophyllaceae | *Stellaria media* | 11.25 | 23.75 | 0 |
| Asteraceae | *Taraxacum sp.* | 20 | 26.25 | 0.9 |
| Apiaceae | *Torilis sp.* | 0 | 25 | 0 |
| Fabaceae | *Trifolium sp.* | 0 | 0 | 24.1 |
| Plantaginaceae | *Veronica hederifolia* | 1.25 | 10 | 1.3 |
| | **Total** | **2346.25** | **1683.75** | **148.75** |

**Table 4** - Plant density (pl/m²) of each weed species identified in each sampling area (inter and intra-row spacing) for the different IWM strategies during the pre-control sampling date

control (326 g/m$^2$ vs. 176 g/m$^2$) and post-control sampling dates, due to the higher weed plant density of the *Sinapis alba* and *Lolium rigidum* species (Table 6). Post-control sampling was done in spring, and Strategy NT, which chemically treated the fields with glyphosate, showed a total control of weeds. Additional post-control sampling was carried out in early summer with biomass production found to be practically zero in Strategy NT when compared with spring, but almost double in Strategy CC (627 g/m$^2$).

**Olive yield** and **quality** was obtained in November 2019, since the field trial was installed and *Sinapis alba* sown at the same time as the harvest (autumn 2018). Despite the existence of these weeds and the cover crops in Strategy CC fields, there were no significant reductions in olive yield compared to weed management with herbicide (1,404 and 1,473 kg/ha respectively) (Figure 6). It was not possible to analyse the olives separately, but the quality parameters of samples showed good values (fruit moisture 40.27%,

| | | CC | NT |
|---|---|---|---|
| Apiaceae | *Ammi visnaga* | 0.03 | 0 |
| Asteraceae | *Anacyclus clavatus* | 5.75 | 2 |
| Primulaceae | *Anagalis arvensis* | 0 | 0.06 |
| Asteraceae | *Andryala integrifolia* | 0 | 0.01 |
| Asteraceae | *Aster sp.* | 0.08 | 0.13 |
| Poaceae | *Avena sterilis* | 0.34 | 0.06 |
| Amaranthaceae | *Beta maritima* | 0.08 | 0.01 |
| Poaceae | *Bromus diandrus* | 2.50 | 0.56 |
| Poaceae | *Bromus hordaeceus* | 0.13 | 0 |
| Poaceae | *Bromus rubens* | 7.63 | 1.56 |
| Amaranthaceae | *Chenopodium album* | 0 | 0.01 |
| Amaranthaceae | *Chenopodium vulvaria* | 0.06 | 0.08 |
| Asteraceae | *Chondrilla juncea* | 0.01 | 0.01 |
| Asteraceae | *Cirsium arvense* | 0.06 | 0 |
| Convolvulaceae | *Convolvulus arvensis* | 27.75 | 53.50 |
| Asteraceae | *Conyza canadensis* | 0.35 | 0.75 |
| Fabaceae | *Coronilla scorpioides* | 0 | 0.01 |
| Apiaceae | *Daucus carota* | 0 | 0.08 |
| Asteraceae | *Ditrichia viscosa* | 1.50 | 3.50 |
| Onagraceae | *Epilobium sp.* | 0.01 | 0 |
| Cruciferae | *Erucastrum sisymbrifolium* | 0.13 | 0.38 |
| Euphorbiaceae | *Euphorbia sp.* | 0 | 0.01 |
| Poaceae | *Hordeum murinum* | 6.25 | 0.25 |
| Asteraceae | *Lactuca serriola* | 0.56 | 0.31 |
| Poaceae | *Lolium rigidum* | 29.63 | 3.75 |
| Fabaceae | *Melilotus oficinalis* | 0.01 | 0.01 |
| Asteraceae | *Pallenis spinosa* | 0 | 0.01 |
| Papaveraceae | *Papaver rhoeas* | 0.01 | 0.01 |
| Asteraceae | *Picris sp.* | 0.10 | 0.00 |
| Plantaginaceae | *Plantago lanceolata* | 0.01 | 0.05 |
| Polygonaceae | *Polygonum aviculare* | 0 | 0.01 |
| Dipsacaceae | *Scabiosa columbaria* | 0 | 0.01 |
| Asteraceae | *Scorzonera laciniata* | 1.33 | 2.94 |
| Asteraceae | *Sonchus oleraceus* | 4.13 | 3.38 |
| Asteraceae | *Taraxacum officinalis* | 0 | 0.01 |
| | **Total** | **88.41** | **73.48** |

**Table 5** - Ground coverage (%) of each weed species identified in the inter-row spacing of the different IWM strategies during the post-control sampling data

| | CC | NT |
|---|---|---|
| **Pre-control (14/02/2019)** | 326 | 176 |
| **Post-control (15/04/2019)** | 627 | 0 |

**Table 6** - Weed dry biomass (g/m²) in the inter-row spacing of the different IWM strategies during the two different dates (pre- and post-control)

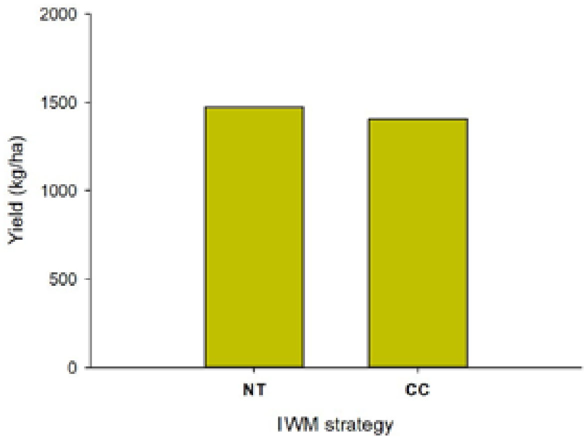



**Figure 6** - Olive yield (kg/ha) in the different IWM strategies of northern Spain. Only significant differences are shown

| | INTRA-ROW | | INTER-ROW | |
|---|---|---|---|---|
| | **NT** | **CC** | **NT** | **CC** |
| **N (%)** | 0.13 | 0.14 | 0.14 | 0.15 |
| **OM (%)** | 1.64 | 1.89 | 1.79 | 1.94 |
| **K (ppm)** | 185.46 | 208.41 | 208.08 | 238.5 |
| **P (ppm)** | 25.69 | 33.84 | 20.51 | 19.53 |
| **C/N ratio** | 7.5 | 7.65 | 7.34 | 7.66 |

**Table 7** - Soil fertility parameters evaluated in the 0-30 cm profile: organic nitrogen content 'N' (%), organic matter 'OM' (%), potassium 'K' (ppm), phosphorus 'P' (ppm) and C/N ratio for the different IWM strategies

fat content 24.73% and acidity 0.36).
Soil fertility was sampled in autumn 2019 and our results showed that Strategy CC had higher values of N, OM, K and C/N ratio near the ground surface in absolute terms than Strategy NT (Table 7).

## Conclusions

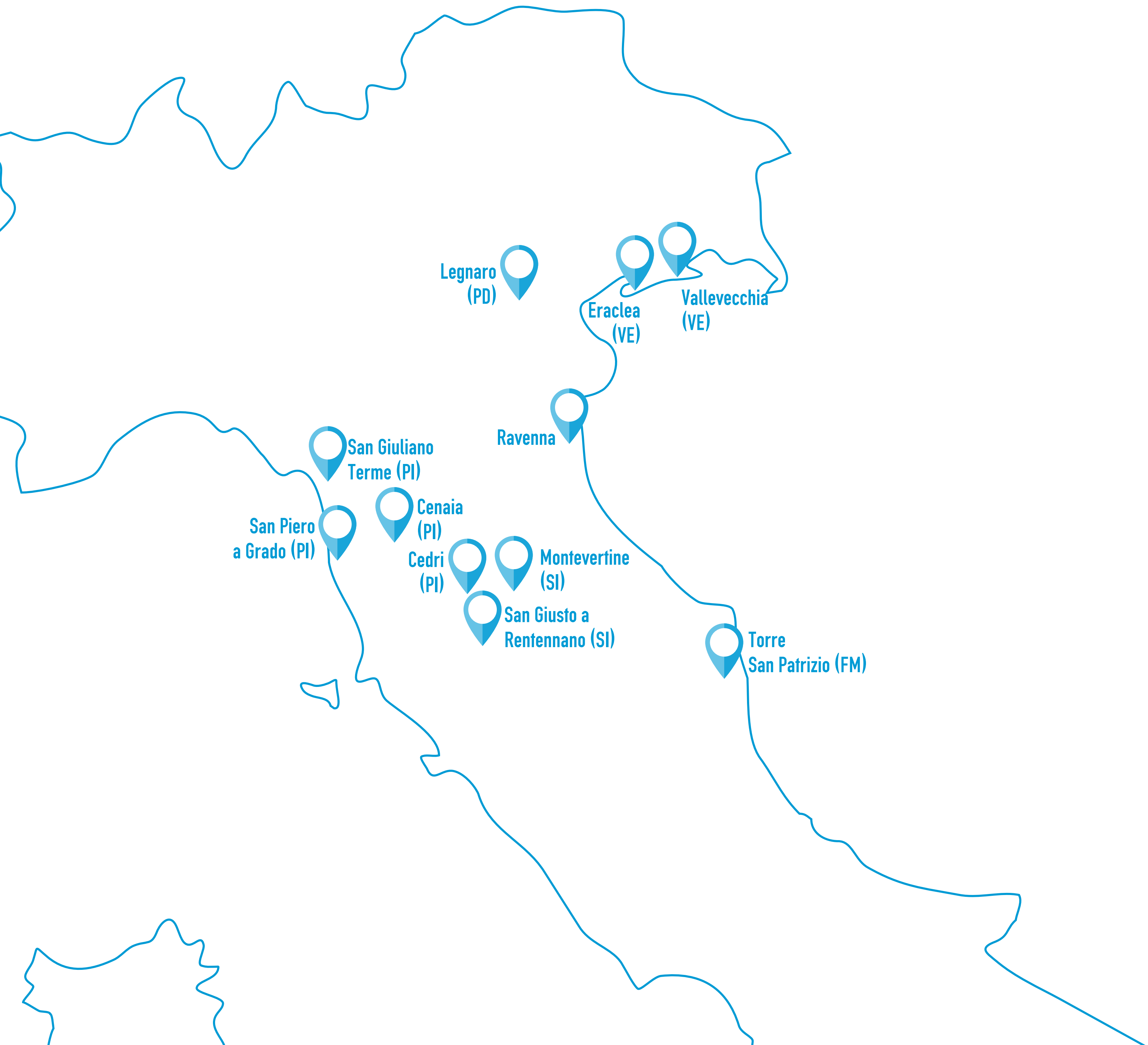
The installation of cover crops in perennial woody crops, such as olive orchards in northern Spain, is attracting considerable interest among local farmers. However, there are no previous local experiences, and it is believed that the installation of autumnal cover crops could cause some difficulties with soil and weed management in northern Spain. For example, mechanical harvesting in rainy autumns can hinder proper installation and development, as occurred during the study year.
For these reasons, there are still many questions and doubts about which form of cover crop management would strike a balance between reseeding the existing species (both white mustard and the spontaneous species) and the potential competition they could create with the olive orchards.
Consequently, further verification of these strategies is required during this three-year study.

## References


- Abu-Irmaileh, B., Abu-Rayyan, A., 2004. In-row preplant manure composting reduces weed populations. Hortscience 39, 1456–1460.
- Alcántara, C., Pujadas, A., Saavedra, M., 2011. Management of cruciferous cover crops by mowing for soil and water conservation in southern Spain. Agric. Water Manag. 98, 1071–1080. https://doi.org/10.1016/j.agwat.2011.01.016
- CAP, 2006. Manual de buenas prácticas agrarias en los diferentes sistemas productivos del olivar andaluz. Programa de mejora de la calidad de la producción de aceite de oliva y aceitunas de mesa. Consejería de Agricultura y Pesca. Junta de Andalucía. Sevilla, España. 60 pp.
- CAPDR, 2017. Superficies y producciones agrícolas. Olivar. Consejería de Agricultura, Pesca y Desarrollo Rural. URL https://bit.ly/2N45rfn (Last accessed 02.08.19).
- Fracchiolla, M., Terzi, M., Frabboni, L., Caramia, D., Lasorella, C., De Giorgio, D., Montemurro, P., Cazzato, E., 2016. Influence of different soil management practices on ground-flora vegetation in an almond orchard. Renew. Agric. Food Syst. 31, 300–308. https://doi.org/10.1017/S1742170515000241
- Holland, J.M., 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agric. Ecosyst. Environ. 103, 1–25. https://doi.org/10.1016/j.agee.2003.12.018
- Huqi, B., Dhima, K., Vasilakoglou, I., Keco, R., Salaku, F., 2009. Weed flora and weed management in established olive groves in Albania. Weed Biol. Manag. 9, 276–285. https://doi.org/10.1111/j.1445-6664.2009.00351.x
- Kuo, S., Sainju, U.M., Jellum, E.J., 1997. Winter cover crop effects on soil organic carbon and carbohydrate in soil. Soil Sci. Soc. Am. J. 61, 145–152.
- MAPA, 2017a. Encuesta sobre Superficies y Rendimientos Cultivos (ESYRCE). Encuesta de Marco de Áreas de España. Ministerio de Agricultura, Pesca y Alimentación. URL http://bit.ly/2igtnjv (Last accessed 02.10.19)
- MAPA, 2017b. Informe sectorial. Técnicas de mantenimiento de suelo. Encuesta sobre Superficies y Rendimientos Cultivos (ESYRCE). Ministerio de Agricultura, Pesca y Alimentación. URL http://bit.

ly/2jzTRZz (Last accessed 02.06.19)
- Martinelli, R., Monquero, P.A., Fontanetti, A., Conceição, P.M., Azevedo, F.A., 2017. Ecological mowing: An option for sustainable weed management in young citrus orchards. Weed Technol. 31, 260–268. https://doi.org/10.1017/wet.2017.3
- Perdigao, A., Coutinho, J., Quimica, C., Moreira, N., 2012. Cover crops as nitrogen source for organic farming in Southwest Europe, In: Mourao, I., Aksoy, U. (Eds.), XXVIII International Horticultural Congress on Science and Horticulture for People (Ihc2010): International Symposium on Organic Horticulture: Productivity and Sustainability. Int Soc Horticultural Science, Leuven 1, pp. 355–361.
- Saavedra, M., Hidalgo Moya, J.J., Pérez, D., Hidalgo Moya, J.C., 2015. Guía de cubiertas vegetales en olivar. Instituto de Investigación y Formación Agraria y Pesquera. Consejería de Agricultura, Pesca y Desarrollo Rural. Junta de Andalucía. 32 pp.

# ITALY


Legnaro
(PD)
Eraclea
(VE)
Vallevecchia
(VE)
Ravenna
San Giuliano
Terme (PI)
Cenaia
(PI)
San Piero
a Grado (PI)
Cedri
(PI)
Montevertine
(SI)
San Giusto a
Rentennano (SI)
Torre
San Patrizio (FM)

# 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 important 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.*

**Address:**
**Azienda Vallevecchia**
**Via Dossetto, 3**
**Loc. Brussa - 30021 Caorle (VE) - Italy**
**GPS coordinates: 45°38'49.5"N 12°57'01.0"E**
**e-mail: vallevecchia@venetoagricoltura.org**
**tel. +39 049 8293930**

**For further information and guided visits please contact:**
**Lorenzo Furlan**
**e-mail: lorenzo.furlan@venetoagricoltura.org**
**tel. +39 345 3819635**

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

### 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 1) 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-sorghum-soybean) with cover crops during the intercropping periods. Minimum tillage was performed in autumn 2017 to prepare the seedbed of the first crop (wheat), while no-till was adopted from the second year. The experiment compares three treatments, i.e. three different management strategies, characterized by various 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 minimizing initial weed dissemination and consequently reducing the 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 (Figure 1), or by adopting cover crops which are killed by winter frost.

Detailed information about the different management types for the three treatments are presented in Figure 3 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 $m^2$; total experiment size: about 4.5 ha).

After the previous crop (soybean) had been harvested in October 2017, minimum tillage was carried out 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 2017. The first weed assessment was made in March 2018 to evaluate whether herbicide was needed and to

**Figure 1** - Cover crop termination with Roller crimper


**Figure 2** - Cover crop undersowing in wheat plots


**Figure 3** - Experimental scheme of the WP7 trial

**Figures 4 and 5** - Cover crop (clover) size in May 2018 (left) and two months after the wheat harvest (right)

| | Treatment 1 | Treatment 2 | Treatment 3 |
|---|---|---|---|
| **October 2017** | Wheat sowing | Wheat sowing | Wheat sowing |
| March 2018 | | | Cover crop undersowing |
| **April 2018** | 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 | | |
| **October 2018** | Autumn cover crop sowing | Summer cover crop termination<br>Autumn cover crop sowing | |
| March 2019 | Chemical cover crop termination | Chemical cover crop termination | Chemical cover crop termination (if necessary) |
| **April-May 2019** | Sorghum sowing | Sorghum sowing | Sorghum sowing |
| May-June 2019 | Pre- and Post-emergence herbicide | Post-emergence herbicide | Post-emergence herbicide |
| September 2019 | Sorghum harvest | Sorghum harvest | Sorghum harvest |
| **October 2019** | Autumn cover crop sowing | Autumn cover crop sowing | Autumn cover crop sowing |
| **April 2020** | Chemical cover crop termination (glyphosate) | Chemical cover crop termination (glyphosate) | Cover crop termination with roller crimper (if needed) |
| **May 2020** | Soybean sowing | Soybean sowing | Soybean sowing |
| June 2020 | Pre and Post-emergence herbicide | Post-emergence herbicide | Post-emergence herbicide (if needed) |
| **October 2020** | Soybean harvest | Soybean harvest | Soybean harvest |

**Table 1** - Main operations for the 3 treatments from 2017 to 2020

choose a suitable herbicide mixture. Given that weed presence was low, no herbicide was applied on T3 plots, while a post-emergence herbicide (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 2018 in the cereal plots of Treatment T3 (Figure 2). A second assessment was made in May to evaluate the level of weed control achieved with the different treatments, as well as cover-crop establishment and growth (Figures 4 and 5). Weed density was very low in all plots; clover emerged but remained at the 2-3 leaf stage until crop harvest.
No differences were observed between the wheat yield (6-6.5 t/ha) achieved with the three treatments (Figure 6).
After the wheat harvest, a summer cover crop (sorghum) was sown in T2 plots on 12 July 2018 (Figure 7), while the clover mixture covered the soil surface among cereal stubbles in T3 plots (Figure 8). However, the clover mixture was not able to prevent the growth of perennials, such as *Sorghum halepense, Cirsium arvense* and other species, therefore a mechanical operation (mulching) was required to control them. This operation did not terminate the cover crop, which continued to grow. No operations were conducted on the T3 plots until cover-crop termination in spring 2019 for all plots. Glyphosate was applied to T1 plots during the intercropping period in September and it controlled all emerged weeds. The summer cover crop sown in T2 plots grew very well, producing high amounts of biomass thanks to some summer rainfall (Figure 9). It was therefore decided to partially harvest the biomass as silage for livestock to avoid potential problems related to an excessive amount of residues during the subsequent sowing operations. Approximately 10 t/ha of fresh sorghum biomass were harvested at the end of September and removed from the field.
The autumn cover crop (wheat for biomass) was supposed to be sown in early October. However, the sowing was postponed to early December because of rainy weather and, in the end, biomass production was scarce. The clover cover crop managed to cover the soil completely during winter and produced a large amount of biomass before termination (Figure 10). The cover crops were terminated in April 2019 in all plots by applying glyphosate. Sorghum, which was chosen instead of maize for its much higher tolerance to water stress, was sown as a main crop for silage production in June 2019.
A range of weed-management strategies were planned for the three treatments: application of pre-

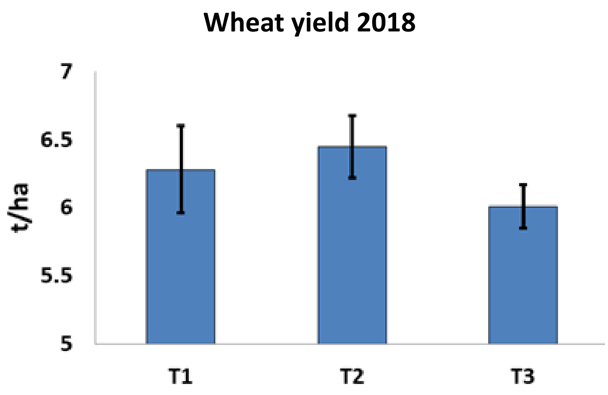



**Figure 6** - Wheat yield obtained with the three treatments (T1, T2 and T3) in 2018. Vertical bars represent standard errors

**Figure 7** - Sowing summer cover crop in wheat stubbles

**Figure 8** - Clover cover crop with high weed presence just before mulching in September 2018

**Figure 9** - Sorghum cover crop at harvest in September 2018

**Figure 10** - T3: clover cover crop completely covering the soil when glyphosate was applied before spring crop sowing

**Figure 11** - 15 July 2019. Poor crop emergence in the T3 plot (left side) and T1 plot (right side) due to drought. T3 plots: clover cover crop partially regrew after glyphosate application, with limited weed emergence

**Figure 12** - 10 October 2019. Sorghum harvest. Good yields (30 t/ha of fresh biomass), with no differences between treatments and few weeds

emergence followed by post-emergence herbicide for T1; and post-emergence for T2 and T3, but only when needed in T3. However, an extremely dry period after sowing (almost no rain in June) hindered the utilization of pre-emergence herbicides; only post-emergence herbicides (dicamba 150 g/ha, prosulfuron 15 g/ha) were therefore applied on T1 and T2 plots on 9 July. Lower weed emergence was observed in T3 plots, where the clover cover crop was able to produce a good amount of biomass. Consequently, a significant amount of dead mulch was also present on the soil surface, and no herbicide was applied (Figure 11).
A drought the month after sorghum sowing also hindered crop emergence and the final density was not optimal. No difference was observed between treatments for this aspect. Sorghum was harvested for silage production on 10 October 2019. Yields were satisfactory (30 t/ha of fresh biomass with 70% RH) despite non-optimal crop density due to summer drought (Figure 12). Weed presence was low and located in the gaps of crop canopy caused by failed crop emergence. No differences could be detected between treatments regarding crop yield or weeds.
After the sorghum was harvested, red clover, which had remained small under the crop canopy, covered the soil surface again in T3 plots (Figure 13).
On 24 October 2019, the following two autumn cover crops were sown with direct drilling in all plots: rye (*Secale cereale*, 160 kg/ha) for T1 and T2 plots; and lopsided oat (*Avena strigosa*, 60 kg/ha) for T3 plots. In the latter, lopsided oat was direct drilled without removing or destroying red clover biomass in order to improve soil cover in early autumn (Figure 14). Lopsided oat was selected because it is usually killed by winter frost and therefore no chemical or mechanical operations are normally required for

termination. Cover crops grew during the autumn-winter period; however, the late sowing date limited their biomass production before winter growing. Consequently, lopsided oat was able to overwinter and restart its growth in February 2020 (Figure 15). However, red clover, which was initially sown in February 2018, did not survive its second winter. The cover crops were terminated with glyphosate application (T1 and T2) or by roller crimper (T3) in April 2020 before the sowing of the next cash crop, namely soybean. A range of weed-management strategies will be adopted for the three treatments: application of pre-emergence followed by post-emergence herbicide for T1, and post-emergence for T2 and T3, only when needed in T3.

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

### Objectives

Given that environmental conditions can strongly affect the feasibility and efficacy of mechanical and chemical weed control tools, developing alternative solutions for low herbicide input strategies is crucial for guaranteeing flexibility when you deal with weather trends. This study aims at evaluating 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 the sowing machine followed by inter-row soil cultivation) (Figure 16);
- evaluate the efficacy of an innovative system for herbicide band application (with a prototype that simultaneously performs herbicide application along the crop rows and inter-row soil cultivation);
- 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).

A prototype of an inter-row cultivator equipped with nozzles for herbicide band application (Figure 17) 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

**Figure 13** - 24 October 2019. After sorghum harvest, clover covered the entire soil surface of the T3 plots (right)

**Figure 14** - 24 October 2019. Direct drilling: rye (*Secale cereale*, 160 kg/ha) for T1 and T2 plots, and lopsided oat (*Avena strigosa*, 60 kg/ha) for T3 plots

**Figure 15** - 18 February 2020. Cover crop conditions at the end of winter: rye (*Secale cereale*) for T1 and T2 plots (right), and lopsided oat (*Avena strigosa*) for T3 plots (left)

**Figure 16** - Sowing machine equipped with nozzles for herbicide band application

**Figure 17** - The Maschio-Gaspardo prototype, which combines inter-row soil cultivation and herbicide band application along crop rows

**Figure 18** - Imaging camera that identifies crop rows and enables equipment position to be adjusted

repeatability, i.e. the ability to return precisely (± 2.5 cm) on the same run-lines at any later date;
2) an imaging camera (Figure 18) 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 19) and managed by a control unit in order to adjust the volume applied according to tractor speed and the band size being treated.

### Results 2018/2019

The trial was conducted at "La Fagiana" farm, a commercial farm at Eraclea, Province of Venice, Northeastern Italy. The experiment was set up in one field and included 4 treatments:
T1) broadcast application of pre-emergence herbicides (control standard management 1);
T2) pre-emergence herbicide band application with the sowing machine (traditional band application management);
T3) broadcast application of post-emergence herbicides (control standard management 2);
T4) herbicide band application with an innovative system (the Maschio-Gaspardo prototype that simultaneously performs herbicide application along the crop rows and inter-row soil cultivation).
Inter-row cultivation was 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 150 m x 9 m = 1350 $m^2$ and total experiment size around 2 hectares.
Maize was sown on 19 April 2019 using a tractor equipped with RTK/GPS positioning and an autosteering system to map crop rows. Pre-emergence herbicide band application (mesotrione 37.5 g/ha, S-metolachlor 312.5 g/ha, terbutilazina 187.5 g/ha, band width treated 25 cm, spray volume 100 L/ha) was performed on T2 plots using a sowing machine equipped with specific nozzles (Figure 21).
The following day, broadcast pre-emergence herbicide application (mesotrione 112.5 g/ha, S-metolachlor 937.5 g/ha, terbutilazina 562.5 g/ha, spray volume 300 L/ha) was carried out on T1 plots with a boom sprayer.
The 5-6 weeks after maize sowing were characterized by continuous rainy weather, with total precipitation of almost 350 mm. As a consequence, no operation could be done during that period and the first post-emergence herbicide application and inter-row soil cultivation with the Maschio-Gaspardo prototype was performed on 7 June. Maize was already

at BBCH 17-18, and weeds were larger than the optimal size. Post-emergence herbicide application (tembotrione 30 g/ha, dicamba 80 g/ha, treated band width 25 cm, spray volume 100 L/ha), with simultaneous inter-row soil cultivation being carried out with the Maschio-Gaspardo prototype on 7 June in T4 plots.

On the same day, broadcast post-emergence herbicide application (tembotrione 90 g/ha, dicamba 240 g/ha, spray volume 300 L/ha) was performed on T3 plots with a boom sprayer, and the following day inter-row soil cultivation was performed on all plots, apart from T4 ones. An initial weed assessment was undertaken on 30 May 2019 before inter-row cultivation and post-emergence herbicide application to evaluate initial weed density in the untreated plots. Weed population included the usual spring and summer species (*Abutilon theophrasti, Chenopodium album, Echinocloa crusgalli, Polygonum aviculare, Polygonum persicaria, Solanum nigrum* and *Sonchus asper*) with a total density of 15-20 plants/m$^2$.

Weed assessments were repeated one month after post-emergence control (26 June 2019) and before crop harvest (12 September 2019). Maize was harvested on 24 September 2019. Pre-emergence herbicide application, both banded and broadcast, was very effective. Although the application timing of post-emergence herbicide and inter-row cultivation was not optimal, weed control was satisfactory. Some plants, however, were too large and survived the mechanical control in T4 plots. Weed density at crop harvest was therefore higher in T4 plots, i.e. 4-5 plants/m$^2$, while the lowest values, below 2 plants/m$^2$, were observed in the two treatments with broadcast herbicide application (T1 and T3). These differences increased when weed fresh biomass was considered. The value for T4 (115 g/m$^2$) was ten-fold higher than all the other treatments (Figure 23), and this result was due to the presence of a limited number of large weed plants that survived post-emergence control operations because of their size. However, no differences could be detected between treatments regarding maize yield, with means ranging from 9.7 to 10.4 t/ha of maize grain at 14% RH (Figure 24). Moreover, the highest yield, as an absolute value, was observed in T4. We therefore believe that the two treatments with herbicide band application (T2 and T4) obtained an adequate weed control level to keep weed competition below the economic damage threshold, although weather conditions during spring 2019 delayed post-emergence operations and hindered inter-row hoeing.

**Figure 19** - Nozzles for herbicide band application along crop rows positioned on the cultivator structure

**Figure 20** - Maize sowing with herbicide band application along crop rows

### 2019/2020 experiment

Given the positive results of the 2018/19 experiment, even though weather conditions were not optimal, the same experimental design was maintained for the 2019/20 experiment in order to confirm these promising indications. In 2020, this experimental trial was relocated to Vallevecchia farm.

Figure 21 - Nozzle for herbicide band application positioned on the sowing machine

Figure 22 - Weed population before inter-row cultivation

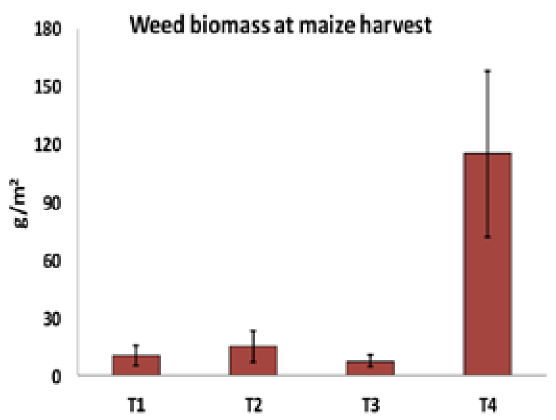



Figure 23 - Weed fresh biomass at crop harvest. Values are the mean of three replicates and bars represent standard errors

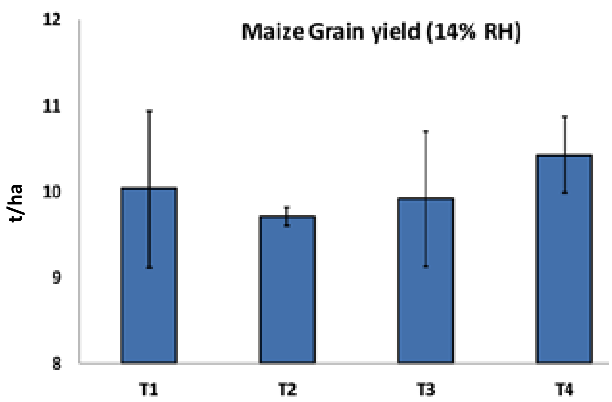



Figure 24 - Maize grain yield (at 14% RH) for each treatment. Values are the mean of three replicates and bars represent standard errors

## Materials and methods

The field experiment is arranged in three adjacent fields and includes four treatments (Table 2):
T1) broadcast application of pre-emergence herbicides (control standard management 1);
T2) pre-emergence herbicide band application with a sowing machine (traditional band application management);
T3) broadcast application of post-emergence herbicides (control standard management 2);
T4) herbicide band application with an innovative system (the Maschio-Gaspardo prototype, which simultaneously performs herbicide application along the crop rows and inter-row soil cultivation).
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 has been adopted, with a plot size of 250 m x 14 m = 3500 $m^2$ and a total experiment size of around 4.5 ha. Maize was sown on 16 April 2020 using a tractor equipped with RTK/GPS positioning and an autosteering system to map crop rows. Pre-emergence herbicide band application (mesotrione 48.75 g/ha S-metolachlor 406.25 g/ha, terbutilazina 243.75 g/ha, band width treated 25 cm, spray volume 100 L/ha) was performed on T2 plots using a sowing machine equipped with specific nozzles (Figure 21).
The following day, broadcast pre-emergence herbicide application (mesotrione 150 g/ha,


| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Margin | T 4 | T 3 | Margin | T 1 | T 2 | Margin | T 3 | T 4 |
| | T 2 | T 1 | | T 3 | T 4 | | T 1 | T 2 |

**Figure 25 and Table 2** - Experimental scheme of the WP4 trial

**Legend**
T 1 Broadcast application of pre-emergence herbicides with boom sprayers
T 2 Band application of pre-emergence herbicides with a sowing machine
T 3 Broadcast application of post-emergence herbicides with boom sprayers
T 4 Band application of post-emergence herbicides with a Maschio-Gaspardo prototype

**Figures 26, 27, 28 and 29** - Images of the open field day on conservative agriculture at Vallevecchia farm and La Fagiana farm

S-metolachlor 1250 g/ha, terbutilazina 750 g/ha, spray volume 300 L/ha) was carried out on T1 plots with a boom sprayer. When maize plants reach the BBCH 14-15 stage (4-5 true leaves), post-emergence herbicide application (nicosulfuron 20 g/ha, dicamba 64 g/ha, treated band width 25 cm, spray volume 100 L/ha) with simultaneous inter-row soil cultivation will be performed with the Maschio-Gaspardo prototype in T4 plots. On the same day, broadcast post-emergence herbicide application (nicosulfuron 60 g/ha, dicamba 192 g/ha spray volume 300 L/ha) will be performed on T3 plots with a boom sprayer, and inter-row soil cultivation will be performed on all plots apart from T4 ones.
Weed assessments will be conducted before post-emergence herbicide application, one month after post-emergence application, and at crop harvest. Weed biomass at harvest and maize grain yield will be measured for each plot to compare the weed-control efficacy of each treatment.

On 26 June 2019, Vallevecchia farm opened its doors for an open field day focused on conservation agriculture, as it did in summer 2018. This event was also an opportunity to present the IWMPRAISE project to farmers and advisers and to witness the Maschio-Gaspardo prototype in action. A visit was also made to La Fagiana farm, with its experimental trial of weed management on maize with reduced use of herbicides (Figures 26, 27, 28 and 29).

### Further developments

The experiments at Vallvecchia farm are continuing until a total of at least three years in order to monitor its evolution during the transition phase and evaluate the mid-term efficacy of the techniques. This experimental site its being used to organize field visits and demonstration activities to promote a fruitful exchange with local farmers and technicians, and the experimental protocol is being progressively adjusted according to results and feedback from local stakeholders.

**Contact:**
**Donato Loddo, CNR**
donato.loddo@cnr.it - tel. +39 049 8272822

# EXPERIMENTAL TRIALS AT THE "LUCIO TONIOLO" FARM

Consiglio Nazionale delle Ricerche

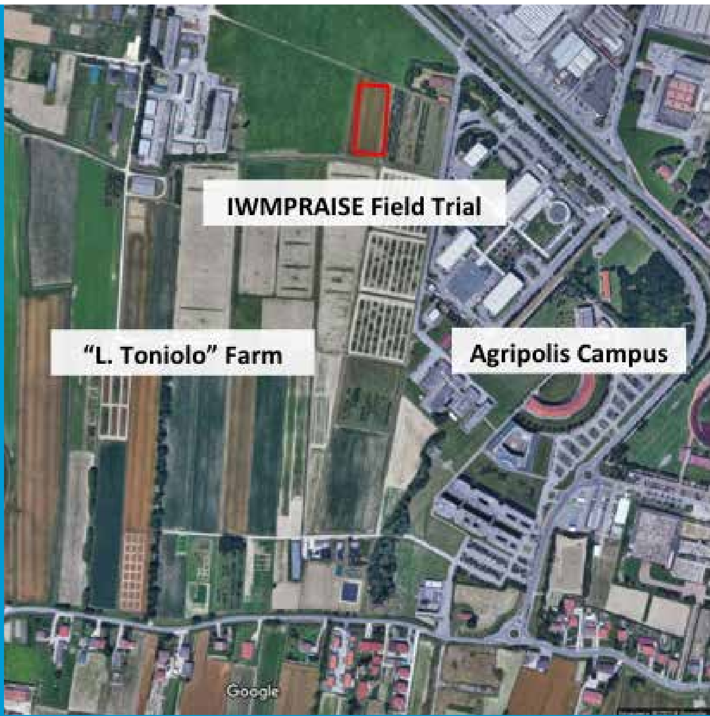



**Figure 1** - Location of the trial at the "Lucio Toniolo" farm

*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 running several long-term experiments. It conducts field research on a variety of topics, such as the long-term effect of different cropping or management systems, 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.*

Address:
Azienda agraria sperimentale "Lucio Toniolo"
dell'Università degli studi Padova
Viale dell'Università, 4
35030 Legnaro (PD) - Italy
GPS coordinates: 45°20'48.9"N 11°57'00.3"E

For further information and guided visits please contact:
Donato Loddo
e-mail: donato.loddo@cnr.it
tel. +39 049 8272822

## WP3 – INTEGRATED WEED MANAGEMENT IN WHEAT

### 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; since the 2018/2019 cropping season, it has also assessed the effect that relay cropping with clover has on wheat.
The compared strategies are based on:
1) chemical control only (for the 2017/2018 season);
2) integration of chemical and mechanical control;
3) mechanical control only;
4) mechanical control plus relay cropping (2018/2019 and 2019/20 seasons).
The specific objectives of this study are to:

- design mechanical weed-control strategies for wheat according to both local environmental conditions and the limitations due to the 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;

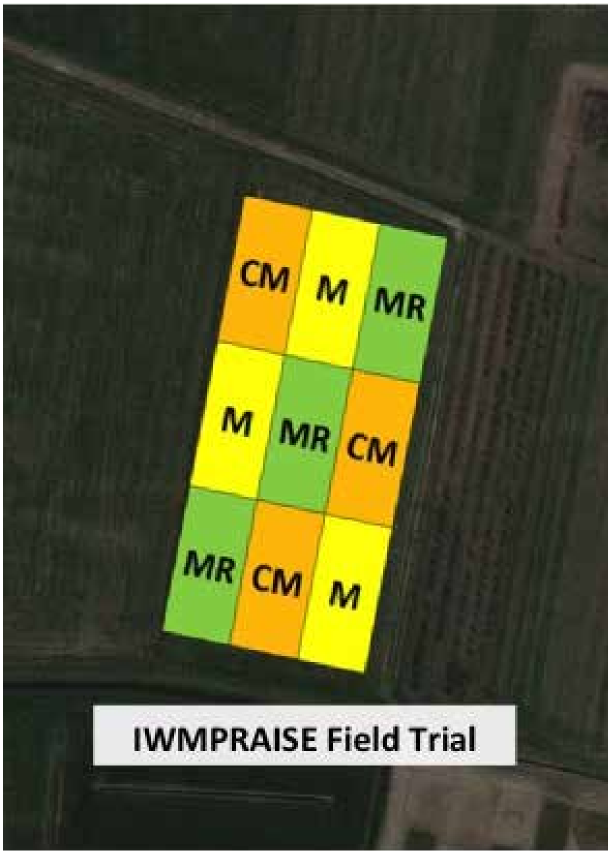



Figure 2 - Experimental design of the WP3 field trial

- evaluate the effect of including relay cropping of clover in wheat in order to facilitate the adoption of cover crops and reduced interventions.

### Results 2018/2019

Given the positive results of the 2017/18 experiment, probably due to the cropping system (rotation with spring crops) which reduced weed density, the experimental design was modified for the 2018/19 experiment in order to test another IWM tool, i.e. relay cropping of clover, and to advance towards low herbicide use in weed management for wheat. Treatments CM (chemical and mechanical control) and M (mechanical control) were maintained, while Treatment C (chemical control) was substituted with Treatment MR (mechanical + relay), which includes an autumn false seedbed, flexible tin harrowing and relay cropping of red clover undersown in wheat. The false seedbed period (16 October - 14 November) was rather rainy and considerable weed-seedling emergence was observed, meaning that this technique was effective. However, prolonged high soil-humidity forced the wheat to be sown much later than in standard local management practices. On 25 February, a cover crop (red clover, 25 kg/ha of seed) was spread on the soil surface of MR plots, and flexible tine harrowing was then performed on MR and M plots to control weeds and bury clover seeds (Figure 3). The lack of precipitation in March 2019 slowed clover germination and establishment, with the first emerged seedlings being observed three weeks after the sowing date (Figure 4). Herbicide was applied on 22 March on CM plots. Low weed density (less than 10 plants/$m^2$) and biomass (less than 20 g/$m^2$) was observed in all treatments. Good grain yields (6.8-7.3 t/ha at 14% RH) were achieved for all treatments without any significant differences (Figure 5). Cover-crop growth was monitored after cereal harvest, but the hot, dry weather in June (less than 10 mm of precipitation) hindered clover growth, and its biomass was below 0.5 t/ha (fresh weight) in mid-July. Given the scarce growth of the cover crop, its competitive ability towards weeds was scarce and a mechanical operation (mulching) was needed in August to destroy all the weeds to prevent their dissemination

### 2019/2020 experiment

During the 2017/18 and 2018/19 experiments, satisfactory weed control and good yields were achieved for all treatments, including those with only mechanical weed control operations. Relay cropping of red clover tested in the 2018/19 experiment was not successful due to the prolonged cold, rainy period in April and May, followed by a hot, dry period in June, which significantly reduced clover density and growth. This technique is being tested again in the 2019/20 experiment.

## Materials and methods

The experimental design adopted for the 2018/19 experiment has also been used for the 2019/20 experiment, which was set up at the same site: "L. Toniolo" farm, Legnaro.
It included three treatments, each with its own weed-management strategy:
1) integration of chemical and mechanical control with the false seedbed technique in autumn, plus spring post-emergence herbicide application (only when necessary) and attempts to minimize herbicide use (Treatment CM);
2) mechanical control only with the false seedbed technique in autumn, plus flexible tine harrowing at the crop-tillering stage (Treatment M);
3) mechanical control, as in the previous treatment, plus relay cropping of red clover (Treatment MR).
The same strategy for fertilizer application and crop protection (i.e. fungicide and insecticide application) was uniformly adopted for all treatments. A randomized block design with three replicates was set up (replicate plot size: 30 m x 10 m = 300 $m^2$, total experiment size: about 5000 $m^2$).
The experiment was set up on a field where sugarbeet and maize had been cultivated previously. Just after the sugarbeet harvest in mid-September 2019, a cultivator was used to prepare the false seedbed. Soil cultivation for seedbed preparation was then performed with rotary harrowing on the whole field on 21 October, and wheat was sown on 23 October. The false seedbed period (15 September - 21 October) was rather rainy, and considerable weed-seedling emergence was observed, meaning that this technique was effective. Weed assessment was conducted on 17 February 2020.
Weed density was quite high, with mainly broadleaf species, such as *Lamium purpureum, Stellaria media* and *Veronica persica*, while *Poa annua* and *Lolium multiflorium* were the most common grasses. On 18 February, a cover crop (red clover, 25 kg/ha of seed) was spread on the soil surface of MR plots, and flexible tine harrowing was performed on 20 February on MR and M plots to control weeds and bury clover seeds. Herbicide application (mesosulfuron-methyl 15 g a.i./ha + iodosulfuron-methyl-sodium 3 g a.i./ha) was performed on 18 March 2020 on CM plots.
A second weed assessment will be conducted at wheat flowering. Grain yield will be measured for all treatments. Red clover growth will be monitored throughout the cropping season and during the summer inter-cropping period after cereal harvest.

**Figure 3** - Flexible tine harrowing after undersowing clover in wheat (February 2019)

**Figure 4** - Clover seedlings emerging between wheat rows (March 2019)

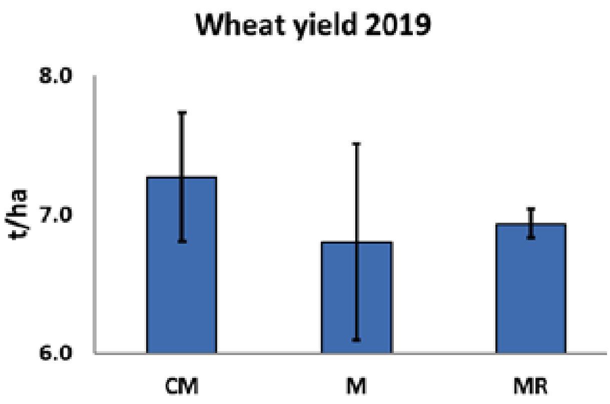



**Figure 5** - Wheat yields (14% RH) obtained with the three control strategies (CM: chemical and mechanical control; M: mechanical control; MR: mechanical control + relay cropping). Vertical bars represent standard errors

### Further developments

When innovative or uncommon tools, such as relay cropping of clover in cereals, are tested, promoting and maintaining a constant exchange with local farmers and consultants 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 are organized for this purpose and the list of control tools and strategies for next year's experiment will be amended according to the outcomes. They will also be calibrated according to local environmental conditions and farming practices. An additional reason for farmer involvement is to replicate on-farm experiments to test IWM strategies for wheat next year.

**Contact:**
**Donato Loddo, CNR**
donato.loddo@cnr.it - tel. +39 049 8272822

# EXPERIMENTAL TRIALS AT THE "ENRICO AVANZI" CENTRE FOR AGRO-ENVIRONMENTAL RESEARCH (CIRAA)

*The University of Pisa's CiRAA is the largest agricultural experimental centre in Italy and one of the largest in Europe (> 500 ha of agricultural land). 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, plus economic and environmental impact. Due to its acreage, CiRAA is both a research station and a commercial farm.*

*A considerable portion of its agricultural land is managed for marketable production of arable crops and field vegetables. Due to these features, CiRAA has been formally included among the Centres for Innovation Transfer in Agriculture by the Tuscany Regional Government. CiRAA is located in the Regional Park of "Migliarino - San Rossore - Massaciuccoli" and within the* "Selva Pisana" *biosphere reserve. It was founded in 1963 after the Italian Republic donated land to the University of Pisa with the aim of supporting research and teaching in veterinary and agricultural science. The research centre is named in memory of Enrico Avanzi, professor of agronomy and rector of the University of Pisa from 1947 to 1959.*

**Address:**
"E. Avanzi" Centre for Agro-environmental Research (CIRAA)
Via Vecchia Marina, 6
San Piero a Grado (PI) - Italy
GPS coordinates: 43°40'11.7"N 10°18'49.2"

**For further information and guided visits please contact:**
Daniele Antichi
e-mail: daniele.antichi@unipi.it
tel. +39 050 2218962
Stefano Carlesi
e-mail: stefano.carlesi@santannapisa.it
tel. +39 050 883569

## LTE – LONG-TERM EXPERIMENT IN COVER CROPS

This long-term experiment started in 1993 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 crops and for optimizing the use of external inputs. Two tillage systems were included in the experiment.
In 1998, durum wheat (as a reference autumn-sown crop) was introduced into the system, leading to a two-year rotation. This change was made in order to mirror changes in the local cropping system. For the same reason, sunflower was introduced in 2007 as an additional spring-sown cash-crop. This raised the crop rotation to four years (durum wheat, maize, durum wheat, sunflower), with the cover crop being grown before each spring-sown cash-crop. The experiment takes place in strictly rainfed conditions. No irrigation is allowed, even in the event of an extreme drought emergency.

### 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 system)
(ii) four N fertilization levels of the main crop
(iii) four soil cover types (*Brassica juncea, Trifolium squarrosum, Vicia villosa* and a control).

### Materials and Methods

The three constant factors studied in the trials are tillage, nitrogen fertilization and cover-crop type (Table 1). 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: chiseling 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 for maize; and 0, 50, 100 and 150 for sunflower.
The four cover-crop plots are nested in each fertilization strip: C, control (weedy); BJ, *Brassica juncea* L.; TS, *Trifolium squarrosum* L.; Vv, *Vicia villosa* Roth. Cover crops are grown in winter before maize and sunflower, and terminated at the end of April. Disk harrowing or herbicide is used in CS and a crusher in LIS. Weed control is differentiated in the two tillage systems. In CS,


**Figure 3** - Experimental site for the LTE trial

| FIELD 1 | | FIELD 2 | | FIELD 3 | | FIELD 4 | | FIELD 5 | | FIELD 6 | | FIELD 7 | | FIELD 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 BJ | 37 C | 44 TS | 45 Vv | 52 C | 53 BJ | 60 TS | 61 Vv | 68 Vv | 69 BJ | 76 C | 77 TS | 84 BJ | 85 Vv | 92 Vv | 93 C |
| 35 C | 38 BJ | 43 BJ | 46 TS | 51 TS | 54 C | 59 Vv | 62 BJ | 67 C | 70 TS | 75 BJ | 78 Vv | 83 TS | 86 BJ | 91 C | 94 TS |
| 34 Vv | 39 TS | 42 Vv | 47 C | 50 BJ | 55 Vv | 58 C | 63 TS | 66 BJ | 71 Vv | 74 TS | 79 C | 82 Vv | 87 C | 90 TS | 95 BJ |
| 33 TS | 40 Vv | 41 C | 48 BJ | 49 Vv | 56 TS | 57 BJ | 64 C | 65 TS | 72 C | 73 Vv | 80 BJ | 81 C | 88 TS | 89 BJ | 96 Vv |
| 4 Vv | 5 TS | 12 C | 13 Vv | 20 BJ | 21 C | 28 TS | 29 BJ | 97 C | 104 BJ | 105 BJ | 112 Vv | 113 Vv | 120 BJ | 121 C | 128 TS |
| 3 BJ | 6 C | 11 Vv | 14 BJ | 19 TS | 22 Vv | 27 C | 30 TS | 98 Vv | 103 TS | 106 TS | 111 C | 114 BJ | 119 Vv | 122 Vv | 127 BJ |
| 2 TS | 7 BJ | 10 TS | 15 C | 18 C | 23 TS | 26 BJ | 31 Vv | 99 BJ | 102 C | 107 Vv | 110 BJ | 115 C | 118 TS | 123 TS | 126 C |
| 1 C | 8 Vv | 9 BJ | 16 TS | 17 Vv | 24 BJ | 25 Vv | 32 C | 100 TS | 101 Vv | 108 C | 109 TS | 116 TS | 117 C | 124 BJ | 125 Vv |
| N0 | N1 | N2 | N3 | N2 | N1 | N0 | N3 | N0 | N1 | N2 | N3 | N2 | N1 | N0 | N3 |
| 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 squarrosum
Vv = Vicia villosa

I Block
II Block
III Block
IV Block

**Table 1** - The experimental layout of the Long-Term Experiment on Cover Crops

post-emergence (for maize and wheat) and pre-emergence (for sunflower) herbicides are used; hoeing is usually applied to spring crops. 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 availability of personnel, different intensities of sampling were performed from 1993 until the current growing season. The data collected in most seasons include the aboveground biomass of cash crop at harvest; the aboveground biomass of cover crops and weeds at the devitalization phase; and weed density at the early stage of a cash crop / cash crops. From 2008, weed cover at the full development of the cash crop /the cash crops was included in the sampling calendar.

## Results

*Soil fertility*
The two main parameters assessed to estimate the 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 first 15 years). Similarly, a significant increase is registered when fixing nitrogen cover crops are applied (the mean for the two-nitrogen fixing cover crop type is a 13.3% and 4.4% increase for organic carbon and total nitrogen respectively in 15 years). No-nitrogen fixing cover crop do not show any difference from the control (no cover crop applied) (Mazzoncini *et al.*, 2011).
Regarding soil biological fertility, the positive effect of reduced tillage on soil respiration and microbial biomass increased by 44% and 71% respectively when compared with conventional tillage systems. The abundance and diversity of micro-arthropods was another of the soil-health indicators used. Both indicators had higher values when tillage was reduced when compared with conventional tillage systems (Sapkota *et al.*, 2012).

*Weed control*
According to weed-composition measurements from 2012 to 2015, cover-crop type strongly influences weed-community composition during the cover-crop growth cycle. This effect was not clearly detectable in summer and winter cash crops. A low-input system mainly favoured the

**Figures 2 and 3** - Sorghum grown in spring 2018 showing the effects of the previous cover-crop plots (photos by Lorenzo Tramacere and Massimo Sbrana)

presence of perennial weeds. In this system, weed total biomass increased when compared with the conventional tillage system. This suggests that some adjustments to 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


- Bàrberi, P., & Mazzoncini, M. (2001). Changes in weed community composition as influenced by cover crop and management system in continuous corn. Weed Science, 49(4), 491-499.
- Carlesi S., Antichi D., Bigongiali F., Mazzoncini M., Bàrberi P. Long term effects of cover crops on weeds in Mediterranean low input arable management systems. 17th European Weed Research Society Symposium “Weed management in changing environments”, 23-26 June 2015, Montpellier, France (Oral presentation)
- Iocola, I., Bassu, S., Farina, R., Antichi, D., Basso, B., Bindi, M., ... & Giglio, L. (2017). Can conservation tillage mitigate climate change impacts in Mediterranean cereal systems? A soil organic carbon assessment using long term experiments. European Journal of Agronomy, 90, 96-107.
- Lechenet, M., Deytieux, V., Antichi, D., Aubertot, J. N., Bàrberi, P., Bertrand, M., ... & Debaeke, P. (2017). Diversity of methodologies to experiment Integrated Pest Management in arable cropping systems: Analysis and reflections based on a European network. European journal of agronomy, 83, 86-99.
- Mazzoncini, M., Sapkota, T. B., Barberi, P., Antichi, D., & Risaliti, R. (2011). Long-term effect of tillage, nitrogen fertilization and cover crops on soil organic carbon and total nitrogen content. Soil and Tillage Research, 114(2), 165-174.
- Moonen, A. C., & Barberi, P. (2004). Size and composition of the weed seedbank after 7 years of different cover-crop-maize management systems. Weed Research, 44(3), 163-177.
- Sapkota, T. B., Mazzoncini, M., Bàrberi, P., Antichi, D., & Silvestri, N. (2012). Fifteen years of no till increase soil organic matter, microbial biomass and arthropod diversity in cover crop-based arable cropping systems. Agronomy for Sustainable Development, 32(4), 853-863.


GPS coordinates: 43°40’11.7”N 10°18’49.2”E

**Contact:**

Daniele Antichi
daniele.antichi@unipi.it - tel. +39 050 2218962
Stefano Carlesi
stefano.carlesi@santannapisa.it
tel. +39 050 883569

# PERMANENT LIVING LEGUME MULCH FOR ORGANIC VEGETABLE AGROECOSYSTEMS

Vegetable crops are highly susceptible to weed competition. Crop rotation, mechanical control and transplanting are thus the main tactics for weed control in organic vegetable systems, but these techniques are often not enough to contrast weeds properly.
In this experiment, we focus on whether legume cover crops can be used as permanent living mulch to improve weed control in organic-vegetable cropping systems.
Living mulch is a cover crop planted either before or with a main crop and maintained as a living ground cover throughout the growing season. If the living mulch is perennial (i.e. using perennial or annual self-reseeding species), it may be possible to maintain it from year to year without the need for reseeding.
In this system, vegetable crops are usually planted or transplanted into the established living mulch by a no- or minimum tillage method each year. The living mulch is supposed to cover the inter-row space.
Both perennial and annual self-reseeding legumes may be suitable for the target system. Perennial legumes as living mulch are expected to ensure weed control all year round. Annual self-reseeding legumes are able to re-generate from the soil seed bank in autumn and therefore improve weed control during winter as living mulch, while they act as dead mulch during summer, hence limiting potential water competition.
However, when living mulch growth is too high, even a relatively vigorous crop, such as potato or cabbage, may suffer from competition and yield loss (Rajalahti & Bellinder, 1996 and Bottenberg et al., 1997). Indeed, selection for specific morphological, physiological and phenological characteristics is important, both to ensure the success of a living mulch system in suppressing weeds over the years and to prevent over-competition with the main crop.
The availability of suitable legumes for this system seems limited because the cultivars available on the market are normally selected for other uses, e.g. high biomass production, and, hence, they are likely to compete strongly with the main crop. The selection of a specific legume ideotype is therefore needed, exploring commercial cultivars or even native germplasms, which are often more suited to local environmental conditions.

### Objectives

We conducted a field experiment to screen several perennial and annual self-seeding commercial legume cultivars belonging to five legume species commonly used as permanent living mulch. The aim was to investigate the viability of morphological and physiological characteristics for their potential use as permanent living mulch, with a focus on their weed-suppression capacity.
An additional experiment was conducted to screen local ecotypes of *M. polymorpha*. The screening of ecotypes is expected to better identify legumes that are more suited to local environmental conditions than commercial cultivars. Ecotypes may have morphological and physiological characteristics that better fit with the legume ideotype required for the successful establishment of a permanent living mulch.
In general, the selection of legumes with the required traits may increase the practical application of this practice. Legumes with a prostrate growth habit, moderate biomass production and low water-requirement could be good candidates.

### Materials and methods 2019

The experiment was carried out in Pisa within an organic certified area of the “Enrico Avanzi” Centre for Agro-Environmental Research (CiRAA). Nineteen legumes, including commercial cultivars and ecotypes (perennial and annual self-reseeding), were tested in 4.5 $m^2$ plots.
Each legume type was repeated in four randomized blocks. Within the legume self-reseeding group, a collection of seven ecotypes of *Medicago polymorpha* L, among others, was tested. These were collected by Prof. Luigi Russi of Perugia University and kindly donated for this experiment.
Legumes were sown in November 2017 on a field previously ploughed at 25 cm depth and refined with a rotary harrow. No herbicides, fertilizers and fungicides were used. Legumes and weed growth were constantly monitored for two years, and three key biomass samplings were performed in spring and autumn 2018, and in spring 2019 in order to simulate what would be the most common practice at farm level in this system (before the hypothetical transplantation of summer and/or winter vegetable crops).
Germination capacity and seed hardness of both the *M.polymorpha* ecotype and commercial cultivars were also evaluated during autumn 2018 (Figure 4).

**Figure 4** - Evaluation of self-reseeding capacity in September 2018

As per the experiment's objectives, legumes were divided into two sub-sets and analysed separately as follows:
*Experiment 1:* treatments consisted in 12 legume commercial cultivars belonging to four legume types with spontaneous vegetation as control (Table 2).
*Experiment 2:* treatments consisted in seven ecotypes and three commercial cultivars of *M. polymorpha*, which were also used in Experiment 1 (Table 3). Bare soil was used as a control plot. Ecotypes were collected in Central Italy and were provided by the Germplasm Bank of the Institute of Genetic Improvement at the University of Perugia, the Pasture Research Centre, and the National Research Council (CNR) of Sassari (Figure 5).

| Legume species | Cultivars |
|---|---|
| *Lotus corniculatus* L. | Giada |
| *Lotus corniculatus* L. | Leo |
| *Trifolium repens* L. | Huia |
| *Trifolium repens* L. | Haifaa |
| *Trifolium repens* L. | RD84 |
| *Medicago polymorpha* L. | Scimitar |
| *Medicago polymorpha* L. | Anglona |
| *Medicago polymorpha* L. | Mauguio |
| *Trifolium subterraneum* L. | Fontanabona |
| *Trifolium subterraneum* L. | Antas |
| *Trifolium subterraneum* L. | Dalkeith |
| *Trifolium subterraneum* L. | Campeda |

**Table 2** - List of legume cultivars used in Experiment 1

## Results

Results from the first experiment showed no significant differences in terms of weed control among cultivars of the same legume species. Significant differences were, however, detected at species level when compared with the control (Figures 6A and 6B).
Annual self-seeding legumes had a stronger effect on weed biomass during the first year when compared with perennial legumes. This result might be explained by the perennial legumes' slower growth in the early stage and their lower level of maximum biomass accumulation. In addition, in spring 2018, the perennial legumes' annual biomass accumulation was on average only 20% of the self-seeding legumes'.
In spring 2019, the perennial legumes significantly affected weed biomass when compared with the control, while the annual self-seeding legumes had

| Legume species | Cultivars |
|---|---|
| **Ecotypes** | |
| *Medicago polymorpha* L. | Pitigliano (SI) |
| *Medicago polymorpha* L. | Manciano (GR) |
| *Medicago polymorpha* L. | Talamone (GR) |
| *Medicago polymorpha* L. | Principina (GR) |
| *Medicago polymorpha* L. | VIlla Salto (SS) |
| *Medicago polymorpha* L. | San Felice Circeo (LT) |
| *Medicago polymorpha* L. | Tarquinia (VT) |
| **Commercial** | |
| *Medicago polymorpha* L. | Scimitar |
| *Medicago polymorpha* L. | Anglona |
| *Medicago polymorpha* L. | Mauguio |

**Table 3** - List of *M. polymorpha* ecotypes and commercial cultivars used in Experiment 2

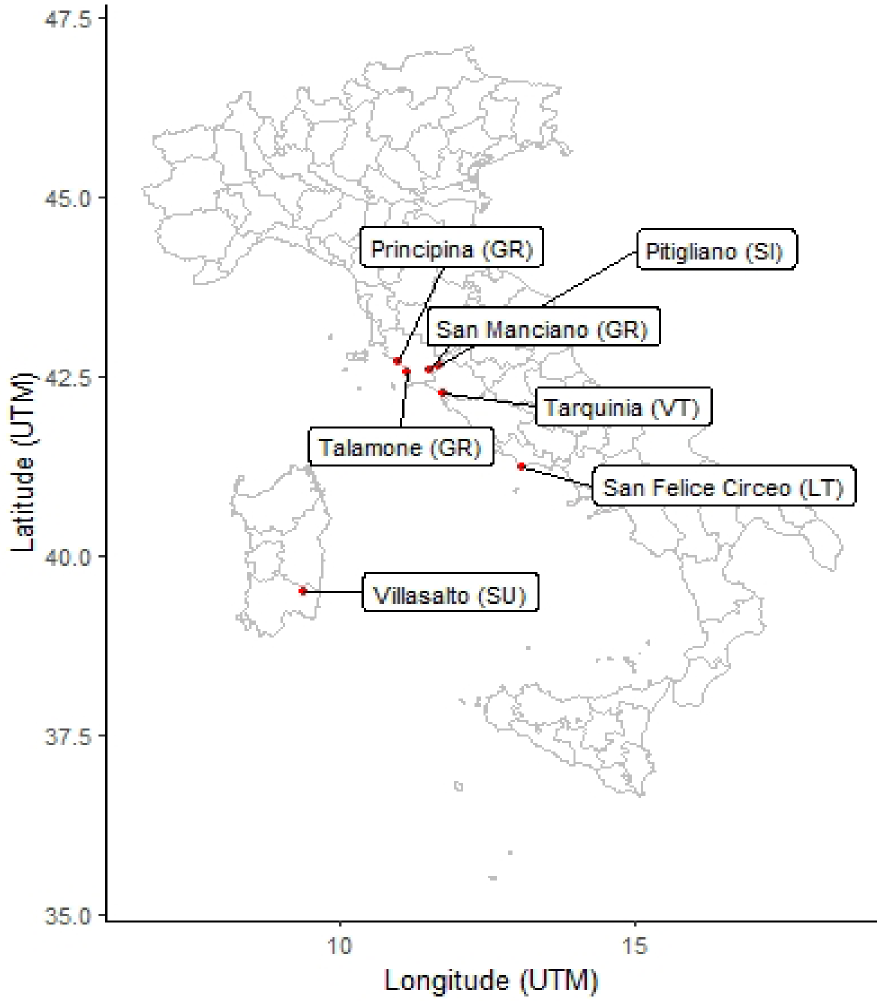



**Figure 5** - Location of *M. polymorpha* ecotypes used in Experiment 2


**Figures 6A and 6B** - A) weed infestation in the control plot in spring 2018; B) weed infestation with living mulch of *T. subterraneum* subsp. Brackycalicinum cv Antas in spring 2018

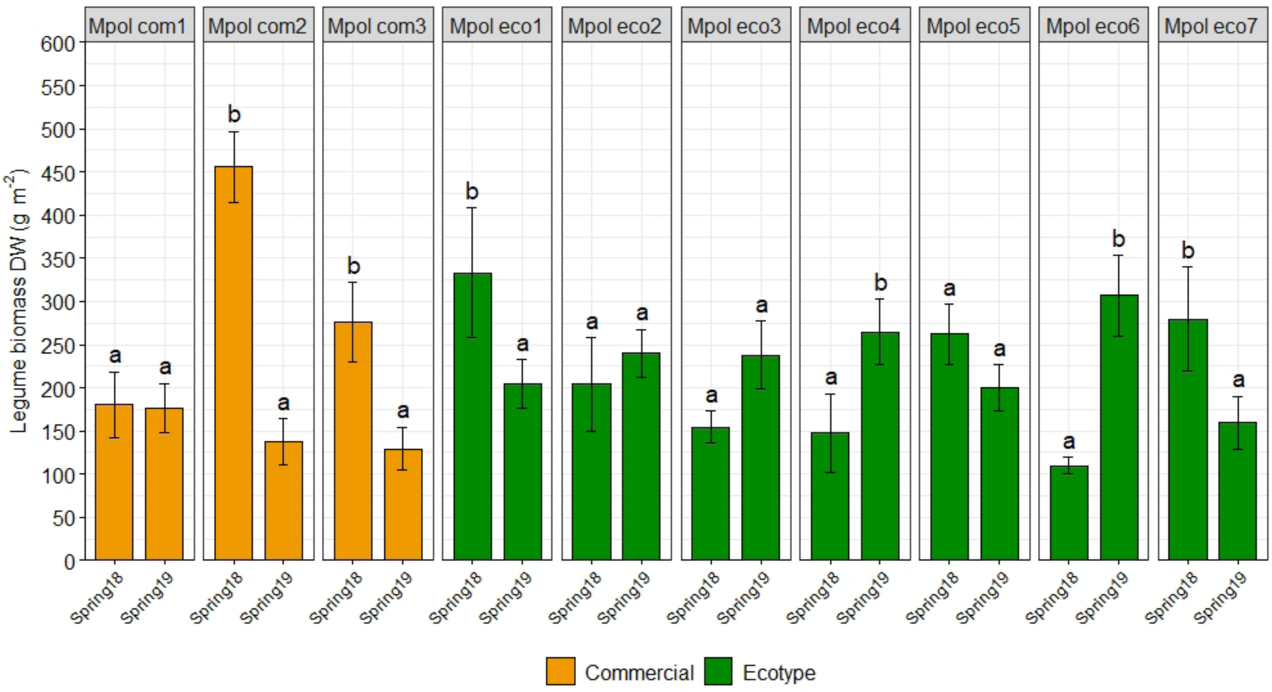



**Figure 7** - Comparison between legume biomass of *M. polymorpha* (ecotype and commercial cultivar) in spring 2018 and spring 2019.

**Legend**

**Mpol com1**: *M. polymorpha* cv Mauguio, **Mpol com2**: *M. polymorpha* cv Anglona, **Mpol com3**: *M. polymorpha* cv Scimitar, **Mpol eco1**: *M. polymorpha* ecotype Pitigliano (GR), **Mpol eco2**: *M. polymorpha* ecotype San Manciano (GR), **Mpol eco3**: *M. polymorpha* ecotype Talamone (GR), **Mpol eco4**: *M. polymorpha* ecotype Principina (GR), **Mpol eco5**: *M. polymorpha* ecotype Villasalto (SU), **Mpol eco6**: *M. polymorpha* ecotype San Felice Circeo (LT), **Mpol eco7**: *M. polymorpha* ecotype Tarquinia (VT)

no major effect against weeds.
This result might be explained by legume behaviour in autumn 2018. Our hypothesis is that the perennial legumes covered the soil as living mulch and significantly reduced weed biomass on average by 70% when compared with the control. The dead mulch of annual self-seeding legumes, however, marginally affected weed biomass, thus favouring their growth and dissemination. Among the annual self-seeding legumes, only *Trifolium subterraneum* subsp. Brachycalicinum cv Antas produced a dense and suppressive dead mulch, which was able to contrast weeds as effectively as the perennial legumes.
The purpose of the second experiment was to extend legume screening to native germplasm level. Seven ecotypes of *M. polymorpha* collected from Central Italy were evaluated and compared with commercial cultivars of the same species.
No significant differences in terms of weed control, for both ecotype and commercial cultivar, were detected in spring 2018 when compared with the control. In spring 2019, some ecotypes (e.g. Manciano (GR), Talamone (GR), Principina (GR), and San Felice Circeo (LT)) significantly affected weed biomass when compared with the control, while no differences were detected among commercial ecotypes.
This result seemed positive in terms of (i) the capacity of legumes to maintain or increase their biomass year by year; and (ii) their self-seeding capacity. Ecotypes, in general, increased their biomass in the second year, and they were characterized by a better self-seeding capacity when compared with commercial legumes. In spring 2019, the ecotypes of Manciano (GR), Talamone (GR), Principina (GR) and San Felice Circeo (LT) (the best-performing legume in terms of weed control) were characterized by a stronger increment of biomass accumulation than the previous year, up 35%, 65%, 125% and 200% respectively, (Figure 7) and by good self-seeding capacity (20%, 65%, 63% and 63% respectively).
The results of these experiments confirmed that

it is potentially interesting to further investigate the use of legumes as perennial living mulches as a tool for weed management in organic-vegetable systems. These experiments highlight how the effects on weeds may change according to the legume choice (at species level) and, more in general, between perennial and annual self-seeding legumes.
Perennial and annual self-seeding legumes showed complementarity over time in terms of weed control. Annual self-seeding legumes grow very fast during the first stage and produce a good amount of biomass during the first year. However, their weed-suppression capacity seems to decrease in the following year because of insufficient dead mulch coverage during the summer. In contrast, perennial legumes seem able to cover the soil throughout the year and control weeds effectively in the years after living-mulch establishment. Further experiments, therefore, should be conducted to study the use of mixtures of perennial and annual self-seeding legumes in this system with the objective of taking advantage of their complementarity for weed control. Interaction with a real vegetable system also needs to be tested.

Experimental site: Centre for Agro-Environmental Research at the University of Pisa (CIRAA), in San Piero a Grado (Pisa, Italy).
GPS coordinates: 43°40’42.9’’N 10°20’05.9’’E

**Contact:**
Stefano.carlesi@santannapisa.it
federico.leoni@santannapisa.it
tel. +39 050 883569

## RELAY INTERCROPPING OF LEGUMES IN DURUM WHEAT

Weed infestation and nitrogen deficiency are two major factors determining yield and grain protein content losses in cereal production. Wheat-legume relay intercrops can be a sustainable and innovating tool for optimizing nitrogen availability and weed control at rotation level.
Relay intercropping consists in growing two or more crops simultaneously, during part of their life cycle. In the current study, legume subsidiary crops are intersown in an already established durum wheat crop stand.
The delayed legume establishment is expected to (i) maintain wheat grain yield by limiting the legume-wheat interspecific competition, (ii) avoid the fallow period between wheat harvest and the following crop (up to 10 months in Mediterranean agroecosystems) and (iii) support weed control at rotation level.
However, the simple delay in sowing may not be sufficient to prevent yield loss and conversely may not properly contrast weeds; the appropriate choice of the associated legume, with specific morphological, phenological and physiological characteristics, is also essential for a successful application of this system. The legume ideotype suitable for relay intercropping should have high early vigour so that it can germinate below the wheat stand; be prostrate so that it covers the soil and controls weed growth; not accumulate too high a biomass to prevent over competition with the crop during the wheat-growing season; and be able to contrast weed germination and growth as dead or living mulch until the following crop is sown.
It is often true that commercial legumes, when selected for sole stand grain production or as forage, may not meet intercropping requirements. Specific legumes therefore need to be selected.

### Objectives

The objective of this study was the agronomic evaluation of legumes and the selection of the most suitable ones for relay intercropping with durum wheat for our local pedo-climatic conditions. The study focused on the effects of wheat-legume intercrops at rotation level.
Perennial, annual and annual self-reseeding legumes can be used for relay intercropping. During the intercropping period, the three groups can support weed control by establishing a living mulch. After the wheat harvest, weed-control

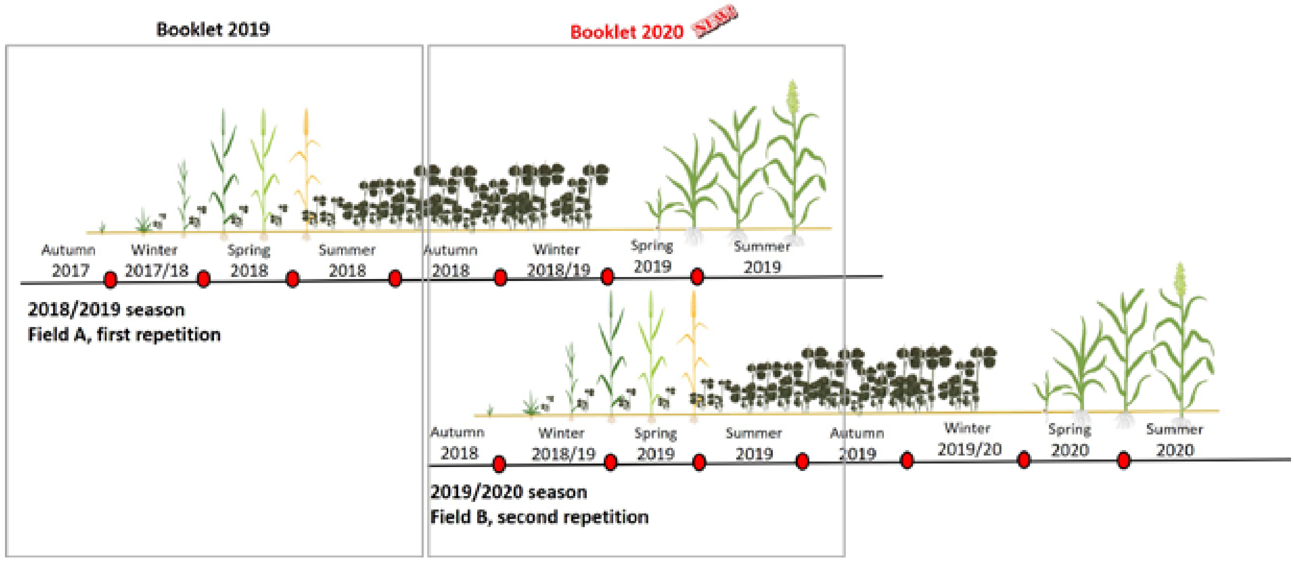



**Figure 8** - Experiment description

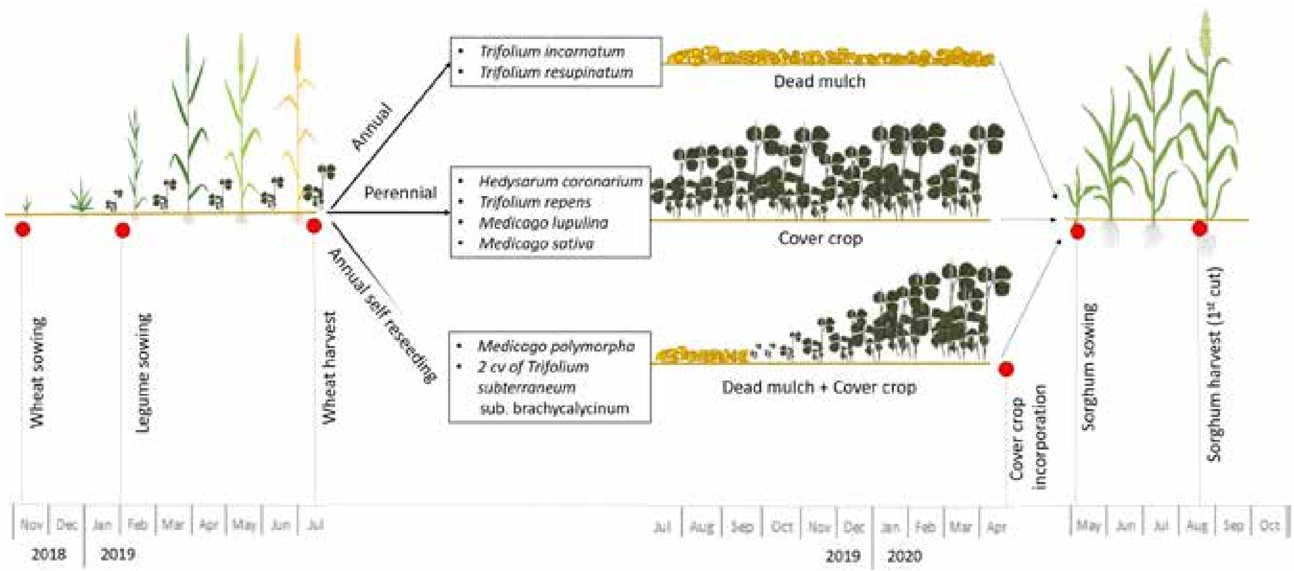



**Figure 9** - Perennial, annual and annual self-reseeding legumes used in a relay intercropping system

effect changes according to the group. Perennial legumes, traditionally used in this practice, can be used as a forage crop for 2-3 following years. Annual legumes with high self-reseeding capacity may be able to re-germinate from their seeds in autumn and serve as cover crops until the subsequent cash crops, while annual legumes support weed control as dead mulch until the following crop. Legume development, weed control, N availability, grain yield and grain quality were monitored in wheat up to the harvest of the following cash-crop (sorghum).

## Materials and methods

We are managing two fields (A and B, Figure 8) in order to replicate the trial for two consecutive wheat-growing seasons within a typical crop rotation for the Pisa plain area and to evaluate the effect of legumes on the following cash-crops. During 2018/2019 season, we performed the relay intercropping of wheat and legumes in Field A (605449.60E 4835806.55N).
After the wheat harvest, legumes continued to cover the soil during the summer as dead mulch (annual and self-reseeding legumes) or to work as cover crops (perennial legumes). In autumn 2018,

| Legume species | Cultivar | Note | Cycle | Sowing technique | Legume in test | |
|---|---|---|---|---|---|---|
| | | | | | 2018/2019 | 2019/2020 |
| *Trifolium alexandrinum* L. | Leila | | A | row | ✓ | |
| *Trifolium incarnatum* L. | Kardinal | | A | row | ✓ | ✓ |
| *Trifolium resupinatum* L. | Laser | | A | row | ✓ | |
| *Vicia villosa* L. | Capello | | A | row | ✓ | |
| *Medicago polymorpha* L. | Scimitar | | ASS | row | ✓ | ✓ |
| *Medicago truncatula* L. | Paraggio | | ASS | row | ✓ | |
| *Medicago scutellata* L. | Sava | | ASS | row | ✓ | |
| *Trifolium subterraneum* L. | Antas | sub. brachycalicinum | ASS | row | ✓ | ✓ |
| *Trifolium subterraneum* L. | Mintaro | sub. brachycalicinum | ASS | row/broadcast | ✓ | ✓ |
| *Trifolium subterraneum* L. | Monti | sub. yanninicum | ASS | row | ✓ | |
| *Trifolium subterraneum* L. | EP 118subJ | sub. subterraneum | ASS | row | ✓ | |
| *Madicago lupulina* L. | Antas | | P | row | ✓ | ✓ |
| *Madicago sativa* L. | Gamma | | P | row/broadcast | ✓ | ✓ |
| *Trifolium repens* L. | Companion | | P | row/broadcast | ✓ | ✓ |
| *Hedysarum coronarium* L. | Carmen | | P | row | ✓ | ✓ |
| Control | | Wheat as sole crop | | | ✓ | ✓ |
| No crop | | Spontaneus vegetation only | | | | ✓ |

A: annual legume, ASS: annual self-seeding legume, P: perennial legume

**Table 4** - Additional information on the legumes tested

self-reseeding legumes re-germinated from the seeds sown in summer, and they behaved as cover crops until the following crop was sown (Figure 9). In May 2019, legume biomass was incorporated into the soil, and sorghum for forage production (cv Sugar Graze 2) was seeded at the recommended seed dose, replacing the legume plot. The effects of legumes as a previous crop on sorghum were evaluated.
During the 2019/2020 season, this experiment was conducted a second time in Field B (608223.35E, 4837815.98N) (Figure 8).
After examining the results of the experiment's first replication, we reduced the number of legumes being tested to exclude the least-performing ones (e.g. *M. rotata, M. scutellate* and *M. truncatula*). Nine legume types were then tested, including annual (*Trifolium incarnatum* and *Trifolium resupinatum*), annual self-reseeding (*Medicago polymorpha* and two cultivars of *Trifolium subterraneum*), and perennial (*Medicago sativa, Medicago lupulina, Trifolium repens* and *Hedysarum coronarium*) (Table 4).
Additional plots with spontaneous vegetation were included in the experiment to evaluate the maximum potential of weed infestation.
The experiment was organized in a randomized complete block design, with four replicates for each legume type and the sole wheat crop as a control. The plot area was double the area used in the first season: 9 m$^2$ in 2017/2018 vs 18 m$^2$ in 2018/2019.
In the first replication, the seed bed was prepared (ploughing at 25 cm depth followed by rotary harrowing), after which we drilled durum wheat var. MINOSSE provided by IWMPRAISE-partner ISEA with an inter-row distance of 18 cm in December 2018. We subsequently drilled legumes in between wheat rows in February 2019 before the wheat stem elongation phase. *Medicago sativa, Trifolium repens* and *Trifolium subterraneum* cv Mintaro were also broadcast sown to evaluate whether the sowing technique would affect legume and wheat performance (Table 4).

### Results

The results on the effects of relay intercropped legume on wheat and weeds in the experiment's first repetition (2018/2019 season) were illustrated in the previous IWMPRAISE booklet.
In the current edition, we will present the new results available on the effects of legume on sorghum (2018/2019 season) and on the effects of the relay intercropped legume on wheat and weeds during the experiment's second replication (2019/2020 season) (Figure 8).

### 2018/2019 season

*Relay intercropped legume in durum wheat: effects on sorghum*

Some legume cover crops provided major benefits to the sorghum in terms of biomass production (Figure 10).

*Hedysarum coronarium, Trifolium subterraneum* subsp. *brachycalycinum, Medicago polymorpha, Trifolium repens, Vicia villosa* and *Medicago sativa* increased sorghum biomass by 410%, 390%, 361%, 325%, 270%, and 185% respectively when compared with the control (Figure 11). In these cases, sorghum reached a production level comparable with the same sorghum variety grown

under conventional systems (700 DW g/$m^2$).
The perennial legumes used in the experiment seem highly suitable for this system. Perennial legumes, except for *M. lupolina*, produce a good amount of biomass after the wheat harvest and provide a strong positive effect on the following crop.
Performances of annual self-seeding legumes appear very diversified among the legume species used in the experiment because of their different self-seeding capacity.
*Trifolium subterraneum* subsp. Brachycalicinum and *Medicago polymorpha* seem to be very good candidates for this system. After wheat harvest, they regrow properly from their soil seed bank and are able to establish a dense, suppressive mat of biomass. Due to their good biomass accumulation, they also provide positive effects on sorghum production and N content. Despite the high amount of seed production, other annual self-seeding legumes (e.g. *M. rotata, M. scutellata, M. truncatula*) do not seem able to re-germinate properly from their soil seed bank, probably due to their high seed-hardness.
Annual legumes, except for *Vicia villosa*, did not affect sorghum production when compared with the control. Annual legumes do not seem able to produce enough biomass during the intercropping period to establish a dense dead mulch until the following crop, ruling out our hypothesis. Thus, annual legumes showed a mild weed suppressive capacity and did not significantly affect sorghum production.

### 2019/2020 season

*Relay intercropped legume in durum wheat: effects on wheat and weeds*

Results from the experiment's second replication confirmed that intercropped legumes did not affect wheat production neither in quantitative or qualitative terms (Figure 12A). Production was on average 5.35 t/ha, in line with the local production level. Grain protein content was on average 12.5%. However, intercropped legumes (except for *Trifolium repens*) showed a significant effect on weeds (Figures 13A and 13B). Legumes decreased the weed biomass on average by 70% when compared with the control (Figure 13B).

### Further developments

We have used this on-going activity at the experimental farm as an open-air catalogue from which to develop intercropping solutions with local farms. The plan is to continue to do so. In

**Figure 10** - A sorghum-seeded plot that replaced a legume plot. This photo highlights the different effects of legume as a previous crop on sorghum biomass and N content (photo by Federico Leoni)

June 2018, a group of farmers participated in an organized open field day that was an occasion to share the challenges and opportunities of including intercropping in local cropping systems. From this exchange, we conducted on-farm experiments at La Viola and Floriddia farms (see pages 67 and 73).

Experimental site: Centre for Agro-Environmental Research at the University of Pisa (CIRAA), in San Piero a Grado (Pisa, Italy).
GPS coordinates: 43°40'06.96''N, 10°18'31.49''E

**Contact:**
federico.leoni@santannapisa.it
stefano.carlese@santannapisa.it
tel. +39 050 883569

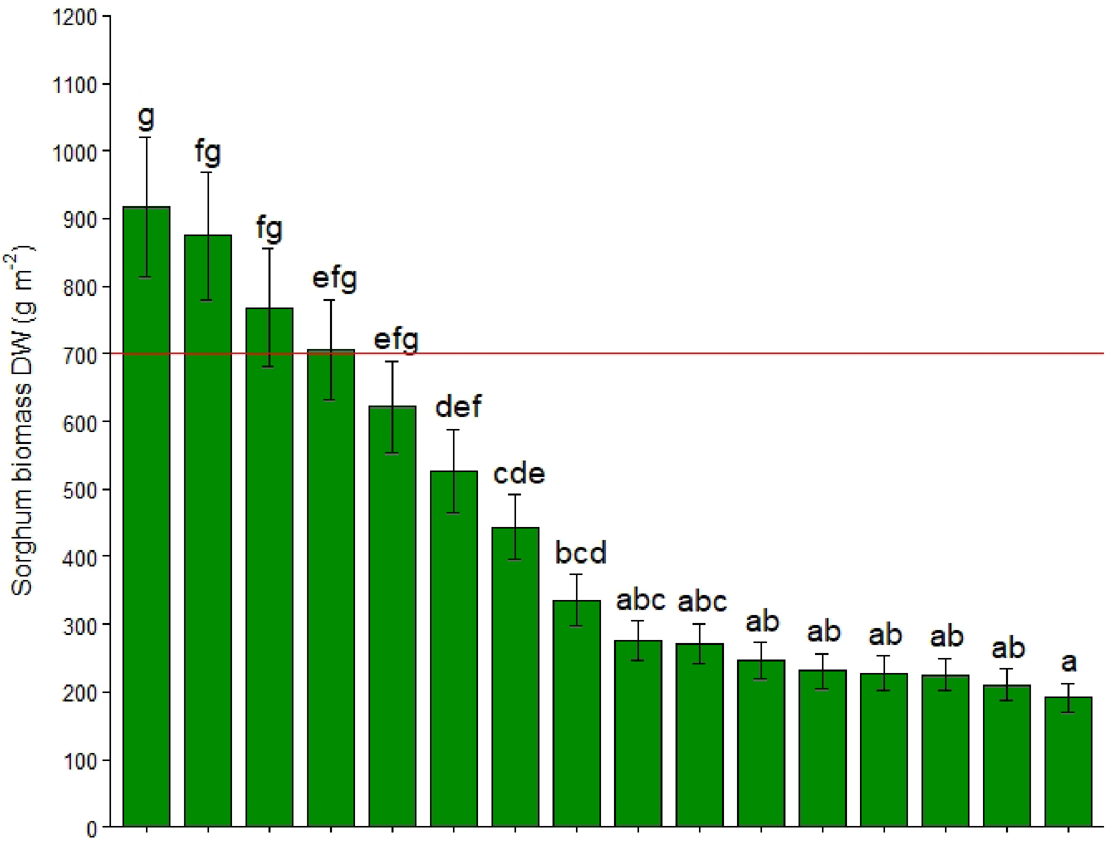
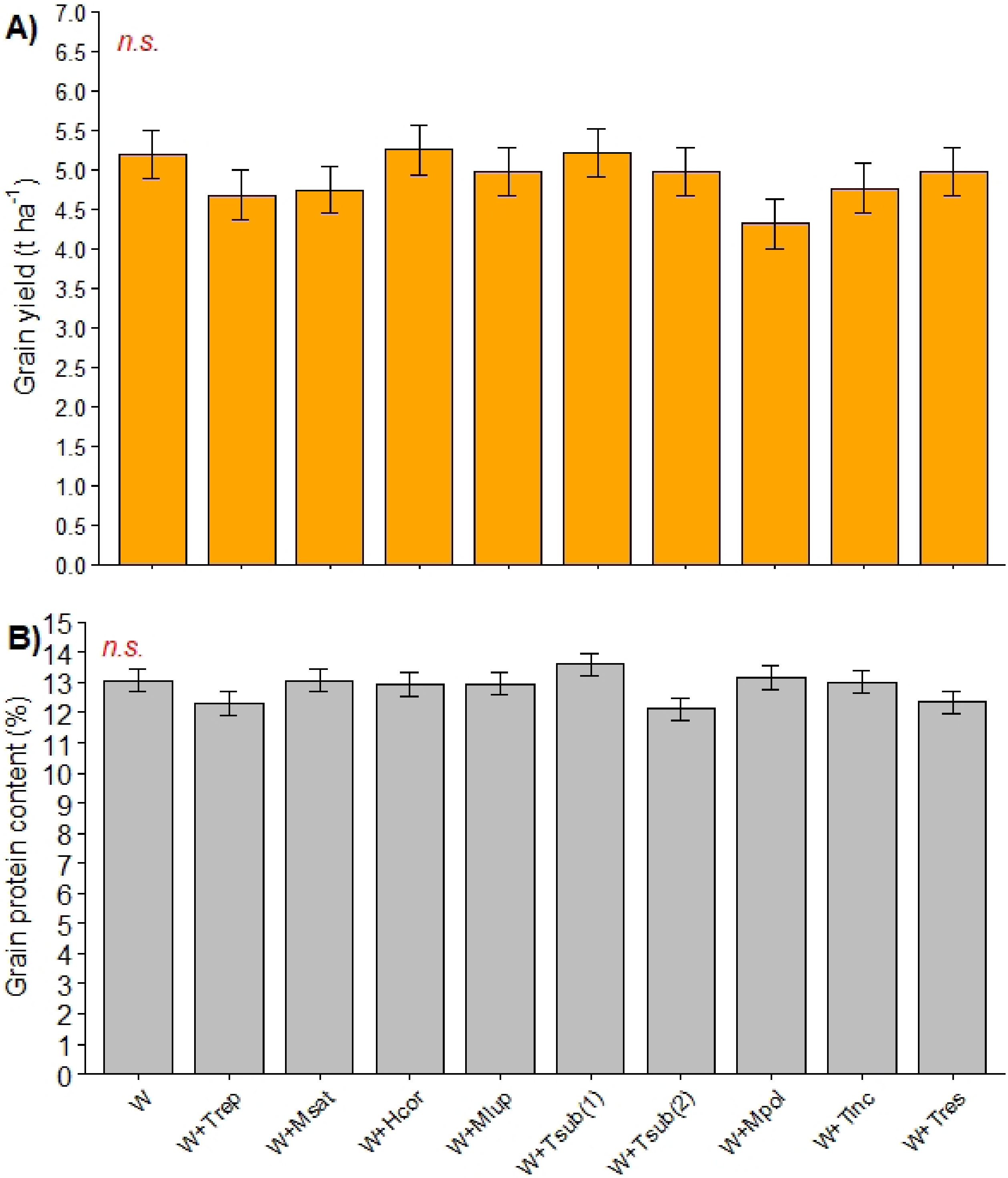



**Figure 11** - Effects of incorporated legume biomass on sorghum biomass production (DW g/m$^2$).

**Legend**
**Tinc**: *Trifolium incarnatum*, **Mscu**: *Medicago scutellata*, **Mtru**: *Medicago truncatula*, **CNT**: wheat as sole stand crop, **Tale**: *Trifolium alexandrinum*, **Tres**: *Trifolium resupinatum*, **Mlup**: *Medicago lupulina*, **Tsub(4)**: *Trifolium subterraneum* subsp. subterraneum , **Tsub(3)**: *Trifolium subterraneum* subsp. yianninicum, **Msat**: *Medicago sativa*, **Tsub(2)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Mintaro, **Vvil**: *Vicia villosa*, **Trep**: *Trifolium repens*, **Mpol**: *Medicago polymorpha*, **Tsub(1)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Antas, **Hcor**: *Hedysarum coronarium*




**Figures 12A and 12B** - Wheat production (A, t/ha) and grain protein content (B, %).

**Legend**

**W**: wheat as sole stand crop, **Trep**: *Trifolium repens*, **Msat**: *Medicago sativa*, **Hcor**: *Hedysarum coronarium*, **Mlup**: *Medicago lupulina*, **Tsub(1)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Antas, **Tsub(2)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Mintaro, **Mpol**: *Medicago polymorpha*, **Tinc**: *Trifolium incarnatum*, **Tres**: *Trifolium resupinatum*

**Figures 13A and 13B** - Wheat as sole stand crop (left) and relay intercropping of Medicago sativa in wheat (right). The presence of legume contrasted weed growth and emergence (photos by Federico Leoni)

## USE OF THE DONDI CUT-ROLLER AS A ROLLER CRIMPER

### Objectives

The objective was to test the effectiveness of a “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 was produced by DONDI S.p.A. and marketed as a tool for crop-residue management. Besides fine-tuning working speed and blade typology, special focus was on weed suppression and soil compaction.

### Materials and methods

An on-station field experiment is being carried out at the “Enrico Avanzi” Centre for Agro-Environmental Research at the University of Pisa (CiRAA), in San Piero a Grado (Pisa, Tuscany). Three cover-crop treatments (rye - *Secale cereale* L.-; hairy vetch - *Vicia villosa* Roth.-; and a rye-vetch mixture) were drilled on 28 October 2019 on three 30 m x 260 m fields. The sowing rates were 180, 120 and 90:60 kg/ha for rye, vetch and the rye-vetch mixture respectively. In sub-plots, we tested the effect of different combinations of blade typology (i.e. sharpened vs not sharpened) and working speed (5, 10 and 15 km/h) on the killing rate for the three cover crops. In 2019, we replicated the 2018 trial, maintaining the same cover crop termination timing, which took place on 5 and 6 June (Figure 15) for sharpened and non-sharpened blades respectively. At that time, the phenological stage was full milky ripening (BBCH 77) for rye and full flowering (BBCH 69) for vetch. As in the previous years, a grain sorghum cash crop (*Sorghum bicolor* (L.) Moench cv. Baggio) was direct drilled into the dead mulch provided by the cover crops immediately after the cover crops had been terminated.

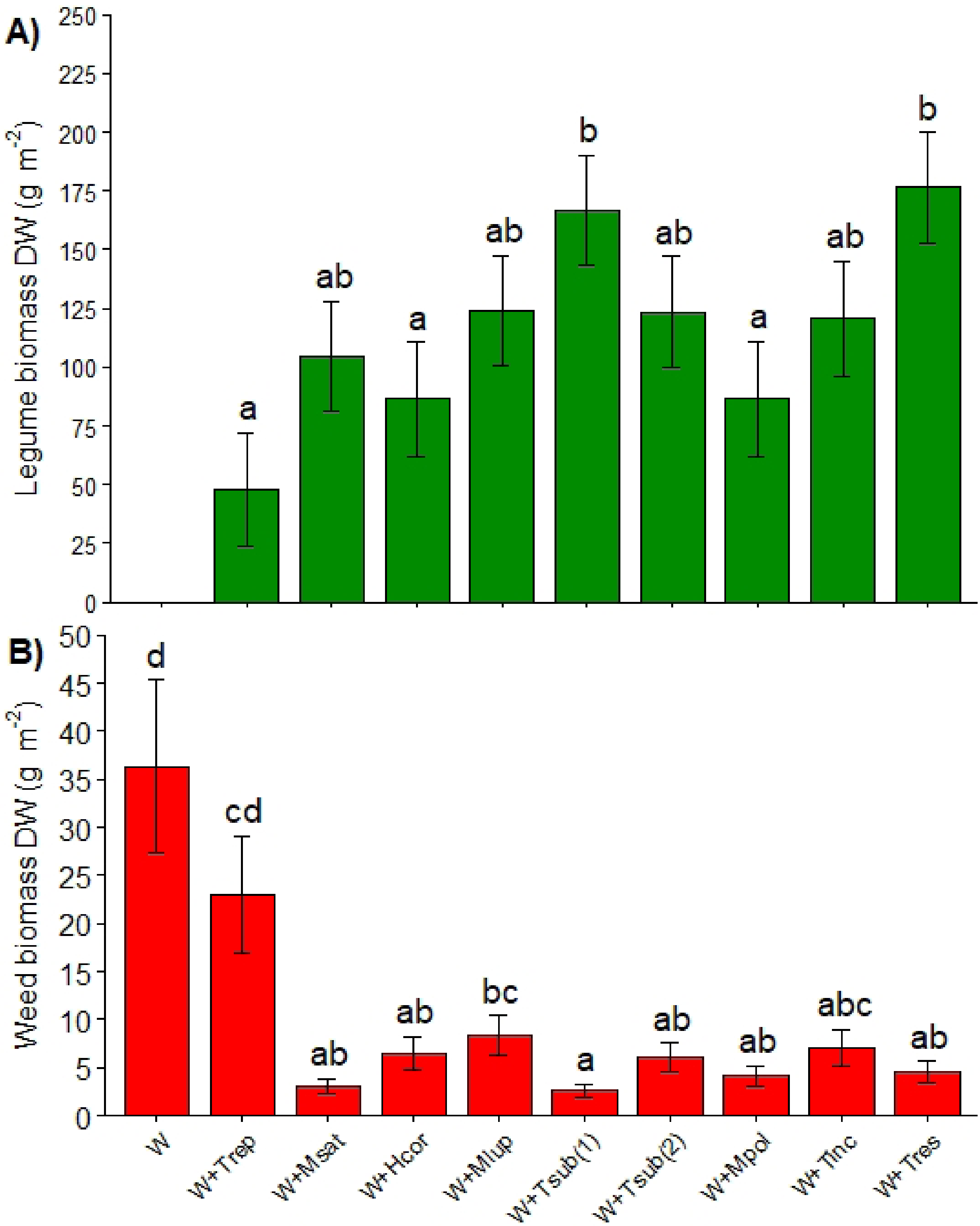
We assessed the following parameters:

- 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 rye plants;
- Killing rate and cover-crop dynamics (through image analysis);
- Weed suppression in the sorghum crop;
- Effect of the termination technique and cover crop species on sorghum emergence, growth, N accumulation and yield;
- Soil compaction;
- Energy consumption and economic issues.

The trial was also repeated in 2019/20 on three different fields (Figure 16).

### Preliminary results

In the second year trial, we obtained very good results for biomass production by cover crops, especially for the pure rye stand, which achieved 8.95 t d.m./ha, a value statistically higher than




**Figures 14A and 14B** - Legume biomass (A, DW g/m²) and weed biomass (B, DW g/m²).

**Legend**

**W**: wheat as sole stand crop, **Trep**: *Trifolium repens*, **Msat**: *Medicago sativa*, **Hcor**: *Hedysarum coronarium*, **Mlup**: *Medicago lupulina*, **Tsub(1)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Antas, **Tsub(2)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Mintaro, **Mpol**: *Medicago polymorpha*, **Tinc**: *Trifolium incarnatum*, **Tres**: *Trifolium resupinatum*

**Figure 15** - Direct sowing of the sorghum on the rye mulch on 6 June 2019


**Figure 16** - 2019/20 field trial at CiRAA (43°39'34.72''N 10°18'06.26''E) (photo ©2017 Google)

**Figure 17** - Termination of rye by the cut-roller in 2019

**Figure 18** - Termination of the vetch cover crop two weeks after the termination date in 2019

both the mixture (6.64 t d.m./ha) and the pure vetch stand (4.60 t d.m./ha). The mixture confirmed the good performance showed in 2017/18 in weed-suppression terms, with a total weed dry matter at cover-crop termination of only 0.20 t/ha. This value was significantly lower than the other two cover-crop treatments. The cut-roller performed very well again in the termination of the cover crops because the rye and vetch were in their late phenological stages (Figure 17). On average, the half-life of the cover crops was far lower (~1 day) than the value of around 4.5 days after termination observed in the first year, with the 90% termination rate being achieved in just one week (Figure 18). This year, we were unable to assess the proportion of crimped and cut biomass in each cover crop, as the vetch plants were not in good shape after rolling, and it was impossible to distinguish between crimped and cut biomass. Although the cut-roller pass produced up to 2.5 cm deep indentations, it did not result in significant soil compaction. The cone index values at 15 cm depth measured by penetrometer showed that, on average, soil-penetration resistance increased more after rolling than before rolling. This was particularly evident in the vetch plots. Nevertheless, the values did not reach the soil-compaction threshold (2000 kPa). The effect of blade typology and working speed were less evident.

**Figure 19** - Well-developed sorghum plants on the vetch plots at 6-leaf stage. The vetch dead mulch is visible on the ground

Sorghum plants directly sown in the vetch and mixture plots took advantage of the higher nitrogen availability provided by the legume cover crop through $N_2$-fixation and quickly overgrew the sorghum plants on the rye plots without N fertilization (Figures 19 and 20). This was well-documented by SPAD values, which were higher in vetch and mixture plots than in rye on all three sampling dates.
At harvest time, the effect of the mixture and vetch resulted in significantly higher grain yield (5.81 and 6.56 t/ha) than rye, leading to very poorly established and developed sorghum plants (grain yield was only 0.55 t/ha). Weed suppression was very good in all treatments, but reached the highest values in the vetch and mixture plots (0.33 t d.m./ha), and the lowest in the rye plots (0.90 t d.m./ha).

### Further developments

The very good results of the cut-roller as a roller crimper obtained in 2017/18 and 2018/19 were clearly determined by the late termination date due to the wet conditions in spring. The key factor for boosting roller-crimper spread would be a late termination date, even in the early stages of cover-crop development. Nevertheless, the good level of grain sorghum yield in the first two years in the vetch and mixture plots confirmed that a late sowing date did not negatively affect sorghum establishment and growth, even without irrigation.

**Figure 20** - Sorghum plants at the flowering stage on vetch plots

**Contact:**
christian.frasconi@unipi.it tel. +39 050 2218922
daniele.antichi@unipi.it tel. +39 050 2218962

## SMOCA LTE – CONSERVATIVE MANAGEMENT OF ORGANIC FIELD VEGETABLES

### Objectives

The main objective was 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 and soil fertility, as well as 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) (Figure 21). Three different cropping systems (ORG, RED, PER) were established there in winter 2017/18, and are being compared with a system approach for three years. ORG is mainly based on standard organic practices, such as annual soil tillage, green manures 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 was 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, while 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, totalling eighteen 3 m x 21 m plots. The field is split into two parts with two crop-sequence segments in order to halve the time needed to replicate the

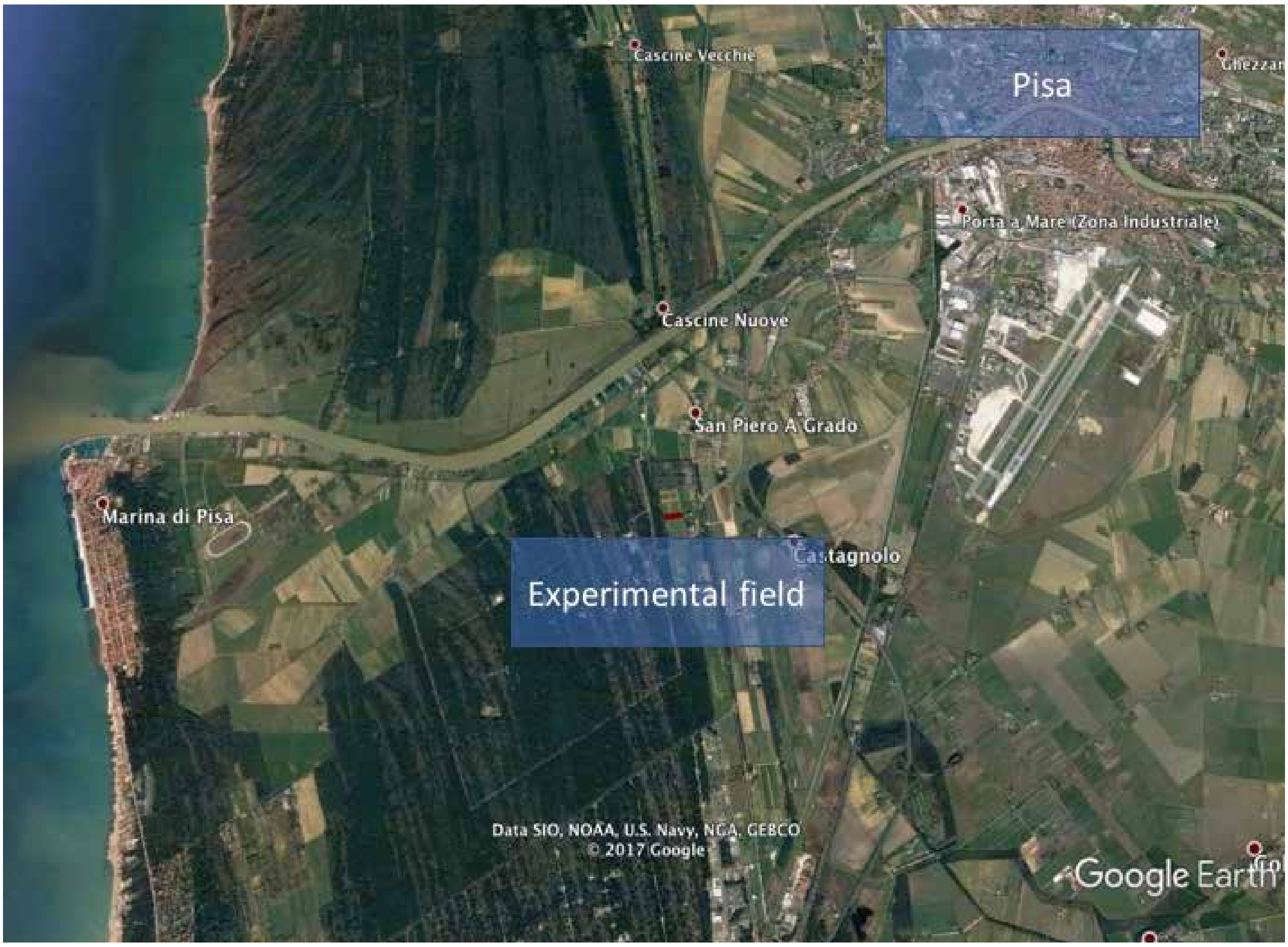



**Figure 21** - 2019/20 field trial at CiRAA (43°40'18.47''N 10°20'40.25''E) (photo ©2017 Google)

crop sequence twice. Each year, the following parameters are 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;
- 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.

### Preliminary results

The trial started with tomato (*Solanum lycopersicon* cv. Brixsol) and melon (*Cucumis melo* cv. Bacir) in 2017/18, but weed-suppression and crop-yield results were not good for either species. In 2018/19, chicory (*Cichorium intybus* Pan di Zucchero cv. Uranus) was transplanted after tomato in early autumn and harvested in December 2018. Melon was followed by fresh bean (*Vicia faba* var. *major*), sown in January 2019. For chicory, we obtained good yield results in all treatments, with PER showing the highest yield (38.06 t f.m./ha), although it was not statistically different from ORG and RED. Weed biomass level at harvest time was very low (0.11 t d.m./ha) on average, although the white-clover living mulch was not well-developed (~15% soil coverage) in PER and RED. We observed better results in faba bean for ORG and then RED, whilst PER achieved the lowest yield (87.5% less than ORG and 50% less than RED). This was likely due to a poorly developed root system and also to low root-nodule activity (not investigated). Melon was transplanted after chicory in Field 1 in May 2019 and harvested in August 2019 (Figure 22).

The results confirmed those of the first year, with a very low fruit yield in all three systems due to very high weed presence (5, 7 and 8 t d.m./ha for ORG, PER and RED respectively), especially for summer species such as *Echinocloa crus-galli*, *Digitaria sanguinalis, Setaria viridis*, and *Cynodon dactylon*. Although resown in spring 2019, the clover did not survive the melon harvest (Figure 23). For fennel (*Foeniculum vulgare* L. cv. Montebianco), which was grown after faba bean in Field 2 in autumn 2019, the head yield results obtained in PER (4.31 f.m./ha) were significantly lower than RED and ORG (10 t f.m./ha, on average) (Figure 24). The weed biomass at harvest was acceptable, with it being very similar among the three systems (~1 t d.m./ha); this meant that weeds were not the main reason behind the difference in crop yield.

**Figure 22** - Melon with weeds in the ORG system

### Further developments

In 2019/20, we will continue testing the three treatments on faba bean, tomato, chicory and fennel. We will also start on-farm trials in organic vegetable farms as part of an EIP-Operational Group called “AMORBIO” that will be linked to IWMPRAISE. The following solutions will be tested to achieve satisfactory weed control:

- an innovative, thick, biodegradable mulch to be used to cover the soil for more than a crop, thus making permanent soil cover possible;
- a combination of living and dead mulch to protect the soil from weeds without hand-weeding in raised beds.

**Contact:**
christian.frasconi@unipi.it tel. +39 050 2218922
daniele.antichi@unipi.it tel. +39 050 2218962

## MANAGEMENT OF WHITE CLOVER LIVING MULCH IN FIELD VEGETABLES

### Objectives

The main objective was to test alternative management options for a dwarf variety of white clover (*Trifolium repens* L. var. Pipolina) grown as living mulch for two field vegetables in sequence, i.e. cauliflower (*Brassica oleracea* L. var. botrytis) and eggplant (*Solanum melongena* L.).

### 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) (Figure 25). Three treatments were established there in winter 2018/19. The treatments were control without cover crop based on conventional tillage; a living mulch system with white clover regularly managed by flaming; and a living mulch system with white clover regularly managed by mowing. In October 2018, the white clover was sown at a 100 kg/ha seeding rate. In spring 2019, the clover was regularly mowed or flamed before the cauliflower was transplanted in August 2019. Cauliflower was established with a wide inter-row (0.8 mx1m) in order to allow for mowing and flaming. The living mulch and weeds were controlled in the two living mulch treatments by mowing (once a week) and flaming (three times over the entire crop-growing period) (Figure 26). In the control treatment, weeds were controlled by inter-row cultivation (twice over the entire crop-growing period). The cauliflower was harvested manually on 4 December 2019 (Figure 27).
The experimental design is a randomized complete block (RCB) with three replications totalling nine 5.6 m x 20 m plots. The field is split into two parts: cauliflower was grown in one half in 2018/19; and eggplant will be grown in the other in 2019/20. A temporal replication of the trial will be carried out from 2018/19. The following parameters are assessed each year:

- Biomass and soil cover produced by cover crops and cash crops (i.e. yield and residues) at maturity;
- Energy consumption and monetary cost of each field operation.

### Preliminary results

The marketable yield of the tilled control was 42% higher on average than the two living-mulch based systems. The system based on regular living-mulch mowing performed better than flaming

**Figure 23** - Partial recovery of the white clover after melon harvest in 2019

**Figure 24** - Fennel in the PER system in 2019


**Figure 25** - 2019/20 field trial at CiRAA (43°40’20.0’’ N 10°20’39.0’’E) (photo ©2020 Google)

**Figure 26** - Living mulch of white clover well-established in cauliflower

in terms of yield (up 23%) and of weed biomass reduction (375% lower). In 2020, eggplant will be transplanted on the field where cauliflower was harvested, and the cauliflower experiment will be replicated in an adjacent field.

**Figure 27** - Cauliflower at harvest time in the living-mulch system

### Further developments

In 2019/20, we will continue testing the three treatments on eggplant on the field of the first-year experiment, and the first-year trial will be replicated in the second field.

### Contact:

christian.frasconi@unipi.it tel. +39 050 2218922
daniele.antichi@unipi.it tel. +39 050 2218962

# EXPERIMENTAL TRIALS AT HORTA SRL

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

**Figure 2** - Main Horta building, Cà Bosco farm (Ravenna)

*Horta is a spin-off company of University Cattolica of Sacro Cuore. It was founded in 2008 and its mission is to add value to research results by transferring technological innovation to practical agriculture. Horta provides agriculture services for crop production at both national and international level in a bid to improve the production of both farmers and agro-food industries in terms of quality, stability and sustainability. Horta conducts experimental trials on Cà Bosco farm, which covers 220 ha and is divided into three 70 ha blocks. The farm has one area run under integrated management and one under organic management.*

*It applies 3-4-year rotations, with durum wheat, bread wheat, maize, sugar beet, pea and soy as its main crops. Soil texture is mainly loamy, with a tendency to silt-loam. The farm has a two-pivot irrigation system, with one pivot being set up as a hippodrome. It also has an underground drainage system. Horta manages about 20 ha of the farm and conducts its experimental trials there in plots. Its main experiments are on small-grain cereal, maize and tomato, with its small-grain cereal trials studying chiefly fungicide efficacy, crop fertilization and sowing density.*

**Address:**
**Horta Srl - Spin Off Università Cattolica del Sacro Cuore**
**Az. Agr. Ca' Bosco**
**Via S. Alberto 327**
**48123 Ravenna - Italy**
**GPS coordinates: 44.482379; 12.177232**

**For further information, please contact:**
**Pierluigi Meriggi**
**e-mail: p.meriggi@horta-srl.com**
**tel. +39 0544 483261**

## SCREENING OF SUITABLE LEGUMES FOR RELAY INTERCROPPING WITH DURUM WHEAT

Durum wheat is the most-cultivated small grain cereal in Italy and it represents a major agricultural commodity because of the country's enormous pasta industry.
Weed infestation is one of the main concerns for cereal production. Relay intercropping of legume in durum wheat may be a sustainable and innovative tool for integrated weed management (Figure 3).
The relay intercropping of legume in wheat is expected to guarantee that the legume remains before and after wheat harvest, contrasting weeds and improving soil fertility at crop rotation level. After wheat harvest, the legumes remain in the field and their presence prevents the bare soil period between wheat harvest and the following crop (Figures 4A and 4B). In Mediterranean conditions, two cash crops are separated by up to 9 months, and the uncovered soil in this period favours weed emergence, growth and dissemination.
Appropriate legume choice is needed for the successful application of this system.
The legume ideotype suitable for relay intercropping should have high early vigour so that it can germinate below the wheat stand; be prostrate so that it covers the soil and controls weed growth; not accumulate too high a biomass to prevent over competition with the crop during the wheat-growing season; and be able to contrast weed germination and growth as dead or living mulch until the following crop is sown.
It is often true that commercial legumes, when selected to produce forage, may not meet intercropping requirements. Specific legumes therefore need to be selected.

**Figure 3** - Relay intercropping of legume in durum wheat

**Figures 4A and 4B** - *Medicago sativa* (left) and *Trifolium repens* (right) immediately after wheat harvest (photos by Matteo Ruggeri)

## Objectives

The study includes annual, annual self-seeding and perennial legumes, and aims to select the best-performing ones for relay intercropping with durum wheat for our local pedo-climatic conditions.
We are studying the effects of the wheat-legume relay intercropping before and after wheat harvest. The hypothesis is that relay intercropping of legume in wheat allows wheat-grain yield to be maintained by limiting the legume-wheat interspecific competition and allows a dense and suppressive living/dead mulch to be established, as per the legume used, until the following crop (Table 1).

## Materials and methods 2020

In this experiment, we are testing 13 commercial legume cultivars. They include annual (1 cv of *Trifolium incarnatum*, 2 cv of *Trifolium resupinatum*, and 1 cv of *Trifolium alexandrinum*), self-reseeding (1 cv of *Medicago polymorpha*, 1 cv of *Medicago scutellata*, and 3 cv of *Trifolium subterraneum*), and perennial legumes (1 cv of *Medicago lupulina*, 1 cv *Medicago sativa*, 1 cv of *Trifolium repens*, and 1 cv of *Hedysarum coronarium*) (Table 2). The control plot consists in wheat as monoculture.
Additional plots include i) *Medicago sativa* as sole crop to evaluate the Land Equivalent Ratio (LER)[1] of this important forage crop; and ii) plots with spontaneous vegetation to evaluate the maximum potential of weed infestation. The experiment was organized in a randomized complete block design, with four replicates for each legume type and the sole wheat crop as control. The plot area was 9 m$^2$ (1.5 x 6 m).
After seed bed preparation, durum wheat var. Minosse supplied by IWMPRAISE-partner ISEA was sown in December 2019, with an inter-row distance of 17 cm. Legume species were then broadcast sown between wheat in March 2020, before the

| | Cropping system | Details on weed control service |
|---|---|---|
| Annual legumes |  | Weed control: **MEDIUM-HIGH**<br>Soil cover: **MEDIUM-HIGH**<br>Soil fertility: **MEDIUM-HIGH**<br>System productivity: **MEDIUM** |
| Self-reseeding legumes |  | Weed control: **HIGH**<br>Soil cover: **HIGH**<br>Soil fertility: **HIGH**<br>System productivity: **MEDIUM** |
| Perennial legumes |  | Weed control: **HIGH**<br>Soil cover: **HIGH**<br>Soil fertility: **HIGH**<br>System productivity: **HIGH** |
| **Durum wheat variety:** MINOSSE, resistant to lodging<br>**Durum wheat seed dose:** 230 kg/ha<br>**Distance between durum wheat rows:** 17 cm<br>**Durum wheat sowing date:** 11/12/2019<br>**Legumes sowing date:** 11/03/2020 | | |

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

[1] Land Equivalent Ratio (LER): the ratio of the area under sole cropping to the area under intercropping needed to give equal amounts of yield at the same management level. It is the sum of the fractions of the intercropped yields divided by the sole-crop yields.

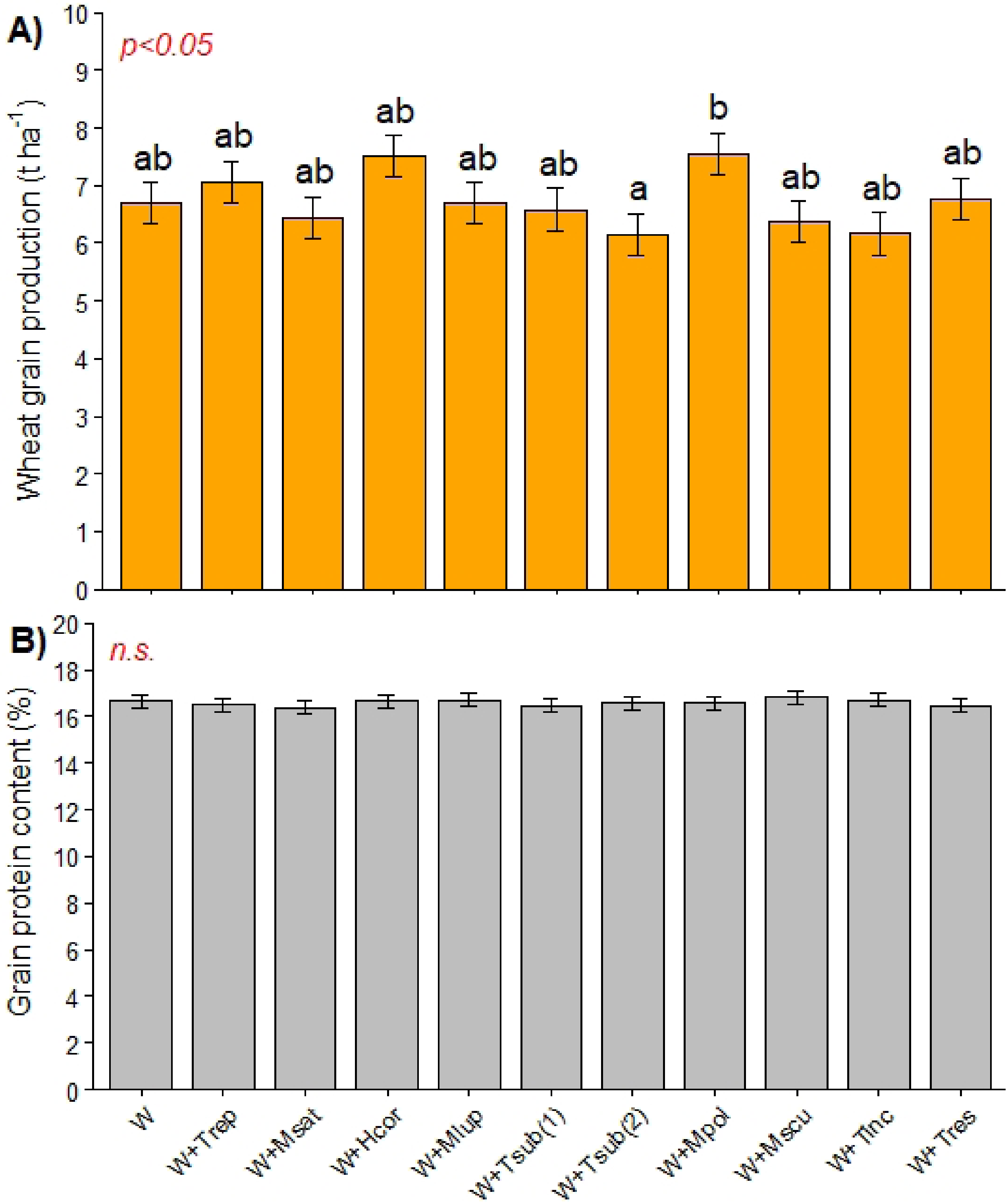
| Legumes | Type |
|---|---|
| *Trifolium incarnatum* cv. Kardinal | Annual |
| *Trifolium resupinatum* cv. Laser | Annual |
| *Trifolium resupinatum* cv. Lightning | Annual |
| *Trifolium alexandrium* cv. Leila | Annual |
| *Medicago polymorpha* cv. Scimitar | Self-reseeding |
| *Medicago scutellata* cv. Sava | Self-reseeding |
| *T. subterraneum* subsp. brachycalcinum cv. Mintaro | Self-reseeding |
| *T. subterraneum* subsp. sp. yanninicum cv. Monti | Self-reseeding |
| *T. subterraneum* subsp. brachycalcinum cv. Antas | Self-reseeding |
| *Hedysarum coronarium* cv. Carmen | Perennial |
| *Medicago sativa* cv. Gamma | Perennial |
| *Trifolium repens Ladino* cv. Fantastico | Perennial |
| *Medicago lupulina* cv. NA | Perennial |
| Control 1 (wheat as sole crop) | |
| Control 2 (*M. sativa* as sole crop) | |
| Control 3 (spontaneous vegetation) | |

**Table 2** - List of legumes tested in the 2019/2020 growing season

wheat stem elongation phase. A harrow was used immediately after legume sowing. The use of a harrow in this system is very interesting because it both allows legume seeds to be incorporated into the soil and contributes to improving weed control. The trial was run under conventional management in order both to combine the production level expected by local conventional farmers and to support the uptake of legume cover crops in this context.
The 2019 experiment plots were maintained in-field during spring 2020 to monitor cover-crop development.

**Results 2019**

At wheat-harvest time (June 2019), the intercropped legumes did not compete with wheat. There were no significant differences in terms of grain production among intercropped wheat stands and wheat as sole crop (Figure 5A). Grain production was on average 7 t/ha, perfectly in line with the high levels of local production. The presence of legumes did not affect grain protein content either (Figure 5B).
According to the hypothesis and the results of the previous replication of the experiment, legume biomass was affected by wheat competition (mainly for light), remaining in a sort of quiescent growing stage until wheat harvest (Figure 6).




**Figures 5A and 5B** - A) Grain yield; B) Grain protein content

**Legend**

**W**: wheat as sole stand crop, **Trep**: *Trifolium repens*, **Msat**: *Medicago sativa*, **Hcor**: *Hedysarum coronarium*, **Mlup**: *Medicago lupulina*, **Tsub(1)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Antas, **Tsub(2)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Mintaro, **Mpol**: *Medicago polymorpha*, **Mscu**: *Medicago scutellata*, **Tinc**: *Trifolium incarnatum*, **Tresps**: *Trifolium resupinatum*

Weed biomass was in general very low at this time. *Trifolium subterraneum* subsp. brachycalycinum cv Antas showed a stronger effect against weeds, reducing weed biomass by a massive 85% when compared with the control (Figures 7A and 7B).
In September 2019, biomass sampling was performed in order to evaluate the effect of legume on weeds after wheat harvest. Data are reported as *Weed control efficiency* (WCE).
A positive value means that the presence of legume improves weed control when compared with the control, while a negative value means that legume worsens weed control when compared with the control.
As reported in Figure 8, *Medicago sativa* reduced weed biomass by 80% when compared with the control and it was significantly more effective in terms of weed control when compared with *Hedysarum coronarium, Trifolium subterraneum* subsp. brachycalycinum cv Antas, and *Medicago scutellata*.

**Figure 6** - *Medicago lupulina* during the intercropping period (photo by Matteo Ruggeri)

### Further developments

The experiment will provide farmers with a list of tested cover crops and sowing techniques, with indicators of species performance in terms of weed suppression, soil coverage, plus quality and quantity of wheat production.

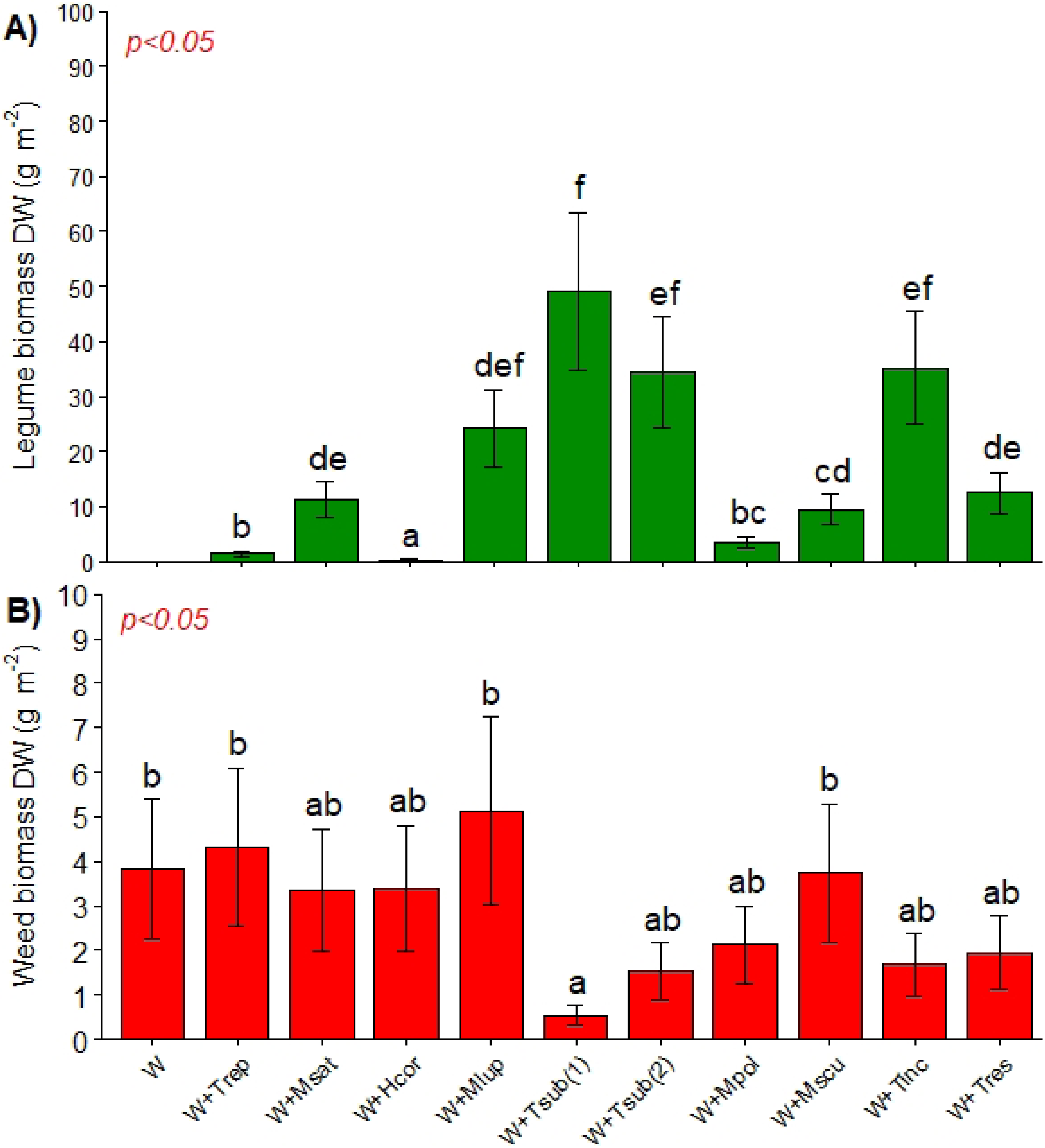



**Figure 7A and 7B** - A) Legume biomass (DW g/m$^2$) and B) weed biomass (DW g/m$^2$)

**Legend**

**W**: wheat as sole stand crop, **Trep**: *Trifolium repens*, **Msat**: *Medicago sativa*, **Hcor**: *Hedysarum coronarium*, **Mlup**: *Medicago lupulina*, **Tsub(1)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Antas, **Tsub(2)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Mintaro, **Mpol**: *Medicago polymorpha*, **Mscu**: *Medicago scutellata*, **Tinc**: *Trifolium incarnatum*, **Tres**: *Trifolium resupinatum*

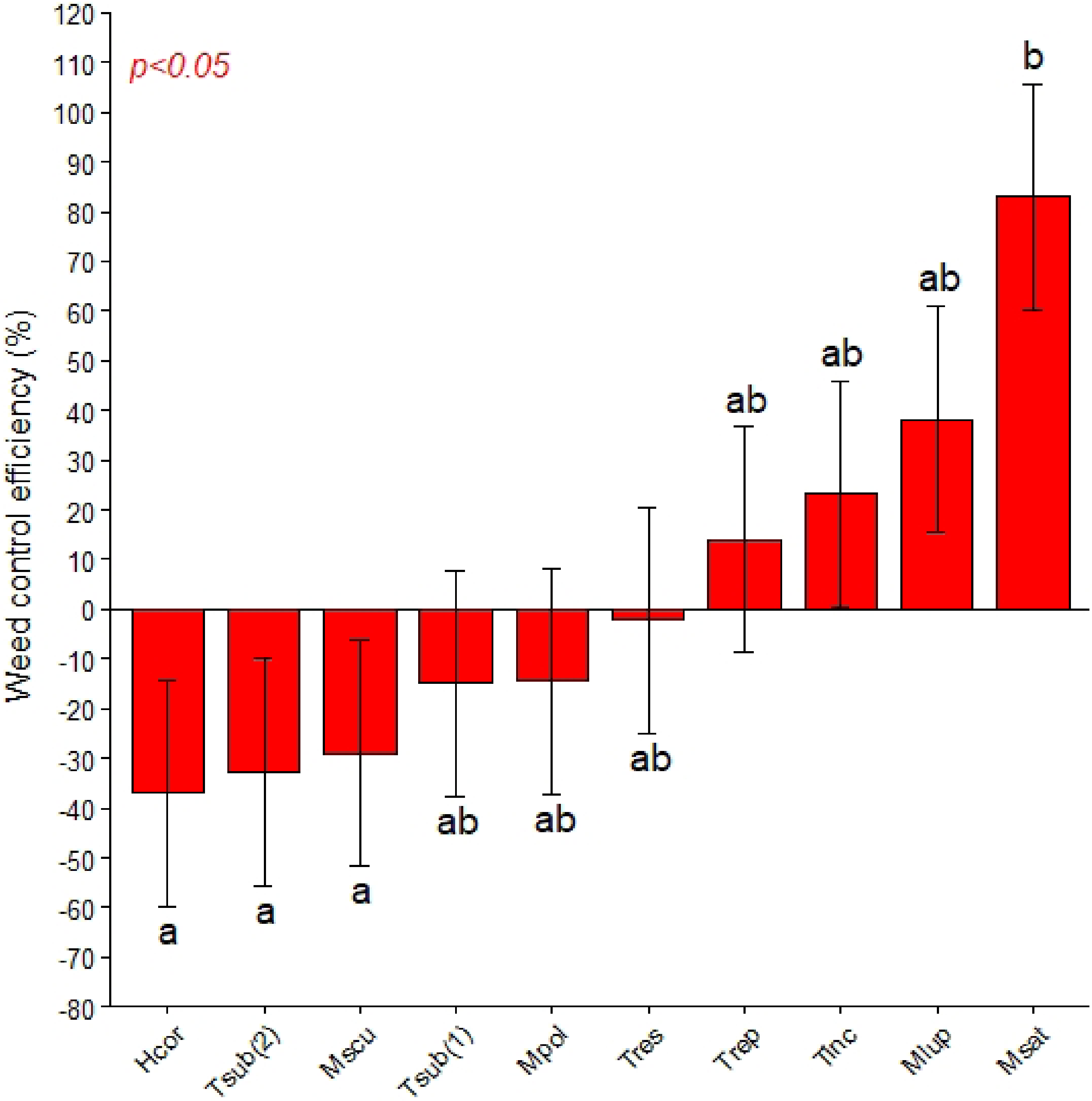



**Figure 8** - Weed control efficiency (WCE)

**Legend**

**Trep**: *Trifolium repens*, **Msat**: *Medicago sativa*, **Hcor**: *Hedysarum coronarium*, **Mlup**: *Medicago lupulina*, **Tsub(1)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Antas, **Tsub(2)**: *Trifolium subterraneum* subsp. Brachycalcinum cv Mintaro, **Mpol**: *Medicago polymorpha*, **Mscu**: *Medicago scutellata*, **Tinc**: *Trifolium incarnatum*, **Tres**: *Trifolium resupinatum*

# ON-FARM EXPERIMENTAL TRIALS

# LA VIOLA FARM

*La Viola (www.agrilaviola.com) is an organic arable farm located in Torre San Patrizio, Marche (Italy). The farm consists of 10 ha of arable land with sloped fields of loamy to clay soils. The main crops are cereals and pulses, cultivated as intercropping. The intercropping is performed between a cereal, which can be durum wheat, bread wheat, rye, barley or oat, and a grain legume such as chickpea, Indian pea, lentil and roveja (an edible cultivar of* Pisum sativum ssp. arvense*). All crops are broadcast sown with a sowing machine composed of two hoppers, one for the cereal and the other for the legume seeds. A two-hopper system allows both crops to be sown simultaneously, each at the desired seeding rate.*
*The two crops are harvested together and divided subsequently in the farm's processing laboratory. The seed types are divided using sifters on the basis of grain dimension and/or density. After the separation process, the wheat is used for flour production at a farm-owned mill with the flour then being sold directly or to local organic stores, together with the other cereals and grain legumes.*

**Address:**
**Azienda Agrobiologica La Viola**
**Via Oliva 19**
**63814 Torre San Patrizio (FM) – Italy**
**GPS coordinates: 43°10'36.2"N 13°35'55.1"E**

**For further information, please contact:**
**Gilberto Croceri**
**info@agrilaviola.com**

## LENTIL AND WHEAT INTERCROPPING

Lentil is an important crop at La Viola and its intercropping with a winter cereal is the best way to grow this legume on the farm (Figure 1). Lentil is very susceptible to lodging and this often makes it impossible to use a combine-harvester. Intercropping of lentil and wheat reduces legume stem lodging significantly because the cereal culms act as a mechanical support for the companion crop.
A mixture of bread wheat landraces is used in intercropping with a mixture of one commercial cultivar with one lentil landrace. When compared with the local production level, intercropping of wheat and lentil ensures sufficient wheat production (1.8 t/ha in average) and good lentil production (0.35 t/ha on average), with it also supporting weed control.
Although intercropping ensures an acceptable production level, it can be optimized by increasing lentil density to maximize yield and weed control.

### Objectives

The aim of this on-farm trial was to optimize wheat-lentil intercropping in the local conditions of La Viola cropland. The specific objectives were to:

- maximize lentil production;
- preserve an acceptable level of wheat production;
- minimize wheat-to-lentil competition;
- maximize weed control.

### Materials and methods

In 2018/2019, this experiment aimed to test four lentil seeding rates (75, 100, 125 and 150 kg/ha) associated with a fixed wheat-seeding rate (185 kg/ha) (Figure 2a). Additionally, lentil and wheat were grown as sole crops, with the standard seeding rate applied by the farmer (185 kg/ha for wheat and 100 kg/ha for lentil) in order to evaluate the Land Equivalent Ratio (LER). LER is a value that measures the yield advantage obtained by growing two or more crops or varieties as an intercrop compared to growing the same crops or

**Figure 1** - Intercropping between bread wheat and lentil (photo by Federico Leoni)

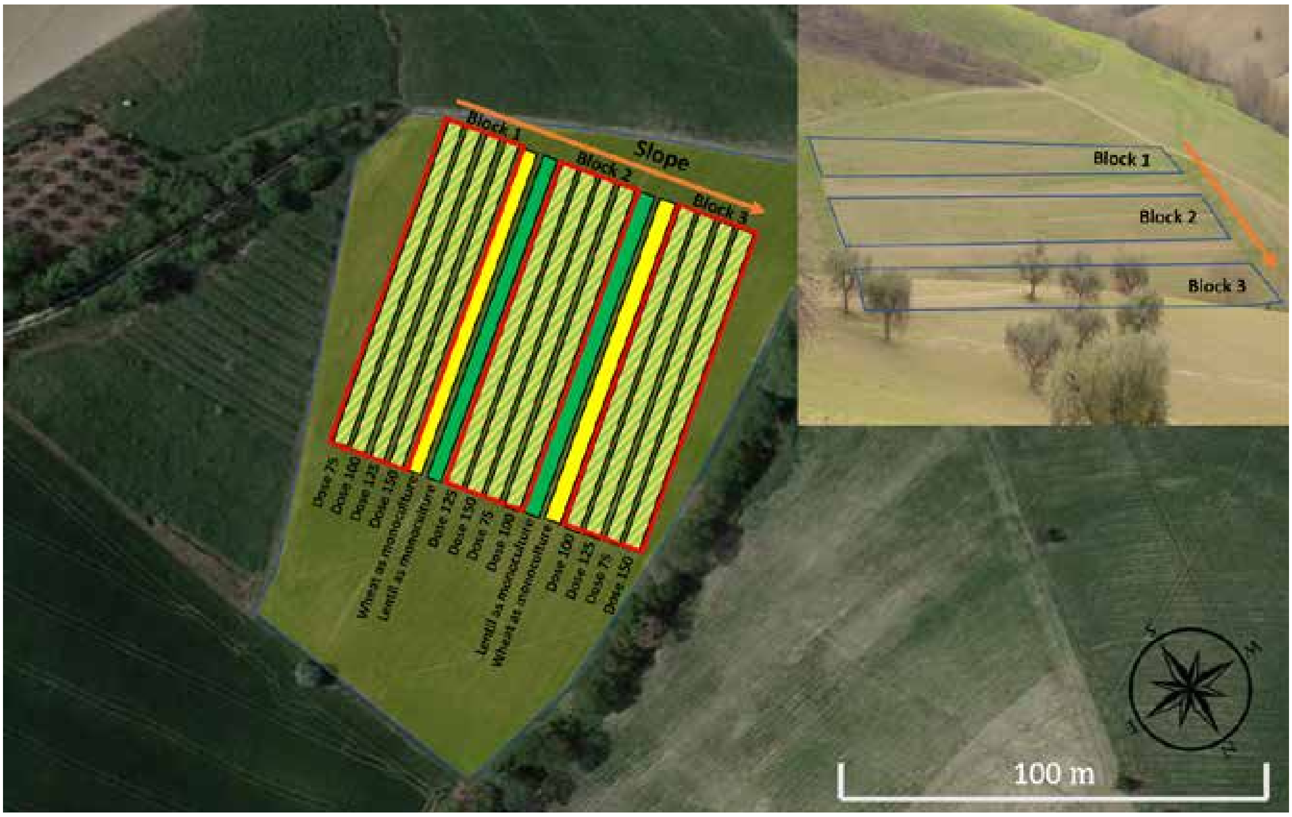



**Figure 2a** - Experiment layout in 2018/2019

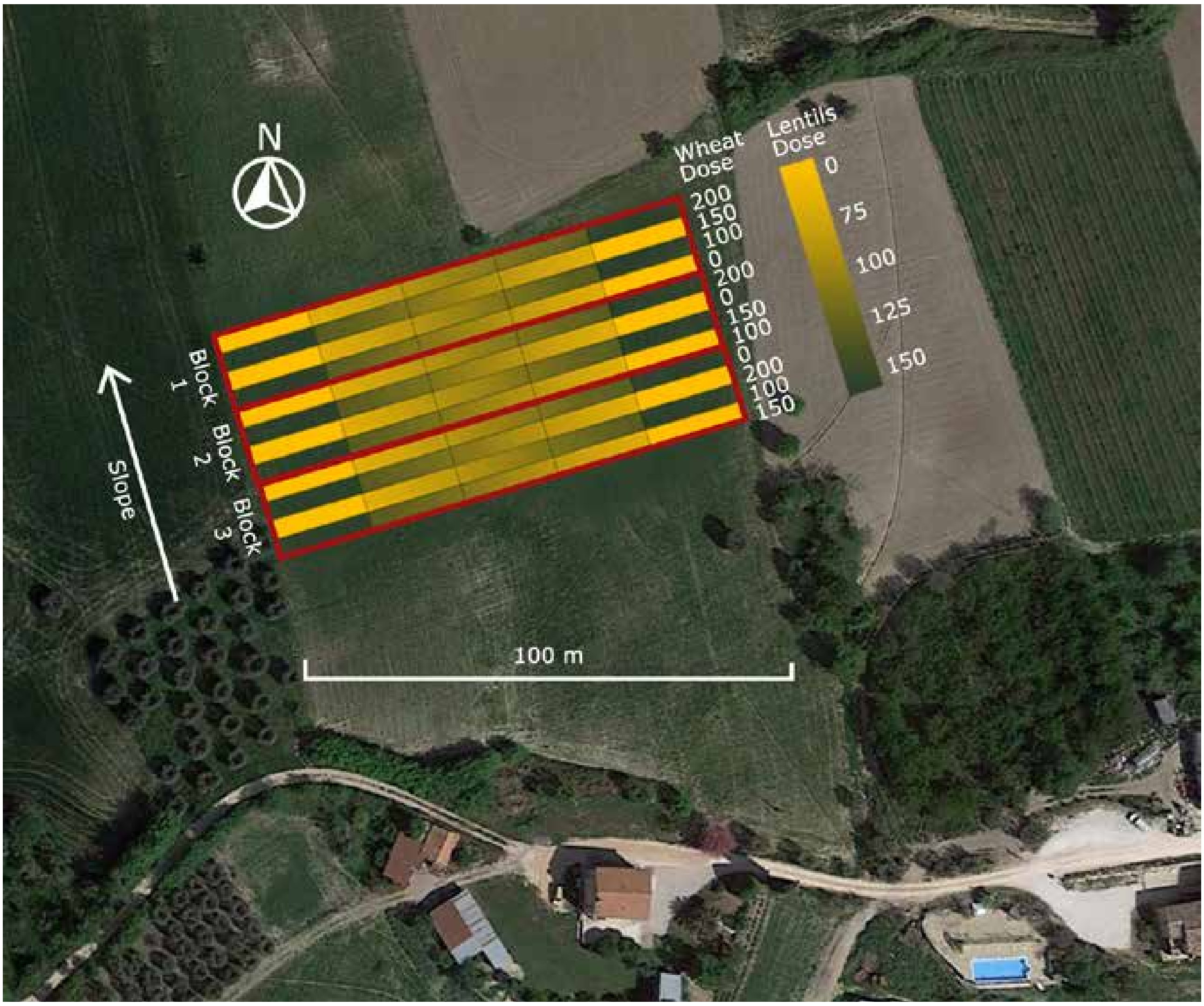



**Figure 2b** - Experiment layout in 2019/2020

varieties as a collection of separate monocultures. The experiment was organized in a randomized complete block design, with three replicates for each lentil-seeding rate. The plots area was 500 m$^2$ (6 m x 80 m). In 2019/2020, the experiment was modified slightly to allow a more detailed study of how wheat and lentil interact when intercropped. Farmers and scientists arranged the experimental plot to study the effect of increasing lentil-seeding rates (0, and from 75 to 150 kg/ha), sown in three different wheat-seeding arrangements, and a control strip (0, 100, 150 and 200) (Figure 2b). The experiment was organized in a randomized strip plot design, with three replicates for each wheat seeding rate, and a continuous gradient of lentil density from 75 to 150 kg/ha. At the beginning of each strip, a control plot with no lentil was established and the strip density gradient orientation was alternated. Each strip was 100m long and 4 m wide, totalling 4800 m$^2$ of experimental area.

Randomization and block orientation were performed taking into account the maximum gradient of variability, i.e. slope, in both experimental fields. After seedbed preparation, wheat and lentil were broadcast sown using a seeding machine equipped with two hoppers: one for cereal and one for grain legume (Figures 3 and 4). The hoppers were set-up to provide a constant dose of wheat seed in each strip and to vary the lentil dose along each strip (Figures 5 and 6).

During the growing season, assessments were performed on both the lentil and wheat in order to collect data on:

i) Lentil and wheat emergence (Figure 7) and yield;
ii) Intercropping efficiency by estimating LER;
iii) Effects of intercropping on weeds.

**Figures 3 and 4** - Seeder used for intercropping (photo by Stefano Carlesi)

**Figure 5** - Seeder set-up (photo by Simone Marini)

**Figure 6** - Seeder density regulation during seeding operation (photo by Martina Panettieri)

### Results 2018/2019

Please refer to the experimental lay-out of the 2019 booklet for treatments. The main results concern the failure of the lentil crop due to a slug attack during the growing season, so no lentil grain was harvested in 2019. As a direct consequence of the lentil failure, no LER estimation was possible. Figures for wheat biomass, grain yield and weed biomass were established.

Concerning crop investment, wheat-plant density was 195 plants/$m^2$ in February 2019, representing between 43% to 50% of the wheat seeded, while lentil-seedling density was very low: 7 plants/$m^2$. Therefore, lentils were seeded again in spring. The spring-seeded lentils performed much better, showing a linear response in seedling density at an increasing lentil-sowing rate (Figure 8).

Dry lentil biomass was also collected despite the slug attack, but total biomass was very low (5.26 g/$m^2$) independent of the lentil-seeding rate. Wheat yield was not affected by lentil-seeding rate, and harvest was on average 2.16 t/ha. Weed dry biomass was also independent of lentil-seedling rate (43.62 g/$m^2$ on average), but strongly affected by wheat presence, with weed biomass reducing by 85% when wheat was grown as sole crop when compared to the sole lentil plots.

Experimental site: La Viola, Torre San Patrizio (FM)
GPS coordinates: 43°10’36.2”N 13°35’55.1”E

**Contact:**
Gilberto Croceri info@agrilaviola.com

**Figure 7** - Wheat and lentil seedling density at emergence (photo by Stefano Carlesi)

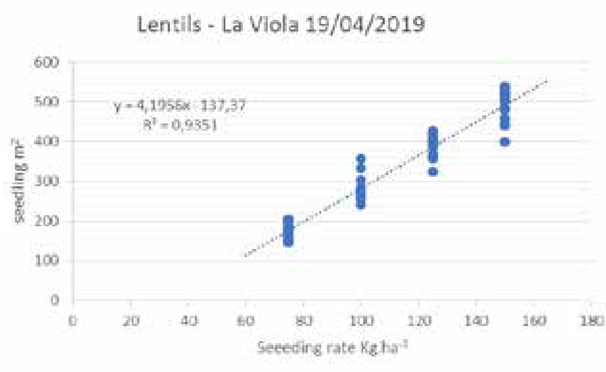



**Figure 8** - Lentil-seedling density as a response to lentil-seeding rate

# FLORIDDIA FARM


*Floriddia (www.ilmulinoapietra.com) is an organic farm located in Peccioli, Tuscany (Italy). It cultivates cereals (bread wheat, durum wheat, emmer, spelt, oats, and barley), grain legumes (chickpea, lentil, chickling vetch) and forage crops. In the last few years, Floriddia was a strong promotor of the cultivation of wheat landraces and composite cross populations for the production of high quality bread and pasta in Tuscany. This process involves researchers (University of Florence geneticists), other farms, advisors and* Rete Semi Rurali *(Rural Seed Network). It is an example of a collaborative approach that aims to set up landrace cultivation techniques in order to optimize yields in an organic production system.*

*Every year, the farms, supported by* Rete Semi Rurali, *arrange a demonstrative field with over 200 types of cereals on display. Floriddia manages a mill with state-of-the-art tools for grain cleaning and a laboratory for pasta and bread production. Floriddia's work can be considered radical, social innovation within the bread supply chain because it takes a collaborative approach and creates a network among various actors, including farmers, researchers, extensionists, consumers and associations, who work along the same sustainability principles. The products of this farm are sold directly at the farm shop and online in Italy only, as well as through community-supported agriculture groups and local markets.*

**Address:**
**Azienda Agriola Floriddia**
**Via della Bonifica 171**
**56030 Località Cedri - Peccioli (PI) - Italy**
**GPS coordinates: 43°29'11.18''N 10°47'54.06''E**

**For further information, please contact:**
**Rosario Floriddia**
**info@ilmulinoapietra.it**

## CHICKLING VETCH AND EMMER INTERCROPPING

Chickling vetch (*Lathyrus sativus L.*) is traditionally cultivated in Tuscany, and it is among the legumes produced by Floriddia farm. This crop grows very well locally, but its high lodging susceptibility makes mechanized harvesting difficult. Intercropping chickling vetch with a cereal may reduce lodging problems significantly and prevent yield loss.
The hypothesis is that intercropping may reduce lodging problems because the associated cereal culms work as a mechanical support for the chickling vetch. Intercropping may also provide benefits in terms of weed control.

### Objectives

In this on-farm experiment, we are studying intercropping between chickling vetch and emmer (*Triticum dicoccum*). The objective is to maximize chickling vetch production and to prevent lodging-related yield loss. Additionally, intercropping with cereal may support weed control in this legume, which is not highly suppressive.

### Materials and methods

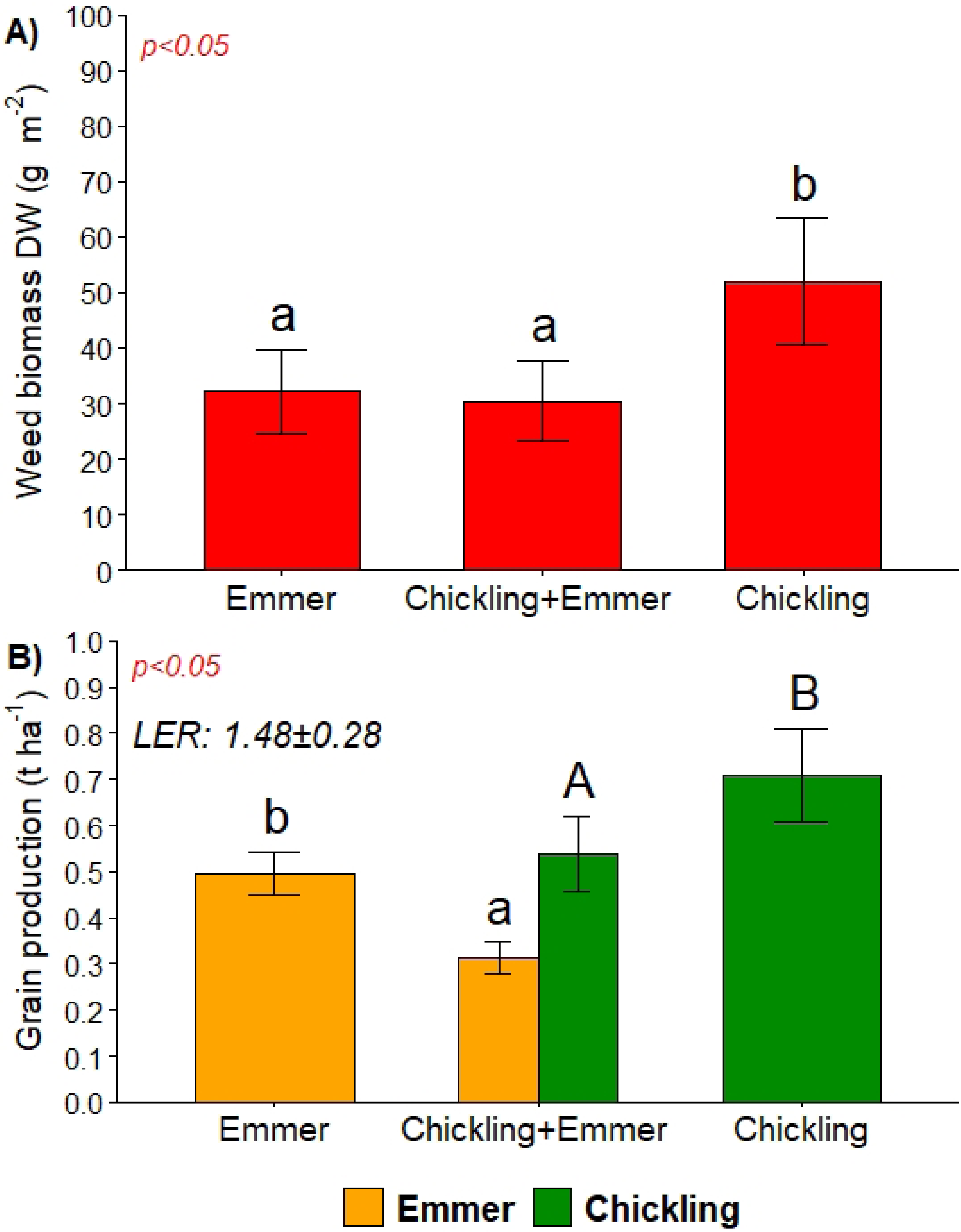
In this experiment, we study the intercropping of chickling vetch and emmer (Figure 1). After seed bed preparation, chickling vetch and emmer were sown in February 2019. Seeding rate of chickling vetch was 100 kg/ha, and emmer-seeding rate was 40 kg/ha (1/3 of the optimum dose). We used a reduced dose of emmer to prevent interspecific competition with the chickling vetch.
In addition to the main intercropped field, chickling vetch and emmer were sown as sole crops to evaluate Land Equivalent Ratio (LER). LER is a value that measures the yield advantage obtained by growing two or more crops or varieties as an intercrop compared to growing the same crops or varieties as a collection of separate monocultures.
During the growing season, we performed assessments both on the chickling vetch and emmer in order to collect data on:

iv) Chickling vetch and emmer emergence and yield;
v) Intercropping efficiency by calculating LER;
vi) Effects of intercropping on weeds.

### Results

The results of this experiment confirmed that intercropping between emmer and chickling vetch is an interesting solution for improving weed control and land-use efficiency.
The intercropping of chickling vetch with emmer significantly improved weed control when compared with chickling vetch stand as sole crop. Emmer efficiently filled the empty space left by chickling vetch and otherwise occupied by weeds, reducing weed biomass by 40% when compared with chickling monoculture.
The LER value was calculated to measure the yield advantage obtained in this intercropping system. As reported in Figures 2A and 2B, the production of both chickling vetch and emmer decreased significantly when grown together. However, this intercropping system was overall more efficient than the respective monocropping systems, with LER value being 1.48. The interpretation of this value is that 1.48 ha of sole cropping area is required to produce the same yields as 1 ha of the intercropped system.

**Figure 1** - Intercropping between emmer and chickling vetch




**Figures 2A and 2B** - A) Weed biomass (DW g/m²) and B) Grain production (t/ha)

# MARTELLO NADIA FARM


**Figure 1** - Field trial at Martello Nadia farm (43°34’51.46’’N 10°32’02.63’’E) (foto ©2017 Google)

*These on-farm field experiments are being carried out at the Martello Nadia commercial farm (Cenaia, Pisa, Tuscany) in collaboration with the University of Pisa’s “Enrico Avanzi” Centre for Agro-Environmental Research (CiRAA).*

**Address:**
**Azienda Agricola Martello Nadia**
**Via Zavagno 60**
**56042 Località Cenaia - Crespina Lorenzana (PI)**
**Italy**

## PARTICIPATORY FIELD TRIAL ON CONVENTIONAL VS CONSERVATIVE MANAGEMENT TO MANAGE RESISTANT RYEGRASS POPULATIONS IN ARABLE CROPS

### Objectives

Long-term implementation of reduced tillage (i.e. minimum tillage or no-till) combined with glyphosate application can lead to a selection of weed populations becoming herbicide-resistant. This is the case for the flatland close to Pisa (Tuscany, Central Italy), where reduced tillage has become a standard practice among farmers since the 1980s. Short crop rotations dominated by winter cereals and frequent use of glyphosate (up to eight times in just three years) in the inter-crop period at sub-optimal rates have led to a selection of ryegrass (*Lolium* spp.) with triple resistance to ACC-ase, ALS and glyphosate. This also happened in the no-till plots of a long-term trial started in 2008 and terminated in 2017 to compare on-farm continuous no-till vs annual ploughing. The presence of resistant ryegrass populations became so severe that the farmer decided to return to ploughing at 25-30 cm in order to devitalize Lolium seeds and be able to yield again. Since then, a new system trial has been set-up under WP7 on a four-year crop rotation (durum wheat-grain sorghum-durum wheat-chickpea) in order to compare two different management options on the two fields formerly managed under no-till:

i) annual ploughing with different types of herbicides, but not glyphosate;
ii) integrated management combining reduced tillage (minimum tillage and no-till), cover crops and limited herbicide application (excluding glyphosate).

Together with the farmer, we aimed to test whether continuous disturbance of ryegrass (mechanically, chemically or agronomically) in the periods of its emergence peaks would result in it still being possible to implement conservation agriculture to preserve soil fertility without significant yield losses due to resistant weed populations.

### Materials and methods

This on-farm field experiment is being carried out at the Martello Nadia commercial farm (Cenaia, Pisa, Tuscany) in collaboration with the “Enrico Avanzi” Centre for Agro-Environmental Research at the University of Pisa (CiRAA). Two different management treatments (CONVENTIONAL vs CONSERVATIVE) are being compared on two plots sizing 2.5 ha each. Each treatment is replicated on five pseudo-replicates. The crop sequence includes:

- Durum wheat (*Triticum turgidum* subsp. *durum* (Desf.)) 2019/20;
- Grain sorghum (*Sorghum bicolor* (L.) Moench 2020/21;
- Durum wheat 2021/22;

**Figure 2** - Resistant ryegrass population earing in a farmer’s wheat field at harvest time

**Figure 3** - Resistant ryegrass population surviving a glyphosate application in a farmer's field

- Chickpea (*Cicer arietinum* L.) 2022/23.

In the conservative system, a cover crop of hairy vetch (*Vicia villosa* Roth.) will be grown between wheat and sorghum and then managed as dead mulch for the direct sowing of sorghum. A red clover (*Trifolium pretense* L.) cover crop will be interseeded in the 2021/22 wheat and left to grow until the pre-sowing period for chickpea when it will be incorporated as green manure by harrowing. Herbicide application will be managed as a main IWM tool in the CONVENTIONAL system, and it will be minimized and tailored to the specific conditions in the CONSERVATIVE one (see the presence of red clover in wheat 2021/22).

We are assessing the following parameters:

- Biomass and soil cover produced by cover crops and cash crops at the termination/harvest stage;
- Weed abundance and composition in each crop at harvest/termination and possibly also at earlier stages (e.g. after crop emergence);
- Evolution of soil seedbank from t0 (early spring 2019) and t1 (end of crop sequence cycle);
- Economic and energy costs.

**Contact:**

andreadeangeli@gmail.com tel. +39 347 0738543
daniele.antichi@unipi.it tel. +39 050 2218962

## UNDERSOWING RED CLOVER IN DURUM WHEAT TO ENHANCE WEED SUPPRESSION AND N NUTRITION

### Objectives

Weed control in organic wheat is mainly performed by flex tine harrowing. In soils with high clay and silt content, a flex tine pass at the end of the winter is not always easy to perform due to wet conditions. In Mediterranean climates, the ever-increasing frequency of mild winters without freezing temperatures is reducing the structuration of the soil by weather agents. If the soil remains too cloddy or is too dry at the end of the winter, the effectiveness of harrowing in detaching weed plants is dramatically reduced. Furthermore, keeping the soil covered in the intercrop period between wheat harvest and the following spring crop sowing is crucial to keeping weed populations under damage thresholds. Autumn sown cover crops can be an effective solution to cover the soil in this period. This, however, might be challenging when the following cash crop is sown in early spring (e.g. chickpea, sunflower), as it reduces the length of the cover-crop growing season and thus its potential biomass production. To maximize soil cover and reduce weed competition in the wheat crop, a legume cover crop can be interseeded in early spring before the cereal's stem elongation stage and kept growing until the following spring. This can be possible when the legume cover crop is a self-reseeding crop, a perennial one, or a biannual species, e.g. red clover (*Trifolium pretense* L.).

In this on-farm trial, we will carry out a two-year test on intersowing red clover in organic durum wheat (*Triticum turgidum* subsp. *durum* (Desf.)) and keeping it growing until the sowing date of the following chickpea (*Cicer arietinum* L.), when the clover is incorporated as green manure.

### Materials and methods

This on-farm field experiment is being carried out at the Martello Nadia commercial farm (Cenaia, Pisa, Tuscany) in collaboration with the "Enrico Avanzi" Centre for Agro-Environmental Research at the University of Pisa (CiRAA). Two different management treatments (INTERSOWING vs WHEAT SOLE CROP) are being compared on two plots sizing 1 ha each. Each treatment is replicated on five pseudo-replicates. The crop sequence will also include chickpea the following year.

We are assessing the following parameters:

- Biomass and soil cover produced by wheat

and clover at the harvest stage and before termination of the clover;
- Weed abundance and composition in each crop at harvest/termination and possibly also at earlier stages (e.g. after crop emergence);
- Economic and energy costs.

**Contact:**
andreadeangeli@gmail.com tel. +39 347 0738543
daniele.antichi@unipi.it tel. +39 050 2218962

**Figure 4** - Red clover interseeded in durum wheat in March 2019 after emergence


**Figure 5** - Field trial at Martello Nadia farm (43°35’55.15’’N, 10°31’48.43’’E) (photo ©2017 Google)

# SAN GIUSTO A RENTENNANO FARM

SAN GIUSTO A RENTENNANO
Fratelli Martini di Cigala

Address:
Loc. San Giusto a Rentennano
53013 Gaiole in Chianti (SI) - Italy
tel. +39 0577 747121
e-mail: info@fattoriasangiusto.it

GPS coordinates: 43°22'14.1''N 11°25'19.4''E

# MONTEVERTINE FARM

MONTEVERTINE

Address:
Loc. Montevertine 1
53017 Radda in Chianti (SI) - Italy
tel. +39 0577 73.80.09
e-mail: info@montevertine.it

GPS coordinates: 43°30'06.2"N 11°23'29.0"E

## COVER CROPPING TO IMPROVE SOILS IN CHIANTI CLASSICO'S VINEYARDS

Viticulture is a critical component of agriculture in Southern Europe. In these countries, vineyards have been historically planted on poor-developed soils (e.g. course texture, high stoniness, low soil organic matter). The combination of (i) poor inherent soil characteristics, (ii) the steep topography which characterizes the majority of the European wine-producing regions and (iii) the typical Mediterranean climatic pattern, make those soils highly susceptible to degradation. In this scenario intensive soil management practices - such as the very common inter-row tillage - has escalated soil degradation and about 9 tonnes of soil per hectare are lost from vineyards every year. In other words, vineyards is, to date, the land use with the highest soil loss rate in Europe.
Cover cropping could play a critical role in reducing soil loss, advancing soil physical, chemical and biological fertility and thus improving the sustainability of the European wine sector. Nevertheless, farmers are often reluctant to apply soil cover practices due to the potential competition between cover crops and vines for water and nutrients. This calls for on-farm experimentations in order to test and discuss with farmers strategies able to improve soils and at the same time guarantee grape production and quality.

### Objectives

A group of innovative farmers in Chianti Classico have applied mixes of cereal and leguminous cover crops or left spontaneous vegetation to grow along with non-inversion tillage to restore and protect their soils. However, those innovations were not supported by local studies and local growers are concerned about the outstanding sugar accumulation in grapes due to temperature increases associated with climate change.
Our on-farm study aims at identifying the most promising cover cropping strategies to manage soil sustainably and at the same time ensure grape yield and quality. To this end we are exploring the effects of different cover cropping practices on: soil (chemical, physical and biological parameters), spontaneous vegetation communities, vine stress, grape production and quality in Chianti Classico. Results will then be discussed with farmers and local technicians.

### Materials and methods

The experiment is being carried out in two commercial organic farms in Chianti Classico:

(i) Fattoria San Giusto a Rentennano (SG) (Gaiole in Chianti, SI); average annual rainfall 801 mm; average annual temperature 14.4°C; elevation 233 m.a.s.l., slope 10%

(ii) Montevertine (MT) (Radda in Chianti, Si); average annual rainfall 824 mm; average annual temperature 12.6°C; elevation 425 m.a.s.l., slope 8%.

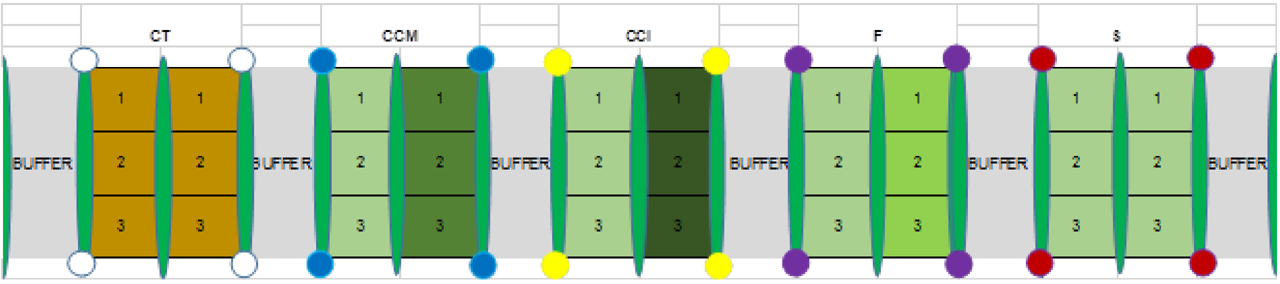



**Figure 1** - Experimental design of the experimental plot in each farm. CT = Conventional Tillage; CCM = Mulched cover crop of barley + squarrose clover; CCI = Cover crop of barley + squarrose clover incorporated in the soil; F = Faba bean cover crop incorporated in the soil; S= Spontaneous grassing


**Figures 2A, 2B, 2C and 2D** - Appearance of the four soil cover types tested in this trial: A) conventional tillage; B) cover crop of faba bean (*Vicia faba minor* L.) incorporated in late spring; C) cover crop of barley (*Hordeum vulgare* L.) and squarrose clover (*Trifolium squarrosum* L.); and D) spontaneous vegetation

The vines (*Vitis vinifera*, L. var. Sangiovese R10, rootstock 420A) had been planted in rows (2.50 x 0.8 m, 5.000 vines/ha). The vineyards' years of establishment are comparable (1995 and 1991 in SG and MT, respectively). The training system is in transition from spurred cordon to the guyot trellis in SG and spurred cordon in MT. Five soil management practices are studied in both farms (Figure 1):

1. Conventional tillage (CT), performed once in autumn, spring and summer with a rigid tine cultivator at 15 cm depth (Figure 2A)
2. Cover crop of faba bean (*Vicia faba minor* L.) sown at 90 kg/ha, incorporated in late spring (F) (Figure 2B)
3. Cover crop of barley (*Hordeum vulgare* L.) and squarrose clover (*Trifolium squarrosum* L.) sown at 85 and 25 kg/ha respectively, mown in late spring and left as mulch (CCM) (Figure 2C)
4. Cover crop of barley and squarrose clover sown at 85 and 25 kg/ha respectively, incorporated in late spring (CCI) ) (Figure 2C)
5. Spontaneous vegetation mown in late spring and left as mulch (S) (Fiugre 2D).

An in-row ventral plough is used to control weeds under the trellis during the season. Each experimental plot consists of three rows and two inter-rows (about 5x100 m). Treatments are displayed in alternate rows as this is common practice in the area. Each experimental plot is divided in three pseudo-replicates according to the slope of the vineyard.

### Parameters measured:

- **Soil**: N, P, K, Soil Biological Quality Index (QBS-ar), Aggregate stability (following grape harvest);
- **Vine stress**: SPAD, stem water potential (from June to September);
- **Grape production**: yield/plant, number of clusters/plant, cluster weight, berries weight (at harvest);
- **Must quality**: total acidity, pH, malic acid, Brix (at harvest);
- **Spontaneous vegetation**: biomass and soil cover per species (before cover crop termination and at harvest);
- **Cover crop**: biomass and soil cover per species (before cover crop termination and at harvest).

### Results

The period between bud break and veraison corresponds to high nutrients and water requirements for vines. For instance, it has been estimated that between fruit-set and veraison

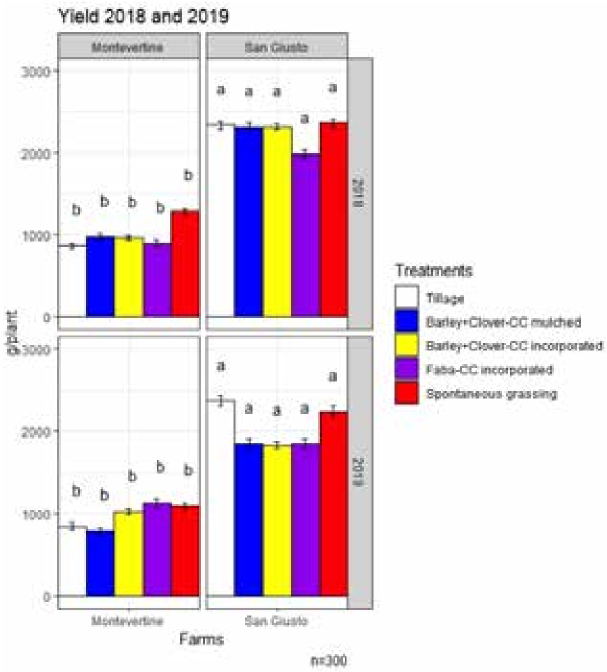



**Figure 3** - Yield per plant (g/plant) in Montevertine (MT) and San Giusto a Rentennano (SG) in 2018 and 2019 (n=300)

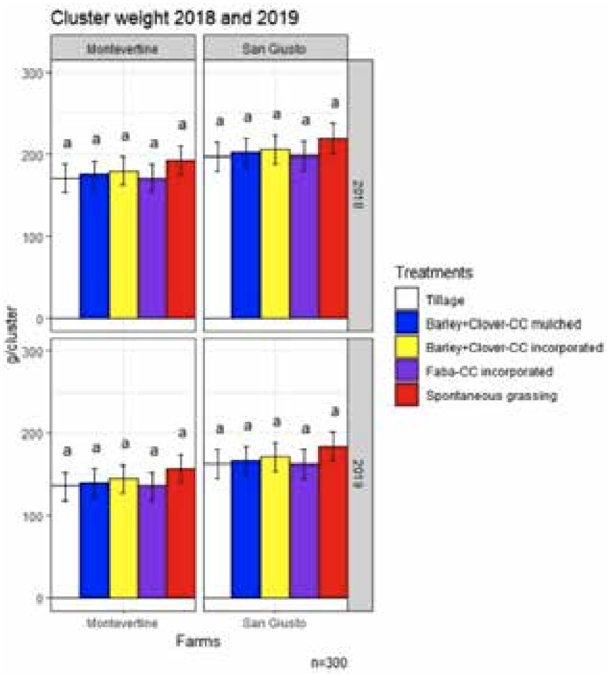



**Figure 4** - Cluster weight (g/cluster) in Montevertine (MT) and San Giusto a Rentennano (SG) in 2018 and 2019 (n=300)

vines require about 50% of the annual water requirements. In this study, cover crops were sown in October and terminated in June between fruit set and veraison, meaning that cover crops were growing during these delicate vine stages. Differences in weed composition/biomass and soil management can therefore trigger different stress patterns, which in turn may affect yields. Nevertheless, spontaneous vegetation and cover cropping did not affect grape yield, as we did not find any significant effect of the treatment on yield and yield composition, namely cluster weight and number of clusters (Figures 3, 4 and 5). "Farm" was the only significant parameter in the yield dataset, mainly due to the various training systems. The reason behind the non-significant effect of soil treatments on yield and yield composition could be due to:

(a) complementary resource uptake between the vines and the cover crop/weeds

(b) rainy vintages that "diluted" the effect of the treatments, especially in Montevertine

(c) importance of in-row management as compared to the inter-row treatments.

These findings will be discussed with farmers in order to design more sustainable soil management practices in the Chianti Classico area.

**Contact:**
Daniele Antichi: daniele.antichi@unipi.it
tel. +39 050 2218962
Dylan Warren Raffa:
dylan.warrenraffa@santannapisa.it
tel. +39 050 883569
Paolo Bàrberi: p.barberi@santannapisa.it
tel. +39 050 883525
Ruggero Mazzilli: rm@spevis.it tel. +39 055 852484
Luca Martini di Cigala: luca@fattoriasangiusto.it
tel. +39 0577 738009
Martino Manetti: martino@montevertine.it
tel. +39 0577 747121

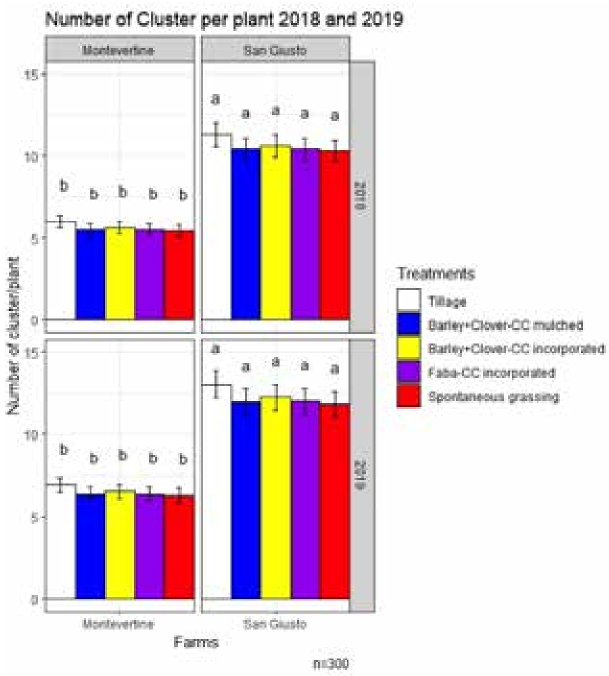



**Figure 5** - Number of clusters per plant in Montevertine (MT) and San Giusto a Rentennano (SG) in 2018 and 2019 (n=300)

# DEL SARTO GRAZIANO FARM


**Figure 1** - Location of the trial at Graziano Del Sarto Farm

*Del Sarto Graziano is a typical Pisa plain farm that produces cereals and protein crops, on a total area of about 160 ha, 13 ha of which are property. The rotation follows the classic sequence of winter cereals, summer crops such as maize, soybean, sorghum and sunflower, alternated with lucerne. It also participates in the INNVOA SOIA (http://www.sonotoscano.it/) and LIFE-Agrestic (https://www.agrestic.eu/) projects. "INNOVATIVE Systems for the Cultivation and Transformation of GMO-free Tuscany SOY" (INNOVA SOIA) is a co-financed by the Tuscany Region - PSR 2014-2020, which aims to transfer innovative techniques with reduced inputs for soybean production in Tuscany; it also focuses on the application of innovative technologies for the processing of soybean for livestock. "LIFE AGRESTIC - Reduction of Agricultural GReenhouse gases EmiSsions Through Innovative Cropping Systems" is part of the broader climate change mitigation objective of the EU-funded "LIFE Program for the Environment and Climate Change 2014-2020" and will promote the adoption of innovative, efficient cultivation systems with high potential to mitigate climate change. It will also contribute to the dissemination of innovative visions and tools for more efficient, climate-aware agriculture.*

**Address:**
**Azienda Agricola Del Sarto Graziano**
**Via Ferrucci, 8**
**56017 San Giuliano Terme (Pisa)**
**Italy**

**GPS coordinates: 43°74'55''N 10°35'95''E**
**For more information, please contact:**
**Graziano del Sarto**
**e-mail: graziano.delsarto@libero.it**

## RELAY INTERCROPPING OF LEGUMES IN WINTER WHEAT IN AN ON-FARM TRIAL NEAR PISA

A catalogue field experiment was carried out at CIRAA and at HORTA for two consecutive years. The aim was to describe and test the most successful legumes for relay intercropping with winter wheat (see relay intercropping experiments at CIRAA and Horta in this booklet on pages 45 and 60). The legume ideotype suitable for relay intercropping should have high early vigour so that it germinates below the wheat stand; have a prostrate habit so that it covers the soil and controls weed growth; not accumulate too much biomass to prevent over-competition with the crop during the wheat-growing season; and be able to contrast weed germination and growth as dead or living mulch after wheat harvest until the following cash crop is sown. Both experiments identified a number of potentially suitable perennial and annual self-reseeding legumes. Annual legumes did not possess all the necessary characteristics. In a new on-farm field trial, we tested two of these legumes by sowing them in-field with machinery the farmer had at his disposal.

### Objectives

The objectives of this trial were to monitor legume development, weed control, N availability, grain yield and grain quality in winter wheat up to the harvest of the following cash crop (sorghum). We wanted to compare how the legumes and the wheat behaved in a farmer's field when they were sown with the machinery and tools available on-farm.

### Materials and methods

This on-farm trial was set up with one of the representative farmers on the Pisa Plain, Graziano Del Sarto. The aim was to test two of the most successful legumes from the previously mentioned catalogue field trials: *Medicago sativa* cv Gamma and *Trifolium subterraneum* subsp. Brachycalcinum cv Mintaro.

The trial was positioned in a 1.8 ha area consisting of two 25-300 m fields separated by a small drainage channel in the centre (Figure 2). The fields are divided in four 150 x 12.5 m areas, totalling eight testing areas. Since previous observations reveal a potential weed gradient along the field length, it was decided to compare the two legumes to the wheat sole crop by planting them in the upper and lower part of both fields in a paired combination.

The field was previously cropped with maize and left uncropped until January 2020. Due to very wet autumn conditions, the crop was sown on 12 January 2020, two months later than usual. We sowed durum wheat Minosse, supplied by IWMPRAISE-partner ISEA, at 250 kg/ha (about 490 seeds/ha) with a row width of 13 cm. This is unusually dense due to the fact that the farmer's

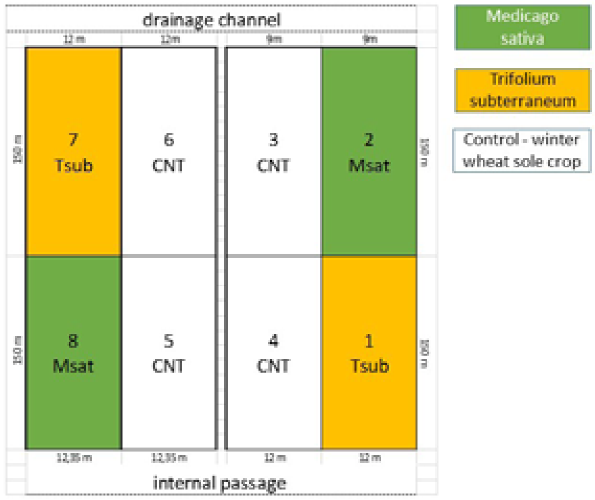



**Figure 2** - Experimental layout

**Figure 3** - Durum wheat cv Minosse at emergence

seeder was not able to enlarge the row width to 17 or 18 cm, which is usually done in relay intercropping to provide more space for the legume to establish. Minosse was used because this variety was successfully tested in the catalogue field and is not prone to lodging. Before sowing, the field was fertilized with 130 kg/ha mineral fertilizer N-P 12-52. Mid-February, the crop had established well, with a mean density of 277 plants/$m^2$ (Figure 3); it was then fertilized with 150 kg/ha of mineral fertilizer containing 32% urea nitrogen and 6% ammoniacal nitrogen. On 25 March, at the start of stem elongation, the legumes were broadcast seeded at a density of 40 kg/ha for both legumes (Figure 4), and the seeds were incorporated by the passage of a harrow (Figure 5).

**For more information, please contact:**
Anna-Camilla Moonen: c.moonen@santannapisa.it
Federico Leoni: f.leoni@santannapisa.it
tel. +39 050 883567

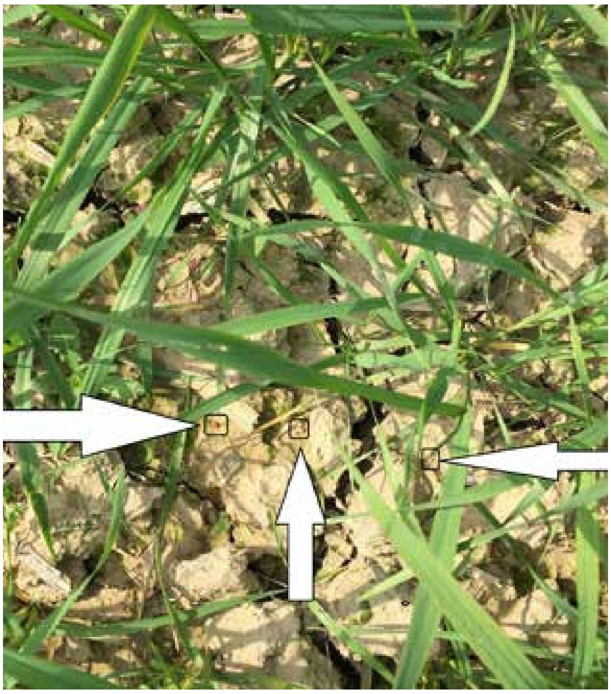
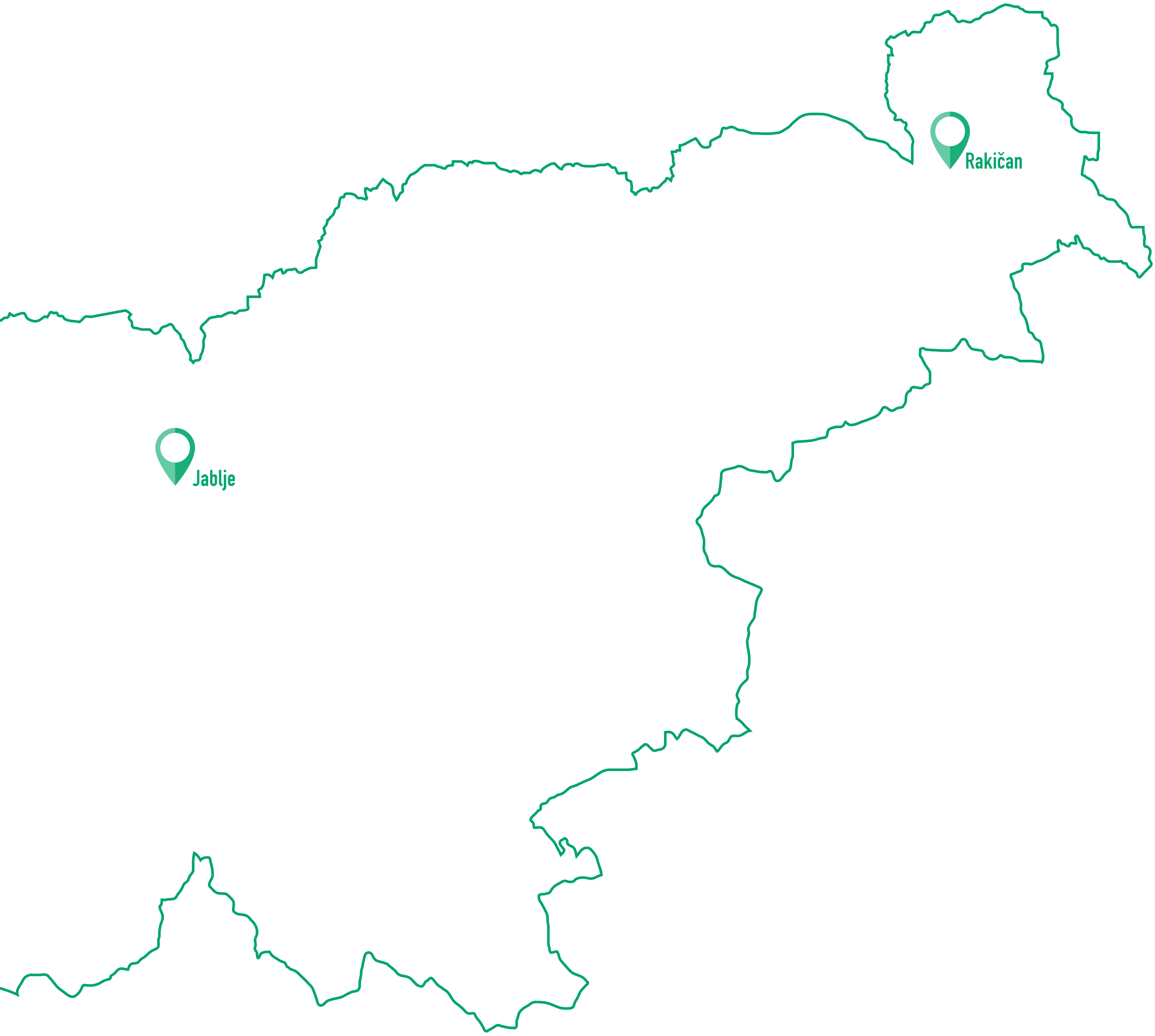


**Figure 4** - *Trifolium subterraneum* seeds under wheat after broadcast sowing

**Figure 5** - Harrowing to incorporate the legume seeds on a very dry soil with a crust that was only partly broken by the passage of the harrow

# SLOVENIA



# EXPERIMENTAL TRIALS MANAGED BY THE AGRICULTURAL INSTITUTE OF SLOVENIA – INFRASTRUCTURE CENTER JABLJE (IC JABLJE)


**Figures 1 and 2** - Location of the WP3 winter barley and WP4 maize trials in Jablje in 2019

*IC Jablje is a part of the Agriculture Institute of Slovenia and is successfully implementing and transferring new scientific findings into agricultural practice. The IC Jablje site is located in central Slovenia, which has a mild, humid continental climate. The farm operates on aproximatelly 410 ha of arable land with a range of soil types, from light sandy-loam to heavier silty-clay. Crop production is based on conventional management practices, with substantial restrictions on water protected areas and minor organic production in the transition phase. The farm has a crew with experience in field research and collaborates closely with an advisory service. Field experiments, joint workshops, education courses and other dissemination events make IC Jablje a leading agricultural research and knowledge transfer centre for end-users, i.e. national experts, farmers and students.*

**Address:**
**Kmetijski inštitut Slovenije**
**IC Jablje, Grajska cesta 1**
**1234 Mengeš - Slovenia**
**GPS coordinates: 46°08'31.02"N 14°33'17.6"E**
**http://www.kis.si/en/Presentation_ICJ/**

**IWMPraise experimental trials in Jablje:**
**WP3 - Winter wheat trial**
**WP4 - Maize trial**

**For information and guided visits of WP3 and WP4 trials, please contact:**
**Aleš Kolmanič**
**e-mail: ales.kolmanic@kis.si**
**tel. +386 1 560 74 12**
**Robert Leskovšek**
**e-mail: robert.leskovsek@kis.si**
**tel. +386 1 280 52 61**

**IWMPRAISE trials at other locations in Slovenia:**
**WP5 - Rumex trial on two sites**
**Location 1: Ajdovščina (45°52'37.294"N 13°54'2.4"E)**
**Location 2: Murski Črnci (46°37'15.2"N 16°6'15.3"E)**

**For information and guided visits, please contact:**
**Andrej Vončina**
**e-mail: andrej.voncina@kis.si**
**tel. +386 1 560 72 51**
**Robert Leskovšek**
**e-mail: robert.leskovsek@kis.si**
**tel. +386 1 280 52 61**

## WP3 – EXPERIMENTAL TRIAL ON WINTER BARLEY AT IC JABLJE

### Objectives

The aim of the experiment, as part of the IWMPRAISE project, was to test and compare the efficiency of standard spring and autumn herbicide-based weed control strategies with two IWM strategies in winter barley production. The objective was to reduce dependence on herbicides by implementing practices which limit weed establishment and germination, as well as reduce competition in the crop.

### Materials and methods

A winter barley demonstration trial with the Sandra variety was set up at the IC Jablje AIS research station in October 2018, in which two IWM strategies were compared to two purely chemical standard approaches. Broadcast herbicide application in autumn or spring represented the standard weed management practice, while the IWM strategies involved reduced herbicide application in combination with mechanical tools. The strategies and tools are presented in Table 1, while details of their implementation are described in the following text.

The previous crop on the experimental field was grain maize. After harvesting, the field was ploughed and the seedbed prepared with the spring tine cultivator at the end of September 2018. Winter barley at the optimum sowing date was drilled on 3.10.2018 (Strategies 1-3). In Strategy 4, a false seedbed was prepared in the delayed sowing period. Conditions were very suitable for promoting weed germination due to warm weather and moist soil. Soil structure was not suitable for spring tine harrowing in the false seedbed preparation. Therefore, in Strategy 4, one pass with a fine spring tine cultivator was carried out. The effect of shallow cultivation was excellent, and a considerable portion of autumn emerged weeds was controlled with this measure.
Winter barley in Strategy 4 was drilled 14 days later (18.10.2018), followed by tine harrowing in the spring. In the standard Strategy 1, herbicide was applied early in the spring, while in standard Strategy 2, herbicide was sprayed in the autumn (24.10.2018; BBCH 12) and recommended doses of herbicides were used in both strategies.

Spring tine harrowing was performed very early (end of February) in favourable soil conditions, but due to a dry spring, a very limited weed population emerged in this period. The effect of harrowing

| Strategy | Standard 1 | Standard 2 | Strategy 3 | Strategy 4 |
|---|---|---|---|---|
| Label | HER_spring | HER_autumn | HAR_spring + HER_reduced 60 % | FALSE + DEL_sow + HAR_spring + HER_reduced 60 % |
| Soil tillage | autumn ploughing | autumn ploughing | autumn ploughing | autumn ploughing |
| False seed bed | NO | NO | NO | YES |
| Sowing time | optimum | optimum | optimum | delayed 14 days |
| Herbicide rate | recommended * | recommended † | reduced * 60 % | reduced * 60 % |
| Herbicide application time | spring application EC 24 | autumn application EC 12 | spring application EC 24 | spring application EC 24 |
| Mechanical weeding | NO | NO | spring tine harrowing | spring tine harrowing |

* iodosulfuron-methyl sodium 100 g/L - Hussar OD: 0,1 L/ha
† prosulfocarb 800 g/L -Boxer: 5 L/ha

**Table 1** - Description of the strategies in the winter barley experiment at IC Jablje

**Figures 3 and 4** - Tine harrowing at the end of February (left) and herbicide spraying at the end of March (right)

**Figures 5 and 6** - Difference in weed density in the delayed sowing plot with false seedbed (left) compared to the plot sown at the optimum time (right) in the autumn

was adequate and a reduced dose of herbicide was applied later in the spring in Strategies 3 and 4.

### Results

The weather conditions in the 2018/2019 season were quite challenging. Unusually warm, dry weather continued in the spring and due to drought in February and March 2019, the crop was unable to achieve the yield potential set following its good performance in autumn. With a cold, wet period in May and June, vegetation was substantially delayed and all applications of insecticides and fungicides were performed in very difficult soil conditions. Delayed sowing combined with the false seedbed had considerably reduced weed infestation in the autumn and the effect was clearly visible until the spring application of herbicide.

Weather conditions after drilling in the autumn of the delayed sowing strategy were favourable. A small delay in winter barley development was visible in the early spring and summer, when the delayed sowing strategy was 2-4 days behind the plots with the optimum sowing date (Figures 9 and 10).

Dry weed biomass (Figure 11) was assessed at the winter barley milking stage (5.6.2019). Autumn herbicide application (Strategy 2) was by far the best with good residual efficacy visible until harvest. In this treatment, only 4 g/m$^2$ of dry weed biomass was determined. Standard Strategy 1 with spring herbicide application (11 g/ m$^2$) and Strategy 4 with delayed drilling, false seedbed, spring harrowing and reduced herbicide application (14 g/m$^2$) were also very effective. Weed density was greatest in Strategy 3 drilled at the optimal time, followed by spring harrowing and reduced herbicide application. Significantly greater dry weed biomass was determined (64 g/m$^2$) compared to the other strategies.

Winter barley grain yields (Figure 14) were closely related to the results of weed infestation within the tested strategies. Dry grain yield was greatest


**Figures 7 and 8** - Weed density in the delayed sowing plot with false seedbed (left) and the optimum time (right) in the spring


**Figures 9 and 10** - Winter barley development in the optimum and delayed sowing plot in the autumn (left) and in the late spring (right)

in standard autumn herbicide application (standard Strategy 2; 6.12 t/ha), followed by Strategy 4 with delayed drilling, false seedbed, spring harrowing and reduced herbicide application (6.09 t/ha). Standard spring application treatment yielded 5.56 t/ha, while the lowest yield was determined in Strategy 3 with spring harrowing followed by reduced herbicide application (5.02 t/ha).

Trial outcomes were presented to around 60 participants (mostly farmers) with a lecture at the Wheat field day in Jablje and discussion during the field tour. The trial was also visited by advisory specialists and experts (15 attendants) where the results of the IWM strategies tested could be observed on-site (Figures 15 and 16).

Weather conditions in 2019 were not favourable, therefore relatively poor yields of winter barley were achieved in the central region of Slovenia. Our results showed that in terms of yields, the IWM strategy 4 with 14-day delayed sowing and false seed bed followed by spring harrowing and reduced herbicide dose was comparable with the standard autumn broadcast herbicide application.

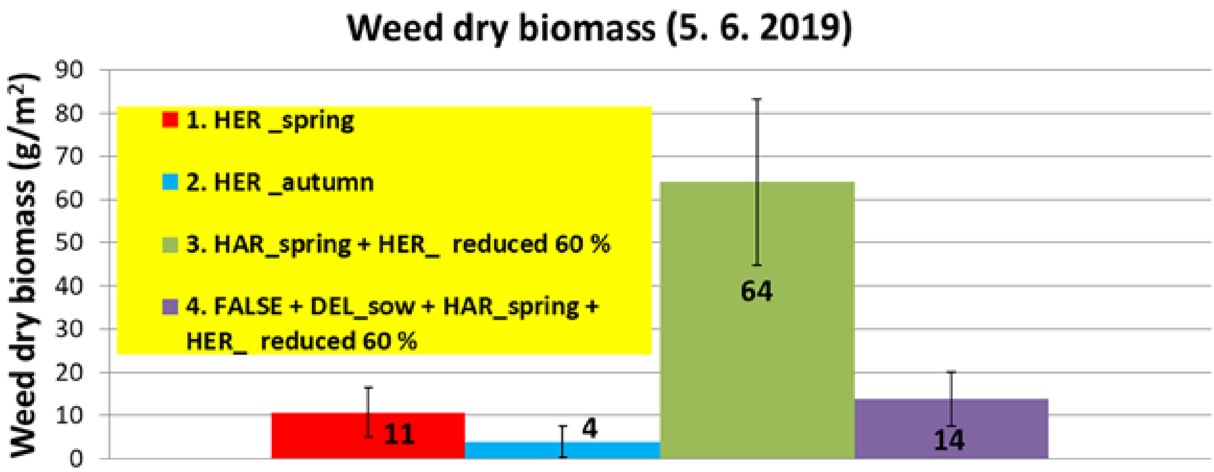



**Figure 11** - Average weed dry biomass in Jablje (vertical bars represent standard errors)

**Figures 12 and 13** - Harvest and yield assessment of winter barley trial on 29.6.2019

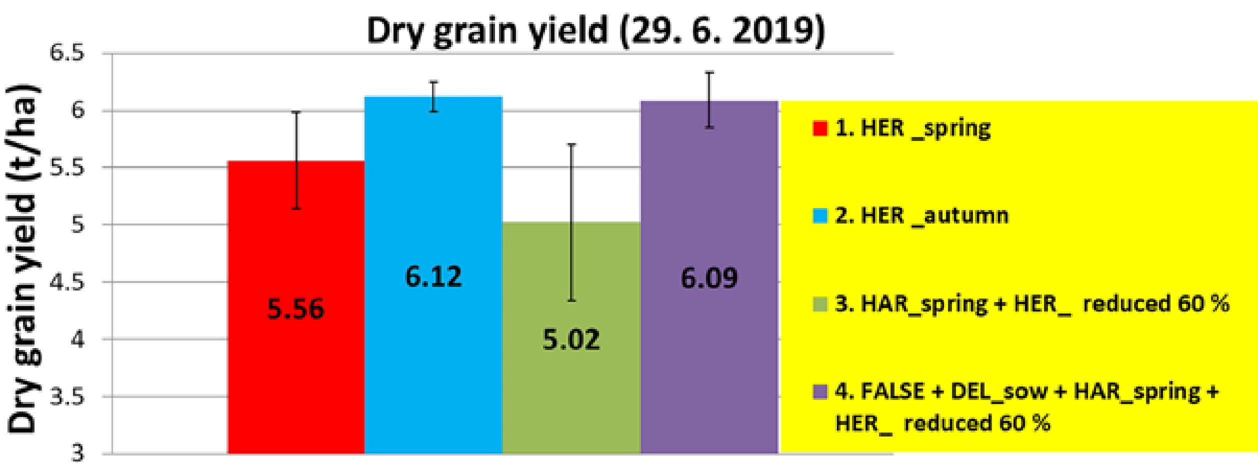



**Figure 14** - Average winter barley dry grain yield in Jablje (vertical bars represent standard errors)

**Figures 15 and 16 -** Impressions from Wheat field day in Jablje

## WP 4 – EXPERIMENTAL TRIAL ON MAIZE AT IC JABLJE

### Objectives

A field trial for demonstration purposes was established at the end of April 2019 to test various combinations of herbicide treatment and mechanical weed control in maize. Due to unfavourable weather conditions in 2018, weed management strategies were not fully implemented in the previous season. Therefore, we decided to follow the same protocol as 2018 and the description of weed strategies is presented in the table below (Table 2).

### Materials and methods

The trial was planted on 26 April 2019 with the Fisixx variety in warm, dry conditions. A couple of days after planting, a cold,wet period started, lasting practically the whole month of May. On top of that, we had two severe weather events with strong showers and hail. Herbicide applications were

| Strategy | Standard 1 | Strategy 2 | Strategy 3 | Strategy 4 |
|---|---|---|---|---|
| Label | CON | HER_red | HER_row | ORG |
| Tillage | autumn ploughing | autumn ploughing | autumn ploughing | autumn ploughing |
| Herbicides | YES | YES | YES | NO |
| Rate | recommended broadcast * | reduced (60 %) broadcast* | recommended in the row (30 cm) ** | / |
| Application time | early post | early post | early post | / |
| | EC 12 | EC 12 | EC 12 | / |
| Mechanical weeding | NO | YES (1 X ) | YES (1 X ) | YES (2 X ) |
| Interrow hoe | / | / | / | EC 14 |
| Finger weeder | / | EC 16 | EC 16 | EC 16 |

* S-metolachlor 375 g/L + therbuthylazine 125 g/L + mesotrione 37,5 g/L – Lumax: 3,75 L/ha
** recommended dose was applied in the 30 cm band along the row (40 % of the dose in the whole area).

**Table 2** - Description of the strategies in the maize field trial at IC Jablje

**Figures 17 and 18** - Very slow development of maize four weeks after planting (left) and first interrow hoeing at the beginning of June 2019 (right)

**Figures 19, 20 and 21** - Season 2019 was characterized by extreme weather events

performed according to the protocol. In Strategy 1, the recommended dose of standard herbicide (Table 2) was applied in the optimum conditions at the 2-3 leaf stage of maize, while most of the weeds were up to the 2-3 leaf stage. In Strategies 2 (reduced dose) and 3 (band application), the same herbicide was applied at the same time as Strategy 1, i.e. at 2-3 leaf stage of maize. Mechanical weeding with a finger weeder was planned at two growth stages of maize in both Strategy 3 with band spraying and Strategy 4 (mechanical weed control only).
In general, conditions for herbicide performance were suitable, the soil was adequately supplied with moisture, and most of the weeds germinated in the spring and early summer flush. Extremely rainy conditions in May and June caused severe crusting of the top soil layer, therefore interrow hoeing (Figures 17 and 18) instead of finger weeding had to be executed at maize 4 leaf stage in Strategy 2 (organic treatment), while a second mechanical pass was performed with the finger weeder (Strategies 2, 3 and 4). By the time the conditions and maize growth stage were suitable for implementing the finger weeder (6-leaf stage), most of the weeds exceeded the optimum growth stage for effective control along the row.

### Results

Overall, the 2019 season was very difficult due to wet conditions. Additionally, we had a hail event at the end of June, which caused some damage and probably also had a minor effect on the maize yield at the end of the season.

**Figures 22 and 23** - Maize trial in early September (left) and at harvest (right)

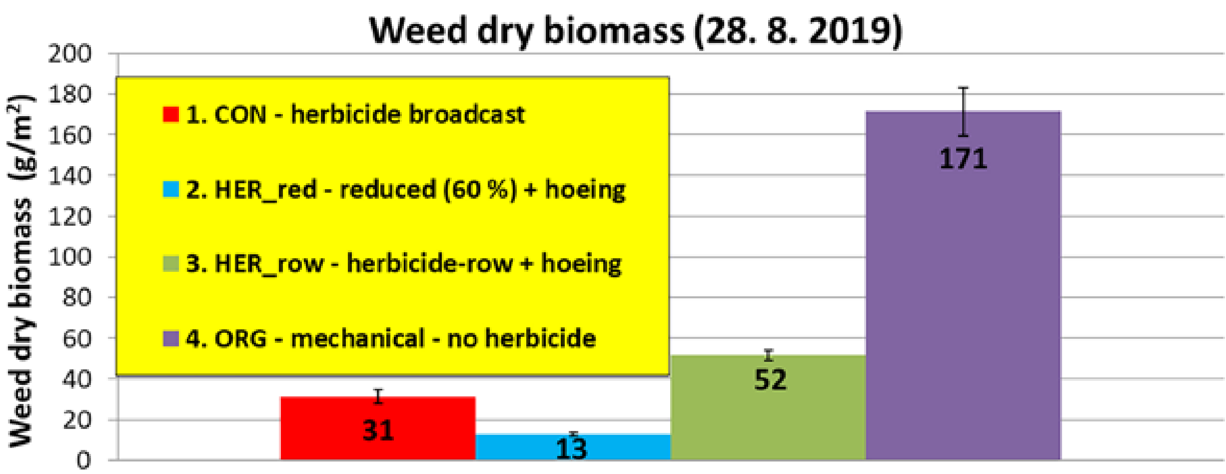



**Figure 24** - Average weed dry biomass in maize in Jablje (vertical bars represent standard errors)

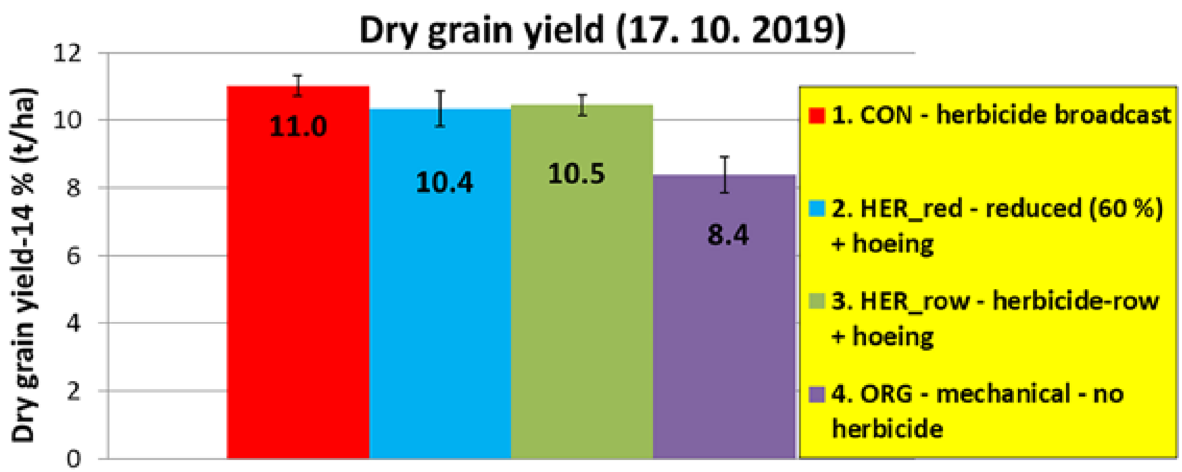



**Figure 25** - Average maize dry grain yield in Jablje (vertical bars represent standard errors)

Results of weed infestation at the end of August 2019 showed that the most effective strategy was reduced herbicide treatment (60% dose) followed by hoeing (Strategy 2; 13 g/m$^2$). Herbicide standard treatment (Strategy 1; 31 g/m$^2$) and herbicide application in the row followed by hoeing (Strategy 3; 52 g/m$^2$) were somewhat less effective. This result can largely be contributed to uneven infestation of field horsetail (*Equisetum arvense*). The greatest dry weed biomass was recorded in the organic treatment (ORG) with only mechanical weed control measures (Strategy 4; 171 g/m$^2$) (Figure 24).

The greatest average yield (11 t/ha) was achieved using standard herbicide application (Strategy 1) (Figure 25). Similar yields were obtained using a reduced herbicide dose (10.4 t/ha) and band spraying (10.5 t/ha), which were followed by finger weeding. The wet season had a strong influence on the performance of mechanical weed tools and, due to considerably greater weed infestation, the lowest yield was measured in the organic treatment (8.4 t/ha).

Trial outcomes were presented with a lecture at the Maize field day in Jablje. Discussion continued during the field tour, when around 70 visitors (mostly farmers and advisors) observed the results of the strategies tested (Figures 26, 27 and 28).

**Figures 26, 27 and 28** - Impressions from Maize field day 2019 in Jablje

## WP4 - MAIZE DEMONSTRATION TRIAL ON FARM (KGZS-ZAVOD LJ)

This season, our partner KGZS-LJ (the Chamber of Agriculture and Forestry of Slovenia – Ljubljana) organized a field trial on farm where standard broadcast herbicide treatment was compared to reduced herbicide application and mechanical weed control. The experiment had a demonstration purpose, where one of the farmers displayed mechanical treatment (harrowing) at the open field day. There was great interest in this event and more than 30 farmers were present at the site (Figures 29, 30 and 31). Besides the presentation of project activities, farmers expressed a great interest in our work and further collaboration.

**Further development**

In both experimental seasons (2018 and 2019), average yields obtained in the WP3 winter wheat and winter barley trials were low, therefore the effect of weed management was not fully reflected on yields. Both of the seasons were characterized by unusual weather events which prevented planned strategies being executed according to the protocol. In the 2019/2020 season, the winter barley trial is already running, with similar strategies being tested. In the WP4 trial on maize, very good results were achieved with reduced broadcast and band herbicide application supplemented with hoeing or finger weeding. The maize trial will also follow the same protocol as the previous seasons, since the strategies and tools planned were executed in very unfavourable weather conditions.



**Figures 29, 30 and 31** - Maize field day on a farmer’s field

## WP5 - BIOLOGICAL CONTROL OF RUMEX IN SLOVENIA (AJDOVŠČINA AND MURSKI ČRNCI)

*Rumex obtusifolius* is a common weed on agricultural land, frequently occurring on meadows and pastures. It is capable of regrowing after frequent defoliation and soil disturbance. Large production of highly dispersive and persistent seeds adds to its successful establishment on agricultural land.
A common practice for *R. obtusifolius* removal is the use of chemical agents or mechanical weeding (including hand-removal). Another option, mentioned by some reviews, is the use of insect species suitable for biological control. Previous studies conducted in Switzerland (CABI) showed the potential of inundative applications of a Sesiidae species *Pyropteron chrysidiforme* to control *R. obtusifolius*. Larvae of the insect feed on *R. obtusifolius* roots thus weaken its growth capability. Plant mortality is likely with high larvae infestation.

### Objectives

The IWMPRAISE project includes a three-year study on the mass-release of *P. chrysidiforme* into environmental conditions that will foster a population build-up. Establishment of *P. chrysidiforme* after targeted release, as well as its impact on *R. obtusifolius* mortality, will be studied in the years following the study.

### Materials and methods

The field trial continues for the third season in two locations in Slovenia, one in the SW - Vipavska dolina region (Location 1), with a mild Mediterranean climate, and one in the NE - Prekmurje region (Location 2), with a continental climate (hot, dry summers, but cold winters). A meadow with relatively high *R. obtusifolius* population was selected at each location.

Pupae of *P. chrysidiforme* were brought from CABI Switzerland to the Agriculture Institute of Slovenia (AIS) in spring 2018. Emergence of adult insects was closely followed, and mating was done according to the protocol. Eggs laid by female insects in plastic containers were picked and glued onto toothpicks (30 per toothpick). The toothpicks were stored for field inoculation.
Second inoculation of *R. obtusifolius* plants was carried out on the two selected field trial locations on 21 June and 2 July 2019. A total of 125 plants


**Figure 32** - Locations of the two study sites in Slovenia

**Figures 33 and 34** - Toothpicks with eggs ready for inoculation (left) and an inoculated plant in the field (right)

**Figures 35 and 36** - Inoculation of *R. obtusifolius* (left) and locating the marked plants with high-precision GPS (right)

**Figure 37** - Empty spot where *R. obtusifolius* was eradicated by *P. chrysidiforme*

were inoculated on each site: a) 50 plants with *P. chrysidiforme* in Years 1 and 2; b) 50 plants with *P. chrysidiforme* in Years 1, 2 and 3; and c) 25 plants for estimation of annual establishment rate. Plants will be inoculated once more next season according to the protocol. The overall impact of insect activity on the mortality of inoculated *R. obtusifolius* plants will be estimated in the final year of the experiment, when the plants will be dug out and assessed.

Toothpicks with eggs were placed in the cores of 125 plants per site. Then, 25 plants out of 125 were inoculated for estimation of annual establishment rate. The plants were located with a high-precision GPS (Stonex S9i by Stonex SRL, Lissone - Italy) on the same spot of the previous year.
Initial observations in-field indicate that biological control of *R. obtusifolius* with *P. chrysidiforme* is

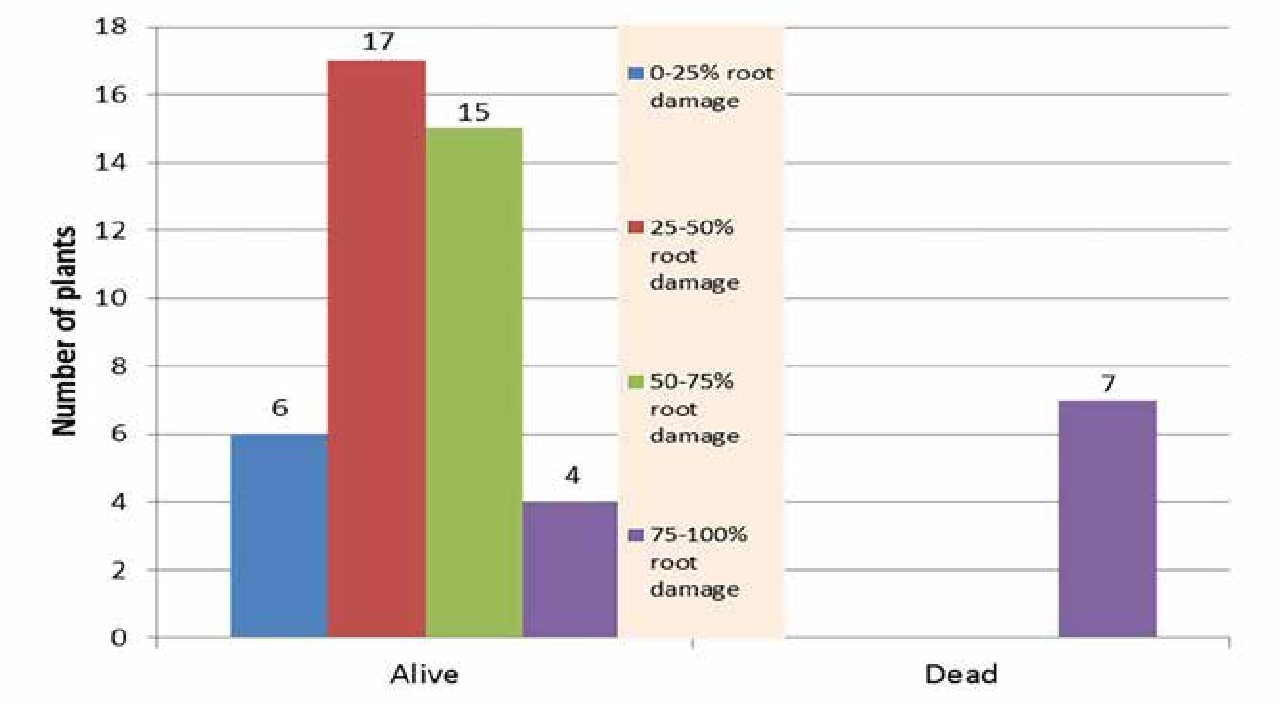



**Figure 38** - Root damage and mortality of *R. obtusifolius* in annual establishment rate assessment (Average results for the two locations)

**Figures 39 and 40** - Plants inoculated in the spring were located (left) and dug out (right) in the autumn for annual establishment rate assessment

already showing promising results. Evaluation of marked *R. obtusifolius* plants demonstrated that a relatively high number of previously inoculated plants were completely controlled (73 dead plants at Location 1 and 18 dead plants at Location 2).

In addition, some 80 plants were also inoculated at AIS grounds for next year's cycle of rearing and inoculating on field sites.

**Primary results of annual establishment rate**

The 25 inoculated plants, selected to estimate the annual establishment rate of *P. chrysidiformae*, were dug out and evaluated on 8 October and 17 October 2019. In the spring, marked plants were re-located with a GPS device and the whole plants were put in bags. Plant roots were later inspected for presence of *P. chrysidiforme* larvae and the level of the root damage.

At Location 1, five plants inoculated in the spring were found to be dead, with root damage being almost 100%. The other plants were alive, but all

**Figures 41 and 42** - *P. chrysidiforme* larvae (left) in *R. obtusifolius* root (right)

showing signs of insect action (average 56% root damage). Additionally, *P. chrysidiformae* larvae were found in all but two dug-out rootstocks.
Results of annual establishment rate assessment at Location 2 showed that two plants were found to be dead, while the other plants were still growing. Root damage of alive plants on this site varied between 1% and 75%. Larvae of *P. chrysidiformae* were found in 10 of the growing plants, and no larvae were found in 13 plants, although signs of insect damage on roots were present on all of them (average 30% root damage).

# EXPERIMENTAL TRIALS AT THE BIOTECHNICAL SCHOOL RAKIČAN (BSR)

BIOTEHNIŠKA ŠOLA RAKIČAN


**Figures 1 and 2** - Location of the WP3 winter barley and WP4 maize trials in Rakičan in 2019

*BSR Rakičan is a public agricultural high school in the Panonian lowland. Besides basic, mainly agricultural education programmes, it conducts various research activities that focus on arable production with variety testing and implementation of new technology and management in practical settings. BSR Rakičan owns around 18 ha of arable land with high-quality silty-loam soil. A warm continental climate offers excellent conditions for outdoor experiments. BSR Rakičan's skilled staff regularly carry out demonstration trials and education courses in collaboration with the local advisory service. Well-attended events, such as traditional wheat and maize field days, confirm that BSR Rakičan is a strong regional education and knowledge-transfer centre.*

Address:
Biotehniška šola Rakičan
Lendavska ulica 3
9000 Murska Sobota - Slovenia
GPS coordinates: 46°39'3.57"N 16°11'32.83"E
http://www.solarakican.si/index.php/en/
tel. +386 2 530 37 50

For information and guided visits of WP3 and WP4 trials at BSR Rakičan, please contact:
Robert Janža
e-mail: robert.janza@guest.arnes.si
tel. +386 1 530 37 50
Primož Titan
e-mail: titan.primoz@gmail.com
tel. +386 51 312 502

## WP3 – WINTER WHEAT TRIAL AT BSR RAKIČAN

### Objectives

The aim of the IWMPRAISE experiment was to test and compare standard autumn and spring herbicide-based approaches with two IWM strategies in winter wheat production.

### Materials and methods

A winter wheat (Falado variety) demonstration trial was set up in October 2018 to compare two IWM strategies to two standard solely chemical approaches. Autumn and spring broadcast herbicide application represented the standard weed management practice, while IWM strategies included reduced herbicide inputs combined with mechanical tools. Strategies were followed according to the protocol in the table below (Table 1), while details of their implementation are described in the text.
The previous crop on the experimental field was maize and the site was ploughed one week before sowing. The seedbed was prepared afterwards with the spring tine cultivator on 12.10.2018.

Soil conditions on both the optimal and delayed sowing dates were favourable, with warm weather and adequate water supply. Winter wheat in the optimum sowing date was drilled on 18.10.2018 (Strategies 1, 2 and 3). The plot with Strategy 4 was drilled 11 days later on 29.10.2018 (Figure 4). Conditions for germination and crop establishment were excellent. Unusually warm weather continued in the late autumn, which enabled the implementation of weed management measures in optimum conditions. A first tine harrowing pass was performed in Strategy 3 just one month after drilling on 14.11.2018, while autumn spraying in Strategy 2 was performed on 5.11.2018.

### Results

Considerable difference in the winter wheat growth stage in the delayed sowing treatment (Strategy 4) was determined. Winter wheat in this plot reached only stage BBCH 12-13 compared to BBCH 15 stage in other strategies. Despite this difference, overwintering of the crop was optimal and no stand loss was determined due to winter conditions.
A first tine harrowing in the spring (Strategies 3 and 4) was performed on 4.3.2019, while a second pass in Strategy 4 was executed three weeks later. Both autumn and spring harrowings performed well, mainly because of adequate soil conditions and crop development.
The crop in the delayed drilling plot had a minor

| Strategy | Standard 1 | Standard 2 | Strategy 3 | Strategy 4 |
|---|---|---|---|---|
| Label | HER_spring | HER_autumn | HAR_aut + HAR_spring + HER_ spring - reduced 50 % | DEL_sow + HAR_spring (2 x ) - no herbicide |
| Soil tillage | autumn ploughing | autumn ploughing | autumn ploughing | autumn ploughing |
| False seed bed | NO | NO | NO | YES |
| Sowing time | optimum | optimum | optimum | delayed 11 days |
| Herbicides | YES* | YES† | YES* | NO |
| Herbicide application time | spring application EC 32 | autumn application EC 12 | spring application EC 32 | / |
| Rate | recommended | recommended | Reduced 50 % | / |
| Mechanical weeding | NO | NO | autumn tine harrowing and spring tine harrowing | spring tine harrowing (2 x ) |

* pyroxsulam 75 g/kg - Pallas: 250 g/ha
† pendimethalin 300 g/L + chlortoluron 250 g/L + diflufenican 40 g/L -Trinity: 2 L/ha

**Table 1** - Description of the winter wheat experiment at BSR Rakičan


Figures 3 and 4 - Winter wheat drilling at optimum (left) and delayed sowing period (right)

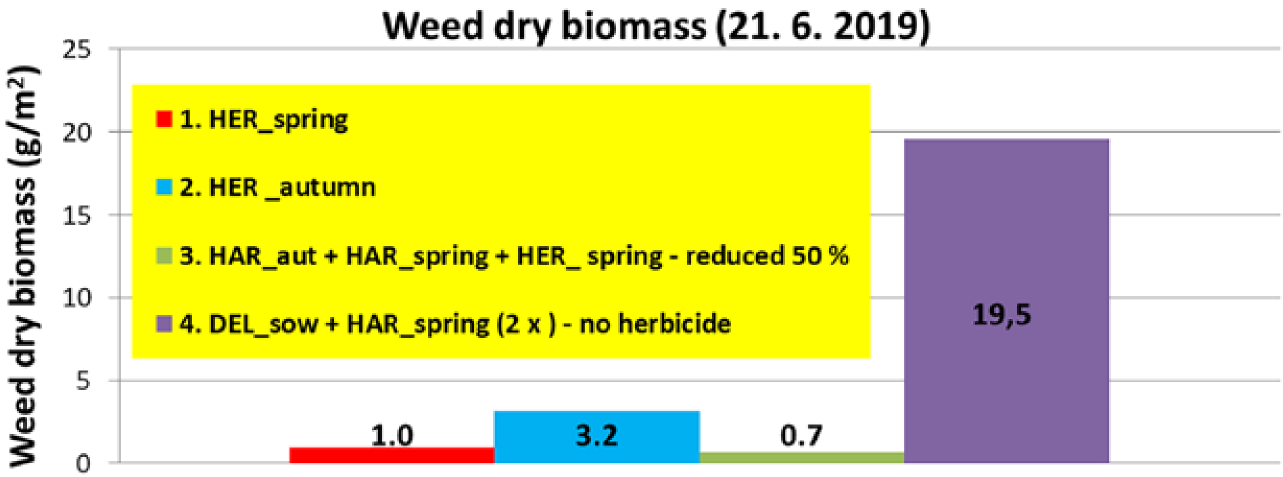



Figure 5 - Average dry weed biomass in Rakičan

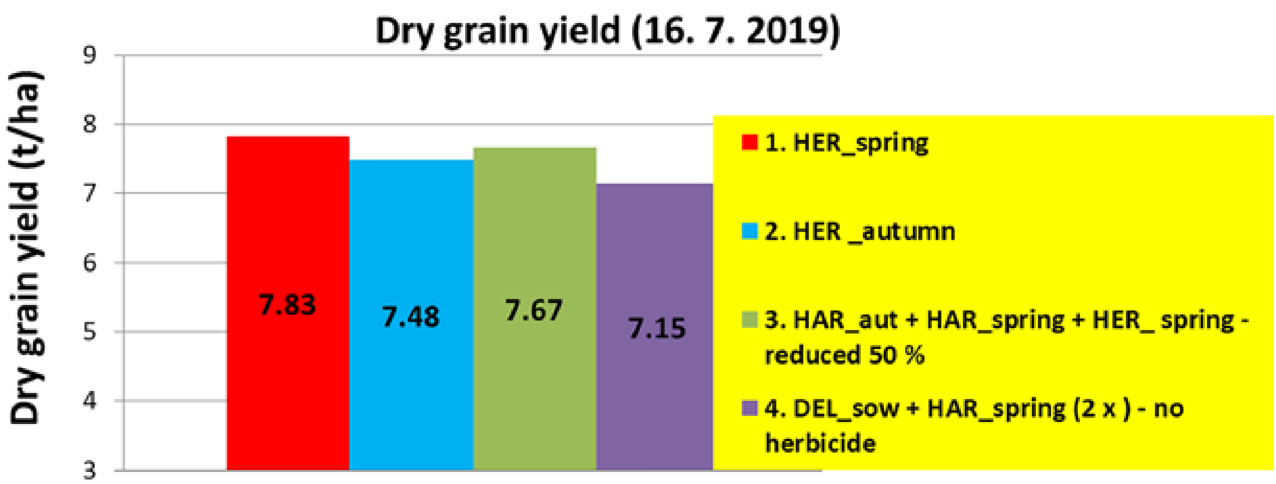



Figure 6 - Winter wheat dry grain yield in Rakičan

**Figures 7, 8 and 9** - Images of the Wheat field day in Rakičan

delay in development and produced 50 heads/ $m^2$ less compared to the other strategies. Weed infestation was generally low across all the plots, only Silky bent-grass (*Apera spica-venti*) appeared on some spots.
Dry weed biomass (Figure 5) was assessed at the winter wheat milking stage (21.6.2019). The greatest weed biomass was recorded in Strategy 4 with delayed drilling, followed by two spring harrowings (19.5 g/$m^2$). Most of the weed infestation in this strategy occurred at the beginning of summer, but the greatest effect on yield loss can be due to less productive tillering. Strategy 3 with two harrowings (autumn and spring) followed by reduced herbicide application performed excellently with only 0.7 g/ $m^2$ of dry weed biomass and was comparable to standard spring herbicide application (1.0 g/$m^2$). The standard autumn herbicide Strategy 2 was also relatively effective with 3.2 g/$m^2$ of dry weed biomass.

Results of winter wheat dry grain yield (Figure 6) were correlated with the results of weed density. The lowest yield was determined in the most weedy treatment, with delayed sowing followed by two spring harrowings, during which no herbicide was applied (7.15 t/ha). Dry grain yield was the greatest in the standard Strategy 1 (7.83 t/ha) and Strategy 3 with two harrowings (autumn and spring) followed by reduced herbicide application (7.67 t/ha). Minor yield loss was determined in the standard autumn herbicide application, which was also relatively effective (7.48 t/ha).

Environmental conditions in the 2018/2019 growing season were not favourable, therefore only average winter wheat yields were achieved in the northeast region of Slovenia. With the exception of Strategy 4, which implemented mechanical weed control only, all strategies were very effective in terms of weed control. Compared to the best yielding standard spring herbicide (Strategy 1), only minor yield decrease was determined in the IWM strategy with autumn and spring harrowing followed by reduced herbicide application. In season 2019/2020, the experiment is being run at the same location, and similar IWM strategies will be tested in winter wheat. Trial outcomes were presented with a lecture to around 30 visitors (mostly farmers) at the Wheat field day in Rakičan. Participants were also given a guided visit of the trial, when the results of the IWM strategies tested could be observed on-site (Figures 7, 8 and 9).

## WP4 – MAIZE TRIAL AT BSR RAKIČAN

### Objectives
A similar protocol to the previous year was executed at the Rakičan site in 2019. The weather conditions in the previous season prevented full implementation of the originally scheduled mechanical weed control, therefore only minor modifications to the weed control strategies were made (Table 2).

### Materials and methods
The trial was planted very early (19 April 2019) with variety P 9234. After planting, maize germination was fast and uniform, however cold, rainy conditions afterwards hindered further development of maize substantially. Excessive rain caused difficulties in executing weed management operations. Due to the wet conditions, the false seedbed planned in Strategies 2, 3 and 4 was not performed, while stale seedbed treatment (with tine harrow) was executed in unfavourable conditions four days after planting within Strategy 2.

Herbicide applications were performed in optimal soil conditions in the 2 leaf growth stage of maize. In Stategy 1, the recommended dose was used, while in Strategy 2 a reduced dose of herbicide was applied. For Strategy 3, a prototype for band spraying and interrow cultivation was developed in which the recommended herbicide dose was applied along the maize rows. Herbicide application in Strategies 2 and 3 was followed by hoeing at the 5 leaf maize growth stage. Mechanical weed control only was implemented in Strategy 4, during which three passes with a tine harrow and one hoeing pass at the 5 leaf maize growth stage were performed.

### Results
Results of weed biomass assessment before maize harvest in Strategies 1 and 2 (Figure 12) showed that both performed very efficiently, with 27 and 36 g/ $m^2$ of dry weed biomass respectively. In the Strategy 3 with band application of herbicide followed by hoeing, 59 g/$m^2$ of biomass was measured, while in Strategy 4 with mechanical weed control only, 179 g/ $m^2$ of dry weed biomass was determined.
The greatest yield was measured in the standard Strategy 1 (13.5 t/ha), followed by 13.3 t/ha and 12.8 t/ha in Strategy 3 and 2 respectively. The lowest yield was achieved in Strategy 4 with mechanical weed control only (11.3 t/ha), in which substantially higher weed infestation was observed compared to the other strategies (Figure 13).

| Strategy | Standard 1 | Strategy 2 | Strategy 3 | Strategy 4 |
|---|---|---|---|---|
| Label | CON | HER_red | HER_row | ORG |
| Tillage | autumn ploughing | autumn ploughing | autumn ploughing | autumn ploughing |
| Herbicides | YES* | YES* | YES* | NO |
| Rate | recommended broadcast * | reduced (50 %) broadcast * | recommended in the row (30 cm) ** | / |
| Application time | early post | early post | early post | / |
| | EC 12 | EC 12 | EC 12 (combined with hoeing) | / |
| Mechanical weeding | NO | YES (1 X ) | YES (2 X ) | YES (4 X ) |
| Tine harrow | / | / | / | EC 03<br>EC 12<br>EC 13 |
| Interrow hoe | / | EC 15 | EC 12<br>EC 15 | EC 15 |

* isoxaflutole 225 g/L + thiencarbazone-methyl 90 g/L + cyprosulfamide safener 150 g/L - Adengo: 0,44 L/ha
** recommended dose was applied in the 30 cm band along the row (40 % of the dose in the whole area).

**Table 2** - Description of the maize experiment at BSR Rakičan

**Figures 10 and 11** - Tine harrowing four weeks after planting and hoeing at the end of June 2019

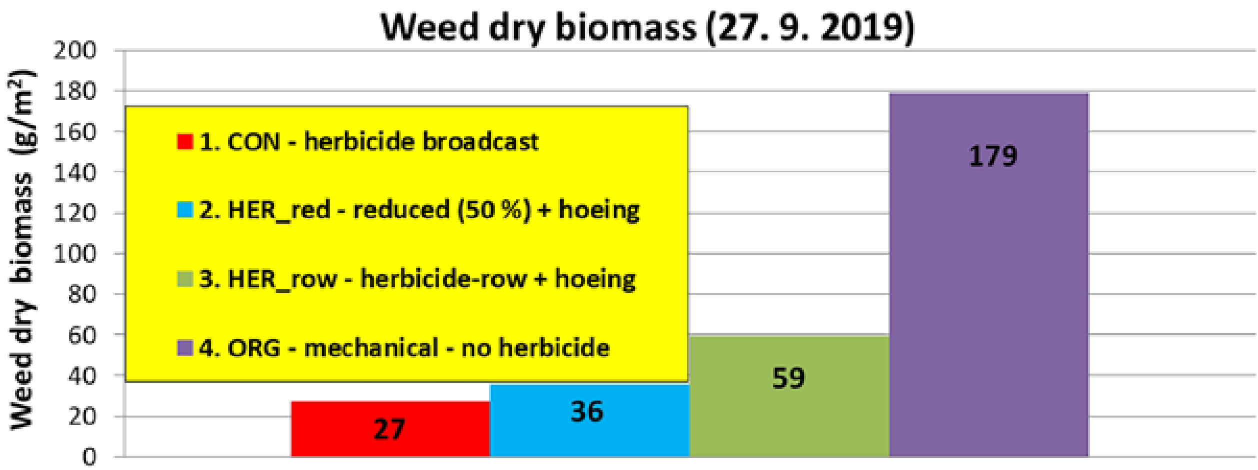



**Figure 12** - Weed dry biomass in maize in Rakičan

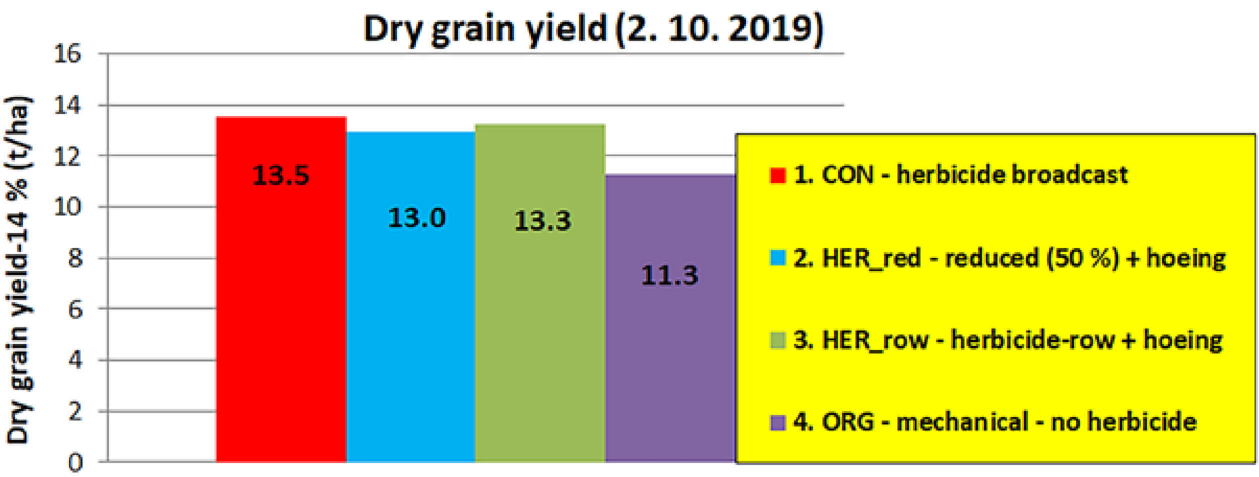



**Figure 13** - Maize dry grain yield in Rakičan

**Figures 14 and 15** - Traditional Maize field day at Biotechnical School Rakičan

The Biotechnical School Rakičan hosted its traditional Maize field day, during which trial outcomes were presented with a lecture to around 30 visitors (mostly farmers). Participants were also given a guided visit of the trial, when the results of the IWM strategies tested could be observed on-site (Figures 14 and 15).

### Further development

The BŠR experimental site has different pedoclimatic conditions to the Jablje site in central Slovenia. In both trial seasons (2018 and 2019), very dry years had a significant effect, resulting in very low cereal yields. Furthemore, due to drought, weed pressure was also extremely low. Despite unusal environmental conditions, the strategy with a reduced herbicide dose combined with tine harrowing appeared to be the most effective, with only minor yield losses observed in both years. In season 2019/2020, a winter wheat trial is already running, with similar strategies being tested.
In the WP4 trial on maize, very good results were achieved in the strategy with reduced herbicide application supplemented with hoeing; in both years, the first strategy was comparable to standard broadcast herbicide application. The band application and hoeing strategy was less effective, but it had only a limited effect on yields. Based on the results of two trial seasons, the maize trial will follow the same protocol as the previous years, since the strategies and tools planned were executed in highly unfavourable weather conditions.

# SWITZERLAND

# EXPERIMENTAL TRIALS MANAGED BY AGROSCOPE AND AGFF

*Agroscope is the Swiss centre 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.*

**Address:**
**Agroscope**
**Reckenholzstrasse 191**
**8046 Zürich - Switzerland**
**tel. +41 58 468 71 11**

**AGFF**
**Reckenholzstrasse 191**
**8046 Zürich - Switzerland**
**tel. +41 377 72 53**

**GPS coordinates of garden: 47°25'40.1"N 8°30'59.4"E**

**For further information and guided visits, contact:**
**Agroscope: Andreas Lüscher**
**e-mail andreas.luescher@agroscope.admin.ch**
**tel. +41 58 468 72 73**
**AGFF: Willy Kessler**
**e-mail willy.kessler@agroscope.admin.ch**
**tel. +41 58 468 72 76**

# FIELD EXPERIMENT ON THE IMPACT OF TWO SESIID CANDIDATES FOR BIOLOGICAL CONTROL OF *RUMEX OBTUSIFOLIUS* UNDER COMPETITIVE STRESS

A pot experiment set up in 2018 revealed a low impact of the root-boring moths P*yropteron chrysidiforme* and *P. doryliforme* (Lepidoptera, Sesiidae) on the above- and belowground performance of *Rumex obtusifolius* (dock), despite a high number of larvae recovered from the inoculated plants. One explanation is that the *R. obtusifolius* plants in the pots grew without competition from other plants and thus were not as stressed as plants growing under field conditions.

### Objective

In 2019, we set up a one-year field experiment to compare the impact of the two Sesiid moths on *R. obtusifolius* growing with and without competition from other plant species. The establishment rate of the Sesiid moths, as well as their impact on *R. obtusifolius*, was studied on *Rumex* plants differing in initial root size.

### Material and methods

The experiment was set up using an established sward (one-year old) of *Lolium perenne* (English Ryegrass) near Agroscope in Zürich-Reckenholz (Figure 1). The experiment was arranged in a split-plot design with competition as a whole-plot factor with two levels: (A) competition with *L. perenne*, (B) no competition. The split-plot factor was the insect treatment with three levels (1) infestation with *P. chrysidiforme*, (2) *P. doryliforme*, and (3) control (no infestation). Plots were arranged in a randomized complete block design. We also measured the root weight of each transplanted *R. obtusifolius* plant, defined by its initial weight after cutting the root at 15 cm length. This measurement will be included as a co-variate in the analysis. In total, the experiment comprised 432 roots of *R. obtusifolius*.

The *Rumex* plants originated from three different meadows, where plants were dug up in spring 2019. We measured their developmental status (root width, weight, number of secondary taproots, total number of roots, number of rosettes, number of flowering stems) and herbivore damage (presence/absence). Roots were stored in a fridge at 10°C until transplanting.

Roots were transplanted to the experimental field in mid-June at a distance of 40 cm within split-plots and a distance of 80 cm between split-plots. In the competition treatment, a hole was dug into the meadow with a crowbar and the root was placed inside. In the no-competition treatment, roots could be transplanted directly into the soil, which had been tilled twice in early June.

**Figure 1** - Field experiment to test the impact of two Sesiid species, candidates for biological control of *R. obtusifolius* growing with and without competition from *L. perenne* (English Ryegrass). The experiment was set up near Agroscope in Zürich-Reckenholz

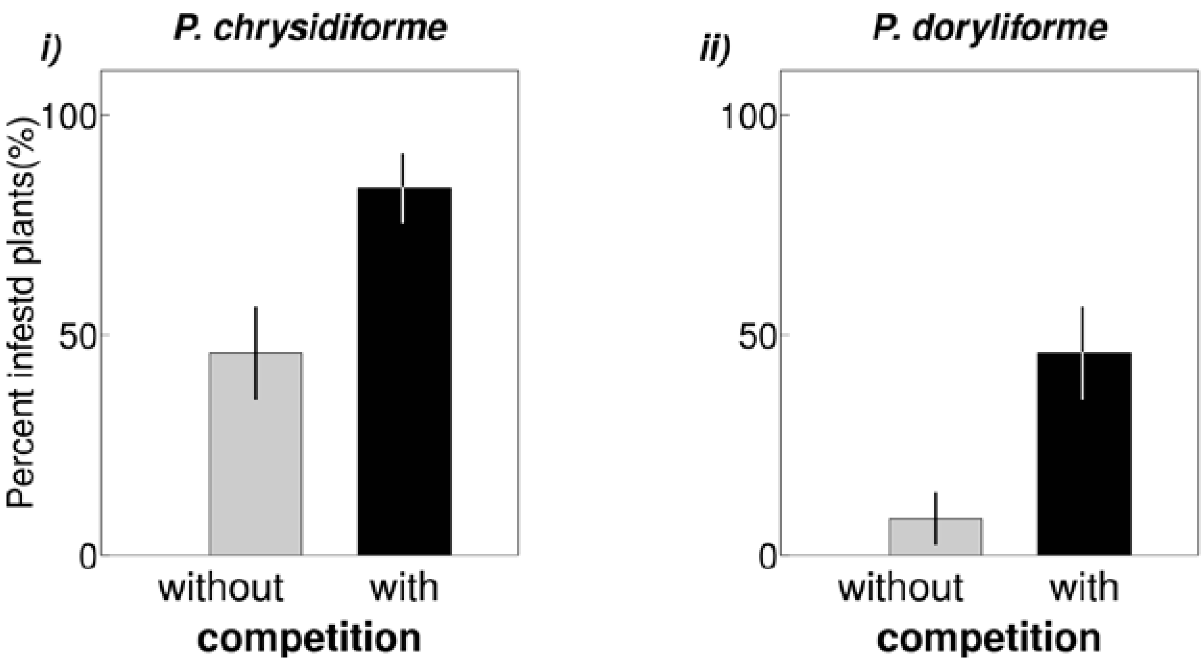



**Figure 2** - Percent of *R. obtusifolius* plants infested by at least one larva depending on the presence or absence of competition and on *Pyropteron* species in autumn 2019 (n = 142, 2 roots not recovered). Mean ± SE from raw data

In mid-July, plants subjected to the insect treatment were inoculated using the same application technique as the previous year (eggs glued on toothpicks, toothpicks inserted into the central rosette of the plant). The toothpicks were removed after three weeks and the number of eggs with exit holes recorded.
The aboveground biomass of *R. obtusifolius* plants was harvested (cut at 5 cm height) in early August, early September and late October. Each time the *Rumex* plants were harvested, the *L. perenne* sward was also mown and its biomass removed. Subsequently, plots were fertilized with mineral fertilizer at a rate of 50 kg N/ha.
In mid-October, one third of the *Rumex* roots (144 plants) were harvested to assess the establishment rate of Sesiid larvae. The dissection of roots took place during November. The following variables were recorded: root length and width, root weight, number of secondary taproots, total number of roots, number of plant rosettes, number of flowering stems, absence/presence of herbivore damage (plant performance, degree of root decay), presence of feeding marks on the root surface, number of *Pyropteron* larvae recovered alive, number of larvae recovered dead, total number of larvae, presence of empty larval head capsules, individual weight of larvae recovered alive and their position in the root, and presence of parasites in frass or on dead *Pyropteron* bodies. The remaining *R. obtusifolius* roots will be harvested and dissected in May 2020.

### Preliminary results

#### Rate of establishment

When grown under competition with *L. perenne*, the proportion of *Rumex* plants being infested by at least one larva in autumn 2019 was higher than when grown without competition (Figure 2). Irrespective of competition, plants inoculated with *P. chrysidiforme* showed higher rates of infestation than those inoculated with *P. doryliforme* (Figure 2).

Under the competition treatment, the number of larvae retrieved from *Rumex* plants infested with *P. chrysidiforme* was higher than for plants infested with *P. doryliforme* (Figure 3). When grown without competition, the number of larvae retrieved from infested plants appeared to be similar for the two *Pyropteron* species.

## *RUMEX OBTUSIFOLIUS* CASE-CONTROL STUDY

#### Objective

This on-farm study aims to identify management practices to prevent *R. obtusifolius* infestation on permanent grasslands. The study follows a case-control design: it compares parcels with high densities of *R. obtusifolius* with nearby parcels free of or with very low densities of *Rumex* plants. The pedo-climatic conditions of these pairs of parcels

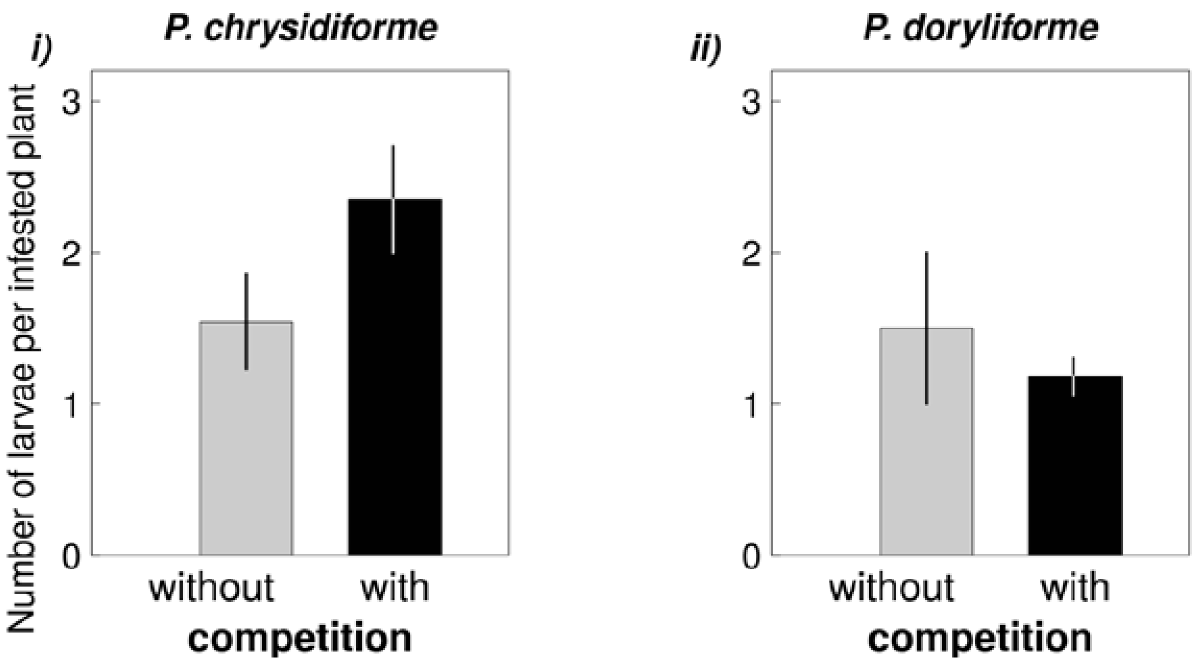



**Figure 3** - Number of larvae retrieved from infested *R. obtusifolius* plants with and without competition (without n = 13, with n = 31), given for two *Pyropteron* species (*P. chrysidiforme* n = 31, *P. doryliforme* n = 13) in autumn 2019. Note: 142 roots harvested, 2 not recovered (both in *P. doryliforme*). Mean ± SE from raw data

are thus very similar; however, their management can differ substantially. The sampling occurred on 40 farms in Switzerland located in the Jura region, on the Swiss Plateau and in the Prealps (Figure 4); data from a pair of parcels (case/control) was recorded at each farm. Contact with farmers managing parcels with high *Rumex* occurrence was established with support from the agricultural advisory service.

In February 2019, a common protocol was designed. The study focuses on intensively managed grassland established at least 5 years ago and being relevant

**Figure 4** - 40 sites with a pair of parcels each, one with high (case) and one with no or low occurrence (control) of *R. obtusifolius*, spread across the Jura region and the Swiss Plateau/Prealps

for forage production for dairy and meat cattle. The parcels were visited before the actual sampling to ensure that all requirements were fulfilled. In the end, the sampling included 24 pairs of parcels in conventional farming systems, 14 pairs in organic farming systems, and 2 mixed pairs.
A parcel was considered as a case if the density of *R. obtusifolius* was higher than one plant per $m^2$, and as a control if the density was less than four docks per 10 x 10 $m^2$ (Figure 5).

Data collection started in mid-May 2019 and ended in mid-October 2019. The sampling included a vegetation census (species list, percentage of functional groups and of the three most abundant species), record of vegetation cover (0.1–5 cm) and of plant basis covering the soil surface (point-intercept method), as well as the collection of soil samples for assessing physical and chemical soil properties, plus the soil seedbank.
Soil samples to analyze the physical and chemical properties were dried at 40°C, milled to pass a 2 mm sieve, and analyzed for soil texture (% sand, % clay, % silt), phosphorus content (P extracted with $NH_4Ac$/EDTA), potassium content (K extracted with $NH_4Ac$/EDTA), cation exchange capacity, pH, humus content, lime, exchangeable calcium, and salt content.
The number of viable seeds of *R. obtusifolius* in the soil was evaluated by a germination experiment set up in an Agroscope greenhouse. In mid-January

**Figure 5** - Examples of sampling plots (3 m x 3 m) in a case parcel with high dock density (left) and of a dock-free control parcel (right)

2020, samples were concentrated by washing the soil through a coarse and a fine sieve, following established protocols. Seedling germination was recorded for nine weeks (Figure 6). *Rumex* seedlings were counted every second day after identification of the first fully developed leaf.
Farmer interviews started in February 2020 to collect information for the selected pairs of parcels regarding management (e.g. mowing, grazing, defoliation frequency), fertilization (e.g. type and amount of applied fertilizers), disturbance, and parcel history (amongst others).

**Figure 6** - Seed germination experiment set up at Agroscope. Soil samples were evaluated for germination for 9 weeks; *Rumex* seedlings were counted every second day. Case parcel on the left, corresponding control parcel on the right

# FRANCE WP3

Mons
Bonvilliers
Vallangoujard
L'Épine
Saint Hilaire en Woevre
Boigneville
St Martin des Champs
Nancy
Crenay
Lapan
Plaimpied-Givaudins
Rians
Vomay
Gémeaux
Bergerac

## WP3 – EXPERIMENTAL TRIALS ON ANNUALLY DRILLED CROPS IN NARROW ROWS

Several WP3 themes were studied during the 2018-2019 season within the IWMPRAISE project:
- delaying the sowing date;
- integration of agronomic levers (soil tillage);
- mechanical weeding.

### DELAYED SOWING OF WHEAT

Trials combining herbicide and insecticide programmes have been implemented in winter wheat and winter barley to answer the following questions:
- Does a sowing-date delay of about 20 days limit the density of emerged weeds and/or aphid infestations?
- Which control methods are the most appropriate and for which yield differential?
- Does weed-control quality have an impact on the epidemiology of Barley Yellow Dwarf Virus (BYDV)?
- What is the variability of these responses?

In the five wheat trials implemented, no incidence appeared between BYDV and weeds, as pest populations were very low or not present. This report will therefore only include herbicide treatments comparable with the same insecticide programmes to control aphids, vectors of the BYVD. Only the impact on weed management will be studied in these trials. Thus, 0.075 litres of Karate Zéon was applied in all of the treatments studied in the five trials.
The trials, as well as the processes put in place, are described in Table 2 below. Two trials have been set up in Gemeaux (21 – Bourgogne-Franche Comté) on the same plot: the Minimum Tillage (MT) trial was set up on a strip worked under intercultural shallow tillage; while the Direct Seeding (DS) trial was mirrored from this trial on the direct seeding plot.

These trials were implemented on wheat, peas and oilseed rape, according to the following table:

| Topic | Partner | Location |
|---|---|---|
| Delayed sowing in wheat | Arvalis | Gémeaux (21)<br>L'épine (51)<br>Crenay (52)<br>St Hilaire en Woëvre (55) |
| Integration of an IWM tool before sowing of wheat | Arvalis | St Hilaire en Woëvre (55) |
| Comparison of early mechanical weed control strategies (tine harrowing) in wheat | Arvalis | Bergerac (24)<br>Lapan (18)<br>Plaimpied-Givaudins (18) |
| | CA IdF | Bonvilliers (91)<br>St Martin des Champs (78)<br>Vallangoujard (95) |
| Mechanical weed control (hoeing) in triticale | Arvalis | Boigneville (91) |
| Soil tillage strategies, without glyphosate, before sowing spring peas | Terres Inovia | Rians (18) |
| Mechanical weed control, with or without herbicides, in oilseed rape | Terres Inovia | Mons (80)<br>Nancy (54) |
| Associated crops in organic farming to prevent weed infestation | Terres Inovia | Rians (18) |
| Long-term experiment on IWM-based weed control compared to a reference cropping system (OSR/WW/WB) | Fdgeda 18 | Vomay (18) |

**Table 1** - WP3 trials managed by the National French Cluster (number of geographical Department in brackets)

| Trials | Gemeaux MT (21) | Gemeaux DS (21) | L'Epine (51) | Crenay (52) | Saint-Hilaire-en-Woëvre (55) |
|---|---|---|---|---|---|
| **Weeds** | Blackgrass | Blackgrass | Blackgrass | Blackgrass | Matricaria, volunteer OSR, and field pansy |
| **Resistance status** | / | / | Beginning of resistance in the field | Beginning of resistance in the field | / |
| **Soil** | Sandy clayey loam | Sandy clayey loam | Chalk | Clay and limestone superficial on hard limestone | Hydromorphic loam |
| **Variety** | | Unik | Fructidor | Boregar | Chevignon |
| **Sowing date 1** | 01/10/2018 | 01/10/2018 | 02/10/2018 | 05/09/2018 | 21/09/2018 |
| **Sowing date 2** | 24/10/2018 | 24/10/2018 | 18/10/2018 | 27/09/2018 | 11/10/2018 |
| **Sowing date 3** | / | / | 09/11/2018 | 16/10/2018 | / |

**Table 2** - Trials on delayed sowing of wheat in France
Herbicides were adopted in each trial, as described in Tables 3, 4 and 5 below.
*Fosburi = diflufenicanil + flufenacet*
*Tolurgan = chlortoluron*
*Atlantis Pro = mesosulfuron-me + iodosulfuron-me-na*
*Actirob B = esterified rapeseed oil*
*Actimum = ammonium sulphate*
*Défi = prosulfocarb*
*Flight = picolinafen + pendimethalin*
*Daiko = prosulfocarb + clodinafop-propargyl + cloquintocet-mexyl*

| Early post-emergence 1-2L | End of winter (tillering) | Price (in €/ha) |
|---|---|---|
| Fosburi 0.5L + Tolurgan 50SC 3L | / | 77.9 |
| Fosburi 0.5L + Tolurgan 50SC 3L | Atlantis Pro 0.9L + Actirob B 1L + Actimum 1L | 124 |

**Table 3** - Herbicides trial set up in Gémeaux

| Pre-emergence | Early post-emergence 1-2L | End of winter (tillering) | Price (in €/ha) |
|---|---|---|---|
| / | / | Atlantis Pro 0.9L + Actirob B 1L + Actimum 0.5L | 43.6 |
| Défi 2L + Flight 3L | Fosburi 0.5L + Tolurgan 50SC 3L | / | 146.7 |
| / | Fosburi 0.5L + Tolurgan 50SC 3L | Atlantis Pro 0.9L + Actirob B 1L + Actimum 0.5L | 121.5 |

**Table 4** - Herbicide trials set up in Crenay & L'Epine

| Early post-emergence 1-2L | End of winter (tillering) | Price (in €/ha) |
|---|---|---|
| Fosburi 0.5L + Daiko 2.25L + Actirob B 1L 50SC 3L | / | 80.3 |
| Fosburi 0.5L + Daiko 2.25L + Actirob B 1L 50SC 3L | Atlantis Pro 0.9L + Actirob B 1L + Actimum 1L | 126.4 |

**Table 5** - Herbicide trial set up in Saint-Hilaire

As occurred in previous campaigns, the 2018-2019 trials highlighted the importance of delaying the sowing date in wheat when grass-weeds are present. The shortest delay was about 20 days between early and mid-October; the delays were mostly equivalent to a sum of nearly 200 degree days (base 0°C). A shift of 200 degree days allowed a reduction in the populations of blackgrass and ryegrass. Efficiencies were variable and ranged from 18% to 87%. For a shift of 200 degree days, the average reduction observed was close to 60%. As the sum of the degree days increased between the two trial seeding dates, the reduction in the weed populations of untreated controls also increased. Thus, with delays of 250 to 300 degree days, efficiencies are between 60% and 82%, with a 70% average.  Both trials saw reductions close to 85% between 350 and 400 degree days.
Within the five trials of this campaign, the effects of a 50%-plus reduction were visible on blackgrass in three out of the five trials. One of the trials had a low impact, but had a very low infestation, while the fifth trial included three broadleaved weeds which were partially impacted.
Effects on yields and economic margin were visible in three trials, confirming the value of this method. However, the idea is not to switch to the general recommendation of postponing the sowing date. These practices are effective when conditions are so ready, so they must be implemented on heavily infested fields, i.e. where weed control has failed and/or resistance is a problem, or on reduced populations in order to limit the amount of herbicide. In small populations (Gemeaux No Till trial), loss of potential can compensate for loss via less competitive weeds, so it would not be wise to postpone the sowing date on clean fields.
On difficult fields, the economic risk of a 20-day delay in wheat is limited, even in a rainy autumn.

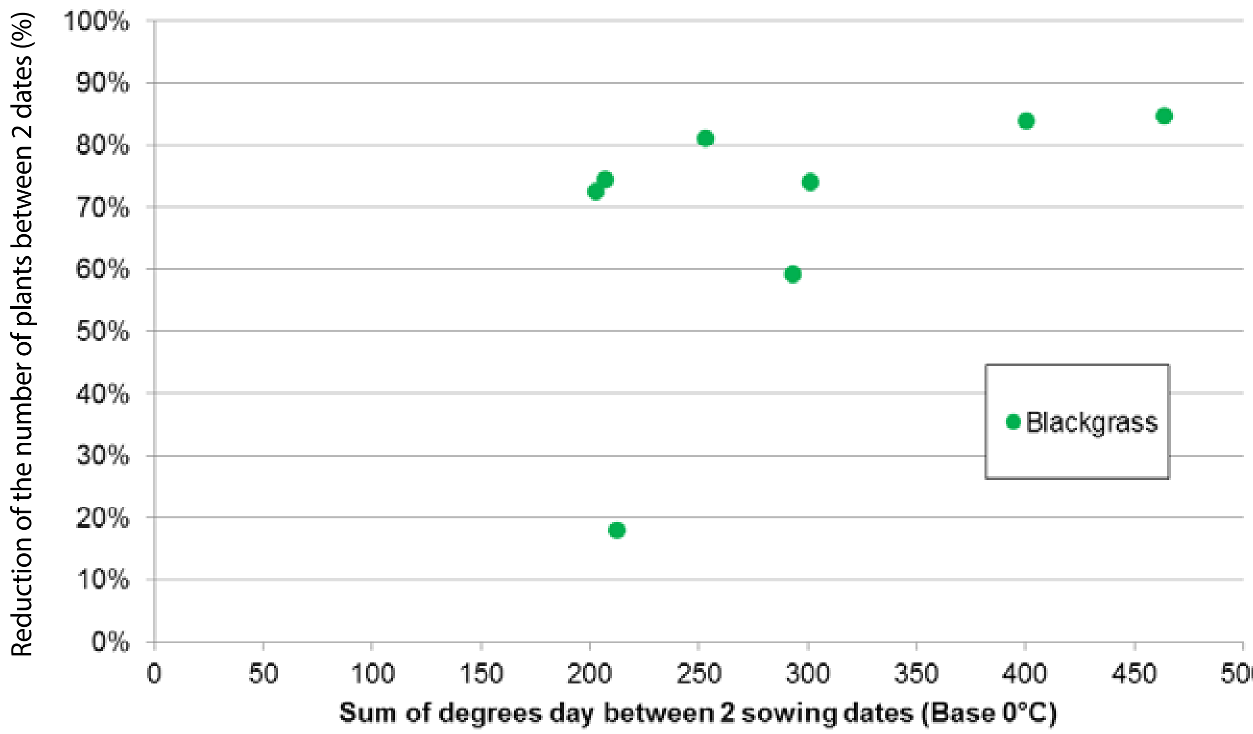



**Figure 1** - Effect of delayed sowing on grass populations in wheat (%)

## INTEGRATION OF AN IWM TOOL BEFORE SOWING OF WHEAT

A trial was implemented in Saint Hilaire-en-Woëvre (55) with a comparison of soil tillage before wheat was drilled, crossed with herbicide programmes in cultivation. The table below summarizes the treatments put in place.

The plot compares a “Ploughed” and a “No Till” situation infested with blackgrass. The technical itinerary included a passage with an Optimer stubble cultivator (by Kuhn) on the entire plot on 7 July 2018. The ploughing was performed on 20 August 2018, with subsoil being added to the “No Till” (NT) part on the same day. After this, the itinerary was the same on both parts: two passages with a rotary harrow to refine the seedbed (21 August and 27 August), then the sowing on 3 October 2018 (combined rotary harrow + disc sowing machine).

**Figure 2** - Field visit during the Gémeaux trials on 27/05/2019

Blackgrass counts were carried out after sowing on 25 October 2018. Overall, 400 blackgrass plants/m² were found in the “No Till” part and only 2 blackgrass plants/m² in the “Ploughed” part.

| Soil tillage | Sowing date & Variety | | Herbicides | Stage & Dates |
|---|---|---|---|---|
| Ploughing (20/08/2018) | 2 passes with rotative harrowing (21/08/2018 + 27/08/2018) | KWS Extase, 3/10/2018 (320 seeds/m²) | DÉFI+CODIX 2L+2L | Pre-emergence (05/10/2018) |
| | | | FOSBURI 0.5L<br>DAIKO+FOSBURI+H 2.25L+0.5L+1L | 1-2 leaves (17/10/2018) |
| | | | DÉFI+CODIX 2L+2L then DAIKO+FOSBURI+H 2.25L+0.5L+1L | Pre-em fb 3 leaves (5/10/2018 then 5/11/2018) |
| No till (Sub soiling on 20/08/2018) | | | DÉFI+CODIX 2L+2L<br>ATLANTIS PRO+H+ACTIMUM 0.9L+1L+1L | Pre-em fb tillering (5/10/2018 then 20/02/2019) |
| | | | DAIKO+FOSBURI+H 2.25L+0.5L+1L 1-2F then ATLANTIS PRO+H+ACTIMUM 0.9L+1L+1L | 1-2 leaves fb tillering (17/10/2018 then 20/02/2019) |
| | | | ATLANTIS PRO+H+ACTIMUM 0.9L+1L+1L TallFinTall | tillering (20/02/2019) |

**Table 6** - Experimental plan of trial on integration of an IWM tool before sowing of wheat in Saint Hilaire-en-Woëvre.
*Défi = prosulfocarb*
*Codix = diflufenicanil + pendimethalin*
*Fosburi = diflufenicanil + flufenacet*
*Daiko = prosulfocarb + clodinafop-propargyl + cloquintocet-mexyl*
*H = Actirob B = esterified rapeseed oil*
*Atlantis Pro = mesosulfuron-me + iodosulfuron-me-na*
*Actimum = ammonium sulphate*

This trial illustrates the complementarity between agronomic levers and weed control in cultivation. In very infested situations (in this case, no-till with 400 blackgrass plants/m²), even the best herbicide programme will not be able to control weed populations. This will result in an economic loss (unprofitable investment) and re-infestation of the field. However, weed control in cultivation on only a few blackgrass plants/m² allows better control of the population in the ploughed part, even when it is not perfect. A limited herbicide programme in the ploughed part can achieve a very good result when compared to the NT part. Doubling the programme in the NT part failed to achieve the efficiency of the "light" programme in the ploughed part.

## COMPARISON OF EARLY MECHANICAL WEED CONTROL STRATEGIES (TINE HARROWING) IN WHEAT

Six trials were set up. The main objective of four was to study the early passages of a weed harrow (sometimes pre-emergence) and their frequency, crossed with the herbicide programmes. Only three trials were usable, and one trial had to be abandoned due to a lack of weeds.
In the three usable ARVALIS-led trials, the results were very variable, with tine harrowing showing limited efficiency. The herbicides used ensured a good performance, even when doses were limited.

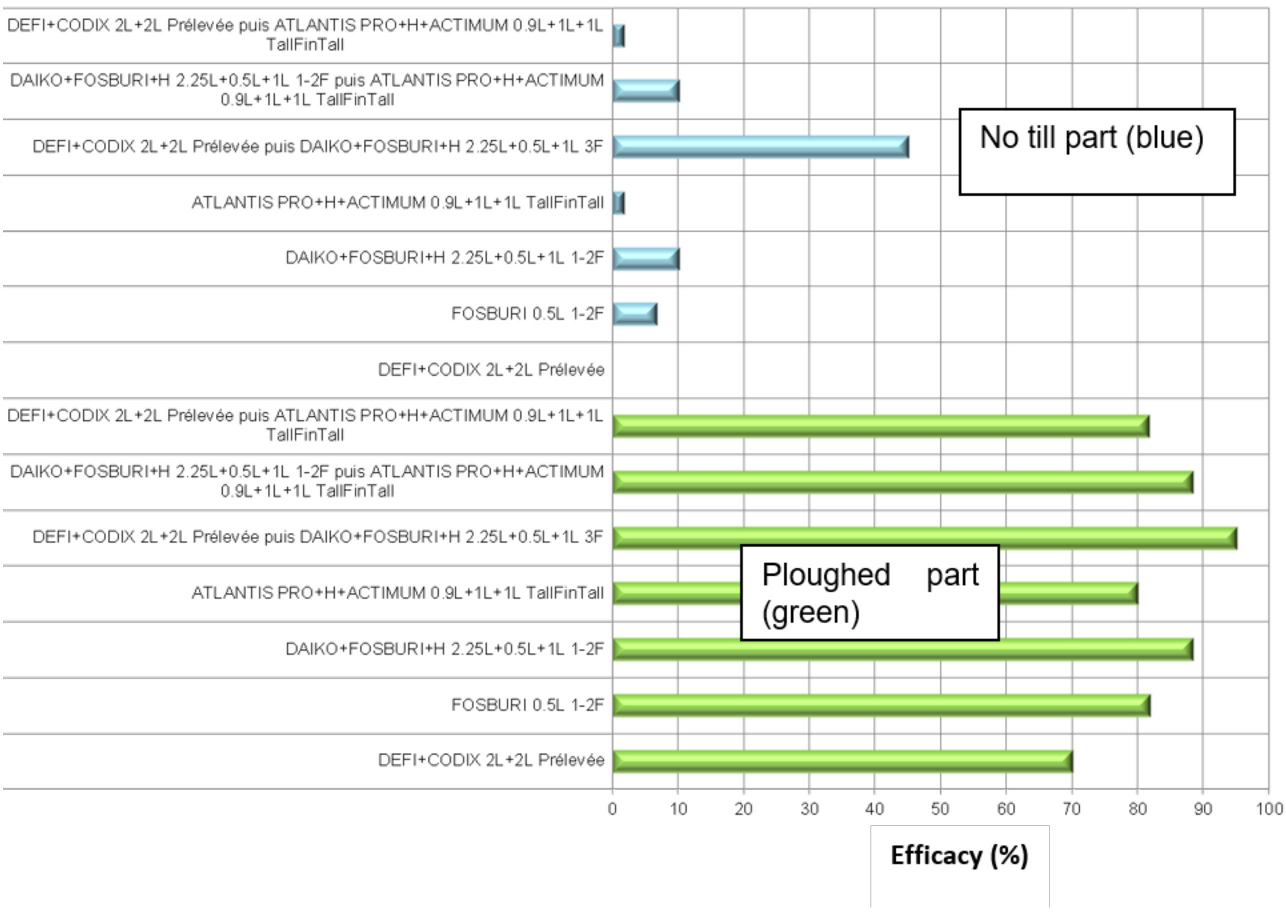



**Figure 3** - Effect of ploughing of wheat/herbicide programmes on foxtail populations in wheat (%)

## TRIAL IN BERGERAC

| Itinerary | Dates of pass | Herbicides | Weeds |
|---|---|---|---|
| Sowing | 30/10/2018 | TROOPER 2.5L 1-2F<br>FOSBURI 0.6L 1-2F<br>NESSIE 1L 1-2F<br>PICOSOLO 0.08KG 1-2F<br>PICOTOP 1.3L Tall/FinTall<br>PIXXARO EC 0.5L Tall/FinTall<br>FOSBURI 0.6L 1-2F then PICOTOP 1.3L Tall/FinTall | *Papaver rhoeas* (≈50 pl/m²)<br>*Senecio vulgare* (25 pl/m²)<br>*Juncus bufonius* (12 pl/m²) |
| Herbicide 1-2 leaves | 20/11/2018 | | |
| Tine harrowing no. 1 – 3 leaves | 28/11/2018 | | |
| Tine harrowing no. 2 | 19/02/2019 | | |
| Herbicide (tillering) | 22/02/2019 | | |

**Table 7** - Mechanical weed control strategy in wheat in the Bergerac trial
*Trooper = flufenacet + pendimethalin*
*Fosburi = diflufenicanil + flufenacet*
*Nessie = bromoxynil + diflufenicani*
*Picosolo = picolinafen*
*Picotop = picolinafen + dichlorprop-p*
*Pixxaro EC = haloxyfen-me +fluroxypir + cloquintocet-mexyl*

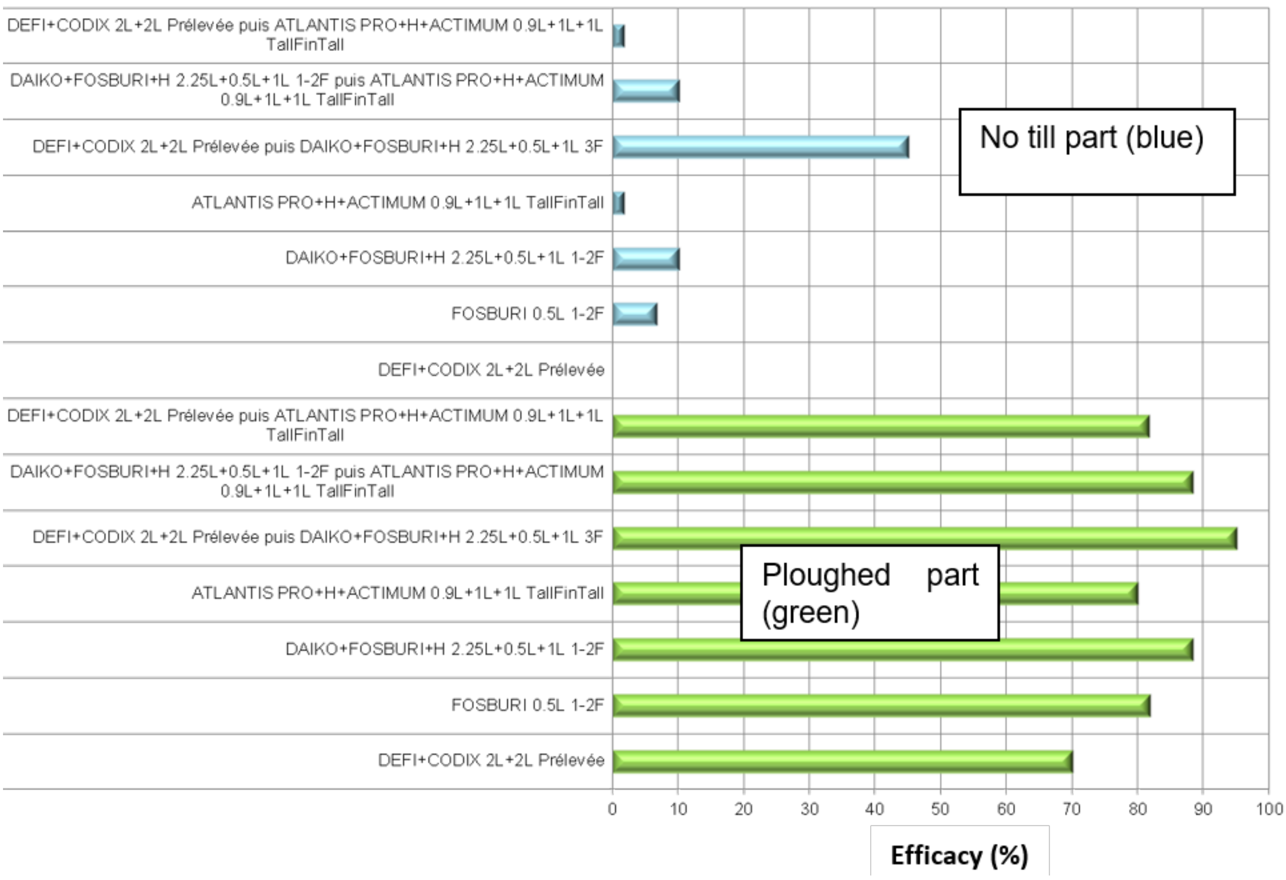



**Figure 4** - Efficacy of mechanical weed strategy in the Bergerac trial

## TRIAL IN LAPAN

| Itinerary | Dates of pass | Herbicides | Weeds |
|---|---|---|---|
| Sowing | 19/10/2018 | DÉFI+CODIX 3L+1.5L pre-emergence<br>DÉFI+FOSBURI 2.5L+0.5L 1-2F<br>DÉFI+CODIX 3L+1.5L pre-emergence then FOSBURI 0.6L 1-2F<br>DÉFI 2.5L + FOSBURI 0.5L then ARCHIPEL DUO 1L + ACTIROB_B 1L + ACTIMUM 1L<br>ARCHIPEL DUO 1L + ACTIROB_B 1L + ACTIMUM 1L | Rye-grass (400 pl/m²) |
| Herbicide pre-emergence | 23/10/2018 | | |
| Tine harrowing no. 1 – pre emergence | 23/10/2018 | | |
| Herbicide 1-2 leaves | 16/11/2018 | | |
| Herbicide tillering | 05/02/2019 | | |
| Tine harrowing no. 2 | 25/02/2019 | | |
| Tine harrowing no. 3 | 22/03/2019 | | |

**Table 8** - Mechanical weed control strategy in wheat in the Lapan trial
*Défi = prosulfocarb*
*Codix = diflufenicanil + pendimethalin*
*Fosburi = diflufenicanil + flufenacet*
*Archipel Duo = mesosulfuron-me + iodosulfuron-me-na*
*Actirob B = esterified rapeseed oil*
*Actimum = ammonium sulphate*

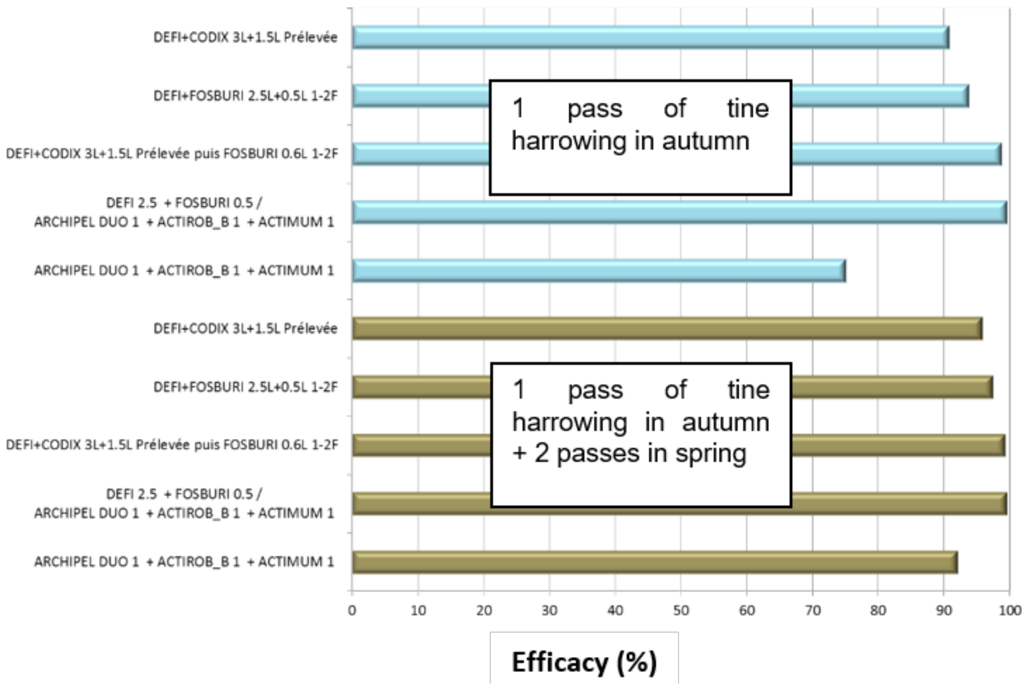



**Figure 5** - Efficacy of mechanical weed strategy in the Lapan trial

## TRIAL IN PLAIMPIED-GIVAUDINS

| Itinerary | Dates of pass | Herbicides | Weeds |
|---|---|---|---|
| Sowing | 12/10/2018 | DÉFI+FLIGHT 2L+3L pre-emergence<br>DAIKO+FOSBURI+H 2.25L+0.6L+1L 1-2F<br>DÉFI+FLIGHT 2L+3L pre-emergence then DAIKO+FOSBURI+H 2.25L+0.6L+1L 1-2F<br>DAIKO+FOSBURI+H 2.25L+0.6L+1L 1-2F then ATLANTIS PRO+H+ACTIMUM 1.5L+1L+1L TallFinTall<br>ATLANTIS PRO+H+ACTIMUM 1.5L+1L+1L TallFinTall | Blackgrass (5 pl/m²) |
| Tine harrowing no. 1 – pre emergence | 16/10/2018 | | |
| Herbicide – pre-emergence | 18/10/2018 | | |
| Herbicide 1-2 leaves | 10/11/2018 | | |
| Herbicide Tillering | 05/02/2019 | | |
| Tine harrowing no. 2 | 22/02/2019 | | |

**Table 9** - Mechanical weed control strategy in wheat in the Plaimpied-Givaudins trial
*Défi = prosulfocarb*
*Flight = picolinafen + pendimethalin*
*Daiko = prosulfocarb + clodinafop-propargyl + cloquintocet-mexyl*
*Fosburi = diflufenicanil + flufenacet*
*H = Actirob B = esterified rapeseed oil*
*Atlantis Pro = mesosulfuron-me + iodosulfuron-me-na*
*Actimum = ammonium sulphate*

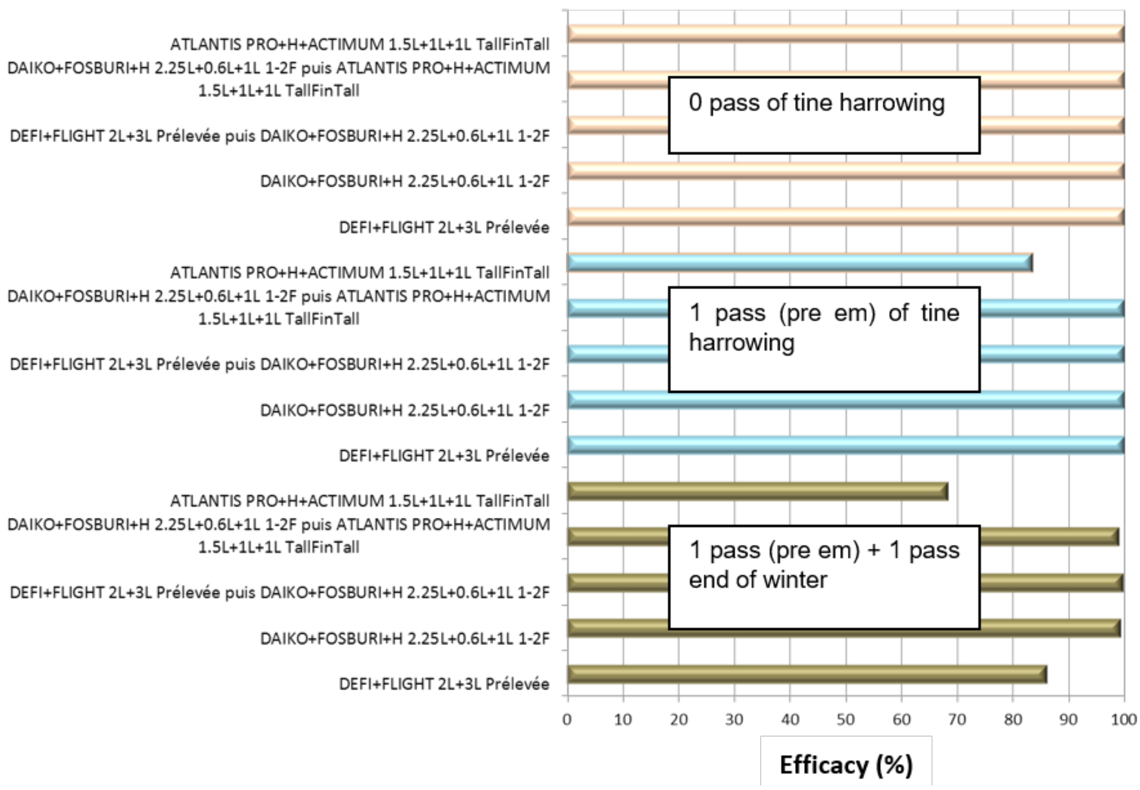



**Figure 6** - Efficacy of mechanical weed strategy in the Plaimpied-Givaudins trial

In conclusion, these three trials did not show a strong trend towards effective integration of mechanical weeding. In Lapan trial, we observed that when combined with herbicides harrowing shows little interest in situations of heavy infestations. The conclusions were more mixed for the two other trials, with mechanical weeding proving to be very low efficiency, or even counterproductive.
Nevertheless, these trials will be implemented again in 2019-2020.

### "ILE DE FRANCE" CHAMBER OF AGRICULTURE TRIALS

Three trials were set up by the partner "Ile de France" Chamber of Agriculture.
One trial was located in Saint-Martin-des Champs (78) in a field moderately infested by blackgrass. The goal of this trial was to find ways to complement chemical treatment. Over the last few years, weed infestation has not been sufficiently eradicated. The field was last ploughed in August 2017.

Wheat was sown at a minimum depth of 3-4 cm in order to protect seedlings from harrowing. Sowing density was increased by 15-20% in order to prevent wheat losses due to mechanical intervention.
In this trial, delaying the sowing date was the most effective way to prevent weed infestation.
For the first sowing date (5 October), all mechanical treatments were found to improve the efficiency of the chemical programme by 31% to 74%. We found that the more the plots were harrowed, the better the efficiency. These results confirmed those from last year's experiments, and they also confirmed that a combination of mechanical and chemical treatments is of interest.
For the second sowing date (25 October), late sowing was sufficient to achieve good weeding results.
The use of a harrow did not improve the results, but rather degraded them because it boosted the emergence of black-grass seeds.
To conclude, when the soil was clean, it should not be tilled in order to prevent weed emergence.
Figure 8 below shows the density of black-grass observed in June 2019 before harvest.

One trial was conducted in Bonvilliers (91) in a plot highly infested by ryegrass (80 to 650 plants/m²).
Chemical weeding was no longer satisfactory and needed to be supplemented with other control methods.
The goal of this trial was to compare 100% mechanical weed control, 100% chemical weed

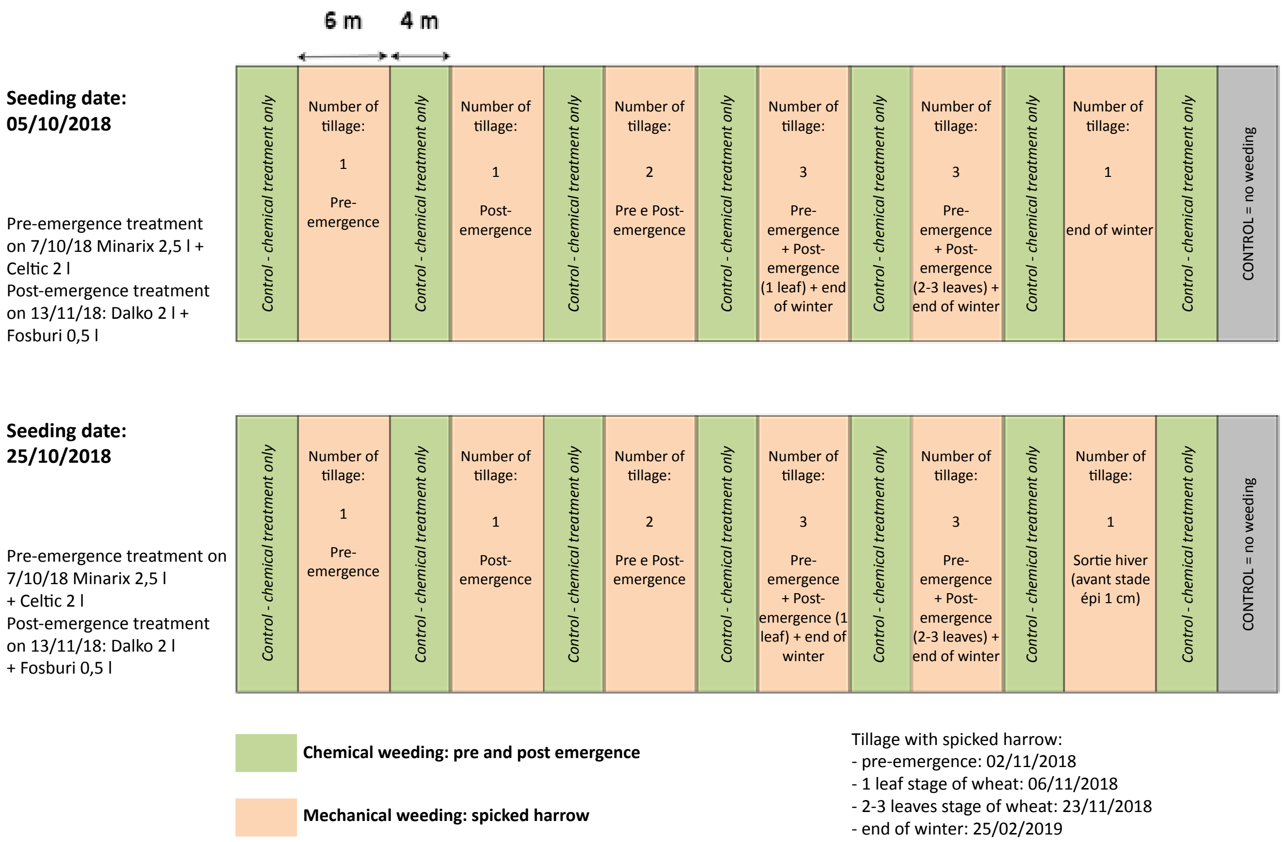



**Figure 7** - Test protocol in Saint Martin des Champs (south of Paris)

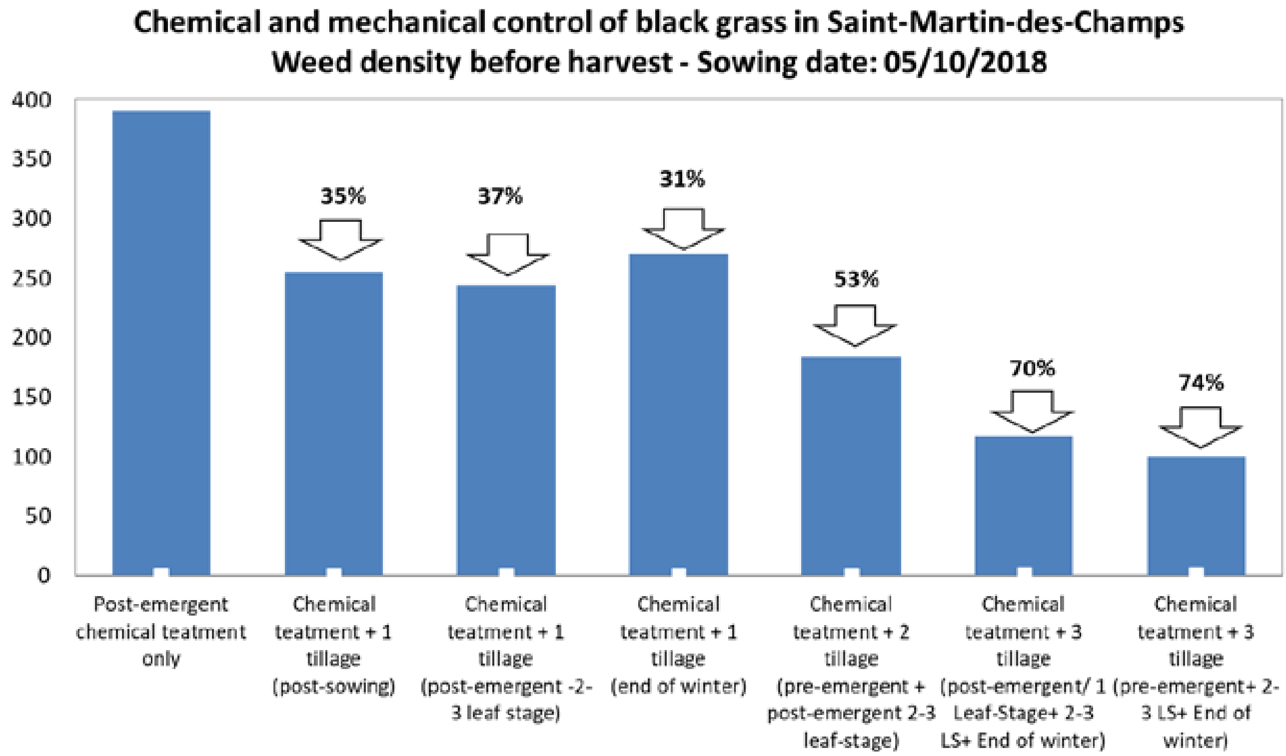



**Figure 8** - Effect of chemical and mechanical control on weed density (black-grass) in the St Martin des Champs trial

**Figures 9, 10 and 11** - Guided visit of the Test Platform on 4 June 2019 (85 visitors)

control and chemical weed control supplemented with spring soil tillage.

Two types of weeding methods were tested, as was a pre- and post-sowing chemical treatment:

- Delayed sowing (early = 5 October or late = 25 October sowing)
- Mechanical weeding = tine harrow, 1 to 3 passes.

Harrowing dates were:

- in pre-emergence phase: 2 November
- 1-leaf stage of wheat: 6 November
- 2-3-leaf stage of wheat; 23 November
- after winter: 25 February

Wheat seeds were sown at a minimum depth of 3-4 cm in order to protect seedlings from harrowing. Sowing density was increased by 15-20% in order to offset wheat losses due to mechanical intervention. The chemical treatment, applied on 2 November on some of the plots, was carried out on moist soil without ryegrass. Poor weather conditions in autumn made it impossible to implement mechanical weed control. Chemical weeding had 85% efficiency, but due to the very high weed infestation, there were still 100 ryegrass plants/m$^2$ by the end of winter.
Harrow operations were performed on 25 February on dry surface soil. In the following days, weeds that were pulled out died quickly thanks to dry weather conditions. The rotating harrow, however, was rarely

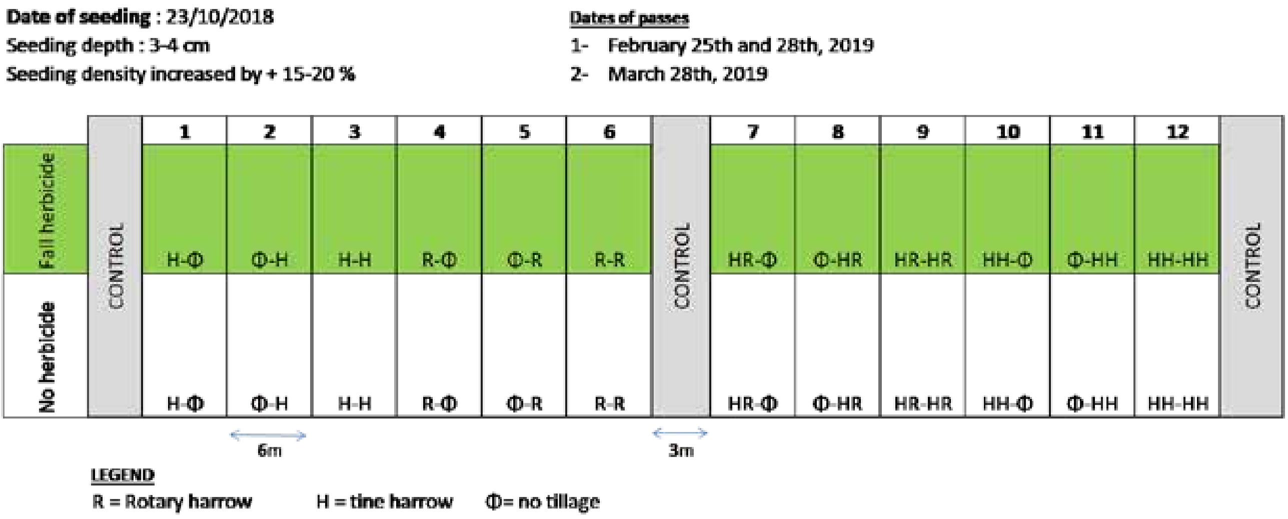



**Figure 12** - Experimental protocol in the Bonviliers trial (south of Paris)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Soil tillage 2017-2018 | Pseudo ploughing | False seed bed | Direct sowing without vegetative cover | Direct sowing with vegetative cover | False seed bed | Pseudo ploughing & False seed bed | Ploughing & False seed bed |
| Type of seeder 2018 | Disc harrow | Disc harrow | Disc harrow | Disc harrow | Rotary harrow | Rotary harrow | Rotary harrow |
| **Soil tillage 2018-2019** | **Pseudo ploughing (15-20 cm depth)** | **False seed bed (3 cm) with rotary harrow** | **Direct sowing without vegetative cover** | **Direct sowing with vegetative cover** | **False seed bed (3 cm)** | **Pseudo ploughing & False seed bed** | **Ploughing & False seed bed** |
| Type of seeder 2019 | Disc harrow | Disc harrow | Disc harrow | Disc harrow | Rotary harrow | Rotary harrow | Rotary harrow |

**Table 10** - Protocol of Vallangoujard trial

more aggressive towards the crop than towards weeds.
The second mechanical treatment took place on 28 March. The soil was dry, and the teeth of the harrow had difficulty digging into the ground. The harrow had to be used another time in order to remove ryegrass.
In this trial, mechanical weeding with normal and rotative harrowing was very disappointing. Only three plots were slightly better than the control, but they failed to provide a satisfactory level for farmers.

The last trial was set up in Vallangoujard, to the north west of Paris.
The objective was to test a range of mechanical weed-management strategies on ryegrass.

The lowest ryegrass infestation was observed in plots that were ploughed deeply in autumn 2017 (Strategies 7 and 6). The worst result was obtained in the direct-seeded plot with cover. In this plot,

**Figure 13** - Field trial visit in Bonvilliers (2019)

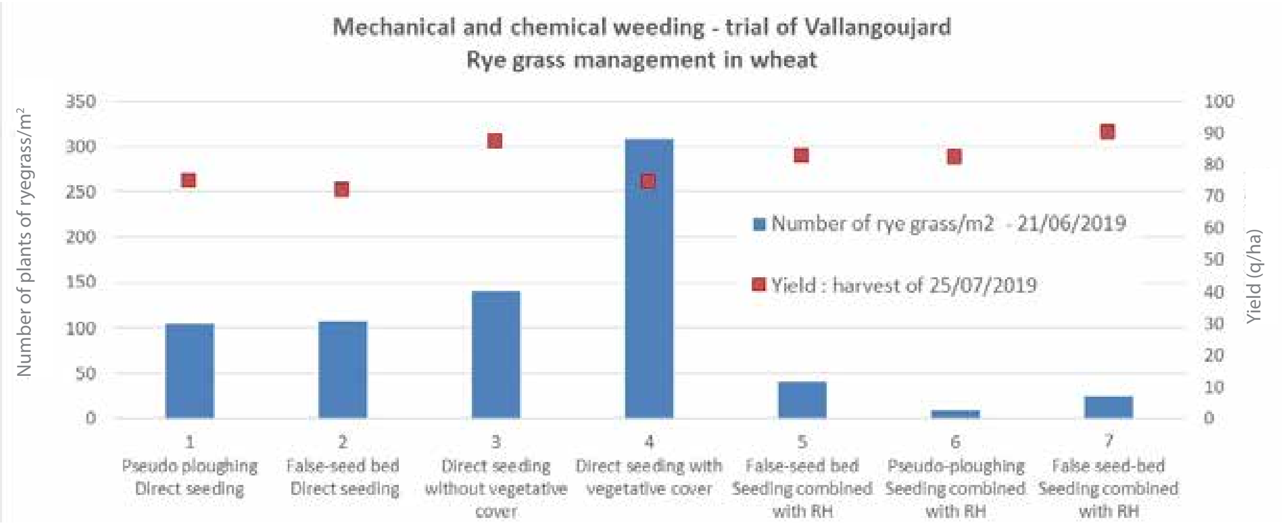



**Figure 14** - Effect of mechanical and chemical weeding on ryegrass

| 1<br>Pseudo ploughing Direct seeding | 2<br>False-seed bed Direct seeding | 3<br>Direct seeding without vegetative cover | 4<br>Direct seeding with vegetative cover | 5<br>False-seed bed Seeding combined with rotary harrow | 6<br>Pseudo-ploughing Seeding combined with rotary harrow | 7<br>False seed-bed Seeding combined with rotary harrow |
|---|---|---|---|---|---|---|
| 4 | 4 | 3 | 1 | 5 | 7 | 6 |

**Acceptability score**
Scale: 0 = control to 10 = no ryegrass

**Table 11** - Acceptability score for the various ryegrass-control strategies

chemical treatment in autumn did not reach the growing ryegrass plants that were protected by the cover.
Before harvest, the visual appearance of the plots was rated by consultants from the Ile-de-France Chamber of Agriculture. The purpose of the rating was to reflect acceptability of grass infestation by farmers. As we can see in Figure 14, the number of ryegrass plants was well-correlated to the rating. However, yield data did not illustrate these observations. This discrepancy was due to the heterogeneity of plot infestation in the band test.

## MECHANICAL WEED CONTROL (HOEING) IN TRITICALE

Hoeing seems to be the most effective mechanical tool on developed weeds, but this control method deserves further investigation to evaluate expected efficiency and feasibility. Currently, where resistance to herbicides (ACCase and ALS inhibitors [HRAC A and B groups]) continues to increase, hoeing could be used to complement autumn applications of herbicides (the only herbicide applications still effective on such ryegrass resistant populations).
Two new trials were set up in Boigneville (91) in 2019 in order to determine whether hoeing would be of interest for catching up on autumn herbicide strategies. The two trials were set up on a triticale plot historically under direct seeding. In 2018, part of the plot was ploughed, while the rest was kept under direct seeding. Each area hosted a trial (same

| Mechanical weed control | Products & Doses<br>Pre-emergence | Early post-emergence 1-2 leaves |
|---|---|---|
| | Control | |
| - | / | Défi 2.5 l |
| | Trooper 2 l | Défi 2.5 l |
| Hoeing in spring followed by tine harrowing | / | Défi 2.5 l |
| | Trooper 2 l | Défi 2.5 l |
| 2 passes of hoeing in spring followed by tine harrowing | / | Défi 2.5 l |
| | Trooper 2 l | Défi 2.5 l |
| Full mechanical weed control = tine harrowing in autumn followed by 3 passes of hoeing in spring | / | |

**Table 12** - Mechanical weed control (hoeing) in triticale at the Boigneville trial
*Défi = prosulfocarb*
*Trooper = flufenacet + pendimethalin*

protocol as below, but with historical differences). The two trials in triticale have the same protocol. The only difference is the soil tillage history: one part was ploughed in 2017, the other part is still conducted under conservation tillage.
All plots were sown at a row spacing of 15 cm to allow the hoeing machine (Garford model self-guided by camera) to pass between the rows. Hoeing was performed on 21 February, 28 March and 12 April 2019. Only the first two passes were followed by a harrow, as the triticale had reached stage 1 node during the third pass on 12 April. A harrowing operation after hoeing enabled small clods to be 'broken' and transplanting to be limited. Climatic conditions before and after each pass of mechanical weeding were optimal.

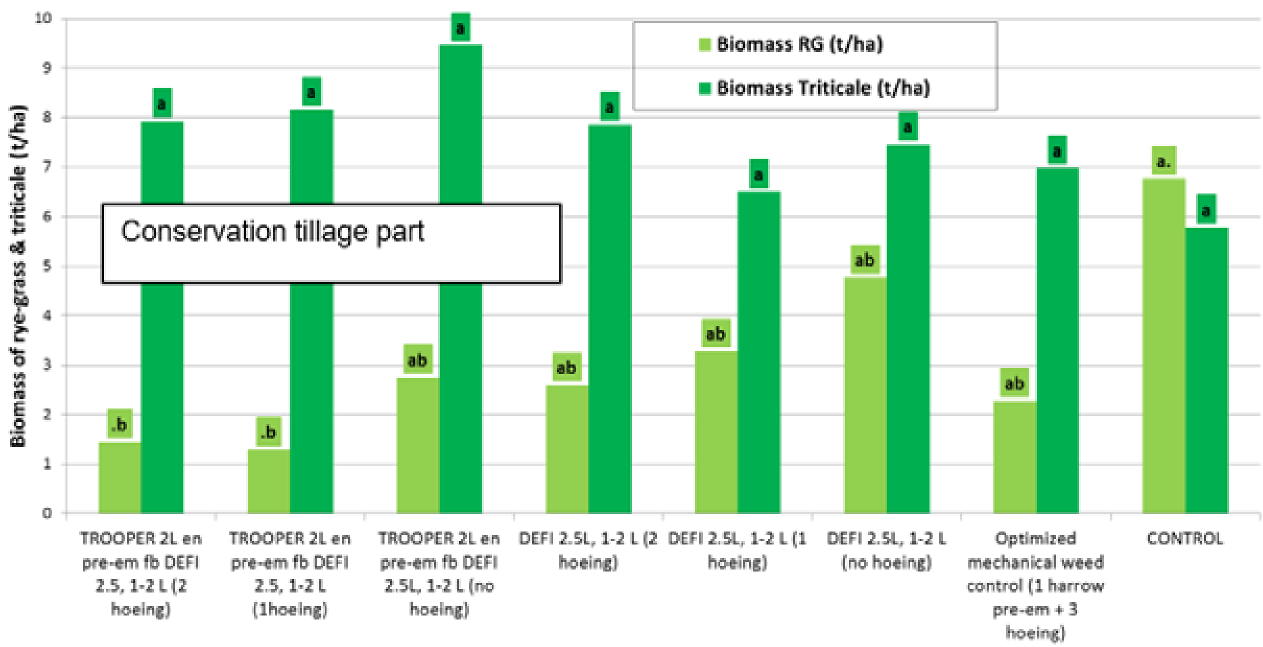



**Figure 15** - Biomass of ryegrass and triticale according to various mixed weeding programmes with conservation tillage (. = significantly different)

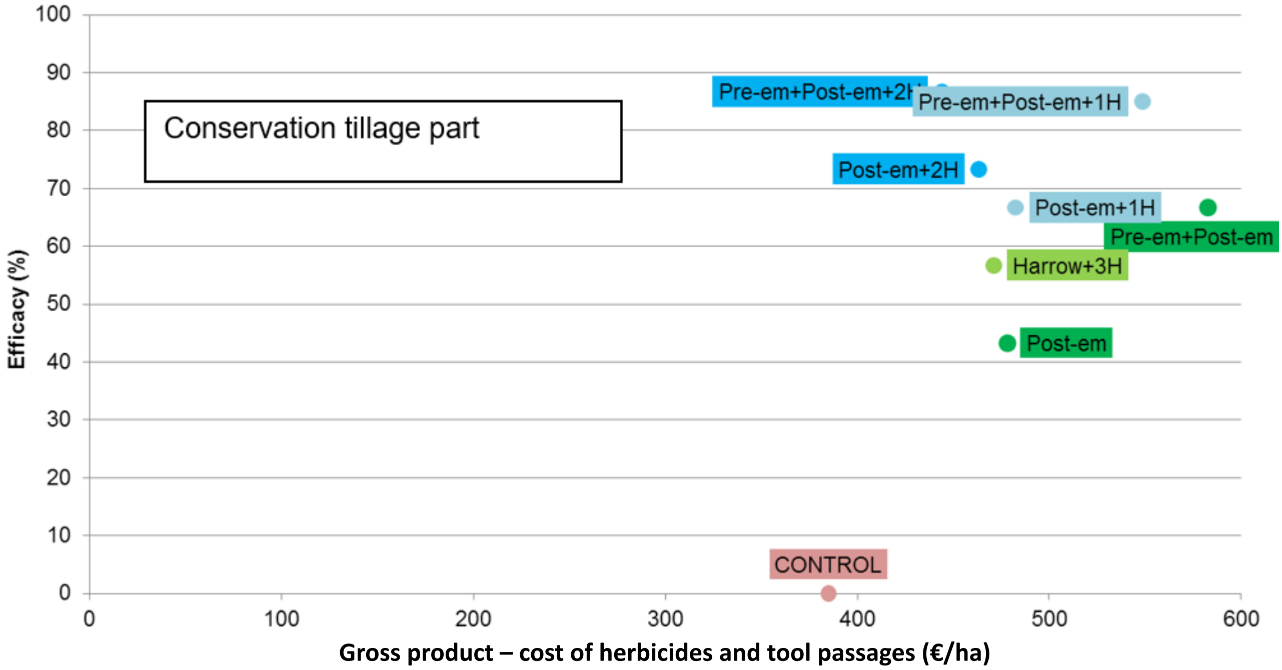



Figure 16 - Gross product and efficacy following mixed weeding programmes with conservation tillage

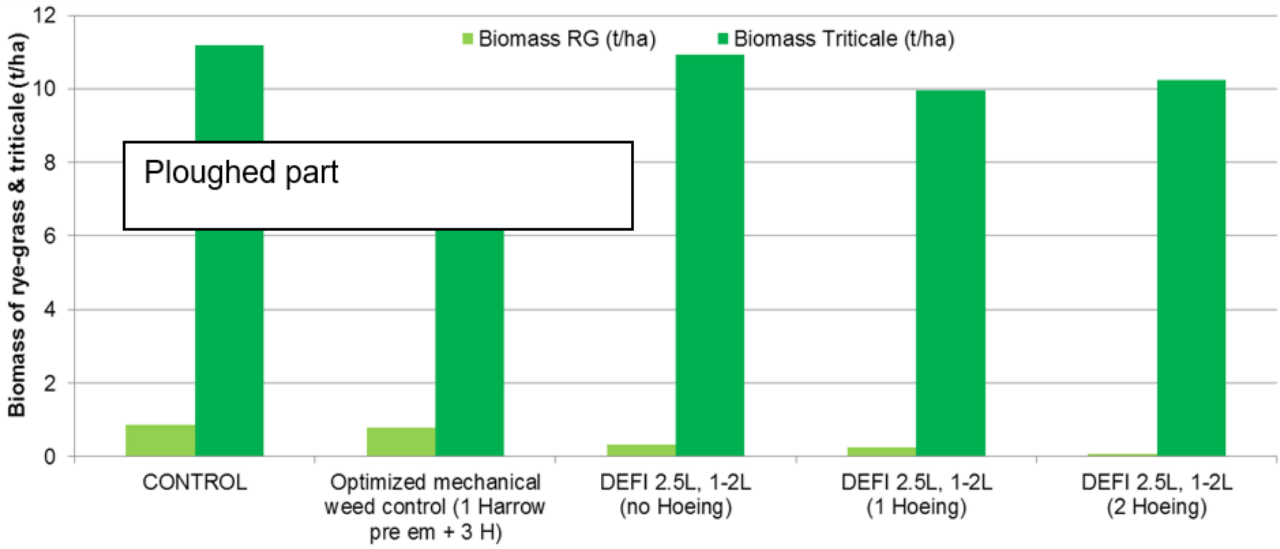



Figure 17 - Biomass of ryegrass and triticale following mixed weeding programmes with conservation tillage

There were around 1000 ryegrass plants/m² in control plots in the conservation tillage part and only 70 ryegrass plants/m² in the ploughed part.

These trials did not enable us to answer all the questions on hoeing in cereals, as the conditions of the year and the trials caused great variability in hoeing response. It should be noted that this variability will also be found in the efficiency of applications in large plots, since mechanical weeding is very dependent on soil and climatic conditions, which can produce very different results. However, these tests make it possible to highlight a few elements:

- Seed spacing of more than 20 cm penalizes yield.
- Hoe passages equipped with 15 to 17 cm spacings are possible without deteriorating the yield a priori, when the hoe passages are carried out under conditions that are not stressful for the crop (particular care is needed in the cereal’s stage over 1

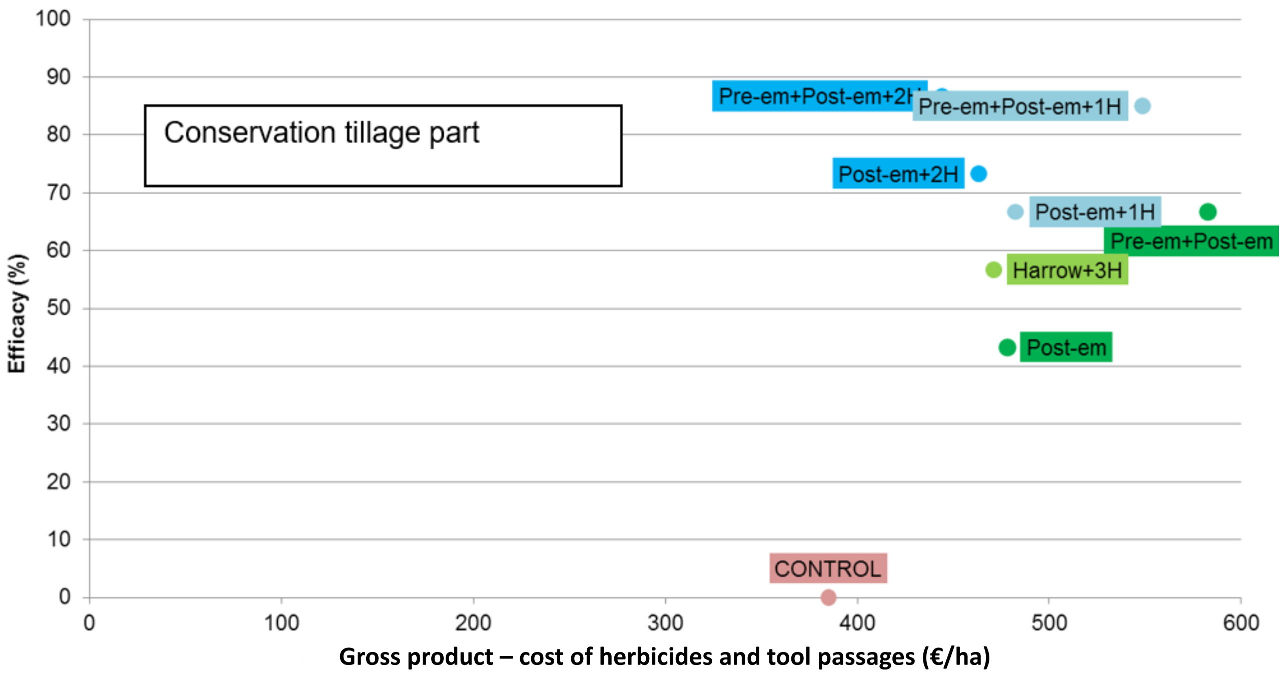



**Figure 18** - Gross product and efficacy following mixed weeding programmes with ploughing

node). Weed-free testing would ideally be required to measure the potentially negative effect on tool passage performance.
- Gains on developed floras (grasses) are moderate but do exist, with them depending on the populations as well as on the soil and climatic conditions surrounding the weeder passage(s).
- Weeding only mechanically in cultivation has advantages in terms of efficiency and yield, but does not make it possible to manage large grass populations completely.

## SOIL TILLAGE STRATEGIES, WITHOUT GLYPHOSATE, BEFORE SOWING SPRING PEAS

This trial was performed by Terres Innovia in Rians (18). In order to sow on clean soil, it was important to test tools and tillage depths before sowing spring peas in order to:
1) verify that weeds present before peas were destroyed;
2) ensure that the quality of crop establishment was not affected;
3) verify that this did not cause too many new weeds to emerge in subsequent crops.
These questions are important, and it is necessary to find the optimal tillage type (tool, depth, passage conditions) both to destroy weeds and to ensure crop growth. The experimental plan was a “strip” trial, the protocol of which is summarized in the following table.
Before the flora was destroyed, major types were found to be present, especially brome (*Bromus* spp.), but also *Veronica*, cleaver (*Galium aparine*), and poppy (*Papaver rhoeas*). There is perhaps a fragmented heterogeneity even before any intervention, because Treatment 3 seemed less infested than the other two, by bromes in particular, even before any intervention.
After flora had been destroyed (mechanical on Treatment 1, chemical on Treatment 3), peas sown and herbicide applied (Challenge then Nirvana) on the 3 treatments, flora was more reasonable in Treatments 1 and 3 (i.e. where flora had been destroyed before sowing), with about 10 plants/m². However, there were about 75 plants/m² on Treatment 2, where flora had not been destroyed before sowing, in particular brome and field pansy, which is not satisfactory. Thus, chemical weeding alone in the pea is not enough to control flora. In the pea-flower bud stage, bromes are in their full tillering stage. Thus, the destruction of the flora before sowing is important.
Although Treatment 3 (glyphosate) appears to be the cleanest under the conditions of this test (the least infested with brome on 24 May), it was noted that Treatment 1 (vibrocultivator) had similar infestation rates in peas to Treatment 3. In this trial, the vibrocultivator seemed to control flora in peas as well as glyphosate.

| Code | Treatment | Effective treatment |
|---|---|---|
| 1 | Soil tillage – with tool available on the farm (rotative harrow or stubble cultivator with a roller, etc.) | 20/02: vibrocultivator (10-12 cm depth) followed by a flat harrow for ground levelling |
| 2 | - | - |
| 3 | Glyphosate before sowing | 16/02: 1.2 L/ha glyphosate (good conditions) |

**Table 13** - Weed control protocols in the Rians trial

**Figure 19** - Flat harrow

**Figure 20** - Cultivator

## MECHANICAL WEED CONTROL, WITH OR WITHOUT HERBICIDES, IN OILSEED RAPE

Two trials were set up by Terres Inovia in Nancy (54) and Mons (80). The main objectives were to
1) acquire references on mixed strategies of OSR (context of reduction in plant protection products) with a new post-emergence weed control product (MOZZAR – halauxifen + picloram) and mechanical weed control;
2) evaluate the technical and economic performance of these strategies, which partially or totally replace herbicides with mechanical or mixed alternatives with a weed harrow.
Trials were set up with three replicates. Weeds in Mons were volunteer cereals and *Matricaria*, whereas in Nancy weeds were *Capsella bursa-pastoris*. The protocol is described in the table below.

## TRIAL IN NANCY

This trial had a low *Capsella* infestation that was heterogeneously distributed over the test. This was due to the weather conditions in late summer and autumn 2018, which were very dry both for weeds and rapeseed emergence. Consequently, not all the treatments were noted on the three blocks.
Overall, the treatments with MOZZAR applied in October at six rapeseed leaves (Chemical treatments 2, 3 and 4) had high efficacy (above 90%) and were better than the Alabama reference (Chemical 1: 80%). Late MOZZAR application alone (Chemical 5) had average efficacy (70%), but this improved when supplemented with weeding beforehand (Mixed 1: 90%). Mixed mode 1 with two passes of a weed harrow at pre-emergence and then at six leaves plus MOZZAR on 1 November was better (90%) than the same programme with IELO (Mixed 3: 80%).
The methods with mechanical weeding alone (pre-

| | Peas/m² |
|---|---|
| Treatment 1 – soil tillage | 78 |
| Treatment 2 – no soil tillage and no herbicide | 85 |
| Treatment 3 – glyphosate | 78.6 |

**Table 14** - Number of plants/m²

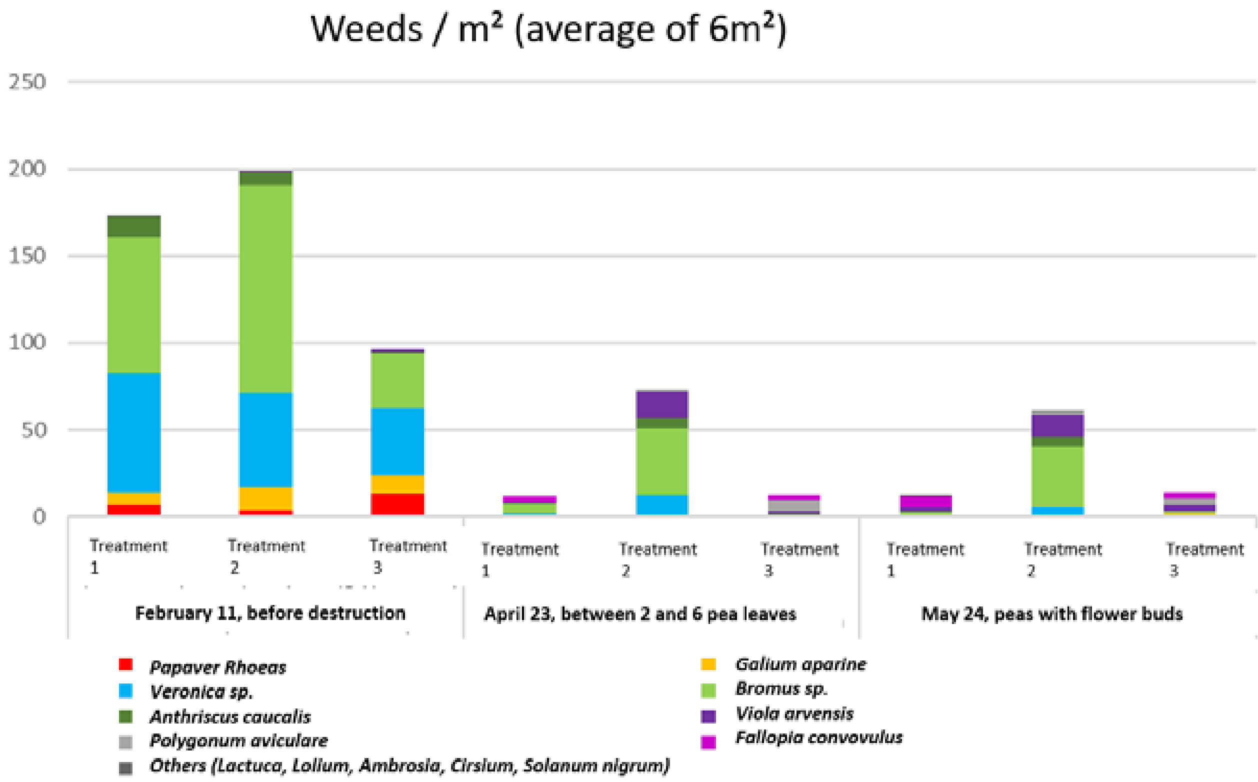



**Figure 21** - Number of weeds/m² following various weeding programmes at three dates (11 Feb, 23 Apr 23 and 24 May)

| | Treatment code | Treatments | | | Cost (€) | tfi |
|---|---|---|---|---|---|---|
| | | Pre-emergence | 4-6 leaves | Around 1 November | | |
| 1 | Chemical 1 | Alabama 2.5 L/ha | - | - | 100 | 1 |
| 2 | Chemical 2 | - | MOZZAR 0.25 L/ha | - | 45 | 0.5 |
| 3 | Chemical 3 | - | MOZZAR 0.25 L/ha | Kerb Flo 1.8 L/ha | 75 | 1.5 |
| 4 | Chemical 4 | Alabama 1.8 L/ha | MOZZAR 0.25 L/ha | Kerb Flo 1.8 L/ha | 150 | 2.25 |
| 5 | Mixed 1 | Tine harrowing (TE) | TE | MOZZAR 0.25 L/ha + Kerb Flo 1.8 L/ha | 75 | 1.5 |
| 6 | Mixed 2 | TE | TE | Kerb flo 1.8 L/ha | 30 | 1 |
| 7 | Mixed 3 | TE | TE | IELO 1.5 L/ha | 55 | 1 |
| 8 | Mechanical 1 | TE | TE | - | 0 | 0 |
| 9 | Mechanical 2 | TE | TE | TE | 0 | 0 |
| 10 | Chemical 5 | - | - | MOZZAR 0.25 L/ha + Kerb Flo 1.8 L/ha | 75 | 1.5 |

**Table 15** - Mechanical weed control treatments in oilseed rape in the Nancy and Mons trials
*Alabama = metazachlor + dmta-p + quinmerac*
*Mozzar = picloram + haloxifen-me*
*Kerb Flo = propyzamid*
*Ielo = aminopyralid + propyzamid*

emergence weeding and then 6-leaf stage weeding: Mixed 2, Mechanical 1 and Mechanical 2) had unsatisfactory efficacy (60%).
Thus, even when the *Capsella* infestation was low and heterogeneous, this trial still answers the initial question, i.e. that blind harrow and early post-emergence weeding at six rapeseed leaves allow the application of MOZZAR to be postponed to 1 November at half-dose (0.25 L/ha). The efficacy obtained with this system is satisfactory (90%), i.e. better than both the Alabama reference (80%) and the same programme with IELO (80%), and almost as good as the modalities with MOZZAR carried out in October with 6 leaves of rapeseed (95%).

| | Treatment code | Treatments | | | Efficacy (%) 20 February | Number of repetitions with enough *Capsella* to score |
|---|---|---|---|---|---|---|
| | | Pre-emergence | 4-6 leaves | Around 1 November | | |
| 1 | Chemical 1 | Alabama 2,5 L/ha | - | - | 80 | 2 |
| 2 | Chemical 2 | - | MOZZAR 0.25 L/ha | - | 95 | 1 |
| 3 | Chemical 3 | - | MOZZAR 0.25 L/ha | Not sprayed<br>~~Kerb 1.8 L/ha~~ | 95 | 2 |
| 4 | Chemical 4 | Alabama 1.8 L/ha | MOZZAR 0.25 L/ha | Not sprayed<br>~~Kerb* 1.8 L/ha~~ | 95 | 3 |
| 5 | Mixed 1 | Tine harrowing (TE) | TE | MOZZAR 0.25 L/ha<br>~~+ Kerb* 1.8 L/ha~~<br>(Not sprayed) | 70 | 1 |
| 6 | Mixed 2 | TE | TE | Not sprayed<br>~~Kerb* 1.8 L/ha~~ | 90 | 2 |
| 7 | Mixed 3 | TE | TE | IELO 1.5 L/ha | 60 | 1 |
| 8 | Mechanical 1 | TE | TE | - | 80 | 2 |
| 9 | Mechanical 2 | TE | TE | Not applied<br>~~TE~~ | 60 | 1 |
| 10 | Chemical 5 | - | - | MOZZAR 0.25 L/ha<br>~~+ Kerb* 1.8 L/ha~~<br>(Not sprayed) | 60 | 2 |

**Table 16** - Weed control treatments in oilseed rape in the Nancy trial
* The plot was grass-free so Kerb was not applied.
Tine harrowing was not carried out a third time due to weather conditions.
Since Kerb application and third tine harrowing were not carried out, Mixed 2, Mechanical 1 and Mechanical 2 are the same.
Satisfaction level: green = good; yellow = average - insufficient; red = completely unsatisfactory

**Figure 22** - *Capsella* infestation (2019/03/18) - control plot

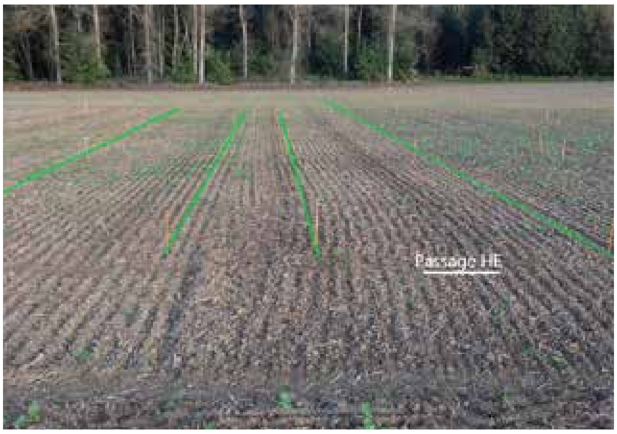



**Figure 23** - Tine harrowing pass

| | Treatment code | Treatments | | | Matricaria (4 leaves) 18 December | Volunteers wheat (3 leaves) 18 December |
|---|---|---|---|---|---|---|
| | | Pre-emergence | 4-6 leaves | Around 1 November | Efficacy (%) | Efficacy (%) |
| 1 | Chemical 1 | Alabama 2,5 L/ha | - | - | 100 | 80 |
| 2 | Chemical 2 | - | MOZZAR 0.25 L/ha | - | 68.3 | 30 |
| 3 | Chemical 3 | - | MOZZAR 0.25 L/ha | Kerb Flo 1.8 L/ha | 73.3 | 65 |
| 4 | Chemical 4 | Alabama 1.8 L/ha | MOZZAR 0.25 L/ha | Kerb Flo 1.8 L/ha | 100 | 81.7 |
| 5 | Mixed 1 | Tine harrowing (TE) | TE | MOZZAR 0.25 L/ha + Kerb Flo 1.8 L/ha | 90 | 70 |
| 6 | Mixed 2 | TE | TE | Kerb Flo 1.8 L/ha | 55 | 68.3 |
| 7 | Mixed 3 | TE | TE | IELO 1.5 L/ha | 71.7 | 70 |
| 8 | Mechanical 1 | TE | TE | - | 65 | 50 |
| 9 | Mechanical 2 | TE | TE | TE | 33.3 | 66.7 |
| 10 | Chemical 5 | - | - | MOZZAR 0.25 L/ha + Kerb Flo 1.8 L/ha | 40 | 43.3 |

**Table 17** - Weed control treatments in oilseed rape in the Mons trial
Level of satisfaction: green = good; yellow = insufficient; red = completely unsatisfactory

## TRIAL IN MONS

Concerning the selectivity of the passages, no differences in vigour, discolouration or deformation were observed on the test after each intervention, whether mechanical or chemical.
The use of pre-emergence weed harrows, however, was highly detrimental to rapeseed with a 50%-or-so loss of feet being observed (Figure 23). This can be explained by the harrowing being a little too late compared to sowing, with it probably being carried out when the seed had already germinated. This mechanical pre-emergence passage is quite a delicate operation because rapeseed is so small, making it sensitive to any intervention; the narrow intervention window and sowing depth, which must be increased for mechanical passage, were also issues.
The following mechanical passages caused only a few foot losses, around 3% to 5%. Indeed, despite more aggressive harrowing, there was almost no foot loss because the rapeseed was well established.
The final observation was made a little too early, as the herbicides did not have time to take full effect; observation should have been made during the winter season. In addition, there were late lifts of weeds. Thus, on chamomile (*Matricaria* sp.), MOZZAR was not completely effective (around 70% in Chemical treatments 1 and 2; 40% for late MOZZAR in Chemical 5). Similarly, the IELO in the Mixed treatment 3 was not completely effective.
Nevertheless, this test shows that Mixed 1 had good efficacy (90%), which means that the two passages of the weed-harrow were a good complement to late-application of MOZZAR (which had only 40% efficacy at the beginning of winter). As MOZZAR is designed to continue working during the winter, we can imagine that the overall efficacy of the mixed treatment will potentially be very good (> 90%). Thus, mechanical treatments (here, weed-harrow) seem to be a good complement to chemical weeding. Mechanical treatments alone, however, do not provide satisfactory efficiency (65% and 33% respectively for Mechanical treatments 1 and 2 on *Matricaria*). It can be assumed that Mechanical 2 is less satisfactory because the last weeding in November caused new chamomile (*Matricaria sp.*) lifts. Indeed, November is traditionally a month when there is little drying time. The third pass of the weed harrow (Mechanical 2) eliminated more cereal volunteers than the two passes of the weed harrow together (Mechanical 1), although weed harrowing alone remains unsatisfactory for good overall weed control.

## ASSOCIATED CROPS IN ORGANIC FARMING TO PREVENT WEED INFESTATION

The management of weed (and also parasitic pressure) poses many problems in organic farming systems. The main objective of this trial was to measure the impact of the association of crops, crossed with sowing densities, on a single crop (wheat or oat or faba bean). This trial was located in Rians (18), central France. The table below summarizes the various treatments.

| | | |
|---|---|---|
| 1 | Winter wheat + faba bean | Normal density: 200 + 20 gr/m² |
| 2 | | High density: 300 + 30 gr/m² |
| 3 | Triticale + faba bean + forage pea | Normal density: 100 + 14 + 13 |
| 4 | | High density: 150 + 21 + 19 |
| 5 | Triticale + forage pea | Normal density: 150 + 20 |
| 6 | | High density: 200 + 30 |
| 7 | Oat + faba bean | Normal density: 150 + 20 |
| 8 | | High density: 200 + 30 |
| 9 | Oat | Normal density: 300 |
| 10 | Triticale | Normal density: 350 |
| 11 | Faba bean | Normal density: 40 |
| 12 | Winter wheat | Normal density: 400 |

**Table 18** - Crop association in the Rians trial

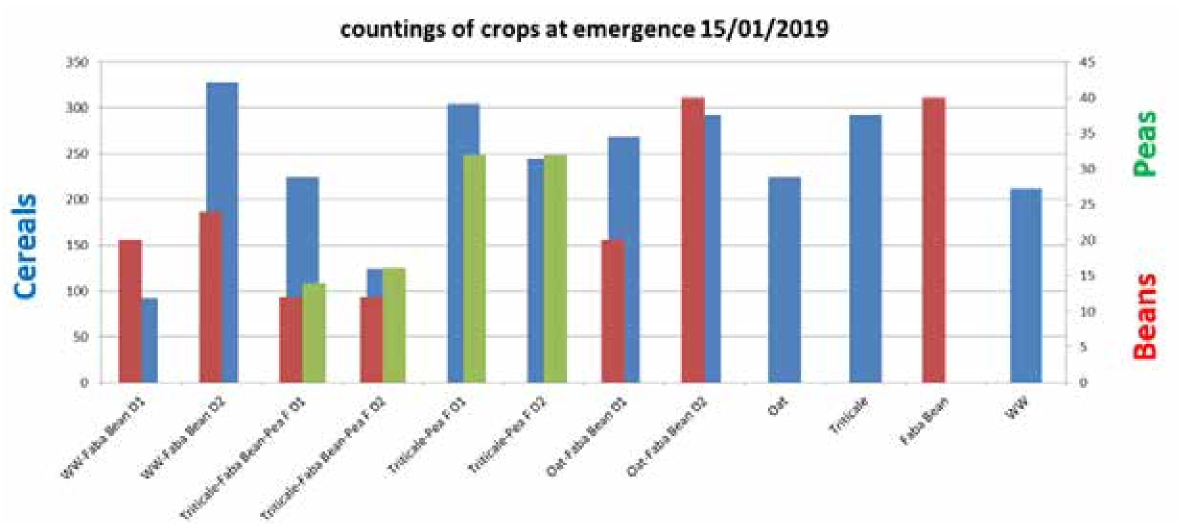



**Figure 24** - Countings of crops at emergence (15 January 2019) in the Rians trial

### LONG-TERM EXPERIMENT ON IWM-BASED WEED CONTROL COMPARED TO A REFERENCE CROPPING SYSTEM (OSR/WW/WB)

This trial, led by FDGEDA 18, is located in Vomay (18). The traditional cropping system in this region is based on autumn cash crops (oilseed rape, winter wheat & winter barley). Due to shallow soils (clay and superficial limestone), no till or direct seeding are common, and weed control is quite difficult (black-grass, including resistant population). The objective was to compare two situations: the reference (no till, OSR/WW/WB crop rotation) and a new one with IWM (change in crop rotation => introduction of winter pea and a spring crop, e.g. sunflower). The weeds present in the wheat part are only broadleaved weeds: mainly cleavers (*Galium aparine*), cornflowers (*Centaurea cyanus*), Anthrisque (*Anthriscus*), and Geraniums.

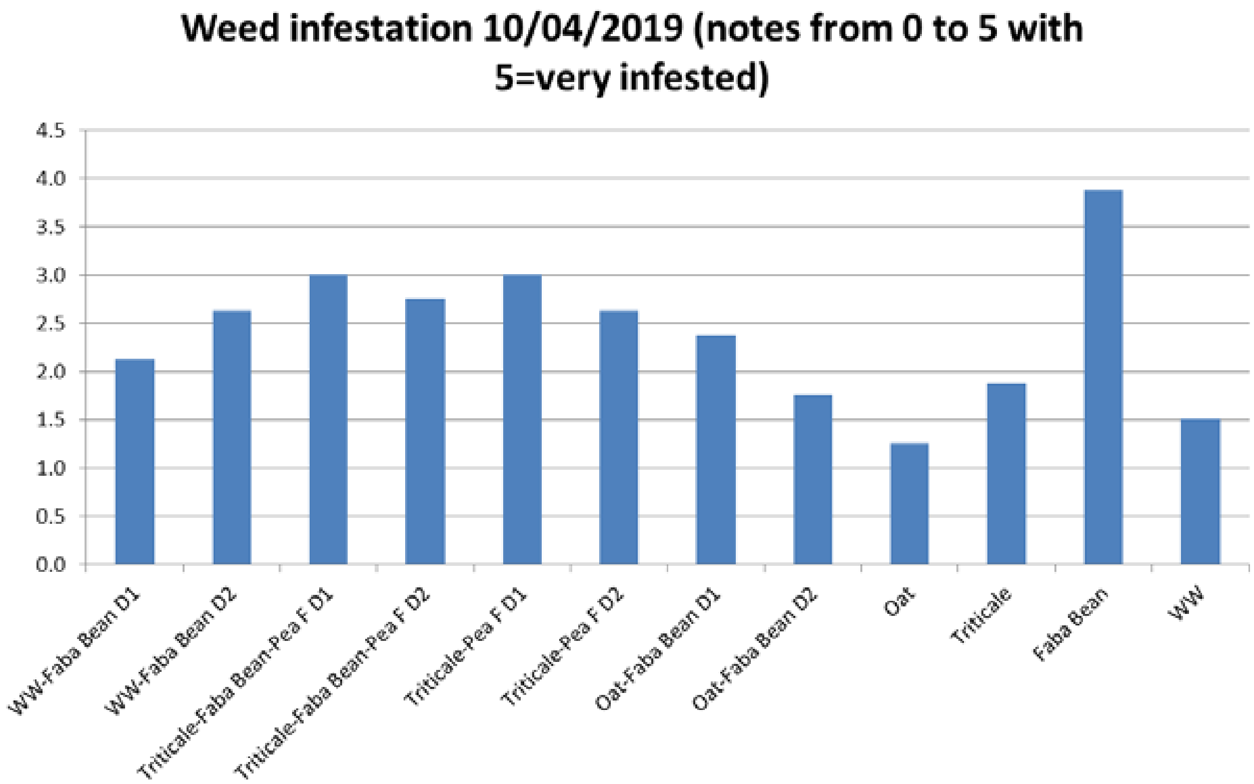



**Figure 25** - Weed infestation (10/04/2019) in the Rians trial

| **Cropping systems** | |
|---|---|
| **Year 2017-2018** | Reference: winter barley<br>IWM: winter pea |
| **Year 2018-2019** | Reference: Oilseed rape (but due to drought in autumn, a sunflower was seeded in 2019)<br>IWM: winter wheat |

**Table 19** - Cropping systems set up in the Vomay trial

| | **Emergence (pl/m²)** | **Weed infestation 14/12/2018 (0 to 5)** | **Weed infestation 17/01/19** | **Weed infestation 19/03/19** | **Weed infestation 12/04/19** |
|---|---|---|---|---|---|
| Wheat | 290 | 2/5 | 3/5 | 3.5/5 | 3.5/5 |
| Sunflower | | 2/5 | 1/5 | 0/5 | 0.5/5 |

**Table 20** - Weed infestation in the Vomay trial

# FRANCE WP4


Mèry les Bois
Subdray
Arçay
St Priest la Feuille
Dijon
Agen
Seignalens
En crambade

Several WP4 themes were studied during the 2018-2019 season within the IWMPRAISE project:

| Topic | Partner | Location |
|---|---|---|
| Comparison of full mechanical and mixed programmes in maize | Arvalis | St Priest la Feuille (23)<br>Méry les Bois (18) |
| Soil preparation before sowing without glyphosate in sunflower | Terres Inovia | Agen (47)<br>Subdray (36)<br>Arçay (18) [2 trials]<br>Seignalens (11) |
| Soil preparation before sowing without glyphosate in soybean | Terres Inovia | Agen (47)<br>Dijon (21) |

**Table 1** - WP4 trials managed by the National French Cluster (number of geographical Department in brackets)

| Treatment | | | |
|---|---|---|---|
| 1. Full mechanical | | Hoeing pass | Hoeing pass |
| 2. Mixed with herbicides on the row | Adengo XTRA 0.44l/ha<br>+ Isard 1.2 l/ha (only on the row) | Hoeing pass | Hoeing pass |
| 3. Full chemical | Adengo XTRA 0.44l/ha | | Elumis 0.05 L/ha +<br>Peak 0.006 L/ha |
| 4. Mixed with herbicides | Adengo XTRA 0.44l/ha | Hoeing pass | Elumis 0.05 L/ha +<br>Peak 0.006 L/ha |

**Table 2** - Protocol of the trials in Méry-les-Bois and St Priest la Feuille

## COMPARISON OF FULL MECHANICAL AND MIXED PROGRAMMES IN MAIZE

During the 2018-2019 season, we were able to consolidate the results obtained in the three maize trials on alternative methods, which aimed to compare strategies and limit herbicide use. It should be noted that out of the three trials, one had to be abandoned due to farmer error (detected late) and one treatment was not traceable.

Weeds:
In Méry-les-Bois: grasses
In Saint Priest la Feuille: broadleaves

The updated results are presented in the graph below, with results in-row and inter-row.

The inter-row results of the "full-mechanical" strategy were, on average, fairly similar to those for the herbicide-based strategies. Its efficacy on the row, however, was nil and unacceptable for the growers.

The most-promising strategies, both in terms of effectiveness and herbicide savings, were those that implemented localised application (Strategies 2 and 4). They reached the reference level (Strategy 3) for weed control on the row. They remained below this level for inter-row efficiency, while being acceptable, scoring 7.
Note that the averages here included a range of weed species (grasses in Mery les Bois and broadleaved weeds in Saint Priest la Feuille). Strictly speaking, these results should be analysed separately. We have grouped them together here because they point in the same direction.
Protocols for the 2020 season are still under discussion; although they will probably be renewed in a similar form (localised application + hoeing); they will also integrate yield in order to have a techno-economic analysis.

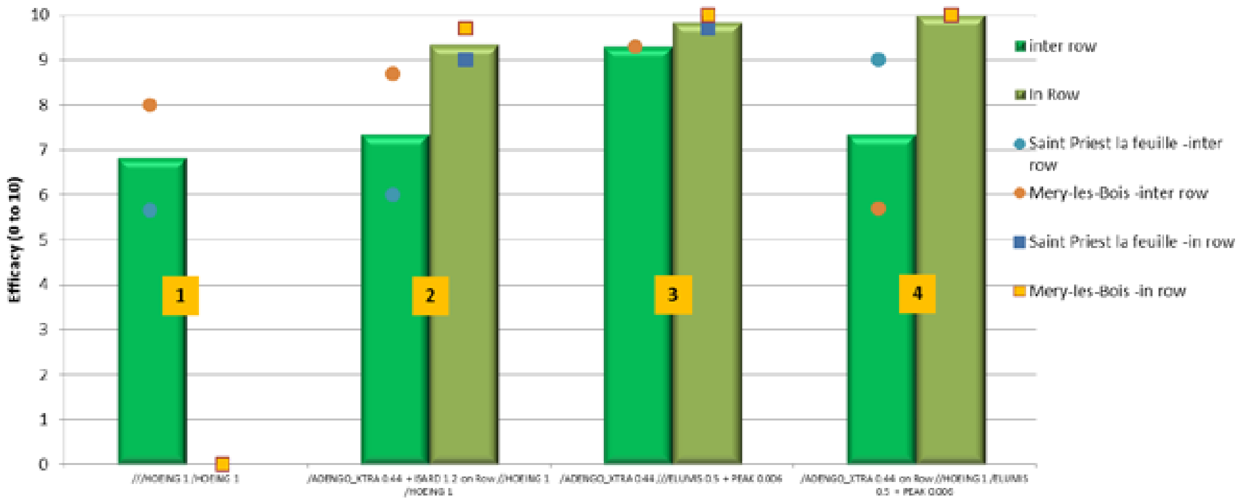



**Figure 1** - Efficacy of mechanical and mixed strategies on maize (two trials)
*Adengo XTra= isoxaflutol + thiencarbazone-me*
*Isard = dmta-p*
*Elumis = mesotrione + nicosulfuron*
*Peak = prosulfuron*

## SOIL PREPARATION BEFORE SOWING WITHOUT GLYPHOSATE IN SUNFLOWER

During the 2018-2019 season, seven trials were set up, with five trials being on sunflower. As the aim was to seed on clean soil, it was important to study tillage tools and depths before sunflower seeding in order to ensure that:
1) the weeds present before crop sowing were destroyed;
2) crop establishment quality was not affected;
3) soil tillage did not cause too many new weed emergences in the crop.

These issues are important and optimal tillage type (tool, depth, conditions) needed to be found both to destroy weeds and to ensure crop establishment. The test principle was to use a soil tillage tool during the month in order to do without applying glyphosate pre-sowing, according to the treatments below.

## AGEN TRIAL

Sunflower sowing was performed with a single seed drill with 66 cm spacing on 1 April 2019 on fresh soil. The sowing density was 73,500 seeds/ha; the seed was the Carrera CLP variety. The day after sowing, pre-emergence herbicide, Mercantor gold (s-metolachlor) 1.05 L/ha + Proman (metobromuron) 2 L/ha, was sprayed on the entire trial. The final stage saw PULSAR 40 (imazamox) applied at 1.25 L/ha at the B6 stage of the sunflower on 16 May 2019.
In sunflower, Treatment 3 had by far the lowest density of weeds. After the two Roundup Innov (glyphosate - potassium salt) treatments (12 March and 9 April) and the pre-emergence treatment, no wild oats and only 0.67 ryegrass plants/m$^2$ remained, although the 12 March treatment was found to be ineffective due to the low dose.
Treatment 1 + pre-emergence treatment had average effectiveness on ryegrass (32.67 plants/m$^2$), but was highly effective on wild oats (1.33 pl/m$^2$).
Treatment 2 + the pre-emergence treatment had the highest ryegrass density (38.67 plants/m$^2$), with all weeds ranging from the seedling to the adult plant stages.

Treatment 2 was the most weed-infested, followed by Treatment 1. Although Treatment 3 was the least infested, its first 1.5 L/ha rate of glyphosate was not effective enough to control weeds properly. Pre-emergence retreatment with 2 L/ha of Roundup Innov (glyphosate - potassium salt) was required. This treatment used a total of 3.5 L/ha of Roundup Innov (glyphosate - potassium salt).
Although it was thought that the fairly dry conditions during tool passes would allow considerable weed control, some weeds were present from the young seedling to the flowering stages in this treatment. This meant that the tools did not totally destroy the weeds, leading to new weed emergences. Only young plants, however, were observed in Treatment 3.
Visual observation confirmed the trends. The vibrocultivator treatment was the most infested, with this being the case from the first tool run (1 April). After the second application, the glyphosate

| Code | Name | Treatment |
|---|---|---|
| 1* | Destruction with soil tillage tool | Tool available on trial site |
| 2* | Destruction with another soil tillage tool | Another soil tillage tool available on trial site |
| 3 | Farmer's treatment with glyphosate | To understand the consequences of tillage on weed emergence and seedbed quality |

**Table 3** - Treatments for trials on sunflower
** for Treatments 1 and 2, two tools were chosen from among these four types:*
*- rotary harrow*
*- vibrocultivator*
*- straight-toothed tool*
*- stubble cultivator or vibrocultivator equipped with a roller*

| Location | Flora | Soil type | Sunflower sowing date |
|---|---|---|---|
| Agen (47) | Ryegrass (+ wild oat) | Clay and limestone | 1 April 2019 |
| Subdray (36) | *Mercurialis annua + Polygonum convolvulus* | Superficial clay and limestone | 21 April 2019 |
| Arçay (18) | Ambrosia *artemisiifolia* and all flora | Candy loam | 19 April 2019 |
| Arçay (18) | Ambrosia *artemisiifolia* | - | 19 April 2019 |
| Seignalens (11) | Ambrosia *artemisiifolia* | Clay and limestone | 23 May 2019 |

**Table 4** - Description of the five trials on sunflower

| Code | Name | Treatments & Dates |
|---|---|---|
| 1 | Destruction with soil tillage tool | Rotary harrow + roller packer: 12 March<br>Rotary harrow + roller packer: 1 April |
| 2 | Destruction with another soil tillage tool | Vibrocultivator + roller: 12 March<br>Rotary harrow + roller packer: 1 April |
| 3 | Farmer's treatment with glyphosate | Roundup Innov 1.5 L/ha: 12 March<br>Roundup Innov 1.5 L/ha: 9 April |

**Table 5** - Scheme of the Agen trial. The main weed in this trial was ryegrass


**Figures 2 and 3** - Destruction on 12 March 2019 with rotary harrow (left) and the visual effect (right)

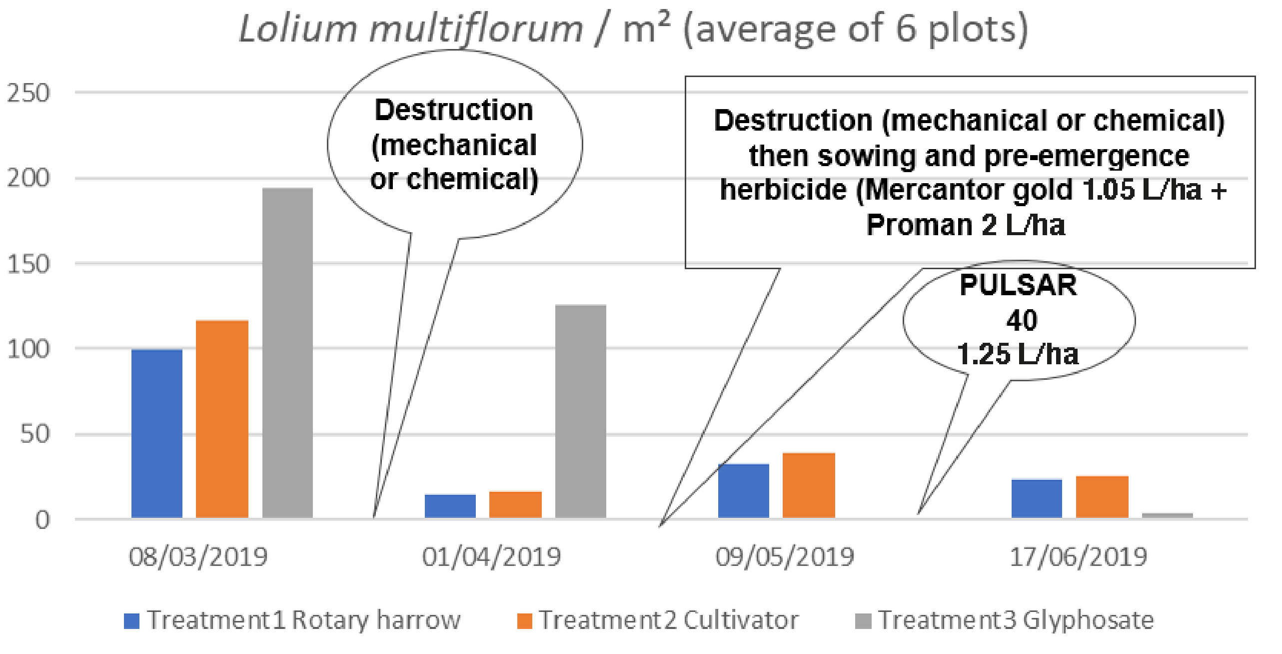



**Figure 4** - Efficacy of mechanical and glyphosate strategies on ryegrass


**Figures 5, 6 and 7** - Sunflower in Treatment 1 (left), Treatment 2 (middle) and Treatment 3 (right)

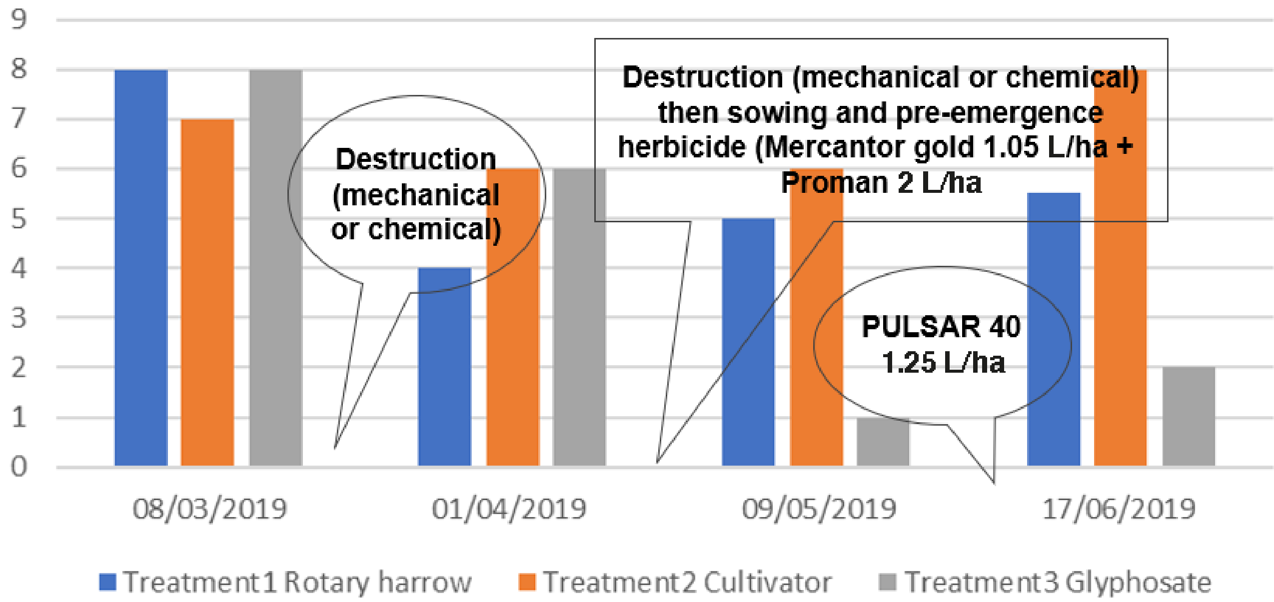



**Figure 8** - Visual observation in the Agen sunflower trial (0 = very clean, 9 = full of weeds)

| | Tillage depth | Soil moisture | Soil structure | Contact soil-grain |
|---|---|---|---|---|
| Treatment 1 (rotary harrow) | 5 cm | Fresh | Clods from 5 to 8 cm | Medium |
| Treatment 2 (vibrocultivator) | Between 4 and 6 cm | Fresh | Clods from 5 to 7 cm | Medium |
| Treatment 3 (glyphosate) | 4 cm | Fresh | Compact soil | Very good |

**Table 6** - Trial specifications

treatment proved to be the cleanest (observations on 9 May and 17 June). The visual observation was global (all weed types, so it also took into account the new emergence that took place in sunflower (mainly broadleaf weeds), and not only ryegrass.
Sunflower establishment quality (crop stand + taproot shape):
emergence appeared in good condition and homogeneous. Heterogeneity in population, to the disadvantage of glyphosate, was minimal and negligible.
At the E2 sunflower stage, an observation on taproot shape was carried out on two plots of 25 plants per treatment to check the quality of crop establishment. The percentage of straight taproots was higher in the rotary-harrow and vibrocultivator treatments (88%) than in the glyphosate treatment (68%).
This situation can be explained on the glyphosate-treated plot, as the soil was wet when the last tillage was done in November (rotary harrow) and no additional tillage was carried out after that date, creating a “plough sole”.
Tillage arrangements had a better percentage of straight taproots because past tools had broken up this “plough sole”, allowing the taproots to develop properly and a little deeper.

### SUBDRAY TRIAL

The main weeds in this trial were *Mercurialis annua* (mercury) and *Fallopia convolvulus* (wild buckwheat).
The rotary harrow treatment was the most weed-infested (mainly mercury) and the vibrocultivator treatment was the “cleanest”, but density was still

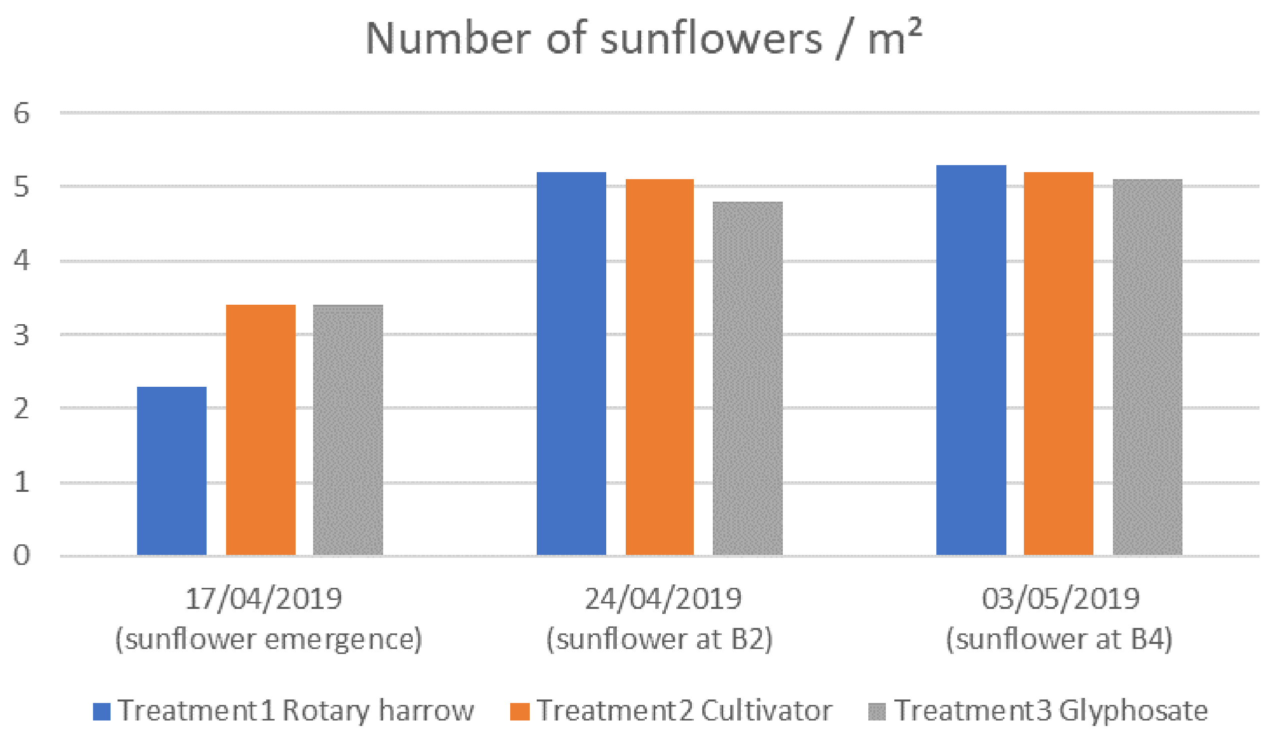
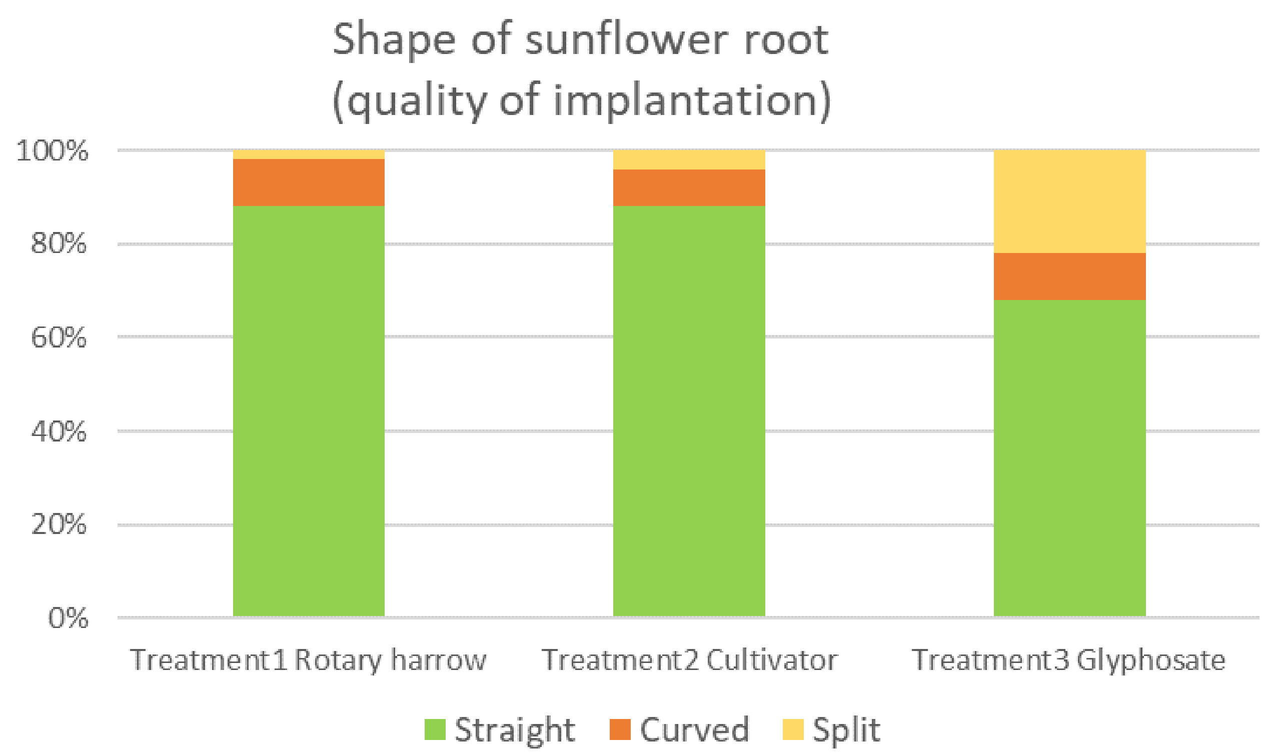



**Figure 9** - Effect of different strategies on sunflower density




**Figures 10** - Effect of different strategies on sunflower implantation

50 mercury plants/m².
Weather conditions in the first ten days of April were not favourable for weed emergence, as temperatures were quite low and rainfall was relatively low. In the end, sunflowers were sown on 21 April, when emergence conditions were more favourable. These results may be explained by glyphosate being applied too early on dry soil, low rainfall and non-emerging flora.
The weeds observed in sunflowers (mercury and wild buckwheat) were only new emergences.

Visual estimation:
As of 26 June, the rotary harrow and glyphosate treatments scored 7/9 (9 being the most-infested situation possible), while the vibrocultivator treatment scored 5/9 (0 being a totally clean plot).

Quality of sunflower establishment (crop stand + shape of taproots):

| | Sunflowers/m² |
|---|---|
| Treatment 1 (rotary harrow) | 5 |
| Treatment 2 (vibrocultivator) | 6 |
| Treatment 3 (glyphosate) | 8 |

**Table 8** - Number of plants/m²

Although the rotary harrow treatment was the most weed-infested, it was the one with the straightest taproots. The vibrocultivator treatment had the most bent taproots. In all three treatments, the quality of sunflower establishment seemed poor.

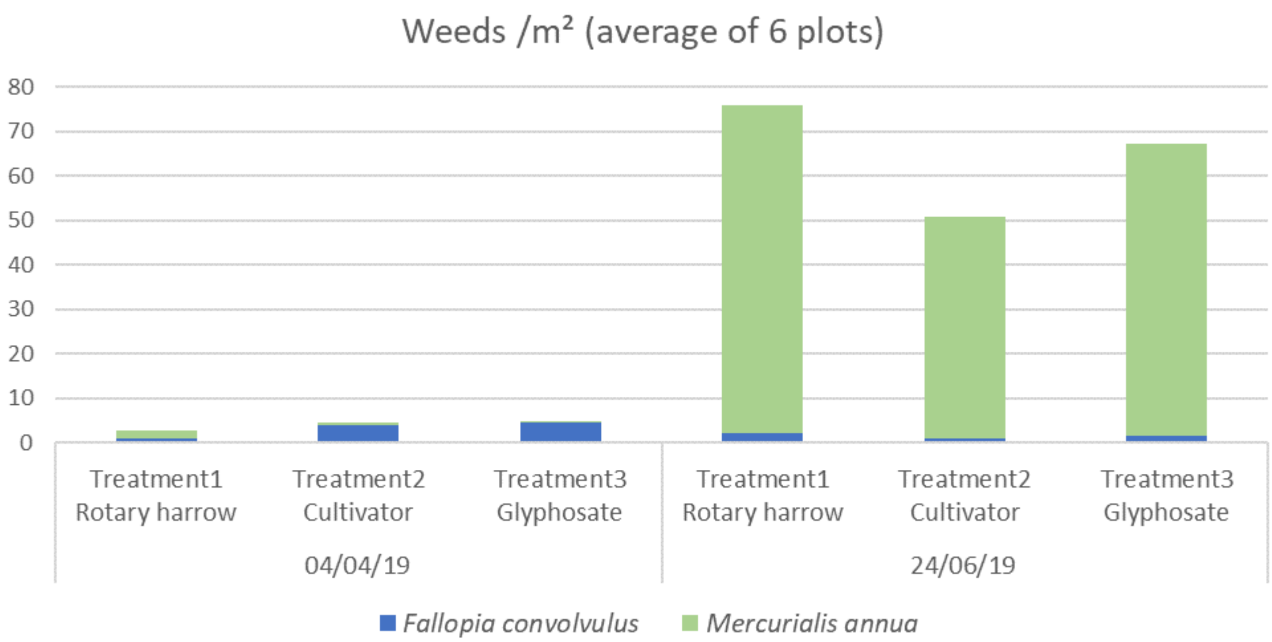
### ARÇAY TRIAL 1

The main weeds in this trial were *Ambrosia artemisiifolia* and different broadleaves (*Solanum nigrum, Erodium cicutarium, Viola arvensis*).
Sowing was carried out with a single seed drill at

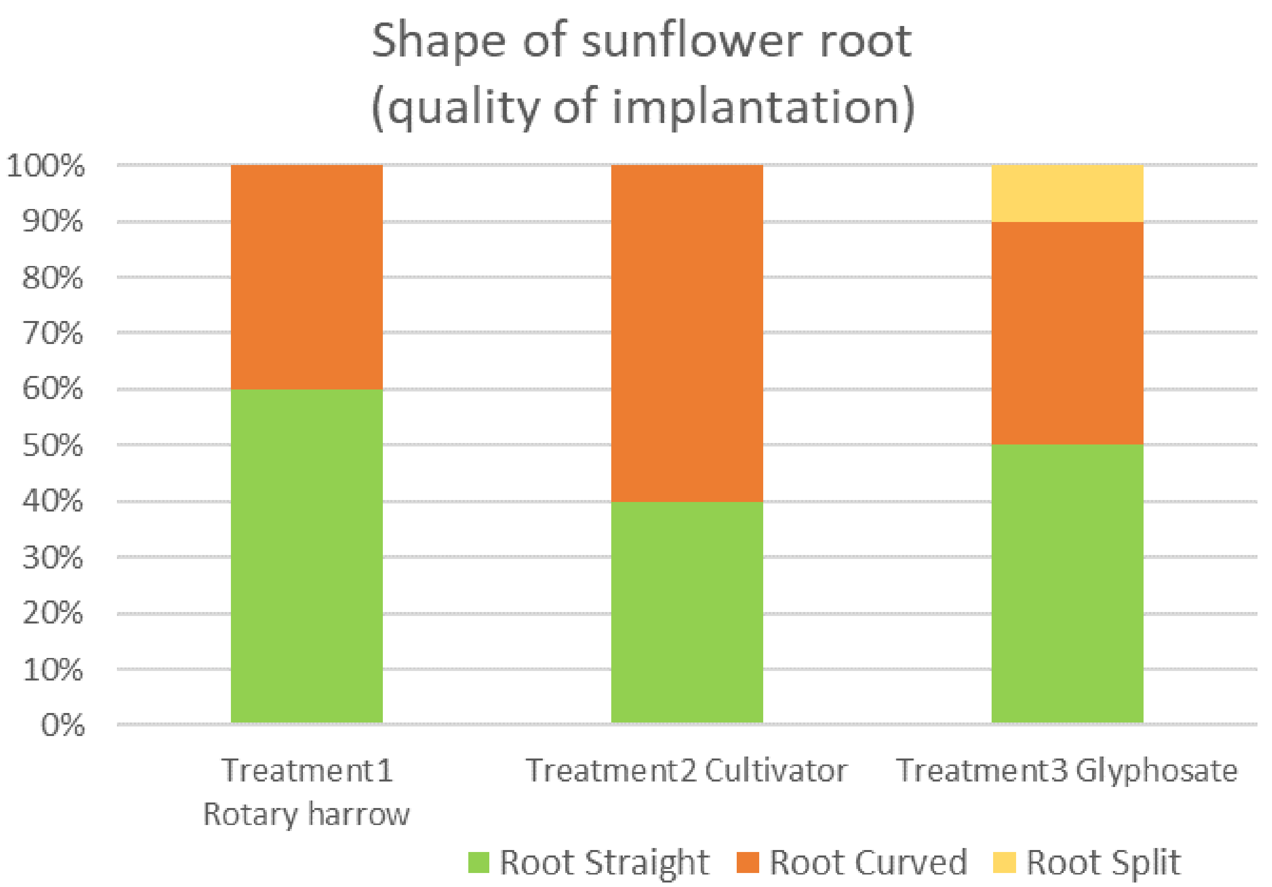
| Code | Name | Treatments & Dates |
|---|---|---|
| 1 | Destruction with soil tillage tool | Rotary harrow + roller packer: 5 April |
| 2 | Destruction with other soil tillage tool | Vibrocultivator + roller: 5 April |
| 3 | Farmer’s treatment with glyphosate | Glyphosate 2.5 L/ha: 8 April |

**Table 7** - Scheme of the Subdray trial

**Figures 11 and 12** - Tools used on the Subdray trial: rotary harrow (left) and vibrocultivator (right)
Sowing was carried out with a single seed drill with 60 cm spacing on 21 April 2019 under optimal conditions. Sowing density was approximately 71,000 seeds/ha. The variety sown was Buffalo. Pre-emergence weeding was carried out on 24 April 2019 on the whole trial with Soléto (metobromuron) at 2.5 L/ha.




**Figures 13** - Effects of weeding strategies on two weeds




**Figures 14** - Effect of different strategies on sunflower implantation

| Code | Name | Treatments & Dates |
|---|---|---|
| 1 | Destruction with soil tillage tool | Rotary harrow+ roller: 15 April |
| 2 | Destruction with other soil tillage tool | Vibrocultivator + levelling rod: 15 April |
| 3 | Farmer’s treatment with glyphosate | Glyphosate 2.5 L/ha: 18 April |

**Table 9** - Scheme of Arçay Trial 1

**Figures 15 and 16** - Vibrocultivator (left) and soil structure after pass (right)

60 cm spacing on 19 April 2019 under optimum conditions. Sowing rate was approximately 75,000 seeds/ha. The variety sown was ES Balistic CL. Pre-emergence weeding of the sunflower was carried out on 20 April 2019 with Pentium flo (pendimethalin) at 1.5 L/ha. The farmer then applied Pulsar (imazamox) in two passes at 0.625 L/ha (split) on 24 and 29 May 2019.

During the first count before destruction, which was carried out to sow on clean soil, mainly ragweed and pansy were found, but other weeds were also present in small numbers. Resurfacing therefore acted well as a stale seedbed.

On the second tillage count on 23 May 2019, about a month after seeding, ragweed and nightshade emerged well on both tillage systems, with their numbers remaining quite low in the glyphosate treatment. Thus, the second pass after ploughing was resumed favoured weed emergence. The counts showed that the rotary-harrow treatment had the highest infestation in this trial. The rotary harrow perfectly levelled the soil for sowing, removing all the weeds present. However, the harrow’s packer roller compacted the soil, which can allow weeds to be “transplanted” to the surface and seed germination to be promoted. The vibrocultivator treatment had a lesser impact, as nothing was re-compacted after the pass. The glyphosate treatment was still relatively clean at the time of observation.

The Pulsar run was carried out on 24 and 29 May 2019 (half dose each), and the last observation was carried out on 17 June 2019 when the sunflower was at the star bud stage. The tillage treatment was more infested than the glyphosate treatment.

Despite a decrease in the number of weeds (nightshade disappeared), the rotary-harrow treatment remained the most infested, mainly with ragweed. The cleanest treatment on this date, and under the conditions of our trial, was glyphosate.

The visual observation scores confirmed the trends in the frameworks. Nevertheless, the glyphosate treatment did not appear to be weed-free, although it remained the most effective.

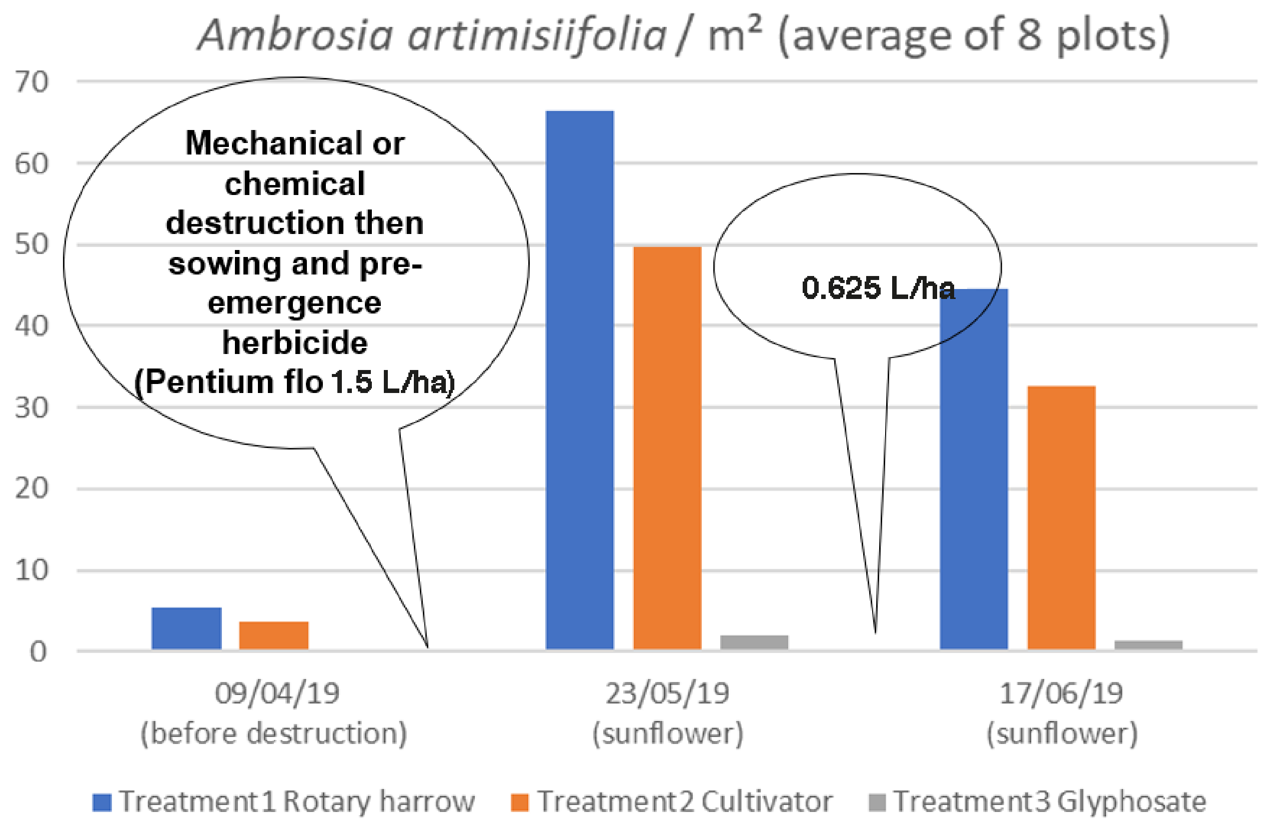



**Figure 17** - Effects of weeding strategies on Ambrosia

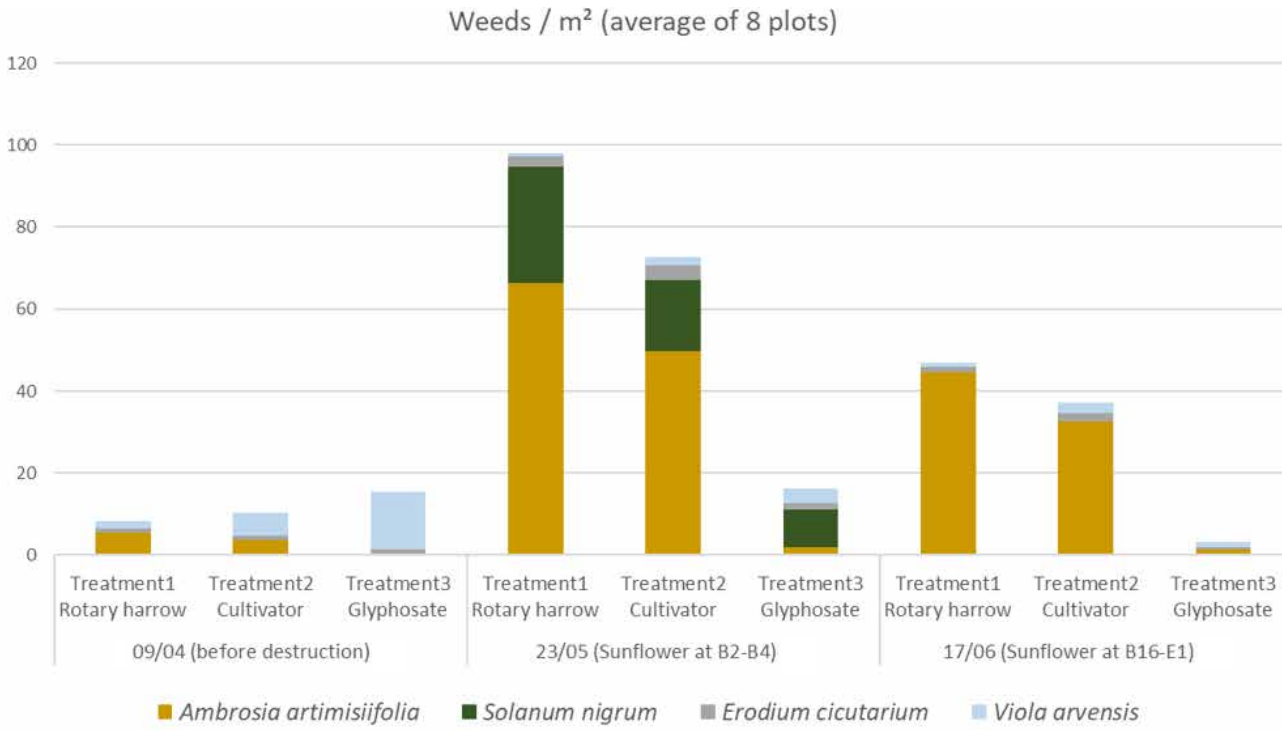



**Figure 18** - Effects of weeding strategies on four weeds at three dates

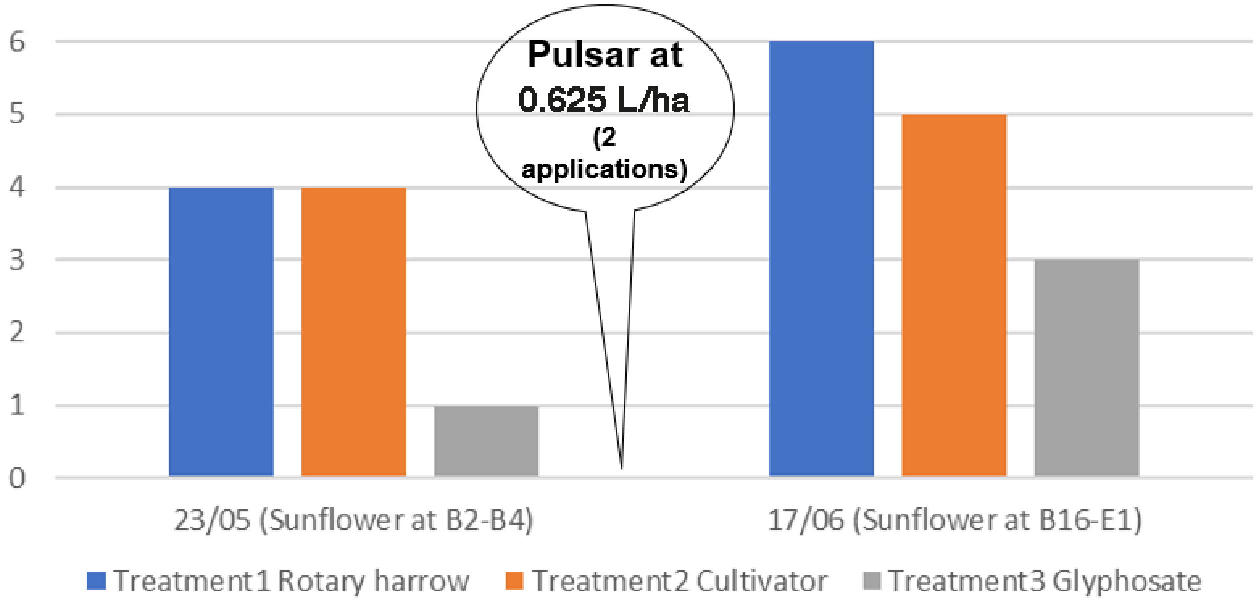



**Figure 19** - Visual observation on Arçay sunflower Trial 1 (1 = very clean, 9 = full of weeds)

**Figures 20 and 21** - Rotary harrow (left) & glyphosate (right)

The sunflower population appeared to be homogeneous throughout the trial. In addition, 100% of the taproots were straight in all three treatments. The soil type was less problematic than in the previous trials (sandy loam and clayey limestone).

Sunflower establishment quality (crop stand + taproot shape):

| | Sunflowers/m² |
|---|---|
| Treatment 1 (rotary harrow) | 8 |
| Treatment 2 (vibrocultivator) | 7 |
| Treatment 3 (glyphosate) | 8 |

**Table 10** - Sunflower plants per m² in Arçay Trial 1

| Code | Name | Treatments & Dates |
|---|---|---|
| 1 | Destruction with soil tillage tool | Rotary harrow + roller: 15 April |
| 2 | Destruction with other soil tillage tool | Vibrocultivator + levelling rod: 15 April |
| 3 | Farmer’s treatment with glyphosate | Glyphosate 2.5 L/ha: 18 April |

**Table 11** - Scheme of Arçay Trial 2


**Figures 22 and 23** - Rotary harrowing (left) was performed at 10 cm depth. All weeds were destroyed (right)

**ARÇAY TRIAL 2**

The main weed in this trial was ragweed *Ambrosia artemisiifolia*.

The trial was set up in a plot where ragweed had been present for a few years and was a problem for sunflowers.

Sowing was carried out with a single seed drill at 60 cm spacing on 19 April 2019 under optimum conditions. Sowing rate was approximately 75,000 seeds/ha. The variety sown was ES Balistic CL. Pre-emergence weeding was carried out on 20 April 2019 on the whole plot with pentium flo at 1.5 L/ha. The farmer then applied Pulsar in two passes at 0.625L/ha (split) on 24 and 29 May 2019.

The count on 9 April before mechanical or chemical destruction of flora showed that early ploughing, carried out in March, created a false seedbed which caused a great deal of ragweed emergence (between 200 and 380/m²), and thus destocking.

Despite this high density, tillage in Treatments 1 and 2, which was carried out under optimal conditions, destroyed the existing ragweed.

The count on 23 May showed that the rotary-harrow treatment saw an increase in the number of ragweeds between the first count (before intervention) and the second (a month later). We can therefore assume that the packer roller of the rotary harrow reconsolidated the soil and allowed ragweed to transplant. Even though the ragweed count in the vibrocultivator treatment on 23 May was lower than the initial count on 9 April, we can assume that the tillage also raised ragweed (even more than in the rotary-harrow treatment), since the 15 April tillage had destroyed most of the ragweed present. Glyphosate induced the least amount of ragweed to emerge since the soil was not disturbed.

**Figure 24** - A vibrocultivator was used at 12 to 15 cm depth. Soil structure appeared more cloddy

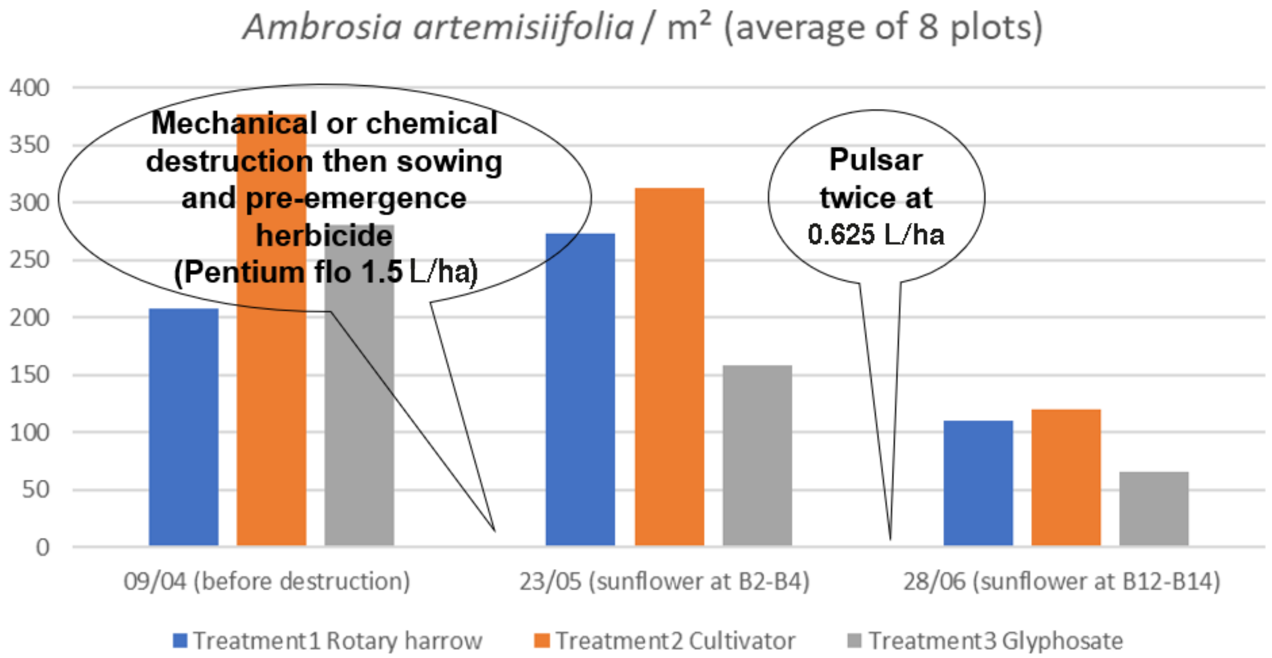



**Figure 25** - Effects of weeding strategies on Ambrosia

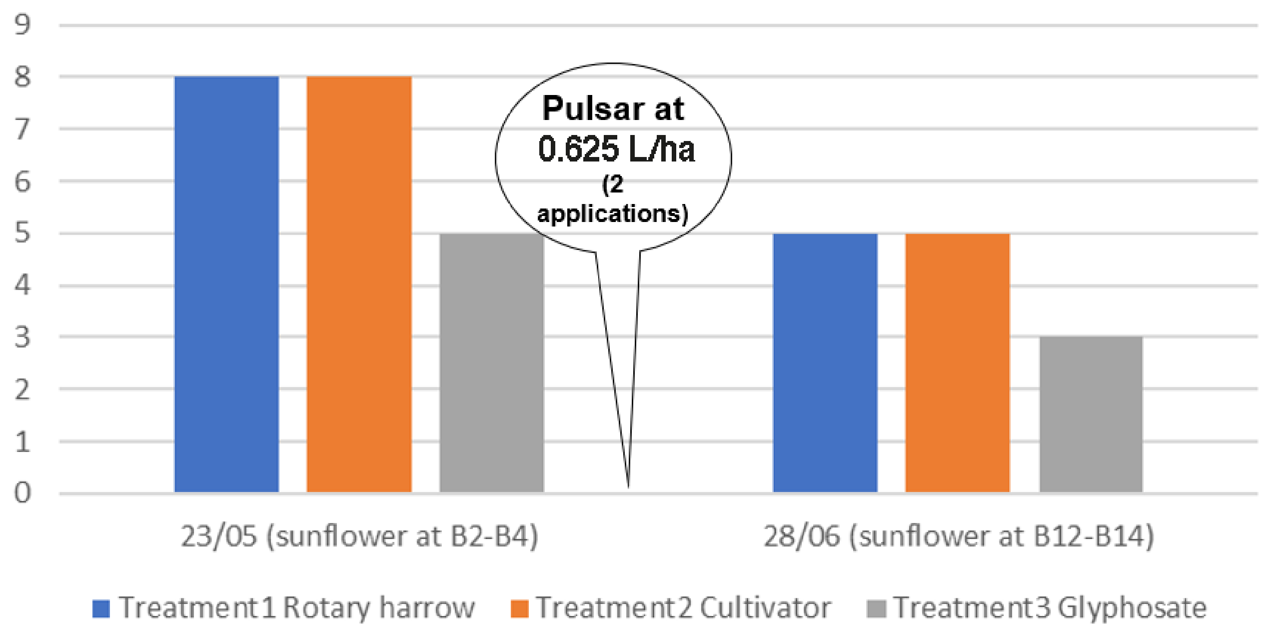



**Figure 26** - Visual observation on Arçay sunflower Trial 2 (0 = very clean, 9 = full of weeds)

Nevertheless, there were still 150 ragweed plants/ m² in this treatment. Indeed, the light but regular rains in April and May, as well as the above average temperatures of the season, caused significant emergence of ragweed on the whole plot.
Observations confirmed the trends seen in the samples. Nevertheless, the glyphosate treatment did not appear to be weed-free, although it remained the best treatment.
For example, during a heavy ragweed infestation, glyphosate combined with Pulsar can greatly reduce the ragweed population, but not eradicate it.
Tillage (rotary harrow or vibrocultivator) was not sufficient to ensure total destruction of ragweeds (even when coupled with Pulsar).
The quality of implantation seemed poor for the

three treatments because the vibrocultivator treatment, even though it was the one with the best implantation quality, had only 60% straight taproots. The no-tillage treatment (glyphosate) did not have satisfactory implantation, but it was no worse, or even better, than the rotary-harrow treatment. The least well-established treatment (only 20% straight taproots) was the rotary harrow.

## SEIGNALENS TRIAL

The main weed in this trial was *Ambrosia artemisiifolia*.
Sowing was carried out on 23 May in good conditions, just after the rotary harrow and vibrocultivator passes. The farmer then carried out pre-emergence post-seeding weeding with Mercantor (s-metolachlor) and Racer (flurochloridon).
Large thistle rings were present on the trial before the sunflower was sown. The regularity of the ragweed stand was far from optimal at the time of sowing, as very few plants were present.
Ragweeds began to emerge in significant numbers between 20 June and mid-July, following the rainy spell that occurred during this period.
The results show that, overall, Treatment 3

Quality of sunflower establishment (crop stand + taproot shape):

| | Sunflowers/m² |
|---|---|
| Treatment 1 (rotary harrow) | 5 |
| Treatment 2 (vibrocultivator) | 4 |
| Treatment 3 (glyphosate) | 4 |

**Table 12** - Sunflower plants per m² in Arçay Trial 2

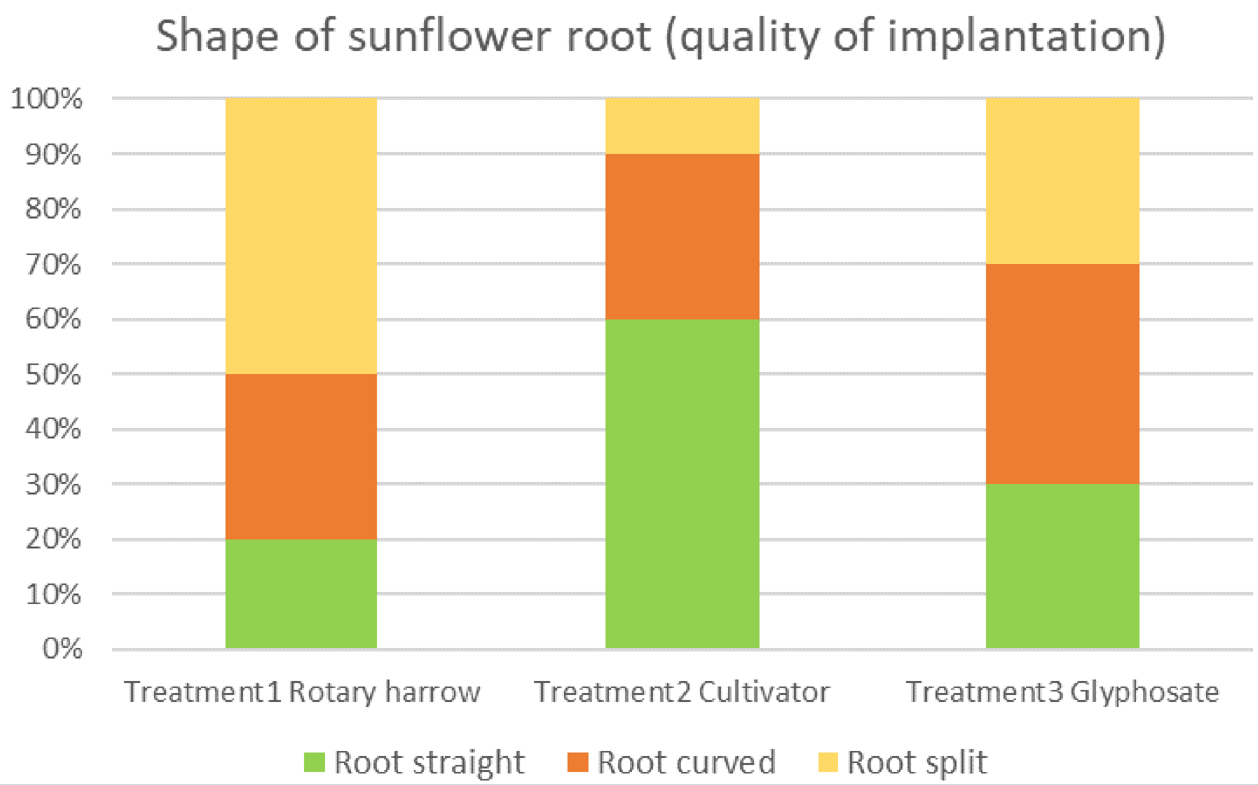



**Figure 27** - Effect of different strategies on sunflower implantation

| Code | Name | Treatments & Dates |
|---|---|---|
| 1 | Destruction with soil tillage tool | Rotary harrow 10 cm depth: 23 May |
| 2 | Destruction with another soil tillage tool | Vibrocultivator 15 cm depth: 23 May |
| 3 | Farmer's treatment with glyphosate | Glyphosate 3 L/ha: 23 May |

**Table 13** - Scheme of the Seignalens trial

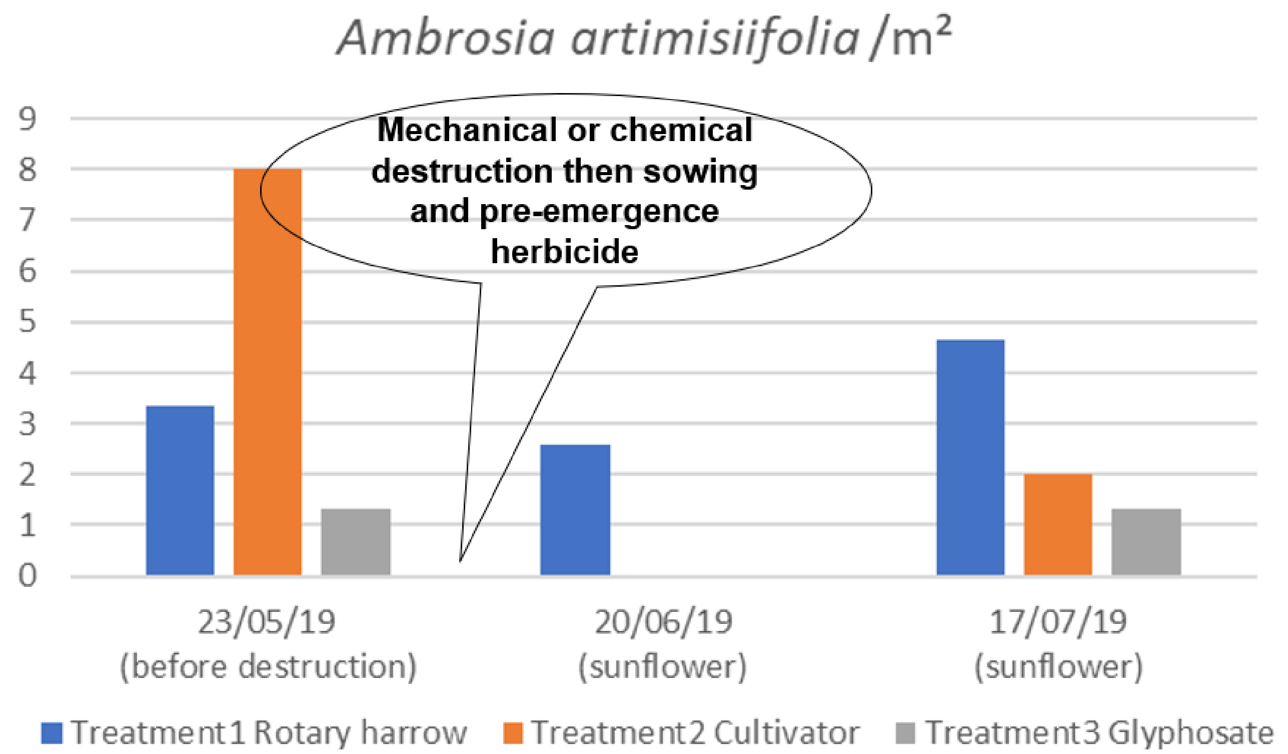



**Figure 28** - Effects of weeding strategies on Ambrosia

(glyphosate) had much less ragweed in sunflower than Treatment 1 (rotary harrow), and less than Treatment 2 (vibrocultivator).

The rotary-harrow treatment seemed to be more infested with ambrosia than the vibrocultivator and glyphosate treatments. The hypothesis was that since the rotary-harrow tillage (10 cm) was shallower than the vibrocultivator tillage (15 cm), it would probably have unburied fewer seeds. This means that there would have been a slightly higher number of emergences. The rotary harrow treatment may have been more infested than the glyphosate treatment because tillage with a rotary harrow can cause new ragweed emergence, or there may have been a gradient in the plot, or at least heterogeneity in the ragweed infestation.

Sunflower emergence was between 5.5 and 6.6 plants/m². The population was relatively homogeneous.

Concerning sunflower rooting, it would appear that on Treatments 1 and 2 (tillage), there were more bent or forked taproots than on the glyphosate treatment. The rotary harrow treatment had the majority. In any case, the quality of implantation was not excellent for any of the treatments. The glyphosate treatment gave the best quality of implantation, with 75% straight taproots.

## SOIL PREPARATION BEFORE SOWING WITHOUT GLYPHOSATE ON SOYBEAN

During the 2019 season, two trials on soybean were set up. The objectives were the same as in the sunflower trials.

As the aim was to seed on clean soil, it was important to study tillage tools and depths before soybean seeding in order to ensure that:

1) the weeds present before crop sowing were destroyed;

2) crop establishment quality was not affected;

3) tillage did not cause too many new weed emergences in the crop.

These issues are important and the optimal tillage type (tool, depth, conditions) needed to be found both to destroy weeds and to ensure crop

Sunflower planting quality (crop stand + tap root shape):

| | **Sunflowers/m²** |
|---|---|
| Treatment 1 (rotary harrow) | 5.6 |
| Treatment 2 (vibrocultivator) | 6.6 |
| Treatment 3 (glyphosate) | 5.5 |

**Table 14** - Sunflower plants per m² in Arçay Trial 2

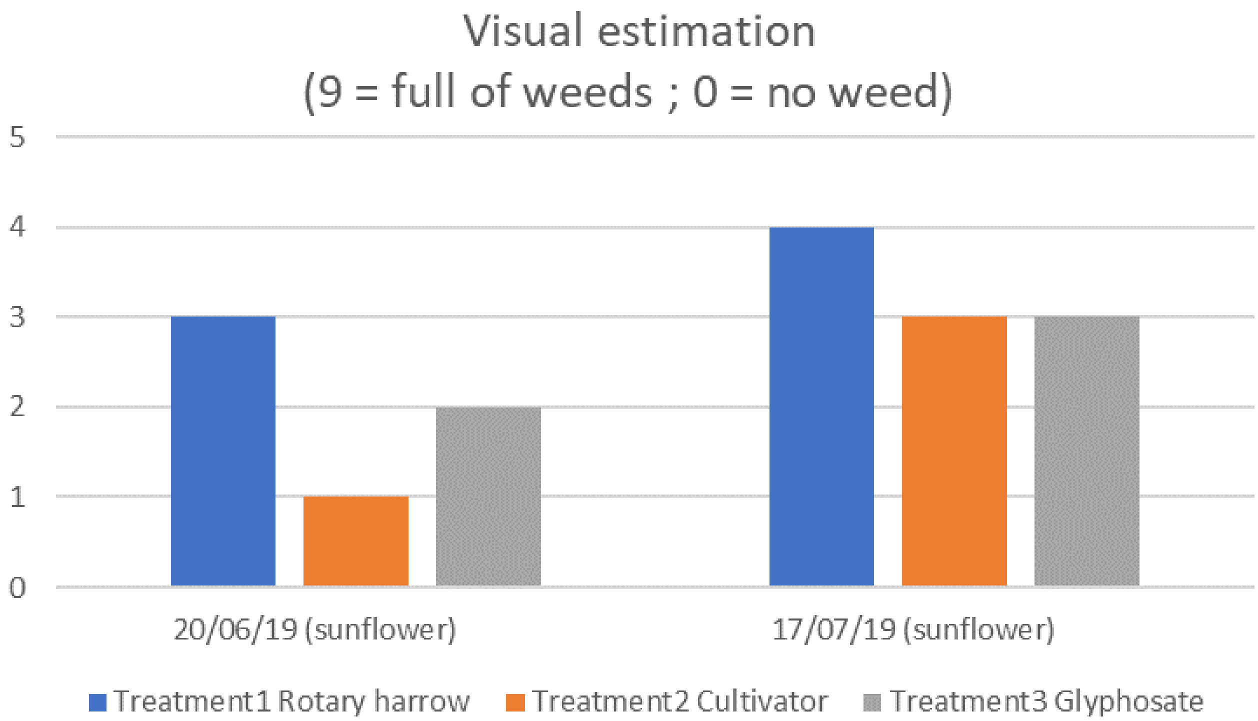



**Figure 29** - Visual observation on Seignalens sunflower (0 = very clean, 9 = full of weeds)

| Trials | Flora | Soil type | Sowing date |
|---|---|---|---|
| Agen (47) | Ryegrass | silty-clay | 06/05/2019 |
| Dijon (21) | All flora | silty-clay | 15/05/2019 |

**Table 15** - Scheme of the soybean trials

establishment.
The test principle was to use a soil tillage tool during the month in order to avoid applying glyphosate pre-sowing, according to the treatments below.
As in sunflower, two trials were implemented, with practically the same protocol, with the main objective being to control weeds during the intercropping period without glyphosate and to ensure good crop implantation.

## AGEN TRIAL

The main weed in this trial was ryegrass.
Rotary harrowing combined with a roller packer (12 April 2019) was carried out on fresh soil up to a depth of 7 cm. Weed control appeared to be effective. Indeed, a subsequent count showed that more than 75% of ryegrass plants had been eliminated. Ryegrass was still present, but in clearly decreased numbers. Rotary harrowing was thus carried out again on 6 May a few hours before sowing in order to sow on clean soil.
A vibrocultivator combined with a cage roller (12 April 2019) was run on fresh soil at a depth of 10 cm. Weed destruction appeared to be moderately effective. It was, however, impossible to sow in this soil structure due to the large clods made by the cultivator. A subsequent count showed that the first pass with the vibrocultivator eliminated 50% of the ryegrass. The ryegrass was still present, but in clearly decreased numbers. Rotary harrowing was carried out on 6 May a few hours before sowing in order to sow on clean soil.
Sowing was carried out with a single seed drill with 66 cm spacing on 6 May 2019 on fresh soil. Sowing density was 400,000 seeds/ha with the ISIDOR variety. On 8 May 2019, a pre-emergence herbicide, Mercantor Gold (s-metolachlor) 1.4 L/ha, was distributed on the whole trial. The farmer applied a PULSAR 40 (imazamox) at 0.8 L/ha at V3 stage on 17 June 2019.
Before destruction on 11 April, there was a very large population of ryegrass (about 260 to 400 plants/m²).
The vibrocultivator treatment was the most infested from the start.

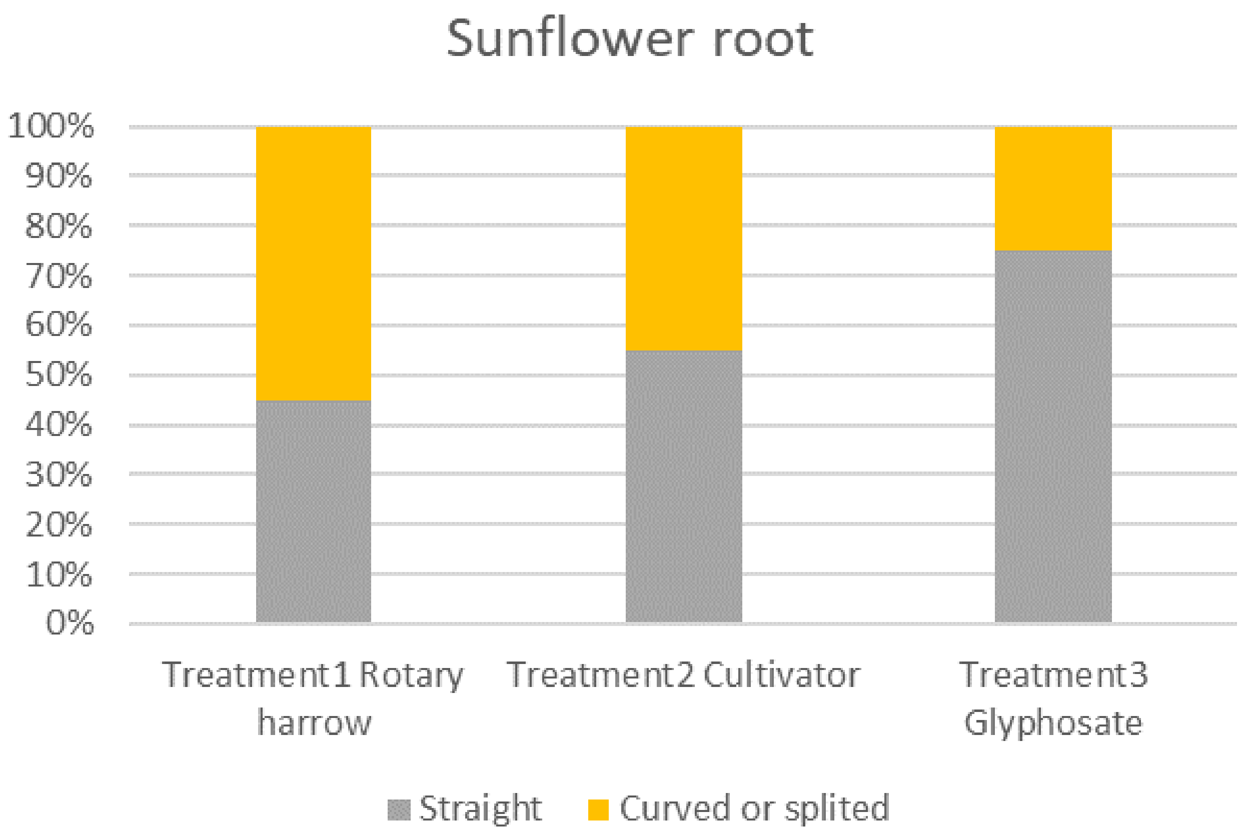



**Figure 30** - Effect of different strategies on sunflower implantation

| Code | Name | Treatments & Dates |
|---|---|---|
| 1 | Destruction with soil tillage tool | Rotary harrow + roller packer: 12 April<br>Rotary harrow + roller packer: 6 May |
| 2 | Destruction with another soil tillage tool | Vibrocultivator + roller: 12 April<br>Vibrocultivator + roller: 6 May |
| 3 | Farmer 's treatment (glyphosate) | Roundup Innov 2 L/ha: 10 April |

**Table 16** - Scheme of Arçay Trial 2

After destruction (mechanical or chemical) and before sowing on 3 May, we noted that glyphosate was very effective (0 ryegrass) and that the rotary harrow was quite effective because it considerably reduced the ryegrass population, but not enough to eradicate it (66 ryegrass plants/m²). This was either because mechanical destruction was not complete, or because tillage caused new emergences (ryegrass plants were at Stage C on 11 April and 3 May). The vibrocultivator was less efficient than the rotary harrow, as the ryegrass population had decreased, but there were still 196 plants per m², which was a large population. This was either because mechanical destruction was not complete, or because tillage caused new germinations (ryegrass plants were at Stage C on 11 April and 3 May).

On 3 June, the tillage method in soybean using vibrocultivator (4 April and 6 May) + pre-emergence treatment was the one with the most ryegrass plants/m² (48.67). The majority of this weed was in the flowering stage. The glyphosate treatment was by far the least infested. Indeed, after the Roundup Innov (glyphosate - potassium salt on 10 April) and pre-emergence treatment, only 0.67 ryegrass plants/m² remained, with there being just a few chickweeds and other broadleaf weeds. It seems that most of the weeds were late flushes, as they were mostly in the young-plant stage. Finally, rotary tillage (12 April and 6 May) + pre-emergence treatment had average efficacy on ryegrass (22.67 plants/m²), but these were

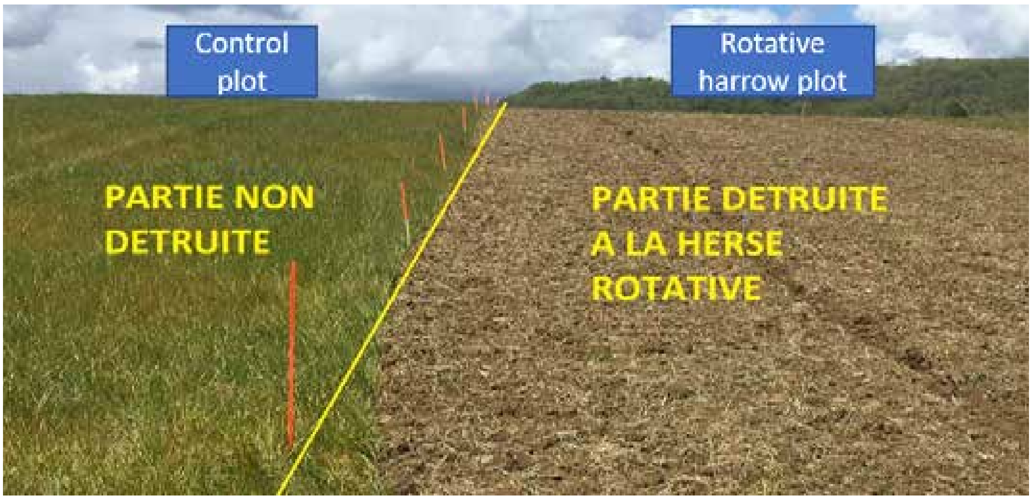



**Figure 31** - Rotary harrow pass (two passes) on 12 April 2019 (right) and control plot (left)

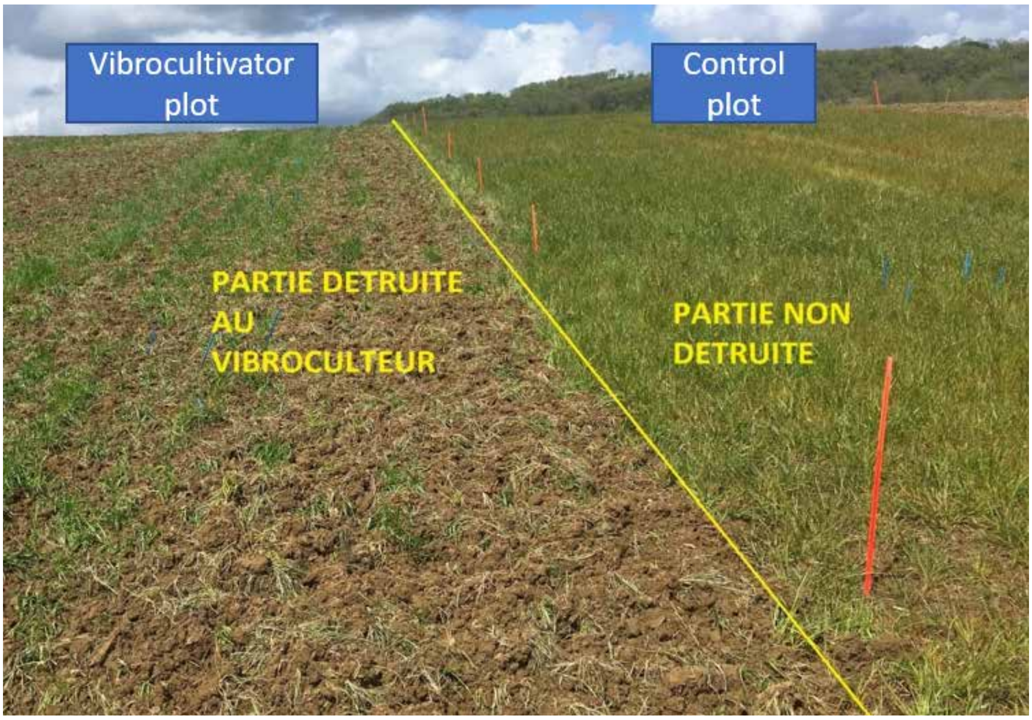



**Figure 32** - Vibrocultivator treatment (two passes) 12 April 2019 (left) and control plot (right)

new plant emergences.
On 18 July, at the R2 stage of soybean, the vibrocultivator treatment had the most ryegrass plants per m² (35.33), the majority of them being at the shot-blasting stage, which meant poor destruction during tool pass. In the rotary-harrow treatment, only 2.67 ryegrass plants/m² remained. Most of them were at the shot-blasting stage. There were a few broadleaf weeds at a fairly young stage. In the 2 L/ha Roundup Innov (glyphosate - potassium salt) treatment, no ryegrass plants were present on the counting plots, although some broadleaf weeds were present at different stages.
The visual ratings confirmed the trends observed in the samples; however, when there was very strong ryegrass pressure, we were unable to discriminate between the treatments.
In light of the observations, Treatment 2 (vibrocultivator + rotary pass) was more weed-infested than both the Treatment 1 (two rotary passes) and Treatment 3 (glyphosate).
Wet conditions after tillage did not allow for good

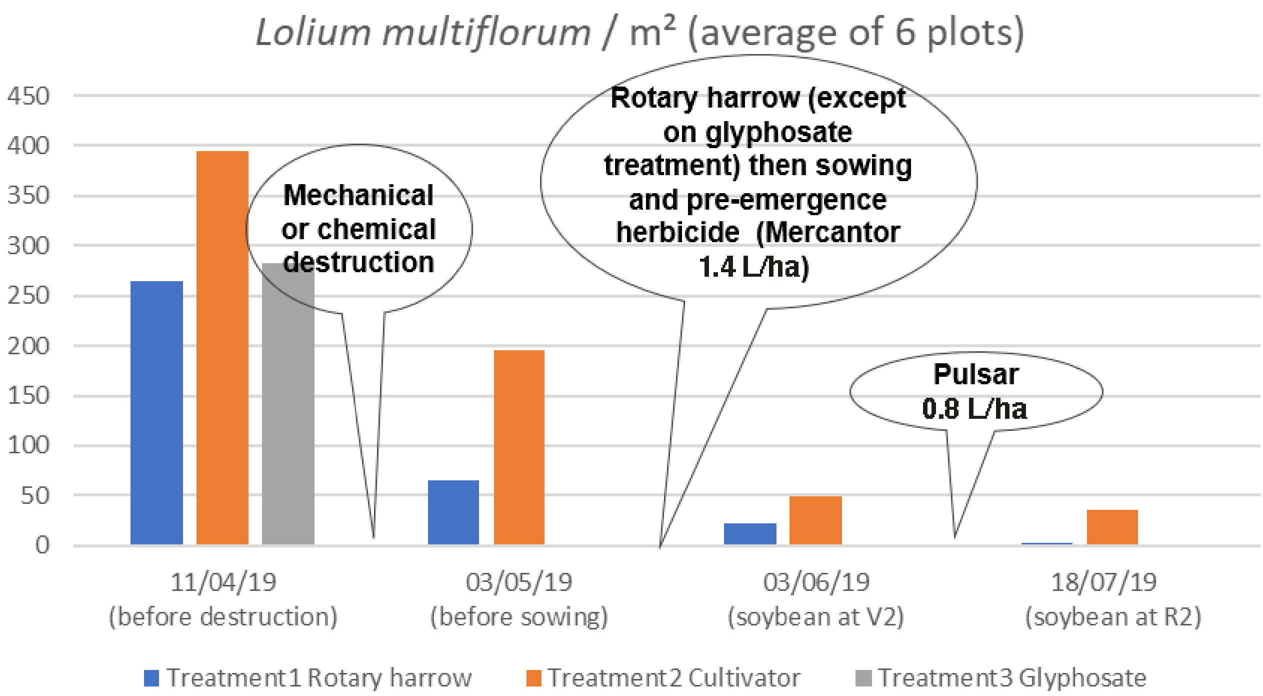



**Figure 33** - Effects of weeding strategies on ryegrass

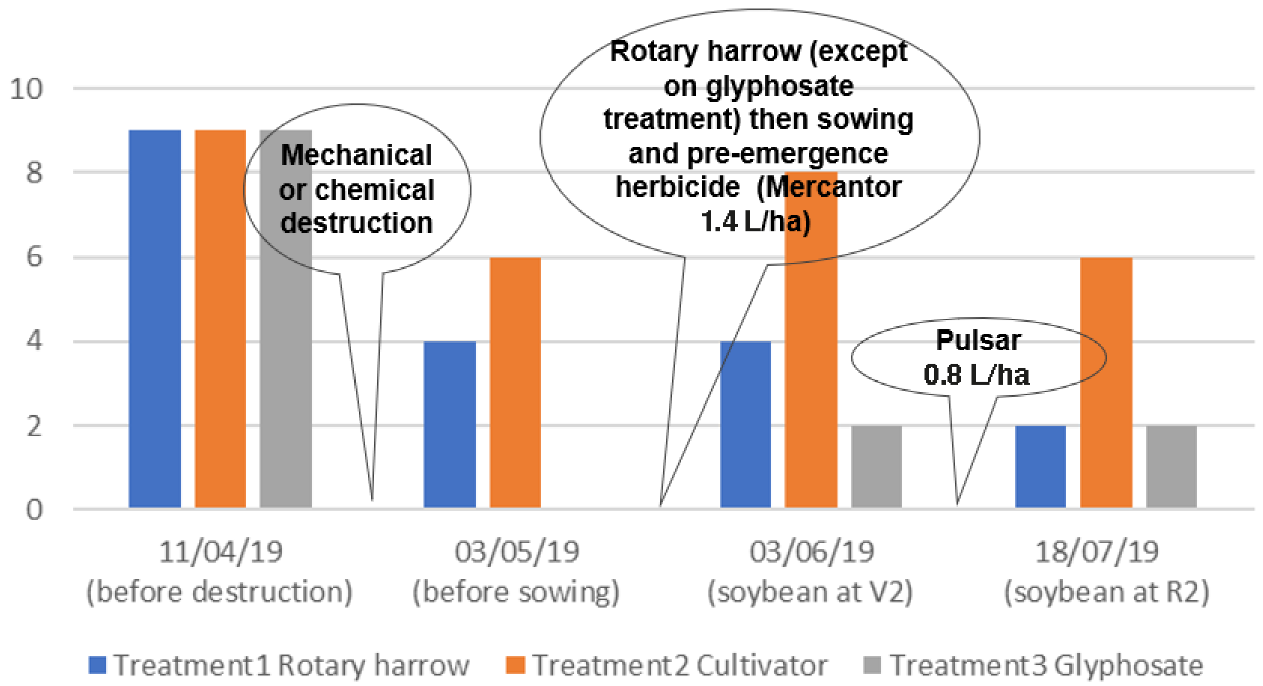



**Figure 34** - Visual observation on the Agen soybean trial (1 = very clean, 9 = full of weeds)

weed control. However, since some weeds ranged from the young seedling to the flowering stages in the rotary-harrow treatment, this meant that the tools did not completely destroy the weeds, and therefore weed surveys were conducted. In Treatment 2, the weed stage was mostly at the shot-blossom or flowering stages, which meant that weed control was not very effective. In Treatment 3, only a few plants were in the shot-bloom and flowering stages, with most being in the young or adult stages. The efficacy of this treatment was thus good according to the broadleaf-weed surveys afterwards.

Soybean establishment quality (crop stand):

Soil preparation was carried out in good conditions and was homogeneous. Heterogeneity in population was minimal and negligible.

### DIJON TRIAL

The weed flora was very diverse. Sowing was carried out at a depth of 2-3 cm in all three treatments. The soil was dry at 2 cm and cool-to-wet underneath.
The herbicide treatments on the trial were as follows:
- 16 May 2019: Prowl 400 (pendimethalin) 1.2L/ha, Mercantor Gold (s-metolachlor) 1.4L/ha
- 13 June 2019: Pulsar (imazamox) at 0.6L/ha at the V2-V3 stage of soybean to begin control of well-developed weeds.
- 20 June 2019: Pulsar (imazamox) at 0.6L/ha at the V3-V4 stage of soybean + new emergence of cotyledon soybean, to finish destroying well-developed weeds and new emergence following the rains that fell between 9 and 15 June 2019.

Note that PULSAR 40 applications showed symptoms of phytotoxicity on soybean with leaf yellowing and soybean compaction.

Soybean establishment quality (seedbed characterization + crop stand):
Seedbed characterization: soil-seed contact was good in all treatments. However, surface clod size differed according to the treatment: the glyphosate and harrow treatments had identically sized clods (from 1 to 5 cm); and the vibrocultivator treatment had surface clod sizes ranging from 2 to 10 cm. Nevertheless, fine soil was observed at seed level for this treatment.
Emergence took place in two waves, the second of which was after a rainy spell between 9 and 15 June, resulting in different stages (from V1 to V4) at the time of counting.

Soybean stand:
This count was carried out on 24 June 2019 at stages V4 (first emergence date) and V1 (second emergence date).

| Code | Name | Treatments & Dates |
|---|---|---|
| 1 | Destruction with soil tillage tool | Vibrocultivator: 7 May |
| 2 | Destruction with another soil tillage tool | Tine harrowing: 13 May |
| 3 | Farmer 's treatment (glyphosate) | Glyphosate 3 L/ha: 10 May |

**Table 17** - Scheme of the Dijon trial

| Count at V1 to V4 stages | Soybeans/m² |
|---|---|
| Treatment 1 (vibrocultivator) | 34.6 |
| Treatment 2 (tine harrowing) | 44.2 |
| Treatment 3 (glyphosate) | 37.5 |

**Table 18** - Soybean plants per m$^2$ in the Dijon trial

# UNITED KINGDOM

# EXPERIMENTAL TRIALS AT NIAB

*The NIAB Group is the UK's fastest growing crop science organisation, having trebled in size over the past decade through a strategic programme of investment, merger and acquisition. NIAB's headquarters is based in Cambridge, with regional centres across the midlands, eastern England and the South, and has farmer membership across the country. NIAB works with a network of scientific partnerships and collaborates with leading commercial and research organisations in the UK, Europe and globally. IWMPRAISE research has been conducted at NIAB Cambridge and East Malling.*


**Figure 1** - NIAB's headquarters and Regional Centres

**Address: NIAB**
**93 Lawrence Weaver Road**
**Cambridge**
**CB3 0LE, UK**
**GPS co-ordinates: 52.2244721, 0.096511**

**For further information and guided visits please contact:**
**John Cussans**
**e-mail: john.cussans@niab.com**
**tel: +44 1223342329**

4 experimental trials have taken place at NIAB within Work Package 3 (WP3 - Annual Narrow Row Crops) of the IWMPRAISE project:

1) The potential of shallow row cultivation to replace glyphosate ahead of spring cropping.
2) The effect of drilling date on black-grass (*Alopecurus myosuroides*) control in cereals.
3) Interactions between drilling date, establishment and herbicide on black-grass management in winter bean crops.
4) Cultural control of Italian ryegrass (*Lolium multiflorum*).

## WP3 – EXPERIMENT 1: THE POTENTIAL OF SHALLOW ROW CULTIVATION TO REPLACE GLYPHOSATE AHEAD OF SPRING CROPPING

### Objectives

- Explore the potential of shallow cultivation treatments to reduce the reliance on glyphosate for the establishment of spring crops within the confines of conservation agriculture (CA)
- Understand if repeated shallow cultivations are capable of influencing black-grass (*A. myosuroides*) emergence and have a tangible effect in future seasons.

### Materials and Methods

The experiment began in autumn 2018 in a field sown with a Spring Barley (variety: RGT Planet), with a total of 10 treatments (Table 1). There were 3 replicate plots per treatment, each measuring 12x6 m (total area = 2160 $m^2$). The shallow-cultivation consisted of a set of tightly packed discs, followed by a packer, operating at a soil depth of 40-50 mm. This was to help stimulate the germination of weed seeds within the upper soil profile, without bringing more seeds to the surface. Glyphosate was applied at a rate of 3 l/ha, with 0.1% volume of Companion Gold water buffer. Black-grass abundance (seedlings/$m^2$) and fecundity (heads/$m^2$) was assessed in the spring at crop emergence and summer 2019 respectively.

### Results

#### *Performance of glyphosate*

Glyphosate was successful in controlling spring black-grass flushes (Figure 2) and also reducing summer head counts (Figure 3). There was no additional benefit where two applications of glyphosate were used for black-grass control compared with a single application, provided that the rate used is at least 3 l/ha and there is no soil movement between application and drilling.

#### *Performance of shallow cultivation*

Shallow cultivations on their own were unable to control black-grass abundance (Figure 2) or reduce head counts (Figure 3) where black-grass had emerged prior to drilling, regardless of intensity or regularity of passes. However some evidence suggests that if carried out in the autumn it is possible for shallow cultivations to contribute to black-grass mortality.

| Treatment | Autumn | Late February | Prior to Drilling |
|---|---|---|---|
| 1 | Full inversion | | Glyphosate (3 l/ha) (1080g/ha) |
| 2 | | | Glyphosate |
| 3 | | Shallow cultivation | Glyphosate |
| 4 | Shallow cultivation | | Glyphosate |
| 5 | | | Shallow cultivation |
| 6 | | Shallow cultivation | Shallow cultivation |
| 7 | Shallow cultivation | | Shallow cultivation |
| 8 | | Glyphosate | Glyphosate |
| 9 | Shallow cultivation | Shallow cultivation | Glyphosate |
| 10 | Shallow cultivation | Shallow cultivation | Shallow cultivation |

**Table 1** - Treatments for experiment 1

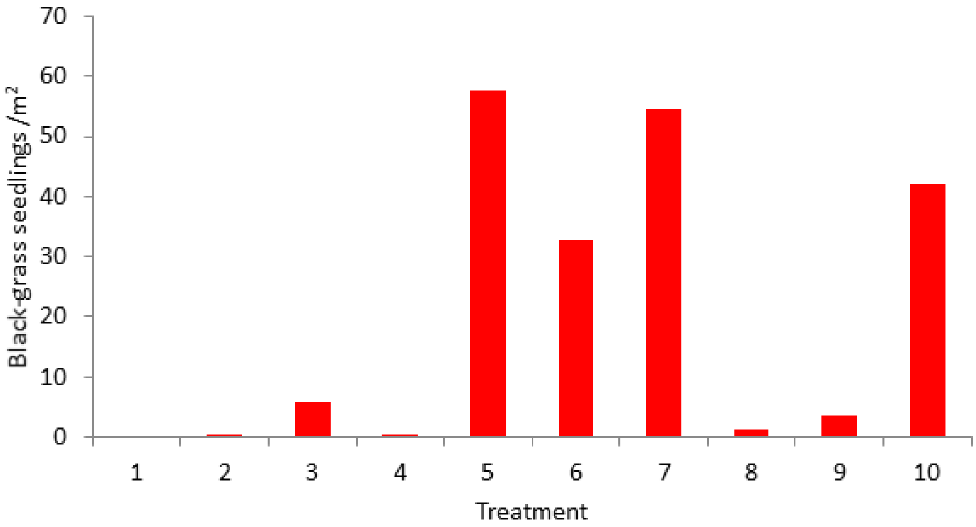



**Figure 2** - Mean black-grass seedlings/m$^2$ from treatment plots (n=3); see Table 1 for Treatment details

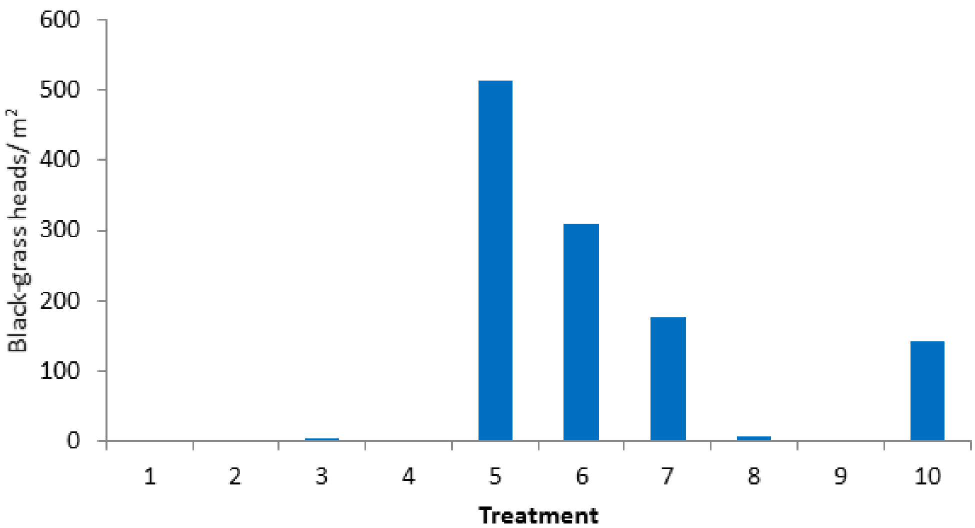



**Figure 3** - Mean black-grass head counts/m$^2$ (n=3); see Table 1 for Treatment details.


## Summary

- The use of pre-drilling glyphosate enabled the establishment of a spring cereal crop with minimal black-grass pressure.
- Increasing the number of cultivations correlated with better control; however in even the best-case scenario (without glyphosate application) the fecundity of black-grass was still high (143 heads/ m$^2$).
- Using a shallow cultivation in the autumn has potential to reduce the reliance on glyphosate, whilst simultaneously encouraging the germination of more black-grass in the soil surface.
- The success of shallow cultivation was strongly influenced by soil conditions; with high soil moisture but low future rainfall seen as ideal.

## WP3 – EXPERIMENT 2: THE EFFECT OF DRILLING DATE ON BLACK-GRASS (*ALOPECURUS MYOSUROIDES*) CONTROL IN CEREALS

### Objectives

- Demonstrate that although spring cropping is an effective black-grass management tool, variable results are possible.
- Evaluate the requirement for pre-emergence herbicides in spring barley crops.

### Materials and Methods

The experiment began in early spring 2019 in fields sown with either Spring Barley (RGT Planet) or Spring Oats (WPB Eylann), with a total of 21 treatments

| | Crop | Drilling Date | Herbicide | |
|---|---|---|---|---|
| | | | Pre-emergence | Post-emergence |
| 1 | Spring Oats | Late January/Early February | Untreated | |
| 2 | | | Hurricane (0.25 l/ha) (active ingredient: diflufenican, 125g/ha) | |
| 3 | Spring Barley | | Untreated | |
| 4 | | | Hurricane (0.25 l/ha) | |
| 5 | | | Liberator (0.3 l/ha) (a.i: flufenocet, 120g/ha + diflufenican, 10g/ha) | |
| 6 | | | Liberator (0.3 l/ha) +<br>Crystal (2 l/ha) (a.i.: flufenocet, 120g/ha + pendimethalin, 600g/ha) | |
| 7 | | | Liberator (0.3 l/ha) | Crystal (2 l/ha) |
| 8 | Spring Oats | Late February | Untreated | |
| 9 | | | Hurricane (0.25 l/ha) | |
| 10 | Spring Barley | | Untreated | |
| 11 | | | Hurricane (0.25 l/ha) | |
| 12 | | | Liberator (0.3 l/ha) | |
| 13 | | | Liberator (0.3 l/ha) +<br>Crystal (2 l/ha) | |
| 14 | | | Liberator (0.3 l/ha) | Crystal (2 l/ha) |
| 15 | Spring Oats | March | Untreated | |
| 16 | | | Hurricane (0.25 l/ha) | |
| 17 | Spring Barley | | Untreated | |
| 18 | | | Hurricane (0.25 l/ha) | |
| 19 | | | Liberator (0.3 l/ha) | |
| 20 | | | Liberator (0.3 l/ha) +<br>Crystal (2 l/ha) | |
| 21 | | | Liberator (0.3 l/ha) | Crystal (2 l/ha) |

**Table 2** - Treatments for experiment 2

divided across sowing dates and herbicide regimes (Table 2). There were 3 replicate plots per treatment, each measuring 12 x 2 m (total area = 1512 m$^2$). Herbicide treatments consisted of Hurricane (diflufenican), Liberator (flufenocet and diflufenican) and Crystal (flufenocet and pendimethalin), either singly or in combination.

For each sowing date, black-grass seedling counts were made at the time of post-emergence applications and used to determine percent control of black-grass. Black-grass head counts /m$^2$ were also determined for all treatments in June 2019 and crop yield (t/ha) was determined in August 2019.

## Results

### *Performance of sowing date and herbicide*

Relative to untreated plots, there was generally a strong effect of delayed sowings on black-grass seedling control (Figure 4) and summer head counts (Figure 5). However the level of control due to herbicides was variable; this may be due to the drying out of soil in February, which reduces the efficacy of actives such as flufenacet, pendimethalin or diflufenican.

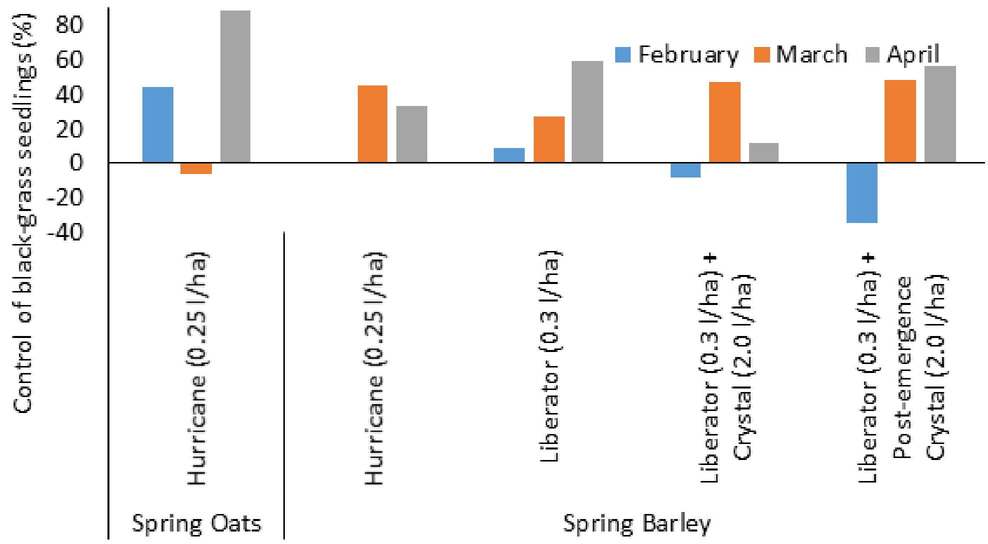



**Figure 4** - Mean control (%) of black-grass seedlings compared to untreated controls (n=3)

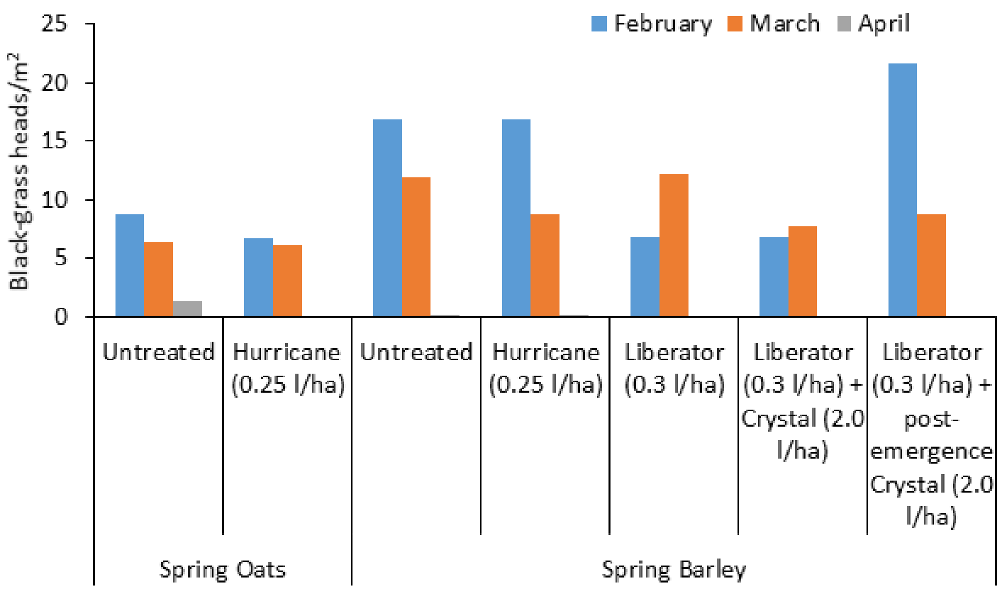



**Figure 5** - June mean black-grass head counts/m$^2$ (n=3)

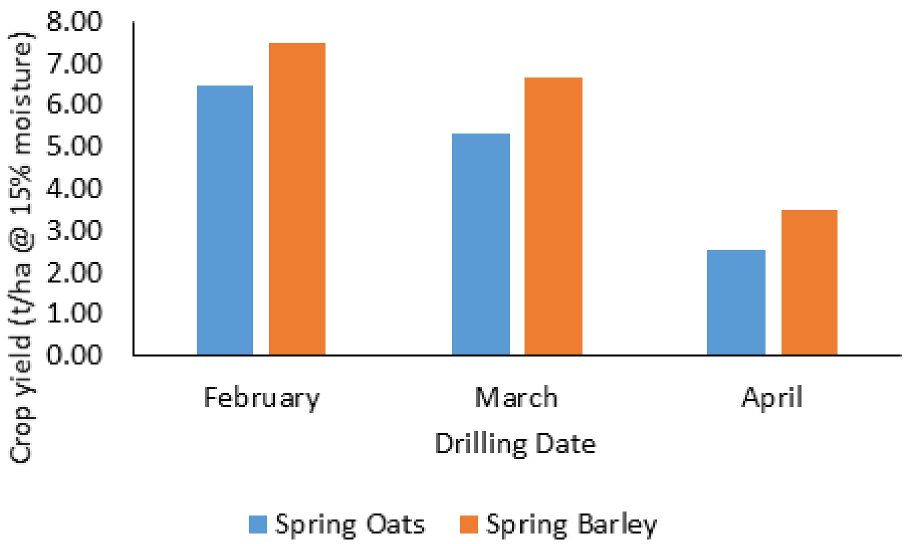



**Figure 6** - Yield data (t/ha) for Spring Oats and Spring Barley treated with 0.25 l/ha hurricane (n=3)

### *Performance of crop species*

Spring oats were the most effective of the two species in controlling black-grass, with the innate competitiveness of the crop reducing black-grass burden substantially. However, spring barley was consistently the higher yielding across all sowing dates under the same conditions (Figure 6).

### Summary

- Drilling date can have a large effect on black-grass abundance/summer fecundity, with earlier sown crops having much higher burdens.
- However, there are yield penalties associated with later drilling. These are minimal in spring barley between February and March but increase in April.
- Spring oats are more competitive than spring barley against black-grass, but are more susceptible to yield penalties.
- Using small amounts of herbicide (Liberator (0.3 l/ha) can be effective in early sown crops, however if drilling is later than February then applications are not necessary.

## WP3 – EXPERIMENT 3: INTERACTIONS BETWEEN DRILLING DATE, CULTIVATION AND HERBICIDE ON BLACK-GRASS MANAGEMENT IN WINTER BEAN

### Objectives

- Demonstrate how the efficacy of propyzamide (Kerb Flo 500) is influenced by crop establishment approach in winter beans.
- Evaluate the interaction between drilling date and cultivation approach on black-grass (*A. myosuorides*) management in winter beans.
- Assess the risks and rewards of an approach combining a delayed application of Kerb Flo 500 with glyphosate (Rosate).

### Materials and Methods

The experiment began in autumn 2018, in a field sown with winter beans (*Vicia faba*; variety Tundra), using 12 treatments across sowing date, cultivation and herbicide options (Table 3). The experiment was conducted with 3 replicates per treatment (n=3), in 12 x 2 m plots (total area= 864 $m^2$). Black-grass seedling counts were determined at post-emergence in autumn for each treatment. Black-grass fecundity (head counts/$m^2$) was also assessed for all treatments in June 2019.

### Results

### *Performance of drilling date, herbicide and cultivation*

There was a strong interactive effect of drilling date, herbicide usage and cultivation technique on black-grass control. The largest effect was due to drilling date, with plots sown at a later drilling in November having much lower black-grass seedling burden in spring (Figure 7) and head count in summer (Figure 8). The effect of cultivation and herbicide were more inconsistent. The largest difference due to cultivation technique was found in untreated plots in October, with a much lower burden following non-inversion tillage compared with direct drill (no till) (Figure 7). However non-inversion tillage produced

| Treatment | Drilling Date | Cultivation | Herbicide |
|---|---|---|---|
| 1 | October | No-Till (direct drill) | Untreated |
| 2 | | | Pre-em:<br>Kerb Flo 500 (1.7 l/ha) (active ingredient: propyzamide; 680g/ha) |
| 3 | | | Delayed:<br>Kerb Flo 500 (1.7 l/ha) + Rosate (3 l/ha) + Companion Gold (0.5 l/ha) |
| 4 | | Non-Inversion | Untreated |
| 5 | | | Pre-em:<br>Kerb Flo 500 (1.7 l/ha) |
| 6 | | | Delayed:<br>Kerb Flo 500 (1.7 l/ha) + Rosate (3 l/ha) + Companion Gold (0.5 l/ha) |
| 7 | November | No-Till | Untreated |
| 8 | | | Pre-em:<br>Kerb Flo 500 (1.7 l/ha) |
| 9 | | | Delayed:<br>Kerb Flo 500 (1.7 l/ha) + Rosate (3 l/ha) + Companion Gold (0.5 l/ha) |
| 10 | | Non-Inversion | Untreated |
| 11 | | | Pre-em:<br>Kerb Flo 500 (1.7 l/ha) |
| 12 | | | Delayed:<br>Kerb Flo 500 (1.7 l/ha) + Rosate (3 l/ha) + Companion Gold (0.5 l/ha) |

**Table 3** - Treatments for experiment 3

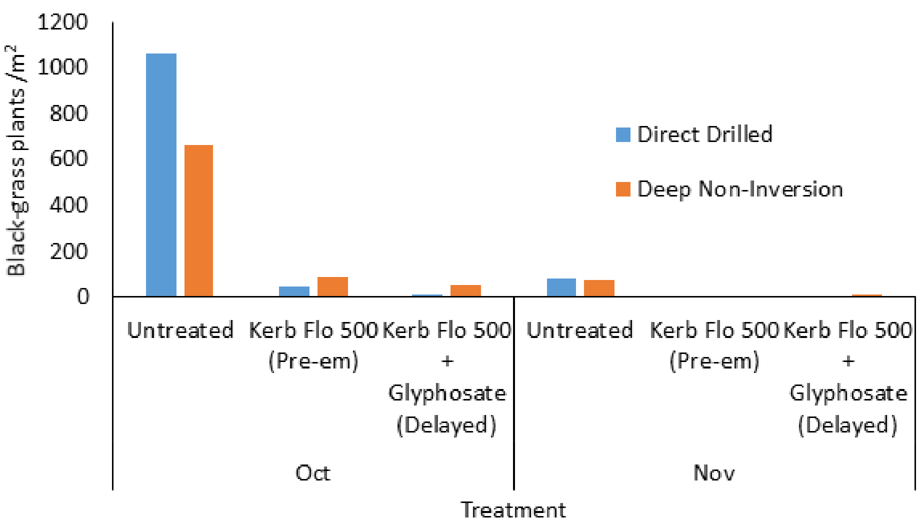



**Figure 7** - Mean autumn black-grass seedling counts (n=3) for treatments across sowing dates, cultivation techniques and herbicide regime

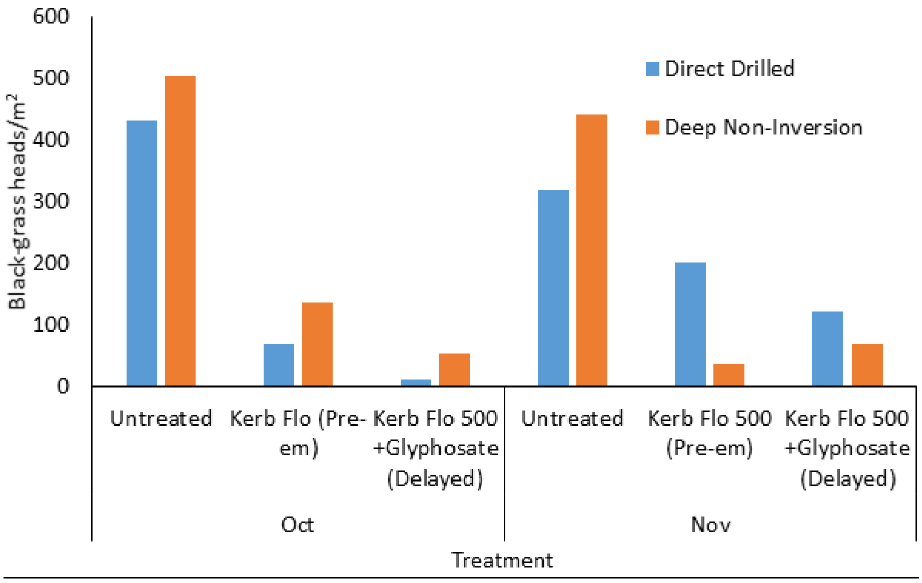



**Figure 8** - Mean black-grass head counts (n=3) for treatments across sowing dates, cultivation techniques and herbicide regime

a higher black-grass head count in untreated plots or in plots sown in October (Figure 8). In general, delayed application of propyzamide and additional treatment with glyphosate after sowing produced additive benefits in reducing black-grass seedling burden (Figure 7) and head counts (Figure 8).

### Summary

- In almost every situation, drilling crops later has a big potential to reduce the number of black-grass plants that emerge in the crop. However the weeds that do emerge must be controlled in the crop. The crop that is established must also be vigorous and competitive to effectively suppress weed growth.
- Lower impact no-till establishment (direct drill) improved the efficacy of propyzamide (Kerb Flo 500) to control black-grass plants, but only at the earlier sowing date.
- The trial tested an approach of delayed herbicide application, and combining Kerb Flo 500 (1.7 l/ha) with an effective dose of glyphosate (1080g active ingredient/ha). This did provide additional control of black-grass plants and heads but was risky in some specific situations. For example, at the earlier drilling date where black-grass plant density was highest, there was a consistent improvement. However, using this approach on a later-drilled crop using deep non-inversion cultivation subsequently increased black-grass heads.
- The effectiveness of delayed drilling as a component of black-grass control was almost entirely lost when head density was considered. This is because of a lack of weed suppression from the crop. The effect of reduced crop competition at the later drilling date was much worse in the no-till crop than when deep non-inversion cultivation was used.
- Lower-impact no-till establishment produced a good crop and was effective at reducing black-grass plant and head density in combination with herbicide but only at the first drilling date.

## WP3 – EXPERIMENT 4: CULTURAL CONTROL OF ITALIAN RYEGRASS (LOLIUM MULTIFLORUM)

### Objectives

- To compare the basic cultural control options for Italian ryegrass (*Lolium multiflorum*).

### Materials and methods

The experiment began in July 2018 in a field matrix design comprising 18 treatments. The experiment tested 3 different cultivation strategies (plough, deep non-inversion and minimum tillage) on winter wheat (September/October sown) and spring wheat, and with or without herbicide treatment (Figure 9; Table 4). Treatments were replicated 3 times in 9x2m plots (total area 1944m$^2$). Ryegrass plant counts were counted at the time of emergence for each sowing date and percent control of cultural controls was determined relative to herbicide treated plots.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Ploughed** | Early drilled | | | | | | |
| | Late drilled | | | | | | |
| | Spring drilled | | | | | | |
| **Min-Till** | Early drilled | | | | | | |
| | Late drilled | | | | | | |
| | Spring drilled | | | | | | |
| **Direct Drill** | Early drilled | | | | | | |
| | Late drilled | | | | | | |
| | Spring drilled | | | | | | |
| | | Treated | Untreated | Treated | Untreated | Treated | Untreated |

**Figure 9** - Treatment matrix for testing ryegrass control

| Timing | Pre-em | Post-em [and timing] |
|---|---|---|
| Herbicide | Liberator (0.6 l/ha) (active ingredient: flufenocet, 240 g/ha + diflufenican, 20 g/ha)<br><br>Defy (4.0 l/ha) (a.i: prosulfocarb, 3200 g/ha) | Atlantis OD (1.2 l/ha) (a.i: mesosulfuron-methyl, 12 g/ha + iodosulfuron-methyl-sodium, 2.2 g/ha) +<br><br>Biopower adjuvant (1.0 l/ha) +<br><br>Stomp Aqua (2.6 l/ha) (a.i: pendimethalin, 1183 g/ha)<br><br>[1-2 lvs of the weed] |

**Table 4** - Herbicide regime used for treated plots in experiment 4

## Results

### *Performance of cultural controls*

There was a strong negative association between ryegrass population and sowing date, with plots having a much lower burden if sown in late autumn or spring (Figure 10). Ploughing was most effective at supressing the ryegrass population, followed by deep non-inversion. Direct drilling (no-till) was the least effective cultivation technique, and the benefit derived from later sowing dates was much smaller (Figure 10). Relative to herbicide-treated plots, Ploughing produced the best percent control of ryegrass plants, and direct drilling was least effective (Figure 11). Plots sown in late autumn were consistent in their level of control, irrespective of cultivation technique (Figure 10), whilst those sown in early autumn produced the worst outcomes.

## Summary

- As with other problematic grass weeds, there is a general advantage to later sowing dates when considering Italian ryegrass (*L. multiflorum*). However, a yield penalty maybe attached to later sowings.
- Ploughing was the most effective cultivation technique in controlling ryegrass numbers and produced the best performance relative to herbicide.
- The conservation agriculture approach (direct drill) was least effective in controlling ryegrass, and benefits due to sowing date were reduced.

Future developments

Future work at NIAB for WP3 will focus on larger-scale system wide changes. For example, research

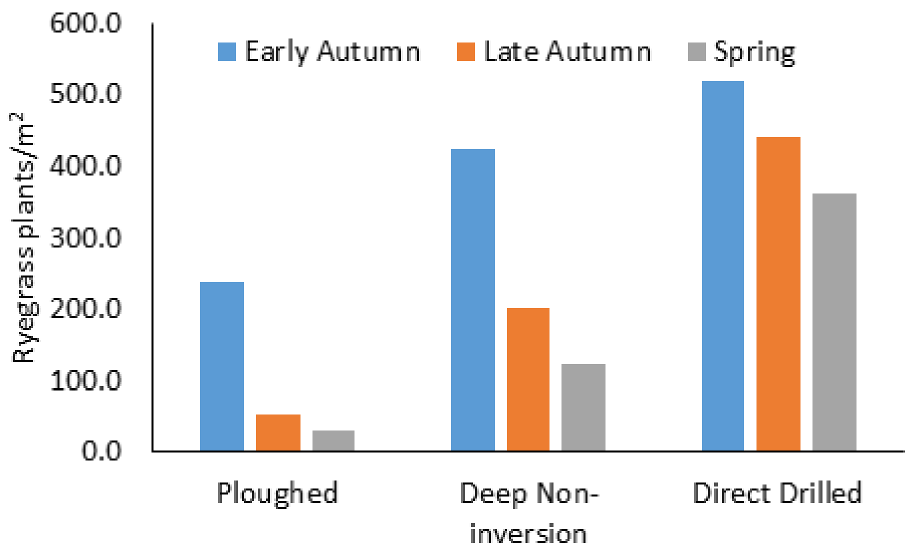



**Figure 10** - Mean ryegrass populations/m² in untreated plots at time of crop emergence (n=3)

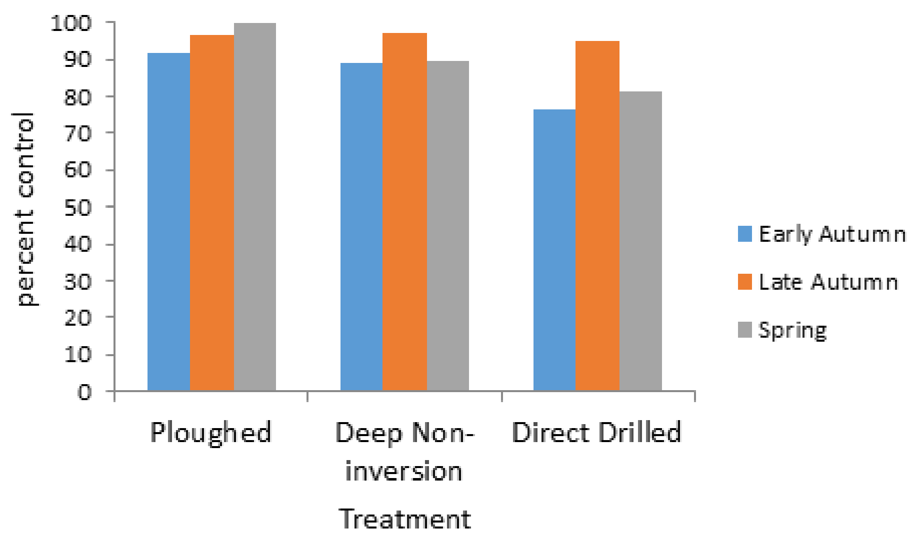



**Figure 11** - Mean percent control of ryegrass plants, relative to herbicide-treated control plots (n=3)

into running crops using 3 systems: business as usual, pure conservation agriculture (no till, cover year-round, bi-cropping, rotational diversity) and adopt and adapt (adopt as many conservation practices as possible).

## WP6 – EXPERIMENTAL TRIAL ON IWM STRATEGIES IN VINEYARDS

IWMPRAISE experimental trials at NIAB East Malling within Work Package 6 (WP6 - Woody Perennial crops):

**1. Newly planted and established wine grapevines**

**Objectives**

In conjunction with two industry partners: the mechanical engineering company Clemens GmbH and the seed merchant Cotswold Seeds, the trials at

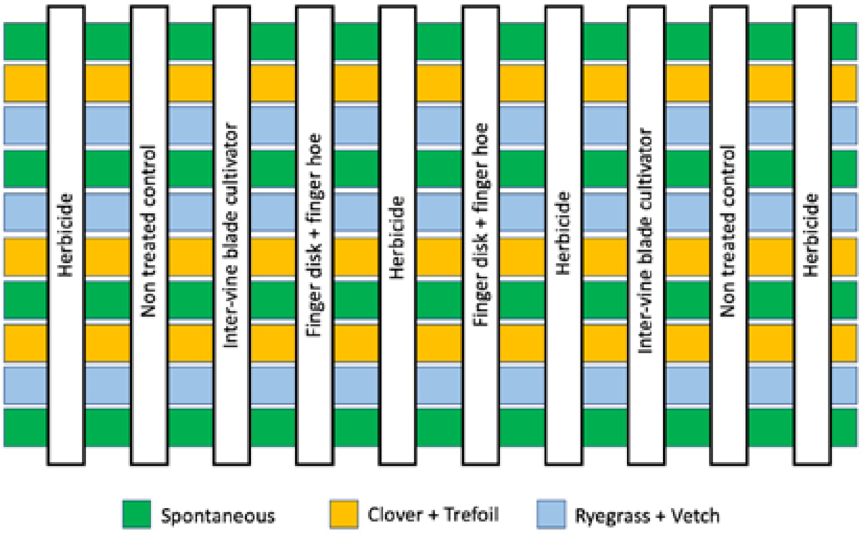



**Figure 12** - Experimental scheme of the trial


**Figure 13** - Experimental vineyard at East Malling

NIAB EMR will assess the efficacy of mechanical and botanical alternatives to chemical weed control in the rows and alleys respectively.
The effect of two types of mechanical weeder (blade and serrated disc) on weeds arising in the rows will be tested against grower standard practice applications of herbicide. In the alleys, two cover crop mixes will be compared with local, naturally occurring vegetation (i.e. spontaneous weeds). One cover crop mix contains clover and the other a vetch-rye-grass mix. In the vineyard, in situ sensors monitor the effects of mechanical weeding and cover crops on soil conditions (water content as matric potential and temperature) and aboveground microclimate (air temperature, humidity and light intensity).
The impact of the integrated weed management strategies on vegetative growth and crop yield (and for vines only, fruit quality) will be determined and incorporated into a cost-benefit analysis of the economics. In 2020 a commercial vineyard joined the project and will demonstrate the reciprocal effects of chemical and mechanical weeding on crop performance as managed by a grower at the Welsh border.

### Materials and methods

The trial started in early summer 2018 at the NIAB EMR research vineyard, a four-year old irrigated vineyard and a newly planted vineyard.
The cover crops and all the sensors were installed and first year results were obtained from June 2018 to November 2019. Botanical surveys determine

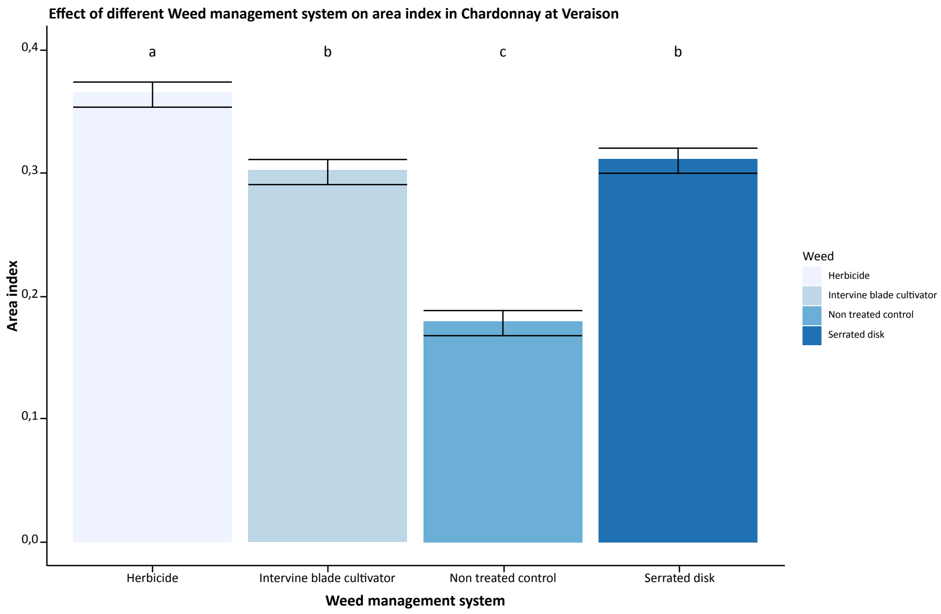



**Figure 14** - Effect of different weed management system on leaf wall area in Chardonnay at veraison

weed species identity and abundance in the rows three times a year. Images taken by a camera are used to estimate the biomass of weeds and cover crops in the rows and alleys, respectively, based on the normalised difference vegetation index (NDVI) of spectral reflectance measurements. This will be combined with a LIDAR scan of the vines canopy in order to link weeds abundance with grapevine rate of growth.
The experiment consists in 30 blocks of 5 plants per weeding solution combined with 3 blocks of 50 plants per cover crop mix (Figure 12).
Experimental validation for the second-year trials are running from April 2019. Pre-control samplings are now completed and they are in progress at the experimental vineyard. The impact of the strategies on crop performance is going to be assessed from 2020 as the vineyard becomes mature.
Following the established methodology, weeds are evaluated at 3 different moments: January, before applying the weed control methods and April-May, 3-4 weeks after applying the control methods, then at veraison stage (August). Main assessments include:

- **Weed data in the inter-row (from 2020) and intra-row spacing: plant density, biomass production.** Additionally, the weed species diversity during the growing season 2018/2019 was assessed and plant density data is going to be treated as presented in this report for southern Spain using the following indices: species richness (S), the exponent of the Shannon-Wiener index, (expH’) and Pielou eveness index (J’)
- **Vines yield (t/ha) and quality (from 2020)** (Sugars, acids, Yeast Available Nitrogen)
- **Soil analyses:** 10 soil fertility samples (N, P, K, MO and organic C) per treatment are going to be extracted from 0-30 cm depth during autumn in southern Spain (4 soil samples in the north), each of which consisted of 2 sub-samples from two positions located in a fixed pattern across each sampling area and block
- **Weather data:** weather data are obtained from Weather Stations located in the vineyard.

## Preliminary results

### *Effect of weed management strategies on vegetative growth (2019)*

Early results show that despite no differences at flowering time (June) were observed between the different treatments, weed competition was only detrimental to vines vegetative growth later in the season when these reached the veraison stage in August 2019. The three weeding solutions assessed in the project (herbicide vs blade vs serrated disk) did not differ in terms of leaf wall area as measured with a LiDAR system on 100 vines per treatment. The Non Treated Control (NTC) however showed a significant reduction in leaf area by 20%. This reduction in growth seems to be the result of weed competition for water and nutrients with a 30% reduction in Nitrogen Balance Index (NBI) at veraison for the NTC. This result is going to be combined with the soil moisture and dynamic growth records at the end of the experiment. Interestingly, both

| Aug-19 | Herbicide | | | Non treated control | | | Serrated disk | | | Blade cultivator | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Clover | Spontaneous | Vetch | Clover | Spontaneous | Vetch | Clover | Spontaneous | Vetch | Clover | Spontaneous | Vetch |
| Amaranthaceae | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Asteraceae | 36 | 20 | 18 | 52 | 83 | 78 | 13 | 24 | 15 | 59 | 39 | 48 |
| Boraginaceae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Brassicaceae | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 4 | 0 | 0 | 0 | 0 |
| Caryophyllaceae | 6 | 0 | 9 | 6 | 1 | 0 | 45 | 9 | 13 | 6 | 18 | 15 |
| Fabaceae | 0 | 0 | 0 | 17 | 15 | 35 | 0 | 5 | 12 | 5 | 0 | 3 |
| Geraniaceae | 1 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Lamiaceae | 11 | 35 | 8 | 3 | 0 | 2 | 7 | 41 | 13 | 18 | 5 | 59 |
| Malvaceae | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| Onagraceae | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Plantaginaceae | 0 | 0 | 0 | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Poaceae | 6 | 0 | 17 | 40 | 7 | 11 | 5 | 27 | 6 | 7 | 0 | 17 |
| Polygonaceae | 0 | 2 | 2 | 2 | 4 | 11 | 3 | 2 | 1 | 1 | 5 | 3 |
| Ranunculaceae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rosaceae | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Solanaceae | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 6 | 0 | 0 |
| **Total** | **61** | **59** | **54** | **122** | **114** | **145** | **76** | **114** | **63** | **102** | **67** | **146** |

**Table 5** – Families of weeds in the row under the vines found on the 19th of August 2019

| Jan-20 | Herbicide | | | Non treated control | | | Serrated disk | | | Blade cultivator | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Clover | Spontaneous | Vetch | Clover | Spontaneous | Vetch | Clover | Spontaneous | Vetch | Clover | Spontaneous | Vetch |
| Amaranthaceae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Asteraceae | 29 | 33 | 48 | 49 | 36 | 20 | 29 | 30 | 23 | 12 | 28 | 13 |
| Boraginaceae | 30 | 88 | 108 | 4 | 6 | 2 | 14 | 23 | 21 | 0 | 18 | 9 |
| Brassicaceae | 13 | 1 | 0 | 0 | 7 | 0 | 0 | 12 | 1 | 1 | 1 | 1 |
| Caryophyllaceae | 1 | 1 | 4 | 0 | 0 | 4 | 0 | 1 | 4 | 1 | 5 | 0 |
| Fabaceae | 12 | 0 | 0 | 30 | 56 | 60 | 2 | 0 | 0 | 3 | 0 | 0 |
| Geraniaceae | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| Lamiaceae | 10 | 8 | 4 | 1 | 6 | 10 | 19 | 30 | 18 | 30 | 6 | 4 |
| Malvaceae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Onagraceae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Plantaginaceae | 2 | 4 | 1 | 2 | 8 | 3 | 32 | 12 | 18 | 17 | 19 | 27 |
| Poaceae | 37 | 23 | 15 | 27 | 18 | 17 | 10 | 6 | 19 | 5 | 14 | 16 |
| Polygonaceae | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 0 |
| Ranunculaceae | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rosaceae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Solanaceae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total** | **134** | **158** | **180** | **117** | **137** | **119** | **107** | **116** | **104** | **69** | **93** | **72** |

**Table 6** – Families of weeds in the row under the vines found on the 20th of January 2020

mechanical weeding technologies assessed resulted in a reduction in NBI when compared to the herbicide treatment, hence not resulting in a decrease in vegetative growth.

### *Weed flora and abundance*

Flora composition assessments have been carried in winter with the complete description of the species present in the seed bank. At flowering and for each treatment, an assessment of the species growing under the vines has been carried out, showing differences in the families and abundance according to the weeding solution. These results are still preliminary as completed in August at the veraison stage and in January 2019 when the vines were dormant. Next assessment is going to be carried in April 2020 at the start of the growing season and will allow the description dynamics of weed population response to the weed management solution. Inter-row cover crop flora description is going to be carried, allowing the assessment of cover-crop sustainability in our growing conditions.

### Future developments

The impact of the integrated weed management strategies on crop yield and fruit quality will be determined first in 2020 and incorporated into a cost-benefit analysis of the economics. This study is going to be carried with the contribution of local growers already using mechanical weeders in their vineyard.

# THE NETHERLANDS

# EXPERIMENTAL TRIALS MANAGED BY WAGENINGEN UNIVERSITY & RESEARCH

*The IWMPRAISE experimental location is in the polders in the north of the Netherlands; it is one of the experimental farms of Wageningen University and Research (WUR) and is located in Lelystad. It is an arable cropping location, with 700 ha on clay soil, and has the use of several high-tech experimental field tools.*

**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**

**For guided visits please contact:**
**Hilfred Huiting**
**e-mail: hilfred.huiting@wur.nl**
**tel. +31 320 291339**

**Two experiments are in place for the IWMPRAISE WP4 in the Dutch national cluster:**
**1. Annual row crops - arable & vegetable crops**
**2. Annual row crops - maize**
Both experiments are located in Lelystad, at the WUR experimental research farm.

## EXPERIMENT ANNUAL ROW CROPS – ARABLE & VEGETABLE CROPS

This experiment was established in the spring of 2018. Two different weed management strategies are compared:
A) a conventional four-year rotation, based on targeted control with herbicides; and
B) a diversified system using an eight-year rotation with optimal variety choice, targeted weed management, and variable targeted weed control, all using state-of-the-art monitoring and evaluation systems.

The crops in the four-year rotation are potato, seed onion, sugar beet, and spring barley. The crops in the eight-year rotation are spring barley, seed onion, grass clover, carrot, potato, cabbage, sugar beet, and autumn cover crops. Potato is grown twice in the eight-year rotation due to the high local economic value of this cash crop. The experiment has three replicates.

Evaluation of the strategies in the winter of 2018 did not lead to changes in the weed management approach in 2019. The diversified eight-year system is based on a combined use of tactics from the following IWM pillars:

**Figure 1** - Experimental layout in 2019

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

I. Diverse systems increase or equal crop yields or profitability compared to conventional systems. In this experiment, we include winter cover crops, carrot and cabbage in the traditional rotation of four crops, as well as other crops, such as cabbage (late sowing date: possibilities for stale seed bed), winter cover crops (improving soil structure & provision of soil coverage to prevent emergence and establishment of species such as *Stellaria media* and *Poa annua*) and carrots (mechanical control options) to diversify the weed management strategy.
II. Suppressive and tolerant varieties when available. In the diversified rotation crop, varieties with early soil coverage are chosen to improve the crop's ability to compete for light.
III. Crop management, enhancing crop growth (nutrient placement, sowing depth, transplanting, tillage systems). Stale seedbeds are used in the diversified eight-year system.
IV. Targeted control tactics to disturb the weeds' life-cycle (e.g. flame weeding, bio-control, targeted herbicide application [site specific]) Mechanical weed control is applied (harrow, hoe, finger weeder, torsion weeder), potato haulm killing with traditional herbicides is replaced with herbicides of natural origin.
V. Monitoring & evaluation (e.g. innovative sensing technologies and Decision Support Systems -DSS).

Weeds are monitored visually (counts) to determine densities and whether controls are needed.

### Results 2019

Changes in the size and composition of the weed seed bank are being used as a parameter for the effects of the IWM system. The weed seed bank was determined at the start of the experiment and was determined again at the end of the trial. Weed density was determined in all crops during the season and used to compare the two weed management strategies. The number of weeds in the IWM strategies appeared to be slightly higher compared to the chemically based reference. However, there were no significant differences between the reference and the IWM strategy.

Onion IWM

Onion reference

Carrot IWM

Carrot reference

Potato IWM

Potato reference

**Figures 2, 3, 4, 5, 6 and 7** - Comparison between Reference and IWM crops

## ANNUAL ROW CROPS: MAIZE AFTER MAIZE CROPPING SYSTEMS

In this long-term experiment, established in 2009, we are investigating the effect of four tillage systems on the weed population in a maize monoculture. Two varieties of maize are being tested: normal and short season. Two weed management strategies are being used: a herbicide-based system and one based on mechanical control. The experiment has three replicates.

In 2019, we had a late start to the maize-growing season, as it started colder than normal and was warmer and dryer than usual in the summer.
Dry matter yield of silage maize was determined after harvest on 18 September 2019. The normal season cultivar (P8057) had a higher yield compared to the short season cultivar (Joy) independent of tillage and weed control strategies (Figure 9). Dry matter yield of the normal season cultivar was more or less similar between the various tillage types and weed control strategies. In the short season, cultivar dry matter yield was lower after deep tine cultivation of the soil

| I | | | | | II | | | | III | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | D | E | C | | E | A | C | | E | C | D | A |
| 19 M2-I | 30 M2-I | 50 M2-II | 57 M1-II | | 79 M1-I | 89 M2-II | 108 M1-II | | 130 M2-I | 140 M1-II | 159 M1-I | 179 M1-I |
| 18 M2-II | 28 M2-II | 49 M2-I | 56 M1-I | | 76 M1-II | 88 M2-I | 107 M1-I | | 129 M2-II | 139 M1-I | 157 M1-II | 178 M1-II |
| 15 M1-II | 23 M1-II | 44 M1-I | 53 M2-I | | 74 M2-II | 83 M1-II | 104 M2-I | | 124 M1-I | 135 M2-II | 154 M2-I | 175 M2-I |
| 11 M1-I | 21 M1-I | 43 M1-II | 51 M2-II | | 72 M2-I | 82 M1-I | 101 M2-II | | 121 M1-II | 133 M2-I | 152 M2-II | 171 M2-II |

**Figure 8** - Layout of the maize field trial at the experimental farm of WUR Field Crops, Lelystad, in 2019

| Code | Description | | | |
|---|---|---|---|---|
| | **Main cultivation** | **Sowing bed preparation** | **Sowing method** | **Remarks** |
| A | Plough Spring 25 cm | rotary harrow | conventional sowing | - |
| C | Deep tine cultivation | rotary cultivator | conventional 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 season 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 |

**Table 1** - Description of the three factors in the long-term maize field trial. Factors include soil tillage (A-E), maize cultivar (M1-M2) and weed control strategy (chemical or mechanical)

without seedbed preparation (E) compared to the other three tillage types. One possible explanation could be unfavourable sowing conditions after this type of tillage, resulting in poor germination and eventually a lower plant number.

In general, the strategy with ploughing as soil tillage and chemical weed control resulted in the lowest soil cover with weeds in both maize cultivars after the growing season (Figure 10).
All of the fields were treated with glyphosate before sowing. Chemical control consisted of two sprayings with a reduced dose of a mixture of herbicides in both cultivars. Mechanical control comprised harrowing twice and hoeing with finger weeding four times in the early cultivar, and harrowing once and hoeing with finger weeding three times in the late cultivar. Compared to other years, there were fewer possibilities for harrowing in the young maize because of dry weather and clods in the soil. To compensate for this, hoeing with finger weeding was carried out more frequently.
In the short season, when the cultivar was grown after tillage with the deep tine cultivator and rotary cultivar (C) or the strip rotary cultivator (D), soil cover with weeds was observed to be higher in the chemical weed control strategies than in the mechanical weed control strategy (Figure 10). The opposite was observed for the other two tillage types with the short season cultivar and for all tillage types with the normal season cultivar.

The location is visited yearly by more than 1,000 farmers, advisors and policy-makers. We present the IWMPRAISE project activities to our visitors during multiple field days with demonstrations on mechanical weeding, precision spray (sections) and lectures on IWM.

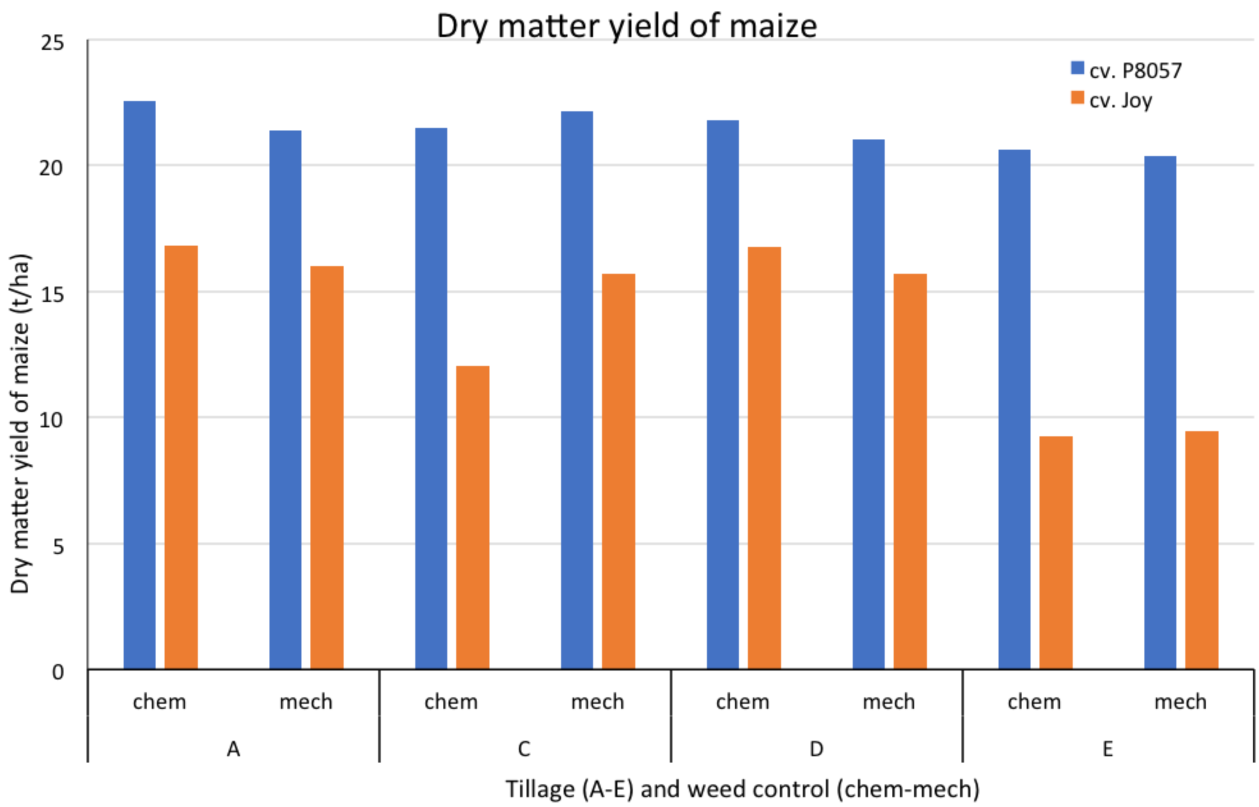



**Figure 9** - Average dry matter yield of silage maize

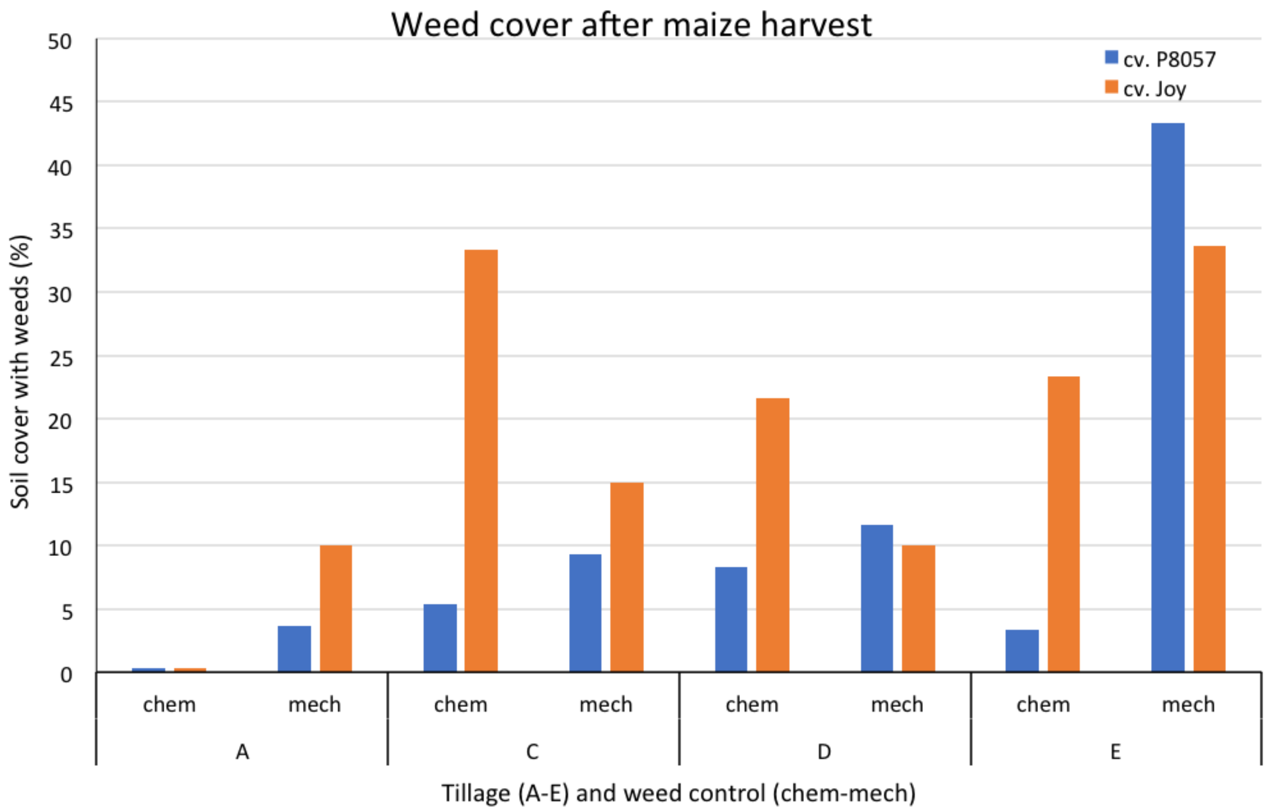
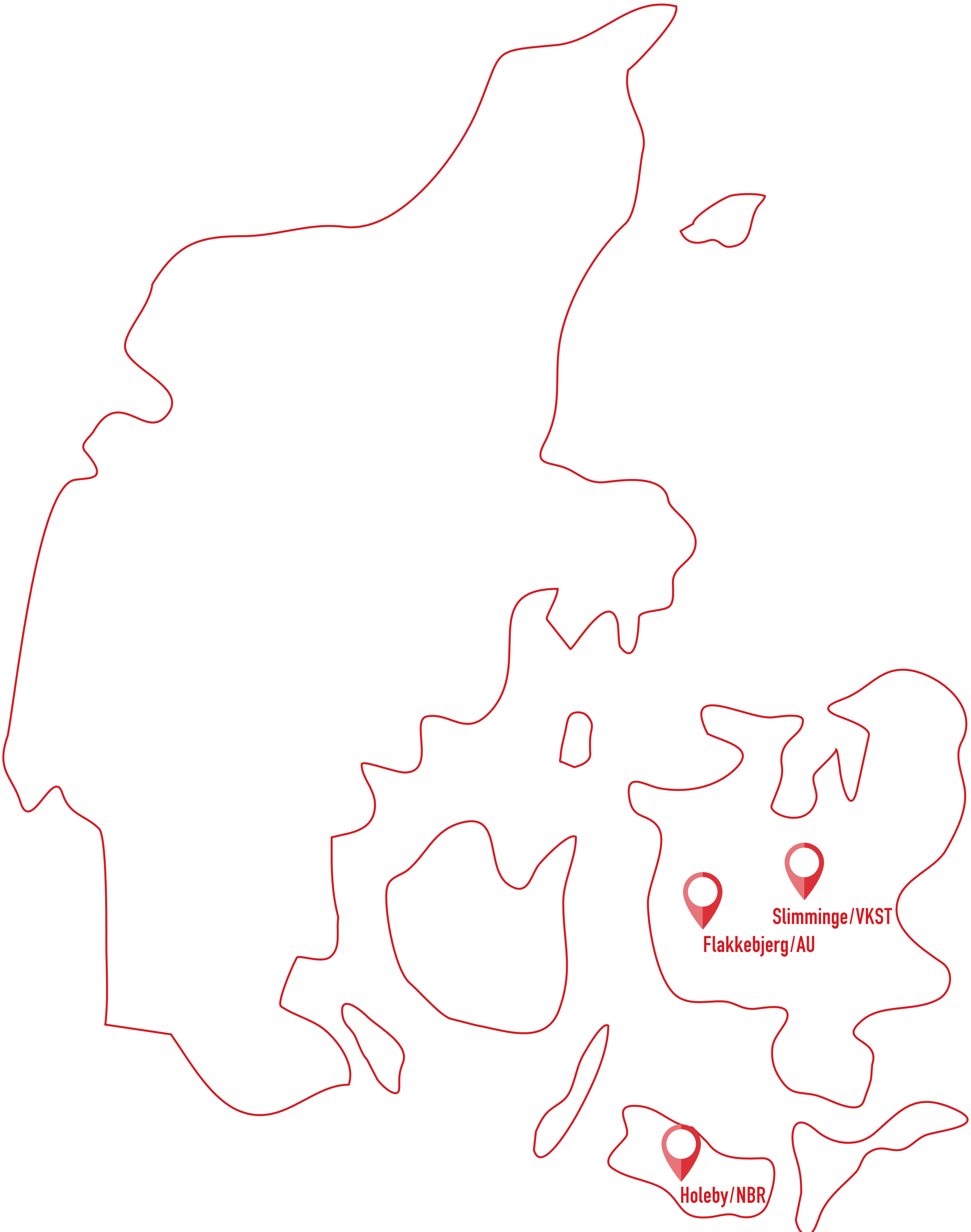



**Figure 10** - Average soil cover with weeds (both dicotyledon and monocotyledon) one day after maize harvest

**Figures 11, 12, 13 and 14** - Images of the field days and symposia with visits to the IWMPRAISE field trials in 2019

# DENMARK



# EXPERIMENTAL TRIALS MANAGED BY AARHUS UNIVERSITY

AARHUS UNIVERSITY


*Aarhus University's Department of Agroecology is located south of Slagelse on the island of Sjælland. It carries out research into agroecology, which is the interaction between plants, animals, humans and the environment within agroecosystems for the production of food, feed, energy and bio-based products. It contributes to sustainable production and growth via research, advice and teaching. Its experimental area covers approx. 200 ha and is managed primarily by conventional farming with some fields devoted to organic trials. The soil is a sandy loam with limited organic matter. The weed populations are mainly broadleaved weeds with some grassweeds, such as perennial ryegrass, blackgrass, silky bent grass and annual meadow grass.*


**Address:**
**Aarhus University**
**Forsøgsvej 1**
**4200 Slagelse - Denmark**
**GPS coordinates: 55°19'31.3" N 11°23'28.6"E**
**e-mail: agro@au.dk**
**tel. +45 8715 0000**

**For further information and guided visits, please contact:**
**Mette Sønderskov**
**mette.sonderskov@agro.au.dk**
**tel. +45 8715 8231**

# WP3 – EXPERIMENTAL TRIALS ON WINTER WHEAT

## Objectives

The objective is to combine management practices into 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. Combinations of sowing time and direct management practices are in focus.

## Season 2018/2019

The demonstration trial was located to the eastern part of Zealand and hosted by VKST (Figure 1). VKST is an independent advisory company owned by farmers in the region and was established in 2017 on the merger of DLS and GEFION (two agricultural advisory service providers). VKST offers a broad range of advisory services for farmers on crop production, which include accounting and economic advice, along with practical management advice. Advisory work for private farmers is the cornerstone of VKST, but it also runs activities such as field testing and trials for companies and SEGES, the national advisory service, as well. VKST conducts field trials on new varieties, fertilizers and plant protection products. VKST has a large area of field dedicated to demonstrations, plus contacts with a large network of farmers within various farming practices, e.g. conventional, conservation agriculture and organic farming. The experimental unit within VKST has the machinery and expertise to conduct the most advanced weed management strategies in winter wheat.
The 2018/19 trials largely followed the same layout as the 2017/18 season. Their focus was on sowing time and seeding density combined with different levels of herbicide application and mechanical weeding. A directly sown strategy had been established, but crop emergence was very poor and the strategy was abandoned in spring.
The weed population of the new location primarily consisted of broadleaved weeds, and volunteer oilseed rape was abundant. Additionally, *Aethusa cynapium, Matricaria sp., Papaver rhoea, Poa annua, Geranium pursillum, Viola arvensis, Galium aparine* and *Veronica sp.* were frequently observed. Some other grass weeds appeared, such as *Lolium, Vulpia* and *Alopecurus*. *Vulpia* was only observed in the early sown strategy, but its appearance was scattered and could have been random.

## Results 2018/2019

In June 2019, biomass of cereal and weed was measured and there was a fairly high weed pressure all over the area (150-300 g/m$^2$ of fresh weight) (Figure 3). As the layout did not facilitate true replicates, the samples were taken in four positions along the strategy strip in 0.25m$^2$ plots. High seeding density (235 pl/m$^2$ emerged in November 2018) tended to suppress weed better than standard density (163 pl/m$^2$ emerged in November 2018), whereas early sowing (119 pl/m$^2$ emerged in November 2018) and standard strategy had the same weed pressure. The strategy with only mechanical hoeing was unsuccessful in managing the weeds this year. This was due to bad timing of weed hoeing, partly because of weather conditions in spring. The fairly high weed amount left after spraying in spring was caused by uneven weed emergence and late-coming flushes of weeds, which were not sprayed.
In both the standard and high-density strategy, it was

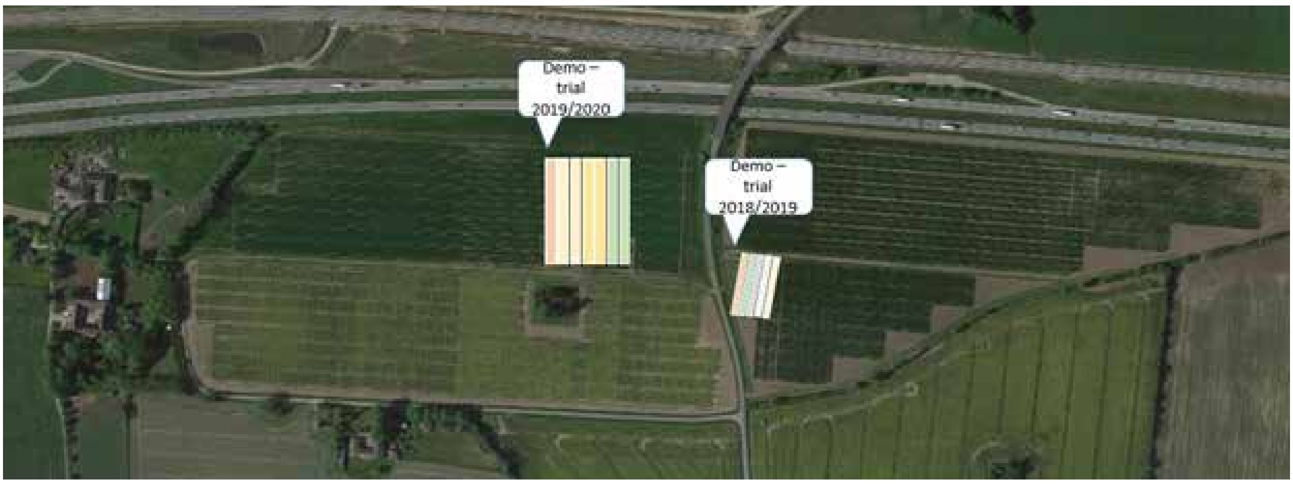



**Figure 1** - Aerial photo of the experimental area including the demonstration trial on winter wheat

| | Strategy 1<br>5 m | Strategy 2<br>5 m | Strategy 3<br>5 m | Strategy 4<br>5 m | Strategy 5<br>5 m |
|---|---|---|---|---|---|
| | Reference/standard | High seeding density | Ploughing<br>Early sowing | Direct sowing | Ploughing<br>No herbicides |
| Soil tillage | Ploughed same timing as strategy 3 | Ploughed same timing as strategy 3 | Ploughed | No ploughing | Ploughed same timing as Strategy 1 |
| Sowing time | Normal sowing time | Normal sowing time | | Normal sowing time | Late sowing<br>normal + 14 days |
| Seeding density | Standard | Standard + 50% | Standard | Standard | Standard |
| Row width | Standard row<br>12 cm | Standard row<br>12 cm | Standard row<br>12 cm | Standard row<br>12 cm | Wide rows<br>18 - 20 cm |
| Herbicides | Standard herbicide application autumn same growth stage of crop as strategy 3<br><br>Need based spring | Standard herbicide application autumn same growth stage of crop as strategy 3<br><br>Need based spring | Standard herbicide application autumn<br><br>Need based spring | Glyphosate before sowing<br><br>No herbicide application autumn<br><br>No herbicides spring | No herbicides |
| Mechanical weeding | - | - | - | - | Row cultivation in spring |

Straw chopped and left in field before trial establishment
Ploughing in the direction of the strategies strips to avoid driving in the no-till strips
Same variety in all strategies
Standard application of fungicides and insecticides as needed
Standard fertilizer standard in all strategies

**Table 1** - Trial plan for season 2018/2019 in winter wheat

**Figure 2** - Border between a strategy sown at normal sowing time and the late-sown strategy just before herbicide application in the normal sowing-time strategy

decided that no spring application was necessary. Herbicide application in the early sown strategy was based on a single weed species (*Galium aparine*) in spring and several other weed species that emerged after spraying. A different herbicide choice might have had a better effect on a larger number of species. This led to the conclusion that a decision support system should be consulted for spring herbicide application.

At harvest, yield was the highest in the high-density and early sowing strategies, closely followed by the standard strategy (Figure 4). The difference in crop biomass in the strategy with mechanical hoeing only was even more distinct at harvest, where high

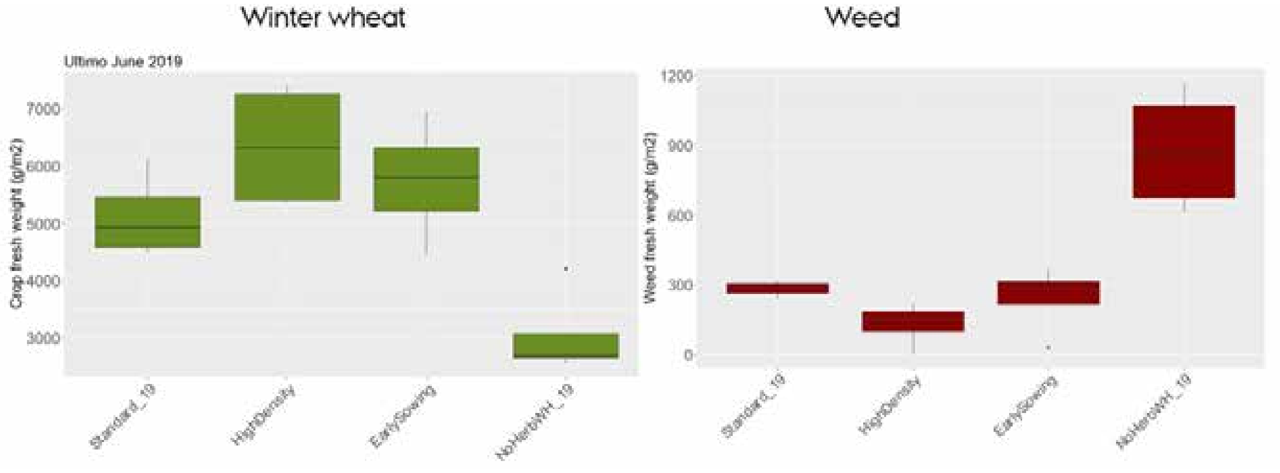



**Figure 3** - Comparison of crop and weed biomass sampling (fresh weight) in June 2019.

**Legend:**
Standard_19: following local standard management with seedbed preparation and sowing in mid-September after ploughing two weeks before. Herbicide application with standard program in autumn around crop emergence.
HighDensity: 50% increase in seed amount otherwise the same as Standard_19.
EarlySowing: ploughed and sowed immediately after at the beginning of September. Autumn herbicide application as Standard_19, plus spring application after inspection.
NoHerbWH_19: sowed late in mid-October with high row distance (25 cm), no herbicide use, and inter-row weed hoeing in spring

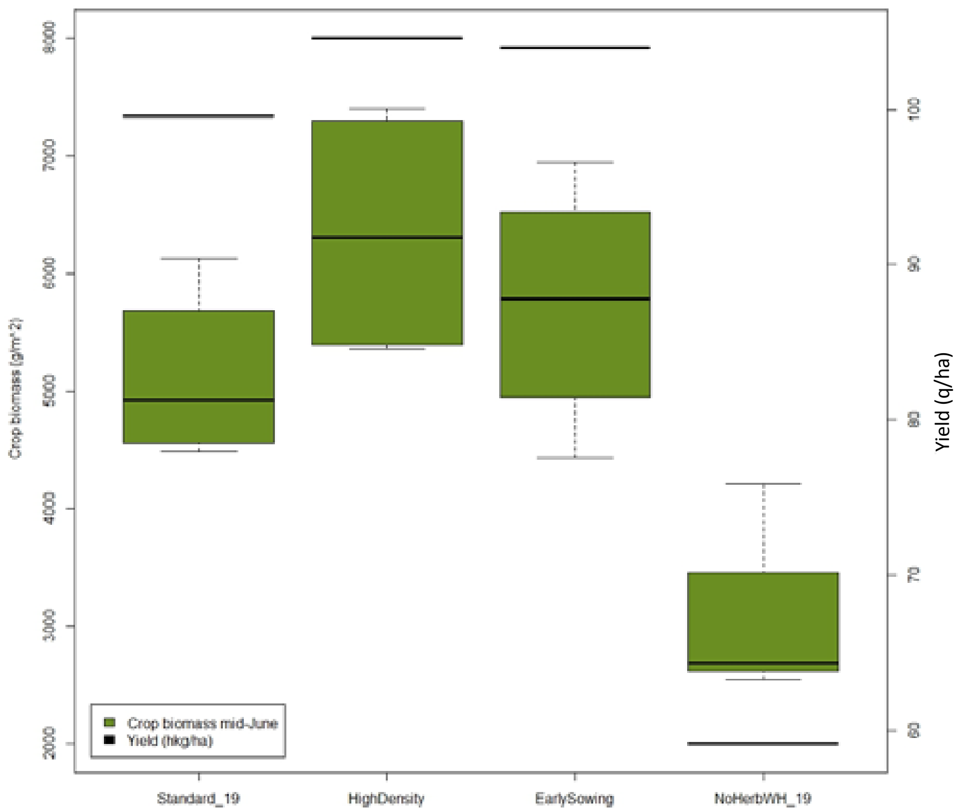



**Figure 4** - Crop biomass in June 2019 (green boxes, left y-axis) and yield (vertical black lines, right y-axis). Yield was registered as a single measure, hence no variation was measured. The yield correlated with the biomass samplings in June 2019, with even more distinct differences

| | Strategy 1<br>10 m | Strategy 2<br>10 m | Strategy 3<br>10 m | Strategy 4<br>10 m | Strategy 5<br>10 m | Strategy 6<br>10 m | Strategy 7<br>10 m |
|---|---|---|---|---|---|---|---|
| | Reference/standard<br><br>Winter wheat | Ploughing<br>No herbicides<br><br>Winter wheat | Ploughing<br>No herbicides<br><br>Winter wheat | Ploughing<br>bandspraying and wide rows<br><br>Winter wheat | Ploughing<br>bandspraying and wide rows<br><br>Winter wheat | No-till<br><br>Winter wheat<br>Cover crop | No-till, spring wheat very late sowing<br><br>Spring wheat<br>Cover crop |
| Soil tillage | Ploughed | Ploughed same timing as Strategy 1 | Ploughed same timing as Strategy 1 | Ploughed same timing as Strategy 1 | Ploughed same timing as Strategy 1 | Direct sowing | Direct sowing |
| Sowing time | Normal sowing time | Normal sowing time | Late sowing normal + 14 days | Normal sowing time | Late sowing normal + 14 days | Late sowing normal + 14 days | Very late sowing November |
| Seeding density | Standard | Higher density in row | Higher density in row | Higher density in row | Higher density in row | Increased | Increased |
| Row width | Standard row 12 cm | Wide rows 25 cm | Wide rows 25 cm | Wide rows 25 cm | Wide rows 25 cm | Standard row 12 cm | Standard row 12 cm |
| Herbicides | Standard herbicide application autumn<br><br>Need based spring based on DSS (CPO) | No herbicides | No herbicides | Bandspraying with normal spraying boom in low height<br><br>Standard herbicide choice in autumn | Bandspraying with normal spraying boom in low height<br><br>Standard herbicide choice in autumn | Cover crop removal with glyphosate<br><br>Consider need based spring application based on DSS (CPO) | Cover crop removal with glyphosate<br><br>Consider need based spring application based on DSS (CPO) |
| Mechanical weeding | - | Row cultivation | Row cultivation | Row cultivation | Row cultivation | - | - |

**Table 2** - Trial plan for season 2019/2020 in winter wheat

weed pressure had suppressed yield substantially. Experiments with this weed control strategy in previous years had a higher success rate, and it will thus be included in the coming season (2019/2020).

## Season 2019/2020

The demonstration trial was established close to the previous trial in VKST fields located in the eastern part of Zealand (Figure 1). The trial plan was agreed upon at a national cluster meeting in September 2019 among the project partners.
Based on the observations from the previous seasons, the 2019/2020 trial plan focuses on strategies with wide rows, band spraying and weed hoeing (Table 2). The standard strategy is being maintained. Observations in 2018/2019 showed that the purely mechanical weed hoeing strategy is dependent on good conditions and careful timing for hoeing. The weather conditions are limiting, even for experienced staff. Therefore, accompanying strategies with band spraying were included to study whether mechanical weed hoeing (Strategy 2-3) could be supported with herbicide application in the crop row (Strategy 4-5). Both strategies were sown at two sowing dates (standard in mid-September and late in mid-October), and sowing density was increased to optimize crop competitiveness in the rows. In 2018, the directly sown strategies were observed to provide high yields under very dry conditions. In 2019, establishment was poor, and the directly sown strategy had to be cancelled. The new plan includes two no-till strategies with cover crops established in autumn 2019 and late direct sowing at two timings with a SLY Boss (https://www.slyfrance.com/en/boss/). Late sowing of winter wheat in mid-October was performed, as was very-late sowing of spring wheat in mid-November. Late sowing of spring wheat in autumn is a practice some farmers have started, as the winters are getting warmer and there is less risk of frost damage. Spring wheat has a better yield potential with very late sowing than winter wheat. The cover crops were destroyed with glyphosate application in autumn before sowing.

**Partner responsible for the 2018/19 and 2019/20 demonstration trials:**
VKST, Independent Agricultural Advisory service, www.vkst.dk, Fulbyvej 15, DK-4180 Sorø

**For further information and guided visits, please contact:**
Mette Sønderskov, tel. +45 87158231
e-mail: mette.sonderskov@agro.au.dk

# WP4 – EXPERIMENTAL TRIALS ON SUGAR BEET

## Objectives

The objective is to combine management practices into strategies for sugar beet cropping in a bid to limit weed germination and inhibit emergence and growth. Different combinations of mechanical weeding and herbicide application are to be demonstrated, including band spraying and weed harrowing. Furthermore, an ALS-tolerant sugar beet variety is to be included in a strategy for the first year.

## Season 2019

In Season 2019, the sugar beet trial was located in the fields of Nordic Beet Research (NBR) on Lolland close to Holeby. NBR is the industry's research and development company founded by sugar-beet growers and the sugar industry in Denmark and Sweden. They contribute to improving beet production through experimental work, innovation, dissemination and demonstration. NBR bridges between research and other stakeholders.

In February 2019, a national cluster meeting at NBR among the Danish partners of WP4 decided to focus the trial on band spraying combined with weed hoeing. As the 2018 season was unusual, with very high temperatures and very few emerging weeds, the ALS-tolerant sugar beets were maintained as a strategy to compare the two seasons' results (Table 3).

## Results 2019

Biomass sampling in June 2019 showed that crop biomass treated with a medium dose rate and band spraying, was in the higher-end regarding fresh weight of sugar beets, whereas the standard, band standard and ALS-tolerant variey had lower biomass (Figure 7). Weeds were best controlled in the standard strategy and the ALS-tolerant variety. The band of Strategy 5 was 37.5 cm, which is much wider than the band of the other band applications (15 cm). The herbicide application rate in the row of the ALS-tolerant sugar beets was the label rate and bandwidth, which is realistic for authorisation in Denmark, although it is not currently authorised as a band application. No statistical tests have been applied. The main weed species in the standard strategy (Strategy 1) and the ALS-tolerant variety (Strategy 5) was *Veronica* sp. This weed species was present in all strategies, but in Strategy 2 (band spraying with three herbicide applications) *Polygonum convolvulus* was the dominant weed species. In Strategy 3, *Veronica sp., Polygonum aviculare* and *Stellaria media* were equally frequent. In Strategy 4, *Raphanus sativus* var. *oleiformis* was most frequent, followed by *Veronica* sp. This indicates that the strategies had a variable effect on weed species.

The differences observed in June 2019 were not evident at harvest, where Strategies 1-2-3 had similar yields (Figure 8). The strategy with finger weeder (Strategy 4) and the one with ALS-tolerant variety (Strategy 5) had lower yields. The finger weeder tool was not observed to damage the sugar beets, but there were slightly more weeds left later in the season and, as sugar beets are highly sensitive to weed competition, this was assessed as the cause of yield reduction. The ALS-tolerant beets generally produced a lower yield. The evaluation of the strategies was positive and there was no problem in lowering the herbicide amount of Strategies 2-3-4 in combination with weed hoeing. Therefore, these strategies will be included in the 2020 trial. The ALS-tolerant variety was included in the first two years with band spraying. This is a viable strategy for using ALS-tolerant sugar beets. As the results from the trials in the previous years were fairly positive, this strategy will not be included in the 2020 trial.

## Season 2020

Based on the experiences from the first two seasons, a trial plan was agreed upon at the online national cluster meeting among the Danish partners in March 2020. The trial is established in the trial fields of NBR (contact details below).
The plan includes Strategies 3 and 4 from 2019, which are Strategies 2 and 4 in 2020 (Table 4). The standard strategy is the same (Strategy 1). Strategy 3 is the same as Strategy 2, except that weed hoeing will be performed with the Robotti automated tool carrier by AgroIntelli (Figure 9). Robotti is a tool carrier, which means that essentially the tool is the same as any weed hoe, but its improved accuracy means that it can come closer to the row. It can also run at higher speed than a manned weed hoe, and thus increase efficacy. Two organic strategies are included. Strategy 5 includes weed hoeing, finger weeder and hoeing ridges, while Strategy 6 includes an automated weed tool, Robovator by Frank Poulsen. In the last two strategies, intensity and frequency will be determined by weed emergence. The Robovator is camera-guided with a software for recognising sugar beets and enabling both inter- and intra-row management (Figure 10).

**Figure 5** - Experimental field of Nordic Beet Research in Lolland

| | Strategy 1 | Strategy 2 | Strategy 3 | Strategy 4 | Strategy 5 |
|---|---|---|---|---|---|
| | Reference/standard | Band spraying standard dose + weed hoe | Band spraying red. dose + weed hoe | Band spraying red. dose + weed hoe/finger weeder | ALS-tolerente beets + band spraying and weed hoe |
| Soil tillage | Plough | Plough | Plough | Plough | Plough |
| Sowing time | 15th April | 15th April | 15th April | 15th April | 15th April |
| Variety | Daphne, KWS | Daphne, KWS | Daphne, KWS | Daphne, KWS | SMART Renja, KWS ALS-tolerant |
| Herbicides | Standard herbicide program 3 applications In total 7.5 g triflusulfu-ron + 1120 g phenmedipham + 2100 g metamitron | 3 applications in 15 cm band Total per ha corresponds to: 2.25 g triflusulfuron + 352 g phenmedipham + 630 g metamitron Same dose in band as standard | 2 applications in 15 cm band Total per ha corresponds to: 1.125 g triflusulfuron + 256 g phenmedipham + 420 g metamitron | 2 applications in 15 cm band Total per ha corresponds to: 1.125 g triflusulfuron + 256 g phenmedipham + 420 g metamitron | 2 band sprayings in 37.5 cm band Total per ha cooresponds to: 175 g ethofumesate + 22.5 g foramsulfuron and 37.5 g thiencarbazone Both products are apllied twice |
| Mechnical control | | 3 x weed hoeing | 3 x weed hoeing | 2 x weed hoeing 1 x finger weeder | 3 x weed hoeing |

**Table 3** - WP4 experimental plan in 2019


**Figure 6** - Photo of the strategies in June 2019. Strategies 1-4 with conventional sugar beet varieties and Strategy 5 with ALS-tolerant variety

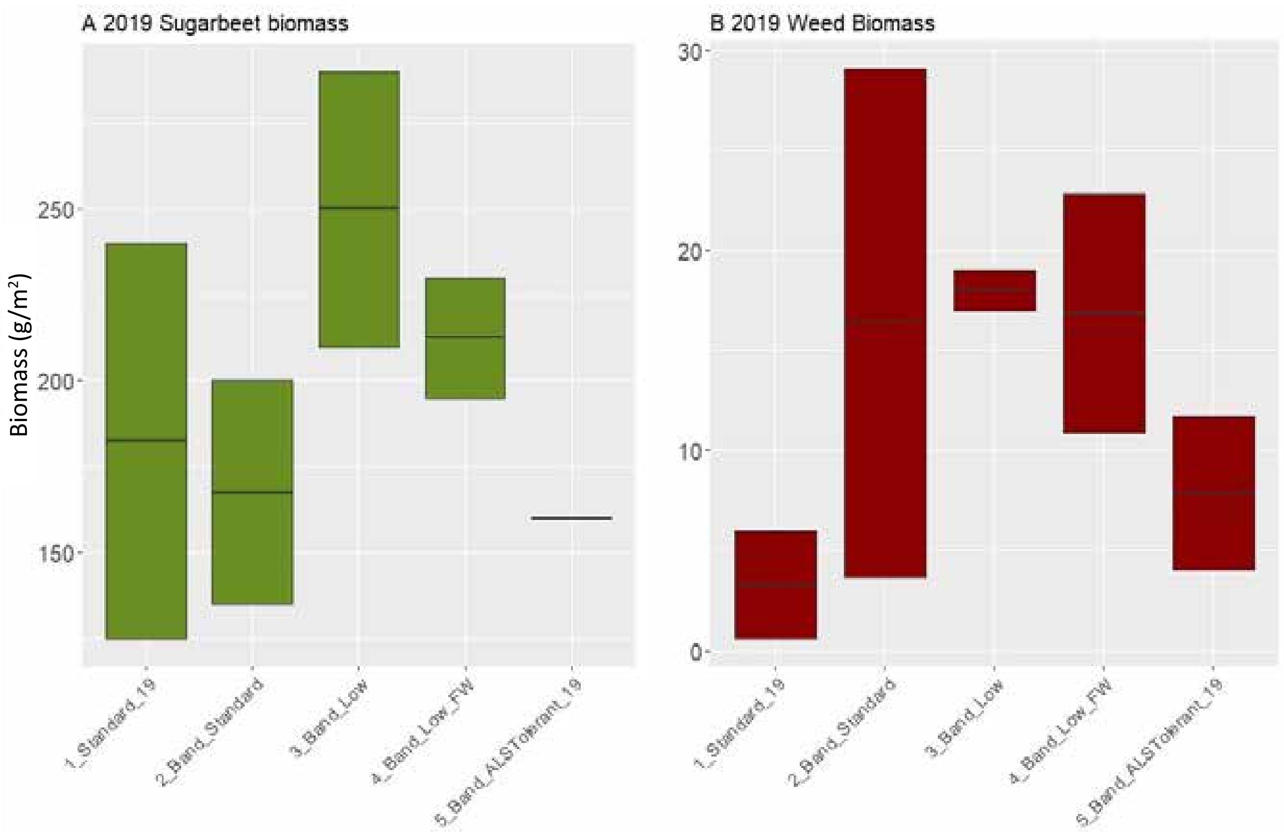



**Figure 7** - Fresh biomass of crop (A) and weed (B) in June 2019 in the five strategies.
**Legend:**
1_Standard_19 (Strategy 1): standard.
2_Band_Standard (Strategy 2): band with dose rates equal to Strategy 1, three band applications, including inter-row hoeing three times
3_Band_Low (Strategy 3): band with dose rates equal to Strategy 1, two band applications, including inter-row hoeing three times
4_Band_Low_FW (Strategy 4): band with dose rates equal to Strategy 1, two band applications, including inter-row hoeing three times, plus a finger weeder in the last two hoeing runs
5_Band_ALSTolerant_19 (Strategy 5): band spraying in broader band with ALS-product strategy, including inter-row hoeing 3 times
These strategies are further described in Table 3

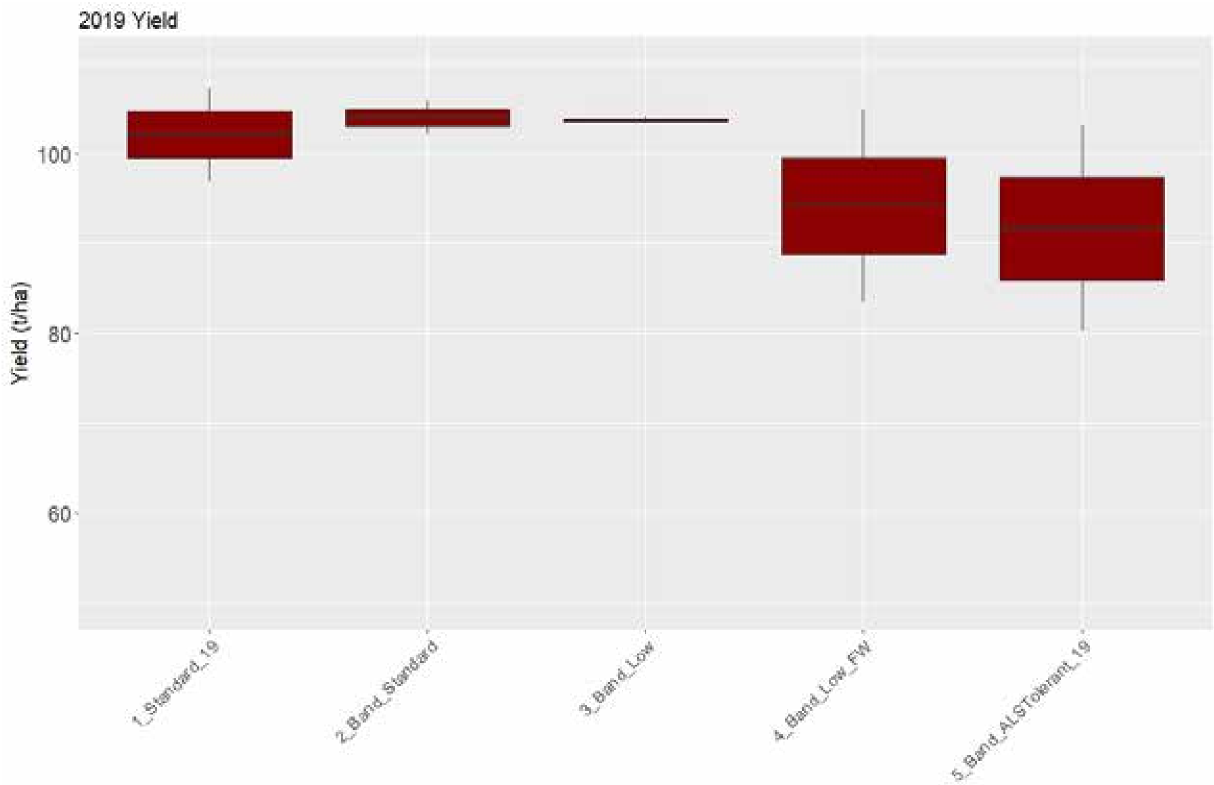



**Figure 8** - Yield of sugar beets in 2019 for the five strategies. Strategies are described in Figure 7 and in Table 3

| | Strategy 1 | Strategy 2 | Strategy 3 | Strategy 4 | Strategy 5 | Strategy 6 | Strategy 7 |
|---|---|---|---|---|---|---|---|
| | Reference/standard | Band spraying Low + weed hoe | Band spraying Low + weed hoe + finger weeder | Narrow band spraying Low + weed hoe + Finger weeder ROBOTTI | Narrow band spraying Low + weed hoe + Finger weeder ROBOTTI/ ROBOVATOR | Weed hoe + Finger weeder + ridge hoeing | Weed hoe + Finger weeder + ROBOTTI/ ROBOVATOR |
| Soil tillage | Ploughed | Ploughed | Ploughed | Ploughed | Ploughed | Ploughed | Ploughed |
| Sowing time | Normal sowing time | Normal sowing time | Normal sowing time | Normal sowing time | Normal sowing time | Normal sowing time | Normal sowing time |
| Variety | Selma KWS | Selma KWS | Selma KWS | Selma KWS | Selma KWS | Selma KWS | Selma KWS |
| Herbicides | Standard herbicide program 3 applications In total 7.5 g triflusulfuron + 1120 g phenme-dipham + 2100 g metamitron | 2 applications Total per ha corre-sponds to: 1.125 g triflusulfuron + 256 g phenme-dipham + 420 g metamitron | 2 applications Total per ha corre-sponds to: 1.125 g triflusulfuron + 256 g phenme-dipham + 420 g metamitron | 2 applications Total per ha corre-sponds to: 0.600 g triflusulfuron + 137 g phenme-dipham + 224 g metamitron | 2 applications Total per ha corre-sponds to: 0.300 g triflusulfuron + 69 g phenme-dipham + 112 g metamitron | No Herbicides | No Herbicides |
| Band width | - | 15 cm | 15 cm | 8 cm | 8 cm | 15 cm | 8 cm |
| Mechanical weeding | - | Between row hoeing 3 times | Between row hoeing 3 times + finger weeder 2. and 3. time | Between row hoeing 3 times + finger weeder 2. and 3. time | Combined weed hoeing/finger weeder and intra-row weeding with ROBOVATOR | Tine harrow combi-ned with weed hoe, finger weeder and ridge hoeing | Weed hoe, finger weeder and Intra-row weeding with Robovator |

Seeding density is the same in all strategies
Fertilizer standard in all strategies

**Table 4** - WP4 experimental plan in 2020

**Figure 9** - The Robotti automated tool carrier, shown here equipped with sowing system (photo by AgroIntelli http://www.agrointelli.com/robotti-electrical.html#rob.electr.)

**Figure 10** - Robovator developed for mechanical weed management, here in lettuce (photo by Frank Poulsen http://www.visionweeding.com/robovator/)

**Partner responsible for the 2018/19 and 2019/20 demonstration trials:**

Nordic Beet Research
Sofiehøj
Højbygaardvej 14
4960 Holeby – Denmark
e-mail: info@nordicbeet.nu
tel. +45 5469 1440

**For further information and guided visits, please contact:**

Mette Sønderskov, tel. +45 8715 8231
e-mail: mette.sonderskov@agro.au.dk

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

Danish farmers want to reduce their costs for arable cropping, and reducing tillage is one major option. Going from inversion tillage to non-inversion tillage has several implications, with reduced yield stability and an increased consumption of pesticides being of greatest concern. Previous research and experiences from practice have often shown that annual grass weeds, cleavers and perennials, such as couch grass and creeping thistle, can become troublesome weed problems in non-inversion tillage systems.
Most results and experiences with weed problems in non-inversion tillage systems in Denmark relate to non-inversion tillage systems where tine tillage has been applied to various depths prior to crop sowing. There is currently little information about direct drilling and conservation agriculture, though these systems receive increasing attention.
Diversified crop rotations are a prerequisite for sound management of non-inversion tillage systems, and this message appears to be accepted by most growers practicing non-inversion tillage.
Diversification means variations in:

1) season of crop establishment (autumn, early autumn, spring, late spring);
2) broadleaved crops versus monocotyledonous crops;
3) growth length (annual versus perennial crops); row crops (e.g. sugar beets, maize) versus narrow-rowed crops (cereals, pulses etc.).

However, more knowledge about measures and methods for weed control with less reliance on herbicides is still needed when transforming a conventional cropping system into conservation agriculture or other non-inversion tillage regimes.

### Objective

Adopting a range of measures to minimize the reliance on herbicides in the transition phase from mould-board based tillage systems to non-inversion tillage systems where 1) some tine tillage prior to crop sowing, and 2) conservation agriculture are used. The experiment studies the situation when a diversified crop rotation is established, and focus is mainly on measures that help reduce the input of herbicides in each crop.

### Materials and methods

The treatments are organized in a split-plot design with three replicates. The cropping system is used on the main plot and sub-plots are planted with the

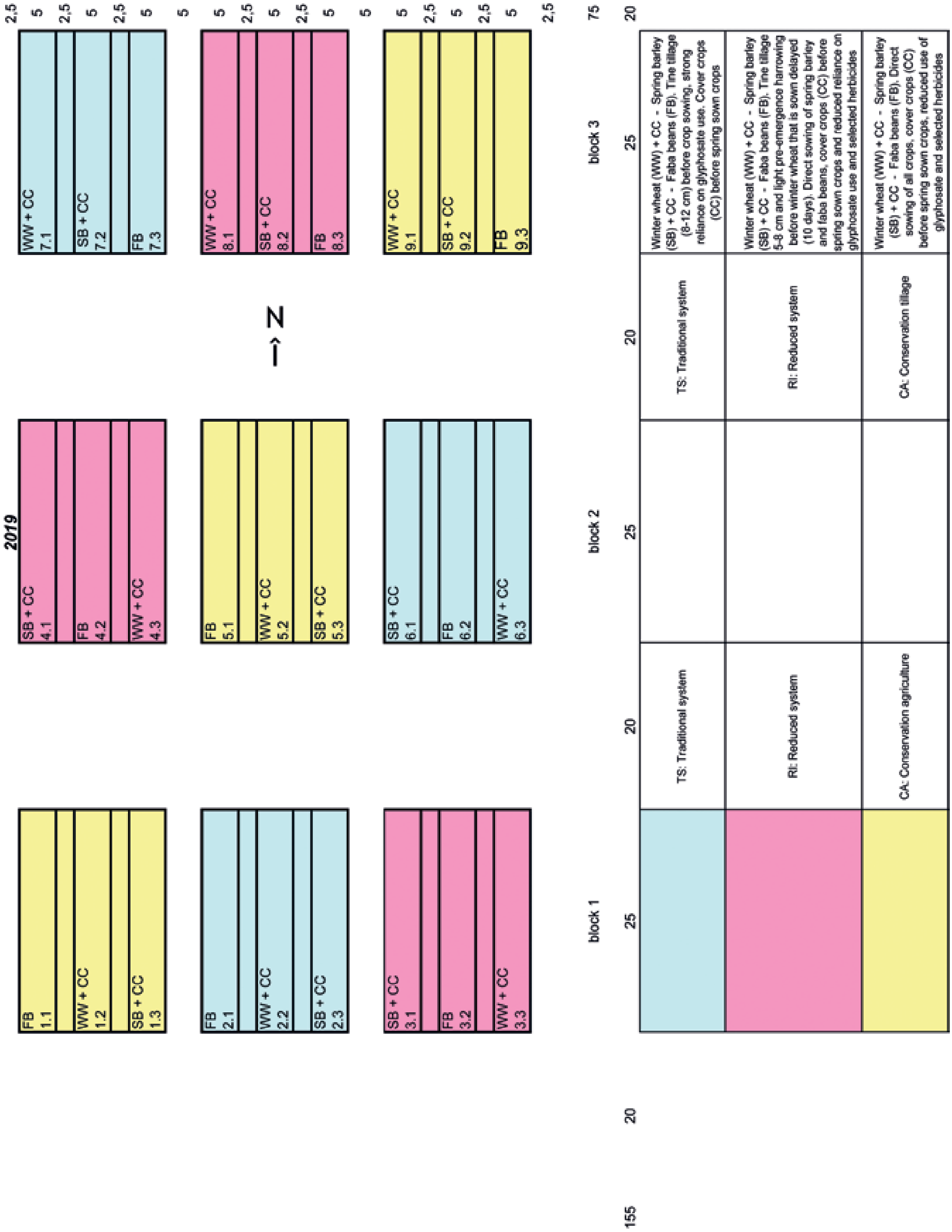



**Table 5** - WP7 experimental layout

**Figures 11 and 12** - Direct drilling

**Figures 13** - Directly sown Faba beans

individual crops in the three-year crop rotation. All the rotation crops are grown each year to eliminate the confounding effects between weather and the actual crop grown. An outline of the experiment is shown in Table 5.

Cropping systems:

TS = traditional mould-board ploughed system with normal herbicide inputs

RI = non-inversion tillage system with reduced herbicide input

CA = conservation agriculture aimed at reducing herbicide input

Crop rotation:

TS = winter wheat → spring barley → faba beans →

RI = winter wheat → spring barley → faba beans →

CA = winter wheat → spring barley → faba beans →

Three-year crop rotation with all crops grown each year in each cropping system. With the three systems, three crops and three blocks, the plot number totals 27. The experiment was established in autumn 2017 and the first crops were harvested in 2018.

Tillage treatments:

TS = tine tillage to 8-12 cm soil depth before crop sowing using a Horsch Terrano stubble cultivator.

RI = direct drilling of faba beans and spring barley. For winter wheat: tine tillage to 5-8 cm soil depth just after the harvest of faba beans using a Horch Terrano stubble cultivator, then light cultivation to create a false seedbed until wheat sowing. Wheat is sown about 10 days later than the sowing time for wheat in the TS and CA systems.

CA = all crops sown directly.

Cover crops:

TS, RI and CA = cover crops are established in the period between winter wheat and spring barley and between barley and faba beans. Cover-crop mixtures known to suppress weeds are used.

Weed control:

TS = glyphosate applied before tine tillage, applied in spring in case of spring-sown crops. Thereafter, selective herbicides according to need.

RI = no glyphosate before winter wheat. Glyphosate in spring before spring-sown crops. Selective herbicides in barley and wheat according to need. Inter-row hoeing is used for the cereals, where possible. For faba beans, the aim is to replace chemical control with inter-row cultivation and weed harrowing.

**Figure 14** - Directly sown winter wheat

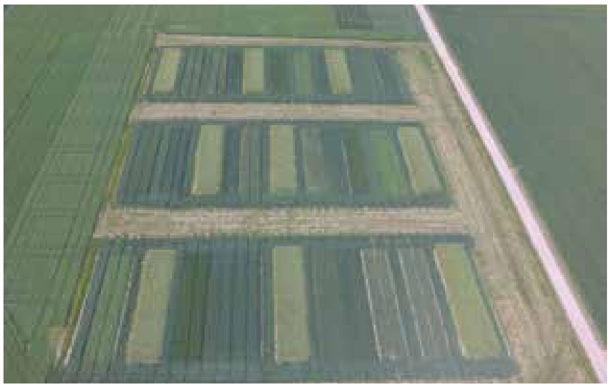


**Figure 15** – Plots of WP7 trials

**Figure 16** - Well-established faba bean in the CA system

CA = glyphosate before direct drilling, but applied in spring before spring-sown crops. Selective herbicides are then applied, but in low doses.

Assessments:
The content of weed seeds in the seed bank was recorded in all plots before the experiment was started. Weed emergence is counted in all crops and systems, and weed biomass remaining after weed control treatments is assessed in late June in all crops and systems. Crop plant numbers are counted, and yields are obtained by plot-wise combining.

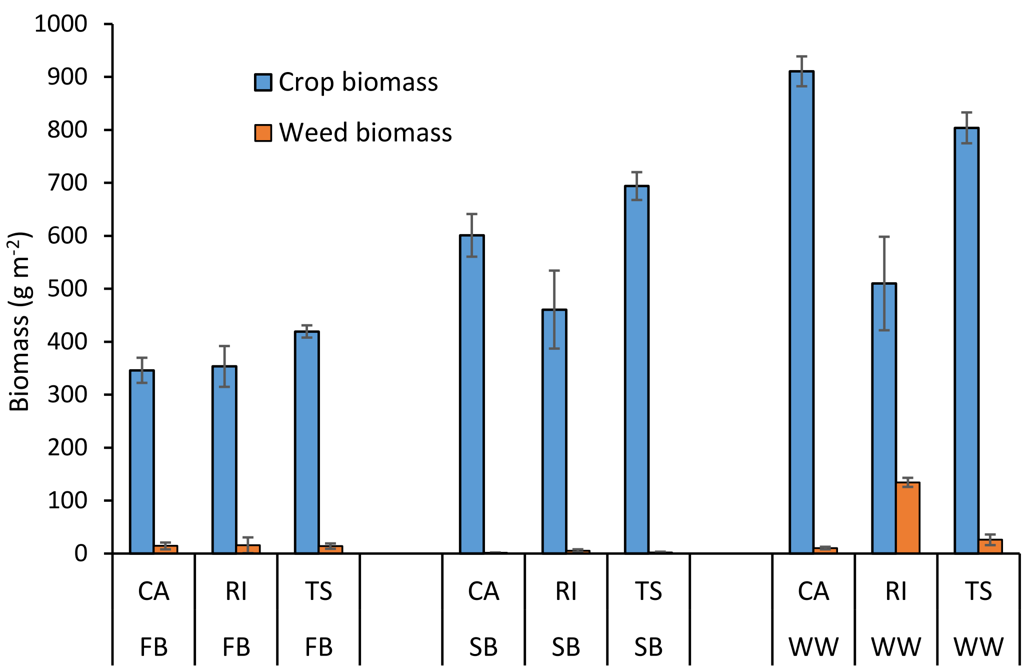



**Figure 17** – Crop and weed biomasses (DM) assessed in late June 2019 in faba bean (FB), spring barley (SB) and winter wheat (WW) in the three cropping systems: CA, RI and TS

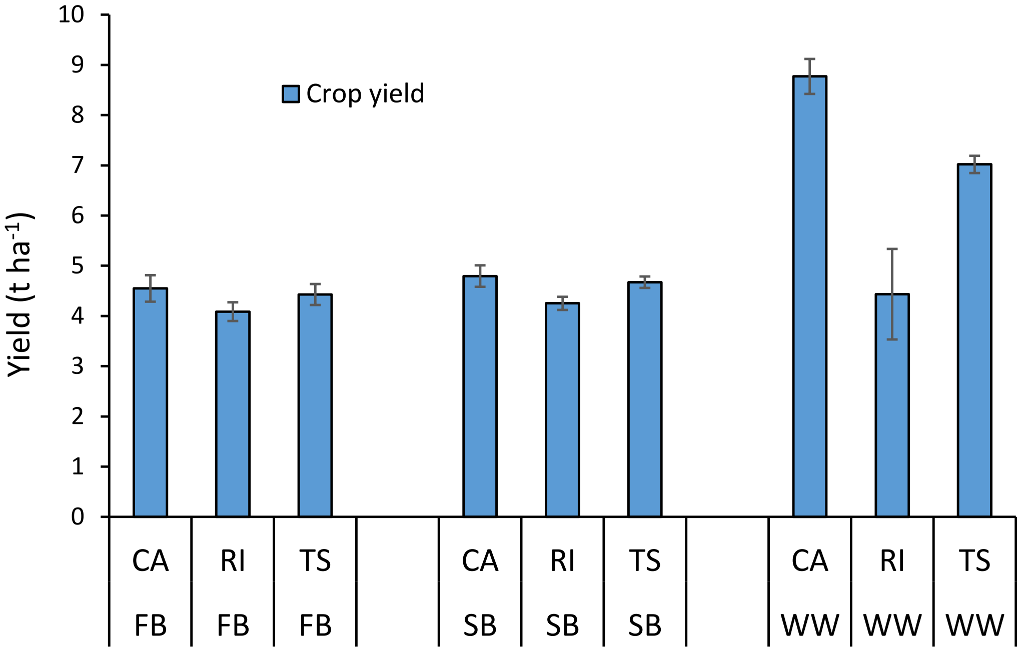



**Figure 18** – Crop yields in 2019 in faba bean (FB), spring barley (SB) and winter wheat (WW) in the three cropping systems: CA, RI and TS

## Location

The experiment is located on a sandy loam at Flakkebjerg Research Centre (55°20'N, 11°23'E), Denmark.

## Results 2019

The 2019 growing season was the second experimental year. The two spring sown crops, faba bean (Figure 16) and spring barley, established well in all three systems: CA, RI and TS. The cover crops sown in autumn 2018 survived into the two spring crops in 2019. Fodder radish and volunteer spring barley were not killed by frost during the mild winter 2018/19, and the pre-sowing glyphosate dose of 540 g/ha did not completely kill the cover crop. However, these 'survivors' did not become serious problems later in the growing seasons; weed biomasses were generally small and crop yields were similar among the three systems, as shown in Figures 17 and 18.
The treatment frequency index (TFI) for the input of selective herbicides in spring barley was 1.65 for the CA and TS systems, and 30% lower for the RI system (TFI 1.15). TFI was 1.56 in faba bean for the CA and TS systems, and 50% lower for the RI system (TFI 0.78). Inter-row hoeing had been scheduled in the RI system as the last treatment in the weed control program, but crop residues blocked the hoe, making it impossible.
Weed control in winter wheat was successful in the CA system (Figure 17) because 20 g metsulfuron-methyl/ha applied in spring removed the extensive

**Figure 19** - Poor weed control in winter wheat in the RI system

weed growth that had survived the pre-sowing glyphosate treatment in the autumn. The use of selective herbicides applied in autumn in the TS system was almost as effective as the spring application in CA (Figure 17). However, TS yielded significantly less than CA (Figure 18). No selective herbicides were used in the RI system, which relied entirely on non-chemical weed control treatments: false seedbed and delayed sowing in autumn, followed by inter-row hoeing, plus weed harrowing in spring. This strategy clearly failed, as shown in Figures 17, 18 and 19.
In conclusion, reducing herbicide input in 2019

was only attempted in the RI system, with success in the two spring sown crops and failure in winter wheat. This shows how challenging it can be to reduce herbicide input in the transition phase from inversion-tillage to non-inversion tillage systems.

**Further development**

The experiment will run during the live time of IWMPRAISE, i.e. at least until 2022. Crop and weed growth are recorded continuously, as is the herbicide input applied to the crops. Weed development and crop responses are reported to Danish agriculture whenever relevant, and the experiment will be shown at field visits and to other stakeholders.

**Contact:**
Bo Melander
Aarhus University
Department of Agroecology
Research Centre Flakkebjerg
DK-4200 Slagelse - Denmark
e-mail: bo.melander@agro.au.dk
mobile +45 2228 3393

ISBN 978-88-6337-244-1