IWMPRAISE

Integrated Weed Management: PRActical Implementation and Solutions for Europe

EXPERIMENTAL TRIALS IN EUROPE

2019 EDITION

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

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IWMPRAISE

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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 € 6.6m 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.

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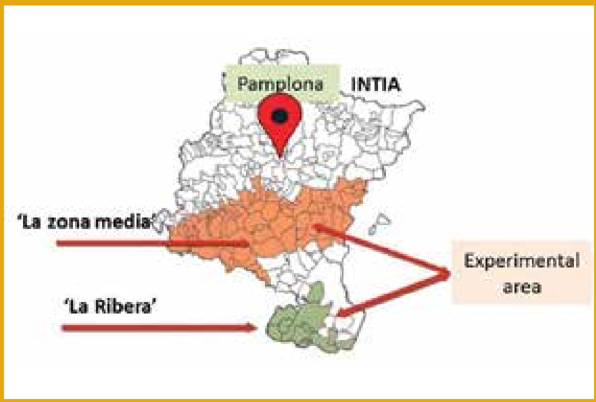
EXPERIMENTAL TRIALS IN NORTHERN SPAIN

The Navarre Institute of Transfer and Innovation in the Agri-food Sector (INTIA) is a public company created by the Government of Navarra to help improve agricultural viability and sustainability, 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.



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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 biggest extension with 1,596,717 ha, mainly concentrated in the provinces of Jaen (582,497 ha) and Cordoba (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, 2017b).
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). Nevertheless, 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 preventing weeds competing with olive trees for water and other mineral resources (Saavedra *et al.*, 2015). The most-used soil management systems are reduced tillage, spontaneous cover crops and no-tillage with application of herbicides (MAPA, 2017c). Moreover, a combination of these practices is often used on farms, since most of the olive orchards have two clearly distinct areas: soil beneath the olive trees, which facilitates harvesting, and 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 (Gómez et al., 2009). No-tillage with chemical control is used in both inter-row and intra-row spacing, with weeds becoming increasingly resistant due to the widespread use of herbicides (Saavedra and Pastor, 2002). Finally, cover crops are commonly used to protect the soil in inter-row spacing (Alcántara *et al.*, 2011), with it being covered by pruning wood residues or spontaneous or sown cover crops, which also facilitate infiltration and water accumulation (Cucci *et al.*, 2016). However, their successful establishment in olive orchards requires careful management and control to reduce the likelihood of pests and diseases appearing (Martinelli *et al.*, 2017).
The fact that there is no practice without problems attached highlights the importance of integrated weed management in olive orchards, as it is designed to reduce negative impacts on soil and production while maintaining beneficial flora at an affordable and manageable threshold. 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 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

The field study started in September 2018 and field trials will be conducted during three growing seasons (2018/2019, 2019/2020 and 2020/2021) at two different locations (south and north of Spain) with a typical Mediterranean climate.
In southern Spain, the experimental farms belong to farmers associated with the olive-growing cooperative 'Virgen del Campo', located at Cañete de las Torres (Córdoba). Olive farms consist of Picual olive cultivar, with farm size averaging 4-6 ha. In northern Spain, the experimental farms belong to farmers collaborating with the Instituto Navarro de Tecnologías e Infraestructuras Agroalimentarias (INTIA), located at Larraga (Navarra). Olive farms have an average size of 1-5 ha and Arróniz is the main olive cultivar.

IWM strategies

In both locations, two IWM strategies commonly used by farmers are being evaluated during the growing season 2018/2019, with there being two different sampling areas per strategy: inter-row and intra-row spacing. 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). 'Tillage' plots in the south of Spain include from three to five different tillage operations per year with vibro-cultivator and rotary cultivator operations at 10-15 cm depth, in addition to pre-emergence herbicide application with oxyfluorfen 48% (1 l/ha) or glyphosate 36% (2 l/ha) and a mixture of diflufenican 2.5% + Chlortoluron 40% (3.5 l/ha)/ diflufenican 15%+ iodosulfuron-methyl-sodium 1% (1 l/ha) in October. 'No tillage with chemical control' areas in the north of Spain are controlled by glyphosate 36% at a rate of 3 l/ha.
Strategy 2 in both locations includes 'no tillage with chemical control' in the intra-row spacing and 'cover crops' in the inter-row spacing (Figure 1.b and 1.d respectively). In the intra-row spacing of

field trials from southern Spain, pre-emergence herbicide application with oxyfluorfen 24% (2 l/ha) is used only when necessary during the autumn (e.g. high emergence of *Malva sylvestris*). Subsequently, post-emergence herbicides composed of glyphosate 36% (4 l/ha) + fluroxypyr 20 % (0.4-1 l/ha) and/or oxyfluorfen 24% (0.3-0.4 l/ha) are applied after olive harvesting. In northern Spain, weed flora in the intra-row spacing is controlled by glyphosate 36% at a rate of 3 l/ha.

The cover crop comprises spontaneous grass species (*Bromus* spp., mainly *Bromus madritensis*) in an inter-row spacing 2 m wide in southern Spain. It was planted 17 years ago and it is self-seeded from the seed bank produced each year. This cover crop is managed after harvesting by applying a broad-leaf herbicide composed of fluroxypyr 24 % (1 l/ha) or a mixture of fluroxypyr 20 % (1 l/ha) and MCPA 40% (2.4 l/ha). Chemical/mechanical killing methods are not necessary because the cover crop dries naturally in late April-early May. In northern Spain, the cover crop is composed of white mustard (*Sinapis alba*), which was sown on 17 October 2018 at a rate of 15 kg/ha.

The inter-row cover crop is allowed to grow during the winter without using herbicides and it is killed by mechanical mowing in May.

Experimental design

The treatments are evaluated from September to April at both locations in a randomized complete block design with four replications per strategy (Figure 2).

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 and 3,400 m^2 in the north of Spain and the plot size corresponds to the distance between five and six trees respectively. 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 (herbicides and tillage)

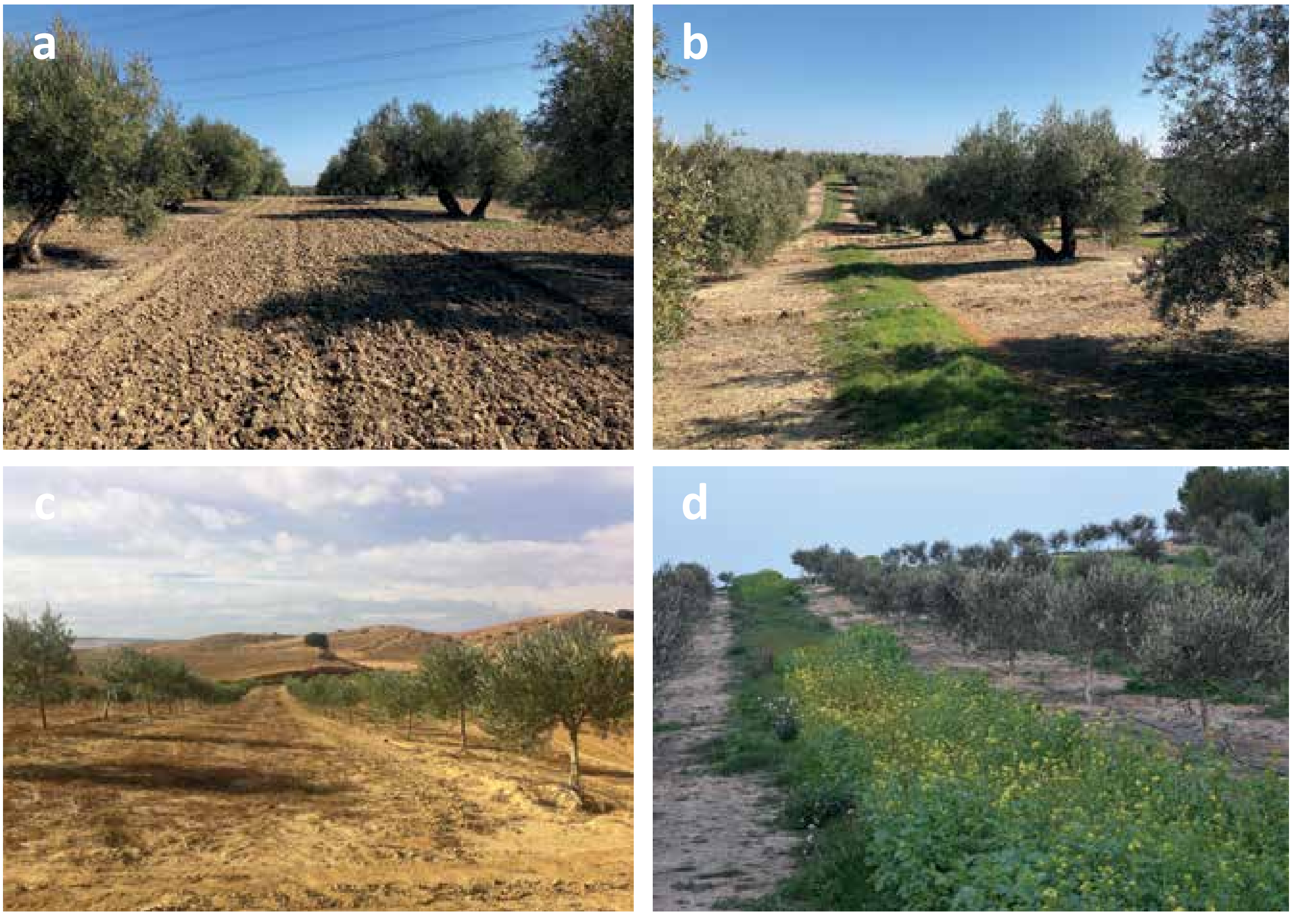


Figure 1 - Tillage (a) and spontaneous grass cover crops (b) in southern Spain and no tillage with chemical control (c) and crucifer cover crops (d) in northern Spain

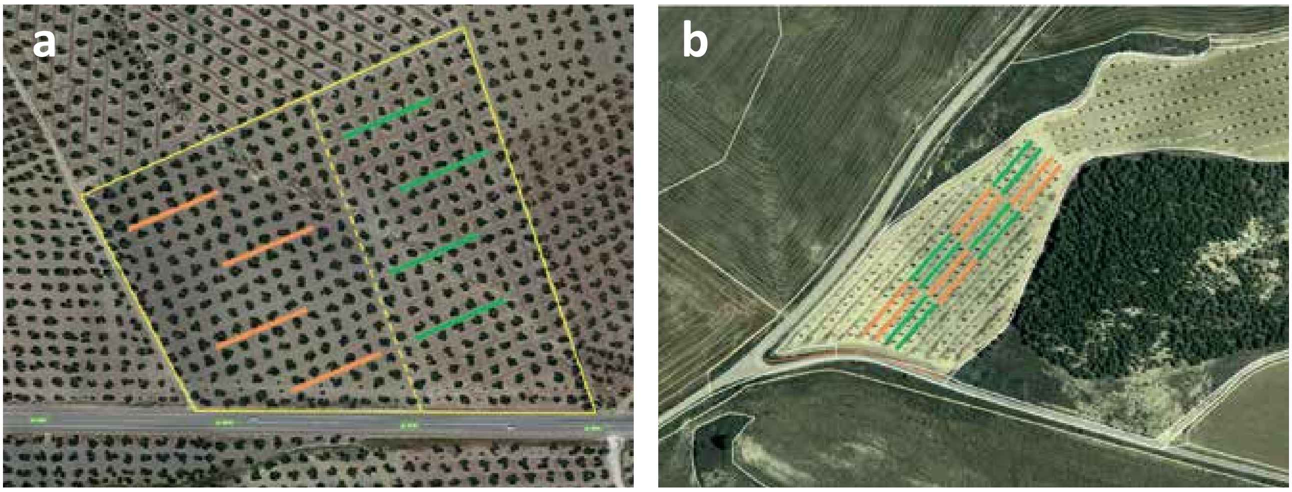


Figure 2 - Experimental design in the south (a) and north (b) of Spain

and February-April, 3-4 weeks after applying the control methods. Main assessments include weed data in the inter-row and intra-row spacing: plant density, ground cover, height, biomass production and phenological growth stage. Plant density is estimated by counting each weed species in four randomly selected 0.5 m^2 areas of each sampling area per plot, with the number of existing species and families being calculated. Plant ground coverage is determined visually in each plot based on the Barralis scale (Barralis, 1976). Plant height is calculated as the modal height. Weed above-ground fresh biomass is evaluated by measuring the fresh weight of the above-ground parts of the

		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*)
	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)	
	Samplings	From **September** to **April**			
	Experimental design	Randomized complete block design and 4 replications			
	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	
	Soil texture	Silty-loam and clay soils		Silty clay loam soils	

Table 1 - Field trial details in southern and northern Spain

plants, and four randomly selected 0.5 m^2 areas of each sampling area per plot are collected. The phenological development stages of each species are monitored with the Hess scale (Hess *et al.*, 1997). The weight is determined after drying for 48 hours in a forced air oven at 70°C.

- **Cover crops in the inter-row spacing:** Ground cover, height and phenological growth stages based on the BBCH scale (Lancashire *et al.*, 1991) are evaluated in the same way as for weeds, but without disturbing the cover crop.
- **Olive crop:** Olive yield (kg/ha) and quality (oil content, fat acidity and humidity) are determined.
- **Soil analyses:** At the beginning of the experiment, 10 soil samples were extracted from 0-15 cm depth per farm for soil physical characterization. Additionally, 16 soil fertility samples (N, P, K, OM and organic C) per farm were extracted from 0-15 cm depth during autumn 2018 before herbicide application and tillage, and this analysis will be repeated each growing season.
- **Weather data:** Weather data are obtained from Weather Stations located at a distance of less than 20 and 10 km from the experimental area in southern and northern Spain respectively.

Preliminary results

Field trials started in the second half of 2018 and the first samplings were taken from December 2018 (southern Spain) to February 2019 (northern Spain). The second samplings are in progress in both locations, given that the harvesting period in southern Spain began in December, but it has been extended to late February for this growing season 2018/2019. Preliminary results from the first sampling provided winter weed community data in olive orchards (Table 2).

In the south of Spain, from 13 to 17 weed species were identified in fields with Strategy 1 and 21-24 species in fields with Strategy 2 (both intra-row and inter-row spacing), representing 7-8 and 11-13 botanical families respectively. Nine species were present in both strategies, 4 from the Compositae family (*Lactuca serriola, Helminthotheca echioides, Sonchus asper, Cirsium arvense*) and 3 from the Poaceae family (*Bromus* spp., *Lolium rigidum, Hordeum leporinum*), which were the families with the highest proportion. Other major families were Cruciferae and Apiaceae, although a greater number of species of the Cruciferae family (6) were found in the cover crop treatment. Moreover, the Apiaceae family showed the same predominance as the Caryophyllaceae and Leguminosae families in both sampling areas using Strategy 2.
Total plant density was 40-44 and 6-8 pl/m^2 in the two fields with Strategy 1, where *Bromus* spp. (40 pl/m^2) and *Helminthotheca echioides* (1.6 pl/m^2) were the most common species respectively. Fields with grass cover crop showed 28 and 18 pl/m^2 in the inter-row spacing and the most abundant species were *Erodium malacoides* and *Malva sylvestris* (5 pl/m^2) or *Cerastium glomeratum* (9 pl/m^2). Grass cover was higher than 50% in most of the plots (mean values

		South of Spain (CSIC)			North of Spain (INTIA)		
		Species	Families	Total plant density	Species	Families	Total plant density
Strategy 1	Inter-row spacing	13-17	6-8 Compositae, Poaceae	40 and 8 pl/m^2	20	11 Compositae, Poaceae	1683 pl/m^2
	Intra-row spacing	14-17	8 Compositae, Poaceae	44 and 6 pl/m^2	26	12 Compositae, Poaceae	149 pl/m^2
Strategy 2	Inter-row spacing 'COVER CROPS'	21-24	11-13 Compositae, Cruciferae, Poaceae	28 and 18 pl/m^2	16	9 Compositae, Poaceae	2128 pl/m^2
	Intra-row spacing 'NO TILLAGE'	21-24	10-11 Compositae, Poaceae, Cruciferae	86 and 14 pl/m^2	26	12 Compositae, Poaceae	149 pl/m^2

Table 2 - Main weed data obtained from the first sampling dates in southern and northern Spain

of 51% and 64% in each field) and plant density was 1540-1656 pl/m^2. In the intra-row spacing (no tillage), weed density before weed control was 86 and 14 pl/m^2 in each sampled field, with *Bromus* spp. (62 pl/m^2) and *Cerastium glomeratum* (2.5 pl/m^2) respectively being the most common species. The different weed density observed between fields with similar strategies (no tillage with chemical control) may be associated with the amount of olive pruning residues incorporated in the intra-row area (22% and 49% of ground cover respectively). Therefore, a higher volume of residues remaining as a mulch layer (around 1.2 kg/m^2) may have reduced the emergence of weeds.

In the north of Spain, 20 weed species representing 11 botanical families were identified in the inter-row spacing of Strategy 1. The family with highest proportion was Compositae followed by Poaceae. Plant density was 1683 pl/m^2, and the most predominant species were *Lolium rigidum* (995 pl/m^2) and *Sonchus* spp. (226 pl/m^2). In the inter-row spacing of Strategy 2 there were 16 species from 9 different families (mainly Compositae / Poaceae). Total weed density was high (2128 pl/m^2), probably due to the better germination conditions created by the shallow tillage operation carried out to sow the crucifer cover crop. *Lolium rigidum* was the most abundant species with a higher plant density than the *Sinapis alba* sown (1707 pl/m^2 vs 218 pl/m^2 respectively). Weed management of the intra-row spacing was similar in both strategies and a great diversity of species was found, with a total number of 26 species from 12 families being identified. However, plant density before weed control was much lower than the previous treatments (149 pl/m^2), ranging from *Filago pyramidata* (0.00125 pl/m^2) to *Sonchus* with 69 pl/m^2.

Weed samplings after applying the control methods have not finished yet at any location. Therefore, the weed biomass results will be presented when assessments are completed, along with those for soil fertility, olive yield and quality results, which are now being analysed.

Comments

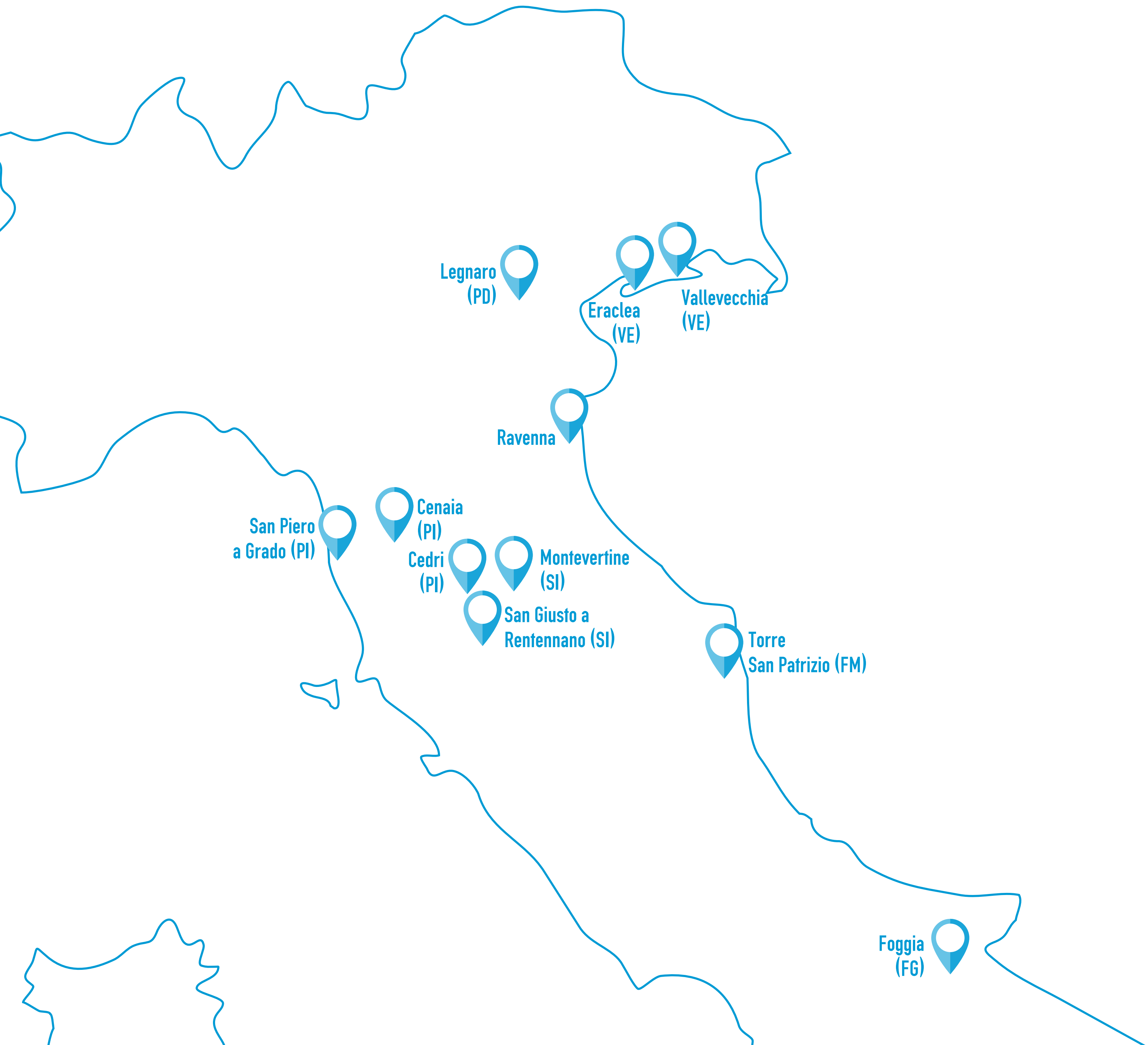
The design of the IWM strategies for the first year was based on the analysis of stakeholder interest from WP1 of this project, whereby experts and farmers were interviewed about their practices and visions for weed management. The first-year results will be available in the second half of 2019. Consequently, the IWM strategies for next year's experiment will be amended or remain similar according to the first-year results and local stakeholders' suggestions obtained from Open Field days and other dissemination activities carried out by IAS-CSIC and INTIA.

References

- 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
- Barralis, G., 1976. Méthode d'étude des groupements adventices des cultures annuelles. En: Vè Colloque International sur l'Ecologie et la Biologie des Mauvaises herbes, vol.1, pp. 59–68.
- 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. 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).
- Cucci, G., Lacolla, G., Crecchio, C., Pascazio, S., De Giorgio, D., 2016. Impact of long term soil management practices on the fertility and weed flora of an almond orchard. Turk. J. Agric. For. 40, 194–202. https://doi.org/10.3906/tar-1502-87
- Gómez, J.A., Guzmán, M.G., Giráldez, J.V., Fereres, E., 2009. The influence of cover crops and tillage on water and sediment yield, and on nutrient, and organic matter losses in an olive orchard on a sandy loam soil. Soil Tillage Res. 106, 137–144. https://doi.org/10.1016/j.still.2009.04.008
- Hess, M., Barralis, G., Bleiholder, H., Buhr, L., Eggers, T., Hack, H., Stauss, R., 1997. Use of the extended BBCH-scale – general for the description of the growth stages of mono- and dicotyledonous weed species. Weed Res. 37, 433–441.
- 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
- Lancashire, P., Bleiholder, H., Vandenboom, T., Langeluddeke, P., Stauss, R., Weber, E., Witzenberger, A., 1991. A uniform decimal code for growth-stages of crops and weeds. Ann. Appl. Biol. 119, 561-601. https://doi.org/10.1111/j.1744-7348.1991.tb04895.x
- MAPA, 2017a. Anuario estadísticas agrarias y alimentación. Superficies y producciones de cultivo. Olivar. Ministerio de Agricultura, Pesca y Alimentación . URL https://bit.ly/2DAn56f (Last accessed 02.08.19)

- MAPA, 2017b. 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, 2017c. 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
- 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.
- Saavedra, M., Pastor, M., 2002. Sistemas de cultivo en olivar. Manejo de malas hierbas y herbicidas, Editorial Agrícola Española, Madrid. 429 pp.

ITALY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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.

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

Conservation Agriculture (CA) is based on tillage reduction, continuous soil cover by crop residues and cover crops, and crop rotation. The adoption of CA produces major benefits, such as reduced fuel consumption, greenhouse-gas emissions and soil erosion, as well as improved soil fertility, but agronomic practices need to be adapted. Weed management, in particular for sod seeding, is more difficult because reduced soil tillage significantly limits the mechanical control of weeds. CA systems are consequently more dependent on herbicide use, including for cover crop termination.
Shifting to CA systems interrupts, caused by the tillage operations, of recurring burial and exhumation of weed seeds. Seeds also accumulate on the top soil layer where they have a higher probability of germinating. Minimizing weed dissemination is therefore crucial for progressively reducing the soil seed bank and consequently weed infestation density, thus allowing future control strategies to use less herbicide. Weed management is particularly important during the transition phase, since transition results affect the future sustainability of CA systems. Poor weed control would lead to a rapid increase in superficial soil seed bank and consequently to increasingly problematic weed infestations. A rational chemical control strategy is necessary, but careful cover-crop management also contributes both to controlling weeds and reducing herbicide use. Cover-crop mixtures and sowing techniques should be adapted to local conditions, since good cover-crop establishment and rapid growth are crucial to control weeds. Furthermore, the adoption of effective no-chemical termination (e.g. mechanical) techniques may reduce the environmental impact of CA systems.

Objectives

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

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

Materials and methods

This experiment is designed to simulate the transition phase, i.e. the first three years, from arable management to a CA system, by adopting a three-year crop rotation (wheat-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 will be adopted from the second year.

Figure 1 - Cover crop termination with Roller Crimper

Figure 3 - Cover crop undersowing in wheat plots

Figure 2 - Experimental scheme of the WP7 trial

Figure 4 - Cover crop size in May (left) and two months after 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 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

Table 1 - Main operations for the three treatments from 2017-2019

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 selecting cover crops which are killed by winter frost.

Detailed information about the different management types for the three treatments are presented in Figure 2 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 choose a suitable herbicide mixture. Given that weed presence was low, no herbicide was applied on T3 plots, while Traxos one (clodinafop 30 g/L, pinoxaden 30 g/L, florasulam 7.5 g/L at o.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 3). 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 (Figure 4).
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 5).

After the wheat had been harvested, a summer cover crop (sorghum) was sown in T2 plots on 12 July 2018 (Figure 6), while the clover mixture covered the soil surface among cereal stubbles in T3 plots. However, the clover mixture was not able to prevent the growth of perennials, such as *Sorghum halepense, Cirsium arvense* and other species, so a mechanical operation (mulching) was required to control them (Figure 7). This operation did not terminate the cover crop, which continued to grow.

No operations were conducted for the T3 plots until cover-crop termination in spring 2019 for all plots. Glyphosate was applied to T1 plots during the inter-cropping period in September and it controlled any emerged weeds. The summer cover crop sown in T2 plots grew very well, producing high amounts of biomass thanks to some summer rainfall (Figure 8).

It was therefore decided to partially harvest the biomass as silage for livestock to avoid potential

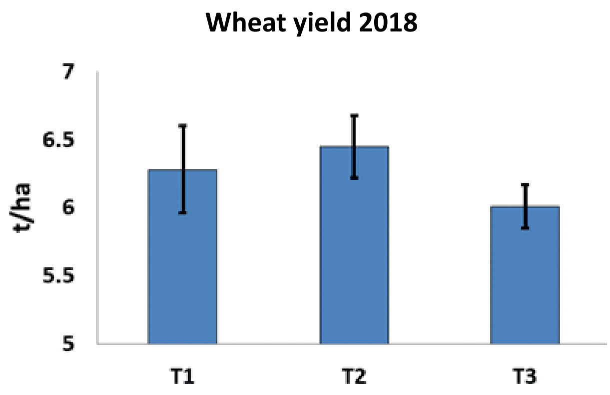

Figure 5 - Wheat yield obtained with the three treatments (T1, T2 and T3). Vertical bars represent standard errors

problems related to the 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 until early December due to rainy weather and consequently biomass production was scarce. Cover crops were terminated in April 2019 in all plots by applying glyphosate.
Sorghum was sown in all plots in June 2019 and a variety 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.

Maize was originally chosen, however water availability during the 2019 cropping season is uncertain due to the extremely low winter precipitation. Sorghum for silage production, which is more resistant to water stress, was therefore sown instead of maize. Sorghum will be harvested for silage production in September 2019 and autumn cover crops will be sown in October 2019 in all plots. Different cover crop species will be used for the three treatments: wheat or barley for T1 and T2, while a mixture of *Avena strigosa* and V*icia benghalensis* will be sown in T3 plots. Those species were selected because they are usually killed by winter frost and therefore no chemical or mechanical operations should be required for termination.

Further developments

This experiment will continue for a total of at least three years in order to monitor its evolution during

Figure 6 - Sowing summer cover crop in wheat stubbles

Figure 7 - Clover cover crop with high weed presence just before mulching in September 2018

Figure 8 - Sorghum cover crop at harvest in September 2018

the transition phase and evaluate the mid-term efficacy of the techniques. This experimental site will be used to organize field visits and demonstration activities to promote a fruitful exchange with local farmers and technicians, and the experimental protocol will be progressively adjusted according to results and feedback from local stakeholders.

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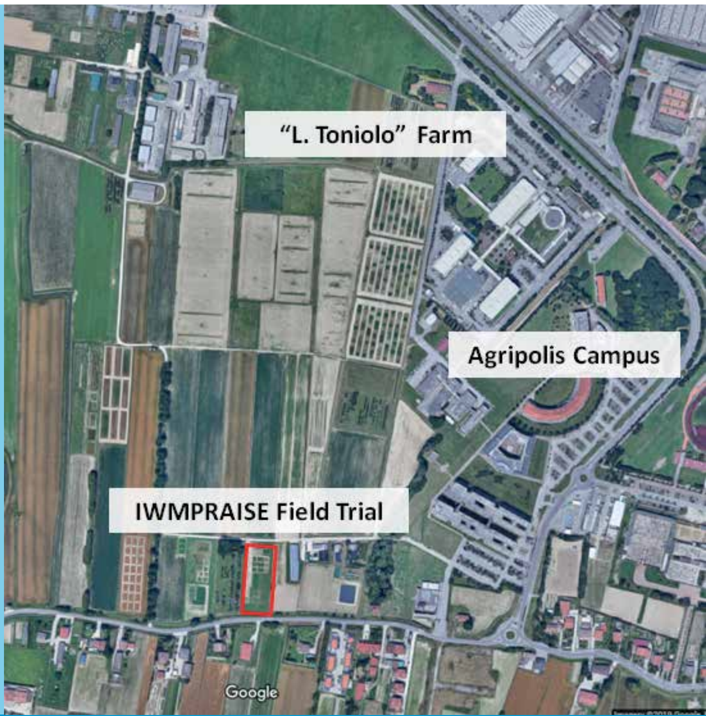
EXPERIMENTAL TRIALS AT THE "LUCIO TONIOLO" FARM

Consiglio Nazionale delle Ricerche



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

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WP3 – INTEGRATED WEED MANAGEMENT IN WHEAT

Cropping systems in Northern Italy are usually based on spring crops (e.g. maize, soybean) and wheat is usually cultivated every three or four years. Wheat-yield potential (7-9 t/ha) is higher in this area than in Italy's traditional wheat-producing regions. Weed infestation can therefore cause economically relevant yield losses, and weed management strategies normally rely on post-emergence herbicide application in spring. However, since spring crops are the majority of crop rotation, weed communities are not as specialized or as hard to manage as in wheat monoculture. Herbicide use can thus be reduced under these conditions by adopting a combination of mechanical and cultural control tools.
Mechanical tools, such as the false seedbed technique or flexible tine harrow, are very effective for weed management in wheat, but environmental conditions, such as soil moisture and weed size at the time of application, can strongly affect control efficacy. Low precipitation in autumn may decrease weed-seed germination and consequently make the false seedbed technique ineffective, while prolonged rainy periods in late winter/early spring may prevent the application of flexible tin harrowing. Cover crops can both facilitate weed management throughout the rotation, e.g. by avoiding weed growth during inter-cropping periods between wheat harvest and sowing of the subsequent spring crop, and maintain soil fertility. However, soil and weather conditions after wheat harvest are not usually optimal for cover crop sowing and establishment due to low soil humidity, low precipitation and high temperatures. The relay cropping technique, i.e. anticipating cover crop sowing by undersowing it in wheat crop, has been proposed as a means of improving cover crop establishment and soil cover during summer months, however limited information is available about its feasibility under Northern Italian conditions.

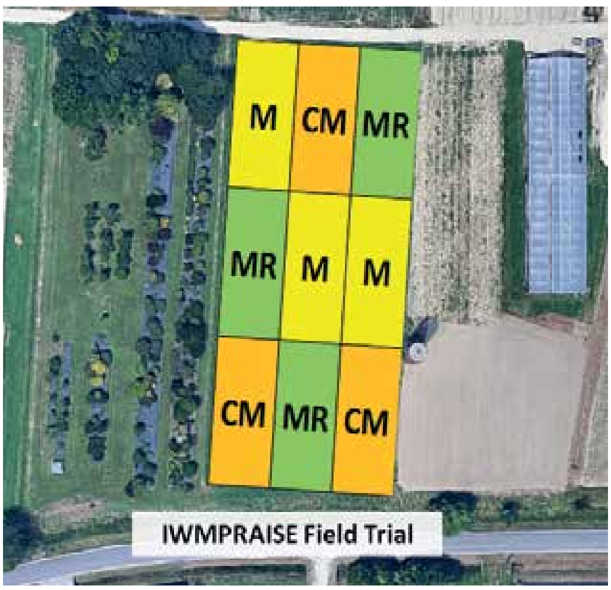

Figure 1 - Experimental design of WP3 field trial

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 of cover crop (clover) has on wheat.
The control strategies compared 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 season).
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;
- evaluate the effect of including relay cropping of clover in wheat in order to facilitate the adoption of cover crops.

2017-2018 experiment results

Prolonged dry periods in October 2017 limited weed emergence and consequently the efficacy of the seedbed technique, while excessive soil moisture throughout February and March 2018 impeded the use of flexible tine harrow in M plots. Two different herbicide mixtures were applied on 28 March 2018 on both the C and CM plots. The lowest weed density (11.7 plant/m^2) and biomass (10.8 g/m^2) were observed in treatment C (only chemical), while the highest (101.8 plant/m^2 and 122.5 g/m^2) was treatment CM (chemical + mechanical), probably due to the very high initial density of *Veronica persica* (above 200 plant/m^2) on one of its plots. High yields were achieved for all treatments, ranging from 8.9 t/ha (14% RH) for treatment C to 8.4 t/ha (14% RH) for treatments CM and M (Figure 2).

2018-19 experiment

During the 2017-18 experiment, satisfactory weed control and good yields were achieved for all treatments, including treatment M where no direct control tool was applied to the crop. This preliminary result was probably partly due to the cropping system (rotation with spring crops), which reduced weed density, and to favorable weather conditions which increased crop competition; however, it underlined the feasibility of low herbicide weed management in wheat. Given this consideration, the experimental design was modified for 2018-19 experiment in order to test another IWM tool, i.e. relay cropping of clover, and to advance in the direction of 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 autumn false seedbed, flexible tin harrowing and relay cropping.

Materials and methods

The experiment is being conducted in a test field where soybean and maize had been grown in the two previous years in order to reproduce the conditions of the area's typical three-year rotation. The experiment involves three weed-management strategies:

1) Treatment CM: integration of chemical and mechanical control with the false seedbed technique in autumn, plus spring post-emergence herbicide application only if necessary and attempts to minimize herbicide use;

2) Treatment M: only mechanical control with the false seedbed technique in autumn, plus flexible tine harrowing at the crop-tillering stage;

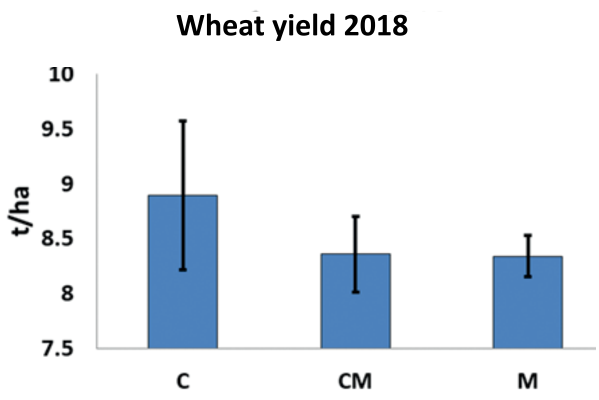

Figure 2 - Wheat yields (14% RH) obtained with the three control strategies (C: chemical control; CM: chemical and mechanical control; M: mechanical control). Vertical bars represent standard errors.

3) Treatment MR: mechanical control plus relay cropping of red clover. The same strategy for fertilizer application and crop protection (i.e. fungicide and insecticide application) was adopted for all three treatments. A randomized block design with three replicates was set up (replicate plot size: 30 m x 9 m = 270 m^2; total experiment size: about 3000 m^2). See Figure 1.

After the soybean had been harvested in October 2018, ploughing and rotatory harrowing were carried out on 16 October to prepare the false seedbed. Soil cultivation for seedbed preparation was then performed with rotatory harrowing on the whole field on 14 November, and wheat was sown on 16 November. The false seedbed period (16 October-14 November) was rather rainy and considerable weed

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

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

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. In order to evaluate whether postponing wheat sowing can affect yield in this area, a comparison will be made with other fields on the same farm with similar management but sown in mid-October 2018.
Weed assessment was conducted on 21 February 2019. On 25 February, 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 (mesosulfuron-methyl 15 g ai/ha+ iodosulfuron-methyl-sodium 3g ai/ha) was applied on 22 March on CM plots.
Weed assessment was repeated at wheat flowering to evaluate control efficacy of the three treaments and low weed density (less than 10 plant/m^2) and biomass (less than 20 g/m^2) was observed for all treatments. Good grain yields (6.8-7.3 t/ha at 14% RH) were achieved for all treatments without any significant differences. Cover crop growth will be monitored and its biomass will be evaluated some weeks after wheat harvest.

Figure 5 - Relay cropping. Clover at wheat harvest

Further developments

Given that any proposed strategy based on progressive reduction of herbicide use and substitution with mechanical control should be calibrated according to local environmental conditions and farming practices, promoting and maintaining a constant exchange with local farmers and consultants is a key issue. This is particularly important when innovative or uncommon tools, such as relay cropping of clover in cereals, are tested. The experimental field will be used as an occasion to spark a debate on weed management with reduced herbicide-use. Field days and other demonstration activities will be organized for this purpose and the list of control tools and strategies for next year's experiment will be amended according to the outcomes of the liaison with local stakeholders.
An additional reason for farmers involvement is to replicate on-farm experiments to test IWM strategies for wheat next year.

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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.*

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LTE – LONG-TERM EXPERIMENT ON 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); (ii) four N fertilization levels of the main crop, and (iii) four soil cover types (*Brassica juncea, Trifolium squarrosum, Vicia villosa* and a control).

Materials and methods

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: chiselling at 30 cm depth for summer crops and direct sowing for durum wheat.
The four levels of fertilization are arranged as a strip plot. The four levels are always constant in the ranking, but the amount of nitrogen changes according to the need of each cash crop: 0, 60, 120 and 180 kg of nitrogen per hectare for durum wheat; 0, 100, 200 and 300 kg for maize; and 0, 50, 100 and 150 kg 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, post-emergence (for maize and wheat) and pre-emergence (for sunflower) herbicides are used;

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

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 or crops. From 2008, weed cover at the full development of the cash crop(s) 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 the 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 crops 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, however, was not clearly detectable in summer and winter cash crops. A low-input system mainly favoured the presence of perennial weeds. In this system, weed total biomass increased when compared with the


Figures 4 and 5 - Sorghum grown in spring 2018 showing the effects of the previous cover-crop plots (photos by Lorenzo Tramacere and Massimo Sbrana)

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).

Further developments/Critical issues

Due to the increasing frequency of drought during the spring-summer period, the cash crops are going to be changed. More suitable species for rainfed conditions with drought risk, such as sorghum, will be tested, instead.

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.

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PERMANENT LEGUME LIVING MULCH FOR ORGANIC VEGETABLE AGROECOSYSTEMS

Vegetable crops are highly susceptible to weed competition. Crop rotation, mechanical control and transplanting are the main tactics for weed control in organic vegetable systems, but these techniques are often not enough to contrast weeds. Legume cover crops are already widely used as green manure in organic vegetable systems, but their role in weed control could be further explored.
We are focusing on the possibility of using legume cover crops as permanent living mulches in organic vegetable cropping systems. In this system, vegetable crops will be transplanted after strip-tillage. The living mulch is used to cover the inter-row space. This system has already been investigated in our pedo-climatic conditions, providing encouraging results. However, when growth of the living mulch is too high, even a relatively vigorous crop like potato or cabbage may suffer from competition and yield loss (Rajalahti & Bellinder, 1996 and Bottenberg et al., 1997).
The implementation of this system suffers from the lack of suitable species and/or cultivars. The availability of suitable legumes for this system is limited because currently available market cultivars are normally selected for other purposes, e.g. high biomass production, and, hence, they are likely to compete fiercely with the main crop.
This study searches for: (i) suitable perennial legumes - used as living mulch - that improve weed control all year round, and (ii) annual legumes that re-generate from the soil seed bank in the autumn and control weeds, used as living mulch during the winter and as dead mulch during the summer, hence also limiting the potential water competition with summer vegetable crops (Figures 6 and 7).

Objectives

The objective of this experiment is the agronomical evaluation and selection of well-adapted legumes (annual self-reseeding or perennial) to create a permanent, dense living mulch for no tillage or minimum tillage (strip tillage) in vegetable systems, thus exploring their weed-suppression potential.
In this experiment, we used 28 legumes (21 self-reseeding annuals and 7 perennials), including (i) commercial cultivars (5 *Trifolium repens*, 4 *Trifolium subterraneum*, 3 *Medicago polymorpha*, 2 *Lotus corniculatus*, and 1 *Medicago rigidula*, *Medicago truncatula, Trifolium vescicolosum* and *Trifolium michelianum*); (ii) wild ecotypes (8 *Medicago polymorpha* collected in Central and Southern Italy); and (iii) mixtures of wild ecotypes (1 *Medicago polymorpha* and 1 *Medicago orbicularis*).
The establishment of a permanent, dense living mulch may allow weeds to be controlled efficiently. The selection of legumes with the specific traits needed for this purpose may increase the practical application of this procedure. It is believed that legumes with a prostrate growth habit, moderate biomass growth and low-water requirement may be good candidates for this cropping system.

Materials and methods 2019

This experiment is being carried out in Pisa on a certified organic area at the “Enrico Avanzi” Centre for Agro-Environmental Research (CiRAA).
Twenty-eight legume species and ecotypes (perennial and annual self-reseeding) are being

Figure 6 - *Trifolium subterraneum* is a self-reseeding legume; in late spring, its plants flower and its seeds mature below the soil surface (photo by Federico Leoni)

Figure 7 - *Medicago polymorpha* is a self-seeding legume. During the vegetative stage, it produces a huge number of pods from which it regrows the following autumn (photo by Federico Leoni)

Legume species	Cultivars	Legume species	Cultivars
Lotus corniculatus	Giada	*Medicago truncatula*	Paraggio
Lotus corniculatus	Leo	*Trifolium repens*	Huia
Medicago polymorpha	Ecotype – Pitigliano (SI)	*Trifolium repens*	Haifa
Medicago polymorpha	Ecotype – Smanciano (GR)	*Trifolium repens*	Rivendel
Medicago polymorpha	Ecotype – Talamone (GR)	*Trifolium repens*	RD 84
Medicago polymorpha	Ecotype – Principina (GR)	*Trifolium repens*	Pipolina
Medicago polymorpha	Ecotype – Vsalto (SS)	*Trifolium michelanium*	Paradana
Medicago polymorpha	Ecotype – SFelceCirceo (SA)	*Trifolium vesiculosum*	Zulu
Medicago polymorpha	Ecotype – Bisenti (TE)	*Medicago orbicularis*	mix Ecotype (from Central Italy)
Medicago polymorpha	Ecotype – Tarqui (VT)	*Medicago polimorfa*	mix Ecotype (from Central Italy)
Medicago polymorpha	Mauguio	*Trifolium subterraneum (sub. Subterraneum)*	Dalkeith
Medicago rigidula	Ampus	*Trifolium subterraneum (sub. brachycalicinum)*	Antas
Medicago polymorpha	Anglona	*Trifolium subterraneum (sub. brachycalicinum)*	Fontanabona
Medicago polymorpha	Scimitar	*Trifolium subterraneum (sub. Subterraneum)*	Campeda

Table 2 - List of legumes used in the experiment entitled “Permanent-legume living mulch for organic vegetable agroecosystems”

tested on 4.5 m² plots. Each legume type is repeated in four randomized blocks. A collection of eight ecotypes of *Medicago polymorfa* L., provided by the University of Perugia, is being tested within the legume self-reseeding group (see Table 2 for details).

The legumes were sown in November 2017 on a field previously ploughed at 25 cm depth and refined with a rotative harrow. No herbicides, fertilizers or fungicides were used. The legumes and weed growth were constantly monitored and three key biomass samplings were performed (spring and autumn 2018 and spring 2019) in order to simulate the most common practices at farm level in this system before the hypothetical transplantation of summer and/or winter vegetable crops. The germination capacity and seed hardness of the self-reseeding legumes were also evaluated in autumn 2018 (Figure 8).

Results 2018

The 2018 season results confirm that legume cover-crops are an interesting and high-potential tool for weed management in organic vegetable systems (Figure 9). Biomass sampling in early spring 2018 showed that the presence of legumes reduced weed biomass by 50% when compared with the control. At this stage, despite the different legume growing speeds (e.g. *Trifolium repens* cultivars were generally characterized by slower growth in the early stage than other legume types), no significant differences between perennial and annual-self reseeding legumes were detected in terms of weed-control capacity.
Biomass sampling in autumn highlighted the strong

Figure 8 - Evaluation of legume self-seeding regrowth capacity (photo by Federico Leoni)

Figure 9 - *Trifolium subterraneum* shows good potential for weed control (photo by Federico Leoni)

weed-suppression effect of perennial legumes, which decreased weed biomass by 72% when compared with the control. At this stage, *Trifolium repens* cv Rivendel (commonly used for lawns) was the best compromise between weed-suppressive capacity and morphological traits for this system. The germination capacity of self-reseeding legumes in the first autumn after sowing showed that, despite the high seed production, some legumes were unable to regenerate a dense green mulch, probably due to the high seed-hardness (e.g. only 1% of *Medicago orbicularis* seeds germinated). However, *M. polymorpha* ecotypes from Principina (Grossetto), Pitigliano (Siena), and Talamone (Grossetto) had a good regeneration rate and were the most interesting for the target system. Evaluation will continue until spring 2019.

Further developments

The experiments ongoing at CiRAA in San Piero a Grado (Pisa) will be used as an open-air catalogue from which to select living-mulch solutions with high potential for local farms. Farmers will participate in organized field activities to share challenges and opportunities for including the use of a perennial living mulch in local organic vegetable cropping systems, with our experimental field being used as a practical example. From this exchange, we foresee being able to try some of the legume-wheat combinations tested directly on-farm.

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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 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 to cover the soil and control weed growth; not accumulate too much biomass to avoid excessive 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 sowing of the following crop. Commercial legumes selected for sole stand grain production or as forage may not always meet the specific requirements for being grown in intercropping; the selection of specific legumes is therefore necessary.

Objectives

The objective of this study is 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.

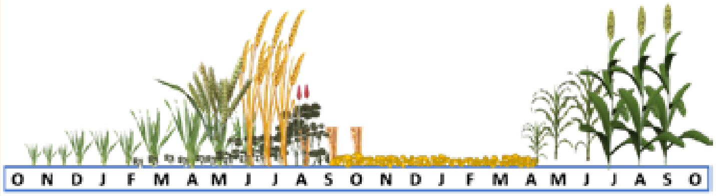
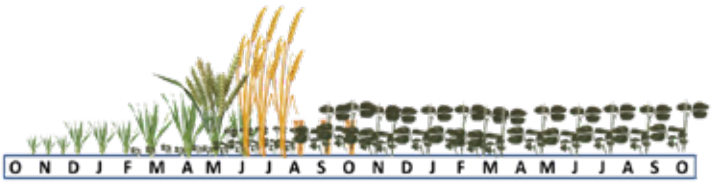
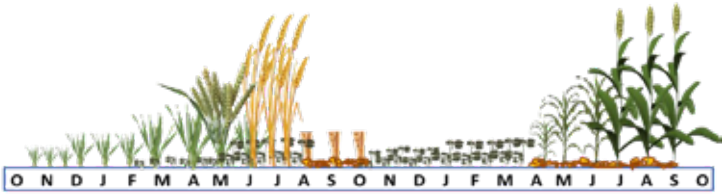
Cropping system	Overall hypothesis	Details on weed control service
Annual legumes / pulse legumes 	↑ weed control ↑ soil fertility ↑ grain quality	• Before wheat harvest as living mulch • After wheat harvest as dead mulch
Annual self-reseeding legumes 		• Before wheat harvest as living mulch • After wheat harvest as dead mulch (during the summer) and as living mulch (during the winter)
Perennial legumes 		• Before wheat harvest as living mulch • After wheat harvest as living mulch

Table 3 - Relay intercropping experiment description

After the wheat harvest, weed-control effect changes according to the group. Perennial legumes, traditionally used in this practice, can be used as a forage crop for the following two-to-three 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 (Table 3). Legume development, weed control, N availability, grain yield and grain quality are monitored in wheat until the following cash-crop (millet) is harvested.

Materials and methods 2019

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-crop, we are managing two fields (A and B, Figure 10). During the 2017/2018 season, we performed the relay intercropping of wheat and legumes in Field A. After the wheat harvest, the 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, self-reseeding legumes re-germinated from the seeds sown in summer and

Figure 10 - Location of experimental fields at the University of Pisa's Centre for Agro-Environmental Research (CiRAA) in San Piero a Grado (Pisa, Italy)

Figure 11 - *Hedysarum coronarium* during intercropping with wheat (left) and after wheat harvest the following spring (right) (photo by Federico Leoni)

Figure 12 - Overview of the experimental field immediately after legume sowing (photo by Federico Leoni)

behaved as cover crops until the sowing of millet (Figure 11). The millet was sod-seeded in May 2019 with the legumes being previously terminated with an adapted roller crimper produced by Dondi Spa (an IWMPRAISE partner company).

During the 2018/2019 season, we are performing the relay intercropping in Field B with maize as a previous crop and millet as a following crop. We are testing 11 legume types, including annual (*Trifolium incarnatum, Trifolium resupinatum, Lens culinaris*), annual self-reseeding (*Medicago polymorpha, 2 Trifolium subterraneum cultivars*) and perennial (*Medicago sativa, Medicago lupulina, Trifolium repens, Hedysarum coronarium*). The number of legumes has been reduced when compared with the 2017/2018 season because we excluded the least-performing ones from the first season.
The experiment is 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 is 18 m^2 (3 x 6 m). *Medicago sativa* and *Lens culinaris* are also being tested as sole crops in order to evaluate the Land Equivalent Ratio (LER) of these commercial crops. Moreover, there is a plot per block with only spontaneous vegetation to evaluate the maximum potential of weed infestation (Figure 12).

After preparing the seed bed (ploughing at 25 cm depth followed by rotary harrowing), in December 2018 we drilled a durum wheat Var. MINOSSE provided by ISEA (an IWMPRAISE partner company) with interrow distance of 18 cm. We subsequently drilled legumes in between wheat rows in February 2019 before the wheat stem elongation phase (Figure 13). *Medicago sativa*, *Trifolium repens* and *Trifolium subterraneum* cv Mintaro were

Figure 13 - Relay intercropping of *Trifolium subterraneum* cv Mintaro and wheat (photo by Federico Leoni)

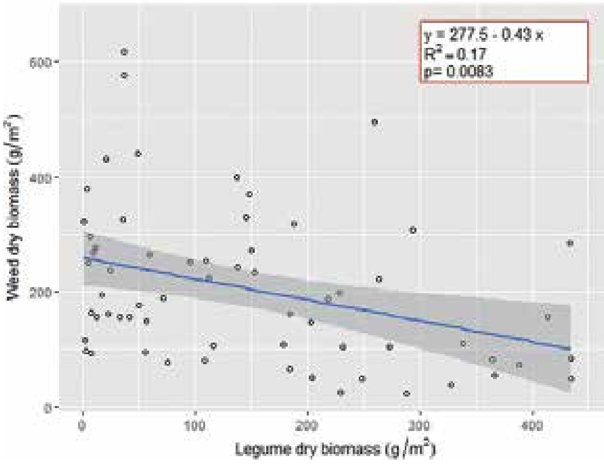


Figure 14 - Legume dry biomass (X axis) and weed dry biomass (Y axis). Weed control increases significantly with an increase in legume biomass

also broadcast sown to evaluate whether sowing technique affected legume and wheat performance.

Results from 2018

Results from Field A in the 2017/2018 season show that, although the legumes tested produced different amounts of biomass, grain yield at wheat harvest was not affected by the presence of legumes. Legume presence, however, decreased weed biomass by 56% when compared with the control. The effect of each legume on weed biomass varied considerably between types, with a higher weed suppression capacity for legumes with a higher biomass. Indeed, there was a significant negative correlation between legume and weed biomass (Figure 14). In autumn, after wheat harvest, perennial legumes reduced weed biomass by 70% when compared with the control. We also detected differences in the regrowth capacity of self-reseeding legumes in the first autumn after sowing. Indeed, despite the high amount of seed production, some legumes were unable to re-grow and establish a dense sward (e.g. *M. rotata, M. scutellata, M. truncatula*). Some other self-reseeding legumes, such as *M. polymorpha* and *T. subterraneum*, however, had good regrowth and are interesting for the target system.

Further developments

We will continue to exploit this on-going activity at the experimental farm as an open-air catalogue from which to develop intercropping solutions with local farms. In June 2018, a group of farmers participated in an organized open field day, which was an occasion for sharing challenges and opportunities

Figure 15 - Presentation of the IWMPRAISE experiments during the field day at CIRAA in June 2018 (photo by Stefano Carlesi)

for including intercropping in local cropping systems (Figure 15). From this exchange, new on-farm trials were initiated at La Viola and Floriddia farms (see pages 59 and 62).

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USE OF THE DONDI CUT-ROLLER AS A ROLLER CRIMPER

Objectives

The main objective of this trial is to test the effectiveness of the "cut-roller" as a roller-crimper for the mechanical termination of some of the most common winter cover crops for arable cropping systems. The cut-roller is produced by DONDI S.p.A. and marketed as a crop-residue management tool. Besides fine-tuning working speed and blade typology, special focus is being placed on weed suppression and soil compaction.

Materials and methods

An on-station field experiment is being carried out at the University of Pisa's "Enrico Avanzi" Centre for Agro-Environmental Research (CiRAA) in San Piero a Grado (Pisa, Tuscany). Three different cover-crop treatments (rye - *Secale cereale* L.-, hairy vetch – *Vicia villosa* Roth.-, rye-vetch mixture) were drilled on October 2017 on three different fields, each measuring 30 m x 260 m. The sowing rates were 180, 120 and 90:60 kg ha^{-1} respectively for rye, vetch and a rye-vetch mixture. 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 hr^{-1}) on the killing rate of the three cover crops. In 2018, the termination date was quite late (on 4 June and 5 June for sharpened and not-sharpened blades respectively) due to unusually wet conditions in spring. At that time, the phenological stage was full milky ripening (BBCH 77) for the rye and full flowering (BBCH 69) for the vetch. These phenological stages are well-known to be optimal for the mechanical termination of these cover crop species by roller crimper, as the plants have a limited ability to re-sprout. Immediately after the cover crops had been terminated, a grain sorghum cash crop (*Sorghum bicolor* (L.) Moench cv. Baggio) was direct drilled into the dead mulch provided by the cover crops.

We assessed the following parameters:

- Biomass and soil cover produced by cover crops at different stages, including termination;
- Weed abundance and composition in cover crops at different stages, including termination;
- Number of crimps per stem produced by the cut-roller on rye plants;
- Killing rate and dynamics of the cover crops (through image analysis);

Figure 16 - The 2018/19 field trial at CiRAA (photo ©2017 Google)

- 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 repeated in 2018/19 on three different fields (Figure 16). The cover crops were drilled later than the year before (11 December) due to very dry autumn conditions and an extended period of rain in early winter.

Preliminary results

The biomass produced by the cover crops at the termination date was quite good: 5.4, 6.5 and 3.5 t ha-1 for rye, mixture and vetch respectively. The mixture resulted in significantly higher biomass than rye and vetch pure stands. The cover crops succeeded in competing with weeds, which produced a maximum of 0.15 t d.m. ha^{-1} in the rye, whilst the weed biomass was significantly lower in the mixture (0.02 t d.m. ha^{-1}). As expected, the cut-roller performed very well when terminating the cover crops because of the late phenological stages of rye and vetch (Figure 17). On average, the half-life of the cover crops was around 4.5 days after the termination date, and a 90% termination rate was reached in less than two weeks.
We also assessed the proportion of crimped and cut biomass in each cover crop, as we thought this was an important indicator of the suitability for using the cut-roller as a roller crimper (i.e. a roller crimper should not cut plant tissues but simply crimp them). The cut-roller resulted in a higher proportion of crimped biomass in the rye (81-90%) than in the vetch (67-76%). The proportion of cut rye significantly increased in the mixture when compared with the pure stand, possibly due to higher water content in the tissue of the rye mixed with vetch. On average, the cut-roller produced five crimps per stem on rye, irrespective of whether it was pure stand or mixture.
Although the cut-roller produced indentations up to 2.5 cm deep when operated at 5 km hr^{-1} in combination with sharpened blades, it did not result in significant soil compaction. The cone index values at 15 cm depth measured by penetrometer did not show significant differences between the before and after termination dates. Overall, the soil penetration resistance values never exceeded the threshold of relevant soil compaction (i.e. 2000 kPa), despite the heaviness of the roller (~1.8 t ha^{-1}).
The sowing of sorghum was performed properly without the seeders clogging, although it was

Figure 17 - Termination of rye by cut-roller in 2018 (A). Sod-seeding of grain sorghum on vetch dead mulch the day after the cover crop had been terminated by cut-roller in 2018 (B)

performed much too close to the cover crop termination date.
Crop emergence was affected by the cover crop species, with higher values of emerged plants per square metre observed in rye plots, followed by the mixture and then by the vetch. On average, crop density was around 21 plants m^{-2}, a fairly low value when compared with sowing density, and most likely due to the amount of undegraded topsoil residues.
Nevertheless, sorghum plants grown in the vetch and mixture plots took advantage of the higher availability of nitrogen provided by the legume cover crop through N2-fixation and quickly overgrew the sorghum plants in the rye plots where N fertilization did not occur. This was well-documented by visual soil-cover analysis (Figure 18) and SPAD values.
At harvest time, this fast growth resulted in significantly higher sorghum yield and biomass in

Figure 18 - Development of sorghum on the three mulches one month and two months after sowing

the mixture and vetch plots, which was double those of the rye-plot sorghum. The final weed biomass was very low in all the treatments, with significantly lower values in the mixture plots (only 0.07 t d.m. ha^{-1}).

Further developments

The very good results obtained by using the cut-roller as a roller crimper in 2017/18 were clearly affected by the late termination date due to the wet spring conditions. The key factor for encouraging the spread of roller crimpers is a late termination date, even at the early stages of cover-crop development. In 2018/19, an additional trial took place on-farm to test the effectiveness of the cut-roller on rye and vetch at three different stages (i.e. before flowering/heading, beginning of flowering/heading, full flowering/end of heading). Additional assessments will also be focused on optimization of working parameters (e.g. speed, typology of blades, number of passes).

GPS coordinates of 2018/19 fields: 43°67’09.35’’N, 10°31’18.84’’E

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SMOCA LTE – CONSERVATIVE MANAGEMENT OF ORGANIC FIELD VEGETABLES

Objectives

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

Materials and methods

The experimental field is located at the University of Pisa’s Centre for Agro-Environmental Research (CIRAA) in San Piero a Grado (Pisa, Tuscany) (Figure 19). 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 is established on plots managed under no-till for the previous three years, is based on permanent soil cover with white clover and no-till transplanting of vegetables, whilst fertilization is reduced to a minimum level and will also involve the use of mycorrhizal formulations.

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

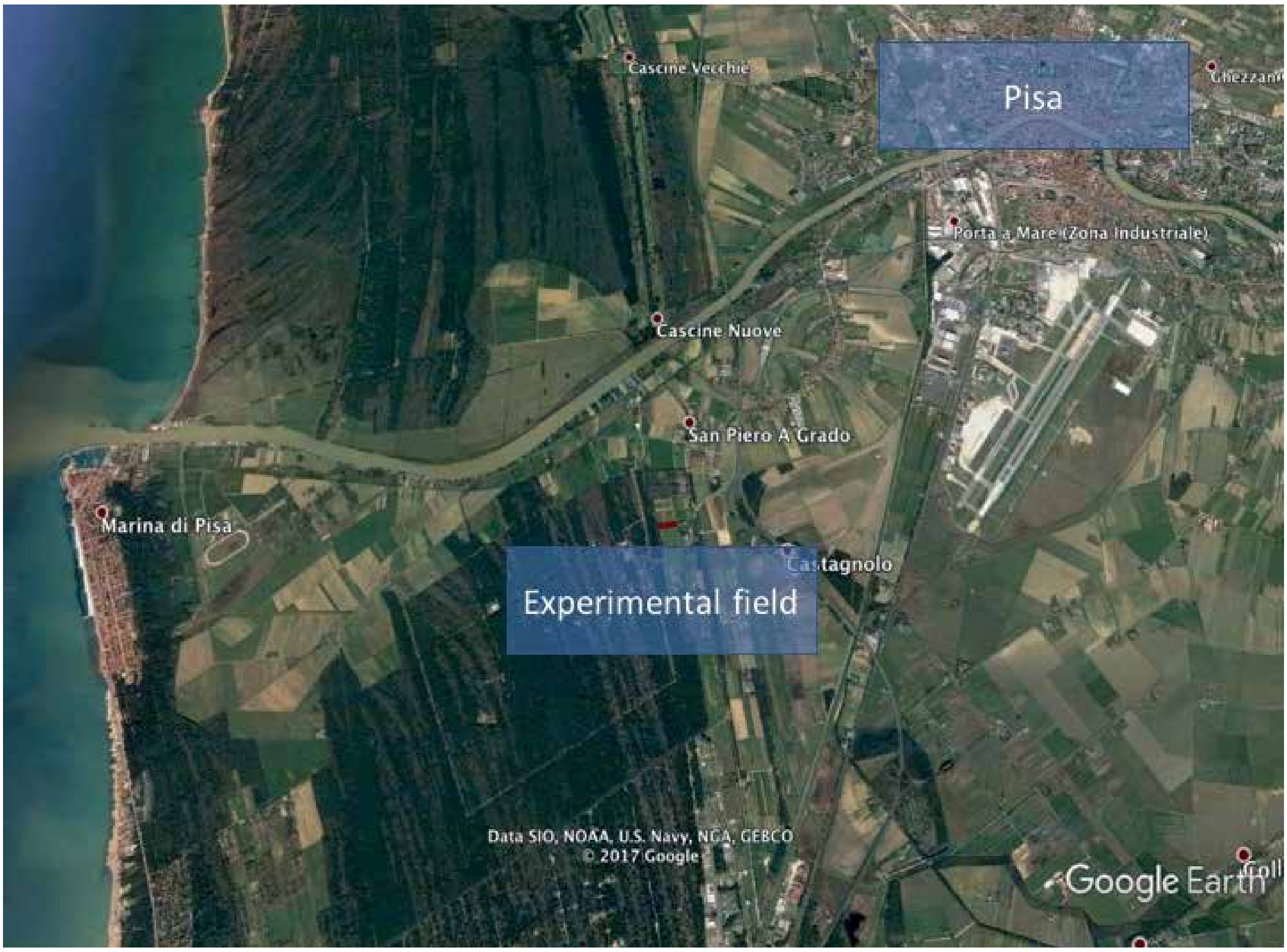

Figure 19 - 2018/19 field trial at CiRAA (photo ©2017 Google)

parameters;
- Rheological quality of crop produce;
- Energy consumption and monetary cost of each field operation.

The trial started with tomato (*Solanum lycopersicon* cv. Brixsol) and melon (*Cucumis melo* cv. Bacir) in 2017/18, but results were poor in terms of weed suppression and crop yield for both species. The main reason was the harsh weather conditions which affected the timeliness of both sowing the living mulch (postponed from autumn 2017 to April 2018) and transplanting the cash crop (from late April 2018 to late May 2018) due to frequent, heavy rainfall (Figure 20). Furthermore, an extremely wet late July 2018 dramatically increased the competition exerted by the weeds, which were mainly summer-growing species (e.g. *Echinocloa crus-galli, Setaria viridis, Digitaria sanguinalis*). After tomato, chicory (*Cichorium intybus* Pan di Zucchero cv. Uranus) was transplanted in early autumn and harvested in December 2018. Melon was followed by fresh bean (*Vicia faba* var. *major*), sown in January 2019.

Preliminary results

For melon, we did not observe statistical differences in fresh marketable yields, although PER and ORG clearly outperformed RED (+22% on average), mainly due to the lower weed biomass, which was significantly higher in the RED treatment. Soil-band cultivation and poor living-mulch establishment were the main reasons behind the poor performance by the RED treatment. However, due to the late transplanting date, the mean level of the field's marketable yield was very low compared with the usual standards (~15 t f.m. ha^{-1}).
For tomato, the ORG treatment yielded significantly higher than PER and RED in terms of fresh marketable yield (Figure 21). Weed biomass was not significantly different between the treatments and was on average very high (~ 6 t d.m. ha^{-1}). The most critical period for weed competition was around tomato flowering in late

Figure 20 - White clover living mulch in tomato grown in 2018

Figure 21 - Samples of tomato fruits at harvest in 2018

Figure 22 - Chicory after transplant in 2018

July, when intense rainfall caused summer-growing weeds (e.g. *Echinocloa crus-galli, Digitaria sanguinalis*) to develop quickly and overgrow the crop. Interestingly, although the same level of weed infestation and NK fertilization occurred in PER plots, we observed an increase in the number of fruits per plant and in N and P uptake. We argue that this might have been due to the effect of AMF inoculum replacing P fertilization.
There were far fewer problems with weeds in chicory grown in autumn-winter (Figure 22) than in melon and tomato. Weed biomass at harvest did not significantly differ between treatments and accounted for just 0.15 t d.m. ha^{-1} on average. In PER and RED plots, the development of white clover was very low, but the competition exerted by weed species, mainly represented by dicot species such as *Matricharia* spp., *Ranunculus* spp. and *Chrisanthemum* sp. present in patches, did not depress crop growth. Fresh marketable yield was not statistically different between treatments and reached the highest values in the PER plots, with 38 t ha^{-1}.

Further developments

The good results obtained by the PER treatment in tomato and melon, despite the very high weed infestation, are promising in terms of agroecologically sound fertilization strategies for no-till organic field vegetable production. Nonetheless, the poor development of white clover limits the performance of the PER and RED treatments, both in terms of crop yield and weed suppression in summer crops. For winter species, we obtained preliminary good results in chicory, but they need to be confirmed in fennel (*Foeniculum vulgare*) scheduled for autumn 2019. In 2019, we will continue testing the three treatments on a second melon crop, faba bean and fennel. At the end of this first round of crop rotation, we will analyze the results and make a decision on what living mulch to choose for the WP3 trials on relay intercropping and characterization of cover-crop species.

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EXPERIMENTAL TRIALS AT HORTA SRL

HORT@
From research to field

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.

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LEGUME AND DURUM WHEAT RELAY INTERCROPPING

Nitrogen deficiency and weed infestation are two of the major factors determining yield and grain protein content losses in cereal production, especially in organic farming. Durum wheat based cropping systems are common in Italy. Durum wheat is a major agricultural commodity because of the importance of Italy's pasta industry and it is the country's most-cultivated small grain cereal. Legumes can be used in durum wheat based crop rotations for optimizing nitrogen availability and weed control. Wheat-legume relay intercrops can be a sustainable and innovating tool for integrated weed management if appropriate legume types are used. Selection of the best-performing species is crucial because it is essential to use legumes with morphological and phenological traits suitable for this cropping system to ensure intercrop success. Legumes selected for sole stand grain production or as forage may not meet the specific requirements for being grown in intercropping. The legume ideotype suitable for relay intercropping should have high early vigour so that it can germinate below the wheat stand; be prostrate to cover the soil and control weed growth; and not accumulate too much biomass to avoid excessive competition with the crop during the wheat-growing season.

Objectives

The study includes annual, self-reseeding 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 the relay intercropping of legumes in wheat will allow farmers 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

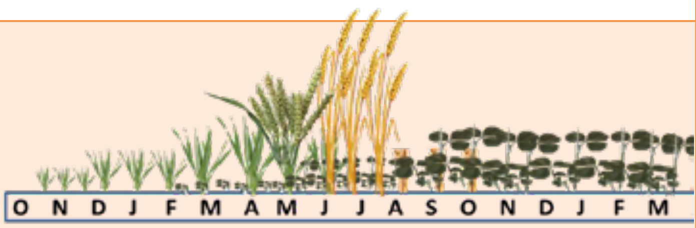
Biological cycle	Cropping system	Details on weed control service
Annual legumes		Weed control: **MEDIUM-HIGH** Soil cover: **MEDIUM-HIGH** Soil fertility: **MEDIUM-HIGH** System productivity: **MEDIUM**
Self-reseeding legumes		Weed control: **HIGH** Soil cover: **HIGH** Soil fertility: **HIGH** System productivity: **MEDIUM**
Perennial legumes		Weed control: **HIGH** Soil cover: **HIGH** Soil fertility: **HIGH** System productivity: **HIGH**

Table 1 - Description of the relay intercropping experiment

agroecosystems); and (iii) support weed control at rotation level.
In this context, self-reseeding legume species are a particularly interesting solution because they will be able to germinate in autumn after wheat harvest and cover the soil as living mulch until the following crop is sown (Table 1). In order to test solutions for different types of farms, the experiment also includes annual legumes (for forage production) and perennial legumes, as well as a test of various sowing techniques and times.

Materials and methods 2019

This experiment tests nine legume species, including annual (*Trifolium incarnatum, Trifolium resupinatum*), self-reseeding (*Medicago lupulina, Medicago polymorpha, Trifolium subterraneum*) and perennial *(Medicago sativa, Trifolium repens, Hedysarum coronarium*) ones (Table 2). *Medicago sativa* is also being tested as a sole crop in order to evaluate the Land Equivalent Ratio (LER)[1] of this important source of forage. Additionally, there is a plot per block with spontaneous vegetation only in order to evaluate the maximum potential

Legumes	Type	Sowing technique
Trifolium incarnatum cv. Kardinal	Annual	Broadcast sowing
Trifolium resupinatum cv. Laser	Annual	Broadcast sowing
Medicago lupulina cv. NA	Perennial	Broadcast sowing
Medicago polymorpha cv. Scimitar	Self-reseeding	Broadcast sowing
Medicago scutellata cv. Sava	Self-reseeding	Broadcast sowing
T. subterraneum sub. brachycalcinum cv. Mintaro	Self-reseeding	Broadcast sowing
T. subterraneum sub. brachycalcinum cv. Mintaro	Self-reseeding	Row sowing
Hedysarum coronarium cv. Carmen	Perennial	Broadcast sowing
Medicago sativa cv. Gamma	Perennial	Broadcast sowing
Medicago sativa cv. Gamma	Perennial	Row sowing
Trifolium repens Ladino cv. Companion	Perennial	Broadcast sowing
Trifolium repens Ladino cv. Companion	Perennial	Row sowing
Medicago sativa cv. Gamma	Perennial	Broadcast sowing
Control 1 (*M. sativa* as sole crop)	Perennial	Row sowing
Control 2 (wheat as sole crop)		
Control 3 (no crop)		

Table 2 - List of legumes tested in the 2018/2019 growing season

[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.

Figure 3 - Legumes sown by broadcasting (on the left) and in-row (on the right) between wheat rows in May 2018 (photos by Matteo Ruggeri)

Legumes	Sowing time (BBCH of wheat)	Seed placement	Seed dose (kg/ha)
Medicago sativa cv. Gamma	BBCH 0	In the wheat row	20
Medicago sativa cv. Gamma	BBCH 0	Between wheat row	20
Medicago lupulina cv. NA	BBCH 0	In the wheat row	40
Medicago lupulina cv. NA	BBCH 0	Between wheat row	40
Trifolium repens Ladino cv. Companion	BBCH 0	In the wheat row	10
Trifolium repens Ladino cv. Companion	BBCH 0	Between wheat row	10
Medicago sativa cv. Gamma	BBCH 21	Between wheat row	10
Medicago sativa cv. Gamma	BBCH 21	Between wheat row	20
Medicago sativa cv. Gamma	BBCH 21	Between wheat row	40
Lens culinaris cv. Elsa	BBCH 21	Between wheat row	120
Lens culinaris cv. Elsa	BBCH 30	Between wheat row	120
Control (wheat as sole crop)			

Table 3 - List of legume/wheat combinations and sowing times tested in the 2018/2019 growing season

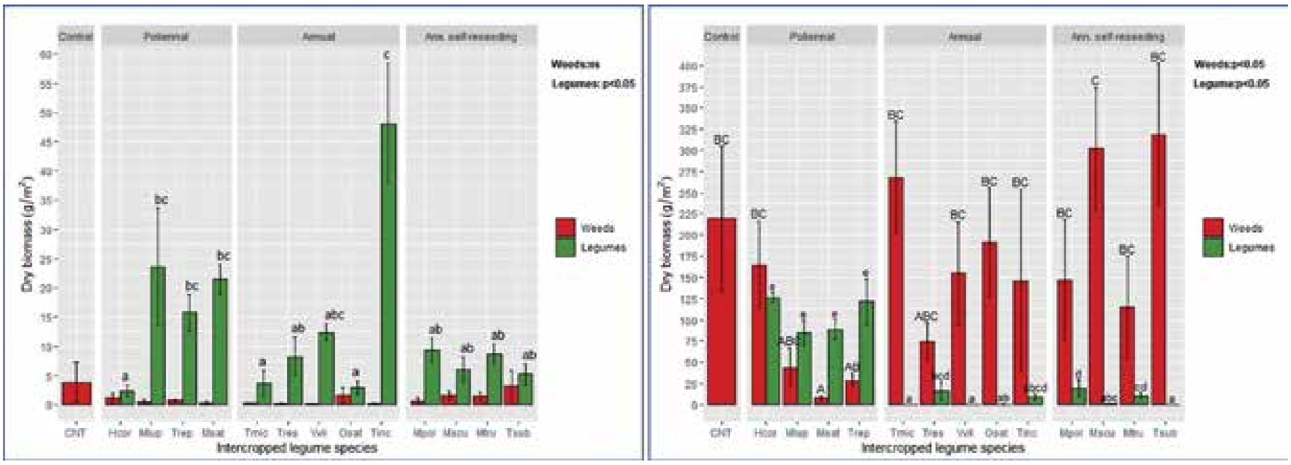


Figure 4 - Weeds (red bars) and legume (green bars) dry biomass for each legume type at wheat harvest (on the left) and in the following autumn (on the right).

Legend: CNT: control (wheat as sole crop), **Hcor:** *Hedysarum coronarium*, **Mlup:** *Medicago lupulina*, **Trep:** *Trifolium repens,* **Msat:** *Medicago sativa,* **Tmic:** *Trifolium michelianum,* **Tres:** *Trifolium resupinatum,* **Vvil:** *Vicia villosa,* **Osat:** *Ornithopus sativus,* **Tinc:** *Trifolium incarnatum,* **Mpol:** *Medicago polymorpha,* **Mscu:** *Medicago scutellata,* **Mtru:** *Medicago truncatula,* **Tsub:** *Trifolium subterraneum*

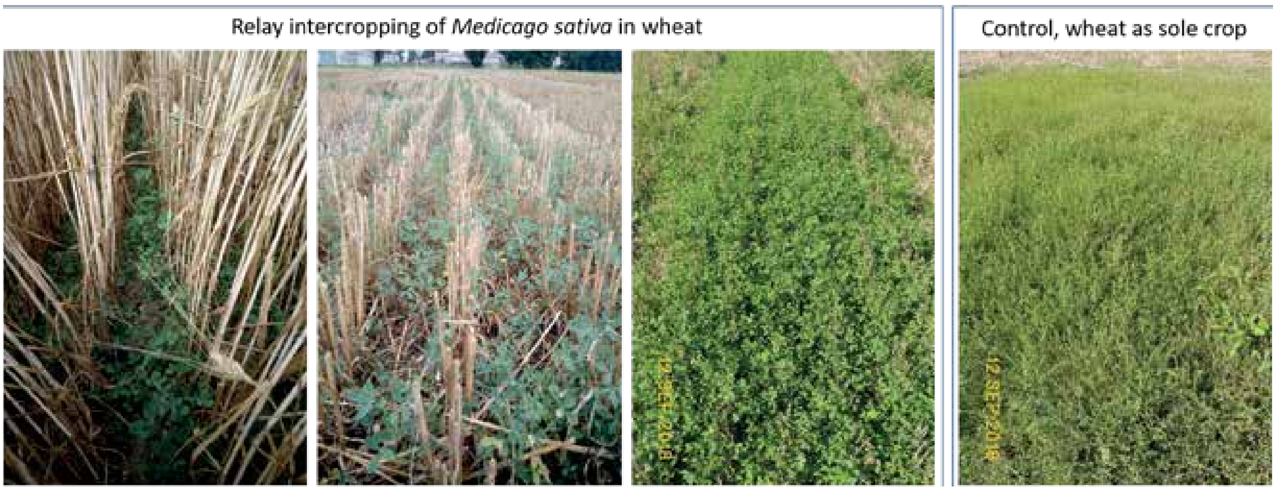


Figure 5 - From left to right: *Medicago sativa* during intercropping, *Medicago sativa* immediately after wheat harvest, and *Medicago sativa* the following autumn. In comparison, the control plot (wheat as sole crop) the following autumn (photos by Matteo Ruggeri)

of weed infestation. The experiment is organized in a randomized complete block design, with four replicates for each legume type and the sole wheat crop as a control. The plots area is 9 m^2 (1.5 x 6 m). After seed bed preparation, durum wheat var. Minosse (provided by IWMPRAISE partner ISEA) was sown in November 2018, with a 17 cm inter-row distance. Legume species were then broadcast sown between the wheat in February 2019 before the wheat stem elongation phase. Harrowing was performed immediately after legume sowing. The use of harrowing in this system is very interesting because it both incorporates legume seeds into the soil and contributes to improving weed control.

Medicago sativa, Trifolium repens and *Trifolium subterraneum* were also sown in-row between the wheat inter-row in order to evaluate whether the sowing technique affected legume and wheat performance (Figure 3). An additional trial was set up in the 2018/2019 season in order to test a range of sowing techniques, timings and doses. Details are reported in Table 3.

Results 2018

Preliminary results from the 2017/2018 growing season are available. Cover crops that led to the worst performance in season 2017/ 2018 were excluded from the 2018/2019 experiment. At wheat harvest time (June 2018), the intercropped legumes did not compete with the wheat. There were no significant differences in terms of grain production between intercropped wheat stands and wheat as the sole crop. The average grain production was perfectly in line with the area's high production level.

This preliminary result seems to confirm the hypothesis that it is possible to avoid competition with the main crop in intercropping systems by delaying legume sowing time. During the intercropping period, legumes seem to be affected by wheat competition (mainly for light), remaining in a sort of quiescent growing stage until wheat harvest. Indeed, legume biomass was generally low before wheat harvest in this location. Weed biomass was also very low at wheat harvest and no differences were detected.

In the post-summer assessment (September 2018), weeds were more developed and weed biomass in plots with perennial legume species was lower than in the ones with other legume types (Figure 4). At this stage, a clear difference among cover-crop development was linked to their biological cycle, with perennial species showing higher biomass than the annual or self-reseeding ones (Figure 4).

As expected, annual and annual self-reseeding legumes were characterized by very low levels of biomass in this period because of their biological cycle. Annual legumes may be used to cover the soil as dead mulch during the winter, even though preliminary results suggest that annual species may not work well in this system because of poor biomass development during the intercropping period. Annual self-reseeding species will germinate from their seeds later, covering the soil as living mulch until the next cash crop. However, it is necessary to explore several years of results to fully understand the effects of different legume types on weeds.

Further developments

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

EXPERIMENTAL TRIALS AT CREA-CI

Figure 1 - View of the CREA-CI main building and experimental farm, Foggia

The Research Centre for Cereal and Industrial Crops (CREA-CI) (Figure 1) is located in Foggia, southern Italy, and it is part of Italy's Council of Agricultural Research and Agricultural Economy (CREA) network of agri-food research centres. CREA-CI deals with the genetics, genetic improvement, breeding and agronomy of cereals for human and animal consumption, as well as the maintenance of cereal germplasm collections from the Mediterranean area. CREA-CI also has a 148 ha experimental farm and laboratories for pasta and bread technology, food chemistry, plant genomics and metabolomics.

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71121 Foggia - Italy
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WHEAT AND LENTIL INTERCROPPING USING SEMINBIO®

Weed competition is a crucial aspect in organic farming systems, especially for annual crops such as cereals and grain legumes. Sowing density and spatial arrangement of plants play a crucial role in weed control.
The seeder prototype SEMINBIO® (http://www.seminbio.it) is an innovative sowing system designed by Foggia's CREA-CI that improves weed control in organic field crops.
SEMINBIO® (Figure 2) optimizes seed distribution, ensuring fast soil cover by the crop, a rapid and improved uptake of nutrients, and enhanced competitive ability against weeds.

Trials with the SEMINBIO® seeder in Southern and Central Italy on wheat showed that, when compared with ordinary seeders, its sowing layout increased wheat yield, irrespective of weed presence, and decreased weed development when weeds were present.
The use of SEMINBIO® to drill cereal-legume intercrops may be an interesting application of this innovative sowing machine. The optimized spatial seed distribution allows farmers both to minimize the interspecific competition between wheat and legume and to maximize crop competition against weeds.
The intercropping of durum wheat and lentil is particularly interesting because lentil cultivation is often dogged by susceptibility to lodging. Intercropping, however, may reduce this problem significantly, as wheat culms can operate as a mechanical support for lentil, thus limiting lodging.

Objectives

This experiment aims to study the use of SEMINBIO® for the intercropping of durum wheat with lentil. The objectives are to (i) optimize the spatial distribution of the plants within the intercrop and (ii) to maximize weed control.

Materials and methods

This experiment is being carried out in Foggia by the Research Centre for Cereal and Industrial Crops in partnership with ISEA Srl, a breeding company and IWMPRAISE partner. The trial aims to test the intercropping of wheat with lentil in on-farm conditions and it is arranged in 500 m² plots managed with on-farm scale equipment. Sowing was performed in February 2019 using the SEMINBIO® seeder.
Durum wheat cv San Carlo and Lentil cv Elsa (provided by ISEA) were used in this experiment. The two plots with sole wheat (Figure 3) and sole lentil (Figure 4) were sown at a rate of 450 and 300 germinating seeds/m² respectively. In the intercrop plot (Figure 5), the seeding rate was kept constant for lentil and deceased to 1/3 of the dose used in the sole crop for wheat. We used a reduced dose of wheat to avoid interspecific competition with the lentil.

During the current growing season, monitoring will be carried out on:

i) Lentil and wheat yields, both for the intercropping and monocultural systems.
ii) Effects of intercropping on weed suppression, with weed density being measured after the wheat and lentil emergence phase and weed biomass at wheat-lentil harvest time.

Figure 2 - The SEMINBIO® seeder (photo by Giovanni Laidò)

Further developments

This experiment will be used as a starting point for promoting both intercropping and an increase in legume cultivation in cereal-based cropping systems in South Italy to improve non-chemical weed control in these systems.

Figure 3 - Plot of durum wheat cv San Carlo in monoculture sown using SEMINBIO® (photo by Giovanni Laidò)

Figure 4 - Plot of lentil cv Elsa in monoculture sown using SEMINBIO® (photo by Giovanni Laidò)

Figure 5 - Plot of intercropping between wheat and lentil sown using SEMINBIO® (photo by Giovanni Laidò)

ON-FARM EXPERIMENTAL TRIALS LA FAGIANA FARM

La Fagiana farm specializes in producing and marketing Superfino Carnaroli rice. It began growing rice in 1960 and for many years its rice was husked manually for the family's consumption. Today, the farm's rice cultivation and husking are partly mechanized, and although this has resulted in higher yields, its rice has all the hallmarks of an artisan product. Rice flour, rice cakes, ready-made risottos, fruit juices, wines and craft beers are also produced and marketed under the farm's brand.

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

Reducing herbicide use and introducing alternative control methods is a key priority in Europe. Mechanical weed-control is usually adopted in inter-row of wide-row crops such as maize via soil cultivation operations that also aim to incorporate fertilizer. However, common weed management in maize is based on the broadcast application of pre- or post-emergence herbicides, so herbicides are also applied in inter-row where mechanical control is performed.
Reducing herbicide use is feasible under these conditions as farmers can switch from a broadcast application to a localized (band) application along the crop row where mechanical control is not performed. The extent of reduced herbicide use would be related to the size of the treated area, which can be narrowed using precision agriculture technologies (semi-automatic deriving systems in tractors with RTK correction). This approach requires the various farming procedures to be carried out with great care, however precision positioning and auto-steering systems based on RTK/GPS technology are now available for tractors. The currently available systems for herbicide band application are based on sowing machines equipped with nozzles that spray along the crop row (Figure 1).

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

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

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

Objectives

Given that environmental conditions can strongly affect the feasibility and efficacy of mechanical and chemical weed control tools, developing alternative solutions for low herbicide input strategies is crucial for guaranteeing flexibility when dealing 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);
- 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).

Materials and methods

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

The experiment is set up in one field and includes four 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 will be performed for all treatments to control weeds and incorporate fertilizer into the soil. A randomized block design with three replicates was adopted with plot size of 150 m x 9 m = 1350 m^2 and total experiment size around 2 ha.

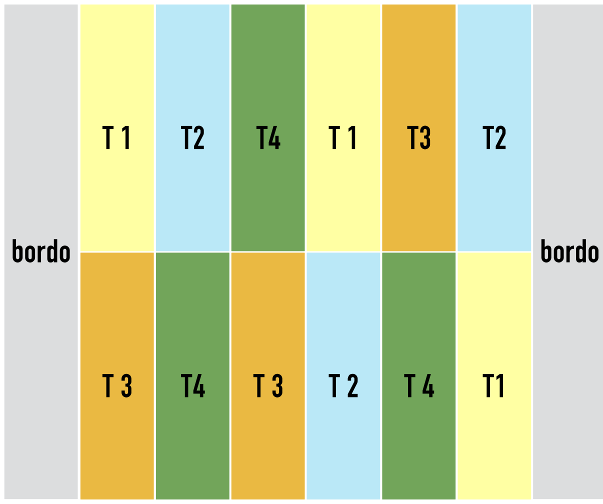
Maize was sown on 19 April 2019 using a tractor equipped with RTK/GPS positioning and an auto-steering system to map crop rows.Pre-emergence herbicide band application (Lumax 1 L/ha, active ingredients: mesotrione 37.5 g/L, S-metolachlor 312.5 g/L, terbutilazina 187.5 g/L, band width treated 25 cm, spray volume 100 L/ha) was performed on T2 plots using a sowing machine equipped with specific nozzles (Figure 6A).

The following day, broadcast pre-emergence herbicide application (Lumax 3 L/ha, active ingredients: mesotrione 37.5 g/L, S-metolachlor 312.5 g/L, terbutilazina 187.5 g/L, spray volume

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

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

Figure 5 - Experimental scheme of the WP4 trial



LEGEND

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

300 L/ha) was carried out on T1 plots with a boom sprayer. 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 crus-galli, Polygonum aviculare, Polygonum persicaria, Solanum nigrum* e *Sonchus asper*) with a total density of 30-40 plants/m^2 (Figure 7).
The first post-emergence herbicide application with the Maschio Gaspardo prototype was done on 7 June 2019 at the maize 5-6 leaf stage on T4 plots. It was a band application of Laudis 0.7 L/ha (tembotrione 44 g/L), Mondak 480 S 0.17 L/ha (dicamba 480 g/L), spray volume 100 L/ha. On the same day, broadcast post-emergence herbicide application was carried out on T3 plots (Laudis 2 L/ha (tembotrione 44 g/L), Mondak 480 S 0.5 L/ha (dicamba 480 g/L), spray volume 300 L/ha). During the following days, inter-row soil cultivation was carried out on all plots apart from T4 plots. A second weed assessment is scheduled one month

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

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

Figure 7 - Weed population before inter-row cultivation

after post-emergence herbicide application to evaluate the weed-control level obtained with the various treatments, after which the harvest yields for each plot are measured.

Further developments

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

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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:
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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. Lentil and wheat intercropping 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 landrace of lentil. When compared with local production levels, the intercropping of wheat and lentil ensures sufficient production of wheat (1.8 t/ha on average), good production of lentil (0.35 t/ha on average) and supports weed control. Although it ensures an acceptable level of production, the intercropping can be optimized by increasing lentil density in a bid to maximize yield and weed control.

Objectives

The aim of this on-farm trial is to optimize wheat-lentil intercropping under the local conditions of La Viola cropland. The specific objectives are to:

- maximize lentil production;
- maintain acceptable wheat production levels;
- minimize wheat-to-lentil competition;
- maximize weed control.

Materials and methods

This experiment tests four seeding rates for lentil (75, 100, 125, 150 kg/ha) combined with a fixed seeding rate for wheat (185 kg/ha) (Figure 2).

Additionally, both lentil and wheat are grown as sole crops with a standard seeding rate being 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 describes the yield advantage obtained by growing two or more crops

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

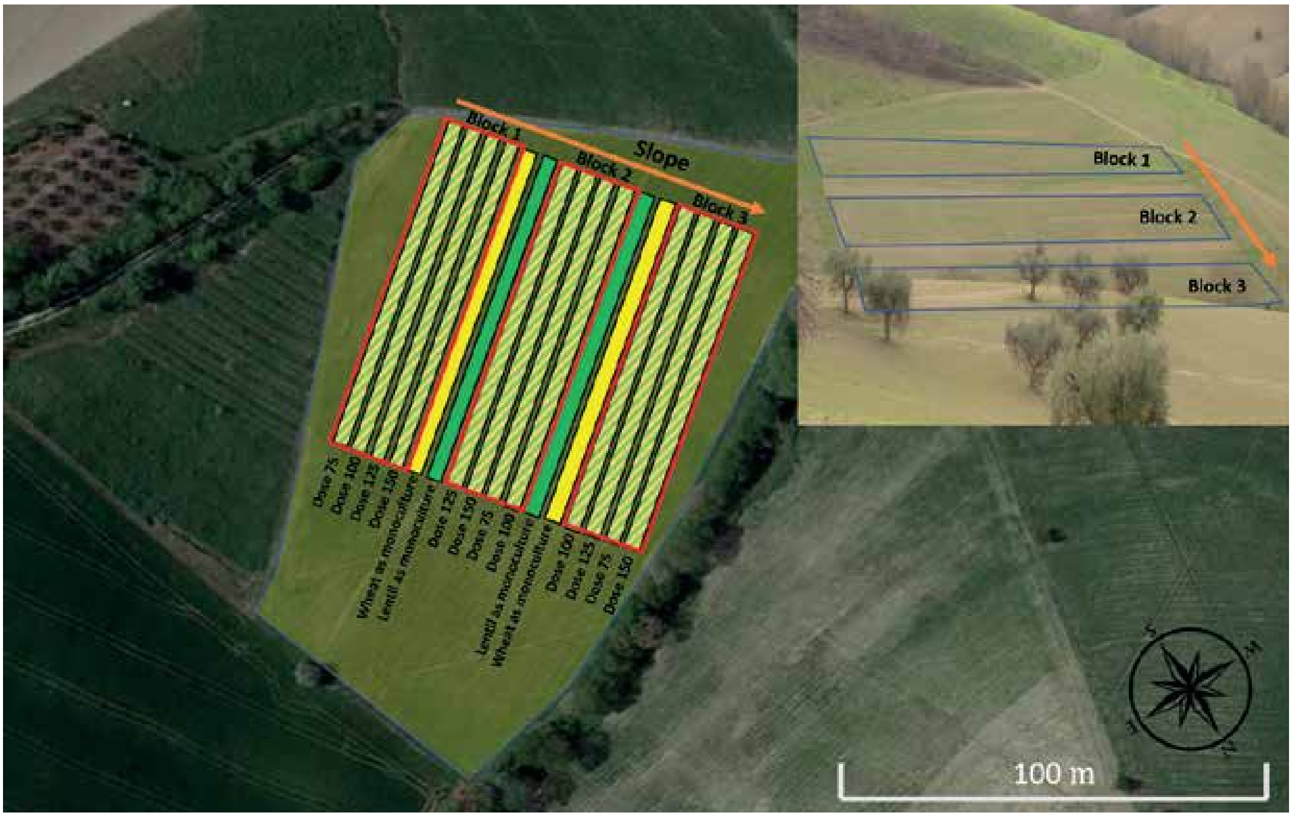

Figure 2 - Experiment layout


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

or varieties as an intercrop when compared with growing the same crops or varieties as a collection of separate monocultures.
The experiment is organized in a randomized complete block design, with three replicates for each lentil seeding rate. The plot area is 500 m^2 (6 x 80 m per plot). Randomization and block orientation were performed taking into account the maximum gradient of variability in the experimental field, which is the slope.
After seedbed preparation wheat and lentil were broadcast sowed using a seeding machine equipped with two hoppers for cereal and grain legume respectively (Figures 3 and 4). Hoppers were set in order to provide a constant seed dose of wheat and vary the lentil dose for each plot (Figure 5).

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

i) lentil and wheat emergence (Figure 6), plus yield;
ii) intercropping efficiency by estimating LER;
iii) effects of intercropping on weeds.

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

Figure 6 - Counting emerged wheat and lentil (photo by Stefano Carlesi)

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.*

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56030 Località Cedri - Peccioli (PI) - Italy
GPS coordinates: 43°29'11.18''N 10°47'54.06''E

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CHICKLING VETCH AND EMMER INTERCROPPING

Chickling vetch is traditionally cultivated in the regions of Central and Southern Italy, and it is among the legumes produced by Floriddia farm (Figure 1). It grows very well locally, but its high lodging susceptibility makes it difficult to harvest mechanically. However, intercropping chickling vetch with a cereal may significantly reduce lodging problems and prevent yield loss.
The hypothesis is that intercropping may reduce lodging problems because the associated cereal culms work as mechanical supports 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. The objective is to maximize chickling-vetch production and prevent yield loss due to lodging. Additionally, intercropping with a cereal may support weed control in this legume, which is not highly suppressive.

Materials and methods

In this experiment, we are studying intercropping of chickling vetch and emmer. After seed bed preparation, chickling vetch and emmer were sown in February (Figure 2). The chickling-vetch seeding rate was 100 kg/ha and the 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 field with the intercropping, chickling vetch and emmer were also sown as sole crops to evaluate Land Equivalent Ratio (LER) (Figure 3). LER describes the yield advantage obtained by growing two or more crops or varieties as intercrops when compared with growing the same crops or varieties as a collection of separate monocultures.

During the current growing season, an assessment will be performed both on the chickling vetch and on the emmer in order to collect data on:

i) chickling vetch and emmer emergence and yield;
ii) intercropping efficiency by calculating LER;
iii) effects of intercropping on weeds;
iv) post-harvest grain separation with on-farm tools.

Figure 1 - Chickling vetch grown on Floriddia farm (photo by Federico Leoni)

Figure 2 - Setting-up the seeder (photo by Stefano Carlesi)

Figure 3 - From left to the right: monoculture of chickling vetch, intercropping of emmer and chickling vetch, monoculture of emmer (Photos by Federico Leoni)

MARTELLO NADIA FARM

Figure 1 - The 2018/19 field trial at Martello Nadia farm (photo ©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
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56042 Località Cenaia - Crespina Lorenzana (PI)
Italy

GPS coordinates: 43°67'08.51''N 10°31'19.57''E

USE OF THE DONDI CUT-ROLLER AS A ROLLER CRIMPER: EFFECT OF TERMINATION DATE AND NUMBER OF PASSES

Objectives

To test the effectiveness of the “cut-roller” as a roller-crimper for the mechanical termination of some of the most common winter cover crops for arable cropping systems at different termination dates. The cut-roller is produced by DONDI S.p.A. and marketed as a tool for crop residue management. It is well-known that roller crimpers are quite effective for killing grass and legume cover crops (e.g. rye, vetch) at late phenological stages (i.e. milky ripening for grasses and full flowering for legumes). Nevertheless, well-timed sowing dates for spring crops are essential in Mediterranean climates to escape severe drought conditions and achieve satisfactory yield results. Improving the efficiency of roller crimpers at the early phenological stages of cover crops could pave the way for a wider adoption of cover crops as an IWM tool.

Materials and methods

Two different cover-crop treatments (rye - *Secale cereale* L.-, hairy vetch – *Vicia villosa* Roth.) were drilled in September 2018 on two separate fields measuring ~1 ha each (Figure 1).

The sowing rates were 180 and 40 kg ha^{-1} for rye and vetch respectively. On sub-plots, we tested the effect of three different termination dates (full vegetation stage vs early earing/flower set vs milky ripening/full flowering) on the termination dynamics of each cover crop species (Figure 2), with the roller crimper being passed once or twice. The second crimp was performed one week after the first in order to raise stress levels on the plants as soon as they started recovering from the first pass.

Each treatment (i.e. the factorial combination of termination date and number of passes for each cover crop) was replicated on five pseudo-replicates. The cut-roller was equipped with not sharpened blades and operated at a working speed of 10 km hr^{-1}. To maximize roller weight and action, the cut-roller was filled with water so that it weighed up to 2.7 tons. After the cover crops are terminated for the last time, a grain sorghum cash crop (*Sorghum bicolor* (L.) Moench cv. Baggio) will be direct-drilled into the dead mulch provided by the cover crops.
We are assessing the following parameters:

- biomass and soil cover produced by cover crops at the termination stage;
- weed abundance and composition in cover crops at the termination stage;
- killing rate and dynamics of the cover crops (through image analysis);

Figure 2 - Termination of rye by cut-roller in 2018 at full vegetation stage (first pass on 28 March)

- 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.

The trial will be repeated in 2019/20 on two different fields.

GPS coordinates of 2018/19 fields: 43°34’32.02’’N 10°32’06.12’’E

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A PARTICIPATORY FIELD TRIAL ON CONVENTIONAL VS CONSERVATION MANAGEMENT TO MANAGE A RESISTANT RYEGRASS POPULATION IN ARABLE CROPS

Objectives

Long-term implementation of reduced tillage (i.e. minimum tillage or no-till) combined with glyphosate application can lead to selection of herbicide-resistant weed populations. This is the case for the flatland close to Pisa (Tuscany, Central Italy), where reduced tillage became a standard practice among farmers in 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 the 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 between 2008 and 2017 that compared continuous no-till vs annual ploughing on-farm. 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

Figure 3 - Field trial at Martello Nadia farm (43°34’51.46’’N, 10°32’02.63’’E) (photo ©2017 Google)

Figure 4 - Resistant ryegrass population earing in a farmer's wheat field at harvest time

Figure 5 - Resistant ryegrass population surviving glyphosate application in a farmer's field

seeds and be able to yield again. A new system trial has since been set-up under WP7 on a four-year crop rotation (durum wheat-grain sorghum-durum wheat- chickpea); it uses two former no-till fields to compare two management options: i) annual ploughing with a range of herbicides, but not glyphosate; and ii) integrated management combining reduced tillage (minimum tillage and no-till), cover crops and limited herbicide application (excluding glyphosate).
Together with the farmer, we aim to test whether the continuous disturbance of ryegrass (either mechanically, chemically or agronomically) in its peak emergence periods would result in it still being possible to implement conservation agriculture, thus preserving soil fertility without significant yield losses due to resistant weed populations.

Materials and methods

Two different management treatments (CONVENTIONAL vs INTEGRATED) are being compared on two plots measuring 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;
- 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 so that sorghum can be directly sown. A red clover (*Trifolium pretense* L.) cover crop will be inter-seeded in the wheat 2021/22 and left to grow until the chickpea pre-sowing period when it will be incorporated as green manure with harrowing.
Herbicide application will be managed as the main IWM tool in the CONVENTIONAL system, but it will be minimized in the INTEGRATED one and tailored to the specific conditions (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 stages;
- 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.

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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, however, this procedure is not always easy to perform at the end of the winter due to wet conditions. In Mediterranean climates, the ever-increasing frequency of mild winters without freezing temperatures is reducing soil structuration by weather agents. If the soil remains too cloddy or is too dry at the end of the winter, the effectiveness of harrowing for detaching weed plants is dramatically reduced.

Furthermore, it is crucial to ensure the soil is covered in the intercrop period between wheat harvest and the following spring crop-sowing if weed populations are to be kept below damage thresholds. Autumn-sown cover crops can be an effective solution for covering the soil in this period. This might, however, be challenging if the following cash crop (e.g. chickpea, sunflower) is sown in early spring, as this 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 inter-seeded in early spring before the cereal's stem elongation stage and grown until the following spring. This may be possible when the legume cover crop is a self-reseeding crop, a perennial one or a biannual species, e.g. red clover (*Trifolium pratense* L.).

In this on-farm trial, we will test the results of intersowing red clover in organic durum wheat (*Triticum turgidum* subsp. durum (Desf.)) for two years and continue to grow it until the sowing date of the following chickpea (*Cicer arietinum* L.), when clover is incorporated as green manure.

Materials and methods

Two management treatments (INTERSOWING vs WHEAT SOLE CROP) are being compared on two plots measuring 1 ha each. Each treatment is replicated on five pseudo-replicates.

Figure 6 - Field trial at Martello Nadia farm (43°35'55.15''N, 10°31'48.43''E) (photo ©2017 Google)

The crop sequence also includes chickpea the following year.
We are assessing the following parameters:

- biomass and soil cover produced by wheat and clover at harvest stage and before clover termination;
- 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.

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Figure 7 - Red clover inter-seeded in durum wheat in March 2019 after emergence

SAN GIUSTO A RENTENNANO FARM

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MONTEVERTINE FARM

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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 this area, 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, makes these 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 are, 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 experiments in order to test and discuss with farmers strategies both to improve soils and to guarantee grape production and quality.

Objectives

A group of innovative farmers in Chianti Classico have either 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, these 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 both to manage soil sustainably and to 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, Siena); 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, Siena); average annual rainfall 824 mm; average annual temperature 12.6°C; elevation 425 m.a.s.l., slope 8%.

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^{-1}). 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 being studied on both farms (Fig. 1):

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

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 5 x 100 m). Treatments are displayed in alternate rows as this is common practice in the area. Each experimental plot is divided into 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).

Preliminary results on the effect of soil management on spontaneous vegetation

A total of 60 quadrants per farm (12 per treatment) were collected both in spring and autumn 2018. The biomass was divided by species, oven-dried and weighed. The datasets were analysed through non-metric multidimensional scaling (NMDS). This analysis is based on a distance or dissimilarity matrix. The resulting plots should be interpreted considering the distance between the points; the closer the points the more similar they are. In this study, the NMDS plots help to demonstrate the effects of the soil management practices on weed composition and biomass.

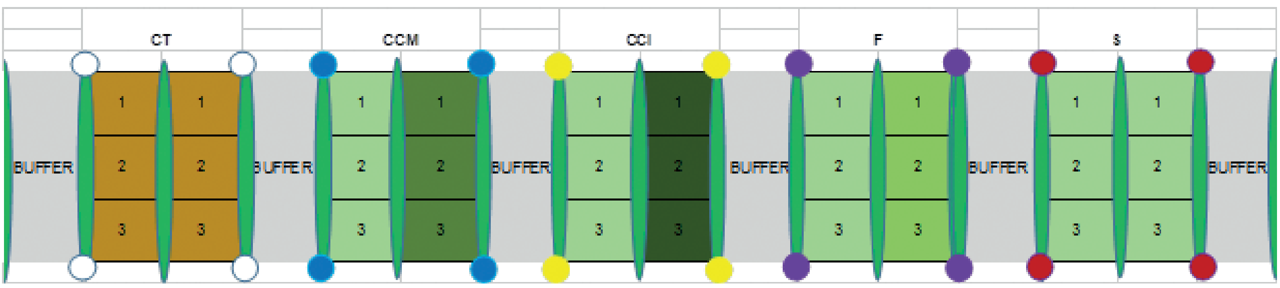

Figure 1 - Experimental design of the experimental plot on each farm. CT = Conventional Tillage; CCM = Mulched cover crop of barley + squarrose clover; CCI = Cover crop of barley + squarrose clover incorporated in the soil; F = Faba bean cover crop incorporated in the soil; S = Spontaneous grassing

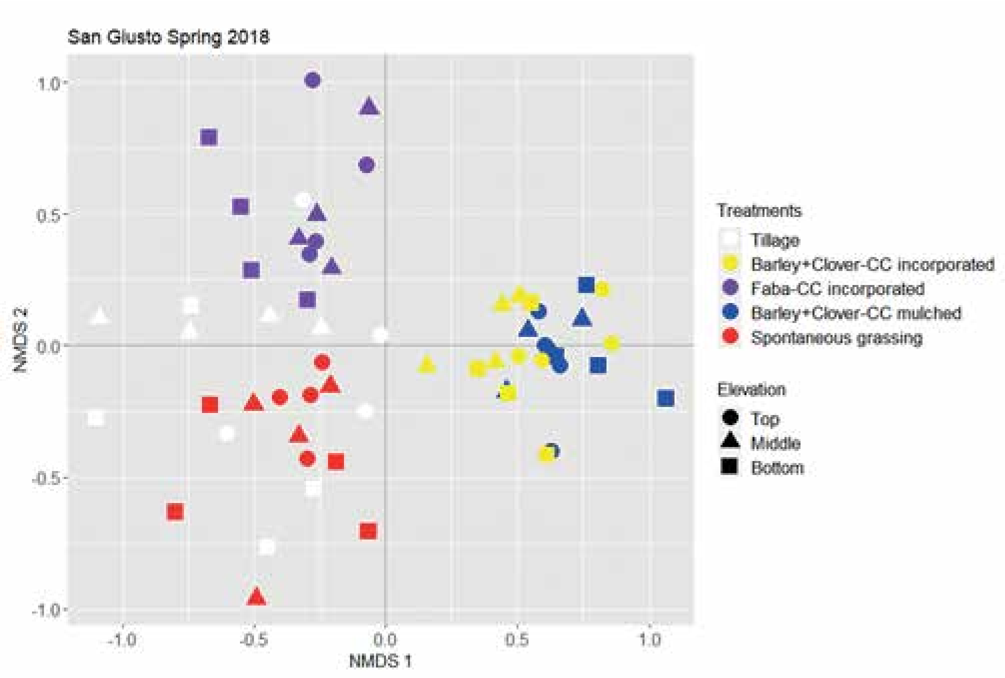

Figure 2 - NMDS analysis on biomass per species database at San Giusto a Rentennano (spring 2018)

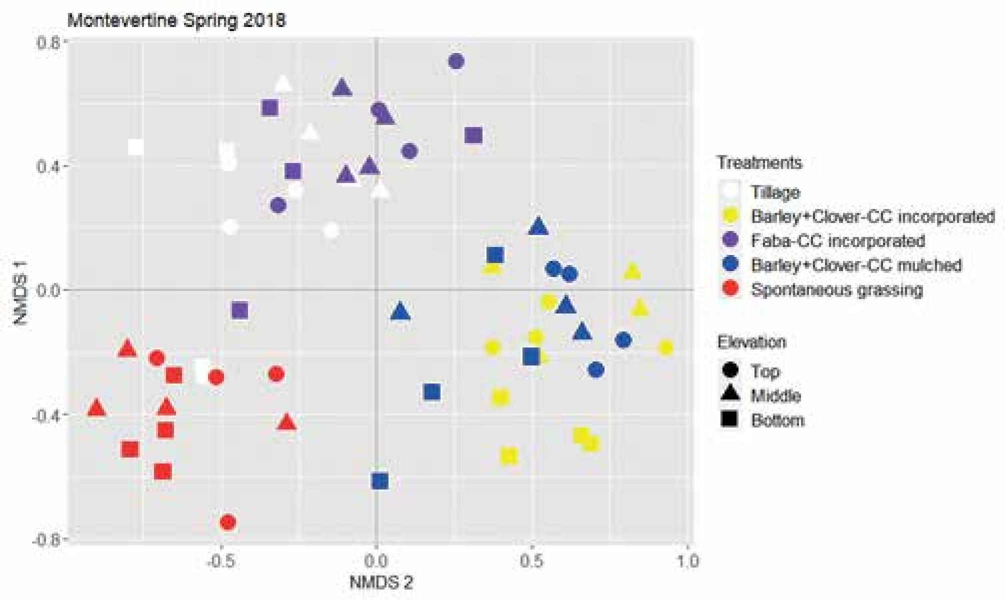

Figure 3 - NMDS analysis on biomass per species database at Montevertine (spring 2018)

The biomass datasets collected in spring before the termination of the cover crops showed marked differences among treatments on both farms (Figure 2 and 3). As expected, the two barley-clover cover crop plots were grouped together. Data pertaining to the faba cover crop were separated from the spontaneous grassing treatments on both farms. However, the tillage treatment highlighted a similarity between the spontaneous grassing at San Giusto and the faba bean cover crop at Montevertine. The altitude of the sample made no difference to the data.

A different scenario was observed in autumn where treatments did not trigger marked shifts in weed composition and biomass (Figures 4 and 5).

No clear trends were identified, neither when looking at treatments, nor with elevation on San Giusto (Figure 4). Tillage and barley-clover cover

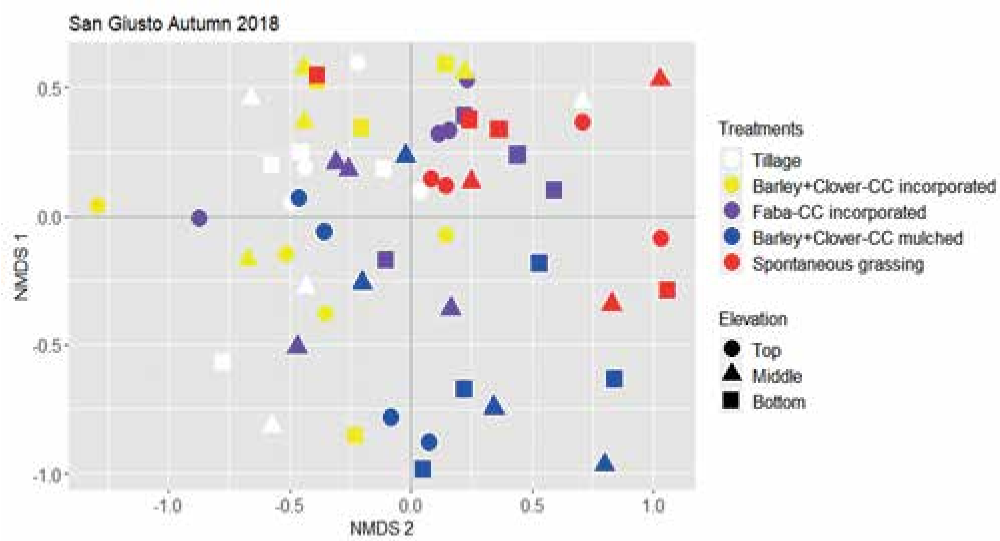

Figure 4 - NMDS analysis of the biomass per species database at San Giusto a Rentennano (autumn 2018)

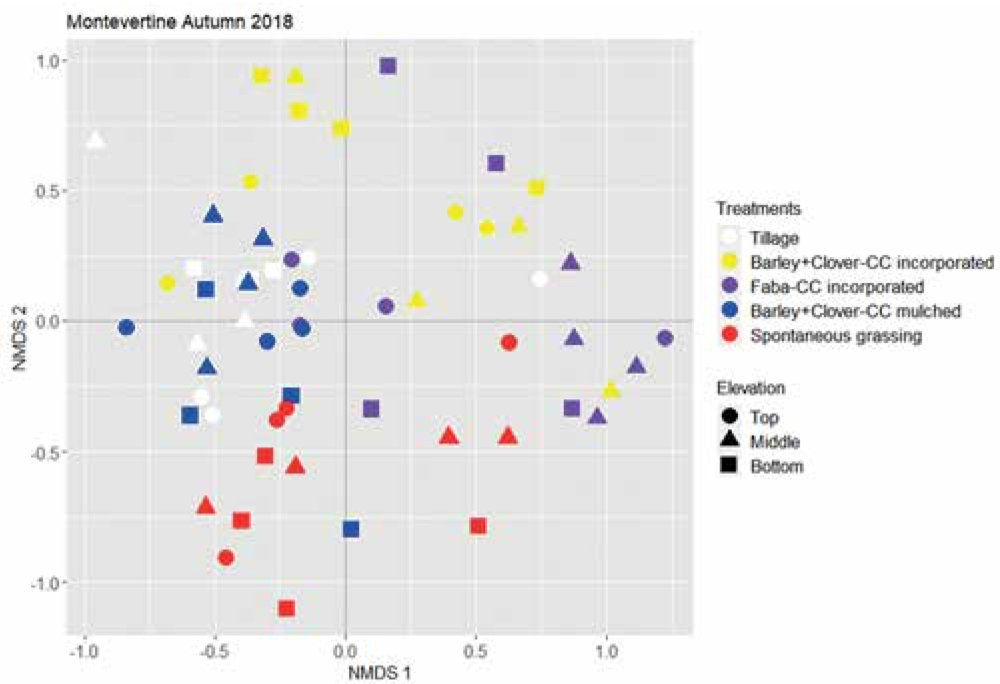

Figure 5 - NMDS analysis of the biomass per species database in Montevertine (autumn 2018)

crop managed as mulch partially overlaid the tillage-treatment data at Montevertine (Figure 5). We did not expect these results and we will further investigate this through more analysis and an additional year of data collection. The other treatments did not highlight particular associations. To sum up:

- Soil management practices influenced weed composition and biomass in spring;
- The residual effect of the soil management practices implemented in spring seems to be very weak in autumn when no strong associations between practices and weed composition/biomass were found.

Preliminary results on the effect of soil management on yield

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

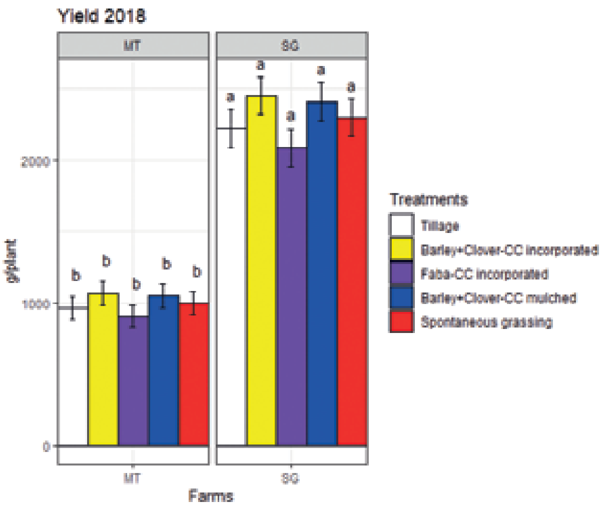

Figure 6 - Yield per plant (g plant^{-1}) in Montevertine (MT) and San Giusto a Rentennano (SG) in 2018 (n=150)

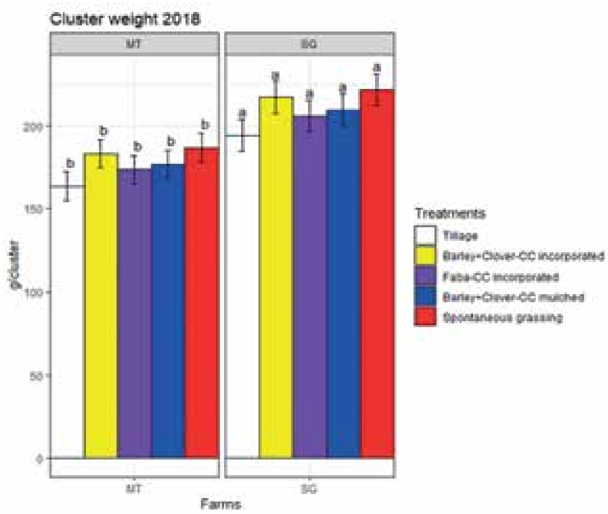

Figure 7 - Cluster weight (g cluster^{-1}) in Montevertine (MT) and San Giusto a Rentennano (SG) in 2018 (n=150)

between fruit-set and veraison, vines require about 50% of their annual water requirements. In this study cover crops were sown in October 2017 and terminated in June 2018 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 can affect yields. Based on the results obtained from the analysis of the weed biomass collected in spring (Figure 2 and 3), we were expecting soil management (cover crop + tillage) to affect yields significantly, especially in San Giusto where rainfall was considerably lower than in Montevertine (239 mm in Montevertine vs 73 mm in San Giusto, from July 1 July to 15 September). Nevertheless, we did not find any significant effect of treatment on yield and yield composition, namely cluster weight and number of clusters (Figures 6, 7 and 8).
“Farm” was the only significant parameter in the yield dataset, mainly due to the different 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) a rainy vintage that “diluted” the effect of the treatments, and (c) the importance of the in-row management as compared to the inter-row treatments. These aspects will be further investigated through the analysis of SPAD and water stress, as well as with an additional year of data.

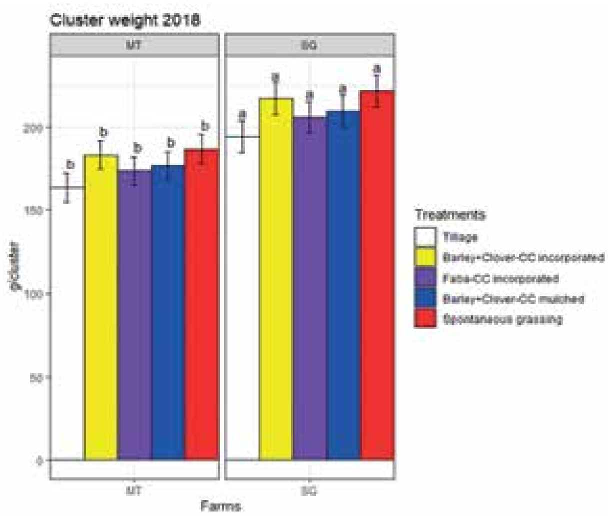

Figure 8 - Number of clusters per plant in Montevertine (MT) and San Giusto a Rentennano (SG) in 2018 (n=150)

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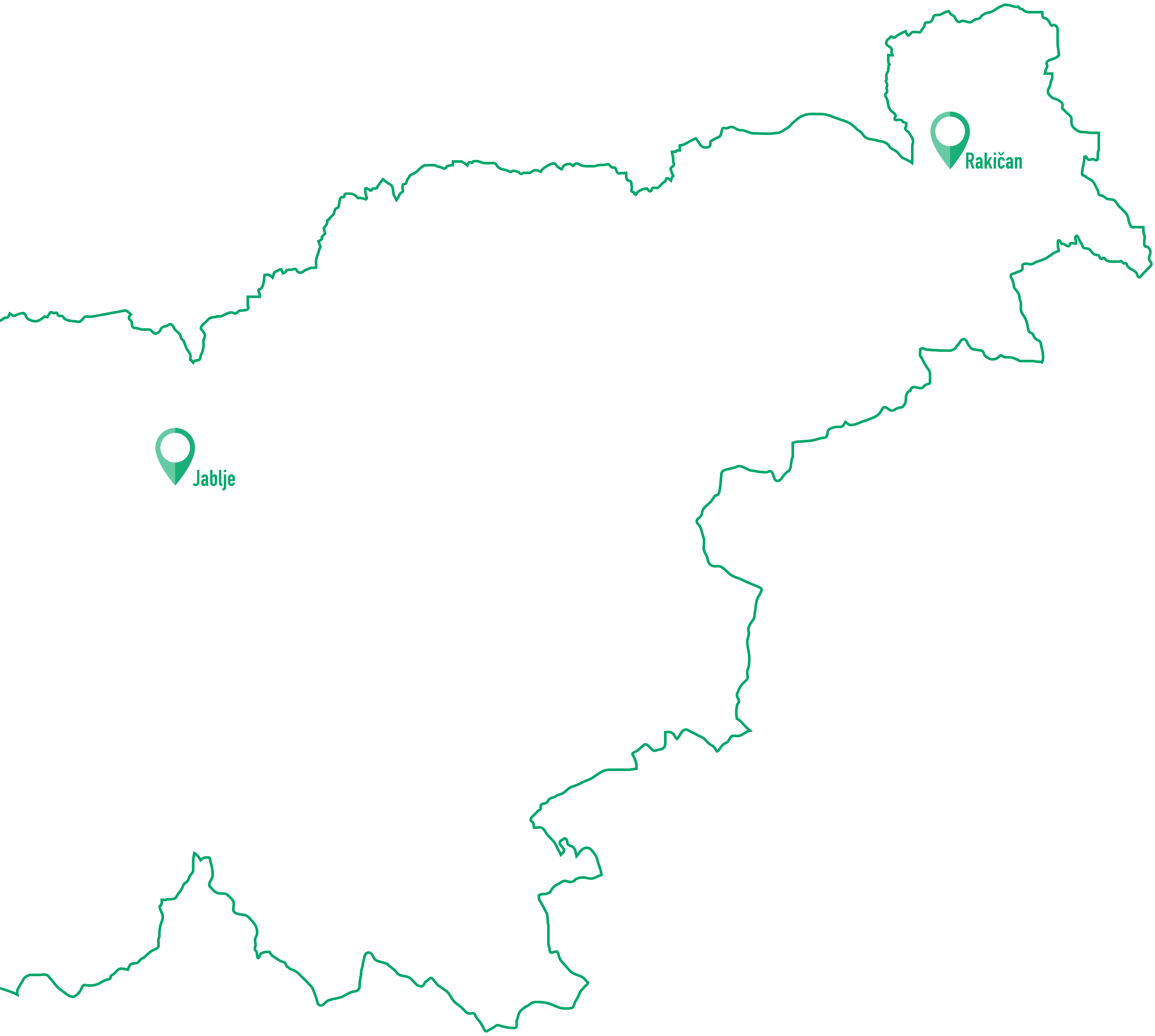
SLOVENIA



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

Kmetijski inštitut Slovenije
Agricultural Institute of Slovenia

Figure 1 - Location of the WP3-winter wheat and WP4-maize trial in Jablje in 2018

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:
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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
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WP3 – WINTER WHEAT TRIAL IN JABLJE

Objectives

The aim of the experiment was to demonstrate several weed management strategies and tools in winter wheat production, where two standard strategies were compared with three alternative ones. Standard strategies included spring and autumn broadcast herbicide application, which are common local weed-management practices. Two alternative strategies aimed to reduce weed germination and establishment in the early crop-development phase with delayed sowing and blind harrowing. In the third alternative strategy, spring harrowing was applied to reduce weed competition in the spring.

Materials and methods

A field trial with five weed-management strategies was established in autumn 2017 at AIS research station IC Jablje with winter wheat variety Vulkan. Details of the crop and weed management are presented in Table 1.
The previous crop in the experimental field was buckwheat. After harvest in August, the site was ploughed and the seedbed was prepared with the spring tine cultivator at the end of September 2017.

The experiment was arranged in 300 m long and 24 m wide strips. Winter wheat was planted on 16 October 2017 and 30 October 2017, i.e. the optimum sowing date and delayed sowing date respectively. In the standard Strategy 1, herbicide was applied early in the spring (10 April 2018; EC 32), while in standard Strategy 2, herbicide was sprayed in the autumn (23 November 2017; EC 12) and recommended doses of herbicides were used in both strategies. Due to ineffective harrowing, recommended herbicide doses were applied in Strategies 3 (10 April 2018; EC 32), 4 (24 April 2018; EC 39) and 5 (24 April 2018; EC 39), where spraying by need was proposed in the protocol.

Results

The winter wheat in the delayed sowing strategy plot was evidently behind with the development in the early autumn. At five and seven weeks after sowing (at optimum and delayed sowing time), only minor differences were observed. By the early spring, no measurable effect on winter wheat development was observed (Figure 2).

In Strategy 5, a false seedbed was established in the delayed sowing period (Figure 3).
The conditions for promoting weed germination in

Strategy	Standard 1	Standard 2	Strategy 3	Strategy 4	Strategy 5
Treatment	HER-spring	HER_autumn	HAR_autumn + HER_early spring	DEL_sow + HER_late spring	FALSE_seedbed + HER_late spring
Soil tillage	autumn ploughing	autumn ploughing	autumn ploughing	autumn ploughing	autumn ploughing
False seed bed	no	no	no	no	tine harrowing
Sowing time	optimum	optimum	delayed 14 days	delayed 14 days	optimum
Herbicide application time	early spring application EC 32	autumn application EC 12	early spring application EC 32	late spring application EC 39	late spring application EC 39
Rate	recommended *	recommended †	recommended ‡	recommended ‡	recommended ‡
Mechanical weeding	no	no	spring tine harrowing	spring tine harrowing	autumn tine harrowing
	24 m	24 m	24 m	24 m	24 m

* iodosulfuron-methyl 50 g/L + metsulphuron-methyl 7.5 g/L - Hussar plus: 0.2 L/Ha
† pendimenthalin 300 g/L + chlortoluron 250 g/L + diflufenican 40 g/L - Rinity: 2 L/Ha
‡ due to ineffective harrowing, a recommended dose was applied instead of a reduced dose

Table 1 - Description and layout of the winter wheat trial in Jablje

Figure 2 - The difference in winter wheat development between optimal and 14 days delayed sowing date in the autumn (left) and before winter (right) maize plots

Figures 3 and 4 - Harrowing in the false seedbed technique (left) and late harrowing in the spring (right)

the false seedbed technique were not favourable due to extremely warm weather for the autumn period and consequently dry soils.

Winter was cold and wet with large amounts of snow settling for a long period of time. Spring harrowing was significantly delayed (Figure 4) and soil was extremely compacted by heavy rain and snow. Consequently, the effect of harrowing was poor, since the tines did not penetrate through the upper soil layer and reach working depth. Recommended doses of herbicide thus had to be applied in the late spring.

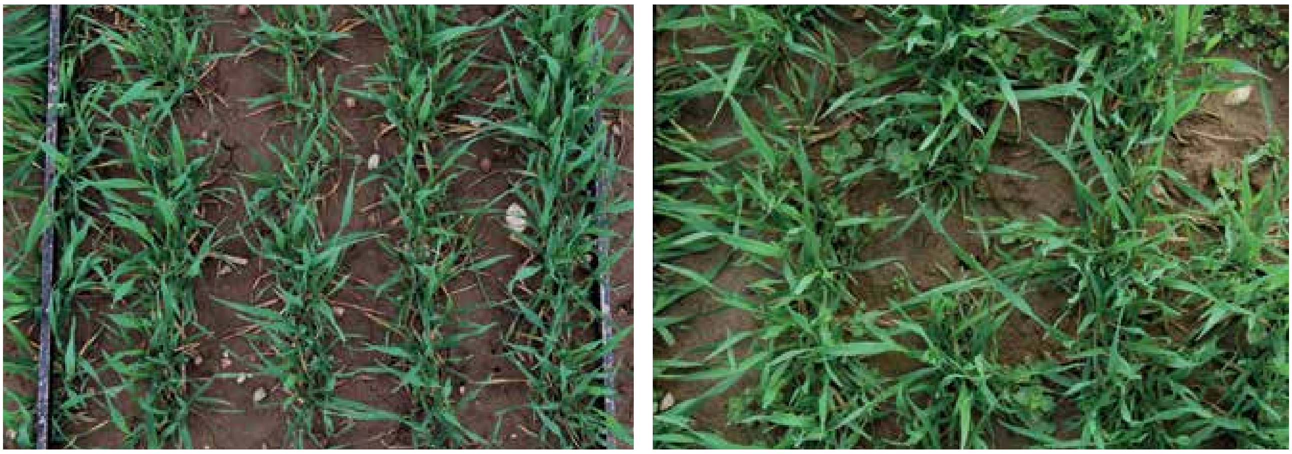
Weed pressure was low-medium, however an additional germination flush appeared very late, probably due to sufficient moisture and delayed vegetation.

Due to extended weed germination, late spring applications performed better (Strategies 4 and 5) when compared with early spring application (Strategies 1 and 3). Autumn herbicide application (Strategy 2) was by far the best, with good residual efficacy remaining visible until the harvest.

The highest dry grain yields (14% moisture) were measured in autumn when standard herbicide was applied (Strategy 2; 6.18 t/ha), followed by Strategy 5 (6.09 t/ha), while other treatments (Strategies 1, 3 and 4) were similar in terms of dry grain yields (5.7 t/ha).

Conclusions

In the 2017/2018 season, average winter wheat grain yields were recorded in central Slovenia. Our results showed that the highest yields were measured in treatments with the lowest weed biomass (Strategies 1 and 5). However, there were moderate yield differences between treatments. Dry grain yields (14% moisture) ranged from 5.7 t/ha in Strategies 1, 3 and 4 to 6.1 t/ha in Strategies 2 and 5. All of the tested strategies will be repeated in the 2018/19 season.



Figures 5 and 6 - Autumn sprayed standard strategy (left) and false seedbed plot before spraying at the beginning of April (right)

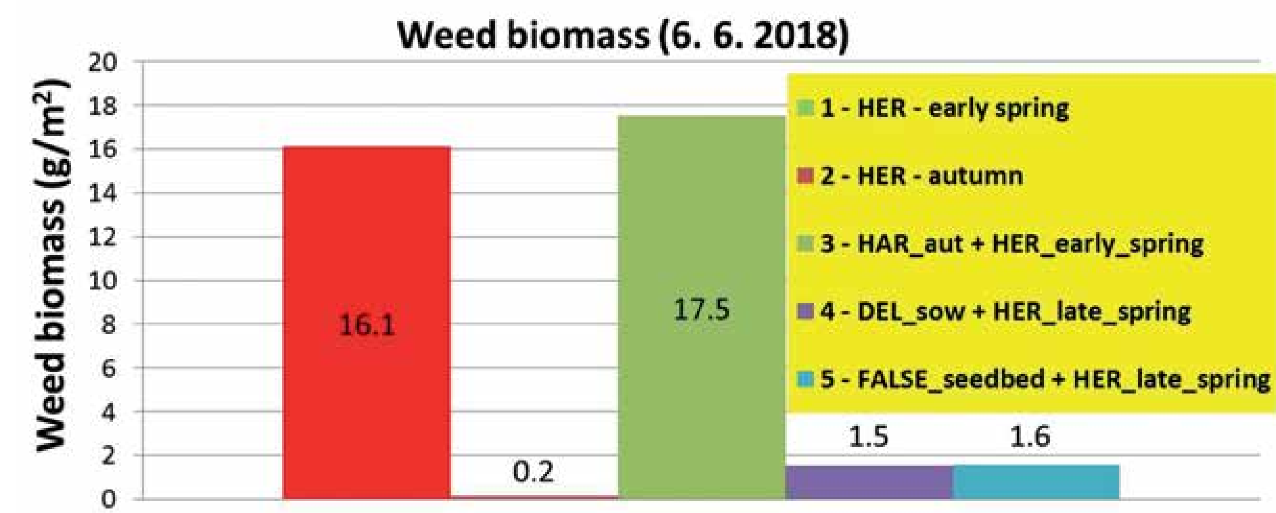


Figure 7 - Weed biomass in winter wheat at the end of the flowering stage

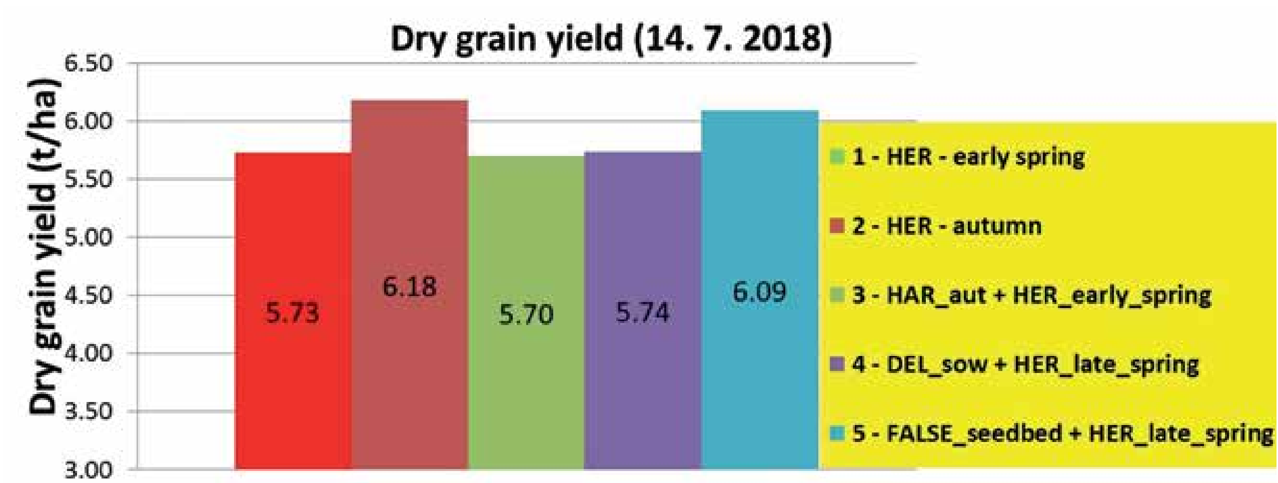


Figure 8 - Winter wheat dry grain yield in different weed management strategies

WP4 – MAIZE TRIAL IN JABLJE

Objectives

The objective of the trial was to test various integrated weed management strategies in maize production with the aim of reducing reliance on herbicides. To achieve this goal, herbicide use was partially replaced by mechanical tools and band spraying.

Materials and methods

A field experiment on maize was established at the end of April 2018 at AIS research station IC Jablje. The trial was arranged in 200 m long and 12 m wide strips and consisted of three alternative weed management strategies which were compared with standard early post broadcast herbicide application. In two of the alternative strategies, reduced herbicide doses and band application were combined with a precise camera-guided finger weeder, while in the third strategy mechanical tools only were used to control weeds.
The trial was planted with the variety Phyton in warm conditions on 30 April 2018. Maize germinated fast (in 7 days) and the first early post herbicide applications were performed on 18 May 2018 (EC 13). The growing season was extremely humid and warm, which facilitated excellent efficacy of applied herbicides.
In Treatment 3 with band spraying and Strategy 4 (mechanical weed control only), mechanical weeding was planned at two maize growth stages. Extreme rain events and soil conditions in May and June did not allow hoeing at the 6-leaf stage, therefore only one pass at the maize 8-leaf stage was performed in Strategies 3 and 4 (Figures 9 and 10).
Dry weed biomass was measured at the end of August (226 g/m^2) in the treatment with mechanical weed control only (Strategy 1). The finger weeder was effective in the interrow space, however most of the weed infestation was recorded along the maize rows and had a significant impact on competition with maize. In the strategy with band spraying (Strategy 2), maize rows were adequately controlled, however late application of hoeing was less efficient in the interrow space. A reduced dose of herbicide (60%) in Strategy 3 did not show any reduction in weed control when compared with the recommended dose (Figure 11).
The highest yield was measured in the standard Strategy 4 (14.64 t/ha), followed by 12.41 t/ha and 13.03 t/ha in Strategies 2 and 3 respectively. The lowest yield was achieved in Strategy 4 - hoeing

Strategy	Strategy 4	Strategy 3	Strategy 2	Strategy 1 Standard
Treatment	ORG	HER_row	HER_red	CON
Soil tillage	Spring ploughing	Spring ploughing	Spring ploughing	Spring ploughing
Herbicide application time	/	early post EC 13	early post EC 13	early post EC 13
Rate	/	recommended dose *	reduced dose 60 % *	recommended dose *
Mechanical weeding	Finger weeder EC 14 †	Finger weeder EC 16 †	/	/
	Finger weeder EC 18	Finger weeder EC 18	Finger weeder EC 18	/
	12 m	12 m	24 m	12 m

* isoxaflutole 225 g/L + thiencarbazone-methyl 90 g/L + cyprosulfamide safener 150 g/L - Adengo: 0.44 L/ha
† due to unfavourable weather conditions mechanical weeding was not performed

Table 2 - Description and layout of the maize experiment in Jablje

Figures 9 and 10 - Heavy weed infestation in the organic plot (left) before hoeing with a finger weeder (right)

only - (10.56 t/ha), where considerably higher weed infestation was observed (Figure 12).

Conclusions

Overall environmental conditions in 2018 were favourable, with high temperatures and sufficient rainfall. Maize did not suffer any water shortage, therefore relatively high yields were achieved this season. In Strategies 2 and 3, weed infestation did not have any significant effect on yield loss; lower yields were, in our opinion, a consequence of maize stand loss due to very aggressive hoeing with a finger weeder.

Results

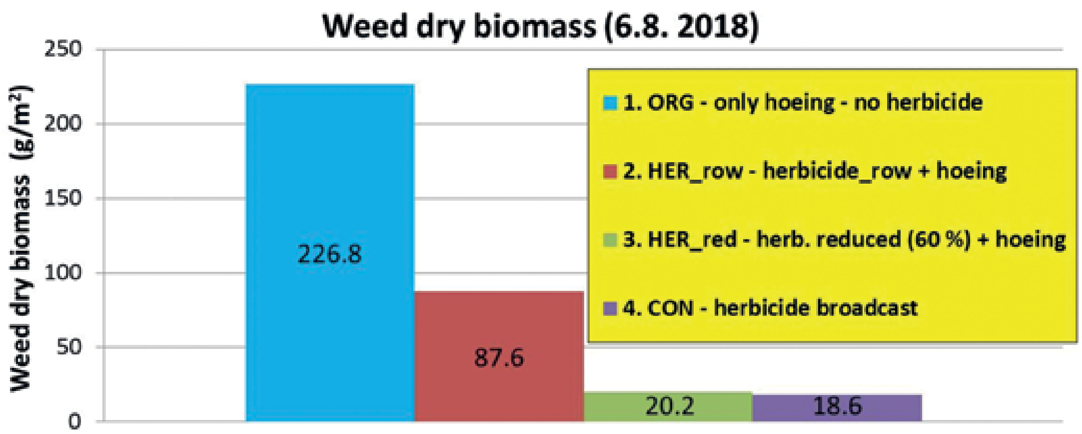


Figure 11 - Weed biomass in maize at the grain filling stage

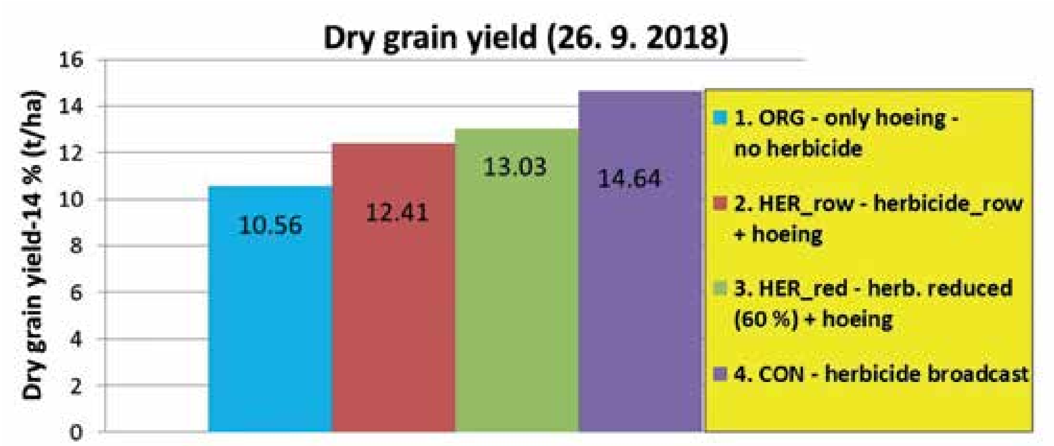


Figure 12 - Maize dry grain yield in different weed management strategies

WP3 AND WP4 NEW TRIALS IN 2019

Winter barley and maize trial in Jablje

The winter barley and maize trial in the 2019 season will be moved to a nearby field due to crop rotation. Both experiments will follow the same protocol as the previous season, since the strategies and tools planned in 2018 were not implemented fully due to unfavourable weather conditions.

Figure 13 - Location of the WP3-winter barley and WP4-maize trial in 2019 in Jablje

WP5 - RUMEX TRIAL IN SLOVENIA (AJDOVŠČINA AND MURSKI ČRNCI)

Rumex obtusifolius is a widespread troublesome perennial weed species and therefore is a good candidate for biological control. Previous studies conducted in Switzerland (CABI) showed a potential for inundative applications of a Sesiidae species, *Pyropteron chrysidiforme*, to control *R. obtusifolius*. The insect's larvae feed on *R. obtusifolius* roots, thus weakening its growing capability and resulting in plant mortality in the event of high larvae infestation.

Objectives

This three-year study aims to apply the method of mass-releasing *P. chrysidiforme* into environmental conditions more favourable for a population build-up. The establishment of *P. chrysidiforme* after a targeted release, as well as its impact on *R. obtusifolius* mortality, will be studied in the following years.

Materials and methods

Two locations in Slovenia were selected for field trials. One in the southwest Vipavska dolina region (Location 1), with its mild Mediterranean climate, and the other in northeast Slovenia – the Prekmurje region (Location 2), with its continental climate (cold winters with hot, dry summers). In each location, a meadow with relatively high *R. obtusifolius* population was selected.
Pupae and eggs of *P. chrysidiforme* were brought from CABI Switzerland to the Agriculture Institute of Slovenia (AIS) in spring 2018. Emergence of adult insects was closely monitored and mating was carried out following the protocol. The eggs laid by the female insects in plastic containers were picked and glued onto toothpicks (30 per toothpick). The toothpicks were stored for field inoculation.
On 12 June and 21 June 2018, the first inoculation of *R. obtusifolius* plants was carried out on the two field-trial locations. Overall, 275 plants were selected in each field. Four different treatments were applied (50 plants per treatment): a) inoculation with *P. chrysidiforme* in Year 1; b) inoculation with *P. chrysidiforme* in Years 1 and 2; c) inoculation with *P. chrysidiforme* in Years 1, 2 and 3; and d) control (natural level of attack). The inoculation of plants will be repeated in the next few years according to the protocol, and the final plant mortality will be estimated in the last year of the experiment.

The toothpicks with eggs were placed in the cores of 225 plants. An extra 25 plants were inoculated in

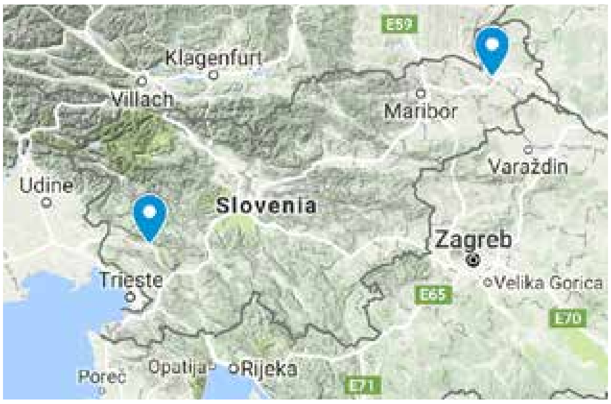


Figure 14 - Location of the two selected Rumex study sites in Slovenia

Figures 15 and 16 - Toothpicks with eggs prepared for inoculation (left) and an inoculated Rumex plant in the field (right)

order to estimate the annual establishment rate. The position of each inoculated plant was marked with a coordinate recorded by high-precision GPS (Stonex S9i, Stonex SRL, Lissone, Italy).
In addition, some 100 plants were also inoculated at AIS grounds for next year's rearing cycle and egg production.

Primary results - annual establishment rate

On 25 September and 2 October, the 25 *R. obtusifolius* plants intended for inspection of establishment rate were located with high-precision GPS. Plants in the stage between one and three rosettes were dug out and rootstocks were later inspected. The larvae in each rootstock were counted and root damage/decay was estimated. Overall, 24 out of the 25 plants dug-out on Location 1 showed signs of root damage (average 55% damage) and 16 rootstocks had one or two larvae inside. Furthermore, eight inoculated plants were found to be dead.
The plants at Location 2 were at a higher development stage and had between one and seven rosettes. Similar to Location 1, 20 of the 25 plants dug-out showed signs of root damage (average 30% damage). Thirteen of these plants had one to three larvae inside, but all of the infested plants were still vital.

Figures 17 and 18 - Inoculation of *R. obtusifolius* (left) and marking of inoculated plants with high-precision GPS (right)

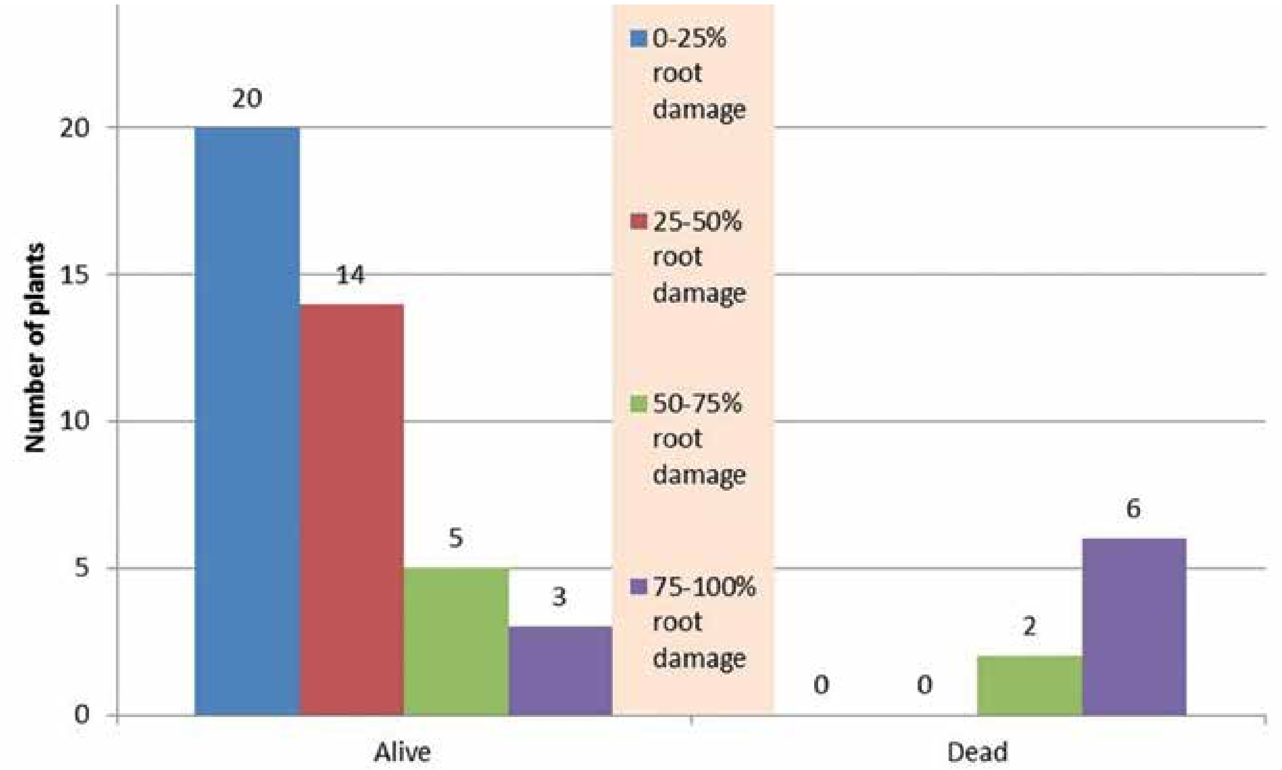


Figure 19 - Root damage and mortality of *R. obtusifolius* in the estimate of annual establishment rate

Figures 20 and 21 - Pattern of GPS-marked Rumex plants at Location 1 - Ajdovščina (left) and at Location 2 - Murski črnci (right)

Figures 22 and 23 - Evaluation of annual establishment rate (left) and Rumex root damage caused by *P. chrysidiforme* larvae (right)

EXPERIMENTAL TRIALS AT THE BIOTECHNICAL SCHOOL RAKIČAN (BSR)

BIOTEHNIŠKA ŠOLA RAKIČAN

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.

Figure 1 - Location of the WP3-winter barley and WP4-maize trial in Rakičan in 2018

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
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Primož Titan
e-mail: titan.primoz@gmail.com
tel. +386 312502

WP3 – WINTER WHEAT TRIAL AT BSR RAKIČAN

Objectives

The objective of the demonstration trial was to test alternative weed-management approaches where mechanical tools were incorporated in weed-control strategies that aimed to reduce herbicide use in winter wheat production. Besides mechanical weeding, measures to prevent weed germination and reduce weed establishment in the early crop development phase were also implemented.

Materials and methods

A field trial at the Biotechnical School Rakičan was established in autumn 2017. Two alternative strategies and one standard weed management practice were compared in winter wheat production. The experiment was arranged in 15 m wide strips. In the two standard weed-control strategies, broadcast herbicides were applied in autumn and spring. In one of the alternative strategies, autumn and spring tine harrowing was combined with reduced herbicide use in spring. In the second alternative approach, delayed sowing and spring tine harrowing were utilized and herbicides were used in spring as needed.

The soil conditions in the period of the optimal sowing date were favourable, with warm weather and adequate water supply. Winter wheat at its optimum sowing date was drilled on 16 October 2017 (Strategies 1,2 and 3). The plot with Strategy 4 was sown 14 days later on 30 October 2017. The winter wheat in the delayed sowing plot needed 12 days to emerge compared with just six days at the optimum sowing date. Unusally warm weather continued in the late autumn, which enabled the implementation of weed management measures in optimum conditions.
Autumn spraying in Strategy 2 was performed on 22 November 2017, while autumn harrowing in Strategy 3 was carried out two days later, i.e. on 24 November 2018. Crop overwintering was adequate despite harsh winter temperatures and long snow cover, which caused a significant delay in vegetation development and crop management.

Results

Although the crop on the delayed sowing plots was thinner in spring, at harvest time approximately 600 heads were counted on average in all treatments. Only a minor delay in development was recorded; heading on the later-drilled plots was only 2 days later when compared with optimal sowing date strategies.

Strategy	Standard 1	Strategy 4	Strategy 3	Standard 2
Treatment	HER-spring	HAR_aut + HER_ spring-reduced 50 %	DEL_sow + HAR_late spring	HER-autumn
Soil tillage	autumn ploughing	autumn ploughing	autumn ploughing	autumn ploughing
False seed bed	no	no	no	no
Sowing time	optimum	delayed 14 days	optimum	optimum
Herbicide application time	early spring application *	early spring application *	/	autumn application †
Rate	recommended	50 % reduced	/	recommended
Mechanical weeding	/	spring tine harrowing	autumn and spring tine harrowing	/
	15 m	15 m	15 m	15 m

* iodosulfuron-methyl 50 g/L + metsulfuron-methyl 7.5 g/L - Hussar plus: 0.2 L/ha
† iodosulfuron-methyl-sodium 7.5 g/L + mesosulfuron-methyl 9 g/L + diflufenican 120 g/L +mefenpyr-diethil 27 g/L) - Alister new: 1 L/ha

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

After fertilization at the end of March, tine harrow was used in Strategies 2 and 3. Both autumn and spring harrowing performed well, mainly because of adequate soil conditions and optimal crop development. Weed infestation was generally low across all plots, with only *Cirsium arvense* appearing on some spots.
The highest weed biomass was recorded in Strategy 4, where only autumn and spring harrowing was conducted. Although weed biomass was considerably greater in Strategy 4 (mechanical tools only without herbicide) when compared with other treatments (Figure 2), the level of weed infestation did not have any effect on yield performance (Figure 3).

Figure 2 - Winter wheat drilled with a two-week delay (left) and optimal sowing date (right) at the end of March 2018

Conclusions

The environmental conditions in 2018 were not favourable, with high temparatures and a water shortage in the spring greatly reducing winter wheat yields. In all of the strategies, remarkably similar yields were recorded, ranging from 6.3 t/ha to 6.4 t/ha. All of the tested strategies will be repeated in the 2018/19 season.

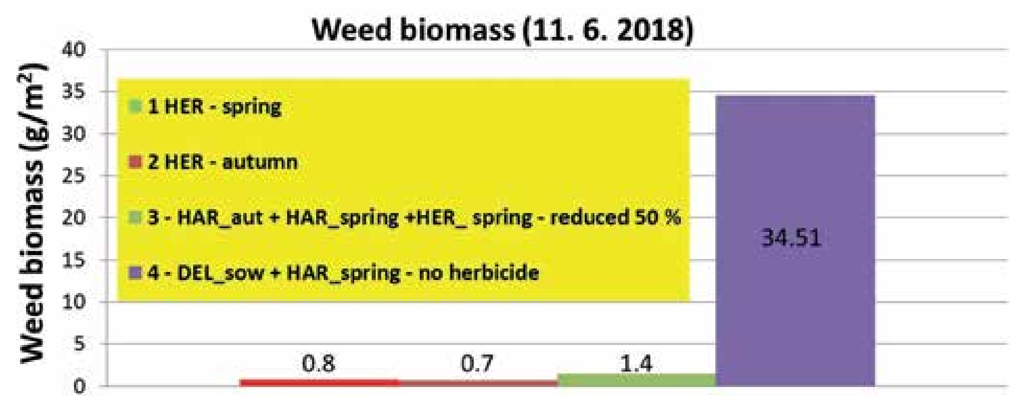

Figure 3 - Weed biomass in winter wheat at the end of the flowering stage

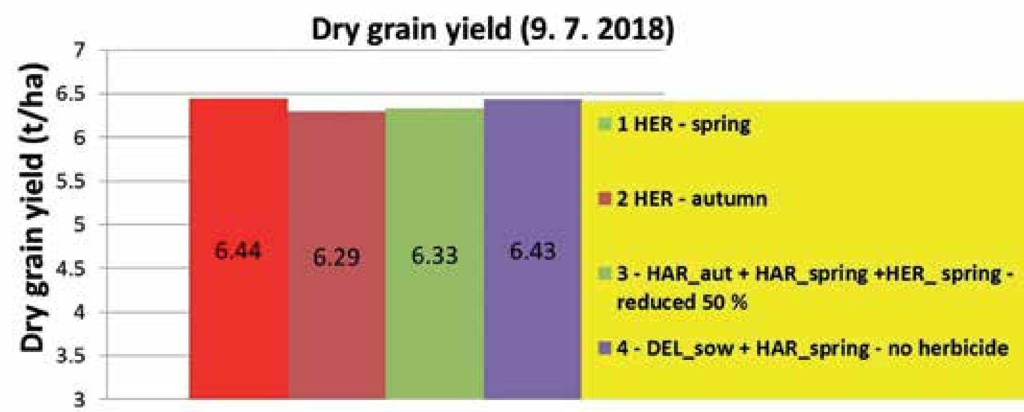

Figure 4 - Winter wheat dry grain yield in different weed management strategies

WP4 MAIZE TRIAL AT BSR RAKIČAN

Objectives

The objective of this demonstration trial was to include mechanical measures in weed management strategies in maize production, using only herbicides for weed control in the standard practice. Strategies were demonstrated in real field conditions and designed to reduce reliance on herbicides. To achieve this goal, herbicide use was partially replaced by mechanical tools and band spraying.

Materials and methods

A field experiment in maize was established at the beginning of April 2018 at the Biotechnical School Rakičan. The demonstration trial was arranged in 12 m wide strips and consisted of three alternative weed management strategies which were compared with standard early post broadcast herbicide application. In alternative Strategy 2, an interrow weeder was adapted for the band application of herbicides in the row and combined with hoeing. In the second alternative, Strategy 3, a reduced herbicide dose was applied.
Conditions after planting were favourable. Maize germinated in seven days and, with optimum water supply, it developed rapidly. Afterwards, heavy rain caused compaction of the soil and a delay in performing weed management operations. Additionaly, the harrowing operation in Strategy 1 was postponed due to standing water on part of the field. Furthermore, weeds overgrew their optimum development stage, therefore harrowing was less effective than expected, with the majority of the grassweeds surviving in the compacted soil area. Even after two passes with a harrow and one hoeing, the weeds were not sufficiently controlled. In Strategy 3, soil conditions for herbicides were favourable and enabled effective weed control in the early season. Late-emerging weeds were controlled with hoeing at the maize 6-leaf growth stage and did not create any significant competition with maize in the early growth period. Our prototype, which was developed for band spraying and interrow hoeing, showed some deficiencies. The nozzles were placed in front of the hoes, meaning that the spray did not cover the weed plants adequately. A range of weeds, especially perennial ones, such as bindweed, was not sufficiently controlled. In Strategy 4, mechanical measures only were implemented and overall this strategy was less effective.

Strategy	Standard 1	Strategy 4	Strategy 3	Standard 2
Treatment	HER-spring	HAR_aut + HER_ spring-reduced 50 %	DEL_sow + HAR_late spring	HER-autumn
Soil tillage	autumn ploughing	autumn ploughing	autumn ploughing	autumn ploughing
False seed bed	no	no	no	no
Sowing time	optimum	delayed 14 days	optimum	optimum
Herbicide application time	early spring application *	early spring application *	/	autumn application †
Rate	recommended	50 % reduced	/	recommended
Mechanical weeding	/	spring tine harrowing	autumn and spring tine harrowing	/
	15 m	15 m	15 m	15 m

* iodosulfuron-methyl 50 g/L + metsulfuron-methyl 7.5 g/L - Hussar plus: 0.2 L/ha
† iodosulfuron-methyl-sodium 7.5 g/L + mesosulfuron-methyl 9 g/L + diflufenican 120 g/L +mefenpyr-diethil 27 g/L) - Alister new: 1 L/ha

Table 2 - Description and layout of the maize experiment at BSR Rakičan

Results

Substantial dry weed biomass was measured at the end of August (265 g/m²) in the treatment with mechanical weed control only (Strategy 1). Band spraying in Strategy 2 was less effective due to incorrect nozzle placement and significant weed infestation was recorded along the maize rows. A reduced dose of herbicide (60%) in Strategy 3 did not lead to a considerable reduction in weed control when compared with the recommended dose (Figure 30). Dry grain yields of maize were correlated to weed infestation. The highest yield was measured in standard Strategy 4 (8.95 t/ha), followed by 8.84 t/ha and 8.52 t/ha in Strategies 3 and 2 respectively. The lowest yield was achieved in Strategy 1, which used mechanical weed control only (7.89 t/ha); in this case, substantially higher weed infestation was observed (Figure 31).

Conclusions

Overall, environmental conditions in 2018 were not favourable in this region. Excessive water supply after planting and high temperatures in the late summer greatly reduced maize yield potential. Minor yield losses in Strategies 1 and 2 were related to difficult soil conditions and to the timing of mechanical weeding, consequently the efficacy of harrowing and hoeing decreased.

WP3 AND WP4 TRIALS AT BSR RAKIČAN IN 2019

In the upcoming season, the field trial in maize and winter wheat will be repeated and the main weed management tools and strategies will remain the same.

Figure 5 - Heavy rainfall created compacted soil, and harrowing was performed in difficult conditions

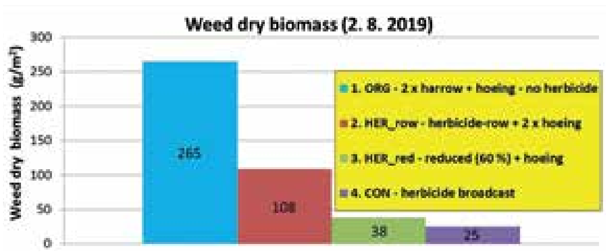

Figure 6 - Weed biomass in maize at the grain filling stage

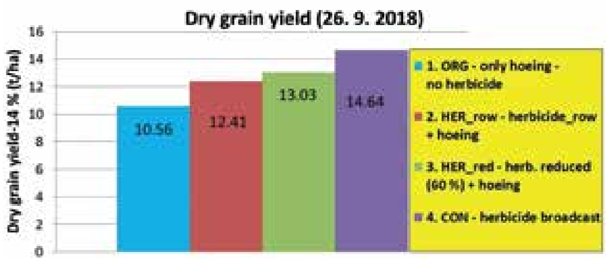

Figure 7 - Maize dry grain yield in different weed management strategies

Figure 8 - Location of the WP3-winter wheat and WP4-maize trials in 2019 in Rakičan

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.

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Reckenholzstrasse 191
8046 Zürich - Switzerland
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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
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tel. +41 58 468 72 76

EXPERIMENTAL TRIAL ON THE AUGMENTATIVE BIOLOGICAL CONTROL OF *RUMEX* SPP IN GRASSLANDS

Rumex obtusifolius is a major weed in European grasslands. Currently, the standard control method is herbicide in conventional farming systems and hand-removal in organic farming systems (Grossrieder & Keary, 2004). Here we test an innovative approach by using native root-feeding Sesiid moths for the biological control of this dock species in Europe (Grossrieder & Keary, 2004, Hatcher et al., 2008). The potential of the two *Sesiidae* species *Pyropteron doryliforme* and *Pyropteron chrysidiforme* is particularly promising due to their ability to feed on roots during the larval stage (Scott & Sagliocco, 1991a, b). In Australia, invasive *Rumex* species of European origin were successfully controlled by importing *Pyropteron doryliforme*.

Figure 1 - Larva retrieved in the root collar of *Rumex obtusifolius* taproot

Figure 2 - Core tunnel made by a *Pyropteron* larva damaging *Rumex obtusifolius* taproot

In 2008, the Centre for Agriculture and Biosciences International (CABI) launched a biological control project in Switzerland against *Rumex obtusifolius*, which is the most problematic weed in Swiss grassland. As both the target weed and its natural enemies are native to Europe, the objective is to develop an augmentative biological control approach, i.e. targeted mass-release of the biological control agent over a short duration to significantly reduce dock densities.
First attempts focused on *P. chrysidiforme* as the biological control agent, as it has a wider distribution in Europe than *P. doryliforme*. In pot experiments, *P. chrysidiforme* was found to significantly reduce dock growth and survival (U. Schaffner, results not published). Under field conditions, however, this effect was not observed, largely due to a low larval infestation rate (Hahn et al., 2016).

Objectives

In this project, we will assess which of the two sister species (*P. chrysidiforme* and *P. doryliforme*) have a higher establishment and impact potential on docks, and whether a combination of both *Pyropteron* species would further increase this impact. We will also test whether our target weed, *R. obtusifolius*, differs in terms of susceptibility to larval attack from *Rumex pulcher*, the main target weed in Australia. Once we have identified the key factors influencing the establishment rate and the impact of these two Sesiid moths under field conditions, we will advance the development of technologies for mass-rearing and mass-releasing the insect(s).

Experiment set up in 2018

Materials and methods

In 2018, a multifactorial pot experiment was set up in the Agroscope garden in Reckenholz to evaluate the infestation and impact potential of the two biological control candidates *P. doryliforme* and *P. chrysidiforme*, alone or combined, on the two *Rumex* species *R. obtusifolius* and *R. pulcher*. The experiment includes four biological control treatments: (1) *P. chrysidiforme*, (2) *P. doryliforme*, (3) *P. chrysidiforme* & *P. doryliforme* (mixed treatment), plus (4) an untreated control. Field-collected one-year-old-plus *R. obtusifolius* plants and younger seed-reared *R. obtusifolius* and *R. pulcher* plants were tested. The experimental design was arranged in a randomized block design with 15 replicates, resulting in 360 plants (3 plant types x 4 *Pyropteron* treatments x 2 harvesting times x 15 replicates).
In June 2018, the *Pyropteron* treatments were

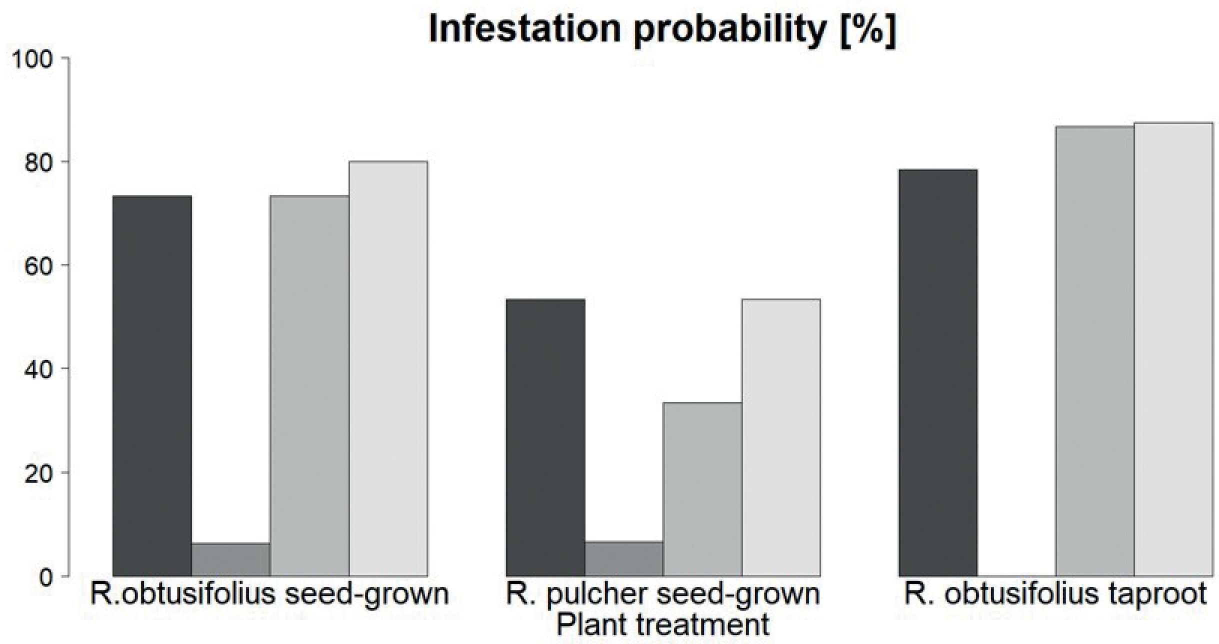


Figure 3 - Probability of infestation (at least one larva alive per plant) of *Rumex obtusifolius* and *Rumex pulcher* under the different *Pyropteron* treatments in autumn 2018. Black bar = *Pyropteron chrysidiforme*, dark grey bar = control; grey bar = *Pyropteron doryliforme*; light grey bar = both *P. chrysidiforme* and *P. doryliforme*

applied by inserting one toothpick per plant into the soil near the plant base after cutting the above-ground biomass at 6-7cm. The plants and egg sticks were protected from rainfall for two weeks after inoculation. The parameters recorded during dissection were above-ground biomass, below-ground biomass, number of roots, number of feeding marks, number of larvae alive and dead , weight and length of larvae, place of larva on root (Figure 1) and plant performance (Figure 2). The first batch of dissections assessing the infestation took place in autumn 2018 and the second batch assessing impact on *Rumex* performance started at the end of March 2019.

Preliminary results

a. Probability of infestation

The probability of being infested by at least one larva alive was significantly different for the Rumex treatment (degrees of freedom: 2, deviance: 13.99, residual degrees of freedom: 175, residual deviance: 168.88, Pr(>Chi): 0.001). Differences in infestation probability were observed between *R. obtusifolius* (field-collected plants with taproots: 38 plants infested; seed-grown plants: 35 plants infested) and *R. pulcher* (seed-grown plants: 22 plants infested; estimate *R. pulcher*: -1,2282, z value: -2.72, p-value = 0.010, residual deviance 172.17 on 176 degrees of freedom; Figure 3). The *Pyropteron* treatments significantly affected the infestation probability (degrees of freedom: 3, deviance: 67.60, residual degrees of freedom: 177, residual deviance: 182.88, Pr(>Chi): <0.001); the three treatments with Sesiid inoculation showed similar infestation probabilities, but they all differed from the control treatment (*P. chrysidiforme*: 30 plants infested; *P. doryliforme*: 29 plants infested, mixed treatment: 34 plants infested; control: 2 plants infested; estimate of control coefficient: -4.01, z value: -4.97, p-value: >0.001, residual deviance: 172.17 on 176 degrees of freedom). No interaction was observed among the *Rumex* and the *Pyropteron* treatments with regard to infestation probability (degrees of freedom: 6, deviance: 5.30, residual degrees of freedom: 169, residual deviance: 3.57, pr(>Chi) = 0.50). Hence, our results indicate that, contrary to our expectations, *P. doryliforme* does not prefer *R. pulcher*, its natural host plant and target plant in the successful classical biological control in Australia, over *R. obtusifolius*. Also, our results suggest that overall infestation probability cannot be increased by inoculating *Rumex* plants with both Sesiid species.

b. Number of larvae retrieved alive per infested plant

No significant difference was found among the *Pyropteron* treatments with regard to the number of larvae retrieved alive per infested plant (degrees of freedom: 2, deviance: 1.49, residual degrees of freedom: 90, residual deviance: 153.01, Pr(>Chi): 0.47). The control treatment was omitted from this

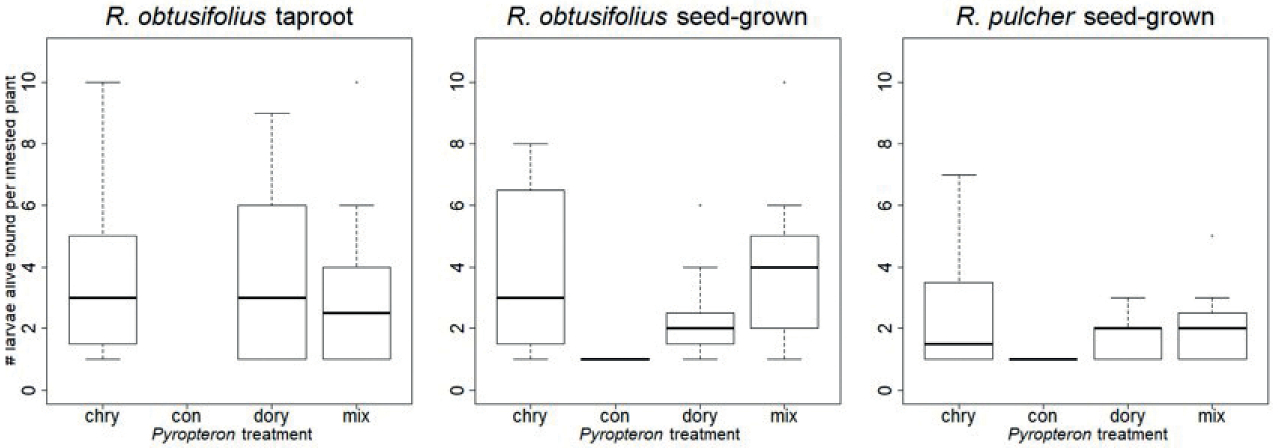


Figure 4 - Number of larvae retrieved alive per infested plant after *Rumex* and *Pyropteron* treatments. Chry = *P. chrysidiforme*; con = control; dory = *Pyropteron doryliforme*; mix = both *P. chrysidiforme* and *P. doryliforme*

analysis due to the very low number of infested plants. In contrast, the number of larvae found alive per infested plant differed significantly among the *Rumex* treatments (degrees of freedom: 2, deviance: 9.86, residual degrees of freedom: 90, residual deviance: 144.63, Pr(>Chi):0.005). Significantly more larvae were found alive in *R. obtusifolius* (mean (sd): field-collected plants with taproot = 3.55 (2.77); seed-grown=3.43 (2.38)) than in *R. pulcher* (mean (sd): seed-grown=2.14 (1.55), with *R. pulcher* estimate: -0.47, z value: -2.699, p < 0.001) (Figure 4). There were no significant interaction terms among the *Pyropteron* and the *Rumex* treatments (degrees of freedom: 4, deviance: 6.01, residual degrees of

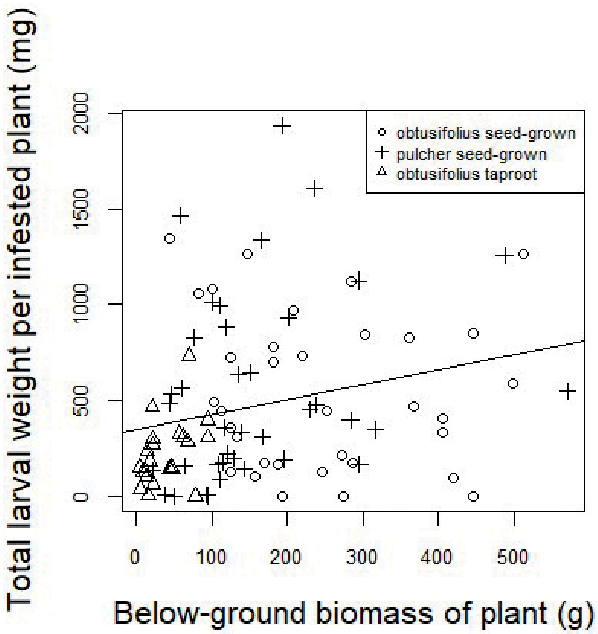


Figure 5 - Relationship between total larval weight per infested plant and below-ground biomass

freedom: 84, residual deviance: 136.38, Pr(<Chi) 0.20). The same pattern was observed when the number of dead larvae was combined with the number of living larvae (graph not shown).

c. Plant biomass

In autumn 2018, neither the *Pyropteron* treatment (degrees of freedom: 3, deviance: 2668.6, residual degrees of freedom: 178, residual deviance: 469792, Pr(>Chi): 0.80) nor the *Rumex* treatment (degrees of freedom: 2, deviance: 3747.7, residual degrees of freedom: 176, residual deviance: 466045, Pr(>Chi): 0.49) significantly affected plant biomass. Moreover, no significant interaction was found between the *Pyropteron* and *Rumex* treatments (degrees of freedom: 6, deviance: 10082.8, residual degrees of freedom: 170, residual deviance: 455962, Pr(>Chi): 0.70).

The analysis was also performed separately for the different *Rumex* treatments due to non-overlapping below-ground biomass. With regard to seed-grown *R. obtusifolius* plants, the below-ground biomass was higher for the control than for the Sesiid-infested plants (degrees of freedom: 3, deviance: 194110, residual degrees of freedom: 56, residual deviance: 818454, Pr(>Chi): 0.004, estimate of control: 131.54, t-value 3.027, Pr(>t): 0.004). For *R. pulcher*, the *Pyropteron* treatment also had a significant effect on below-ground biomass (degrees of freedom: 3, deviance 6113.6, residual degrees of freedom: 56, residual deviance 28310, Pr(>Chi): 0.007, estimate of control: 28.08, t-value 3.42, Pr(>t): 0.001, estimate of *P. doryliforme*: 17.00, t-value 2.07, Pr(>t): 0.04); the control and the *P. doryliforme* treatments had a higher below-ground biomass than both the *P. chrysidiforme* and the mixed treatments. These results indicate that the *Pyropteron* treatments had already reduced the root biomass of seed-grown *Rumex* plants a few months after inoculation, while the effect on *R. obtusifolius* with taproots was less pronounced (degrees of freedom: 3, deviance: 8223.8, residual degrees of freedom: 57, residual deviance: 650523, Pr(>Chi): 0.87). We expect that the impact of *Pyropteron* on root biomass will further increase and become significant for all *Rumex* treatments in spring 2019.

d. Larval weight
Total larval weight per infested plant was related to the below-ground biomass of the infested *Rumex* plants (F-statistic: 5.904 on 1 and 92 degrees of freedom, adjusted R-squared: 0.05, p = 0.017, Figure 5). The larger the root, the higher the total larval biomass.

BEHAVIOURAL EXPERIMENTS

The aim of these experiments was to assess whether there is intraspecific cannibalism or interspecific competition among freshly hatched larvae of the two *Pyropteron* species. Both cannibalism and interspecific competition would be disadvantageous with regard to the efficiency of our candidate biological control agents, as it might restrict the number of larvae feeding on the roots of individual *Rumex* plants.

Materials and methods

Pyropteron eggs provided by CABI Switzerland were stored in petri dishes, separate from the female/s. The petri dishes were checked daily and freshly hatched larvae used for the behavioural bioassays. For the control treatment, one larva was transferred onto each root piece and their survival monitored. For the intra- and interspecific competition studies, four larvae of the same species, or two larvae of each of the two species, were transferred onto root pieces. Roots of seed-grown *Rumex* spp. were cut into pieces of 1.5 cm (for larval mortality assessment) and 4 cm (for intra-and interspecific competition studies). The root pieces were wrapped in three-folded moist paper. Freshly hatched larvae were inserted individually into the space between the root and moist paper with a fine paintbrush. Single inoculated root pieces were placed in an individual petri dish, which was sealed with medical tape. The petri dishes were left for 5, 10 and 15 days, and the paper was remoistened when necessary. At the end of a test interval, the petri dish was inspected for larvae (alive, dead or missing), the presence of head capsules, feeding marks and tunnelling patterns.

Figure 6 - dead (left) and alive (right) larvae retrieved in the same tunnel in a Rumex root

The larvae recovered from these experiments were used in a second bioassay. Various combinations of surviving larvae were tested for direct competition by keeping them for at least 24 hours in a small petri dish with a black background glued onto the bottom. The black background provided a good contrast for taking pictures and provided moisture for the larvae. A camera (TimeLapse Camera (TLC100), Brinno) taking a photo every minute was placed above the petri dishes to monitor whether the larvae attacked or ate each other. The petri dishes were checked after 24 hours, with alive, dead and missing larvae, as well as evidence of attack, being recorded. If both larvae were still alive, they were left in the petri dish and their status recorded again after an additional 24 hours.

Results

The results of the behavioural experiment have yet to be analysed. Signs of cannibalism have, however, been detected among larvae of both species (Figure 6).

EXPERIMENTS PLANNED FOR 2019

Influence of climatic conditions on infestation rate, root decay and mortality of *Rumex obtusifolius*

Abiotic stresses affect the hatching, infestation and establishment rates of biological control agents. Besides potential intraspecific and interspecific competition, climatic preferences by *P. chrysidiforme* larvae were cited as possible explanations for the low number of larvae recovered from field-grown *R. obtusifolius* plants in Switzerland in a study conducted by Hahn et al. (2016). The warmer and drier conditions at the sites where *P. doryliforme* was used for the classic biological control of *R. pulcher* in Australia can also be an explanation for its success

because these are the preferred conditions for many Sesiid species.
The objective of the experiment planned for summer 2019 is to identify the environmental factors affecting the larval attack rates for the two *Pyropteron* species.
Three abiotic factors are of interest regarding *Pyropteron* infestation and survival: precipitation, temperature and soil properties. Our experiment will focus on precipitation and soil properties. To test the precipitation factor, three water treatments mimicking rainfall in different climate scenarios (humid, normal and drought) will be applied to plants grown in an open tunnel. To test the soil properties, we will sample soil monoliths with *R. obtusifolius* taproots from sites with heavy soil with high compaction and from sites with light, less compacted soil.

Specifically, we will test the following hypotheses:
a. Concerning infestation probability:
- *Pyropteron* larvae are expected to show the lowest infestation probability under the humid scenario treatment due to aggravated movement through the soil under high soil moisture conditions and possible wash-off;
- *Pyropteron* larvae are expected to show lower infestation probability under the drought scenario treatment due to possible desiccation of larvae under low soil moisture conditions;
- *P. doryliforme* is expected to show higher infestation rates under the drought treatment than the *P. chrysidiforme* due to the drier conditions in its native range in the Mediterranean habitat;
- *Pyropteron* infestation levels are expected to be higher for fine soils with high clay/sand ratios, as has been shown for the grape root borer (Rijal et al., 2014); high soil compaction will hinder the movement of larvae through the soil and negatively impact infestation probability.

b. Concerning impact on *Rumex* plants:
- *Pyropteron* larvae are expected to show the lowest impact under the humid scenario treatment due to increased infestation by entomopathogens;
- *Pyropteron* larvae are expected to show decreasing mortality with increasing soil moisture due to reduced risks of desiccation;
- *P. doryliforme* is expected to show higher impact under the drought treatment than *P. chrysidiforme* because these conditions more closely reflect the conditions in its native range in the Mediterranean region;
- *Pyropteron* larvae are expected to show a preference for light, well-aerated soil. Hence, the impact is expected to be lower for *Rumex* plants growing in heavy, compacted soil.

In order to test these hypotheses, we will set up a pot experiment with the *Pyropteron* species, precipitation and soil type as fixed factors applied in a full factorial design and arranged in a randomized complete block design. The monoliths containing the taproots and intact soil structure will be placed under a plastic tunnel on a parcel near to Agroscope Reckenholz. The parameters to be recorded include: larval hatching rate, number of larvae alive, number of larvae dead, larval weight and instar, feeding marks, roots biomass, above-ground biomass, number of roots, and plant performance (estimation with scale, as used in previous experiments).

Literature

Grossrieder, M., & Keary, I. P. (2004). The potential for the biological control of *Rumex obtusifolius* and *Rumex crispus* using insects in organic farming, with particular reference to Switzerland. *Biocontrol News and Information, 25*(3), 65N-79N.
Hahn, M. A., Schaffner, U., Häfliger, P., & Lüscher, A. (2016). Establishment and early impact of the native biological control candidate *Pyropteron chrysidiforme* on the native weed *Rumex obtusifolius* in Europe. BioControl, 61(2), 221–232. https://doi.org/10.1007/s10526-016-9715-6
Hatcher, P.E., Brandsaeter, L.O., Davies, G., Lüscher, A., Hinz, H.L., Eschen, R., Schaffner, U. (2008) Biological control of Rumex species in Europe: opportunities and constraints. In: Proceedings 12th international symposium biology control weeds pp 470–475.
Rijal, J. P., Brewster, C. C., & Bergh, J. C. (2014). Effects of biotic and abiotic factors on grape root borer (Lepidoptera: Sesiidae) infestations in commercial vineyards in Virginia. Environmental entomology, 43(5), 1198-1208.
Scott, J.K., Sagliocco, J-L (1991a) Chamaesphecia doryliforme (Lep.: Sesiidae), a second root borer for the control of Rumex spp. (Polygonaceae) in Australia. Entomophaga 36: 245–251.
Scott JK, Sagliocco J-L (1991b) Host-specificity of a root borer, Bembecia chrysidiforme (Lep.: Sesiidae), a potential control agent for Rumex spp. (Polygonaceae) in Australia. Entomophaga 36:235–244.

FRANCE


Quesmy
Saint Hilaire en Woevre
Richarville
Vallangoujard
L´Épine
Boigneville
Prunay-Le-Temple
Humbligny
Crenay
Reboursin
Jussy-Champagne
Bengy s/Craon
Chaumoy
Saint Pourcain sur Besbre
Le Magneraud
Soupex
En Crambade

During this first trial campaign, several themes were studied in the French cluster trials, namely sowing dates, mechanical weeding, and the importance of cultivated plant cover in limiting weeds.

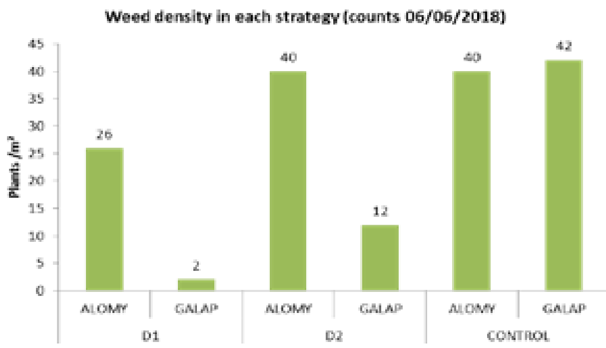
WP3 – EXPERIMENTAL TRIALS ON SOWING DATES OF WINTER WHEAT AND BARLEY

The subject of sowing dates and their impact on weeds was widely studied in the 2017-2018 season. It is a relatively easy method to implement and has immediate results for farmers. Most of these trials were implemented on-farm and were visited during open field days.
Fourteen experimental trials on the theme of delayed sowing, with and without other agronomic methods, were set up by various partners. This method is particularly effective for grassweed management (black-grass, ryegrass), with over 80% efficacy when compared with a conventional sowing date.
In addition, a few trials with yield measurement and appropriate herbicide applications show that the return on investment is real and the technique profitable.
Difficulties may remain, particularly with regard to "feasibility" due to planting periods in unfavourable autumn conditions. Nevertheless, in a context of herbicide reduction, delayed sowing seems to be a major step in the right direction and does not jeopardize the economic viability of the farm.

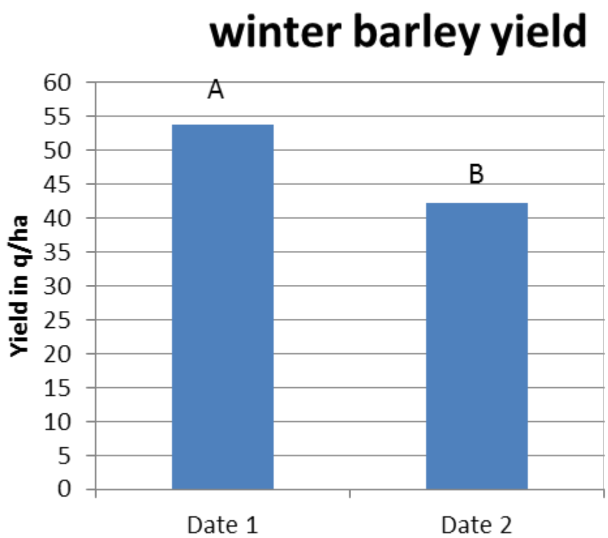
PARTNER: FDGEDA 18

The objective of this trial was to compare two sowing dates, with modulated herbicide lines for Date 2, and to validate whether Date 2, which was less dependent on herbicides, could do as well as Date 1 (Reference).

The initial results are shown in the figures below.
Date 2 limited the presence of weeds a little, but had a limited effect on the loss of yield. Other later dates should be studied to see whether they further limit the presence of weeds.



Legend - Weeds
ALOMY = *Alopecurus myosuroides*
GALAP = *Galium aparine*



PROTOCOL

One trial on winter barley (clay and limestone soil)
Date 1: 16/10/2017
Date 2: 30/10/2017

Experimental site: Jussy-Champagne
GPS coordinates: 46°58'46.013"N 2°39'55.721"E
Contact: Jean Gilet j.gilet@cher.chambagri.fr

Herbicides on Date 1:
Avadex 3L/ha (16/10/2017 incorporated)
Bofix 3L/ha (24/04/2018)
Herbicides on Date 2:
Bofix 3L/ha (24/04/2018)

PARTNER: ARVALIS-INSTITUT DU VÉGÉTAL

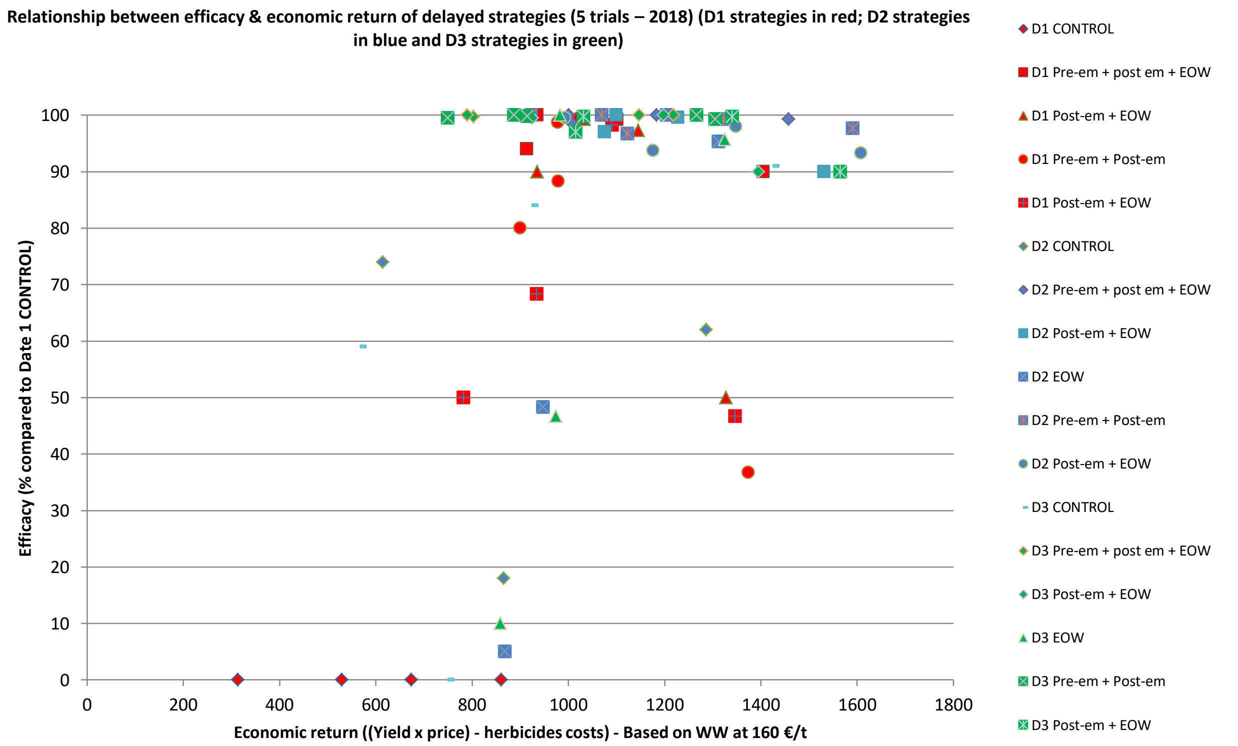
PROTOCOL

Six trials on winter wheat
The sowing dates were chosen according to regional practices. The weeds chosen were blackgrass (5 trials) and rye grass (1 trial). Only 5 trials are usable up to yield.

Date 1: early sowing (generally, beginning of October)
Date 2: intermediate sowing (D1 + 15 days)
Date 3: late sowing (D1 + 25 days to 1 month)

A range of herbicide programmes were evaluated in each strategy: the "Reference" programme; the "Light" programme; and no herbicides. The evaluation is also based on the economic return of each strategy (yield X wheat price – herbicide costs)

Experimental sites: Saint Pourcain sur Besbre (46°29'11.0"N 3°37'37.6"E), L'Épine (48°57'49.0"N 4°27'02.9"E), Le Magneraud (46°08'48.4"N 0°41'40.2"W), Quesmy (49°38'08.8"N 3°03'21.8"E), Crenay (48°01'0.41"N 5°09'42.8"E), Saint Hilaire en Woevre (49°04'21.1"N 5°42'10.6"E)
Contact: Ludovic Bonin l.bonin@arvalis.fr



Legend - Herbicide strategies
Pre-em = Pre-emergence
Post-em = Post-emergence
EOW = Herbicide in spring (end of winter)

Early sowing dates, which were frequently employed by farmers, were the most penalized, as they resulted in weed competition and/or the need for expensive weed-control programmes to control blackgrass populations effectively. The efficacy of sowing dates

D2 and D3 were the most regular, but also made it possible to reduce herbicide programmes by gaining one or even two passages at most. Moreover, control plots in D2 and D3 did better in terms of efficiency and economic return than methods with herbicides in D1.

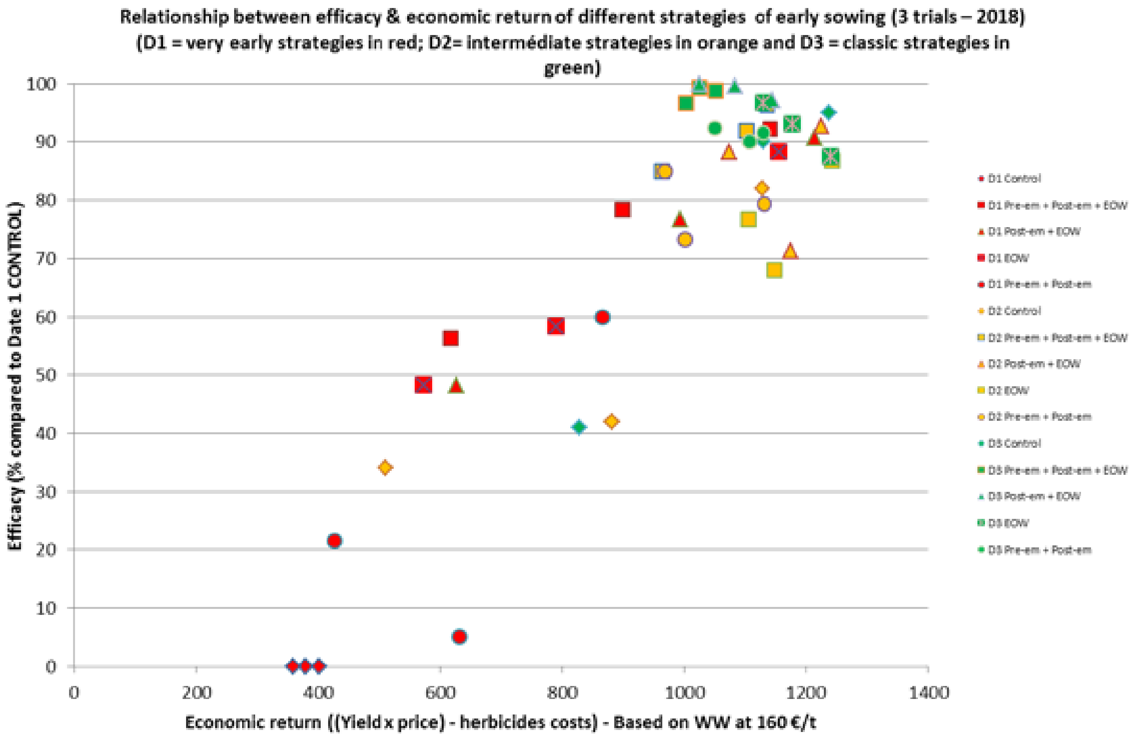
PROTOCOL

Three trials on winter wheat, with very early sowing dates
The objective was to evaluate the impact of very early sowing dates on weeds due to the competitive effect of the crop.

Date 1: early sowing (generally, beginning of October)

Date 2: intermediate sowing (D1 + 15 days)
Date 3: late sowing (D1 + 25 days to 1 month)

A range of herbicide programmes was evaluated in each strategy: the "Reference" programme; the "Light" programme; and no herbicides. The evaluation was also based on the economic return of each strategy (yield X wheat price – herbicides costs)



Legend - Herbicide strategies
Pre-em = Pre-emergence
Post-em = Post-emergence
EOW = Herbicide in spring (end of winter)

Contrary to the initial hypotheses, very early sowings are the most unfavourable for crop competitiveness on weeds. They require substantial herbicide programmes to control weeds, while late sowings, with fewer herbicides, are more economically viable. Moreover, in a context of reduced insecticides (aphids in autumn), early sowings are more exposed.

PARTNER: CHAMBRE AGRICULTURE D'INDRE-ET-LOIRE

PROTOCOL

One trial on winter wheat
Comparison of very early sowing with late drilling
→ **Impact on weeds (nb /m²)**
→ **Impact on yield**
→ **Reliance or not on herbicides**

Contact: Bruno Chevalier bruno.chevalier@cda37.fr

	Very early drilling	05-Sept			weeds /m² before herbicides		
Wheat variety	**Yield 14.5% H_2O**	**PS**	**Proteins**	**Pl/m²**	***LOLSS***	**POAAN**	**Broadleaves weeds (VERPE, etc…)**
Syllon	**15.7**	68.8	14.6	51	**12**	**37**	**37**
	Late drilling	27-Nov					
Syllon	**41.6**	74.5	12.5	116	**3**	**34**	**4**

→ Very early sowings are the most unfavourable. They require substantial herbicide programmes to control weeds, while late sowings with fewer herbicides and better yield are more economically viable.
→ Early sowings are more dependent on herbicides. This strategy, in a context of reduced herbicides, is not viable.

Herbicides in early sowing	**Herbicides in late sowing**
Clortosint 3.6 l/ha => 9/10/2017 (chlortoluron)	Olblack 1 l + H => 26/03/2018 (mesosulfuron + iodosulfuron)
Archipel 0.25 + Actimum 1 + Actirob 1 => 12/01/2018 (mesosulfuron + iodosulfuron + ammonium sulfate + oil seed rape oil	Alkera 1.2 l => 27/04/2018 (pinoxaden + cloquintocet)
Alkera 1.2 l +Simplon25 g => 28/04/2018 (pinoxaden + cloquintocet + metsulfuron)	

PARTNER: AGROSOLUTIONS

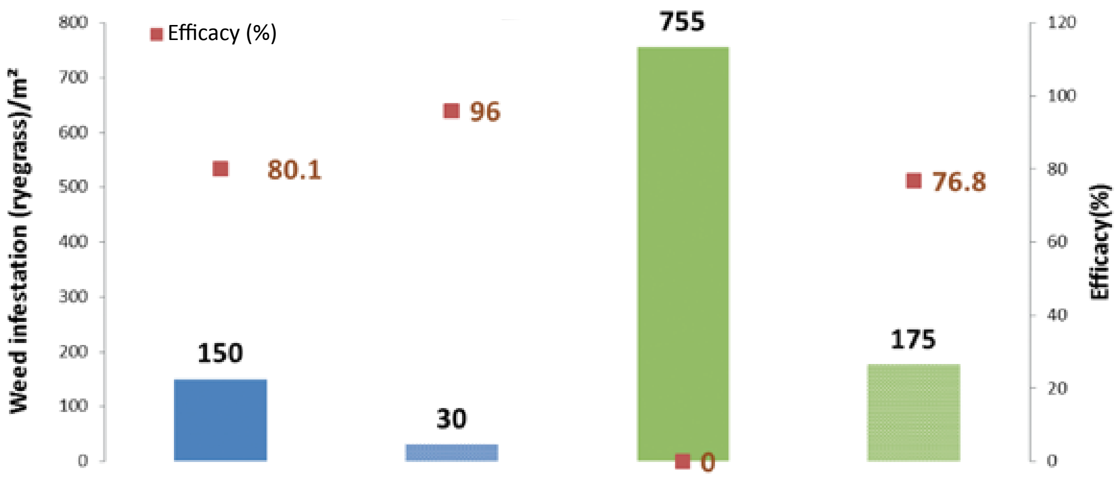
agrosolutions

PROTOCOL

One trial on winter wheat
→ Impact of delayed sowing in winter wheat, with or without ploughing, on infestation by rye grass

Contact: Chloé Cantuel ccantuel@agrosolutions.com

Efficacy of ploughing and delayed sowing on infestation by ryegrass (LOLSS) (1 trial, 2018)



Soil tillage	Ploughing	Ploughing	No till	No till
Sowing date	12/10	Delayed (30/10)	12/10	Delayed (30/10)

First results

The difference between “Ploughing” and “No till” is quite significant (-605 plants/m²). Delayed sowing also allows a substantial decrease in weeds, i.e. between 75% and 80%.

PARTNER: CHAMBRE AGRICULTURE ILE-DE-FRANCE

PROTOCOL

Two experimental weed-management trials on wheat were conducted at two sites located west (Prunay le Temple) and north (Vallangoujard) of Paris. Neither field had been ploughed for 20 years. The following table summarizes the tested protocol. At Prunay-le-Temple, the aim of the trial was to limit Black grass infestation, while at Vallangoujard, the purpose was to limit Ryegrass.

Experimental sites: Prunay-Le-Temple (48°51’51.8”N 1°40’16.3”E) and Vallangoujard (49°08’07.6”N 2°06’24.2”E)

Contacts: Christophe Daule christophe.daule@idf.chambagri.fr
Sabine Snyder sabine.snyder@idf.chambagri.fr

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<tr><th></th><th colspan="2">1</th><th colspan="2">2</th><th colspan="2">3</th><th colspan="2">4</th><th colspan="2">5</th></tr>
<tr><th></th><th colspan="2">Ploughing</th><th colspan="2">Pseudo ploughing</th><th colspan="2">Pseudo ploughing without rotary harrow</th><th colspan="2">Direct sowing without vegetative cover</th><th colspan="2">Direct sowing with vegetative cover</th></tr>
<tr><td rowspan="3">Steps</td><td colspan="2">Summer labour</td><td colspan="2">Post harvest: 15-20 cm deep tillage</td><td colspan="2">Post harvest: 15-20 cm deep tillage</td><td colspan="2">4</td><td colspan="2">Post harvest sowing of the vegetative cover (oat and pigeon bean mix)</td></tr>
<tr><td colspan="2">False seed-bed with superficial rotary harrow</td><td colspan="2">False seed-bed with superficial rotary harrow</td><td colspan="2">False seed-bed with superficial rotary harrow</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Rotary harrow and drill combined sowing</td><td colspan="2">Rotary harrow and drill combined sowing</td><td colspan="2">Rotary harrow free sowing (tillage free sowing)</td><td colspan="2">Direct sowing with adapted drill</td><td colspan="2">Direct sowing with adapted drill</td></tr>
<tr><td>Sowing date</td><td>Mid-October sowing</td><td>Late sowing in mid-November*</td><td>Mid-October sowing</td><td>Late sowing in mid-November*</td><td>Mid-October sowing</td><td>Late sowing in mid-November*</td><td>Mid-October sowing</td><td>Late sowing in mid-November*</td><td>Mid-October sowing</td><td>Late sowing in mid-November*</td></tr>
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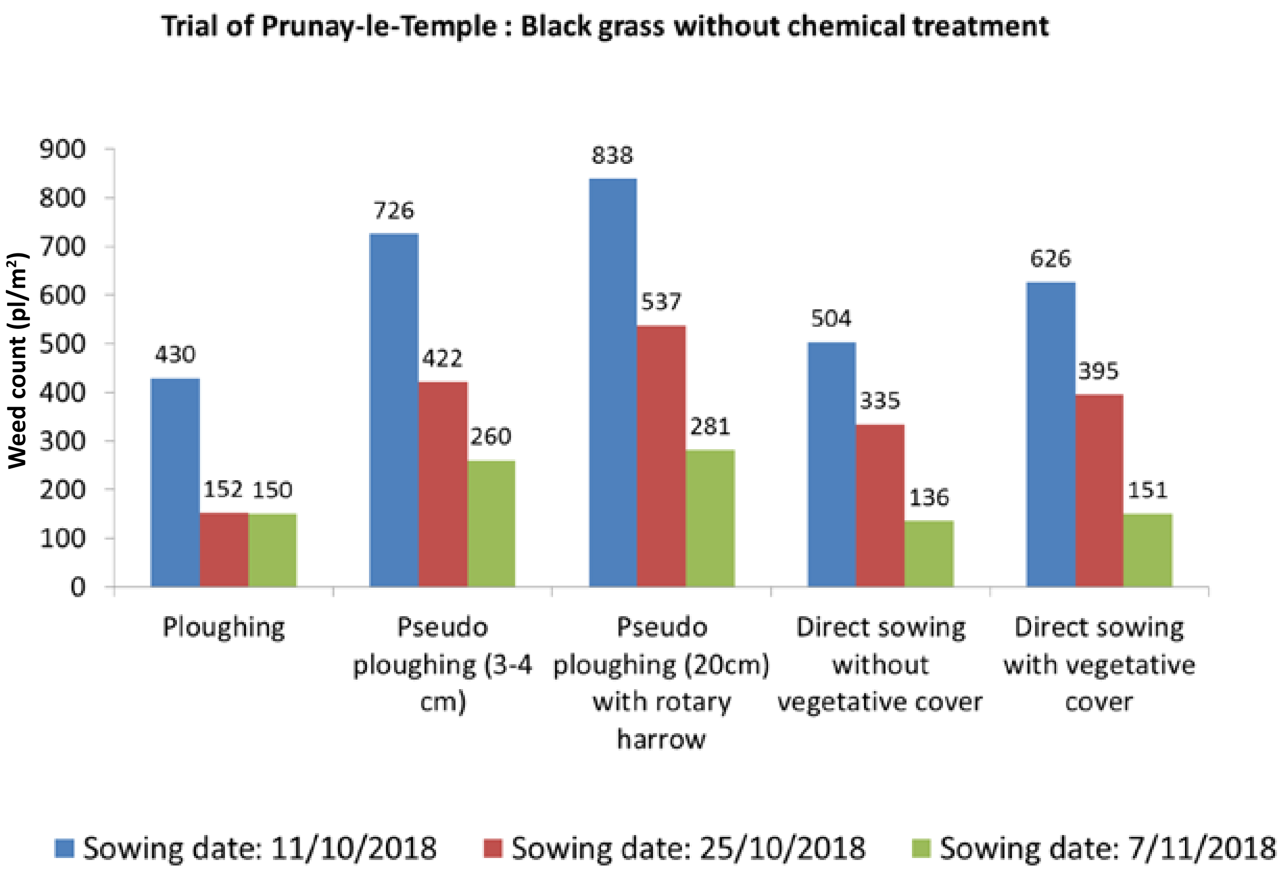
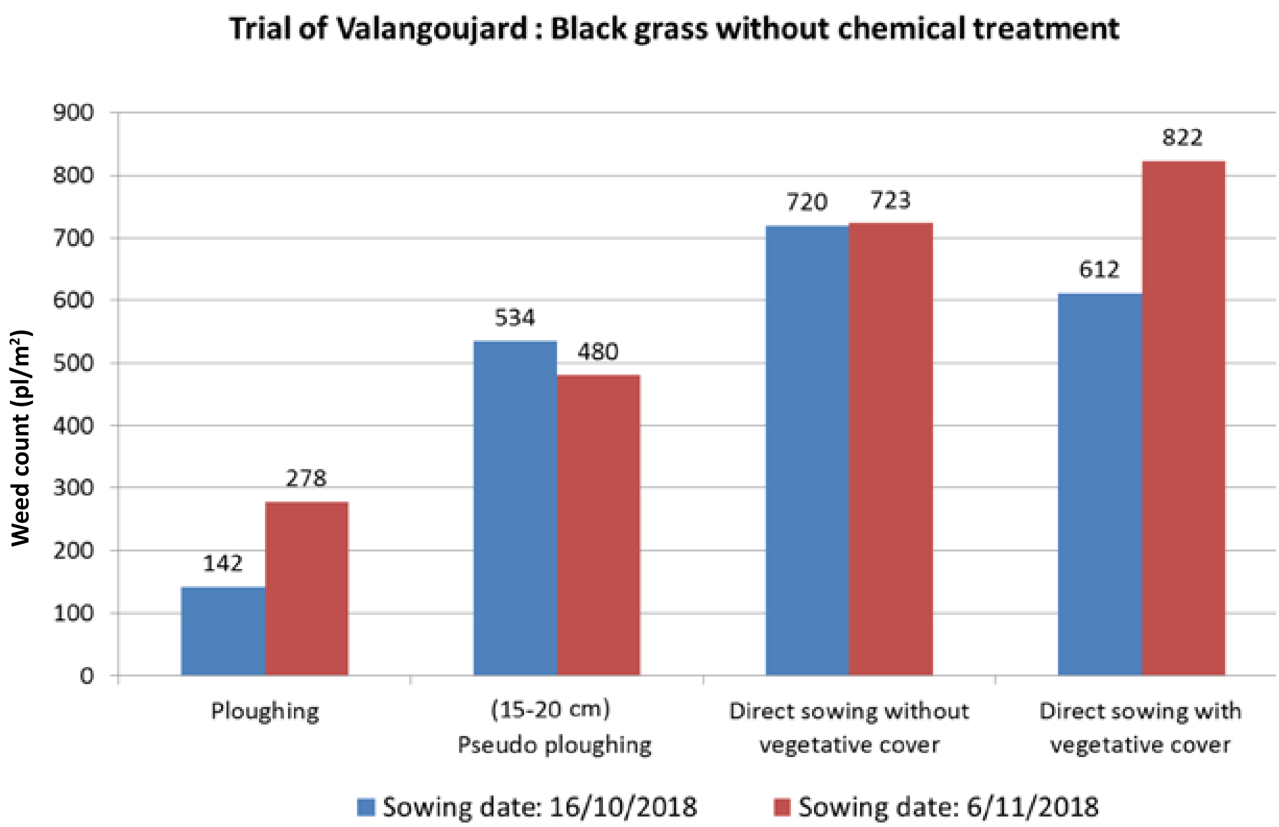
* at least 3 weeks after the first sowing, adapt to the ongoing year conditions
Each modality is compared with an untreated control


Trial of Prunay-le-Temple : Black grass without chemical treatment
Weed count (pl/m²)
900
800
700
600
500
400
300
200
100
0
430
152
150
726
422
260
838
537
281
504
335
136
626
395
151
Ploughing
Pseudo ploughing (3-4 cm)
Pseudo ploughing (20cm) with rotary harrow
Direct sowing without vegetative cover
Direct sowing with vegetative cover
Sowing date: 11/10/2018
Sowing date: 25/10/2018
Sowing date: 7/11/2018


Trial of Valangoujard : Black grass without chemical treatment
Weed count (pl/m²)
900
800
700
600
500
400
300
200
100
0
142
278
534
480
720
723
612
822
Ploughing
(15-20 cm) Pseudo ploughing
Direct sowing without vegetative cover
Direct sowing with vegetative cover
Sowing date: 16/10/2018
Sowing date: 6/11/2018

First results

Late sowing seems to be the second most efficient way to limit infestation by blackgrass after ploughing. Pre- and post-emergent application of herbicide on wheat sown in November gave excellent results for all methods.
Ploughing was the most efficient solution against ryegrass (99% efficacy) because the trial involved deep ground that had not been ploughed for 20 years and was thus probably free of weed seed. Pseudo-ploughing seems to be a rather satisfactory solution (86% efficacy), but it is likely to postpone the problem for one or two years by burying weeds in shallow depths. Direct sowing gave very disappointing results, as the weed-removal rate was about 45%, with or without vegetative cover. At the end of winter, the corresponding plots seemed particularly clean, but heavy rain in spring caused the emergence of ryegrass.

WP3 – EXPERIMENTAL TRIALS ON MECHANICAL WEED CONTROL OF WINTER BARLEY AND WHEAT

Eight mechanical-weeding trials were set up, with and without additional agronomic methods. The results were very variable with efficiencies highly dependent on the context. The other methods studied in these trials were more effective. Nevertheless, mechanical weeding can be an interesting complement, but it does not replace more efficient non-chemical methods, such as tillage and delayed sowing.

PARTNER: FDGEDA 18

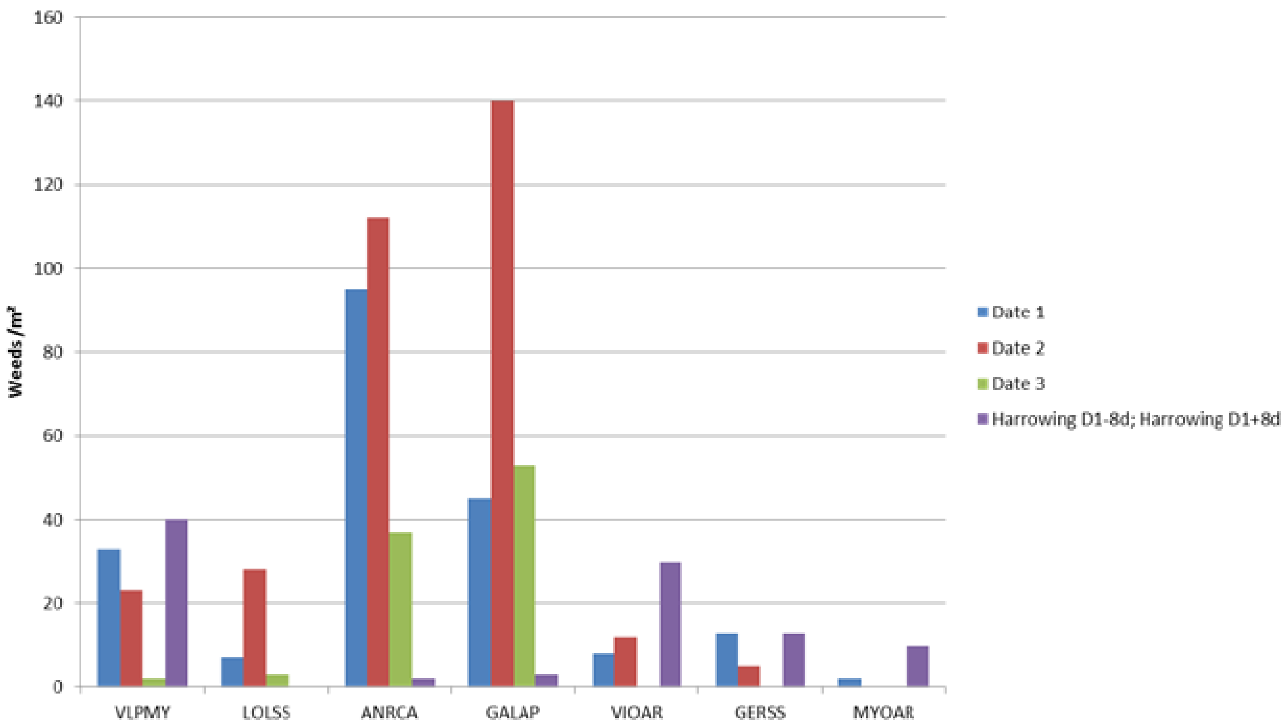
PROTOCOL

Trial on winter wheat (clay and limestone soil)
D1: 18/10
D2: 10/11
D3: 22/11

Introduction of tine harrowing, 8 days before D1, and 8 days after D1.
Comparison with D2 and D3.

Contact: Jean Gilet j.gilet@cher.chambagri.fr

Comparison of different strategies (delayed drilling and tine harrowing), on weed infestation (pl/m²) - countings on 30/03/2018



Legend - Weeds
ALOMY = *Alopecurus myosuroides*
GALAP = *Galium aparine*
LOSSL = *Lolium sp.*
VIOAR = *Viola arvensis*
ANRCA = *Anthriscus caucalis*
GERSS = *Geranium sp.*
MYOAR = *Myosotis arvensis*
VLPMY = *Vulpia myuros*

Initial results

Weed populations were lower in the third sowing date (D3) and when harrowing was performed twice. These methods were very effective on *Lolium* spp., *Vulpia Myuros, Viola arvensis, Geranium* spp. and *Myosotis arvensis*, but less so on *Anthriscus caucalis* and *Galium aparine*.
Date 2 seems to be the least favorable date for impact on *Lolium sp., Anthriscus caucalis* and *Galium aparine*, probably due to rainfall close to drilling.
Harrowing in D1, compared with D1 alone, seems to be effective on *Lolium sp.*, *Anthriscus caucalis* and *Galium aparine*. Nevertheless, it seems to stimulate (or is ineffective on) other weeds (*Vulpia Myuros, Viola arvensis, Geranium* spp. and *Myosotis arvensis*).

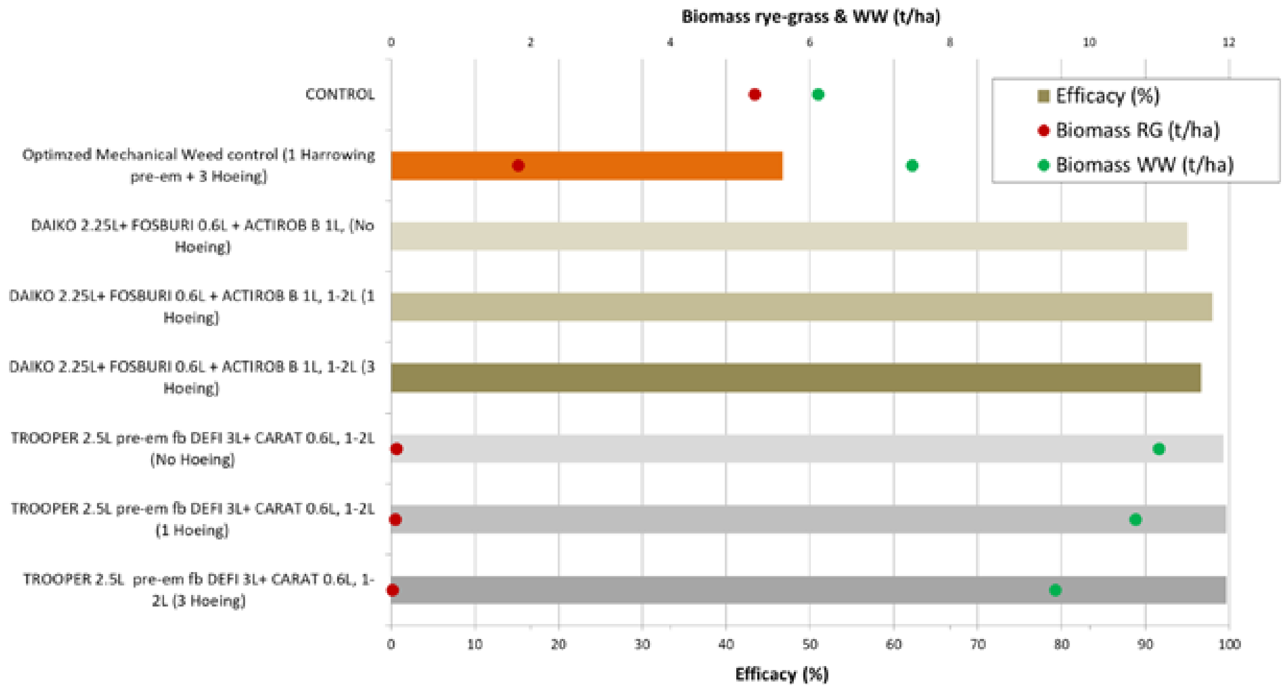
PARTNER: ARVALIS-INSTITUT DU VÉGÉTAL

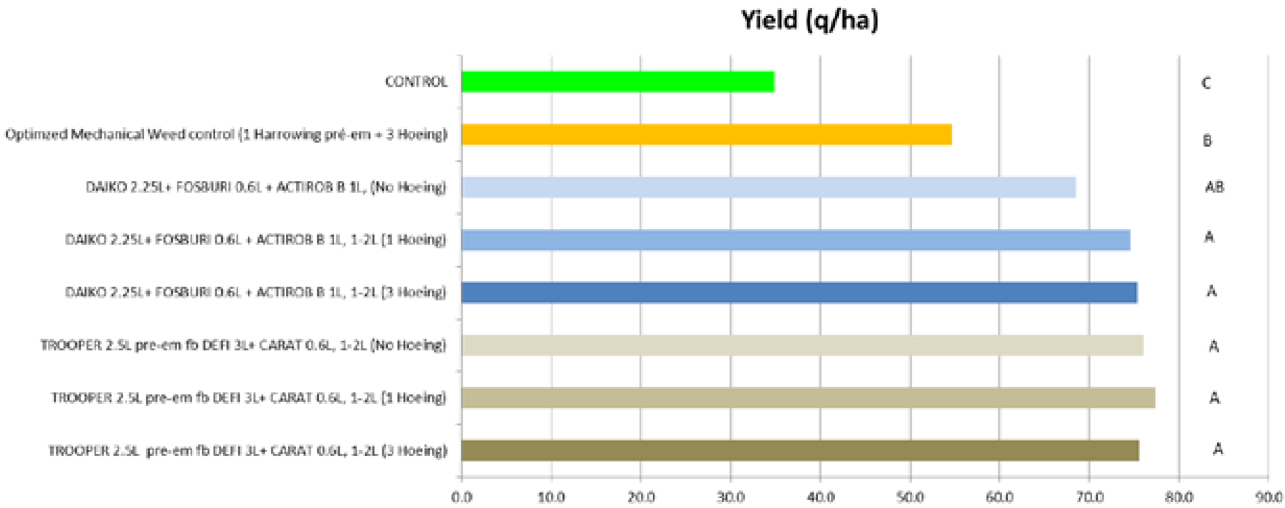
PROTOCOL

One trial on winter wheat
Comparison of different herbicide strategies (low input to high input) combined with hoeing in spring (no pass to multipass).

TROOPER 2.5L pre-em fb DEFI 3L+ CARAT 0.6L, 1-2L (3 Hoeing)
TROOPER 2.5L pre-em fb DEFI 3L+ CARAT 0.6L, 1-2L (1 Hoeing)
TROOPER 2.5L pre-em fb DEFI 3L+ CARAT 0.6L, 1-2L (No Hoeing)
DAIKO 2.25L+ FOSBURI 0.6L + ACTIROB B 1L, 1-2L (3 Hoeing)
DAIKO 2.25L+ FOSBURI 0.6L + ACTIROB B 1L, 1-2L (1 Hoeing)
DAIKO 2.25L+ FOSBURI 0.6L + ACTIROB B 1L, (No Hoeing)
Optimized Mechanical Weed control (1 Harrowing pre-em + 3 Hoeing)
CONTROL

Experimental site: Boigneville (48°19’26.4”N 2°23’11.4”E)
Contact: Ludovic Bonin l.bonin@arvalis.fr





Initial results

The effectiveness of herbicide programmes - including low-input strategies - did not allow us to verify the contribution of mechanical weeding in the spring. The measurement of ryegrass biomass and yield, however, made it possible to validate the value of mechanical weeding alone, with there being a yield gain of 2t/ha. Further studies are needed to validate the integration of mechanical weeding.

PARTNER: AGROSOLUTIONS

agrosolutions

PROTOCOL

Six trials on winter crops (winter wheat & barley)
→ Impact of multiple or single harrowing in autumn, combined with soil tillage/or delayed sowing.
→ Ryegrass or blackgrass.

Experimental sites: Chaumoy (47°1’49.3”N 2°19’47.1”E), Reboursin (47°6’23.7”N 1°49’20.7”E) Humbligny (47°15’9.9”N 2°39’33.9”E), Bengy s/Craon (46°59’55.1”N 2°44’48.0”E)

Contact: Chloé Cantuel ccantuel@agrosolutions.com

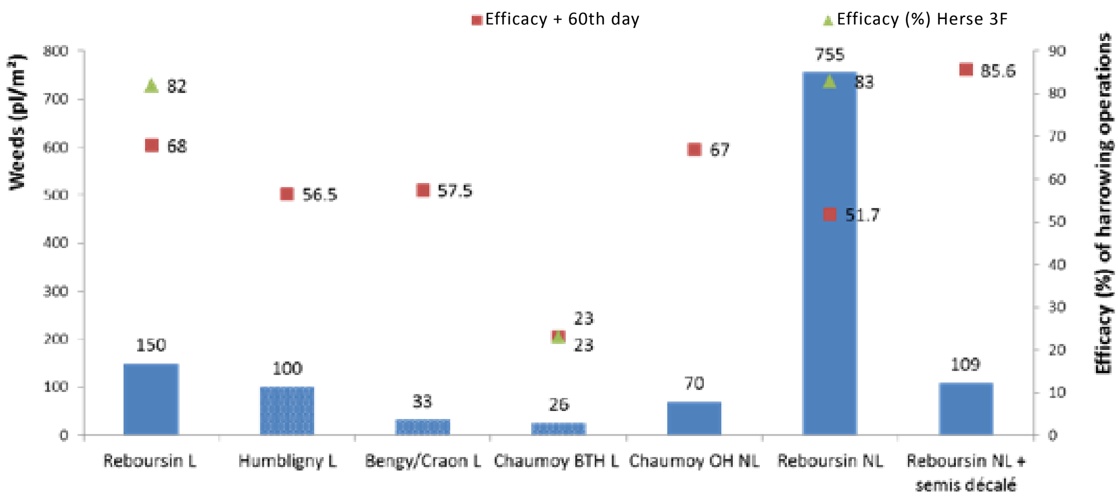
Initial results

Harrowing after sowing led to a significant decrease in weed infestations, on average 60%. Delayed sowing also led to a substantial decrease in weeds (80% efficacy in Reboursin).
In the Reboursin trial, harrowing twice led to a significant reduction in the population (83% efficacy). However, the trials had to be stopped at the beginning of June because weed populations remained too high.

Location of the WP3 trials managed by Agrosolutions

The weed harrow helped the other weed-management tools (e.g. ploughing, delayed sowing), as it compensated for the increase in the ryegrass population due to early sowing.

Efficacy (%) of multi or single pass of harrow (6 trials, 2018)



Legend - Harrowing
Green = efficacy of harrowing twice in autumn
Red = efficacy of harrowing once in autumn

WP3 – OTHER METHODS/TRIALS

PARTNER: CHAMBRE D'AGRICULTURE DU LOIRET

AGRICULTURES & TERRITOIRES CHAMBRE D'AGRICULTURE LOIRET

PROTOCOL

Screening trial of herbicide on a mix of spring barley + red clover.

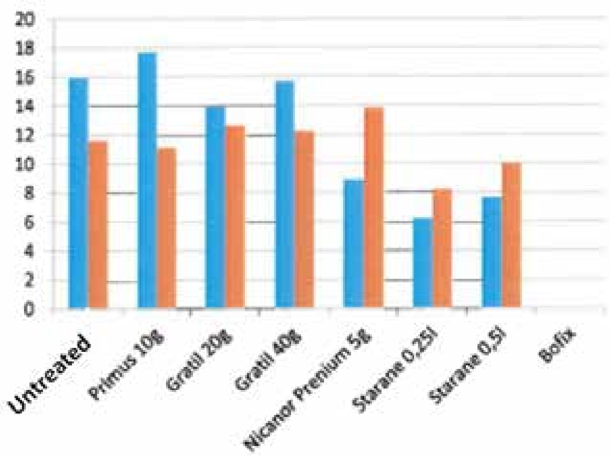
→ The objective is to control weeds and be selective on red clover (3 reps x 3m x 10m)

	Treatment	Dose/ha	TFI
T	Untreated		
1	Primus (florasulam)	10 g	0.3
2	Gratil (amidosulfuron)	20 g	0.5
3	Gratil (amidosulfuron)	40 g	1
4	Nicanor Premium (metsulfuron –me)	5 g	0.15
5	Starane 200 (fluroxypir)	0.5 L	0.5
6	Starane 200 (fluroxypir)	0.25 L	0.25
7	Bofix	2.5 L	0.6

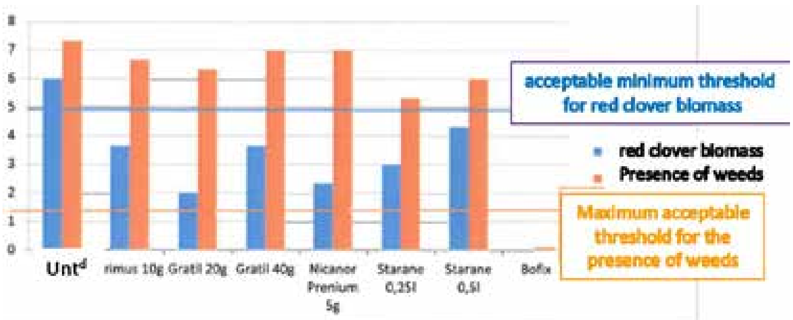
3 Blocks x 3m x 10m

Contact: Laurent Lejars laurent.lejars@loiret.chambagri.fr

Counts of red clover (in blue – pl/m²) and weeds (in orange - pl/m²)



Biomass of red clover (in blue –t/ha) and infestation note (in orange – /10) of weeds



Initial results

The technique of sowing red clover in spring barley is well know by researchers. However, the weed-control results of this combination are currently unsatisfactory. Product dosages will have to be reviewed. Clover density is impacted by herbicides, but is not totally destroyed. Weeds cannot be controlled without impact on red clover.

Adjustments for the next year

Delayed sowing and its combination with other non-chemical methods seems to be the best way to limit the use of herbicides while maintaining margins. Further trials will therefore be set up on this subject, in conjunction with aphid control.
Mechanical weeding will also be studied in order to consolidate data and to study the feasibility (days available) under French conditions.

WP4 – EXPERIMENTAL TRIALS ON IWM STRATEGIES FOR SUNFLOWER, MAIZE, SOYBEAN AND SUGAR BEET

PARTNER: TERRES INOVIA

Terres Inovia
l'agronomie en mouvement

PROTOCOL

Objectives: How to destroy weeds without glyphosate before the seeding of sunflower.
Four trials on the destruction of weeds after false seedbed and before the planting of sunflower. Comparison of the farm's tillage tool and glyphosate, evaluation of efficiency on weeds, and checking whether this tillage tool impacts crop quality.
Two trials were located in the centre of France and two trials in the south-west of France (2018).

Experimental sites: En Crambade (43°49'29.3"N 1°65'90.8"E), Soupex (43°22'43.0"N 1°53' 6.8"E)

Contact: Fanny Vuillemin f.vuillemin@terresinovia.fr

Location of the WP4 trials managed by Terres Inovia

Results

Various efficacies were recorded: with low infestations, there was no difference between tillage and glyphosate, but when the infestation was quite high, tillage was - unsurprisingly - much less effective than glyphosate.

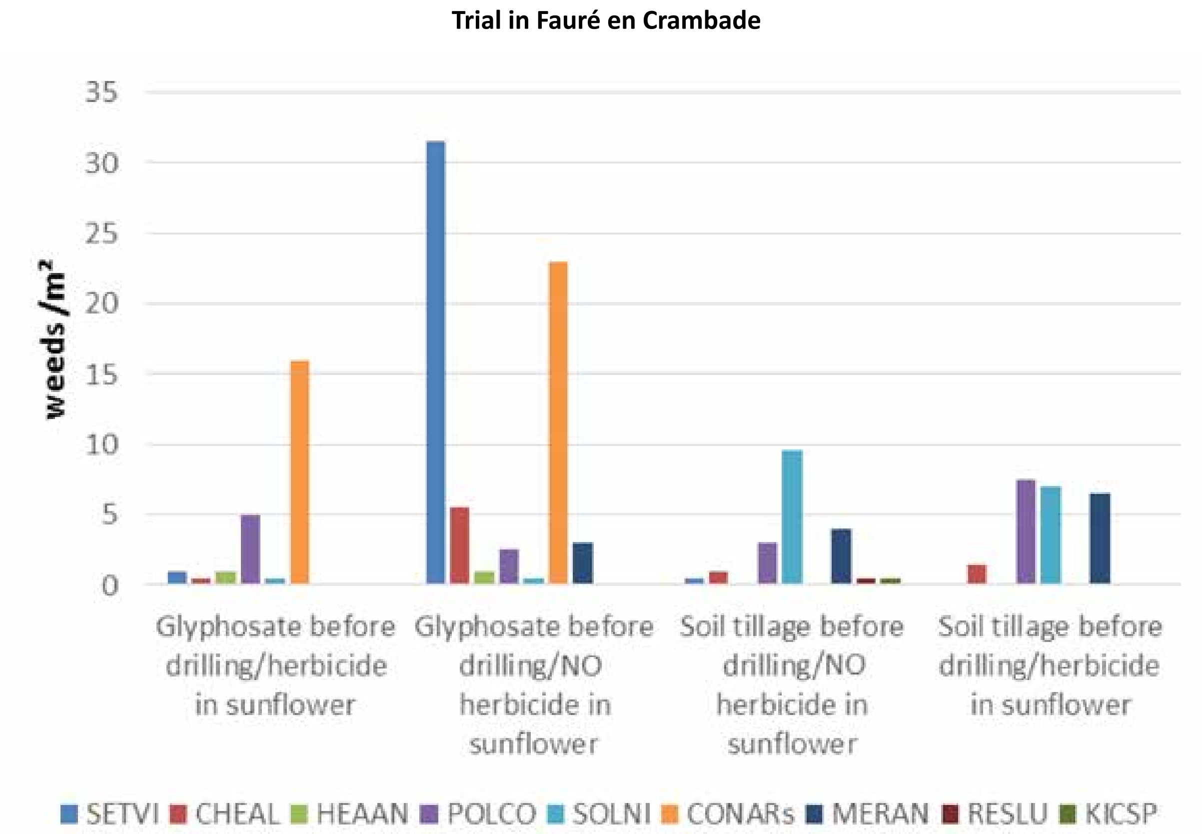


Figure 1 - Number of weeds according to the type of preparation before sunflower sowing. Counts in plots with herbicides and without treatments

Legend - Weeds
SETVI = *Setaria viridis*
ANGAR = *Anagallis arvense*
CIRARi = *Cirsium arvense*
CHEAL = *Chenopodium album*
MERAN = *Mercurialis annua*
SOLNI = *Solanum nigrum*
HEAAN = *Helianthemum angustatum*
SONAR = *Sonchus arvensis*
RESLU = *Reseda lutea*
POLCO = *Polygonum convolvulus*
KISCP = *Kickxia spuria*
CONARs = *Convolvulus arvensis*
AVEFA = *Avena fatua*

Trial 1 in south-west France
In this trial, tillage and glyphosate were both feasible this year. On some weed species (especially *Convolvulus arvensis* and *Setaria viridis*), tillage was more efficient than chemical treatment. This result shows that, in particular conditions, tillage is sufficient to destroy weeds and properly prepare for the sowing of sunflower.

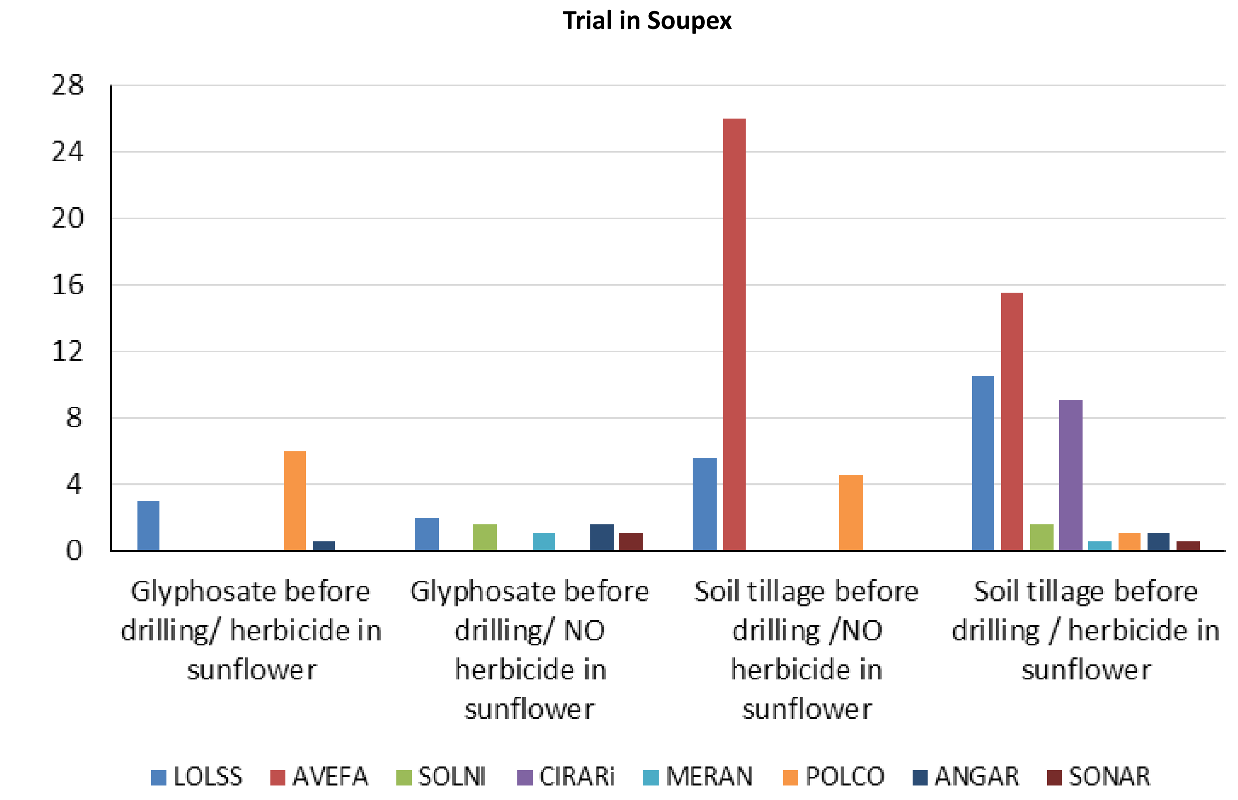


Figure 2 - Number of weeds according to the type of preparation before sunflower sowing. Counts in plots with herbicides and without treatments

PROTOCOL

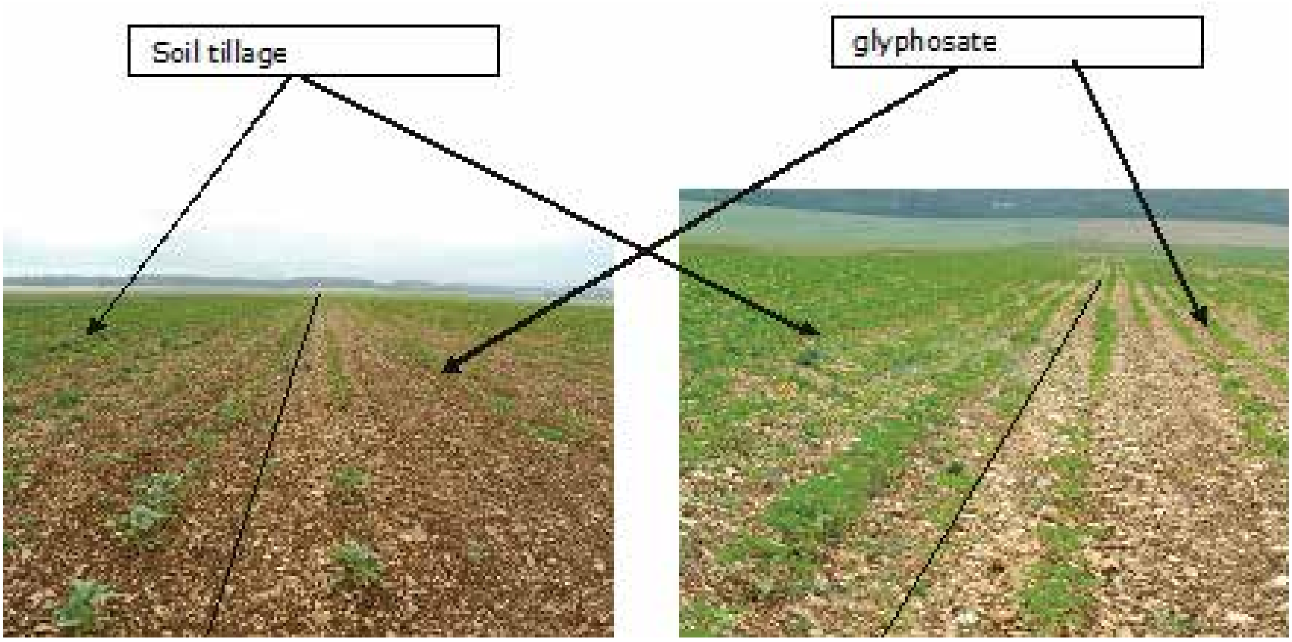
Objectives: How to destroy weeds without glyphosate before the seeding of sunflower.
Four trials on the destruction of weeds after false seedbed and before the planting of sunflower. Comparison of the farm's tillage tool and glyphosate, evaluation of efficiency on weeds, and checking whether this tillage tool impacts crop quality.
Two trials were located in the centre of France and two trials in the south-west of France (2018).

Experimental sites: En Crambade (43°49'29.3"N 1°65'90.8"E), Soupex (43°22'43.0"N 1°53' 6.8"E)

Contact: Fanny Vuillemin f.vuillemin@terresinovia.fr

Trial 2 in south-west France:
In this trial, tillage to destroy weeds and prepare for the sowing of sunflower proved to be difficult. Indeed, the field was tilled four times because grass species had developed, yet this was not sufficient to destroy them. In this case, glyphosate was more effective in terms of cost, efficiency, working time and more.

Fortunately, heavy rain between March and April allowed the sunflower to germinate and develop normally, otherwise the soil perturbations created by tilling four times would have prevented the sunflower being planted properly.



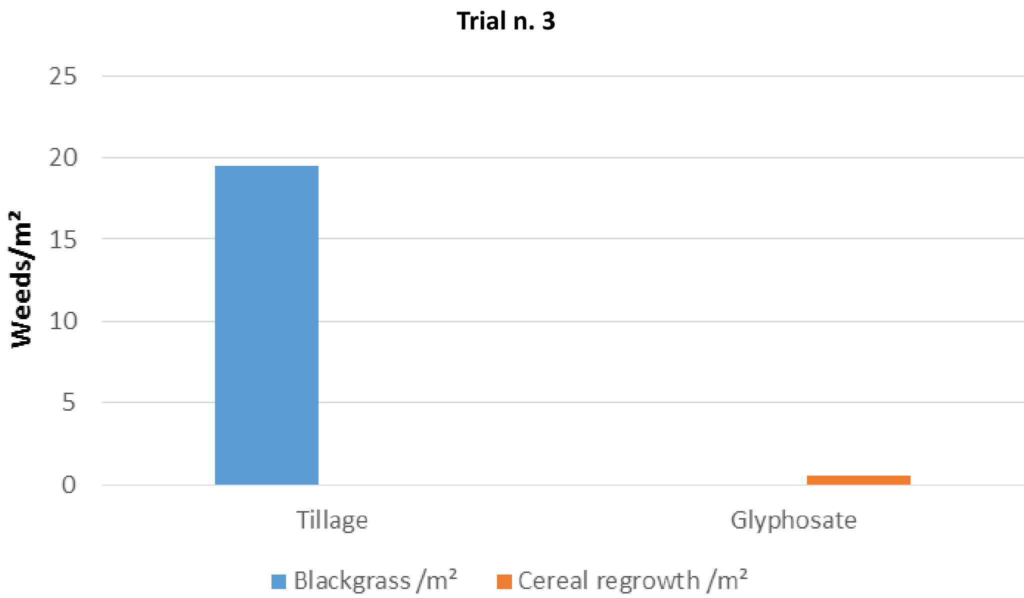


Figure 3 - Number of weeds according to the type of preparation before sunflower sowing. Counts in sunflower field

Trial 3 in central France:
The initial infestation mainly comprised *Alopecurus myosuroides* (around 15-20/m²) and *Polygonum* spp. After the intervention had been carried out and the sunflower sown, the results in sunflower (7 May) showed zero *Alopecurus myosuroides* in the glyphosate strip, but 19 *Alopecurus myosuroides*/m² in the tillage strip. Thus, with this type and level of flora, glyphosate was more efficient than tillage. However, we noticed that when tillage and glyphosate were employed in April, they destroyed all the weeds present. The infestation in the tillage strip was by new germinations of *Alopecurus myosuroides*. However, although tillage destroyed all of the weeds present, it moved the soil and thus caused other weeds to germinate, a problem compounded by the abundant rain during this period. We were therefore wondering whether a dry spring would make tillage as interesting an option as glyphosate. Its impact on the sowing of sunflower must not be forgotten, however, and our research is set to continue.

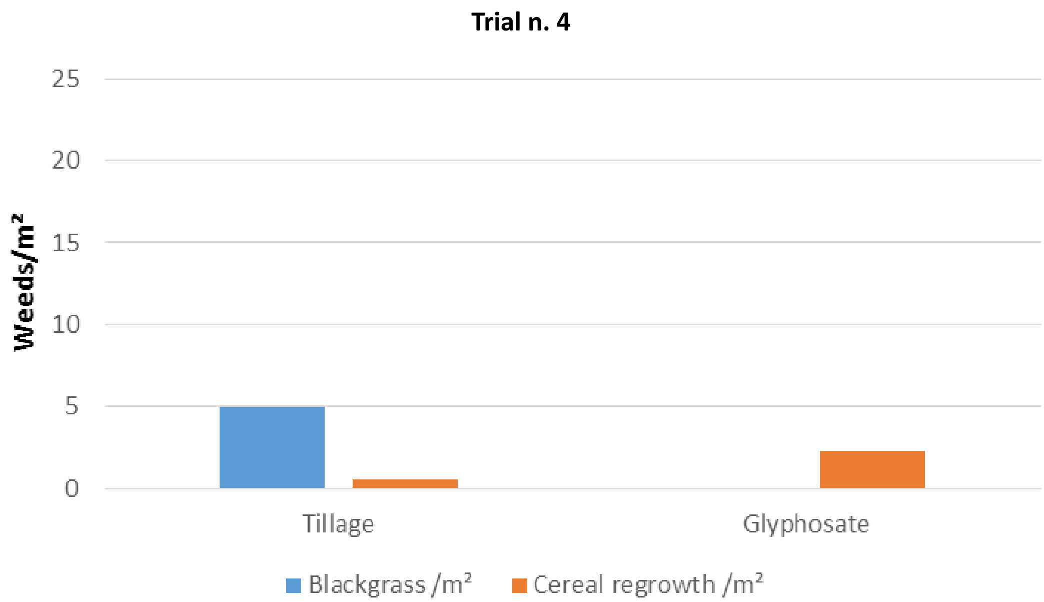


Figure 4 - Number of weeds according to the type of preparation before sunflower sowing. Counts in sunflower field.

Trial 4 in central France:
The initial infestation mainly comprised *Alopecurus myosuroides* (around 5-7/m²). After the intervention had been carried out and the sunflower sown, the results in sunflower (7 May) showed zero *Alopecurus myosuroides* in the glyphosate strip and five *Alopecurus myosuroides*/m² in the tillage strip. There was very little difference between tillage and glyphosate (five blackgrass/m²). Thus, in this case, tillage was almost as effective as glyphosate, a result probably due to the initial infestation level, and especially to the seedbank, being lower in this field than in the previous one. This is why the rainfall after tillage did not cause much germination in this field. These results provide encouragement that glyphosate can be replaced.

These four trials show that successfully replacing glyphosate with tillage depends on the conditions (e.g. seedbank, type of weed species, climate). We will continue these trials to discover more about the conditions that help and hinder glyphosate replacement in a bid to advise farmers better.

PROTOCOL

Objectives: how to destroy *Ambrosia atimisiifolia* without glyphosate before the seeding of sunflower.
One trial on the destruction of ragweed after a false seedbed and before the seeding of sunflower. Comparison of innovative tillage equipment designed to reduce herbicide usage called "glyphomulch", a classic tillage tool, and glyphosate. Evaluation of their efficiency on weeds and checks to decide whether this new tillage equipment impacts the quality of sunflower sowing. The trial was located in Cher, central France (2018).

Experimental site: Chaumoy (47°1'49.3"N 2°19'47.1"E)
Contact: Fanny Vuillemin f.vuillemin@terresinovia.fr

Results

An error was made by the farmer who owns the field, as he treated the entire field with glyphosate after sowing the sunflower. The trial was therefore abandoned, but will be proposed again next year. Before the weeds were terminated, some lessons were learnt: "glyphomulch", which is used to destroy biomass, including weeds, cover crop and straw, is not suitable for destroying young ragweeds and will not be applied in the next protocol. It is more suited to large cover crops with high quantities of biomass.

PROTOCOL

Objectives: manage *Ambrosia atimisiifolia* in a wheat-soybean rotation.

A long trial on the management of ragweed. Comparison of three strategies: repeated tillage in summer to reduce the soil seedbank of *Ambrosia*; ploughing to clean the field, but with the risk of seeds remaining in the soil; no-tillage and direct seeding of soybean to avoid an *Ambrosia* seedling emergency. This trial is located in south-west France and will last three years: from summer 2017 to summer 2020.

Experimental sites: Chaumoy (47°1'49.3"N 2°19'47.1"E)
Contact: Fanny Vuillemin f.vuillemin@terresinovia.fr

Results

This long-term trial was successfully implemented and is proceeding well. It was sown in soybean in spring 2018. At the beginning of June 2018, we saw differences between the types of ragweed infestation. A visit took place on July 2018. The future of this trial is now in question because some technical interventions were not carried out properly and we are wondering whether it would be better to restart the trial.

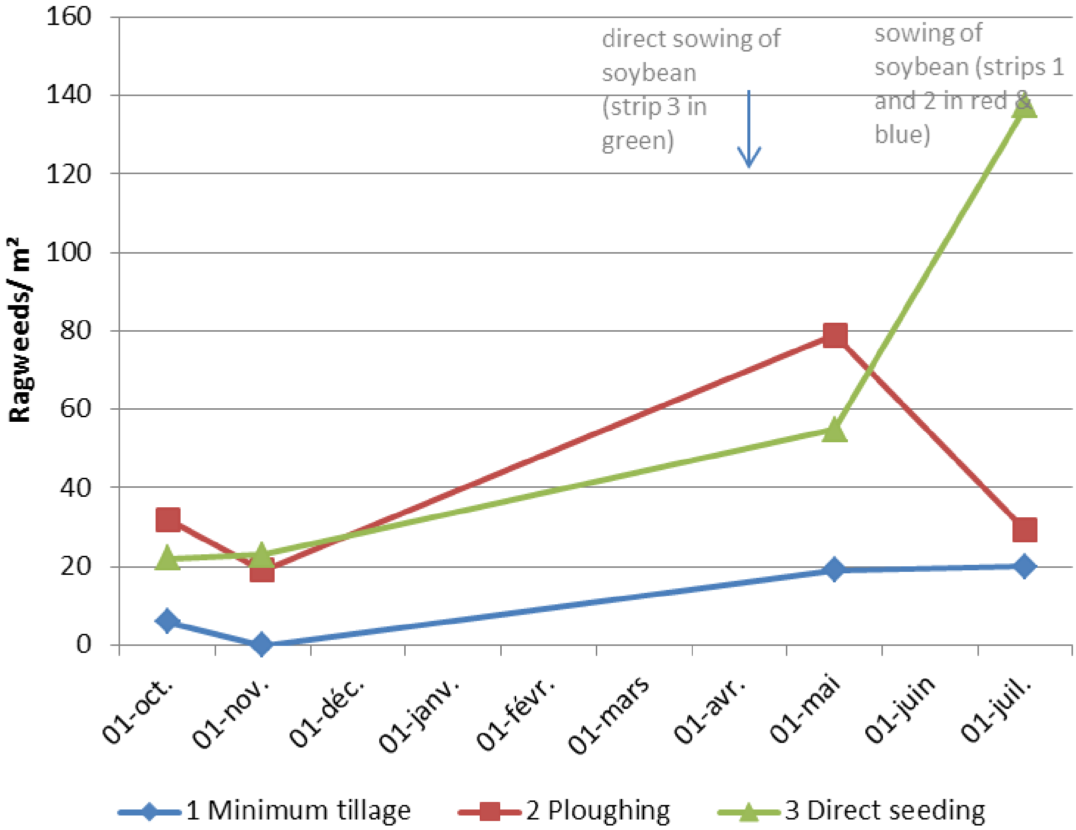


Figure 5 - Number of ragweeds according to the type of preparation

After the first year of this trial, we established that there were some trends that needed verifying at a later date, or tested with other trials. We already know that ploughing is not ideal for ragweed management because ragweed seeds are able to stay viable / can remain dormant in the soil, even after a long time. However, we wanted to see whether the elimination of ploughing would be useful. Now we need to observe the long-term effect on the ragweed population. As we moved the soybean sowing date for Strips 1 and 2, we will see the main impact of this practice on the ragweed population in summer 2018. The goal is to let the ragweed germinate and grow, after which it will be destroyed before sowing. If we sow earlier (as we did in Strip 3), the ragweed doesn't have time to germinate and grow, doing so inside the crop. As we want as little ragweed as possible in the soybean, we prefer to sow later. That is why the strip with direct sowing turned out to be the worst strategy. Indeed, the soil was touched when this strip was sown because the farmer performed tillage at the end of the winter to destroy any ryegrass without glyphosate. This intervention caused a considerable amount of ragweed to germinate, and we were unable to destroy it before sowing soybean because we wanted to touch the soil on this strip as little as possible. This management technique, however, is not efficient on ragweed (see Figure 5).

Between Strip 1 and Strip 2 we can suppose that the ploughing put up some old seeds of ragweed still viable. Next summer, after the wheat of 2018-2019, we will perform more tillage on Strip 1 than in summer 2017 to see the effect on ragweed populations.

The poor weather conditions of spring 2018 meant that the soybean population was far from optimal and regular.

PARTNER: ARVALIS-INSTITUT DU VÉGÉTAL

PROTOCOL

Screening trial of herbicide on a mix of spring barley + red clover.

→ The objective is to control weeds and be selective on red clover (3 reps x 3m x 10m)

	Pre-em	Post 3-4 L	Post 4-6 L	Results (efficacy /10) date: 19/06/2018
	Control			
1		Hoeing	Hoeing	**5**
2	Adengo Xtra 0.44			**7**
3	Camix 2.5	Elumis 0.75 + Peak 6g		**8**
4	Adengo Xtra 0.44	Elumis 0.75 + Peak 6g		**9**
5	Adengo Xtra 0.44 on row	Hoeing	Hoeing	**5**
6	Adengo Xtra 0.44 on row	Elumis 0.75 + Peak 6g full	Hoeing	**6**
7	Camix 2.5 on row	Elumis 0.75 + Peak 6g full	Hoeing	**7**

Contact: Laurent Lejars
laurent.lejars@loiret.chambagri.fr

Results

The weed flora mainly comprised *Echinochloa crus-galli* and *Chenopodium album*. Regardless of the herbicides and their spectrum, hoeing combined with reduced herbicide does not manage weed flora fully. The main difficulty was caused by the soil lifting as the machinery was passed. Further trials will be needed in the next campaign to refine the strategies.

PARTNER: CHAMBRE D'AGRICULTURE ILE-DE-FRANCE

Objectives: Reducing the frequency - and then the quantity - of herbicides used by farmers thanks to mechanical treatment in sugar beet.
This experimental weed-management trial on beets was located in Richarville, south of Paris. The following diagram summarizes the original protocol.

6 meters	6 meters	6 meters	6 meters	6 meters	6 meters
Untreated control	Tilled control	Local practices	Local practices + hoeing	Reduced chemical treatment + hoeing	Reduced chemical treatment + harrow
		3 applicatons of herbicide	*3 applicatons of herbicide*	*2 applications of herbicide*	*2 applications of herbicide + 2 mechanical weeding steps*

Table 2 - Strategies studied in sugar beet

Experimental site: Richarville (48°28'13.2"N 2°00'19.7"E)

Contact: Caroline Roques
caroline.roques@idf.chambagri.fr

Results

The following table summarizes the weed count in the beet field. In the "normal" plot, the farmer carried out only two applications of herbicides because two was enough to achieve the goal of 94% weed removal, with suitable weather conditions, enabling the beets to grow rapidly. Weed-removal efficiency reached 100% when herbicide applications were completed with rotary harrowing. Mechanical weeding only, without using herbicides, was only 69% efficient.

	Type of weed	Untreated control	Tilled control	Farmer practices in year 2018 (2 applications of herbicide)	Reduced chemical treatment (2 applications of herbicide) + hoeing	Reduced chemical treatment (2 applications of herbicide) + hoeing + harrow
Number of plants/m²	Lamb's-quarters	7	2	1	0	0
	Knotweed	3	0	0	0	0
	Matricaria	4	2	0	1	0
	Ragwort	2	1	0	0	0
	Total	16	5	1	1	0
	Efficiency %		**68,75**	**93,75**	**93,75**	**100**

Table 3 - Efficacy of the various strategies in sugar beet

Figure 6 - Sugar-beet sowing machine

PARTNER: CHAMBRE D'AGRICULTURE DU LOIRET

Objectives: evaluation of a new robot for weed control in sugar beet (Ecorobotix)
Two trials to validate the accuracy of the robot (triggering in the presence of weeds, false positives with triggering on beet, etc.). The trials were carried out in two stages: one with a dye that validated application precision and the other with herbicides for operational implementation.

Testing the weed-control robot in sugar beet

Contact: Laurent Lejars
laurent.lejars@loiret.chambagri.fr

Results

The tests experienced a number of technical hitches:

- the robot stopped unexpectedly (e.g. U-turns, shutdowns);
- nozzles clogged, priming problem;
- spraying did not activate;
- delay during advancement (non-recognition of beet rows);
- computer interface sometimes blocked, computer bug, viewing screen very difficult in sunlight.

The robot actually operated for a few metres, which allowed some precision evaluations to be made:

Notes for 2 m²	
Number of sugar beets (SB)	23
Number of SB sprayed	9
Number of weeds	95
Number of weeds totally sprayed	3
Number of weeds partially sprayed	2
Number of weeds non sprayed	90
False positives (e.g. stones sprayed, straw sprayed)	8
Weed-free/stone-free zone sprayed (close to weeds or not)	66

Table 4 - Parameters studied in the “usable” trial of the weed-control robot

There were a lot of bugs, which is unusual as this problem did not arise in other tests with ARVALIS in 2016.The robot was also highly inaccurate, which led to a high presence of uncontrolled weeds. Other material problems were also identified: when the ruts were too deep, the nozzles sometimes touched the ground, meaning that the nozzle holder was too low. When the ground was clumpy, the robot sometimes had difficulty moving and maintaining a correct heading.

Further tests will be conducted on the next campaign.

UNITED KINGDOM

EXPERIMENTAL TRIALS AT NIAB EMR

The Demonstration Farm at NIAB EMR (N40°45’53.28”W73°58’50.88) was established in 1913 as part of a not-for-profit research organization for the purpose of improving best commercial practices in fruit growing through the application of science and to showcase new varieties, novel crops and production systems. The farm is located 46 km south-east of London and occupies 220 ha of land in the County of Kent, one of England’s major fruit growing regions owing to the combination of low rainfall (less than 700 mm p.a.) and good levels of sunlight (more than 1,600 hrs p.a.). The local soils are typical ‘fruit’ soils, being well-drained Luvisols with sandy loam, or sandy clay loam texture. Although strawberries, raspberries and dessert apples are the dominant fruit crops grown on the farm, in response to renewed commercial interest there are also research plantings of pears, plums and cherries. To meet the needs of the expanding UK viticulture industry, the first research vineyard on the farm was planted in 2015.

For information and guided visits, please contact:
tel. +44 (0) 1732 843833
e-mail: enquiries@emr.ac.uk
website: www.emr.ac.uk

IWMPRAISE experimental trials at NIAB EMR:
1. Organic dessert apples
2. Newly planted and established wine grapevines

Introduction

Perennial fruit crops and grapevines are typically grown in rows, separated by alleys for access. To minimize competition for water and nutrients, the area beneath the trees and grapevines is kept as bare soil through the use of herbicides and is known as the 'herbicide strip'. The effects of weed competition are most pronounced in new plantings. Mechanical weeding and tillage are rarely practiced in fruit orchards, but their use is becoming more common in vineyards. Typically, a mixture of perennial grasses is maintained in the alleys to facilitate trafficking and to reduce soil erosion. The grassed alleys are mowed several times a year to reduce plant height and to control the growth of broad-leaved weeds. As part of integrated pest management practices, increasing the botanical diversity of alley groundcover is being promoted to aid the dispersal of pollinating and predatory invertebrates.

Approximately 90% of herbicide use in commercial dessert apple orchards is for general weed control. Glyphosate is the mostly common active substance and accounts for 50-60% (by weight) of the herbicide formulations used. In excess of 6 tonnes are applied annually to dessert apple orchards in England, Wales and Northern Ireland. In recent years, the increase in glyphosate usage has been more than two times

Implement	Mode of Action	Soil Disturbance	Other advantages
Blade 	Severs weed shoots from their roots below the soil surface	XX	
Disk 	Tills the soil to uproot and cut up weeds – mounted in front of the blade.	XXX	Effective at high driving speeds
Serrated disk 	Tills the soil and cuts up weeds	XX	Does not create a sharp edge between row and alley, so doesn't create water run-off channels on sloping ground
Finger hoe 	Breaks up soil mounds around the base of plants and physically damages weeds just above the soil surface. Combined with the serrated disk.	X	Works directly around the plant

Cover crop mix	Weed suppression action	Belowground benefits	Aboveground benefits
With clover 	Out-compete weeds by covering	Fixes nitrogen and releases it quickly	Attracts pollinators and other beneficial insects, when flowering
Pollen and nectar floral mix / spontaneous 		Diversity of root systems alleviates compaction, improves soil structure and adds organic matter.	Increases agroecosystem biodiversity. Attracts a wide range of pollinators and other beneficial insects over an extended period.

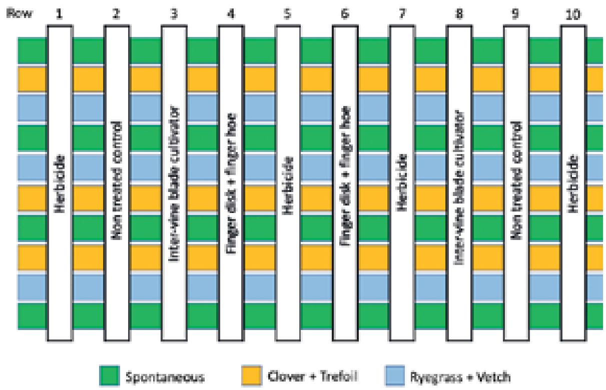
greater than the increase in the area occupied by commercial apple orchards.

Objectives

In conjunction with two industry partners: the mechanical engineering company Clemens GmbH and the seed merchant Cotswold Seeds, the trials at NIAB EMR will assess the efficacy of mechanical and botanical alternatives to chemical weed control in the rows and alleys respectively.

Materials and methods

The trials began in early summer 2018 and include a rain-fed five-year old organic apple orchard, a four-year old irrigated vineyard, and a new vineyard planted in early summer 2018.
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 will contain clover and the other will be a flower-rich mix.
Botanical surveys will determine weed species identity and abundance in the rows three times a year. Images taken by a multispectral camera will be used to estimate the biomass of weeds and cover crops in the rows and alleys respectively, based on the normalized difference vegetation index (NDVI) of spectral reflectance measurements.
In the vineyard, in situ sensors will monitor the effects of mechanical weeding and cover crops on the soil conditions (water content as matric



potential and temperature) and the microclimate aboveground (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.

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

Contact for visits of Trial 1:
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e-mail: joop.esselink@wur.nl
tel. +31 320291439

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Hilfred Huiting
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Two experiments are in place for the IWMPRAISE project:

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

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

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

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

I. Diverse cropping systems
 a. Diverse systems increase or equal crop yields or profitability when compared with conventional systems.
II. Suppressive/tolerant varieties
 a. Selecting weed-suppressive (or weed-tolerant) crops.
 i. Suppressive varieties will reduce weed-seed production, while tolerant varieties will maintain high yield levels under weed pressure, but will not necessarily reduce weed pressure and may therefore lead to potentially increasing weed-population levels.
III. Crop management, enhancing crop growth (nutrient placement, sowing depth, transplanting, tillage systems).
IV. Targeted control tactics to disturb weed life-cycles (e.g. flame weeding, biocontrol, targeted herbicide application, site specific).
V. Monitoring & evaluation (e.g. innovative sensing technologies and decision-support systems - DSS).

ANNUAL ROW CROPS: ARABLE & VEGETABLE CROPS

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

Results 2018

Figure 2 shows the net yields of the crops in the IWM and the reference systems. Yields in our IWM system with a reduced herbicide dependence were not significantly different from the net yields in the reference systems. The only exception was cabbage yield, as it was significantly lower in the IWM system.

ANNUAL ROW CROPS: MAIZE AFTER MAIZE CROPPING SYSTEMS

In this experiment, we investigate the effects of four tillage systems on the weed population in a maize monoculture. We test two varieties of maize: normal and short season. Two weed-management strategies are used: a herbicide-based system and a mechanical-control based one. The experiment has three replicates and covers 48 plots in total.

Results 2018

Figure 3 shows both the weed cover at harvest of surviving weeds and dry matter yield at harvest of silage maize. At non-inversion tillage (C), the weed cover level was significantly lower after mechanical weed control than after the conventional approach with herbicides, whereas this was inverse after strip cultivation (D). Dry matter yield levels with these two systems were inverse to weed cover levels. Both at the reference system with ploughing (A) and at direct seeding (E), both weed cover and yield showed no differences between conventional and mechanical weed control.

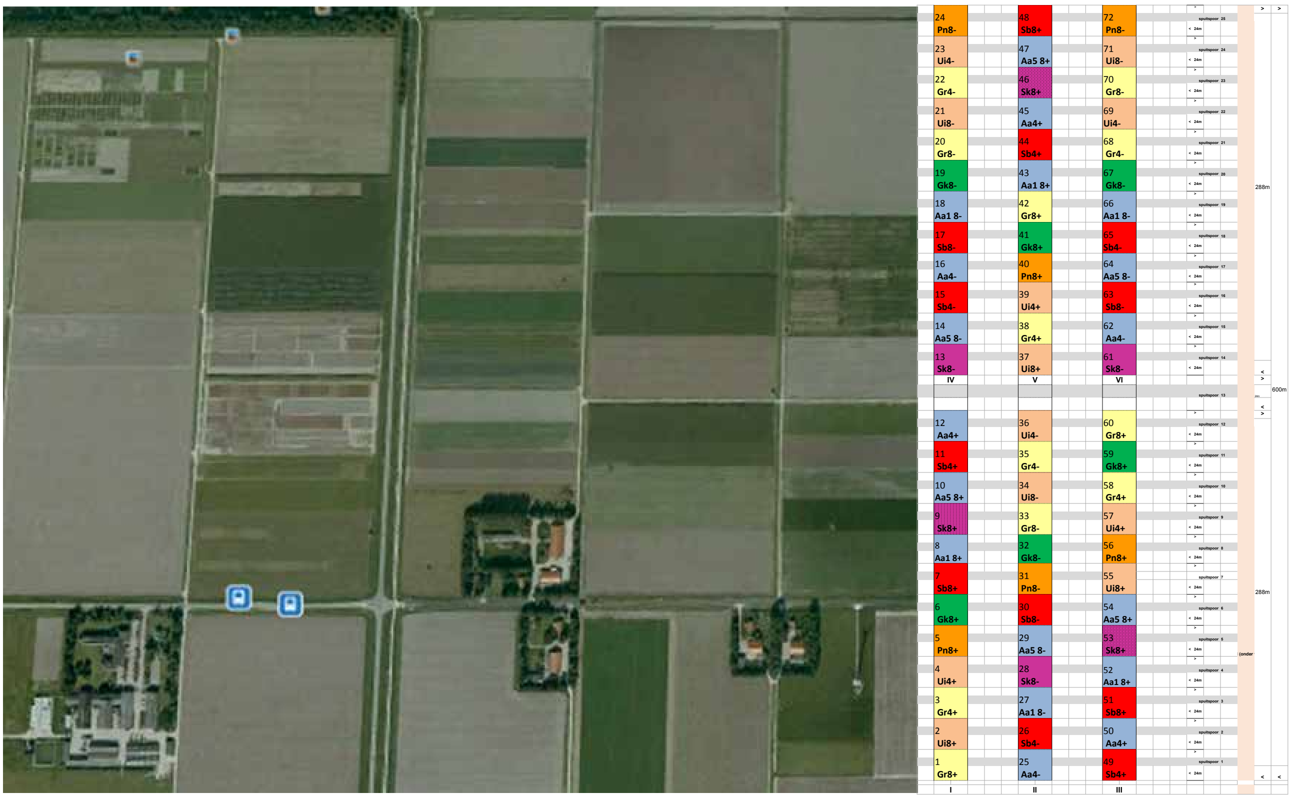


Figure 1 - Location of experiment at the farm

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

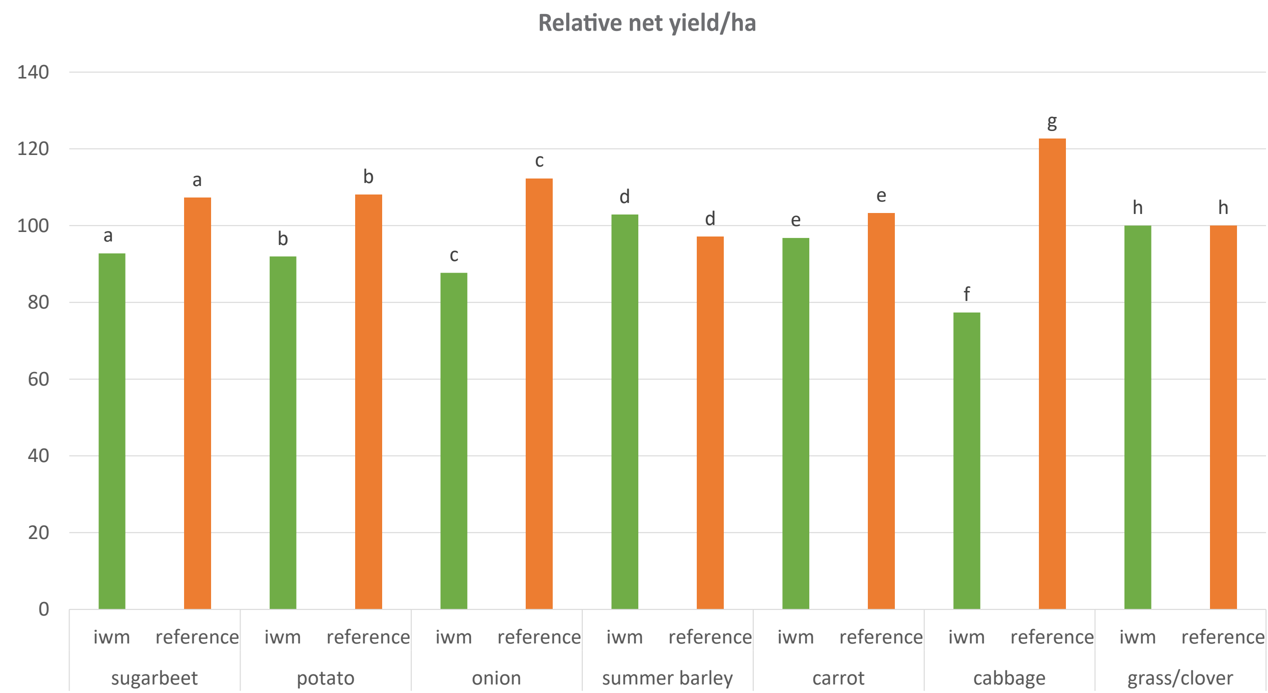


Figure 2 - Relative net yield/ha for the crops in the IWM and reference system. Different letters indicate significant differences at the 95% level

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

Table 1 - Maize trial layout

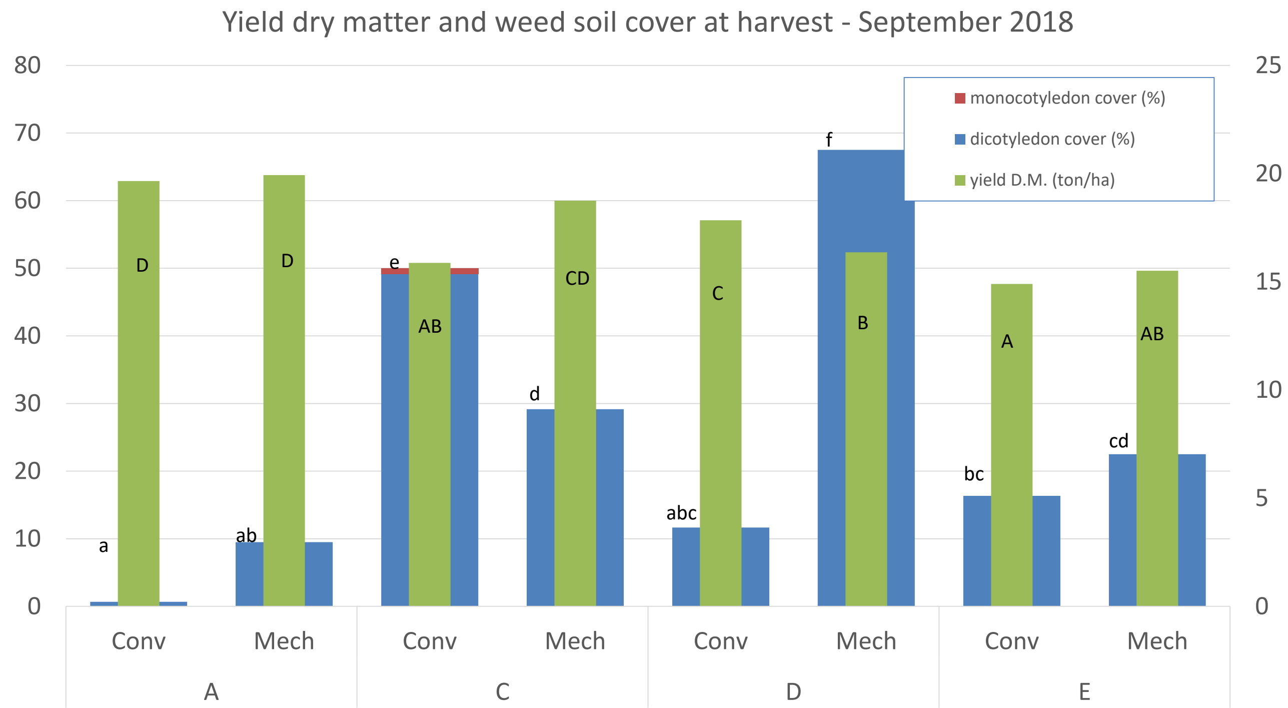
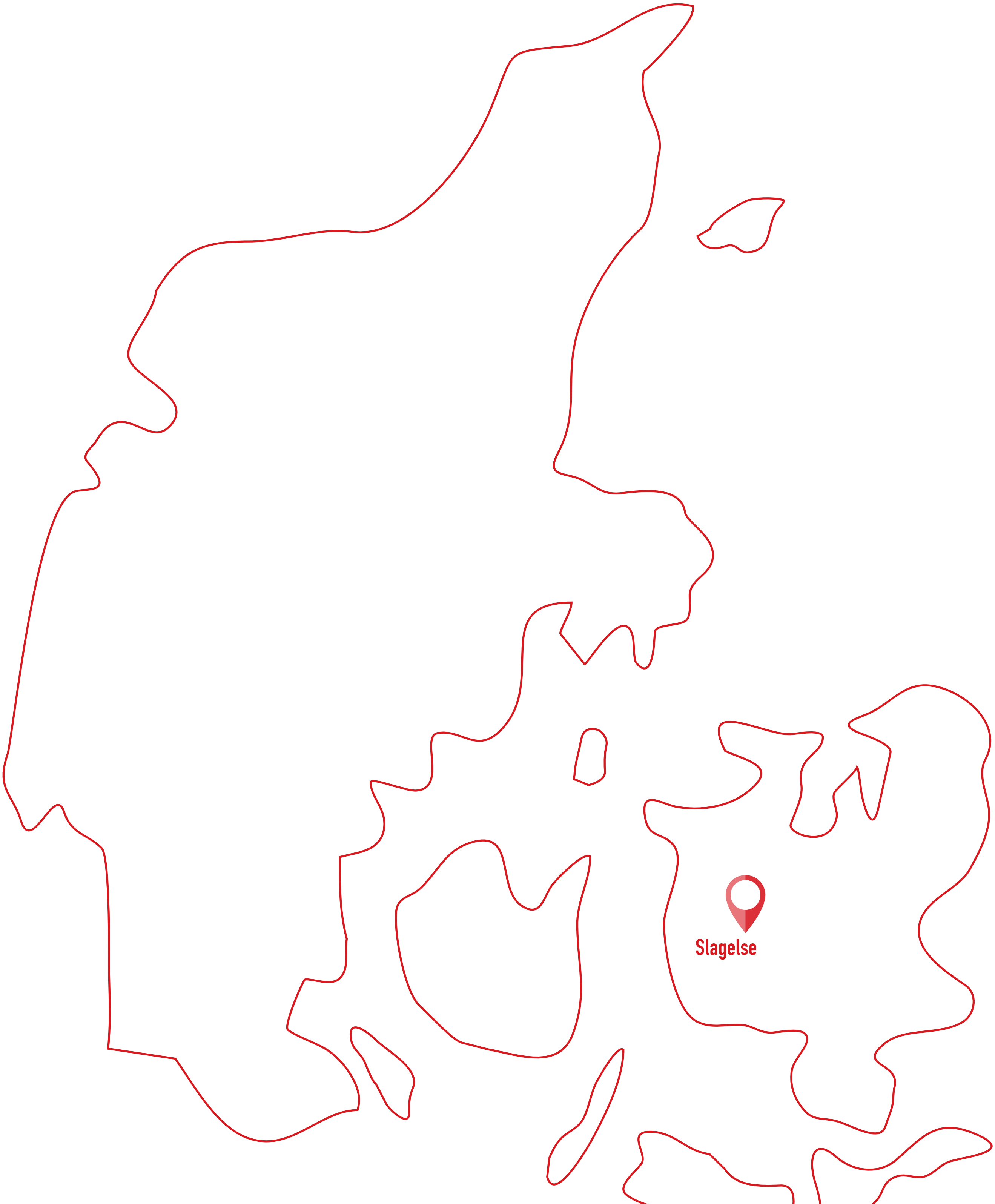


Figure 3 - Weed soil cover (%) for monocotyledons and dicotyledons, left Y-axis, and dry matter yield, right Y-axis, at silage maize harvest in September. Different letters indicate significant differences at the 95% level

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.

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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.

Materials and methods

A one-year trial was established at Aarhus University in Flakkebjerg for demonstration purposes. It includes strategies with no-till and others with conventional ploughing, as well as different levels of herbicide application combined with mechanical weeding. The aim is to lower herbicide application to a minimum by optimizing establishment and crop-growing conditions.

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

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

Straw chopped and left in field before trial was established
Ploughing in the same direction as the strategy strips to avoid driving in the no-till strips
Seeding density and row width is the same in all strategies
Standard fungicides application and insecticides as needed
Standard fertilizer in all strategies

Table 1 - WP3 experimental layout (2017-18)

Fertilizer was broadcast and the winter-wheat variety Sheriff was chosen as a disease-tolerant variety with good competitive characteristics and potentially high yield. In no-till strategies, glyphosate was applied prior to sowing and no other autumn application of herbicides was carried out. The herbicide application strategies for ploughed strategies included autumn application (prosulfocarb, diflufenican and pendimethalin in autumn 2017) combined with need-based spring application or no spring application. In Strategies 4 and 6, mechanical weeding was planned for spring treatment.

Figure 1 - Plots of WP3 trials

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

Results

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

After the problematic weather conditions at sowing with very wet conditions, winter refused to let go of Denmark until just before April, after which came a sudden shift to very high temperatures and no rain. From April to September 2018, the trial location received 198 mm of rain, which was 184 mm less than the year before and very low for the region. At the same time, the temperature of these five months was on average 2°C higher than in 2017, with maximum temperatures in summer 2018 reaching 32°C in July compared with 25°C in 2017. No irrigation was possible in the field, as the need for water was not expected.
This might be one explanation for differences in the best-performing strategy in early season compared with final yield. Even with the poor conditions for establishment, the directly sown strategies had a higher crop plant number per row meter than the standard row width strategies. In June, however, there was a lower crop biomass than in other strategies. The strategies sown in wide row distances had the highest crop biomass at this time of the season. At harvest, however, the directly sown strategies yielded much better than all other strategies, and the strategies with wide rows gave the lowest yield (Graph 1). The standard strategies had intermediate values for crop biomass in June and yield.
Weed biomass in June was sampled at the same time as crop biomass, but the amounts of weeds in all of the strategies were very low (Figure 3). The dry summer inhibited any new weed flushes after control measures in spring. It is difficult to reach a conclusion on the results regarding strategy performance, but there was an indication of better conditions in the directly sown strategies during the drought. The ploughed strategies with wide rows showed promising establishment and early summer biomass production, but were the least resilient during the drought. The difference in yield between Strategies 4 and 6 is hard to explain, as both had very low weed biomass and the only management practice to differ in spring was a tine harrowing in Strategy 6.

Season 2018-2019

VKST is an independent advisory company owned by farmers in the region and was established in 2017

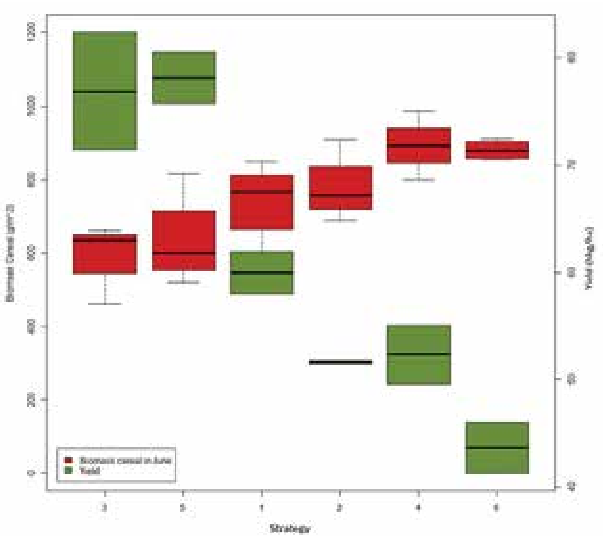


Figure 3 - Crop biomass and yield. There was a shift among the strategies during the very dry summer and, in the end, the directly sown strategies yielded higher than other strategies despite a poor emergence rate and lower biomass in early summer. For strategy explanation, see Table2 or the legend in Figure 4.

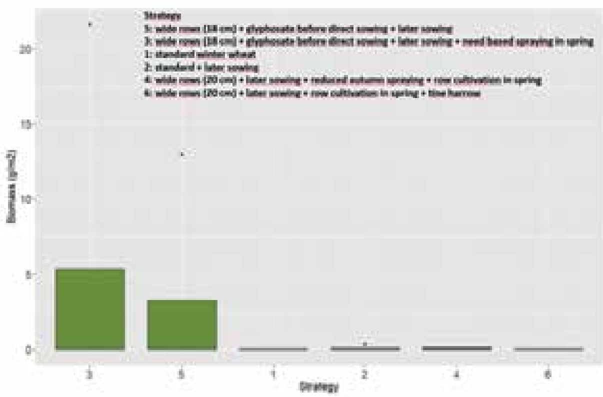


Figure 4 - Weed biomass in June

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 devoted 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.

Next season's trials will focus on sowing time and seeding density combined with various levels of herbicide application and mechanical weeding. It is hoped that these trials will succeed in differentiating the sowing dates according to the plan (Table 2). The trials will largely follow the same layout, but the location will be different. VKST is responsible this year and the demonstration trial will be located in an experimental field area with other winter wheat trials, thus increasing the demonstration value. There will be special field days with information on all trials. These days will be announced during the season on the national cluster webpage in Denmark and on the project webpage for IWMPRAISE. The weed population of the new location primarily consists of broadleaved weeds, with volunteer oilseed rape being abundant (Figure 6).

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.

Materials and methods

A one-year trial was established for demonstration purposes in spring 2018 at the research station of Aarhus University in Flakkebjerg. In sugar beets, several herbicide applications with herbicide mixtures made up standard weed management. In order to lower herbicide application to a minimum, further inclusion of mechanical weeding was necessary. Several options for herbicide reduction were available in combination with band spraying. Three alternative strategies were established and arranged in wide strips with a standard strategy for comparison. Three strategies with herbicide band application were combined with weed harrowing, with one using ALS-tolerant sugar beets. The management practices, which varied in the strategies, included band spraying, weed harrowing between rows, and false seedbed before sowing.

Figure 5 - Aerial photo of the experimental area including the demonstration trial on winter wheat

	Strategy 1 5 m	Strategy 2 5 m	Strategy 3 5 m	Strategy 4 5 m	Strategy 5 5 m
	Reference/standard	High seeding density	Ploughing Early sowing	Direct sowing	Ploughing 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 normal + 14 days
Seeding density	Standard	Standard + 50%	Standard	Standard	Standard
Row width	Standard row 12 cm	Standard row 12 cm	Standard row 12 cm	Standard row 12 cm	Wide rows 18 - 20 cm
Herbicides	Standard herbicid application autumn same growth stage of crop as strategy 3 Need based spring	Standard herbicid application autumn same growth stage of crop as strategy 3 Need based spring	Standard herbicid application autumn Need based spring	Glyphosate before sowing No herbicide application autumn No herbicids 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 fungicide application and insecticides as needed
Fertilizer standard in all strategies

Table 2 - Trial plan for season 2018-2019

Results

A follow-up treatment with flaming was planned for the strategy with false seedbed (Strategy 3), but the conditions were highly favourable for germination and the beets germinated quickly. Therefore, there was no opportunity or need for flaming. The soil preparation before sowing controlled the weed population until after germination.

From April to September 2018, the trial location received 198 mm of rain, which was 184 mm less than the year before and very low for the region. At the same time, the temperature of these five months was on average 2°C higher than in 2017, with maximum temperatures in summer 2018

Figure 6 - Border between a strategy sown at normal sowing time and the late-sown strategy just before herbicide application in the normal sowing-time strategy

reaching 32°C in July compared with 25°C in 2017. No irrigation was possible in the field, as the need for water was not expected.
The very dry conditions made the standard herbicide application programme difficult. The weeds developed a thick wax layer and were less susceptible than under normal conditions. Volunteer oilseed rape and *Chenopodium album* were especially difficult to control with the normal herbicide programme, which consisted of metamitron, ethofumesate and phenmidipham. The band spraying in Strategies 2 and 3 had the same actives as the standard confined to the crop row. The ALS-tolerant variety was treated with foramsulfuron and thiencarbazone, which were less inhibited by the wax layer. Due to the poor efficacy of the herbicides, weed harrowing was added to all strategies. This means that weed harrowing was conducted twice in Strategies 2 and 4 and once in Strategies 1 and 3. Strategy 3 was sown 2 weeks later than the other strategies, and the first weed harrowing (Strategies 2 and 4) was obsolete.
In the end, the yield was poor due to drought, but some differences were observed between strategies (Figures 8 and 9).

Figure 7 - Plots of WP4 trails

Season 2019

In the coming season (2019), the sugar beet trials will be 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 better beet production through experimental work, innovation, dissemination and demonstration. NBR bridges between research and other stakeholders.
A demonstration trial will be located close to other sugar beet trials, including organic experiments. NBR hosts a field day every second year, which is scheduled for 13 June 2019. On this day, there will be opportunities to see all the trials and talk to the project managers. The final experimental plan has not been completely finalized at the time of publishing, but the plan from 2018 has been modified to focus mainly on different combinations of bandspraying and weed harrowing, with various herbicide programmes. The layout of the demonstration trial will resemble the 2018 trial.

Address:
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
e-mail: mette.sonderskov@agro.au.dk
tel. +45 8715 8231

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

Table 3 - WP4 experimental layout

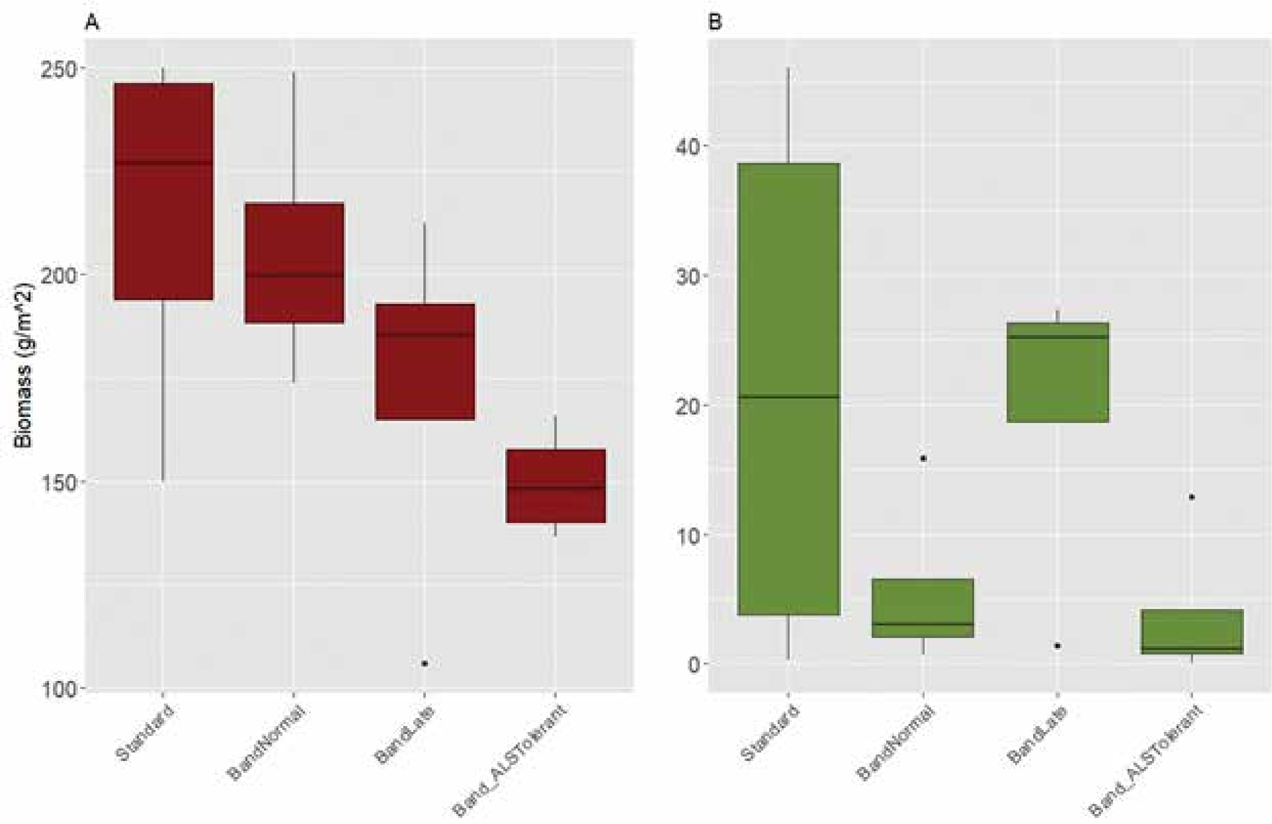


Figure 8 - Fresh biomass of crop (A) and weed (B) in June in the four strategies. Standard (Strategy 1), BandNormal (Strategy 2), BandLate (Strategy 3) and Band_ALStolerant (Strategy 4). The strategies are described in the table.

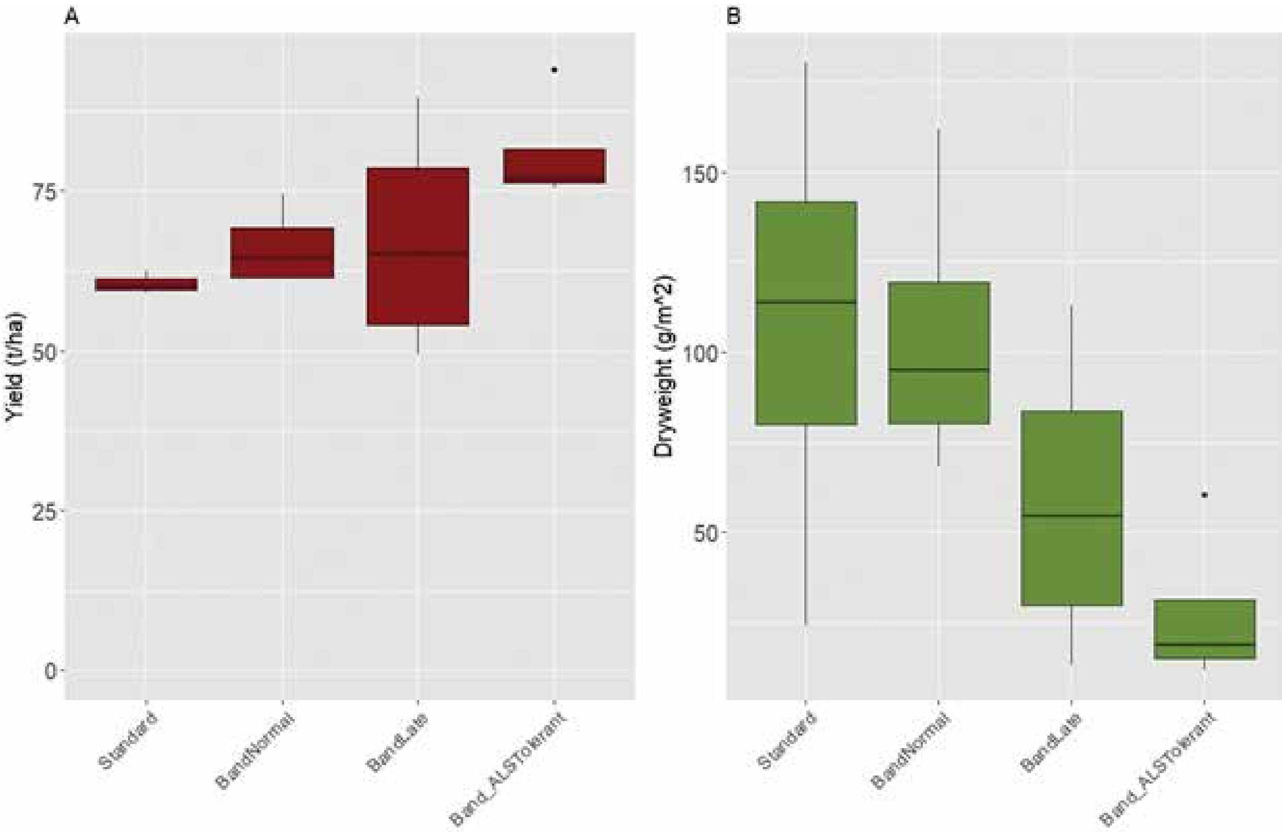


Figure 9 - Yield (A) and weed biomass (B) at harvest. Standard (Strategy 1), BandNormal (Strategy 2), BandLate (Strategy 3) and Band_ALStolerant (Strategy 4). The strategies are described in the table.

Figure 10 - Experimental field of Nordic Beet Research on Lolland

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 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 4.

Cropping systems:
TS = traditional non-inversion tillage system with normal herbicide inputs
RI = non-inversion tillage system with reduced herbicide input
CA = conservation agriculture aimed at reducing herbicide input

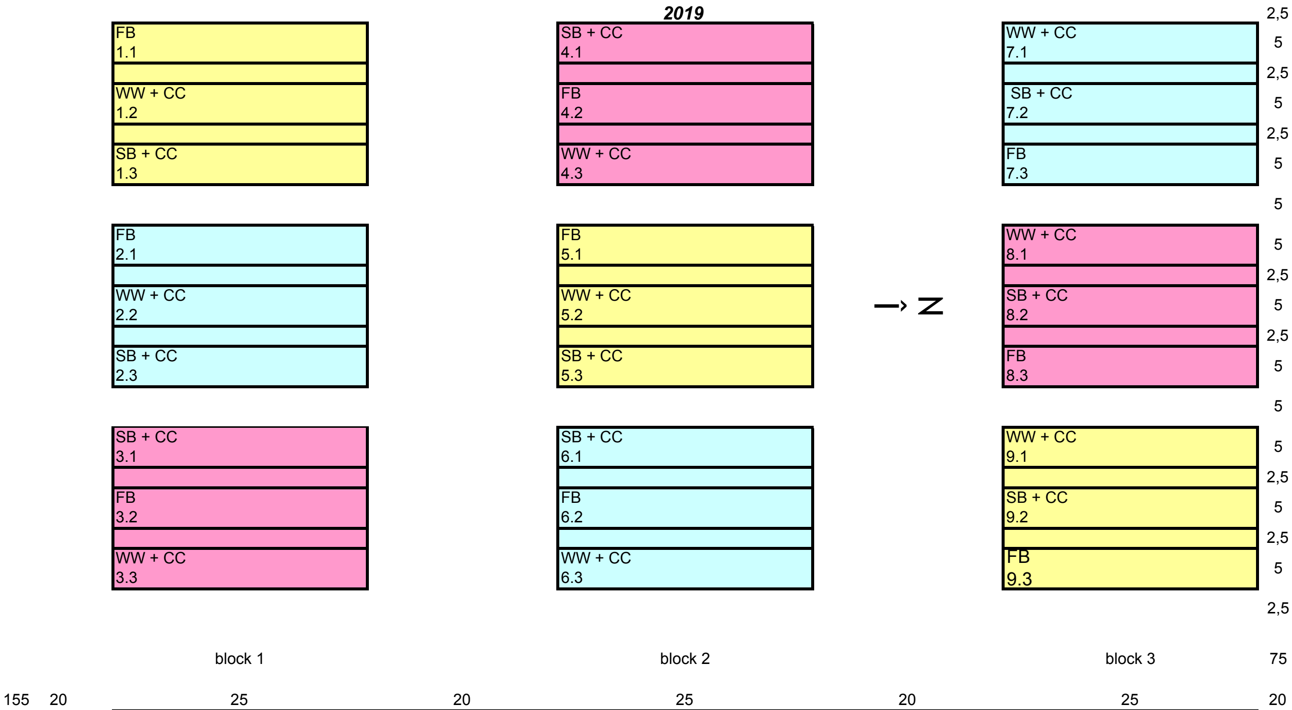
Crop rotation:
TS = winter wheat → spring barley → faba beans →
RI = winter wheat → spring barley → faba beans →
CA = winter wheat → spring barley → faba beans →

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 cases 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.
CA = glyphosate before direct drilling, but applied in spring before spring-sown crops. Selective herbicides are then applied, but in low doses.



	TS: Traditional system		TS: Traditional system	Winter wheat (WW) + CC - Spring barley (SB) + CC - Faba beans (FB). Tine tillage (8-12 cm) before crop sowing, strong reliance on glyphosate use. Cover crops (CC) before spring sown crops
	RI: Reduced system		RI: Reduced system	Winter wheat (WW) + CC - Spring barley (SB) + CC - Faba beans (FB). Tine tillage 5-8 cm and light pre-emergence harrowing before winter wheat that is sown late (10 days). Direct sowing of spring barley and faba beans, cover crops (CC) before spring sown crops and reduced reliance on glyphosate use and selected herbicides
	CA: Conservation agriculture		CA: Conservation tillage	Winter wheat (WW) + CC - Spring barley (SB) + CC - Faba beans (FB). Direct sowing of all crops, cover crops (CC) before spring sown crops, reduced use of glyphosate and selected herbicides

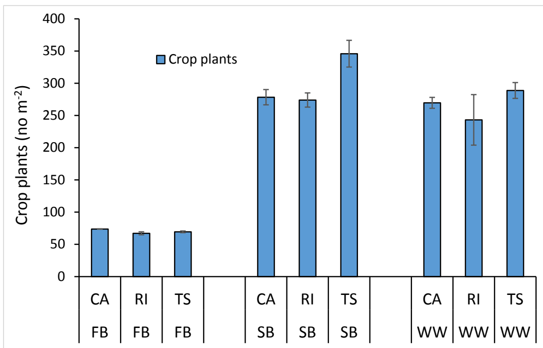
Table 4 - WP7 experimental layout

Figure 11 - Direct drilling

Figure 12 - Directly sown Faba beans

Figure 13 - Directly sown winter wheat

Figure 14 - Plots of WP7 trials



Crop plants counted shortly after crop emergence in faba bean (FB), spring barley (SB) and winter wheat (WW) in the three cropping systems CA, RI and TS.

Figure 15 - Crop plants

Assessments:

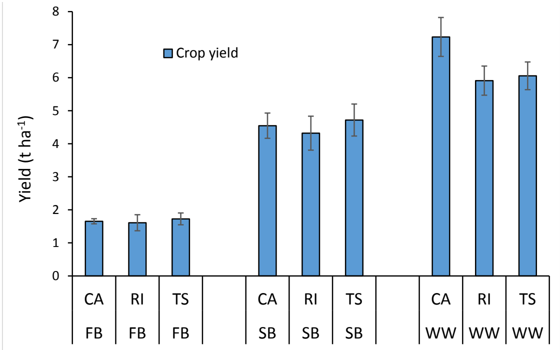
The content of weed seeds in the seed bank was recorded in all plots before the experiment was started. Weed emergence is counted in all crops and systems, and weed biomass remaining after weed control treatments is assessed in late June in all crops and systems. Crop plant numbers are counted, and yields are obtained by plot-wise combining.

Location

The experiment is located on a sandy loam at Flakkebjerg Research Centre (55o20’N, 11o23’E), Denmark.

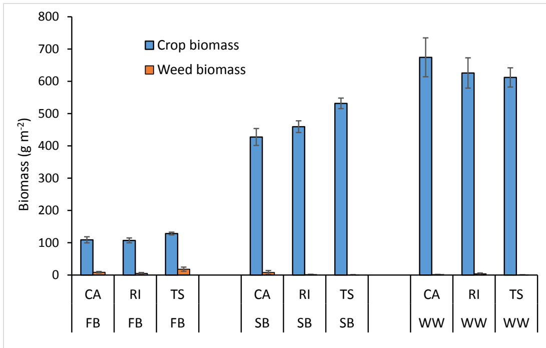
Results from 2018

2018 was the first experimental year. It was very difficult to differentiate the herbicide inputs for the cereals in all three cropping systems; the weed pressure required similar herbicide inputs. However, for faba beans, it was possible to reduce the herbicide input in the RI system, mainly by inter-row cultivation. The TS and CA cropping systems had three inputs of herbicides in faba beans, namely one treatment with glyphosate plus two with selective herbicides. The input of glyphosate and the first selective herbicide treatment were the same for the RI system but, in contrast to TS and CA, inter-row cultivation replaced the second selective herbicide treatment. Crop establishment was successful in all



Crop yields in 2018 in faba bean (FB), spring barley (SB) and winter wheat (WW) in the three cropping systems CA, RI and TS.

Figure 16 - Crop yield



Crop and weed biomasses (DM) assessed in late June 2018 in faba bean (FB), spring barley (SB) and winter wheat (WW) in the three cropping systems CA, RI and TS.

Figure 17 - Crop biomass and weed biomass

crops and systems (Figure 12, 13 and 15) and yields were similar for all systems (Figure 16). Weed control was satisfactory in all systems and crops, resulting in very little weed biomass in proportion to crop biomass (Figure 17).

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.

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