Enable Conservation Tillage (ECT)

Wider Adoption of Sustainable Conservation Tillage Systems

Final Report

March 2024

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An Roinn Talmhaíochta, Bia agus Mara
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Contents

List of Tables

List of Figures

Acknowledgements

At the project's outset, ten farmers volunteered to collaborate with the Enable Conservation Tillage (ECT) project. These Focus Farmers demonstrated courage by acknowledging grass weed issues and were open to sharing their experiences by allowing access to their farms.

These farmers have provided valuable insights into achieving grass weed control across various establishment systems, benefiting the entire industry. On behalf of the ECT team, I express sincere gratitude to these ten farmers for their cooperation and openness to change over the past five years. Their contributions were pivotal, making the project more impactful for the industry.

I would also like to extend my appreciation to the ECT project team, other dedicated Teagasc staff, and those involved in research. Their hard work resulted in a comprehensive package of information for both the focus farmers and the industry.

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Michael Hennessy
ECT Project leader and Head of Crops Knowledge Transfer in Teagasc.
March 2024

Abbreviations & Definitions

Arable farmers includes all those involved in the plant.

CA	Conservation Agriculture
CT	Conservation Tillage
CPS	Conventional Plough System
ECT	Enable Conservation Tillage
IWM	Integrated Weed Management
IPM	Integrated Pest Management
NIT	Non Inversion Tillage (non-plough based systems including; minimum tillage, Strip tillage, Direct drill or reduced tillage
NPS	Net Promoter Score
NTSR	Non-Target-Site Resistance
MOA	Mode Of Action
TSR	Target-Site Resistance

Executive Summary

The Enable Conservation Tillage (ECT) project was initiated to enhance the industry's understanding of grass weeds, enabling more farmers to successfully adopt conservation tillage practices, specifically non-inversion tillage (NIT) establishment techniques. The adoption of NIT techniques offers numerous benefits to farmers, including reduced labour and fuel costs, improved soil health, erosion control, and a diminished environmental footprint. While not all of these benefits are thoroughly established in a maritime climate, farmers perceive clear advantages in terms of work efficiency and costs.

A comprehensive nationwide survey conducted through the project highlighted that grass weeds pose a challenge in both conventional plough-based (CPS) and non-plough-based or Non-Inversion Tillage (NIT) systems. The survey included 103 growers, of which 62 employed CPS, and 41 utilised NIT (15 shallow, 11 deep min-till, 4 strip-till, and 11 direct drill). The primary weeds of concern for farmers were bromes, particularly sterile brome and spring wild oats, which were found on 62% and 56% of farms, respectively, with blackgrass, Italian rye-grass, and lesser canary grass present on fewer farms. Notably, 38% of growers with blackgrass were unaware of the weed until project staff discovered it.

The survey revealed that herbicide-resistant grass weeds are widespread throughout the country, with twenty-two resistant populations identified on 18 farms. Resistance to main post-emergence ACCase and/or ALS selective herbicides was identified in wild oats, blackgrass, and Italian rye-grass. Besides the survey, our testing identified several resistant grass weeds from industry-submitted suspect samples between 2019 and 2022, and the project team gave feedback/recommendations to growers/advisors having resistance problems.

The project collaborated with ten Focus Farms, each using different establishment systems and weed challenges. The project team closely collaborated with farmers to develop management strategies for reducing grass weeds on their farms, monitoring the outcomes in a designated "Validation Area." All farmers reported significantly increased knowledge of weeds and necessary farming system changes by the project's conclusion. Within the validation area, most farms experienced an overall reduction in grass weeds, but some farms experienced mixed results due to emerging issues like herbicide-resistant Italian rye-grass and blackgrass, rat's tail fescue or difficulties in implementing certain action plans due to a challenging season, which resulted in some weed problems to resurface. Nevertheless, the experiences of individual farmers and co-validation programme offered valuable lesson to the participants for a broader population grappling with grass weed issues.

The project established weed screen and cover crop demonstrations on farms and at Teagasc Oak Park. The weed screen proved invaluable for assessing the impact of herbicide on cereal crops and the impact of herbicide timing and stacking on grass weeds. Cover crop demonstrations were established on various farms, displaying varying degrees of success. Variable establishment and subsequent growth in some sites and years contrasted with excellent establishment and high biomass growth in other sites and years. Grass weed counts indicated that a more open crop (Phacelia or vetches) had more grass weeds than denser crops (Brassica-based cover crops). However, more detailed research is needed to determine whether either approach resulted in an overall reduction in the weed seed bank on the farm.

Overall, the outreach from the project was extensive, with over thirteen thousand participants in various events over the five years, despite interruptions caused by Covid lockdowns. The project surpassed expectations, generating a substantial number of publications, including four peer-reviewed scientific papers. An end-of-year survey involving a diverse spectrum of industry professionals yielded overwhelmingly positive feedback, with participants reporting improved knowledge of grass weeds and expressing the likelihood of using project messages and tools in their businesses in the coming months and years.

The success of conservation tillage or NIT in Ireland hinges on farmers developing robust plans to minimise grass weeds on their farms. A crucial starting point when embarking on the NIT journey is to start with soils relatively free of grass weeds. Farmers should possess sufficient knowledge or have access to expertise to promptly identify new weed challenges on the farm and employ all available cultural tools in conjunction with judicious herbicide use to minimise their spread across the entire farm.

Introduction

In this book Ploughman's Folly[1] , first published in 1945, Edward Faulkner argued that ploughing resulted in soil degradation and that discing the soil surface would improve crop yields and soil quality. The concept was researched worldwide and became known as Conservation Agriculture[2 3] (CA), which seeks to improve a range of ecosystem services, including food security (i.e., yield response increases), nutrient cycling, biodiversity and climate moderation (Figure 1). In other words, it can contribute to more sustainable Irish tillage crop systems.

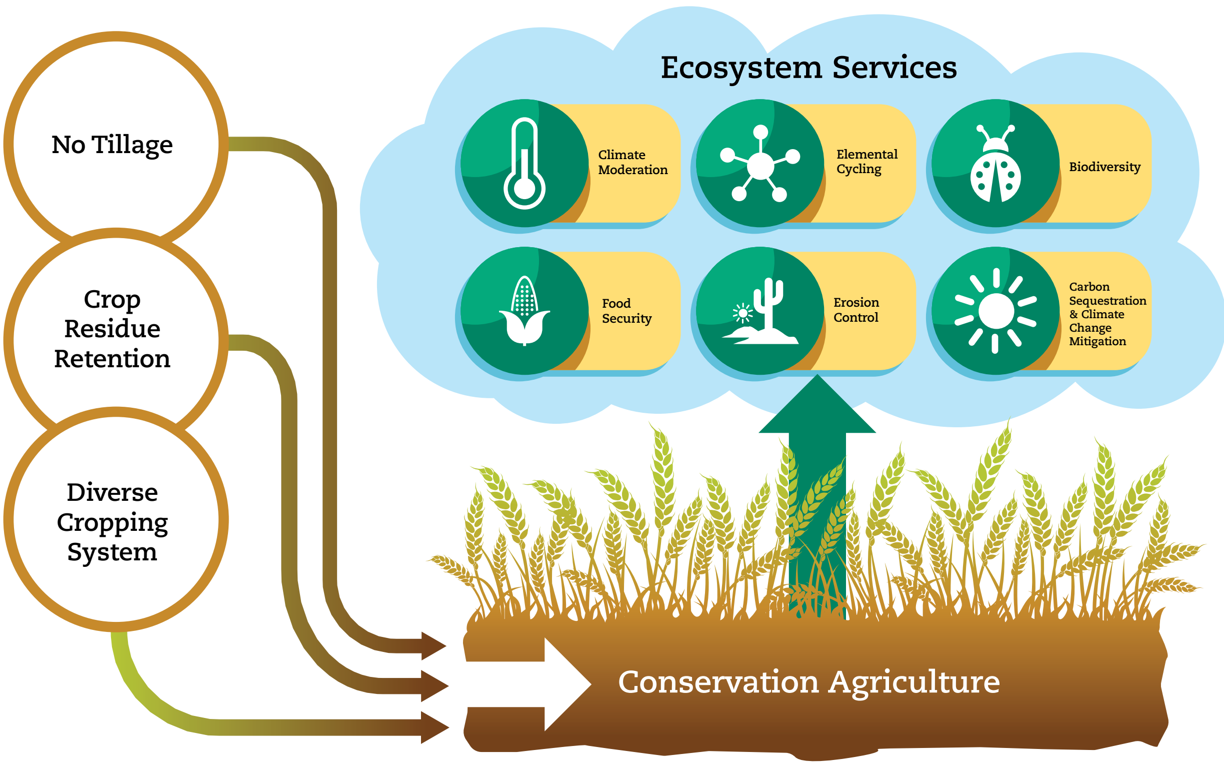


Figure 1. A graphical representation of CA and the ecosystem services it can provide
Source: https://www.mdpi.com/2077-0472/11/8/718#

1 http://journeytoforever.org/farm_library/folly/follyToC.html
2 https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/conservation-agriculture.
3 https://www.fao.org/conservation-agriculture/overview/what-is-conservation-agriculture/en/

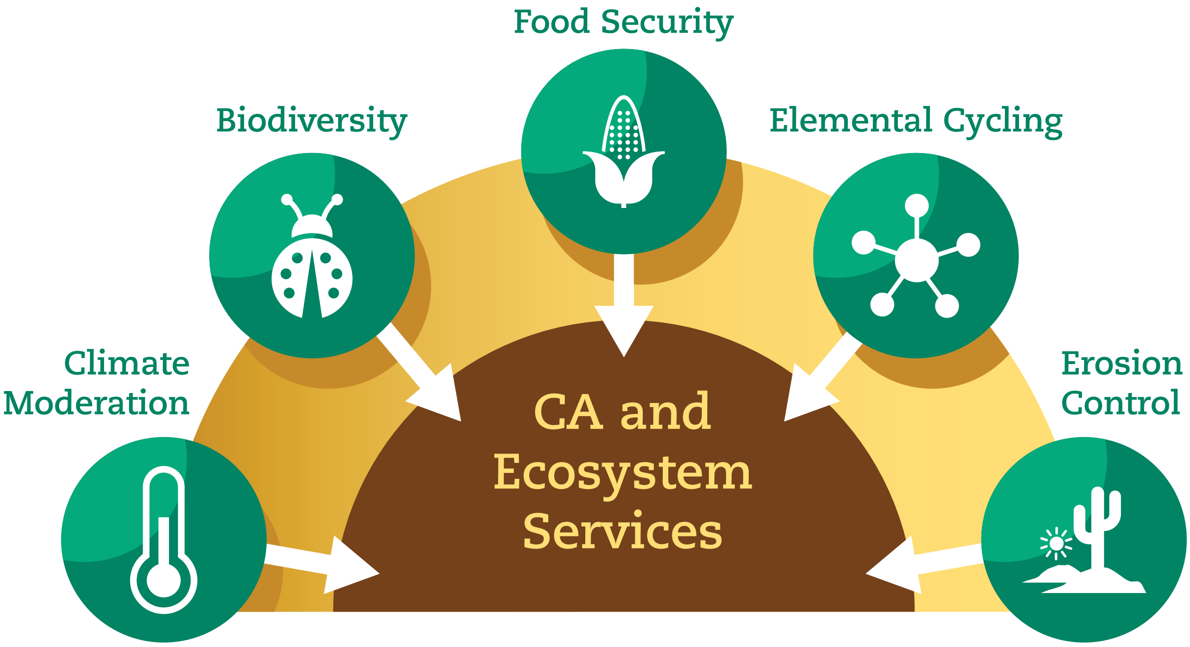


Figure 2. *Ecosystem services from CA*
Source: https://www.mdpi.com/2077-0472/11/8/718#

NIT soil cultivation /sowing uses non-inversion, shallower and less intensive soil disturbance and has been extensively researched worldwide[4] in various soil and climatic conditions. NIT includes a range of non-plough cultivation techniques[5] , including:

- Minimum tillage.
- Strip tillage.
- Direct drilling.

The sustainable benefits of NIT in a particular field, farm, county or region are determined by weather, soil type, length of growing period, erosion hazards and farming conditions. There are reports of yield reductions in wet seasons in Ireland[6], and the UK[7], with slower soil warming[8] in Europe[9]. NIT can deliver similar or occasionally better yields in drier seasons than plough-established crops[10].

CA has gained recognition worldwide as an important sustainable and productive farming approach and implemented in dry climates primarily to improve water conservation. It offers a way to address environmental concerns while maintaining or increasing agricultural productivity, making it a valuable tool for promoting sustainable food systems[11].

4 For example. https://doi.org/10.3389/fagro.2021.671690
5 https://www.teagasc.ie/crops/crops/grass-weeds/enable-conservation-tillage-ect/crop-establishment-systems/
6 https://www.sciencedirect.com/science/article/abs/pii/S1161030113001767
7 https://www.sciencedirect.com/science/article/pii/S0308521X16300701
8 https://www.sciencedirect.com/science/article/abs/pii/S0167198710000437
9 https://www.sciencedirect.com/science/article/abs/pii/S0378429001001460
10 https://www.sciencedirect.com/science/article/pii/S1161030113001767
11 A sustainable food system is a food system that delivers food and nutrition security for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised.

In the last two decades, there has been an increase in the adoption of NIT in climates similar to Ireland's Atlantic-influenced (Gulf Stream) weather - mild, moist and changeable with abundant rainfall. The general benefits of the ecosystem services provided by NIT include[12]:

1. **Soil health improvement[13]:** NIT systems can enhance soil organic matter in the soil surface layers[14] and result in improved nutrient supply in some circumstances[15] but this is not universal with Irish research showing only a marginal advantage in crop nutrition[16]. The impact on soil carbon (C) is less clear, with many reviews showing little evidence of soil C change (ref) when depths of up to 30 or 60 cm are considered. However in one trial, low disturbance tillage systems were shown to increase soil C retention, in an Irish climate (Van Groeningen et al., 2011).
2. **Erosion control[17]:** Minimising soil disturbance and keeping it covered significantly reduces soil erosion caused by water and wind.
3. **Water conservation[18]:** Maintaining soil cover helps reduce water runoff, improves water infiltration, and increases the soil's water-holding capacity. Consequently, it leads to more efficient water use and can be particularly beneficial in areas prone to drought or with limited water resources. However, in the wetter Irish climate NIT systems tend to dry out more slowly after extended periods of heavy rain, which can hindering planting particularly in the spring.
4. **Climate change mitigation[19]:** In wetter climates, the impact of the adoption of non-plough tillage on greenhouse gas emissions is quite small (Abdalla et al., 2012), but positive effects on soil invertebrates such as earthworms have been recorded (Kennedy et al., 2013). While the agronomic benefits are not overwhelming in Ireland's climate, there is a substantial saving in energy input by adopting non-plough less intensive systems (Davies and Finney 2002) with the possibility of reducing the machinery component of establishment costs by 40-45% (Forristal and Murphy 2009, Morris 2010) and overall production costs by 20% (Cook et al., 2006). A review of no-till arable systems (Godwin, 2014) showed the benefits of higher work rates, lower costs, greater soil bearing capacity and lower greenhouse gas emissions (GHG) amongst others.

NIT agriculture practices may positively or negatively affect the delivery of food production and other ecosystem services. The type and extent of the response depends on the particular management practices implemented.

On the negative side, no-till systems rely heavily on herbicides to control weeds particularly glyphosate. Glyphosate resistance is widespread across many parts of the world (Beckie, H.J.,2011) but is not present in the Ireland. Forristal and Murphy (2009) also indicated that in Ireland's mild climate, grass weed control was a major constraint to the adoption of non-plough cultivation systems. The wet season challenges to autumn crop establishment exacerbate the grass weed problem in wetter climates, as early sowing may help avoid crop establishment problems, it will exacerbate the grass weed problems (Brennan, et al. 2014). While grass weed problems are more likely to develop under non-inversion tillage, where problems develop, some aspects of these systems can allow valuable control options such as grass weed seeds remaining at the surface in no-till systems allowing effective stale-seedbed controls to be adopted (Godwin, 2014).

12 https://www.sciencedirect.com/science/article/abs/pii/S0167880913003502
13 https://www.mdpi.com/2571-8789/6/4/87
14 https://www.sciencedirect.com/science/article/abs/pii/S0167198709001093
15 https://www.sciencedirect.com/science/article/pii/S2095633923000242
16 https://www.sciencedirect.com/science/article/abs/pii/S1161030113001767
17 https://link.springer.com/article/10.1007/s13593-018-0545-z
18 https://www.mdpi.com/2073-4395/11/9/1681
19 https://www.sciencedirect.com/science/article/abs/pii/S0167880916300056

The Enable Conservation Tillage (ECT) project

For successful crop establishment, farmers must implement measures to prevent increased grass weed occurrence, requiring higher knowledge and management levels for adopting NIT and Integrated Weed Management (IWM).

Minimising grass weeds in both NIT and conventional plough system (CPS) systems is more successful with farmers possessing:

- Knowledge of grass weed biology in both NIT and CPS systems.
- Familiarity with available cultural and chemical control measures.
- Understanding of weed hygiene options to exclude weeds from the farm.

This knowledge assists farmers in developing and implementing appropriate control measures for their specific situations, recognising that no one-size-fits-all NIT solution exists, but basic control principles apply across all cultivation systems.

The **Enable Conservation Tillage** (ECT) project, funded by the European Innovation Partnership and administered by the Department of Agriculture, Food and the Marine, has two objectives:

- To enable the adoption of NIT practices on Irish tillage farms.
- To provide farmers with the knowledge, skills and capacity for effective grass weed control.

The project approach was based on the following innovations:

- Establishing a network of ten 'Focus Farms' to seek evidence on how site-specific IWM can be fully implemented at the farm level to address the grass weed problems without excessive reliance on herbicides.
- Reducing the barriers for farmers such as; poor farmer knowledge of grass weed identification/biology, herbicide resistance, improving crop rotations, to NIT systems by maximising farmer-to-farmer knowledge exchange.

The project activities included:

- Developing an innovation hub that linked the project group, including participating farmers, to a large group of stakeholders, including seed assemblers, merchants, farm advisors, specialist advisors, researchers and herbicide manufacturers. The focus was on addressing the grass weed challenge in NIT and CPS.
- Establishing ten "Focus Farms" using various cultivation systems and who have different grass weed problems. The work on the farms contributed to co-developing techniques for grass weed control and practical aids to quantify and control grass weed populations.
- Identifying the factors that determine grass weed prevalence on farms.
- Evaluating a range of cultural grass weed control practices.
- Establishing the extent and source of grass weed herbicide resistance.
- Assessing and demonstrating novel weed control approaches.

This report describes the project activities, the results and lessons learnt and their implications for stakeholders.

Crop Establishment Systems

The four crop establishment systems (Figure 7) and their classification as CPS and NIT most commonly used in Ireland are:

1. Conventional Plough based System (plough-based) - CPS.
2. Minimum tillage -NIT.
3. Strip-till -NIT.
4. Direct drilling (no-till, zero-till) - NIT

Two noteworthy points should be considered. Firstly, the less intensive soil cultivation methods, namely NIT (minimum-till and direct drilling), were initially developed in drier and warmer climates with soils that may significantly differ from those in Ireland. Consequently, the delivery of NIT ecosystem services could be compromised due to our wetter autumn and spring periods and fewer moisture deficit periods.

Secondly, there exists considerable variation in tillage intensity (i.e., the extent of soil inversion) and depth within both plough-based and minimum-till systems. In some instances, the minimum-till system may operate at the same soil depth and intensity as a plough-based system.

Figure 3. *Ploughing*

1. **Ploughing:** inversion to 17.5 – 27.5 cm deep, followed by secondary cultivation before sowing.

Figure 4. *Min-till drilling*

2. **Minimum tillage:** Stubble cultivation to 5 -20 cm deep), to produce a stale seedbed[20], followed by herbicide application and seeding by a cultivator drill. It may be operated with a shallow initial cultivation post-harvest followed by deeper pre-drilling cultivation.

Figure 5. *Strip Till drill*

3. **Strip-till:** Cultivation in strips centred at approximately 30cm followed by a sowing coulter leaving about 40-60% of the soil undisturbed.

Figure 6. *Direct Drilling*

4. **Direct drill (no-till, zero-till):** Direct placement of the seed with minimum soil disturbance.

Figure 7: *Cultivation Systems in Ireland*

20 https://extension.umd.edu/resource/stale-seedbed-technique-relatively-underused-alternative-weed-management-tactic-vegetable-production#:~:text=Stale%20seed%20bed%20is%20a,and%204)%20the%20crop%20is

Ploughing

Ploughing, or CPS, is Irish farmers' most common establishment system. It works to a depth of 17.5-27.5 cm (7-10 inches). The plough inverts the soil, buries crop residues, and cultivates. Adopting combined cultivation and sowing units (one-pass) in the 1980s facilitated winter crop establishment in spells of broken weather. In addition, it reduced traffic and wheeling damage and avoided excess moisture loss.

In spring, the plough and one-pass system allowed soils to dry and warm up quickly compared to less disturbed soil.

Table 1. Benefits and constraints of Plough based systems

Benefits	Constraints
• A well-established system with known practices and techniques. • Effective in controlling certain weeds and pests, as ploughing buries crop residues and other organic matter, which can harbour pests and diseases. • Improves soil aeration and water infiltration by loosening compacted soil and increasing pore space, which can lead to better, near-surface drainage and reduced risk of waterlogging in winter and faster establishment in spring. • Adaptable to various soil types and conditions and within-field variations, including headland compaction.	• Increased fuel consumption, machinery cost and labour requirements compared to NIT systems. • It can lead to soil structure damage and reduced water-holding capacity in the long term if poorly managed under wet conditions. • Continuous mechanical restructuring of soil reduces the chances of developing vertical porosity in non-loosened soils. • Soils loosened to depth are more prone to compaction • It may: • Increase soil erosion and runoff due to the significant soil disturbance and removal of surface cover, primarily when used in late autumn. • Have reduced beneficial species such as earthworms compared to NIT. • Accelerate soil carbon loss. • Restrict establishment and early growth in spring due to dried-out seedbeds.

Non-inversion tillage systems (NIT)

Non-inversion tillage encompasses all systems that refrain from soil inversion, comprising minimum-till (reduced tillage), strip-till, direct-drill (no-till, zero-till), and other methods besides ploughing. However, there is substantial variation within this category regarding the depth and intensity of cultivation. These factors dictate the degree of disturbance and the distribution of crop residue in the topsoil profile. Consequently, when describing each system, it is crucial to include information about the depth and cultivation intensity, reflecting the extent of soil mixing during cultivation.

Minimum Tillage

Minimum tillage describes shallow (5 to 10 cm) soil cultivation with the lowest cultivation necessary and retaining 30% of the previous crop residues on the soil surface. It is a reduced cultivation level (depth and intensity) compared to ploughing. A tine or disc cultivator completes the cultivation and is designed to cope with different surface residue levels.

Initially, only one cultivation between crop harvest and sowing was practised. However, over time in Ireland, the depth and intensity generally increased with two frequently used cultivation runs up to 150 mm deep, but occasionally more, resulting in a similar level of soil disturbance as ploughing.

The type of cultivation equipment used and the depth and number of cultivations will depend on soil stone content, user preference, soil type, previous cropping, the crop to be sown, and the time of year.

Strip-till

Strip-till limits cultivation to strips in a one-machine pass. For cereals, a lead tine working at 100 to 200 mm depth cultivates strips of soil at a row spacing of 300 to 330 mm in advance of a sowing coulter. Strip tillage typically cultivates about 33% of the field area, and seeds are sown in these strips of disturbed soil while the space between the sown strips is left untouched.

For weed and volunteer plant control, some farmers complete light surface cultivations followed by herbicide application to create a stale seedbed. Claydon and Mzuri are examples of strip-till drills used in Ireland.

No-till (Direct drill, Zero till)

Direct drilling is a crop establishment method where crops are planted without disturbing the soil beyond that necessary to place the seed at the required depth. There are two machine types.

- A disc drill, which makes a narrow slit in the soil, then puts the seed in the slit before covering it with soil.
- A tine coulter machine opens a narrow band just deep enough to place the seed and then covers it with soil.

No-till systems allow a more resilient soil structure, which may help to reduce carbon loss and increase biological activity.

Examples of direct drills used in Ireland include Weaving, John Deere, Cross Slot and Duncan machines.

Table 2. Benefits and constraints of Non Inversion Tillage systems (NIT)

Benefits	Constraints
• Reduced fuel, machinery and labour costs due to the tillage depth and intensity reduction. • Reduced soil erosion due to minimal soil disturbance which preserves the soil structure and reduces runoff. • Can produce yields equal to or greater than plough-based systems in most years. • It can retain more organic matter near the soil surface, increasing water-holding capacity, soil stability, and friability. • Potentially improved soil health and biodiversity due to reduced soil disturbance and improved soil organic matter status. • Versatile drill suitable for deep sowing if required (beans) (Strip till) • Soil bearing strength for machinery is high as it is undisturbed (Strip till/No- till). • Will increase work rates enabling a greater area to be covered in narrow weather windows	• It does not alleviate deeper (25 cm) soil compaction that may occur in wet seasons. • There is an increased risk of poorer crop establishment in wet autumns, often forcing earlier sowing with consequences for more difficult disease and weed control. • Where shallow cultivation is used before spring sowing, heavier textured soil may be slower to dry, resulting in later sowing. • With heavier soils, nitrous oxide emissions may be increased due to greater water retention, resulting in increasing GHG emissions. • If used in wetter conditions risk of smearing and compaction. • Increased potential for problematic weed growth, as strip tillage disturbs only a portion of the soil, leaving other areas for weed growth. • Limited ability to control pests and diseases, as strip tillage does not incorporate crop residues, which can harbour pests and diseases. • Grass weeds can increase in autumn as the wide rows provide more light, encouraging grass weed emergence and establishment (Strip Till). • Initial investment costs for specialised equipment and technology can be high, particularly for small or medium-sized farmers. • More likely to practice early planting to take advantage of drier soils, which may promote the growth and spread of weeds. • Soils may consolidate /compact over time, requiring remedial action and preventing the achievement of resilient vertical porosity. But the use of cover crops/catch crops to maintain constant crop cover with active roots may alleviate this risk and help keep soils friable and resilient especially during longer fallow periods.

Tillage Grass Weeds

This chapter outlines the eight common grass weeds on Irish tillage farms and fields. A short description and the key features of each weed as well as cultural and chemical control measures are provided.

Wild oats

There are two types of wild oats[21] – spring (*Avena fatua*) and winter (*Avena sterilis*). Spring wild oats are the most common type in Irish tillage soils. Occasionally, fields can have a mix of spring (Fig 8) and winter wild oats.

Figure 8. *Spring Wild Oats*[22]

Avena fatua (spring wild oats)

- Awns are present on the third seed within the spikelet.
- Seeds separate when mature and shed singly.

Avena sterilis (winter wild oats)[23]

- Awns are absent on the third seed in a spikelet.
- Seeds remain attached when mature and shed as a unit.

21 https://www.teagasc.ie

22 https://www.weedimages.org/browse/detail.cfm?imgnum=5443373

23 https://cropscience.bayer.co.uk/threats/grass-weeds/wild-oat-and-winter-wild-oat/

Spring wild oats: key features

- A population of 1 plant per m^2 has the potential to cause a yield loss of 1%.
- Predominately spring germinating, but sporadic and unpredictable emergence patterns (i.e. a proportion of seedling may germinate between September and May) complicates control options.
- Seeds can survive in soil for several years and are therefore unaffected by seed burial depth.
- Light promotes seed germination.
- Most seeds emerge from the top 10 cm of soil, but some emerge from greater depths (15 to 25 cm).
- It flowers from June onwards and sheds seed from July.

A single well-tillered plant can produce up to 200 seeds.

Identification of spring wild oats

- Leaf blades twisted anti-clockwise, which is apparent even at the 2-4 leaf stage
- Fine hairs along the edge of the leaf blade and sheath,
- Ligule long (6-8 mm) and serrated
- Loose drooping panicle
- Leaves rolled in shoot

Link to identification video:
https://www.youtube.com/watch?v=v9CykxLfkc&list=PL751pzOnZmAPqP26RoI8A3Q6pY911Qwe&index=13

Control Measures:
See pages 33-36

Herbicide resistance
See the results for the Survey on page 44 and Herbicide resistance status page 59.

Bromes

Five main brome species occur as weeds of arable crop[24]. Sterile brome (*Bromus sterilis*) (Fig 9) is Ireland's most common brome grass weed. Other brome species include Great Brome (*Anisantha diandrus*), Soft Brome (*Bromus hordeaceus*), Meadow Brome (*Bromus commutatus*) and Rye Brome (*Bromus secalinus*).

Accurate brome identification is critical to achieving reasonable brome control. Each brome has specific identifying characteristics, making identification easier when the plant is headed with mature seeds.

Figure 9: *Sterile Brome*

Key features

- Germination of sterile and great bromes peaks in autumn, the other types have more protracted emergence
  - It is not unusual to find sterile brome emerging in spring, mainly where winter crops are thin or have failed.
  - Great brome is similar to sterile brome but much larger in appearance, with similar characteristics. It is often mistakenly identified as sterile brome, resulting in underreporting its occurrence.
- Sterile and great brome seeds require vernalisation (overwintering) to produce seeds and readily germinate in darkness. Soft, meadow and rye brome seeds require a period of post-harvest ripening and light for germination.
- Key facts
  - 5 plants per m^2 can cause a yield reduction of 5%.
  - High populations will cause crop lodging.
  - High seed production capacity (200 seeds per plant)
  - Annual seed decline is 80% in the soil
  - Persistence in the soil is < 5 years
  - Seeds will emerge mainly from the top 10 cm of soil

24 https://ahdb.org.uk/knowledge-library/arable-weeds-which-brome-species-is-in-your-field

Sterile brome: Key cultural control options

- Sterile or great brome only, shallow cultivation (5 cm down to a maximum of 15 cm) immediately after harvest encourages the germination of freshly shed seeds. A post-harvest chopped straw cover evenly spread may trigger rapid germination. Both options provide the opportunity to control the weed with pre-sowing glyphosate.
- Soft, meadow and rye brome seeds require a period of post-harvest ripening and light to induce germination. Delay cultivation for 3-4 weeks post-harvest is recommended.

A video highlighting the key identification of sterile brome is available here https://www.youtube.com/watch?v=yrqMw_71D5w&list=PL751p-zOnZmAPqP26RoI8_A3Q6pY-911Qwe&index=11

Control Measures

See page 30 -36

Herbicide resistance

See the results for the Survey on page 45 and herbicide resistance status page 61

Identification of sterile bromes

- Very hairy leaf blades and sheaths
- Purple leaf sheath with a stripe effect
- Ligule medium (2-4 mm) and serrated
- Open drooping panicle

Hairy leaf often striped green/purple.

Ligule pointed and deeply serrated.

Blackgrass

Blackgrass is a significant weed control challenge in Ireland. Blackgrass populations have been located and identified in most tillage counties but still at a low level (Figure 11). Blackgrass populations have been identified in 1980's but imported herbicide resistant blackgrass presents a major risk to all farms. The majority of farms do not have blackgrass and with careful stewardship this can remain the position.

Figure 10: *Blackgrass heads with head on right of flower*

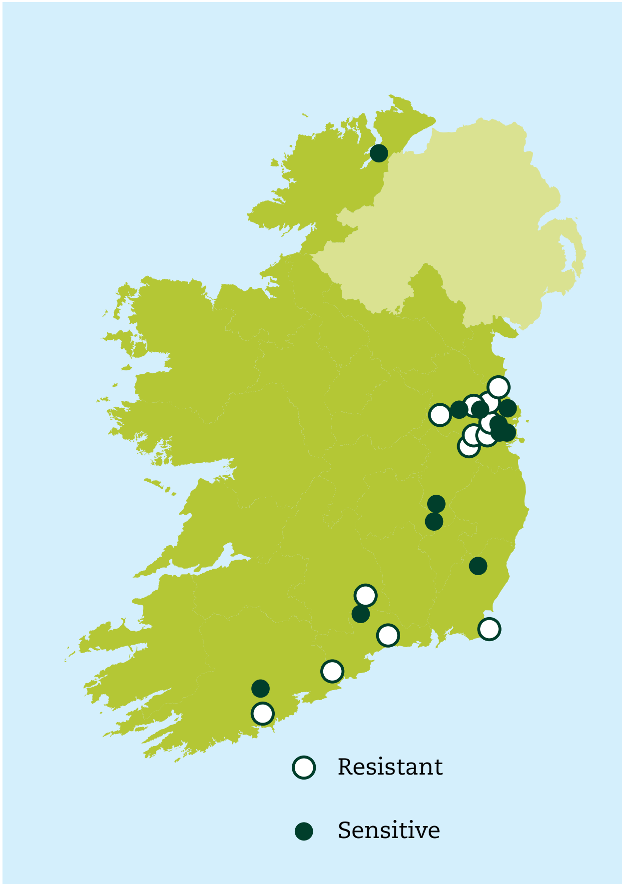


Figure 11: *Distribution of blackgrass resistance tested by Teagasc, Oakpark.*

Controlling Blackgrass on your farm

- Every farm should employ a zero tolerance policy with blackgrass.
- Careful observation and vigilance around bio-security will allow hand rogueing of any plants (before seed set) entering the farm thus preventing seed return and further populations.
- Where hand rogueing is not possible crop destruction before seed set will prevent seed build up. This area should be taken out of crop production for at least 4-5 years to manage/eliminate the weed from the field/farm.
- Farms who are trying to "manage blackgrass" will allow further spread and subsequently result in a larger populations on the farm! if not already present, all blackgrass populations will continue to develop herbicide resistance which will reduce yields/profitability to a level making crop production unviable.

Blackgrass: Facts

- Blackgrass is the number 1 herbicide resistance weed in Europe.
- Predominately autumn-germinating, between September and November with a smaller plant population establishing in spring cropping.
- Seeds have a short dormancy (< 5 years).
- Seed numbers decline rapidly (70% per year) when buried, and seeds do not emerge from > 5 cm depth.
- Innate dormancy is moderately high due to cool wet weather during seed maturation (i.e. flowering and seed formation).
- Obligate cross-pollinator –high risk of developing herbicide resistance.
- If left uncontrolled, a blackgrass plant can produce up to 600 seeds per plant but significantly more from a well tillered plant.
- Confirmed resistance in Ireland to both ACCase (eg. Falcon, Stratos Ultra) and ALS (eg. Pacifica, Monolith) herbicides. High rates of glyphosate should be used for plant destruction even when the plants are small.

Identification

- Compact spike (slender) heads.
- Ligule is medium (2-4 mm), blunt and serrated.
- Leaves rolled in shoot.
- Purple leaf sheath (not all populations will have colouration)

A video highlighting the key identification of blackgrass is available here https://www.youtube.com/watch?v=Pu9ncoh-vcU&list=PL751pzOnZmAPqP26RoI8_A3Q6pY911Qwe&index=15

Control Measures
See page 33 -36

Herbicide resistance
See the results for the Survey on page 45 and herbicide resistance status page 56



Italian rye-grass

Italian ryegrass (Fig 12) is present on a small number of farms (Fig 13), however growers who have Italian rye-grass have found the weed extremely difficult to control. In farms where it is present it should be treated as seriously as blackgrass as both have similar biology and a high risk of developing herbicide resistance.

Figure 12: *Italian ryegrass headed out*

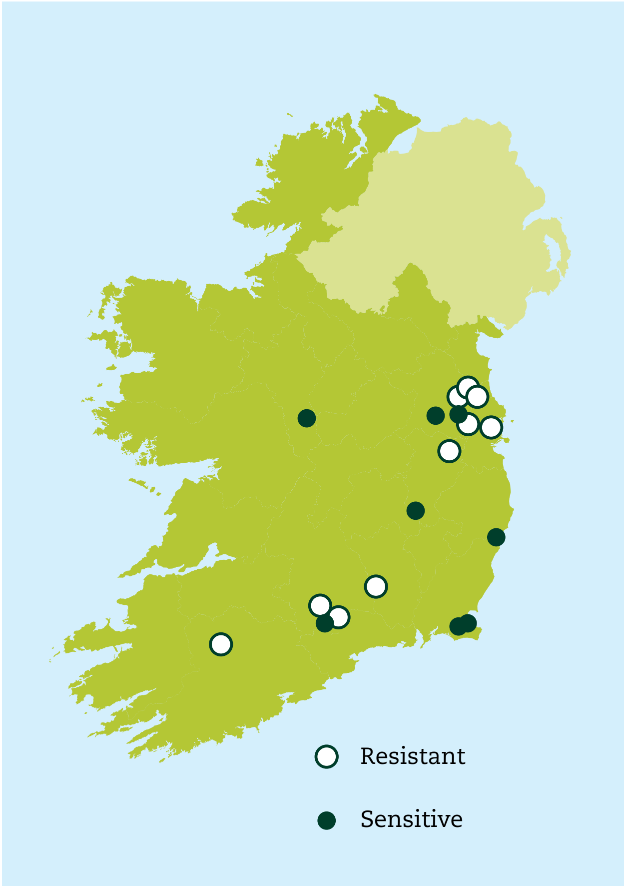


Figure 13: *Distribution of Italian ryegrass*

Controlling Italian rye-grass on your farm

- Every farm should employ a zero tolerance policy with Italian rye-grass.
- Careful observation and vigilance around bio-security will allow hand rogueing of any plants (before seed set) entering the farm thus preventing seed return and further populations.
- Where hand rogueing is not possible crop destruction before seed set will prevent seed build up. This area should be taken out of crop production for 4-5 years to eliminate the weed from the field/farm.

Italian Rye-grass Facts

- It has an early autumn emergence pattern, between September and November.
- Seeds have a short dormancy (< 7 years).
- Seed numbers decline rapidly (80% per year) when buried, and seeds do not emerge from >5 cm depth.
- Obligate cross-pollinator – high risk of developing herbicide resistance.
- If left uncontrolled, Italian rye-grass can produce up to 200 seeds per plant but isolated plants with no crop competition can produce up to 1,000 seeds per plant.
- Herbicide resistance is confirmed in Ireland to both ACCase (eg. Axial, Falcon, Stratos Ultra) and ALS (eg. Pacifica, Broadway, Monolith) herbicides
    - Suspect herbicide resistance in both wild types and cultivated varieties.

Italian ryegrass:

- Flattened spike heads with spikelets on their edge arranged alternatively on the opposite side of the stem.
- Short awns on the spikelet.
- Ligule is short (1-2 mm) and blunt.
- Leaves rolled in shoot.

Control Measures

See page 30 -36

Herbicide resistance

See the results for the Survey on page 45 and herbicide resistance status page 58

Lesser canary grass

Lesser canary grass is an emerging problem for the Irish tillage industry. On the past five years there has been a rapid rise in canary grass populations, with an increasing number being mapped across the country. (Fig 16). Canary grass is generally under reported due to successful control with wild oat herbicides. Populations can explode quickly on farm to the point where the weed lodges the crop and causes severe yield losses.

Figure 14: *Lesser canary grass damage in Spring Barley*

Figure 15: *Lesser canary grass at harvest*

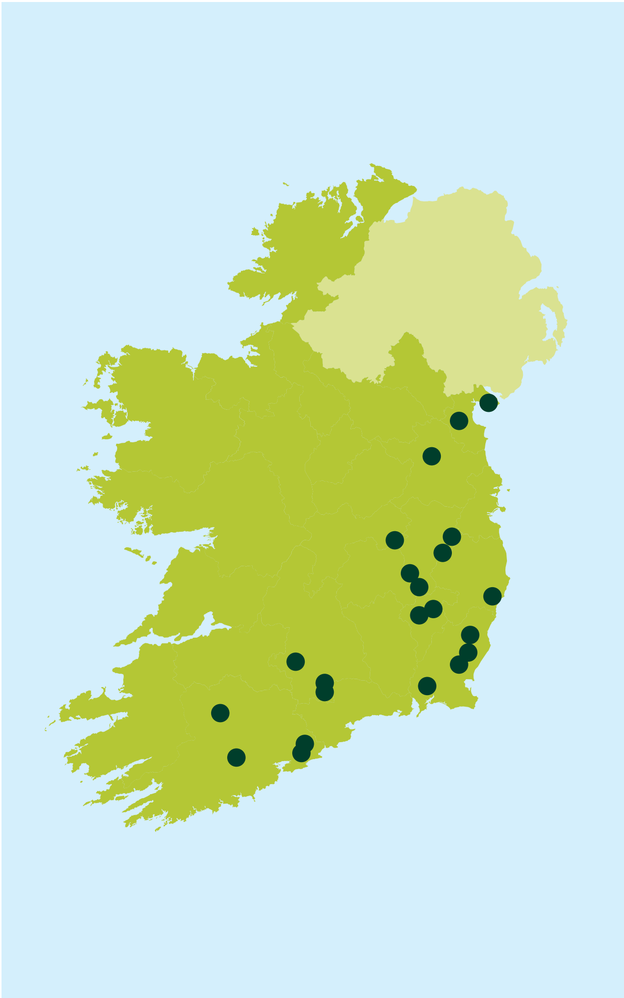


Figure 16: *Location of canary grass populations confirmed by Teagasc (2019-2023)*

Controlling canary grass on your farm

- Every farm should employ a zero tolerance policy with canary grass.
- Careful observation and vigilance around bio-security will allow hand rogueing of any plants (before seed set) entering the farm thus preventing seed return and further populations.
- Where hand rogueing is not possible crop destruction before seed set will prevent seed build up. This area should be taken out of crop production for at least 4-5 years to eliminate the weed from the field/farm

Herbicide control of canary grass to date has been reasonably good. However the correct herbicide timing in the field is often challenging due to the staggered spring germination of canary grass (ideally delay herbicide application for as long as possible to ensure full emergence of canary grass) and achieving adequate spray droplet penetration through the crop canopy.

Lesser Canary Grass: Facts

- It has protracted emergence patterns, with prolific seed returns and long-lived seedbank.
  - » Detailed information about growth habit and biology for Irish conditions is sparse.
- Predominately self-pollinating.
- On average, a single head can produce 150-200 seeds.
- Severe infections can lodge crops and make harvesting very difficult.
- Efficacy studies within the ECT project found both ACCase/ALS herbicides when applied at full recommended label rates and at GS 12-13 (2-3 leaf stage) were highly effective on populations tested.
  - » No ACCase/ALS herbicides (as per label) claim lesser canary grass control.

Identification:

- Long dense spike heads.
- Ligule is medium to long (3-8 mm) and pointed.
- Leaves rolled in shoot.
- The root tip has a distinct red sap.

A video highlighting the key identification of canary grass is available here https://www.youtube.com/watch?v=-QBYxuRtaP4&list=PL751pzOnZmAPqP26RoI8_A3Q6pY911Qwe&index=12

Annual meadow grass

Annual meadow grass (*Poa annua*) grows across all soil types in Ireland. Other meadow grasses like rough-stalked (*Poa trivialis*) or smooth-stalked meadow (*Poa pratensis*) grasses are also widespread, especially in grassland, field margins and headlands, but also occur as an in-crop arable weed, mainly where grass seed mixes are used in field margins.

Figure 17: Annual meadow grass

Meadow-grass: key features

- Germinates throughout the year, especially in September, due to more reliable soil moisture.
- Under ideal conditions, it can flower and set seeds within six weeks of germination. Several generations per year of annual meadow grass are possible.
- Rough-stalked and smooth-stalked meadow grass germinate mainly in autumn and shed seeds in the following summer.
- Plants can emerge from seeds found within the top 5 cm of soil.
- Individual plants can produce 100 to 500 seeds.
- There is an annual 45% decline in seed viability in the soil.
- Low populations in crop do not reduce crop yield.
- Seed dormancy (> 5 years).

Identification:
Bright green leaf blade with boat shaped tip and pale green underside sheath.
ligule medium (2-5 mm), roundly pointed and serrated.
Open-branched and spreading seed heads.
Leaves flattened in shoot.

Control Measures
See pages 33-36

Herbicide Resistance
Herbicide resistance status page 60

Main control options for grass weeds

At the core of effective weed control lies a set of measures that, when employed collectively, yield the best results. This approach is recognised as Integrated Weed Management (IWM). While certain measures may prove more effective against specific weeds, no single control measure guarantees complete weed control. The measures discussed here predominantly revolve around cultural control techniques, although some involve a combination of both cultural and chemical control. Detailed information about the main herbicides is provided elsewhere in the document. A summary of these measures, including their effectiveness rates (rated on a scale of 0-5), against the main grass weeds is presented at the end of this section.

Post Harvest

Stale seedbed

- Shallow cultivations (up to 5 cm) to encourage germination of weeds.
  - For Soft Brome, Rye brome and blackgrass, leave uncultivated for a minimum of 3 weeks to encourage dormancy break and/or increased predation.
  - Glyphosate (at the 1 - 2 leaf stage) after weed establishment.
- Multiple stale seedbeds & glyphosate (as above).

Fallow

- Fallow fields left idle after harvest for an entire growing season.
- Glyphosate is applied to desiccate any regrowth.
- No cultivation is carried out until the following crop is due to be drilled.
- It will suit species that need light to break dormancy, e.g., meadow grasses, soft and rye bromes, and wild oats.
- Increased predation of seeds by insects, birds and small mammals are to be expected.

Rotation

- Plant autumn non-cereal break crops - allowing change to different herbicide mode of action.
- Plant different species types in the autumn and spring - allowing change to different herbicide mode of action.
- Sow spring non-cereal break crop - allowing multiple stale seedbed/cover crops in the autumn and change to different herbicide mode of action.
- Sow spring cereal crop - allowing stale seedbed/cover crop establishment.
- Sow short-term ley (3 to 5 years) to allow short lived weeds seeds to disappear thereby facilitating a return to annual cropping with a lower weed burden.

Establishment Method

Ploughing

Ploughing should be completed to a depth of 15-20 cm to ensure optimal burial of surface trash, proving highly effective in managing sterile brome, great brome, and rat's tail fescue.

However, annual ploughing poses challenges as it mixes seeds throughout the soil profile, making weed control more challenging, particularly for wild oats, Italian ryegrass, blackgrass, and canary grass.

Non Plough based Systems

A common feature of all non-plough based systems is that they rely on dry soils for success. Delayed autumn planting is generally not a practical option in a wetter climate, thereby giving an advantage to grass weeds which prefer to germinate in early autumn.

Min-till

The cultivation can be deep (15 cm or greater) or shallow (up to 7 cm). It is usually deep to help drainage through the seedbed in wet years. The system can allow increased workloads and reduced labour input. Deep cultivations will mix weed seeds through the profile and can lead to higher levels of sterile brome (and other weeds) if not managed carefully.

Strip-Till
This technique cultivates approximately one-third to a half of the seedbed. Strip-till planters have a narrow leading leg generally set to a depth of 8 – 12 cm, creating a drainage channel ahead of the seeding tine, which is 1.0 -2.5 cm. The system can mix seeds to different levels in the soil, but the mix is less aggressive than deep min-till systems. Bromes can be problematic as most weed seeds are left on the surface, so careful management is necessary.

No-Till or direct drill systems
As the name suggests, the system employs no cultivation other than planting the next crop with a disc or tine machine. The system relies on rotations, cover crops and good soil management to ensure success. The system is relatively efficient and with lower costs compared to others cultivation systems but it relies heavily on glyphosate and dry soils for success. Grass weeds can build in these systems, with rat's tail fescues and some broad-leaved weeds becoming more problematic.

Rotational ploughing (1 year in 4 to 5 years) – Non-plough based systems
This technique relies on excellent soil inversion for trash/weed seed burial. The lower weed burden in newly exposed soil (coming from depth) by the plough will have a lower seed burden of many weeds, due to rapid seed decline of many weeds e.g. bromes, blackgrass, rats tail fescue, etc. After ploughing, continue to work the surface (using minimal soil disturbance) and avoid ploughing again for several years.

Establish non-cereal break crop by min-till/ no-till methods – Plough-based systems
Similar to rotational ploughing, the new seedbed should have a lower seed burden which can be combined with excellent grass weed control in a non-cereal break crop (alternative herbicide modes of action can be used in oilseed rape, beans, etc.). Following a break crop, the seed burden should be lower, allowing min-till/direct drill establishment.

Use narrow (normal) spaced rows (125 mm)
Crop competition helps with weed control; however, wide rows may allow inter-hoe machinery to be used to supplement herbicide control. Narrower spaced rows will increase competition and help suppress weeds, especially with wild oats and blackgrass; however, this practice should be used with other weed control practices for best effect.

Sowing

Delay autumn planting
Delaying planting in the autumn capitalises on the biological vulnerability of grass weeds to early-year germination, consequently minimising weed establishment. Opting to sow crops in the later slot for your region, particularly after mid-October, will decrease the germination and establishment of bromes, blackgrass, and canary grasses. However, prolonged delays in planting carry the risk of poor crop establishment, diminishing the competition against grass weeds.

Use competitive cultivars & varieties e.g. hybrids
Crop competition serves as a valuable means of suppressing grass weeds. A competitive crop exhibits vigorous growth, effectively capturing light and crowding out the grass weed. However, it's essential to note that this effect has limitations and cannot deliver adequate control when employed in isolation.

Increase seed rate by 15% to 20% above normal rates
Similar to competitive cultivars, elevating the seed rate has the potential to enhance crop competition, effectively crowding out grass weeds. Lower seed rates may result in sparser crops, providing space for grass weeds to compete. However, surpassing these recommended seed rate levels becomes cost-prohibitive, heightens the risk of lodging and disease incidence, and may lead to lower grain quality.

In Crop

Crop walking & monitoring
Spotting and hand-rogueing individual grass weeds in a field represents the simplest method to prevent the development of a problematic population. Conducting crop walks from May to the end of June is crucial for all fields. Diligent observation during this period allows identification of potential resistance issues that may be emerging. It is essential to maintain detailed records noting which herbicides are effective each year. Reviewing these records before applying herbicides in the following year ensures informed decision-making.

Weed mapping – manually or precision

Mapping can be conducted during hand-rogueing. Sketch the weed populations onto a map, either online or on an old DAFM LPIS map. Note the weed type, density, and size/area in the field. This map proves valuable in subsequent years for implementing targeted actions in these areas, such as hand-rogueing, spot spraying, or reverting to grassland.

Capture ripe seed sample and test for herbicide resistance

Determining the grass weed species is crucial for implementing the correct management practices. It is also essential to be aware of the herbicide resistance status of the weed for effective management. When conducting herbicide resistance testing, focus on live plants where the appropriate herbicide was applied correctly at the label-recommended rate. For herbicide resistance testing in grass weeds, collect two cups full of ripe seeds, provide the necessary crop management information, and send them to Teagasc Oak Park, Carlow.

Crop destruction – Total crop kill or removal for silage

Preventing weed seed set and return is crucial for reducing the weed seed burden in a field. Focus on areas with a moderate to heavy weed infection and take targeted actions, such as either using a total herbicide to destroy both the crop and weed or cutting and removing the crop and weed. This intervention needs to be carried out before the seeds ripen and fall to the ground. While this approach may seem drastic and expensive, the cost of crop removal can be weighed against the potential expense of future weed control if the population spreads across the entire field or farm.

Hand Rogueing

Preventing the return of weed seeds to crops is essential for reducing the weed population. Hand-rogueing is particularly effective for small weed populations, primarily aiming to hinder the initial spread of a grass weed. Ensure the entire plant is pulled before the weed seeds fall from the head, and transport the rouged plants to an area away from the field for safe disposal.

Mechanical Weeding

This can involve either removing the weed from the ground using a tined hoe or extracting the weed seed heads above the crop. The ground-level weed removal necessitates planting the crop in wide rows, utilising specialised machinery, and requiring dry conditions during the operation and for a few days afterward to allow the weed to dry out and perish. On the other hand, removing the heads of weeds above the crop can be effective but is constrained by both the height of the crop and the specific target weed.

Harvest

A combine fitted with an additional piece of equipment can address weed seed management (although not adequately tested in Ireland).
There are three main approaches:

1. The chaff from the combine is concentrated into a narrow band, facilitating composting to destroy weed seeds contained in the chaff.
2. A set of high-speed rollers is used to squash/roll the seeds, effectively destroying them.
3. All chaff expelled from the grain separator is collected before reaching the ground, aiming to collect both chaff and weed seeds. This material is then dumped in a designated area outside the field and can be composted.

However, all of these method may be limited in crops with very high biomass and these techniques are mostly used in drier countries with low yields (e.g. Australia).

Hygiene/Biosecurity

Ensure that purchased seeds, whether cereals, oilseed rape, cover crops, etc., entering the farm are certified by a competent authority. Whenever possible, request additional assurances or proof of the highest seed standards, particularly for cover crops. It is important to prioritise harvesting and baling fields with grass weed problems last. Thoroughly clean the combine/baler before entering or leaving badly infested fields.

Prevent the return of weed contaminated organic material

Thoroughly check the origin of straw in farm yard manures to be imported. Ideally only use straw which came from your farm e.g. swap deal with the livestock farmer.

Machine hygiene

Ensure that newly purchased machinery or contractor’s machinery is thoroughly cleaned before entering your farm. Begin by blowing down all crop material from the head/main combine, including behind all safety guards, starting from the top. Open trap doors on stone traps, elevators, etc. Subsequently, run the machine with all sieves and fans opened for at least 10 minutes. Finally, give the combine another thorough blowdown. For balers, ensure that the chambers are empty, then blow down all material both inside and outside. Again, run the machine for 10 minutes followed by another blowdown of the entire machine.

Use certified seed

Source certified seed whenever possible for main crops (wheat, barley, oats, etc.) or cover crops. Ensure that the seed's source is known, and be familiar with the national guidelines for certified seed if it is coming from outside Ireland. If you are unsure about the seed, do not bring it onto the farm. Continue to hand-rogue the crop for grass weeds regardless of the source of the seed.

Home-saved seed with known weed-free status

When selecting seed, choose only from a known grass weed-free field. Hand-rogue the area two or three times before harvest. Ensure the combine and trailers are thoroughly blown down and cleaned to prevent contamination from other fields. Continue hand-rogueing the crop for grass weeds, regardless of the source of the seed.

Summary of the main control options for five common grass weeds

Table 3. Summary of the main control options for five common grass weeds
(key ★ = some effect, ★★★★★= effective measure)

Measure	Effectiveness of Control Practice				
	Wild Oats	Bromes	Blackgrass	Canary grass	AMG
Cultural Control					
Post-Harvest					
Stale Seedbed– shallow (to a depth of 5cm) one flush of weeds. For Soft & Meadow brome, for rye brome leave uncultivated for 3 weeks to encourage dormancy break.	★★★	★★	★★	★	★
Multiple stale seedbeds & glyphosate (as above).	★★★★★	★★★	★★★	★★	★★
Sow Cover Crop - early after harvest for best establishment (open crops will allow increased germination of weed seeds).	★	★★	★★	★	★
Rotation					
Plant autumn break crop - allowing change to herbicide mode of action.	★★★★	★★★	★★★	★★	★★★
Plant different species type in Autumn and/or Spring- allowing change to herbicide mode of action.	★★★★★	★★★	★★★	★★	★★★
Sow spring break crop - allowing multiple stale seedbed/cover crop in the autumn and change herbicide mode of action.	★★★	★★★★	★★★	★★	★★★
Sow spring cereal crop - allowing stale seedbed/cover crop establishment.	★	★★★	★★★	★★	★★
Sow short term ley (3 to 5 years).	★★	★★★★★	★★★★	★★	★
Establishment Method					
Ploughing.		★★★★	★★★		★
Min-till.		★			
Strip Till .	★	★★			
No Till.	★★	★	★	★	
Rotational ploughing (1 year in 4 to 5) in a non plough based systems.		★★★	★★★		★
Establish break crop by min-till/no-till methods – Plough based systems.		★★	★★		★
Use narrow spaced rows.		★	★		★★
Sowing					
Delay Autumn planting.		★★★	★★★	★	★
Use competitive cultivars & varieties, e.g. hybrids.	★	★	★		★
Increase seed rate by 15% to 20%.		★	★★		★★★
In Crop					
Crop walking & monitoring.	★★★	★★	★★★★★	★★★★★	★
Weed mapping – manually or precision.	★★★	★★	★★★★	★★★★	★
Capture ripe seed sample and test for herbicide resistance.	★★★★★	★★★★★	★★★★★	★★★	★★★★★
Crop destruction before seed set e.g. patch spray glyphosate if heavily infested.	★★★★★	★★★★	★★★★★	★★★★★	
Hand Roguing (low level of infection).	★★★★★	★★★★★	★★★★★	★★★★	
Mow for silage if heavily infested (early removal before seed shead).	★★★★★	★★★★★	★★★★★	★★★★★	
Hygiene/Biosecurity					
Ensure grass weed problem fields are harvested and baled last	★★	★★	★★	★★★	
Thoroughly clean down combine/baler (inc contractors machinery) - entering/leaving badly infested fields.	★★★★★	★★★★★	★★★	★★★	★
Prevent the return of organic material to tillage ground originating from straw from infected fields.	★★★★★	★★★★★	★★★★	★★★★★	
Thorough hygiene check prior to machinery working in non infected tillage fields - newly purchased machinery or contractor's machinery.	★★★★★	★★★★	★★★★★	★★★★★	
Use certified seed.	★★★★★	★★★★★	★★★★★	★★★★★	
Or use own home-saved seed with known weed-free status.	★★★★	★★★★	★	★★★	

ECT Focus Farms

An integral component of the ECT project involved collaboration with a group of commercial farmers, referred to as Focus Farmers. These individuals utilised diverse establishment systems and faced grass weed challenges on their farms. The selection criteria for the ten tillage "focus farms" included:

- Type of establishment system (plough-based, Min-till, Strip Till, and direct drill systems)
- Presence of at least one key grass weed (bromes, wild oats, blackgrass, canary grass) as a significant issue on the farm
- Geographical diversity to represent various soil and climatic differences across the country
- An area on the farm of approximately 4 hectares with a grass weed issue
- Willingness to change existing practices and implement new techniques for improved grass weed control
- Farmers with a good knowledge of agronomic practices and effective communication skills to others in the industry

The selection process involved nominations from Teagasc Tillage Advisors and ECT project stakeholders, including BASE Ireland, Claydon Discussion Group, BAYER, and CORTEVA. All nominated farmers underwent evaluation using a standard scoring system considering the outlined parameters. The selected farmers were compensated for their participation in the ECT project, covering their time for tasks, open days, etc. Additional payments were made for extra expenses incurred by farmers to implement additional measures on the farm.

The Focus Farms collaborated with the project for five years, implementing measures annually to combat grass weeds. They employed a combination of crop establishment techniques and integrated weed management (IWM). At the project's outset, all farms underwent assessment for problematic grass weeds, and a specific field was chosen for detailed monitoring (Validation Area). This area allowed tracking of farmer interventions and the resulting weed control measures over time.

At the start of the project all of the farm were assessed for the problematic grass weed and a field selected to specifically monitor (Validation Area) the farmer interventions and the resulting weed control from these measures over time.

The farmers convened on multiple occasions to enhance their skills in grass weed identification/biology, control measures, field assessment techniques, resistance management, etc. These sessions also provided a valuable platform for farmer interaction and the collaborative development of solutions.

The farmers outlined have different establishment systems as follows; yellow circles use plough or combination of plough and min-till, green circles use min-till (deep non inversion), purple use strip-till, and orange use direct drill system .

Farmer Network

Adam Goodwin	Plough
Gavin Curran	Plough-in conversion to Min-till
Bill Shanahan	Min-till
Donal McGrath	Min-till
Simon Neville	Min-till
Gareth Browne	Strip-till and Min-till
Michael Grace	Strip-till
Gareth Culligan	Reduced till/Direct drill
Rob Coleman	Reduced till/Direct drill
Eoin Lyons	Reduced till/Direct drill

Figure 18: *Location and names of focus farmers*

Table 4. Focus farms – Baseline data for each focus farmer

	Adam Goodwin	Gavin Curran	Simon Neville	Gareth & Mark Browne	Donal McGrath	Bill Shanahan	Rob Coleman	Michael Grace	Gareth Culligan	Eoin Lyons
County	Kildare	Meath	Wexford	Wexford	Tipperary	Waterford	Cork	Kildare	Louth	Kilkenny
Tillage Area (ha)	180	150	360	325	130	120	445	160	220	60
Soil Type	Heavy	Heavy	Light	Medium	Medium	Medium	Medium-heavy	Medium	Medium	Medium
Current Establishment System	Ploughing	Ploughing	Deep non-inversion tillage (Min-till)	Deep non-inversion tillage and Strip Tillage (Min-till)	Deep non-inversion tillage (Min-till)	Deep non-inversion tillage (Min-till)	Deep non-inversion tillage, direct drill and broadcasting (Min-till)	Strip tillage	Direct drill	Direct drill
Arable Rotation (Yes or No)	WW, WB, WO, WW, Peas/ WOSR, WW, WB,WO, WW	WOSR/ SBeans, WW, WB, WO, WW, WB	Continuous cereals predominantly. WOSR and SBeans now being used more	WB, WOSR/ SBeans, WW, SB, SB	Continuous cereals with WO as a break	Continuous cereals with WO as a break	SBeans, WW, WB, some continuous WW and WB	WB, WOSR/ SBeans, WW, WO, WW	WB, WOSR, WW, WBeans	WOSR, WW/WB, WO, WW/ WB
Transition to Current system (yr)	-	-	2008	2004	2001	2017	2002	2012	2001	2017
Major Grassweed (Focus Weed)	Great brome and Spring wild oats	Sterile Brome	Canary Grass	Wild oats	Sterile brome and great brome	Black grass	Sterile brome and meadow brome	Sterile brome and soft brome	Sterile brome	Sterile brome
Minor Grassweed	Sterile brome and canary grass	Wild oats	Sterile brome and wild oats	Sterile brome	Wild oats, Italian ryegrass	Wild oats	Wild oats and Italian rye grass	Wild oats	Wild oats, rat's tail fescue	Wild oats
Infestation levels (Low/Med/High)	Medium	Medium	Medium	Medium	High	High	Medium	Low	Medium	High
Weed Pressure in Last 10 Years	Increased	No change	Decreased	No change	increased	Decreased	Decreased	Decreased	No change	increased
Levels of Weeds in Validation Area	Low levels scattered across the field	Moderate levels coming from boundaries	Moderate in patches	Scattered through at low levels	Heavy infestation throughout	Heavy infestation throughout	Moderate infestation throughout	Low to moderate levels scattered across the field	Moderate levels scattered through the field	Heavy infestation throughout
Grassweed Herbicide Resistance on Farm	None	None	Wild oats -ACCase	Wild oats -ACCase Corn marigold - ALS	Italian rye grass - ALS	Black grass - ALS and ACCase	Italian rye grass - ALS and some ALS	None	Rats tail fescue naturally resistant to ACCase	None

Co- creation of weed management actions

The focus farmer, in collaboration with the project advisor, designated an area on the farm as a "Validation Area" to experiment with various strategies aimed at improving the control of the predominant grass weed. Through a co-creation process involving discussions with the farmer, the best actions were selected to suit the farm and target weed(s). Once these plans were agreed upon, the farmer implemented them, incorporating actions such as rotation, stale seed beds, increased seed rates, spring cropping, targeted herbicides, hand-rogueing, etc.

The weeds in the validation area were monitored by conducting visual counts of grass weed heads across the crop on a grid basis throughout the field before harvest from 2019 to 2023. The results of these counts were regularly communicated to the farmers throughout the project, and the findings were used to guide actions for the following year.

Resistance testing

Seeds from the key weeds were collected in year one and tested in the glasshouse for herbicide resistance. Subsequently, the seeds were further examined using PCR to identify the exact genetic form of resistance. Half of the farms encountered herbicide resistance issues, and one farmer had a developing population of Rats Tail Fescue, which is naturally tolerant to an important group of grass weed herbicides.

Results

Across the farms there were mixed results with all farmers trying hard to decrease the grass weeds within their establishment system.

Table 5. End of project summary of Focus Farmers weed status

	Adam Goodwin	Gavin Curran	Simon Neville	Gareth & Mark Browne	Donal McGrath	Bill Shanahan	Rob Coleman	Michael Grace	Gareth Culligan	Eoin Lyons
County	Kildare	Meath	Wexford	Wexford	Tipperary	Waterford	Cork	Kildare	Louth	Kilkenny
Tillage Area (ha)	180	150	360	325	130	120	445	160	220	150
Soil Type	Heavy	Heavy	Light	Medium	Medium	Medium	Medium-heavy	Medium	Medium	Medium
Current Establishment System	Ploughing	Ploughing	Deep non-inversion tillage (Min-till)	Deep non-inversion tillage and Strip Tillage (Min-till)	Deep non-inversion tillage (Min-till)	Deep non-inversion tillage (Min-till)	Deep non-inversion tillage, direct drill and broadcasting (Min-till)	Strip tillage	Direct drill	Direct drill
Arable Rotation-changed since the project commenced	No change	Changed to Winter crop rotation with break crop of beans	Changed from mainly Spring to a mix of Winter and Spring with break crops	No change	No change	Changed to a more diverse rotation to include oil seed rape	No change	Changed to include more break crops in a Winter crop rotation	No major change but based on incorporating more companion crops	Change to Winter and Spring with oil seed rape as a break crop
Major Grassweed (Focus Weed)	Great brome and Spring wild oats	Sterile Brome	Canary Grass	Wild oats	Sterile brome and great brome	Black grass	Sterile brome and meadow brome	Sterile brome and soft brome	Sterile brome	Sterile brome
Minor Grassweed	Sterile brome and canary grass	Wild oats	Sterile brome and wild oats	Sterile brome	Wild oats, Italian ryegrass	Wild oats	Wild oats and Italian rye grass	Wild oats	Wild oats, rat's tail fescue	Wild oats
Measures used to reduce grass weeds (Scale 1 = low ands 5 = high)	4	4	4	5	3	5	5	5	2	5
Current level of infestation	Low	Medium	Medium	Medium	High	High	Medium	Low	Medium	High
Weed level increasing or decreasing	↘	↘	→	→	↑	↘	→	↘	↗	↓
Grassweed Herbicide Resistance on Farm	None	None	Wild oats -ACCase	Wild oats -ACCase Corn marigold - ALS	Italian rye grass - ALS	Black grass - ALS and ACCase	Italian rye grass - ALS and some ALS	None	Rats tail fescue naturally resistant to ACCase	None

While there has been notable progress reducing populations on many farms, grass weed seeds have a long life span or dormancy period (wild oats, canary grass blackgrass, etc), therefore achieving a substantial reduction in the overall populations of these weeds will take longer than the projects duration.

Case Studies

The case study for each Focus Farmer documents the actions taken by the farmer throughout the project. It presents the available options for each farmer and details the corresponding actions taken annually. The outcomes of these actions are reflected in the success or failure of controlling grass weeds in that particular year.

Weed counts were carried out on the validation area each year and the results were displayed on a grid map using standard protocols. An example of the maps is below in Figure 20.

Each of the Case Studies (https://www.teagasc.ie/crops/crops/grass-weeds/ect-project/) is accompanied by a video featuring the Focus Farmer. In each video, the farmer discusses their reasons for changing their system and outlines the measures taken to control weeds in their establishment system. You can locate the videos on the www.teagasc.ie website by searching for the ECT project or here https://www.youtube.com/playlist?list=PL751pzOnZmAPqP26RoI8_A3Q6pY911Qwe.

Co-designed Weed Control Actions	2019 crop WW	2020 crop WO	2021 crop SB	2022 crop SB	2023 crop WOSR
Post-Harvest					
Stale seedbed – immediately post-harvest	✔				
Stale seedbed – delayed to break dormancy					
Stale seedbed – multiple		✔			
No post-harvest cultivation. Glyphosate @ 1-2 leaf					✔
Establish cover crop		✔	✔		
Plant and maintain a grass margin	✔	✔	✔	✔	✔
Rotation					
Break crop – autumn		✔			✔
Break crop – spring					
Change cereal type			✔		
Plant spring cereal			✔	✔	
Sow short-term ley (3 to 5 years)					
Establishment Method					
Plough			✔		
Min-till					
Strip Till					
Direct drill (with some light cultivation)	✔	✔		✔	✔
Min-till cover crop (plough-based systems)					
Sowing					
Delay autumn planting	✔				
Use competitive cultivars & varieties, e.g. hybrids					✔
Increase seed rate by 15% to 20%			✔		
Use narrow-spaced rows					
In Crop					
Crop walking & monitoring	✔	✔	✔	✔	✔
Weed mapping – manually or precision	✔	✔	✔	✔	✔
Test for herbicide resistance	✔				
Crop destruction – badly infested areas		✔			
Mow for silage – badly infested areas					
Hand Roguing (low level of infection)	✔	✔	✔	✔	✔
Herbicide use					
Pre-emerge residual herbicide targeting grass weeds	✔				✔
Post- emerge control targeting grass weeds	✔		✔	✔	✔
Leave section of field unsprayed					
Hygiene/Biosecurity					
Infested fields are harvested and baled last					
Thoroughly clean machinery post-operation	✔	✔	✔	✔	✔
Organic manure – only from known weed-free status					
Thorough hygiene check before machinery working	✔	✔	✔	✔	✔
Use certified seed	✔	✔	✔	✔	✔
Home-saved seed with known weed-free status					

Figure 19: Example of a co-designed actions for a Focus Farmer's valedation area.

Farmer action and grass weed control results each year

Pre-harvest weed counts

0	1	2	3	4	5	6	7	8	9	10
No Weeds										Very High Infestation

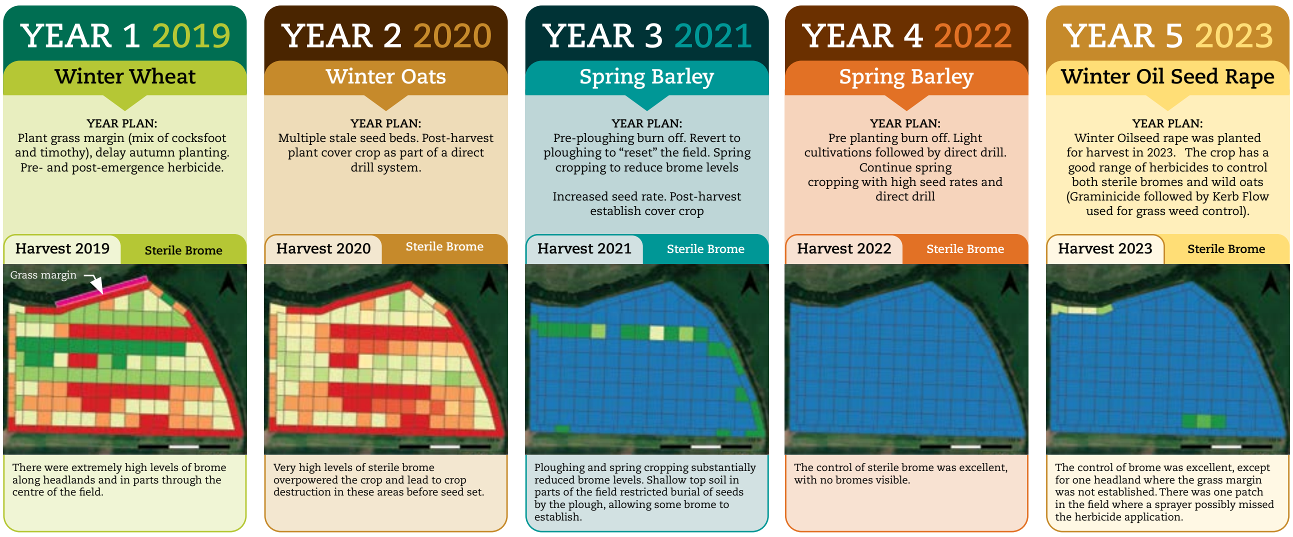


Figure 20: Example of weed maps from a Focus Farmer's vaildation area

Main learnings from the Focus Farms

The focus farmer reflected on farm practices in both the validation area and how the overall farm practice has evolved while working with the project. There are several significant lessons and messages from the farms, which can be categorised into farm biosecurity, farmer knowledge upskilling, and specific lessons related to using both plough-based and non-plough-based systems.

Farm bio-security –

- Prevent weed seeds from entering the farm by meticulously cleaning machinery, particularly combines and balers.
- Early identification and management of weeds are crucial to prevent a population from becoming problematic.
- Taking actions such as hand rogueing or crop destruction in small infested areas will prevent seed return and further build-up of these weeds.
- Implementing targeted crop destruction in areas with a high weed burden will yield significant long-term benefits.

Enhance expertise in grass weed identification and biology.

- Understanding the biological strengths and weaknesses of grass weeds enables early, effective actions, such as adjusting planting times to avoid peak germination.
- Conduct herbicide resistance testing in areas where weed control is challenging.
- Ensure that all farm advisors are informed about the issue and are aware of resistance problems on the farm.
- Regularly inspect crops from May onward to promptly identify any potential grass weed problems.
- Develop a comprehensive action plan for weed control, including measures to prevent seed set, hinder seed return, reduce seed in the seed bank, and eliminate weed seedlings.

Implement crop rotation, including cereals and break crops.

- A combination of winter and spring crops is advantageous, exploiting the natural germination timing weaknesses of weeds (e.g., for sterile brome—later planting or spring planting).
- Use varied herbicide types over an extended period to minimise the development of herbicide resistance.
- Avoid consecutive crops with limited herbicide options for grass weeds (e.g., winter barley).
- Most grass weeds (Italian ryegrass, blackgrass, wild oats, canary grass) thrive in any establishment system and, if left uncontrolled, can lead to significant issues within a few years.
- Consider returning fields to grassland sooner, particularly for grass weeds like blackgrass and highly herbicide-resistant Italian ryegrass.
- Grass weeds such as wild oats and canary grass have a long life in the soil and may take several years to reduce populations to hand-roguable levels. Blackgrass and Italian ryegrass are shorter-lived but require close to 100% control to prevent further weed multiplication.
- Grass margins can effectively reduce sterile brome encroachment from boundaries.

Plough-Based Systems and Grass Weeds:
For the focused farmers employing ploughing or incorporating rotational ploughing as a cultural control measure for grass weeds in their system, the following considerations should be taken into account
:

- Plough-based systems may encounter grass weed issues for nearly all types of weeds.
- Rotation is crucial in plough-based systems to minimise the prevalence of grass weeds.
- Sterile brome can be effectively managed by burying the seeds through soil inversion (rotational ploughing) and can serve as a valuable tool to reset non-plough-based systems where controlling bromes is particularly challenging.
- Ploughing provides flexibility in crop establishment, especially in wetter conditions, allowing for later planting to avoid the peak germination of many problematic grass weeds.

Non-Inversion Tillage Systems and Grass Weeds:
The focus farmers practicing non-plough systems have

highlighted the following factors crucial for the success of non-plough based systems:

- Stale seedbeds are essential to reduce the grass weed seed bank.
- A diverse rotation is crucial to minimise the presence of all grass weeds.
- Spring cereals play a valuable role in the rotation to exploit the germination profile of grass weeds.
- Systems are most effective in dry soil conditions, compelling earlier planting in autumn and later planting in spring.
- Avoid consecutive crops of winter barley, especially for sterile brome.
- Be guided by soil conditions and refrain from planting where conditions are likely to result in a poor crop.
- Earlier autumn planting can lead to increased grass weed pressure.
- Non-inversion systems demand a higher level of flexibility, for example, using light cultivation to benefit spring crops in a direct drill system.
- Pre-emergence herbicides are crucial in winter cereals to achieve effective grass weed control, particularly in populations with resistant to herbicides, and to reduce the selection pressure on post-emergence herbicides.
- Overreliance on a narrow range of post-emergence herbicides increases the risk of herbicide resistance developing on the farm.
- Companion cropping will limit weed control options for cereals, requiring careful consideration with regard to grass weeds in each field.
- The inclusion of cover crops appears to be beneficial for direct drill systems.
- All establishment systems will favour one weed over others, and weeds will adapt to the system. Rats Tail fescue is emerging as a problematic weed in direct drill systems

A full outcome or case study from each farm is available here (https://www.youtube.com/playlist?list=PL751pzOnZmAPqP26RoI8_A3Q6pY911Qwe)

Figure 21: *The Enable Conservation Tillage project leaders and participants*

Grass Weeds

This section describes the output from the large grass weed survey, which includes assessing the prevalence and distribution of grass weeds, including herbicide resistance. The section also examines the main control tactics used by the survey participants and how these tactics may influence the weeds on their farms.

Grass weed survey

To quantify the extent of grass-weed challenges on tillage farms, we surveyed eastern and southern Ireland growers from 2020 to 2021 (Figure 22). The aim was to collect data on the geographic location of the problem grass weeds, such as blackgrass, Italian ryegrass, bromes, wild oats, canary grass, etc., In addition, the resistance status of the weed population required quantification to mitigate against further spread and resistance development.

1. The survey included 103 growers, of which 62 used conventional plough-based system (CPS), and 41 used NIT (15 used shallow, 11 deep min-till, 4 strip-till and 11 direct drill).
2. The growers were selected from Teagasc and commercial advisors' contact lists based on the crop establishment system used (on >50% of their cropped land) and cereals (wheat, barley or rarely, oats) as their primary crop type.
3. There were three components to the survey:
   - » Record grower demographics and their concerns about grass weeds and weed control practices used on their farms.
   - » Assessing grass weed populations using a 24 m x 24 m grid sampling technique in a 4 ha area within the field before harvest in both 2020 and 2021 ensures accurate and comparable grass weed field data. Each grid square was visually assigned a score from 0 (absent) to 10 (total weed cover) corresponding to the variation in weed pressure. A limited number of weed counts validated the scores.
   - » Analysis of collected samples for herbicide resistance

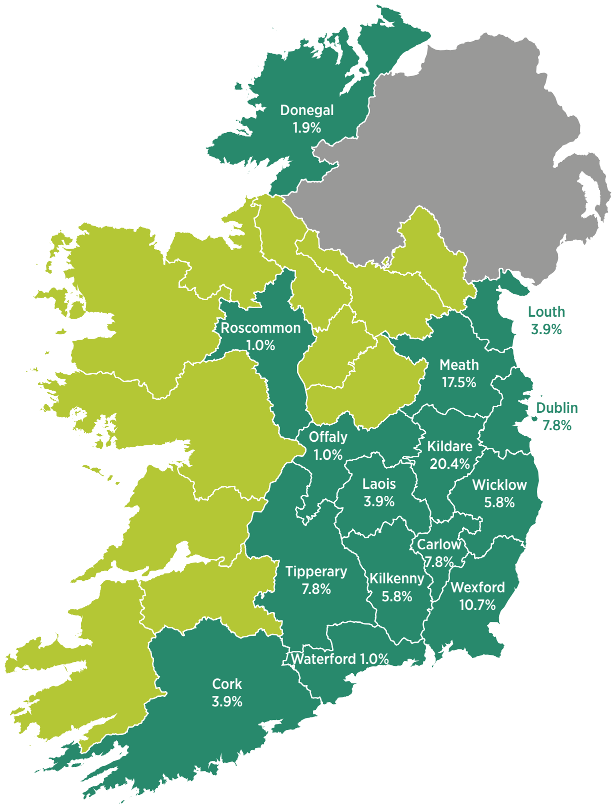


Figure 22. Distribution of the surveyed participants on a county basis (percentage of the surveyed growers in each county) in Ireland (n=103)

The growers

1. NT was associated with larger farms (>350 ha) and younger growers (<50 years) with more formal education (i.e., Agriculture college or level 7 and above).
2. Most of the growers were aware of herbicide-resistant grass weeds (>80%), and most (>90%) used IWM practices to some extent.
3. More than 85% of growers were concerned about herbicide resistance and felt it would pose a significant economic challenge.

Frequency, distribution and weed pressure of critical grass weeds

1. Bromes, specifically sterile brome and spring wild oats, were found on 62% and 56% of farms, respectively, making them the most common weeds on surveyed farms. The invasive species, Italian ryegrass, lesser canary grass, and blackgrass, were found on between 13% and 16% of farms.
2. NT farms had significantly higher weed frequency and population pressure from bromes and Italian ryegrass than farms using the CPS (Figure 24).

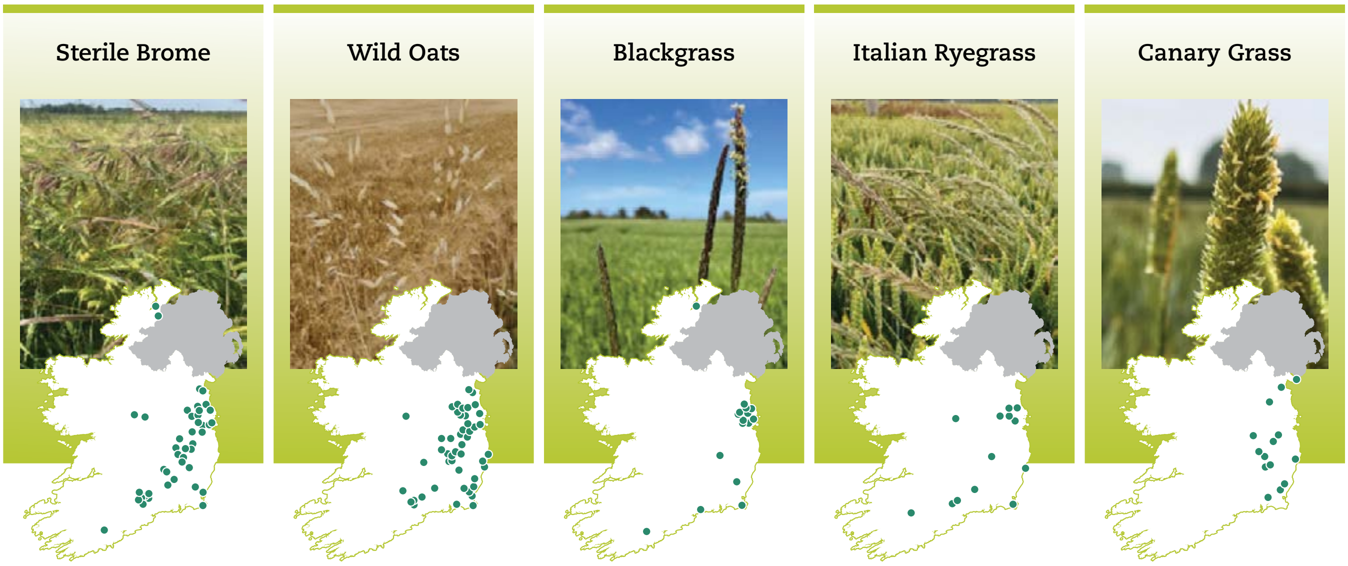
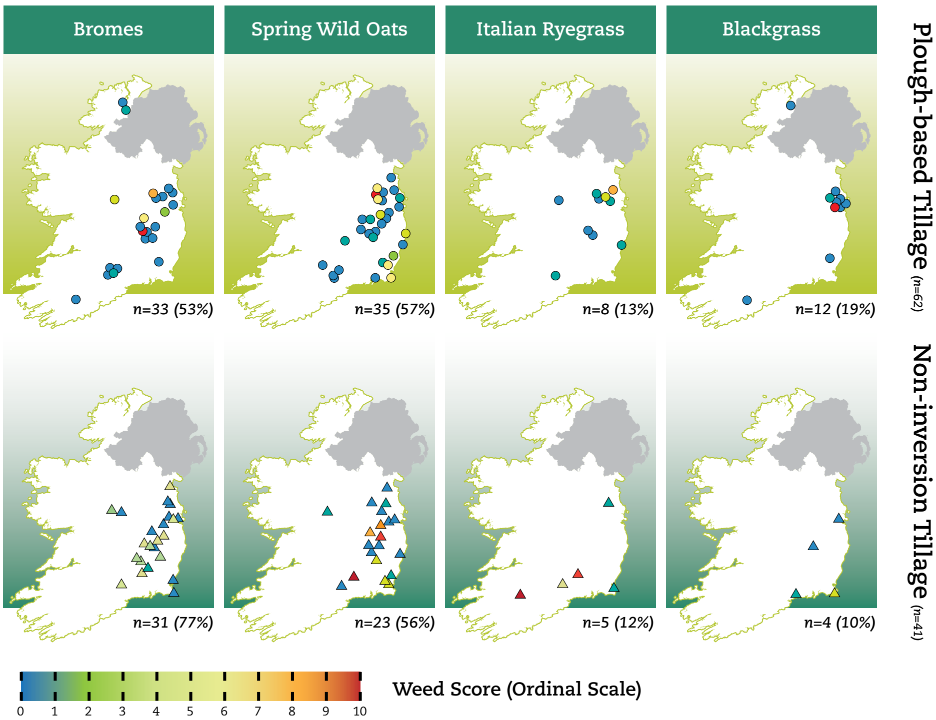


Figure 23. Difficult-to-control grass-weed distribution on our surveyed farms (n=103).



The colours relate in Figure 24 to the mean weed score measured on an ordinal scale from 0 (absent) to 10 (total weed cover). Bromes, spring wild oats, Italian ryegrass, canary grass and blackgrass were found on 64, 58, 13, 14 and 16 farms, respectively. Each farm would have more than one difficult-to-control species, surveyed fields, or cereal crop type.

Figure 24. Field-level grass weed pressure on 103 tillage farms surveyed in 2020 and 2021

Resistance status

1. One hundred and sixty-one grass-weed populations were screened for resistance. They included bromes (n=64), wild oats (n=58), Italian ryegrass (n=9), blackgrass (n=14), lesser canary grass (n=14) and annual meadow grass (n=2). Twenty-two populations, found on 18 of 103 farms, were shown to exhibit herbicide resistance. Three farms had two or more resistant species (Figure 25).
2. Among the 22 resistant populations, five were ALS-resistant sterile bromes (low levels), six ACCase-resistant spring wild oats, five were either ACCase or ALS-resistant or both Italian ryegrass and six ACCase/ALS-resistant blackgrass.
3. About 40% of the 64 sterile brome populations exhibited a degree of tolerance to half-field rates of ALS-Pacifica and or ACCase-Stratos Ultra. It may result from frequently using lower herbicide application rates than recommended.
4. Resistance was recorded on 15% of the CPS and 22% of NT farms. Resistance was recorded in blackgrass and Italian ryegrass, even at low population pressure. It suggests keeping these two problem grass weeds even at low infestation levels does not necessarily minimise resistance risk.

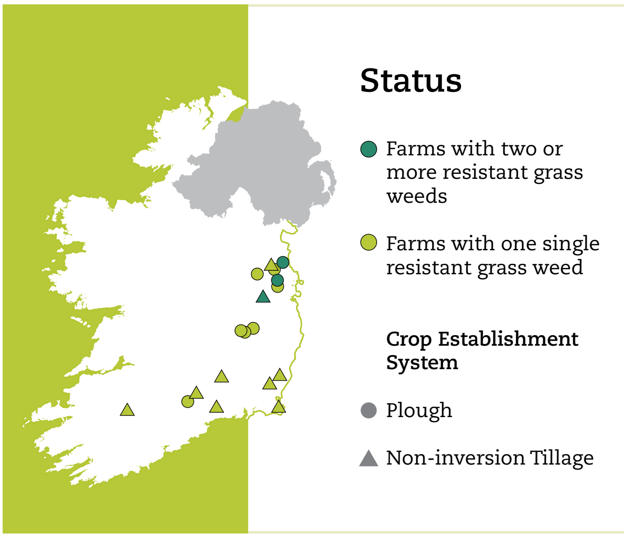


Figure 25. The farm's location where herbicide-resistant grass weeds were found

Grass weed control strategies

1. A higher proportion of NIT farmers (>80%) used crop rotations (cereal and non-cereal break crop or alternate spring and winter rotations) and more cover crops (71%) than those who CPS (Figure 26).
2. Almost twice as many CPS farmers adopted delayed drilling compared with NIT farmers. However, only 47% of CPS farms use a stale seedbed strategy, compared to over 65% of NT farms.
3. Herbicide strategy did not differ between crop establishment types, and rotating herbicide types within crop rotation was common on the surveyed farms. Nevertheless, 55% of CPS farms and 39% of NIT farms never use recommended field label rates of ACCase/ALS herbicides.

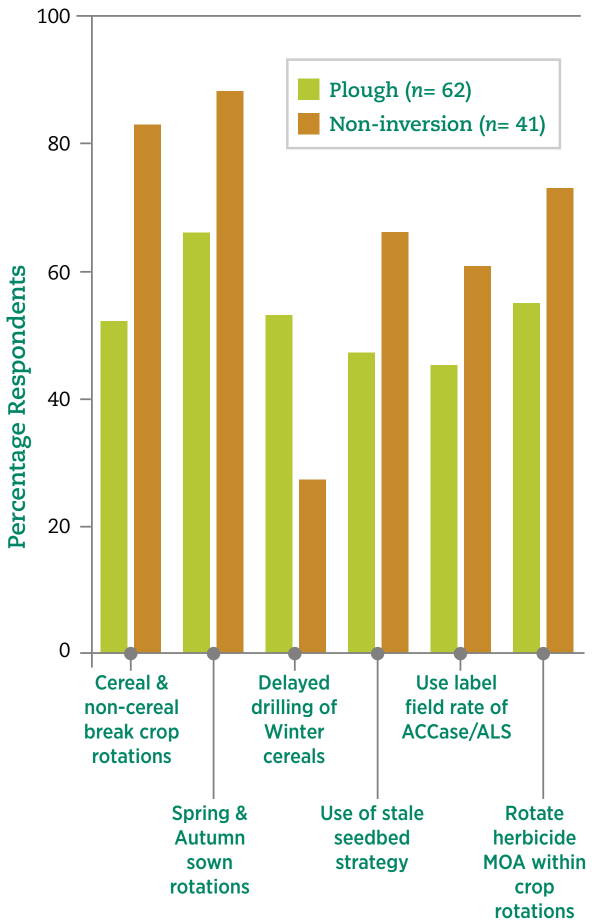


Figure 26. On-farm grass-weed control tactics of plough (n=62) and non-inversion tillage (n=41) farms

Key survey outcomes

This research identified some critical concerns regarding grass weed control on Irish tillage farms.

They confirm:

1. Blackgrass and Italian ryegrass are now a serious threat to Irish crop production.
2. Of the farms with blackgrass, 38% of growers did not know they had the weed until the surveyors found it.
3. Bromes, wild oats, and other species create an increasing challenge, particularly with the evolution of herbicide resistance.
4. There was widespread use of herbicide rates lower than the recommended, irrespective of crop establishment systems.
5. NT, particularly when coupled with earlier sowing, increases the grass-weed threat.

The survey established:

- There is an urgent need to develop effective IWM for all crop production systems, considering the challenges of weed and herbicide resistance.
- A useful grass weed baseline that can be used to monitor the challenge of problem grass weeds and evaluate the effectiveness of IWM control measures.

Herbicide weed screen

The use of herbicides requires a comprehensive and diverse approach to guarantee effective control of grass weeds and to minimise the risk of resistance. The project illustrated treatment programs that utilise stacking and sequencing of different herbicide modes of action. This approach aims to enhance the knowledge and skills of growers and the industry regarding herbicide application timing and diversification.

Stacking involves a technique where more than one active substance (or herbicide product) is applied simultaneously for a given target weed. This can be achieved through mixtures or by applying products that contain more than one active substance. Sequencing, on the other hand, is the application of different active substances or mixtures of active substances in succession.

Methodology

Weed screen demonstration were established at Teagasc Oak Park Research Centre over three seasons. This was not a replicated trial and intended for visual assessment by farmers and industry professionals.

- Different grass-weed species (wild oats, sterile brome, Italian ryegrass, soft brome, annual meadow-grass and rough stalked meadow-grass) were sown from purchased seed to ensure an even weed population. In addition, separate strips of wheat, barley and oats were also sown to observe if any phytotoxicity issues arise from any herbicide or herbicide sequence. Grass-weed trial design for evaluating herbicide effectiveness using stacking and sequence approach (Figure 27).
- Application timings were low-Residual herbicides applied pre-emergence (24-48 hours after drilling) and/or early post emergence (before late October/November of the crop and weed. Early-spring post-emergence in mid-Feb; spring post-emergence in early-March and late post-emergence treatments in mid to late-March (Figure 25).
- Residual herbicides, specifically, for grass-weed control were based on flufenacet (Firebird) or pendimethalin (Stomp) as single active or stacking with prosulfocarb (Firebird + Defy) or using more than one active products like flufenacet + DFF + metribuzin (Firebird met or Bacara triple); autumn/spring post-mergence treatments were based on: mesosulfuron + iodosulfuron + DFF (Alister flex) or pyroxsulam (Broadway Star) or mesosulfuron + iodosulfuron (Pacifica Plus).
- As the trials were for demonstration purposes only, notes (weed scores or weed counts, where possible) were taken based on visual effects and no detailed measurements conducted.

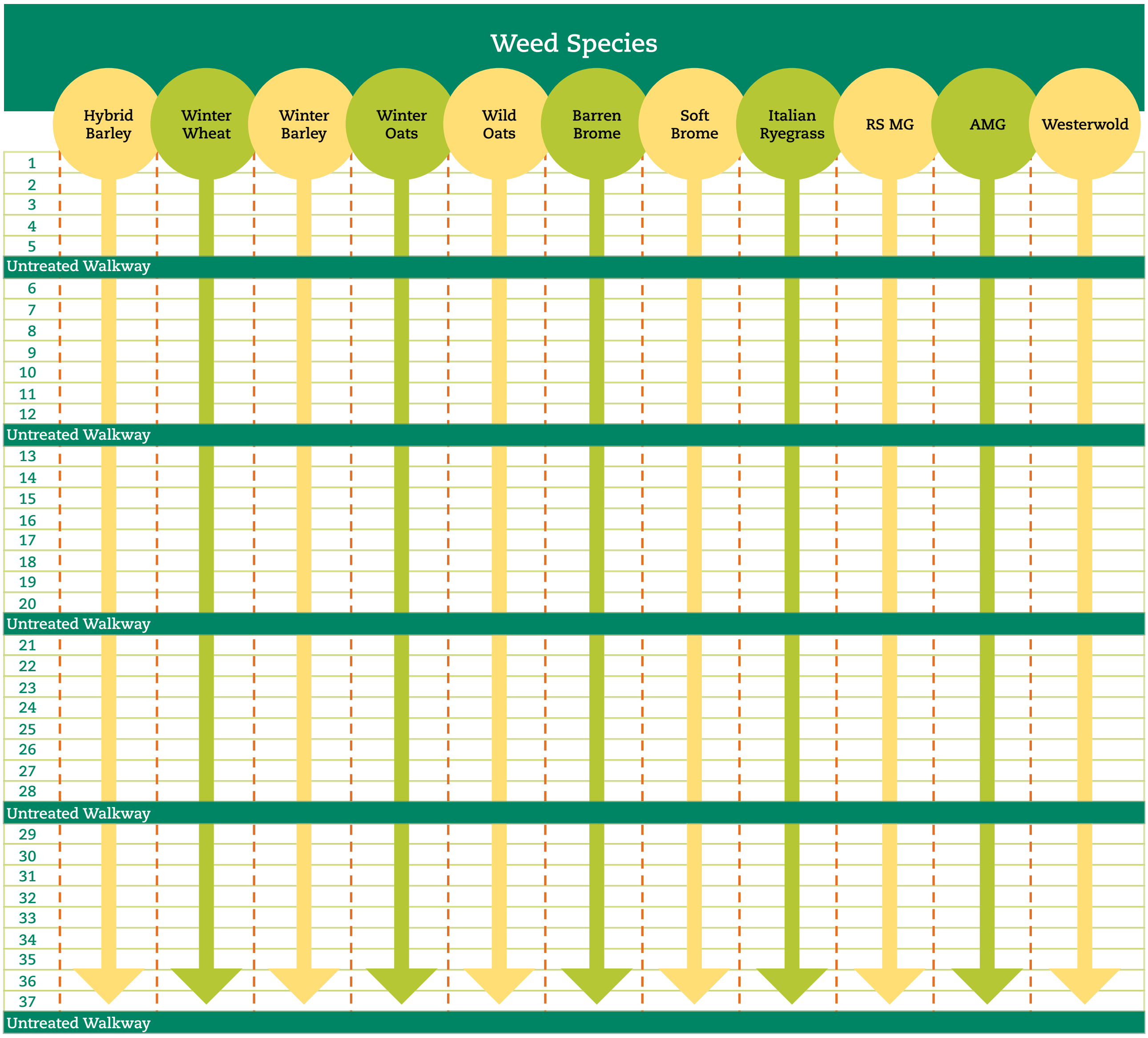


Figure 27. *Grass-weed trial design for evaluating herbicide effectiveness using stacking and sequence approach*

2020-21 PROPOSED IRISH GRASS WEED SCREEN					
Treatment No.	OCTOBER (A) pre/early post emerge	NOVEMBER (B) 11/6/2020	Mid FEB (D)	EARLY MARCH	MID-LATE MARCH (E)
Untreated	Pre emerge only NB fB plus Vigon				
1	Firebird (0.3L/Ha)				
2	Bacara triple 0.7L/Ha				
3	Firebird (0.3L/Ha plus Defy 2L/Ha				
4	Stomp 4L/Ha				
5	Firebird Met 1L/ha				
Untreated	Pre emerge FB Autumn post emerg				
6	Firebird (0.3L/Ha)	Alister Flex 1L/ha + Biopower 1L/ha			
7	Bacara triple 0.7L/Ha	Alister Flex 1L/ha + Biopower 1L/ha			
8	Firebird Met 1L/ha	Alister Flex 1L/ha + Biopower 1L/ha			
9	Stomp 4L/Ha	Alister Flex 1L/ha + Biopower 1L/ha			
10	Stomp 4L/Ha	Broadway Star 265g/Ha + adj			
11	Bacara triple 0.7L/Ha	Broadway Star 265g/Ha + adj			
12	Firebird (0.3L/Ha)	Broadway Star 265g/Ha + adj			
13	Firebird Met 1L/ha	Broadway Star 265g/Ha + adj			
Untreated	Preemerge FB early spring post emerg				
14	Firebird (0.3L/Ha)		Pacifica 0.5L/Ha + Biopower 1L/ha		
15	Firebird (0.3L/Ha)		Monolith 0.33kg/Ha+ Biopower 1L/ha		
16	Firebird Met 1L/ha		Pacifica 0.5L/Ha + Biopower 1L/ha		
17	Firebird Met 1L/ha		Monolith 0.33kg/Ha+ Biopower 1L/ha		
18	Bacara triple 0.7L/Ha		Pacifica 0.5L/Ha + Biopower 1L/ha		
19	Bacara triple 0.7L/Ha		Monolith 0.33kg/Ha+ Biopower 1L/ha		
20	Stomp 4L/Ha		Pacifica 0.5L/Ha + Biopower 1L/ha		
21	Stomp 4L/Ha		Broadway Star 265g/Ha + adj		
22	Bacara triple 0.7L/Ha		Broadway Star 265g/Ha + adj		
23	Firebird (0.3L/Ha)		Broadway Star 265g/Ha + adj		
24	Firebird Met 1L/ha		Broadway Star 265g/Ha + adj		
Untreated	Preemerge FB spring post emerg				
25	Firebird (0.3L/Ha)				Pacifica 0.5L/Ha + Biopower 1L/ha
26	Firebird (0.3L/Ha)				Monolith 0.33kg/Ha+ Biopower 1L/ha
27	Bacara triple 0.7L/Ha				Pacifica 0.5L/Ha + Biopower 1L/ha
28	Bacara triple 0.7L/Ha				Monolith 0.33kg/Ha+ Biopower 1L/ha
29	Firebird Met 1L/ha				Pacifica 0.5L/Ha + Biopower 1L/ha
30	Firebird Met 1L/ha				Monolith 0.33kg/Ha+ Biopower 1L/ha
31	Stomp 4L/Ha				Pacifica 0.5L/Ha + Biopower 1L/ha
32	Stomp 4L/Ha				Broadway Star 265g/Ha + adj
33	Bacara triple 0.7L/Ha				Broadway Star 265g/Ha + adj
34	Firebird (0.3L/Ha)				Broadway Star 265g/Ha + adj
35	Firebird Met 1L/ha				Broadway Star 265g/Ha + adj
Untreated	Post-em. treatment only				
36	Bacara triple 0.7L/Ha				
37	Firebird Met 1L/ha				
38		Alister Flex 1L/ha + Biopower 1L/ha			
39				Broadway Star 265g/Ha + adj	
40				Pacifica 0.5L/Ha Plus Biopower	
Untreated					

Figure 28. Herbicides, pre- only, early pre- + post- and post-emergence treatments for grass-weed populations

Demonstration area in Teagasc, Oak Park

Overhead view of the trail from the side

Overhead view looking down the trial

View of the trial from the left - visible plants in a line are uncontrolled by herbicide

Figure 29. *Weed Screen trial in pictures*

Key results

- In general, tank-mixed residual herbicides (eg. Firebird + Defy) or stacked products (eg. Firebird Met or Bacara Triple) applied as pre-emergent treatments were found to be very effective and faster acting than single actives (eg. Firebird or Stomp) in controlling grass weeds (Figure 30 & Figure 31).
    - » The addition of metribuzin in both Firebird Met and Bacara Triple reduced crop vigour on the cereal crop, specifically, on winter oats.
- Pre-emergent followed by post-emergent herbicides (Alister flex or Broadway Star) in November resulted in good grass-weed control.
    - » However, Alister Flex seemed to perform slightly better, as it tends to work better in early autumn and at lower temperatures than Broadway Star, which is usually used in February or spring.
    - » The use of Alister Flex alone in early autumn or November resulted in good grass-weed control, despite not using any of the pre-emergent treatments
- The two late spring-applied post-emergent treatments (Pacifica Plus or Broadway Star) were comparable, offering good weed control.

Staples J.(2021).Weed screen trials.https://www.youtube.com/watch?v=VFEWAVcnBQA

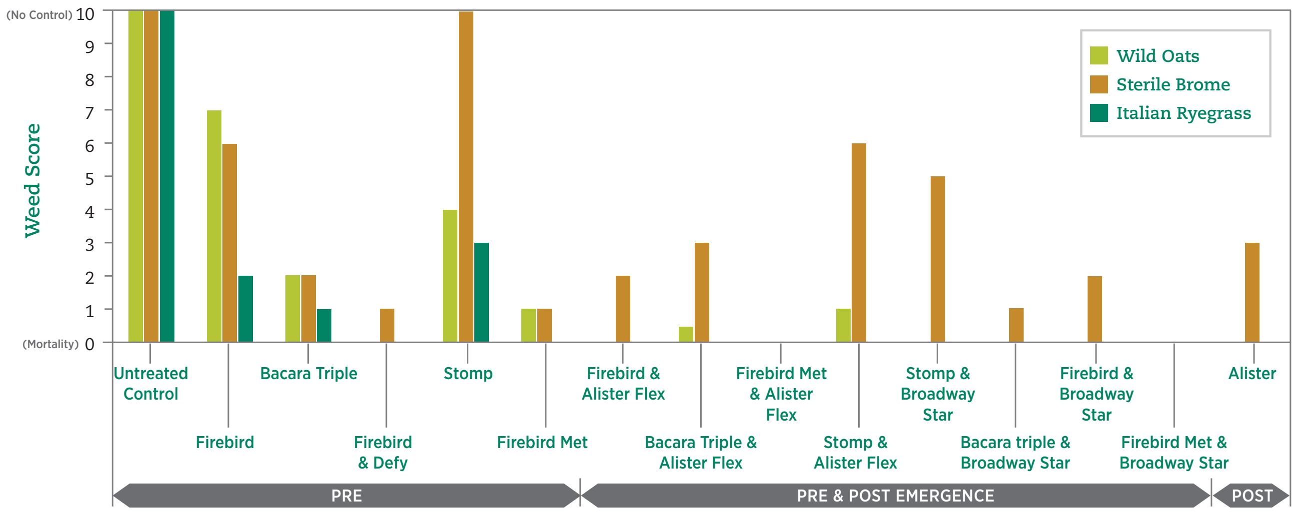


Figure 30. *Weed scores from the demonstration trial 2019*

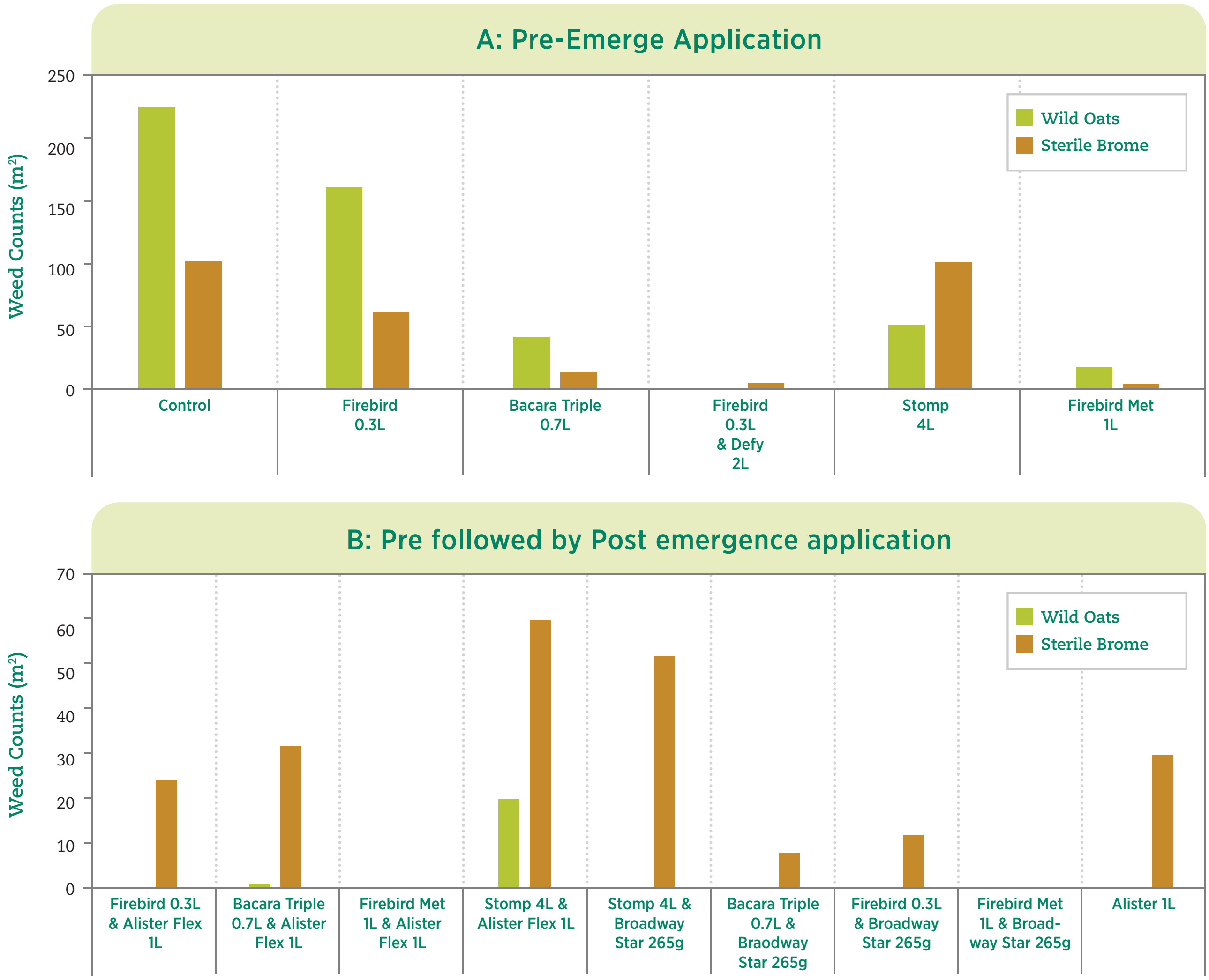


Figure 31. *Collated results from the demonstration in other seasons (A & B)*

Herbicide resistance

Herbicide resistance is defined as 'the evolved ability of a weed population to survive a maximum dose rate of a herbicide previously known to be lethal'.

1. Herbicide resistance is naturally acquired through plant selection.
2. It is not caused by the application of herbicides.
3. Once target-site resistance is present in a population, it will not disappear, even if the herbicide selection pressure is removed.

The following factors influence grass weed herbicide resistance:

1. Selection intensity[25] – herbicide dose (using rates lower than full recommended field rates), frequency (using herbicides from the same mode of action (MOA) for two or more consecutive years) and timing of application (spraying on older or larger plants) all increase population size and place pressure on herbicides.
2. Frequency of resistance present in populations – A few resistant individual plants exist naturally within populations, even before herbicide use. When a herbicide is applied, these individuals survive and set seed, while most susceptible plants die. Repeated use of the same herbicide eventually results in a larger population of resistant survivors in that field.
3. The biology–outcrossing species[26] (e.g., blackgrass, Italian ryegrass) with high seed bank populations and short soil seed bank life are likely to develop resistance rapidly, compared to predominantly self-pollinating (e.g., wild oats, bromes) species.
4. Weed pressure – the greater the population size, the greater the likelihood of any herbicide selecting resistant individuals within that population.

Key herbicides

In Ireland, the two most widely used post-emergence herbicide types for selective grass weed control within crops have acetyl-CoA carboxylase (ACCase)- (Group 1) or acetolactate synthase (ALS)- (Group 2) inhibiting Mode of Action (MOA). MOA is how a herbicide interrupts the biological pathways of susceptible plants, causing immediate damage and plant death.

The ACCase herbicides control grass weeds by disrupting fatty acid synthesis, causing main shoot death at the growing point. ACCase herbicides include three chemistries: Axial, Falcon, or Stratos Ultra.

The ALS herbicides disrupt the synthesis of critical amino acids, causing stunted growth or abnormal growth at the growing point. ALS herbicides include five chemistries, of which Pacifica and Broadway Star are used for grass-weed control.

The use of ACCase/ALS herbicide chemistries is determined by the specificity of the crop and the weed species involved. There are several chemical control options for wheat, but no herbicide options to effectively control sterile brome or black grass in barley, and virtually no control options for oats (Table 6).

Furthermore, where the limited herbicides belonging to the ACCase/ALS groups are used repeatedly (and at lower than recommended rates), these factors pose a very high risk for developing herbicide cross resistance.

25 Selection intensity refers to how many weeds are killed by the herbicide.

26 The transfer of genes from one plant of a species to another plant of the same species.

Table 6. ACCase/ALS herbicide mode of action for selective control of critical grass weeds in cereals and non-cereal break crops (Product label claims)

Herbicide MOA	Trade name (examples)	Active	Weed susceptibility				Crop
			Wild oats	Sterile brome	Italian ryegrass	Black-grass	
ACCase	Axial	Pinoxaden	x		x		Wheat & Barley
	Falcon	Propaquizafop	x	x	x	x	Oilseed rape & beans
	Stratos Ultra	Cycloxydim	x	x	x	x	Oilseed rape & beans
	Centurion Max	Clethodim				x	Winter oilseed rape
ALS	Pacifica Plus	Mesosulfuron + iodosulfuron	x	x	x	x	Winter wheat
	Monolith	Mesosulfuron +propoxycarbazone	x	x	x	x	Winter wheat
	Broadway Star	Pyroxsulam	x	x	x		Winter wheat

Resistance mechanisms

The primary mechanism of ACCase/ALS resistance in grass weeds is either:

1. Target-site resistance (TSR) is where a plant changes the structure of its herbicide-binding site due to mutation(s), which blocks herbicide activity.
2. Non-target-site resistance (NTSR) is where plants can degrade herbicides rapidly before reaching the binding site.

TSR is specific to Mode Of Action (MOA), whereas resistance developed through NTSR mechanisms can affect multiple herbicide chemistries. Herbicide cross-resistance to the same (ACCase) or different MOA (ACCase and ALS) via either TSR or NTSR or sometimes both can occur within a single field population.

Symptoms of herbicide resistance

Herbicide resistance may go unnoticed initially due to low plant numbers that are resistant, and or symptoms may initially look like weed escapes from spraying or small irregular weed patches. However, herbicide-resistant plants can quickly become dominant, primarily where the same herbicides are used repeatedly. Visual symptoms of suspected resistance post herbicide application are shown in Figure 32 and include:

1. A mix of healthy and dead plants of the same species
2. Inadequate control of one species alongside other susceptible species well-controlled

It is essential to conduct resistance testing rather than relying on your own judgment and field observations. If the weed population resists one herbicide, it does not mean it is resistant to another herbicide within the same Group.

Glasshouse testing will confirm herbicide weed resistance and the herbicide's MOA. Predicting cross-resistance patterns is difficult in the field and creates uncertainty about herbicide use.

Figure 32. *Resistant annual meadow-grass plants (green) alongside herbicide controlled (yellow) and poorly controlled (green/yellow) in wheat*

Herbicide resistance testing

Prevention is better than cure is the best way to describe the approach to stop the development of grass weed herbicide resistance in arable crops. A critical prevention step in addressing the herbicide resistance threat is resistance testing. It will:

1. Confirm whether surviving weed populations are resistant or poorly controlled from sub-optimal herbicide application rates, poor spray coverage, application timings, weather, etc.
2. Determine what herbicides are effective against the weeds present in your crop.
3. Suggest integrated methods to eliminate or control resistant populations.
4. Allow mapping of resistance evolution and monitoring of the impact of resistant management.

The project conducted controlled glasshouse screens using ACCase (e.g. Axial or Falcon) or ALS (e.g. Pacifica Plus or Broadway Star) glyphosate herbicides and pre-emergence herbicides (e.g. pendimethalin) and used target-site resistance analysis where possible.

Timeline for resistance testing:

- Seed cleaning, sorting individual population samples and germination testing (7 days)
- Seed dormancy breaking treatments (requires 6-7 weeks, especially for black-grass)
- Initial screening with a single rate (i.e. field label rate). Plants will be sprayed at 2-3 (black-grass, bromes, Italian ryegrass) or 3-4 (spring wild oats) leaf stages. Visual assessment for survival conducted 28 or 35 days (bromes) after spraying. (8 weeks)
    - At this point, individual sensitivity results will be communicated to farmers who submitted seed samples, with information concerning less and highly effective herbicide options.
- Detailed dose-response analysis will be conducted on populations that are least sensitive to full label rate of ACCase/ ALS herbicides, with dose rates from 0.25 to 8 times the full label rate to assess resistance levels. (8 weeks)
- In parallel, DNA and PCR techniques will be deployed to identify the target-site mutation(s) that contribute to resistance.

We conduct glasshouse screening for broadleaf weeds using ALS (e.g. Ally Max, Boxer, Zypar, etc.) and synthetic auxin (e.g. 2,4 D) herbicides.

Quality and quantity of seeds required for accurate resistance testing

- Seed samples must be harvested when at the ripe stage
    - For smaller seeds (e.g. Italian ryegrass, lesser canary grass, black-grass) two cupful of seed is required.
    - For larger seeds (e.g. Wild oats, sterile brome) a pint glass of seed is required.
- Ensure samples are dry and stored in a cool dry place.
- Do not mix seeds from other fields or species.

Seed submission form for resistance testing:
https://www.teagasc.ie/media/website/crops/crops/Grass-Weed-Seed-Collection-Form-2022-pdf.pdf

How to collect seeds for resistance testing
https://youtu.be/ckfugVvWeWc

Typically testing will not begin until 4-7 weeks after seeds arrive at the laboratory because most grass weeds have a dormancy period. Different test types are used to detect resistance in the population.

The most common type is glasshouse seed testing. Different post-emergence herbicides (Table 7) are tested on the young plants (at 2-3 leaf stage for grass weeds or 4-6 leaf stage for broad-leaved weeds) grown from the weed seed samples and compared with known-sensitive or resistant populations. Visual assessments for plant survival are conducted 28-35 days post-spraying.

For pre-emergence herbicides, treatments are applied on unchitted or chitted seeds immediately after sowing. Detailed dose-response and molecular assays are conducted on those showing less sensitivity or resistance.

Lab petri dish seed assays are also conducted. The seeds are grown in herbicide solutions, and seedling growth will be evaluated after 14 days. For example, seedling growth in pendimethalin (pre-emergence) herbicide solutions is tested. Pendimethalin resistance is used as a proxy for NTSR in grass weeds. This quick test is not suited for all weed/herbicide types.

Table 7. Herbicides used in the glasshouse screens

Weed	Herbicides tested
Blackgrass	Falcon, Stratos, Centurion, Pacifica, Glyphosate
Italian ryegrass	Axial, Falcon, Stratos, Centurion, Pacifica or Monolith, Broadway, Glyphosate
Wild oats	Axial, Falcon, Stratos, Pacifica or Monolith, Broadway
Bromes	Falcon, Stratos, Pacifica, Broadway. Glyphosate
Canary grass	Axial, Falcon, Stratos, Pacifica or Monolith, Broadway, Glyphosate
Meadow grass	Pacifica, Broadway, Centurion, Glyphosate
Rat’s tail fescue	Pacifica, Broadway, Centurion, Glyphosate
Scutch	Glyphosate, Falcon, Stratos

Herbicide efficacy research and weed resistance

The ECT project addressed recent reports of poor grass weed control. It also monitored and mapped herbicide-resistant weeds.

Below is a pictorial presentation of glasshouse screens conducted on difficult-to-control grass weeds collected from several problem fields nationwide since 2019.

- Initial screening with a single rate (i.e. field label rate). Plants will be sprayed at 2-3 (black-grass, bromes, Italian ryegrass) or 3-4 (spring wild oats) leaf stages. Visual assessment for survival was conducted 28 or 35 days (bromes) after spraying.
    - At this point, individual sensitivity results will be communicated to farmers who submitted seed samples, with information concerning less and highly effective herbicide options.
- Detailed dose-response analysis was conducted on populations that were sensitive to full label rate of ACCase/ALS herbicides, with dose rates from 0.25 to 8 times the full label rate to assess resistance levels.

Blackgrass

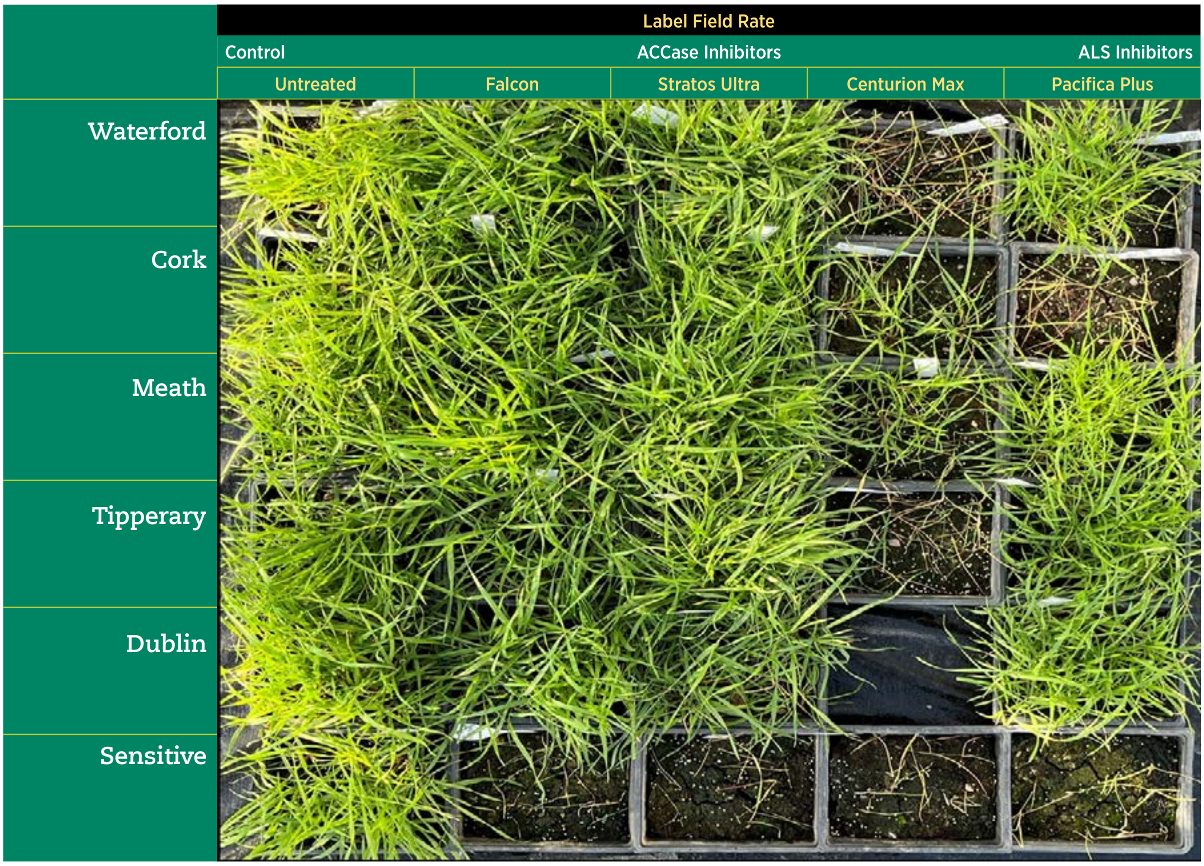


Figure 33. Symptoms of sensitive and resistant blackgrass populations 28 days post-treatment with ACCase/ALS herbicides applied at recommended field rate.

Except for the Cork population, which developed resistance to all herbicides from the ACCase group, the remaining four populations (Waterford, Meath, Tipperary and Dublin) exhibited multiple resistance to both ACCase and ALS groups.

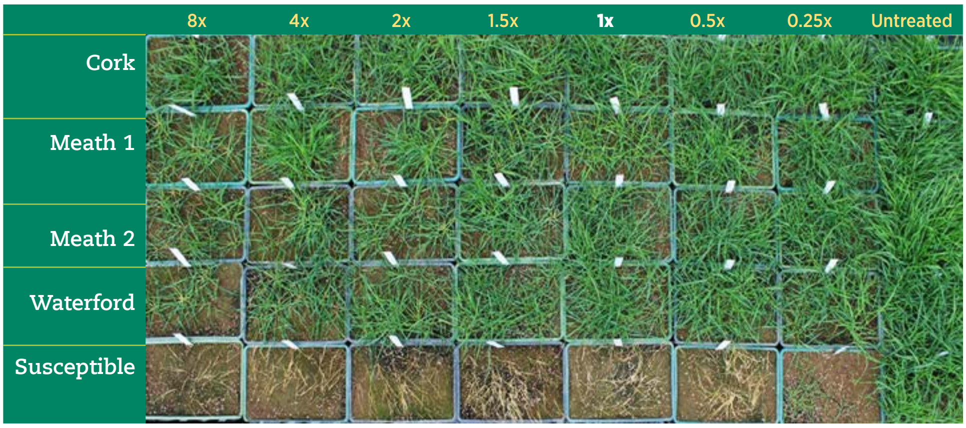


Figure 34. *Symptoms of susceptible and selected resistant blackgrass populations 28 days post-treatment with ACCase-Stratos Ultra at dose rates ranging from 0.25 to 8 times the full recommended rates (2 L/ha).*

Stratos Ultra was ineffective in all four resistant populations (Cork, Meath-1, Meath-2, and Waterford) (Fig 34).

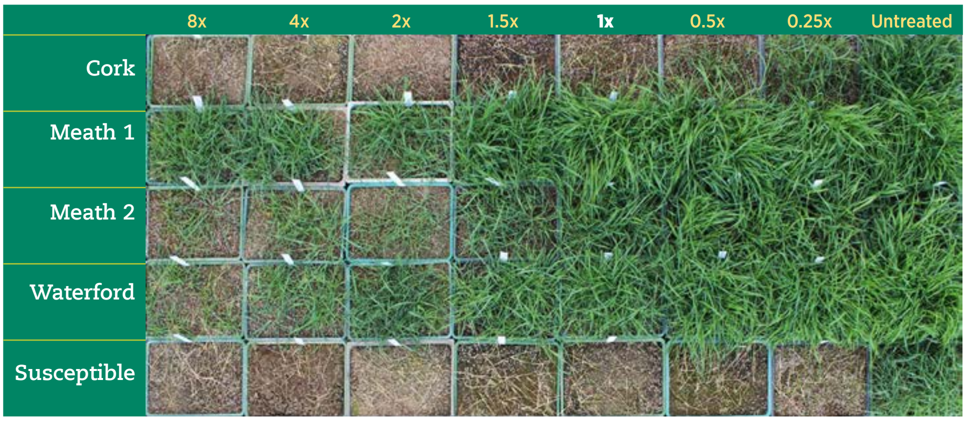


Figure 35. *Symptoms of susceptible and selected resistant blackgrass populations 28 days post-treatment of ALS-Pacifica Plus at dose rates ranging from 0.25 to 8 times the full recommended rates (500 g/ha).*

Pacifica Plus was virtually ineffective in three (Meath-1, Meath-2 and Waterford) of the blackgrass populations (Fig 35).

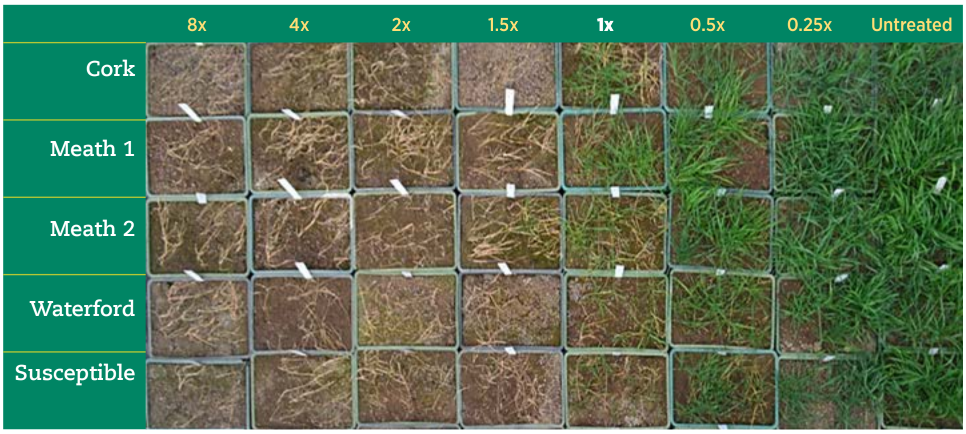


Figure 36. *Symptoms of susceptible and selected resistant blackgrass populations 28 days post-treatment with glyphosate application at dose rates ranging from 0.25 to 8 times the recommended rates (1.5 L/ha product of 360 g/L glyphosate).*

One and a half times or above the recommended field rate of glyphosate was required to kill 99% of the treated plants (sensitive or either ACCase or ALS-resistant or both) (Fig 36).

Italian ryegrass

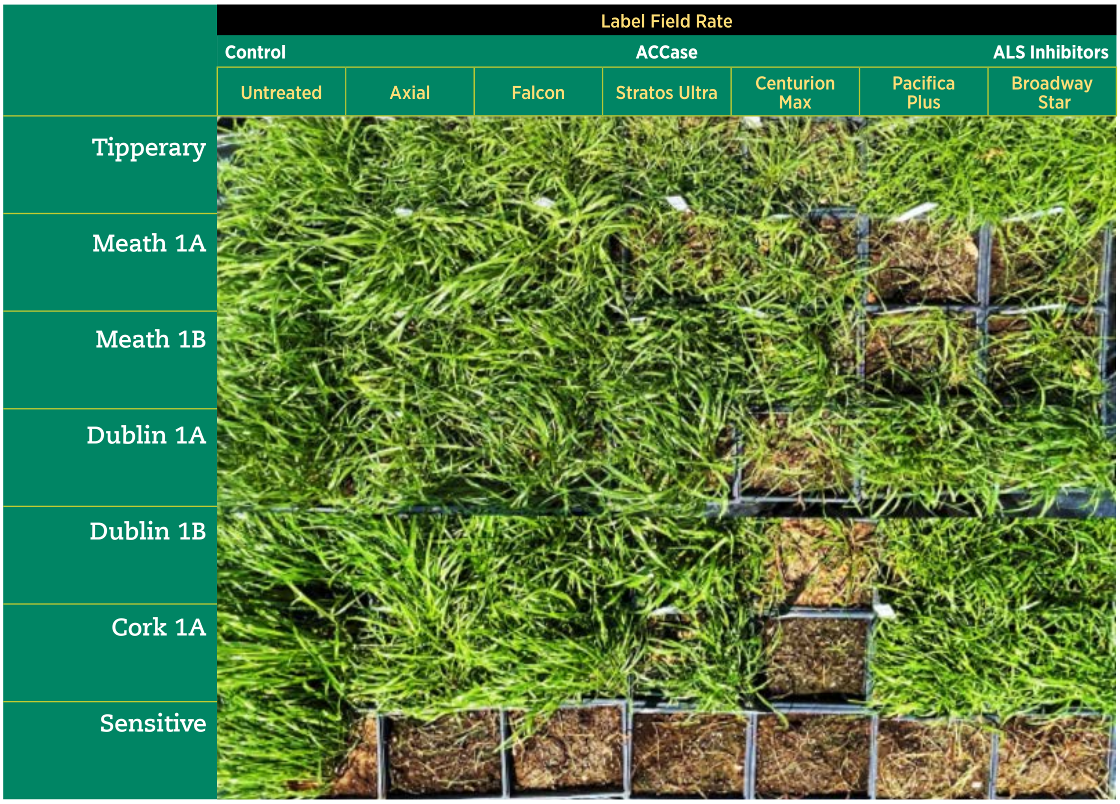


Figure 37. Symptoms of sensitive and resistant populations of Italian ryegrass 28 days post-treatment of ACCase/ALS herbicides applied at the recommended field rate.

All populations (from Tipperary, Meath, Dublin and Cork) exhibited multiple resistance to both ACCase and ALS groups (Fig 37).

Figure 38. Symptoms of sensitive and selected resistant populations of Italian ryegrass 28 days post-treatment of ALS-Broadway Star at dose rates ranging from 0.25 to 8 times the recommended rates (265 g /ha).

Broadway Star was ineffective in three populations (Dublin, Tipperary, and Wexford). At the same time, twice the recommended field rate (well above the legal limit for farmer use) was required to control Meath populations effectively (Fig 38).

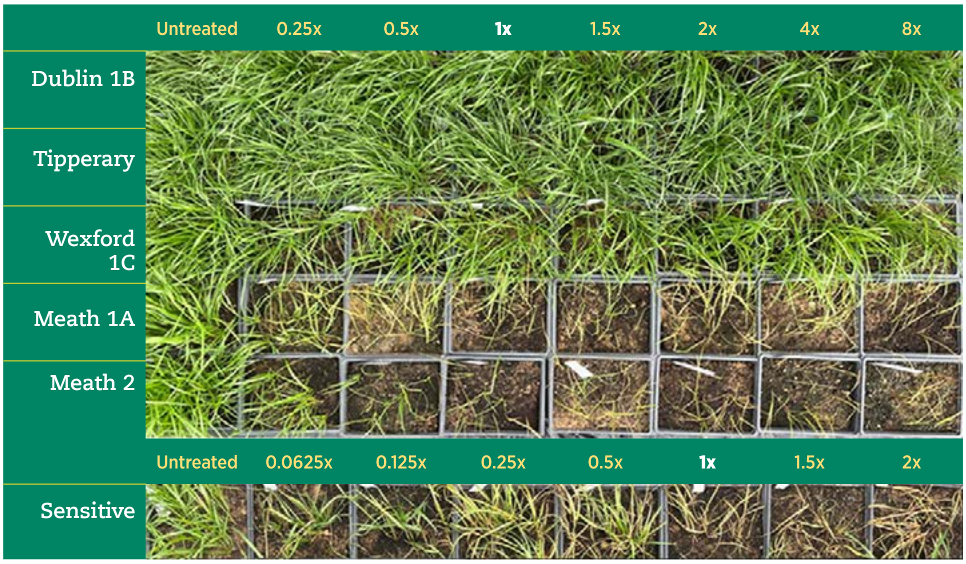


Figure 39. *Symptoms of sensitive and selected resistant populations of Italian ryegrass 28 days post-treatment of ALS-Pacifica Plus at dose rates ranging from 0.25 to 8 times the recommended rates (500 g /ha).*

Pacifica Plus was ineffective in three populations (Dublin, Tipperary, and Wexford). At the same time, 1.5 times the recommended field rate (which is well above the legal limit for farmer use) was required to achieve total control of Meath populations.

Wild oats

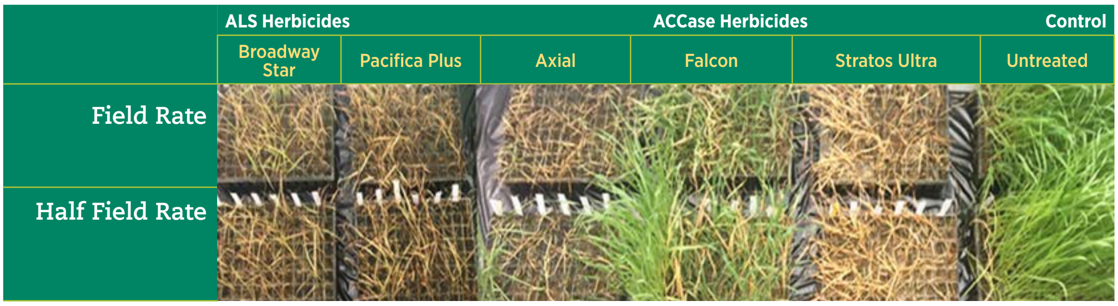


Figure 40. *Control levels of populations of wild oats 28 days post-treatment of ACCase/ALS herbicides applied at the full and half recommended field rates.*

Plants were sprayed at the 3-4 leaf stage. Individual wild oat plants within a population survived Falcon (sprayed at half and full rates) and Axial (half rate only). ACCase-Stratos Ultra and both the ALS herbicides were found to be very effective (Fig 40).

Lesser canary grass

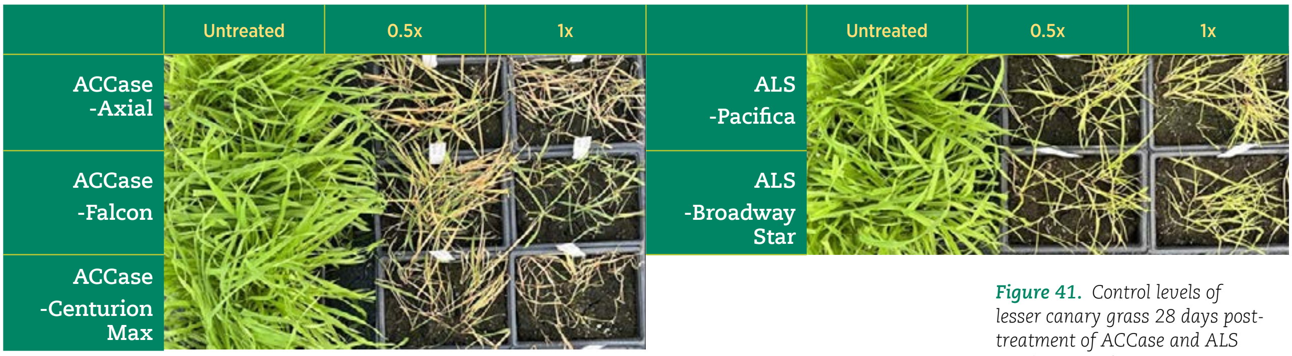


Figure 41. Control levels of lesser canary grass 28 days post-treatment of ACCase and ALS applied at half and recommended rates.

The weed is not listed on ACCase/ALS chemical labels. Effective control was achieved with all herbicides when applied at the recommended rate only (Fig 41).

Annual meadow grass

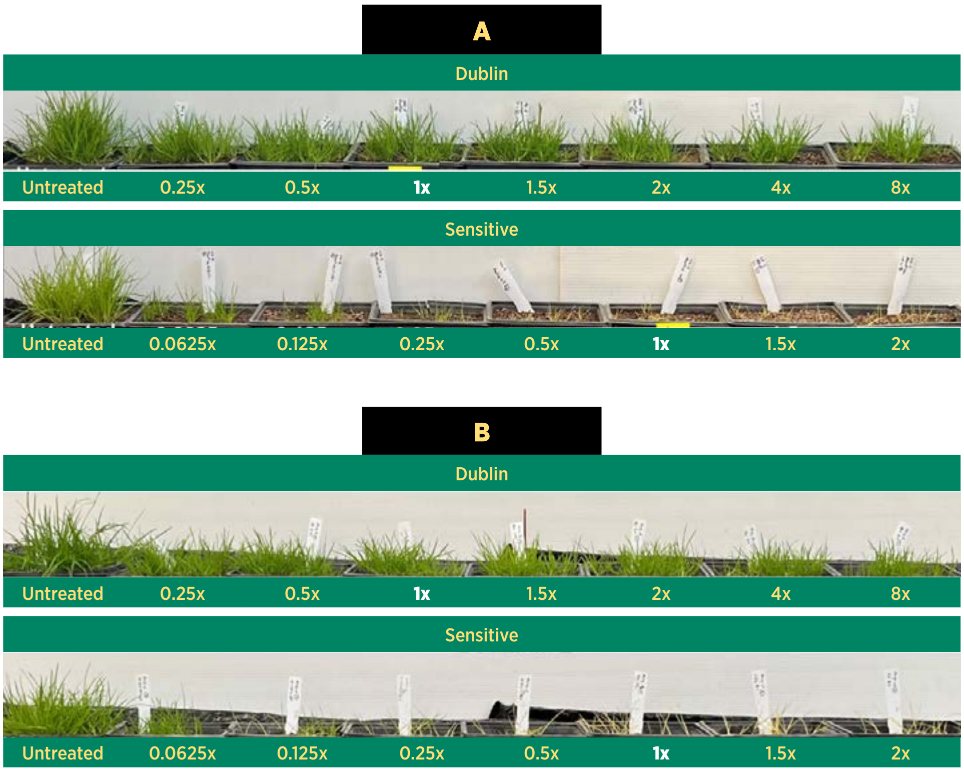


Figure 42. Symptoms of sensitive and resistant populations of annual meadow grass 30 days post-treatment with a range of ± recommended field rates of ALS herbicides Pacifica Plus (A) and Broadway Star (B). Plants were sprayed at the 2-3 leaf stage. Both ALS herbicides were virtually ineffective

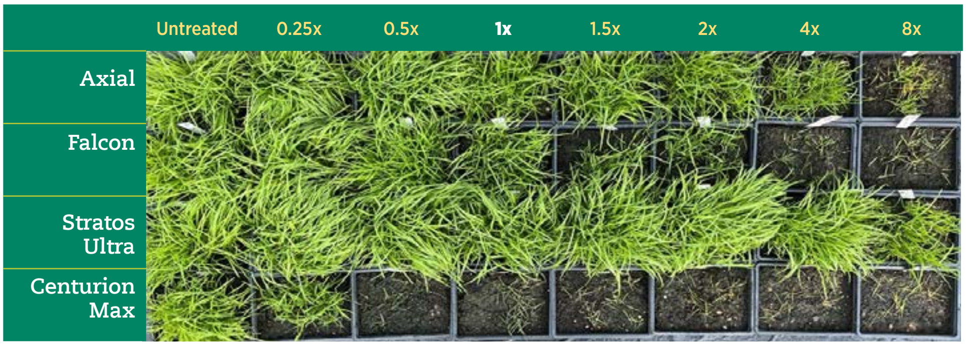


Figure 43. Symptoms of annual meadow grass 30 days post-treatment of ACCase (Axial, Falcon, Stratos Ultra, Centurion Max) herbicides at doses ranging from 0.25 to 8 times the recommended rates. Plants were sprayed at the 2-3 leaf stage.

Annual meadow grass showing natural tolerance to Axial and Falcon (Fig 43). Despite this natural trait, Centurion Max still provides adequate control. Also shown is the control using glyphosate at dose rates between 0.15 and two times the recommended rate.

Bromes

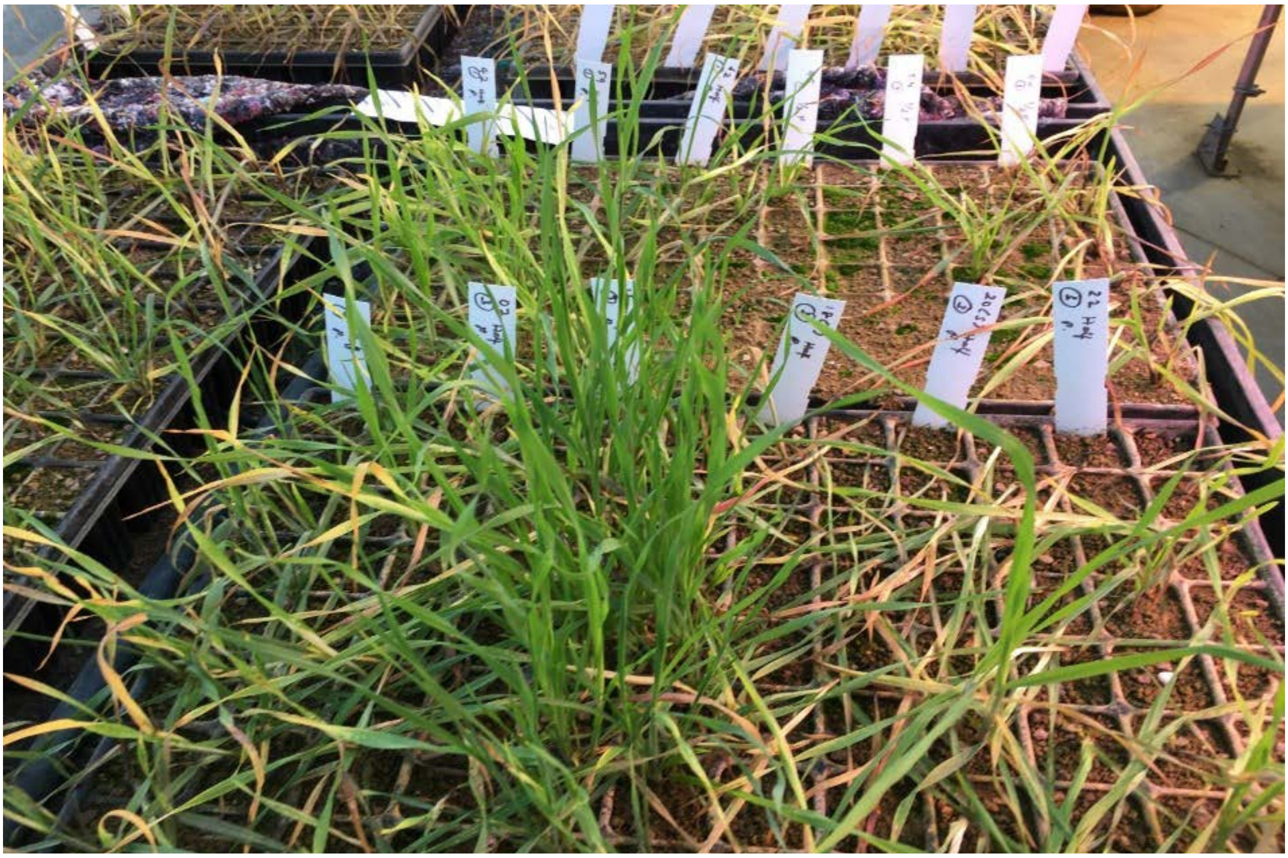


Figure 44. Brome individuals within a population surviving after 35 days of ALS-Pacifica Plus treatment at half rate (250 g/ha). Plants were sprayed at the 2-3 leaf stage

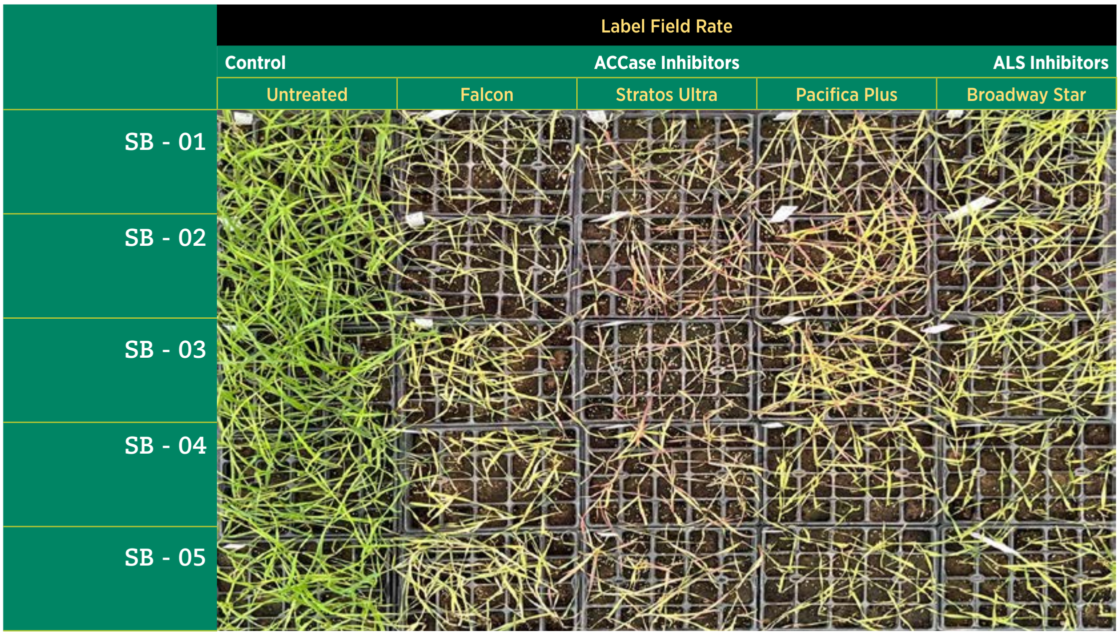


Figure 45. *Control levels of brome populations after 35 days of ACCase and ALS herbicide treatments applied at the recommended rates*

All herbicides were highly effective on all brome types, including less-sensitive ones, when used at recommended rates and at the correct growth stage (2-3 leaves) (Fig 45).

Conclusions of the herbicide testing

1. The project confirmed resistance in blackgrass, Italian ryegrass, wild oats and annual meadow-grass
2. There is widespread tolerance to ALS-Pacifica among brome populations, possibly due to repetitive use of reduced field rates.
3. Resistance testing results have helped farmers plan/deploy integrated weed management (IWM) and resistance management strategies (including alternative chemistry) to eliminate or contain further spread and development of resistance.
4. Glasshouse screening has helped to establish baseline sensitivity of weed populations from which future changes can be monitored.
5. Free resistance testing service via., ECT project has significantly increased awareness of the grass weed challenge across the whole tillage sector
6. Twenty of the 123 wild oat populations collected in Wexford, Cork, Kilkenny, Tipperary and Kildare counties were resistant to at least one ACCase (Axial, Falcon or Stratos Ultra) herbicide (Figure 43A). The primary mechanism of ACCase resistance is TSR (mutant ACCase Ile-1781 or Asp-2078), with NTSR being partial or at an early development stage.
7. Six of the 14 Italian ryegrass populations collected in Cork, Meath, Tipperary, Kilkenny and Kildare were resistant to either ACCase (Axial, Falcon or Stratos Ultra) or ALS (Pacifica or Broadway Star) herbicides or both (Figure 43B). ALS Pro-197 mutation and ACCase NTSR predominates.
8. Thirteen of the 25 blackgrass populations collected in Meath, Cork, Waterford, Wexford and Kildare were resistant to either ACCase (Falcon or Stratos Ultra) or ALS (Pacifica) herbicides or both (Figure 43C). ACCase Ile-1781 or ALS Pro-197 mutations were frequently associated with this resistance, with ACCase/ALS NTSR documented in a few populations.
9. No full herbicide-resistant bromes were documented from>120 brome populations (all types) collected in the southeast. However, there is a high likelihood of tolerance or creeping resistance to either ALS-Pacifica Plus or ACCase-Stratos Ultra via or both. NTSR may be widespread, which may result from the frequent use of reduced herbicide field application rates.
10. Three annual meadow grass samples collected in Dublin and Wexford were confirmed resistant to ALS (Pacifica and Broadway Star) herbicides. The primary mechanism of ALS resistance is TSR (mutant Trp-574).

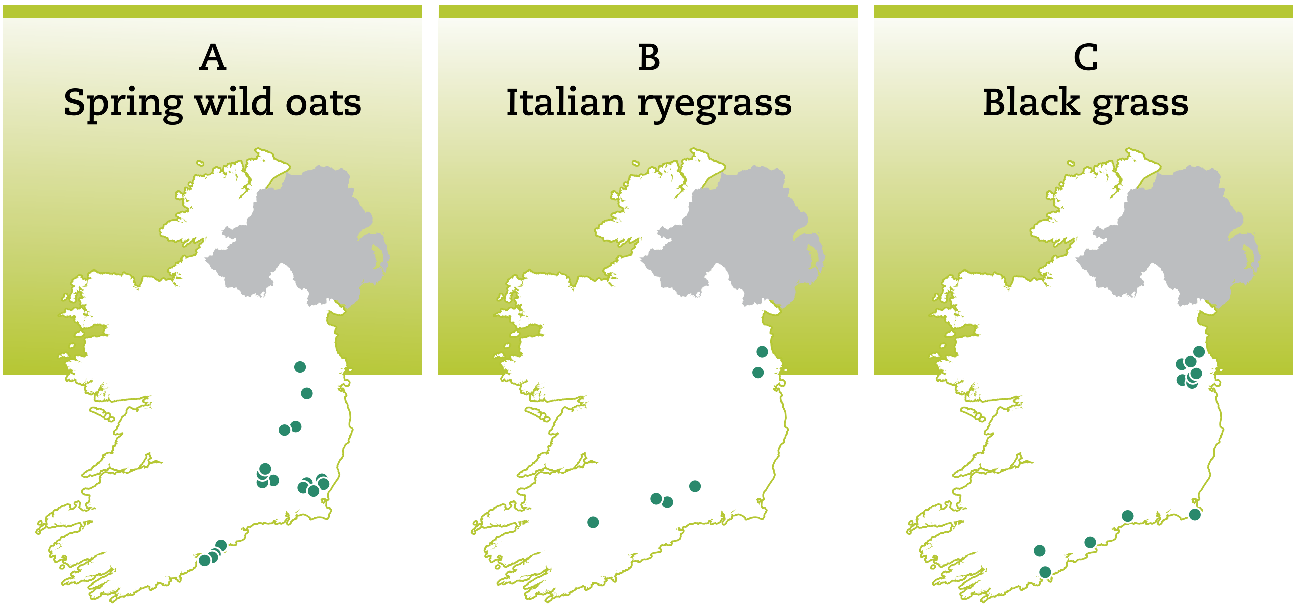


Figure 46. *Maps showing the known prevalence of herbicide-resistant grass weeds.(A, B and C)*

Herbicide resistance management strategies

1. Keep accurate field-by-field records of weed populations and herbicide applications.
2. Use glyphosate before crop sowing, followed by residual herbicides (e.g. pendimethalin, flufenacet, prosulfocarb, etc.) to reduce the target weed population.
3. Use the recommended field rates to ensure maximum efficacy.
4. Always apply ACCase/ALS herbicides on small and actively growing weeds.
5. Avoid using ACCase/ALS herbicides as the only control option
6. If resistance is suspected (especially in fields with a long history of continuous herbicide use), do not use the same herbicide or herbicide with the same MOA.
7. Conduct resistance testing to establish i) the sensitivity status of your weed population and ii) the effective available control options.
8. Ensure surviving plants do not set and shed viable seeds to the soil seed bank using alternative herbicides, spot spraying or hand rogueing.
9. Always use chemical control jointly with cultural/non-chemical control options (e.g., crop rotation, stale seedbed technique, manipulating sowing time, etc.) and on-farm biosecurity measures (e.g., certified seed, machinery hygiene, etc.).

Effective herbicide options are available for controlling resistant or suspected less-sensitive populations (Table 8 & Table 9).

Table 8. Based on sensitivity testing, effective herbicide options are available for controlling resistant or suspected less-sensitive populations

	ACCase herbicides at the recommended rate				ALS herbicides at the recommended rate		Glyphosate	Resistance management tools
	Axial	Falcon	Stratos Ultra	Centurion Max	Pacifica	Broadway Star		
Wild oats	R	R	R	-	S	S	S @ 1.5 l/ha	Glyphosate + ALS
Bromes (all types)	-	S	RS	-	R/RS/S	S	S @ 1.5 l/ha	Glyphosate + Pre-emergent + Falcon/ Broadway
Blackgrass	-	R	R	R	R	-	S @ 3.0 l/ha	Glyphosate + Pre-emergent
Italian ryegrass	R	R	R	R	R	R	S @ 3.0 l/ha	Glyphosate + Pre-emergent
**Annual meadow grass	NT	NT	NT	S	R	R/S	S @ 3.0 l/ha	Glyphosate + Pre-emergent + Centurion
**Rats tail fescue	NT	NT	NT	R/RS	S	S	S @ 3.0 l/ha	Glyphosate + Pre-emergent + Centurion or ALS
*Lesser canary grass	S	S	S	S	S	S	S @ 1.5 l/ha	Glyphosate + Pre-emergent + ACCase/ALS

Grass-weed populations were rated as R-resistant, RS-reduced sensitivity, and S-susceptible.

*In most cases, the use of ACCase/ALS herbicides is not listed on the product label;
**Annual meadow grass and rat's tail fescue show natural tolerance (NT) to most ACCase herbicides due to inherited ACCase TSR.

Table 9. Resistance status of tested grass weeds to main herbicide groups

Grass weed	ACCase herbicides at full rate			ALS herbicides at full rate		Resistance management tools
	Axial	Falcon	Stratos Ultra	Pacifica	Broadway Star	
Wild oats	R	R	R	S	S	Glyphosate + ALS
Bromes	-	S	RS	RS	S	Glyphosate + Pre-emergent + Falcon/ Broadway
Blackgrass	-	R	R	R	-	Glyphosate + Pre-emergent + Centurion Max
Italian ryegrass	R	R	S	R	R	Glyphosate + Pre-emergent + Stratos or Centurion

How to minimise/stop the spread of herbicide-resistance risks:
Herbicide resistance is an irreversible process; however, you can slow its development by adopting good agricultural practices such as:

- Practicing good rotation (spring and autumn-sown crops; cereal and non-cereal break crops).
- Using as many cultural and non-chemical tactics (e.g. delayed sowing, higher than the normal seed rates, stale seedbed technique,etc.).
- Including low-risk pre-emergence residual herbicides.
- Not using ACCase/ALS herbicides as a sole weed control method in consecutive crops.
    - Always use recommended label field rates of ACCase/ALS herbicides
    - Always spray on small, actively growing weeds
    - Correct conditions for spraying (not too cold or not too hot for herbicides to work)
- Using low-risk propyzamide (Kerb) followed by ACCase-centurion max (clethodim) where possible to reduce population size in break crops.
- Walk the crops before and after herbicide application to ensure herbicide performance.
- Practising machine hygiene before coming into fields and before moving field-to-field.
- Conducting resistance testing once every three years for certain grass weeds
    - A resistance test is 'essential' if your field has black-grass and Italian ryegrass species populations. Our study has shown that resistance can develop in these two species even at a low population levels.

Importance of resistance testing:
The resistance profile of your weed population across the entire spectrum of herbicide options and the underlying mechanisms, whether NTSR, TSR, or both contributing, can only be determined by resistance testing (glasshouse and lab-based).

- It is important to note that because your weed population is resistant to an herbicide, it does not necessarily mean that it is resistant to all other herbicides from the same group (ACCase or ALS).

As a farmer you want to know.

- What herbicide options are still available, and how this will influence your crop rotation
- How to develop tailor-made resistance management and IWM strategies with judicious use of effective herbicides for your situation
- Howe to prevent the weed population from developing complete resistance
- How to avoid the spread of resistant weeds from field to field and
- Saving money and herbicide costs

Cover Crops

Cover crops (also known as catch crops) are grown on tillage farms for various reasons including nutrient capture, improving water quality & soil structure, prevention of soil erosion or as a source of livestock feeding over winter. They also contribute to increasing soil organic matter and soil carbon capture helping to reduce the carbon footprint on farm. Cover crop may also contribute to biological and weed control on farm.
As part of the five year EIP-funded grass weed project, the ECT Project team investigated if cover crops help to control grass weed and how effective and reliable are they in an overall Integrated Weed Management (IWM) plan on the farm.
The project team worked with Focus Farmers to plant and manage various cover crops. This is a report on the findings of field based evaluations under different establishment systems and management practices. Farmer interaction and practicalities of implementation were also part of the project observation mechanism.

ECT Project, WP 4 – Cover crops as weed control measures – field based evaluations

The participant farmer planted cover crops in strips in the Focused Validation Area (FVA – the field area used for all validation of ECT Project work for the duration of the project) as per Figure 47.

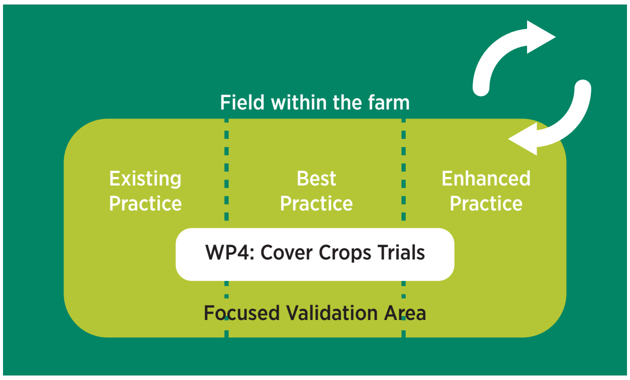


Figure 47. Cover crop trials layout within the Focused Validation Area

The project objective for cover crops were as follows;

- Up to five Focus Farms to plant cover crops each year where conditions allowed
- Cover crops to be planted in years one to four of the five year project
- Cover crops to be selected based on cover crop suitability within the farm crop rotation
- Four out of five possible cover crop options (mustard, oats, phacelia, peas, farmers own mix) would be evaluated
    - » Single species cover crops would allow comparisons between species for weed control and one farmer mixed species to compare with single species mix
- Grass weed counts to be taken within the cover crop and the following crop

Method

In all there were 10 cover crops sown over 4 years in all of the establishment systems. For these cover crops the main grass weed target was Sterile brome (8 sites), Wild Oats (1 site) and blackgrass (1 site). There were a number of years and circumstances where the farmers decided against planting cover crops. These included:

- All farmers reported that planning to incorporate cover crops into the farm rotation is difficult, especially when predominantly (or only) growing winter crops – for grass weed control and some farmers felt the following crop would need to be a spring crop for effective control
- Some farmers reported their preference to carrying out multiple stale seedbeds for grass weed control where very high seedbanks of grass weeds are present, due to the ability to flush out more weed seed in the fallow period compared to a single cover crop
- Many cover crop species mixes contain brassicas, which are not suitable on farms where oilseed rape is grown as the primary break crop
- Cost of establishment of cover crop is high compared to natural regeneration and is only justified if spring cropping is intended

Method

The collection of the data was carried out on each site once the cover crop was mature and the weeds grass weeds were present.

The grass weeds present were assessed but there was no assessment of the potential weeds which were supressed by allelopathy, crop competition, etc. This would require a highly detailed and intensive research methodology to determine the percentage of weed seeds supressed, germinated, out competed at an early stage, etc. More research is needed in this area. The weeds were recorded on merginmaps v2.1.1 weed recording mobile app and the results transferred into Individual counts from merginmaps app converted to Kore software grass weed score map, see Figure 48.

	Cover Crop	Grid Numbers	Sterile Brome
A	Phacelia	10, 26, 42, 57, 72, 87	141
B	Phacelia/Vetch/Tillage Radish	11, 27, 43, 58, 73, 88	45
C	Natural Regeneration	12, 28, 44, 59, 74, 89	6
D	Oats	13, 29, 45, 60, 75, 90	51

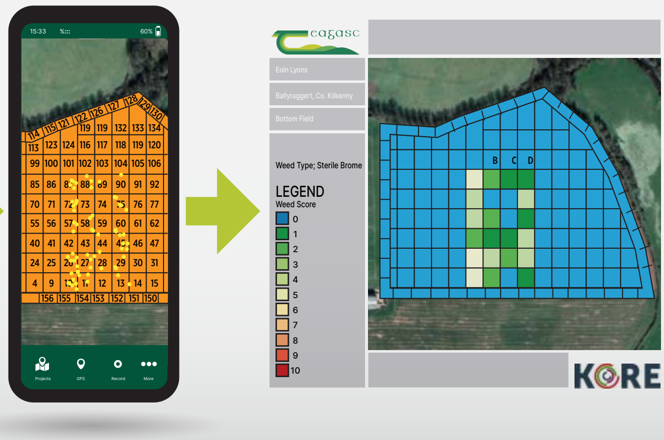


Figure 48. Collection process to count weeds in cover crops

Results

Sterile brome observations:

- Strong flushes of sterile brome were sufficient to smother the establishment of cover crop
- Some suppression of sterile brome by the cover crop was observed early on in autumn but in most cases the areas with high seed populations of sterile brome established and flourished by late winter
- Some cover crop mix types e.g fodder rape/stubble turnip brassicas sown early with a large biomass, helped to suppress sterile brome
- Its speculated the allopathy effect of oats or mustard may help suppression of sterile brome – however this need further research to give definitive results
- Natural regeneration had low emergence of sterile brome vs cover crop, due to the lack of soil disturbance as sterile brome needs soil cover to maximise germination.

Sterile Brome conclusions:

- Cover crop do not allow sufficient sterile brome suppression for the duration of an over-wintered cover crop to be effective
- Where a large seedbank is present it is more useful to flush out as many sterile brome as possible between commercial crops (multiple seedbeds).
- Cover crop mix type has a large bearing on the numbers of sterile brome emerging
    - » if flushing out a large seedbank, more open mixes e.g phacelia/vetch are best
    - » if trying to supress, use thicker cover crop mixes e.g fodder rape/stubble turnip brassicas or allelopathy effect – oats or mustard
- Multiple stale seedbeds plus glyphosate may offer far greater control than cover crops

Wild oats observations:

- No wild oats germinated in the cover crops or in the unsown cultivated strip (the wild oats were spring wild oats which germinate in the spring)
- Volunteer cereals were common in each treatment
- No clear evidence that cover crops will prevent wild oats germinating in the autumn as no wild oats were found anywhere in the FVA field over the autumn/winter period
- No difference between straights and mix species

Wild oat conclusion:

- Ineffective for the control of spring germinating wild oats
- Wild oats require a period of time post-harvest to break dormancy

Blackgrass observations:

- Low germination of blackgrass was observed in early autumn. The project could not determine the exact cause. Potentially due to the previous growing season inducing a stronger dormancy, allelopathy of the cover crop or poor autumn germination of blackgrass seed? The seed number/ m^2 and different species mix types would be required to assess this outcome (only white mustard was grown on the full FVA by the Focus Farmer in this case, so no comparisons were possible)
- Dampened germination of blackgrass in early autumn was followed by a later flush which emerged during a very mild winter 2021/2022 – Met Eireann December 2021 temperature was 1.5°C warmer than LTA/ Jan & Feb 2022 was 0.5°C warmer than LTA)
- The mustard grew vigorously and tall (mild winter), competing with the late germinating blackgrass, however plentiful numbers of small blackgrass were present when mustard was dying back

Blackgrass conclusion:

- The use of cover crops to control blackgrass is limited.
- The preferred option would be to carry out multiple stale seedbeds to flush out the blackgrass seedbank and not to rely on a single cultivation to create the cover crop

Overall Conclusions

- More research is needed in the area of suppression and allelopathy, with trials to observe the effect on the germination of a known quantity of grass weed seeds, and the length of time suppression will persist.
- If high grass weed seed numbers are known to be present in the soil, multiple stale seedbeds will be more effective than cover crop for grass weed control, due to the ability to flush out greater numbers from the seedbank over the fallow period
- No differences were observed between establishment method types from a cover crop grass weed control point of view

Farmer comments on the use of cover crops

- 'I am not in favour of cover cropping on my farm as I use a strip-till Claydon drill for my crop establishment system, and this drill works best in undisturbed soil'
- 'With my high grass weed seedbank, I would prefer to carry out multiple stale seedbed cultivations rather than sowing cover crops on the FVA, as this will germinate more seed for destruction and reduce the seedbank quicker'

An expanded report of cover crops is available upon request.

Project Outputs

The project team generated a diverse range of outputs, spanning from face-to-face workshops, educational events for students to online webinars, YouTube videos, written and social media content. Throughout the project, a significant portion of time and resources was allocated to outreach efforts, both in person and through various channels, aiming to reach the maximum number of farmers and industry personnel possible. Unfortunately, the plans for dissemination faced disruptions due to the Covid lockdowns in 2020 and 2021. As a result, many of the initially planned face-to-face meetings had to be either cancelled or transformed into webinars and other online forums.

Table 10. Events breakdown over the life of the project

Activity	Number of Events	Numbers attended
Discussion Group	7	117
Education	10	334
Industry Event	25	871
Local Event	29	1263
National Event	8	5160
Operational Group	7	90
Podcast	9	3750
Regional Event	31	1847
Training	19	540
Grand Total	**145**	**13972**

Table 11. Events breakdown by Year and Activity

Year and Activity	Number of Events	Numbers attended
2019	**33**	**4852**
Discussion Group	4	57
Education	2	60
Industry Event	1	75
Local Event	11	509
National Event	2	3450
Operational Group	2	31
Regional Event	5	420
Training	6	250
2020	**24**	**1956**
Discussion Group	2	45
Education	1	15
Industry Event	6	161
Local Event	4	185
National Event	1	400
Operational Group	2	20
Podcast	3	900
Regional Event	2	140
Training	3	90
2021	**11**	**1392**
Discussion Group	1	15
Industry Event	1	5
National Event	2	450
Operational Group	1	15
Podcast	1	350
Regional Event	5	557
2022	**46**	**2731**
Education	4	138
Industry Event	9	147
Local Event	7	304
National Event	1	200
Operational Group	2	24
Podcast	3	1300
Regional Event	13	476
Training	7	142
2023	**31**	**3041**
Education	3	121
Industry Event	8	483
Local Event	7	265
National Event	2	660
Podcast	2	1200
Regional Event	6	254
Training	3	58
Grand Total	**145**	**13,972**

Publications

The project diligently contributed to event support and promptly disseminated new information to the industry throughout its lifespan. The staff utilized conventional Teagasc media channels and actively published in national print media. Numerous scientific papers resulting from the research were published, and the findings were further shared through various conferences via papers and posters. Publications over the life of the project included the following:

Table 12. Publications over the life of the project

Type of publication	No. published
Conference	5
National Publication Online Agri-land	7
National Publication Print: Irish Farmers Journal	32
National Publication: Print Farming Independent	4
Press Release	1
Published Research Paper	4
Research Poster	3
Teagasc Todays Farm	5
Teagasc Annual Report	1
Teagasc Daily	5
Teagasc Daily online	4
Teagasc Newsletter	13
Teagasc Website update	4
Technical Note	5
Video	31
TResearch print	3
Grand Total	**127**

Table 13. Publications breakdown by year

Type of Publication	No. published
2019	**20**
Conference	1
National Publication Online Agri-land	2
National Publication Print: Irish Farmers Journal	5
National Publication: Print Farming Independent	4
Teagasc Todays Farm	2
Teagasc Newsletter	2
Technical Note	4
2020	**23**
Conference	1
National Publication Online Agri-land	1
National Publication Print: Irish Farmers Journal	3
Published Research Paper	1
Teagasc Todays Farm	2
Teagasc Daily online	2
Teagasc Newsletter	5
Teagasc Website update	4
Technical Note	1
TResearch print	1
Video	2
2021	**37**
Conference	1
National Publication Online Agri-land	4
National Publication Print: Irish Farmers Journal	15
Press Release	1
Published Research Paper	1
Teagasc Todays Farm	1
Teagasc Annual Report	1
Teagasc Daily online	2
Teagasc Newsletter	1
TResearch print	1
Video - completed	9
2022	**26**
Conference	1
National Publication Print: Irish Farmers Journal	9
Published Research Paper	1
Research Poster	3
Teagasc Daily	5
Teagasc Newsletter	2
TResearch print	1
Video - completed	4
2023	**22**
Conference	1

Type of Publication	No. published
Published Research Paper	1
Teagasc Newsletter	3
Video - completed	16
Teagasc Todays Farm	1
Grand Total	**128**

Closing evaluation

The ECT project has exceeded the delivery milestones for the project. The delivery of outputs such as events and publications is by any standard exceptional from such a short duration project.

End of project survey

The project convened its concluding conference in November 2023, where participants, both present in person and engaged online, were invited to provide feedback on the principal objectives of the project. This diverse group included individuals from the industry, agronomists, and farmers. The survey results underscored the project's significant contribution to the participants' understanding of grass weeds and conservation agriculture.

The survey employed the Net Promoter Score (NPS) as a metric to gauge participants' agreement with a specific statement. For example a question posed was, "How useful do you think the ECT project was in highlighting and educating the industry on grass weed issues?" Responses were collected on a scale from 0 to 10, with participants classified as Promoters (9-10), Passives (7-8), or Detractors (0-6). The NPS was calculated by subtracting the percentage of Detractors from the percentage of Promoters, resulting in a score ranging from -100 to +100. A positive score suggests a higher likelihood of participant recommendations, while a negative score indicates room for improvement.

The Net Promoter Score is always expressed as a numerical value between -100 and 100. A negative score occurs when there are more detractors than promoters, whereas a positive score indicates the opposite. Generally, an NPS of 30 or higher is considered excellent, while below 0 is regarded as poor.

The survey included participants from the conference, comprising a total of 127 individuals who attended either in person or virtually. The ensuing key findings underscore the diverse array of respondents from different sectors within the industry.

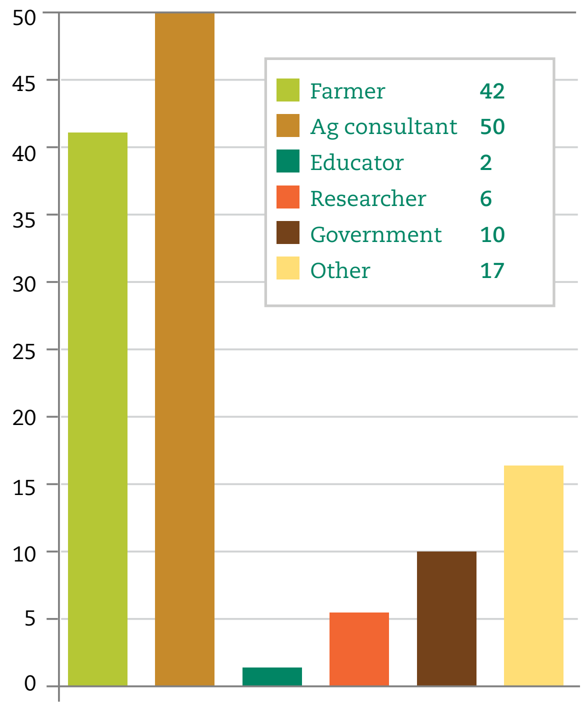


Figure 49: *Participants in the survey*

When asked "How useful do you think the ECT project was to highlight and educate the industry on grass weed issues?" the responses were overwhelming positive with a net promotor score of 63

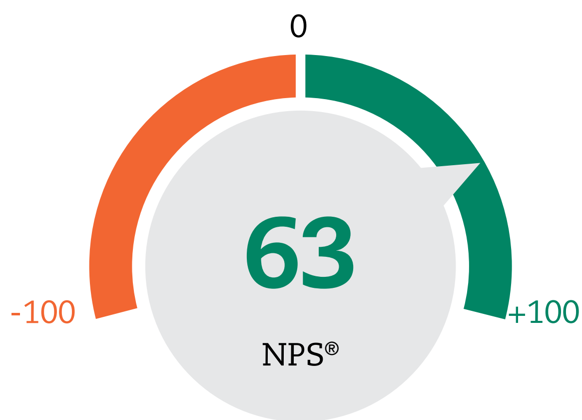


Figure 50: *Net promotor score results of how useful do you think the ECT project was.*

One of the primary goals of the ECT project was to facilitate the industry's comprehension of managing grass weeds in non-plough systems. With this objective in mind, we inquired of participants, "From the ECT project, do you now possess an improved understanding of non-plough-based systems and their interactions with grass weeds?" The outcome is affirmative, as the majority of respondents agreed with the statement, yielding a Net Promoter Score of 16.

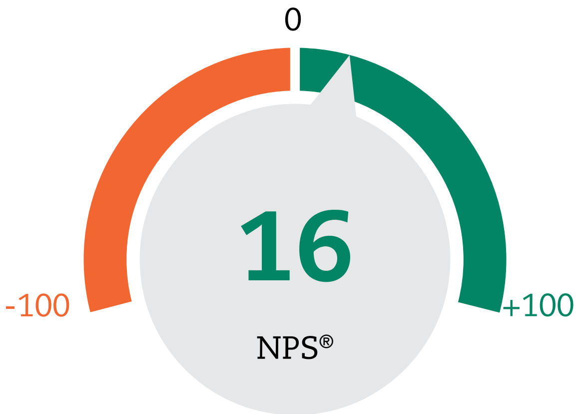


Figure 51. *Net promotor score results from question on the interaction of cultivation system and grass weeds*

Herbicide resistance was inadequately understood in terms of mechanisms and distribution within populations. One of the project objectives was to quantify this distribution and enhance the industry's comprehension of herbicide resistance. The survey included the question, " " From the ECT project, I now have a better understanding of the herbicide resistance risks for various grass weeds" The responses were overwhelmingly positive, resulting in a Net Promoter Score of 36, indicating a significantly improved understanding of the issue among respondents.

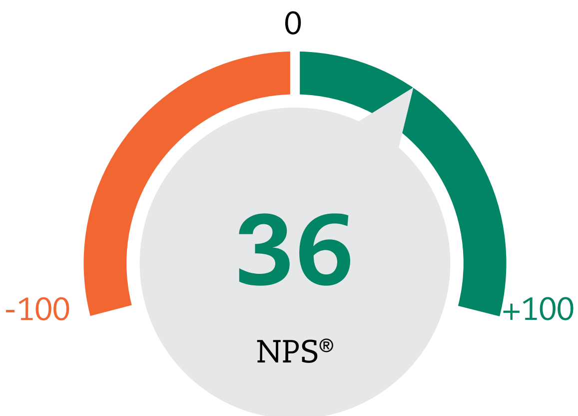


Figure 52. *Net promotor score results from question relating to understanding in herbicide resistance*

The ECT project aimed to develop tools for controlling grass weeds and ensure their accessibility to the industry. This encompassed a variety of resources such as cultural and chemical control tools, videos, guides, scorecards, as well as tools for grass weed identification and herbicide resistance testing. The survey presented participants with two questions: a) "The results from the ECT focus farmers have been very useful in helping me understand the range of tools needed for sustainable grass weed control," and b) "I am likely to use the tools (scorecards, weed identification videos) and materials (ID book, farmer case studies and videos, etc.) available from the ECT in my work over the coming years." The responses to both questions were highly positive, indicating that participants found the tools valuable for understanding and expressed a likelihood of utilising these resources in the future.

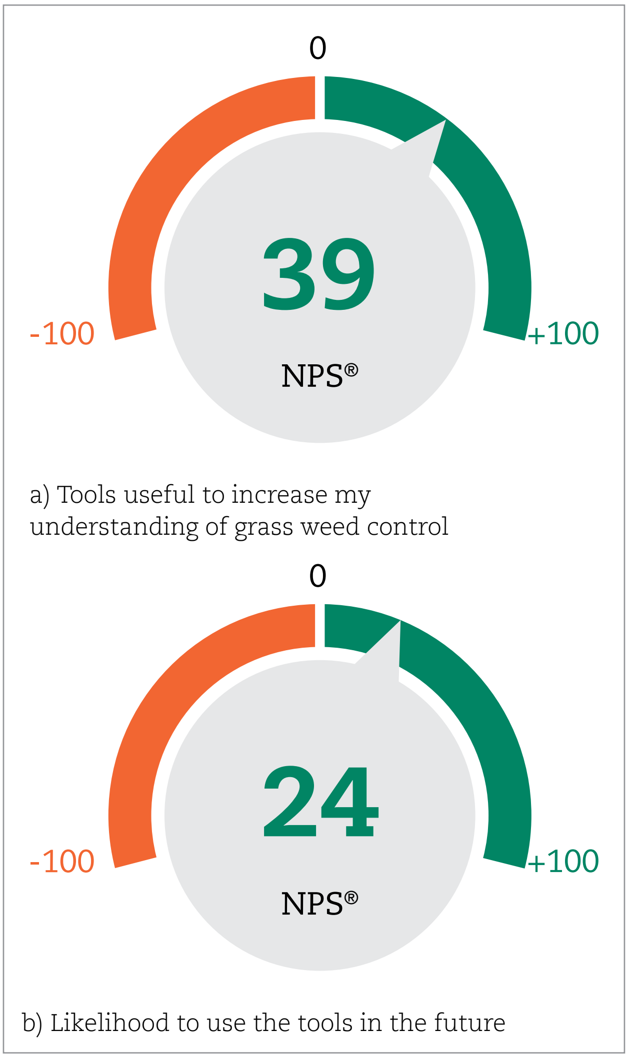


Figure 53. *Net Promotor Score results on how participants will utilise tools from the project*

The ECT Grass Weed Conference featured the presentation of data accumulated over the course of the past five years. A question was posed to participants: "The Grass Weed Conference delivered useful technical messages which I can use in my business in the coming months and years." The responses were highly positive, resulting in a Net Promoter Score of 45. This signifies that participants found significant value in the conference, and it reflects positively on the organisers, indicating that the content was well-tailored. The conference outputs can be accessed at https://www.teagasc.ie/crops/crops/grass-weeds/ect-project/ect-conference-proceedings/

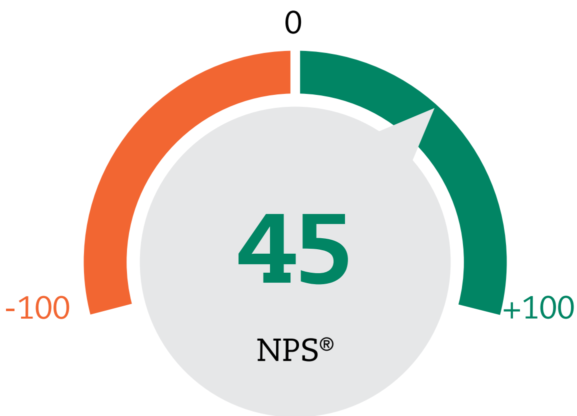


Figure 54. *Net promotor score results on how useful technical information is to put into practice*

Financial Report

1. Total Direct funding for the project was €999,909 with an additional €417,500 contributed to the project by Teagasc (€190,000) in support staff costs and industry (€227,500) as in-kind contributions (setting up and running experiments, attendance at events, farmer recruiting, weed collection, etc.).
2. Budget vs Actual Expenditure

Payment Category	Amount (€'s)	Percentage of Total Cost
Direct Farmer Payment	78,257.00	8%
Contract Staff	514,209.86	52%
Consumables	72,900.53	7%
Travel and subsistence	45,476.59	5%
Consultancy	17,098.40	2%
Other (inc. PR, Videos, printing, etc.)	255,934.40	26%
Total Admin & Implementation costs	983,876.78	100%
Total Expenditure	**983,876.78**	**100%**
Underspend	**16,032.22**	**of Allocated funding 1.63%**

The largest cost for the project was on contract staff to run the project. The project team of an advisor (4.5 years), researcher (4 year) and a technician (3.5 years) all contributed significantly to the project outcome.

The total expenditure for farmers was closely aligned with the planned budget. An additional €52,543 was made available to farmers, but not drawn down, to support extra efforts or corrective actions where high weed burdens were affecting yields—for example, cases where a significant weed infestation was reducing crop yield and incurring long-term control costs. This funding was redirected into knowledge transfer activities and educational materials

3. Project Allocation Underspend.
There was an underspend of €16,032.22 this was primarily due to project staff leaving before the end of the project.

Value for money

The ECT project has delivered significant value for the committed funds. As mentioned in this report, the project output includes the organisation of events (n=145) which attracting over 13,900 attendees. Additionally, there is noteworthy written output across traditional and social media, comprising 128 individual significant outputs, including three peer-reviewed papers.

Considering the outcomes from the grass weed survey, which involved a diverse cross-section of the industry, there is consensus that the ECT project successfully achieved its objectives. These include:

- The ECT project effectively highlighted and educated the industry on grass weed issues (Net Promotor Score NPS = 63, see the previous section).
- The project delivered useful technical messages applicable to businesses in the coming months and years (NPS = 45).
- The industry has gained a better understanding of non-plough-based systems and their interactions with grass weeds (NPS = 16).
- The project provided valuable insights into the range of tools required for sustainable grass weed control (NPS = 39).
- Improved understanding of herbicide resistance risks for various grass weeds (NPS = 36).
- Intent to use tools such as scorecards, weed identification videos, and materials (ID book, farmer case studies, and videos, etc.) from the ECT project in future work (NPS = 24).

The project underscored the significance of grass weed research and emphasised the need for a holistic approach, encompassing all aspects of Integrated Weed Management (IWM). The dedicated efforts of key researcher Vijaya Bhaskar and support staff highlighted the importance of this work to Teagasc and broader funding agencies. Consequently, Teagasc created a permanent staff position for a Weed Researcher, filled by Vijaya Bhaskar, after an absence of 18 years in the organisation and this is the only such researcher position in Ireland. This ensures the continuation of the ECT project's work well into the future.

The establishment of the weed research job/post allows for yearly monitoring of herbicide resistance for grass weed and broad-leaved weeds. This monitoring is crucial for effective weed control, especially considering the limited introduction of new herbicides to the market.

The commitment and contribution from Teagasc support staff were immense. None of the permanent Teagasc staff's time was billed to the project, including contributions from Project leader (Michael Hennessy), Tillage Specialists (Ciaran Collins, Shay Phelan, and Mark Plunkett), Tillage Advisors (8 across the country), Researchers (Dermot Forristal, Susanne Bart), technicians (Deirdre Doyle), and farm staff. At the project's outset, Teagasc agreed not to charge the usual overhead for this type of project (generally 30%+), covering support staff who are involved in admin, finances, human resources, ICT, etc. The project's completion would not have been possible without their invaluable input, and their efforts incurred no additional cost to the project's funding.

The industry contribution, which was unpaid, played a crucial role in conducting the Weed Screen trial (James Byrne, BAYER) and Corteva, ISTA, Base Ireland, and Claydon group members provided general advice to the project.

Lessons learned

During the operation of the project many lessons were learned which could be taken to other projects which are designed to operate in a similar way. The following are the main lessons:

Staffing

- As with all projects their operation is dependent on the hire of new staff. The start date of the project was determined by the signed agreements not the start date of key staff. The hire of staff proved difficult both from the administration burden both within Teagasc and also from the funder and also finding the correct staff for the positions advertised. This delayed the real work of the project and subsequently eroded the total time available with staff to complete the project.
- The project's short-term nature and consequent staff turnover posed significant challenges. Staff departures before project completion resulted in the loss of valuable training and knowledge, compromising data integrity and overall project cohesion.

Farmer participation

- A huge amount of credit should be given to the participating farmers for volunteering for the project and opening up their farm to regular visitors. However, disparities in commitment among farmers were reflected in on-farm results. While some farmers enthusiastically embraced project goals, others prioritised different considerations on their farms.
- Although the project had well-defined plans for each farmer, various factors such as weather, market conditions, physical constraints, and existing assumptions posed implementation challenges. Nonetheless, given the project's co-creation approach, these hurdles were deemed acceptable.
- The project ambition was to cost out the actions undertaken by the farmers and compare to standard prices. However, farmers' reluctance to disclose financial details, often due to the decentralised nature of their records, necessitates future projects to align ambitions with practical realities.

Research

- Establishing research on herbicide resistance in grass weeds was a considerable endeavour, starting from scratch and progressing slower than anticipated. The meticulous efforts of dedicated researcher Vijaya Bhaskar ensured adherence to international testing standards, facilitating the publication of research findings in peer-reviewed journals.
- Despite four years of intensive grass weed resistance testing yielding valuable insights for the Irish tillage industry, numerous unanswered questions necessitate further research.
- The project facilitated the re-establishment of a weed test centre within Teagasc, equipped with specialised expertise to address emerging issues in Ireland. Recognising the value of this work, Teagasc and the government instituted a permanent weed researcher position to tackle long-term challenges.

Knowledge Transfer from the project

- Despite challenges posed by national COVID lockdowns, the project strived to disseminate information effectively. Staff innovation and external resources ensured a continuous flow of information throughout this period.
- Utilising a diverse array of communication channels—from written media & social media, podcasts, seminars, webinars, and workshops—was pivotal in transmitting key project findings across the Irish industry.
- Leveraging the extensive knowledge of Teagasc experts in agronomy, advisory services, media, and research significantly bolstered the project's messaging success.
- Developing an online presence through the Teagasc corporate website proved invaluable in promoting the project nationally.
- There is need to continue to educate farmers and the industry on grass weed identification as this is difficult but essential to establish the long term control methods on farms.

Actions to Carry Forward

The project will leave a legacy of information for farmer, advisors, agronomists, policy makers and the wider industry. This includes technical guides, score cards, farmer case studies, videos and more.

There are many questions which were posed but not answered in this project. These will require further investigation involving research trials. These include:

- How long grass weed species persist in wet soils
- Predation of grass weed seeds in an Irish climate
- The growth habits of canary grass and rat's tail fescue in an Irish climate
- The speed of development of herbicide resistance in the main problematic grass weeds (blackgrass , Italian rye grass and wild oats)
- Has spring wild oats developed ALS resistance
- Can very low disturbance tillage techniques result in higher profitability and sustainability
- At what weed infestation levels would spring cropping be effective and how many years of practice would be needed before switching to winter rotations

- What is the required delay in drilling to overcome the main weed flush in our climate
- Weed introduction routes to farms
- Impact of herbicide resistance on crop yield
- Impact of pre-emergence residual herbicides on weed control in non-inversion tillage
- Impact of one year strategic tillage in a continuous non-inversion tillage system on weeds and soil health
- Are broadleaved weed ALS herbicides preselecting and speeding up the development of resistance in grass weeds to grass-weed herbicides
- Are soils healthier in low soil disturbance systems
- Effect of, and make up of, cover crops to influence allelopathy for weed suppression
- Effect of cover crops for suppression of grass weeds

As the project was led by Teagasc and the repository of information is retained within Teagasc infrastructure this information will continue to be used by the advisory service for knowledge transfer and training purposes.

All of the information and results gathered by the project are contained on the Teagasc website https://www.teagasc.ie/crops/crops/grass-weeds/ect-project/ and a full suite of videos are available here https://www.youtube.com/playlist?list=PL751pzOnZmAPqP26RoI8_A3Q6pY911Qwe

The information and the guidance given is delivered so that it is durable for a number of years and famers and the industry can utilise the key information for some time to come.

All of this information will be retained on these websites for the foreseeable future.

A lasting legacy of the project is the creation of a weed research program based in Teagasc. The weed program will build a team of researchers who will train new researchers and also deliver much needed answers around weed control for the industry in Ireland and further afield.

Appendix

List of many of the ECT outputs

Publications

Final Reports and outputs
Focus Farmers – case studies. All 10 case studies (written and videos) are here
Written https://www.teagasc.ie/crops/crops/grass-weeds/ect-project/ect-focus-farmers/
Video https://www.youtube.com/playlist?list=PL751pzOnZmAPqP26RoI8_A3Q6pY911Qwe

Grass Weed Identification and Biology guide
https://www.teagasc.ie/crops/crops/grass-weeds/identification-and-biology/

Weed Score Guides:
Sterile brome https://www.teagasc.ie/media/website/crops/crops/Score-Card-Sterile-Brome_W.pdf
Wild oats https://www.teagasc.ie/media/website/crops/crops/Score-Card-Wild-Oats_W.pdf

Fact Sheets
Blackgrass https://www.teagasc.ie/crops/crops/grass-weeds/identification-and-biology/blackgrass/
Bromes https://www.teagasc.ie/crops/crops/grass-weeds/identification-and-biology/bromes/
Wild oats https://www.teagasc.ie/crops/crops/grass-weeds/identification-and-biology/wild-oats/
Italian Rye Grass https://www.teagasc.ie/crops/crops/grass-weeds/identification-and-biology/italian-ryegrass/
Annual Meadow Grass https://www.teagasc.ie/crops/crops/grass-weeds/identification-and-biology/annual-meadow-grass/
Rats Tail Fescue https://www.teagasc.ie/crops/crops/grass-weeds/identification-and-biology/rats-tail-fescue/
Lessor Canary Grass https://www.teagasc.ie/crops/crops/grass-weeds/identification-and-biology/lesser-canary-grass/

Final ECT Conference
Session 1 Grass weeds and establishment systems https://www.youtube.com/watch?v=vTq16mNFVmc&list=PL751pzOnZmAPqP26RoI8A3Q6pY911Qwe&index=3

Session 2 How Weeds adapt to your Conservation Tillage System
https://www.youtube.com/watch?v=lYvrkHkvzdY&list=PL751pzOnZmAPqP26RoI8_A3Q6pY911Qwe&index=2

Session 3 Herbicide Resistance https://www.youtube.com/watch?v=XOtyctCulNg&list=PL751pzOnZmAPqP26RoI8_A3Q6pY911Qwe&index=1

Weed identification and biology
Introduction:
https://www.youtube.com/watch?v=ryxAcF_CfaQ
https://www.teagasc.ie/media/website/publications/2019/Weed-workshop.pdf
https://www.teagasc.ie/crops/crops/grass-weeds/identification-and-biology/

Broadleaf and grass weeds identification:
https://www.teagasc.ie/media/website/publications/2014/Guide_to_identifying_Tillage_Weeds_2014.pdf

Grass-weed control and herbicide resistance

4. Vijaya Bhaskar AV.(2021).Effect of herbicide rate on black-grass populations. https://www.youtube.com/watch?v=zk6ZWDQQ0sY
5. Vijaya Bhaskar AV.(2021).Herbicide resistance in Italian ryegrass. https:// www.youtube.com/watch?v=PJ-RHX-wd2U
6. Vijaya Bhaskar AV.(2021).The challenges of herbicide-resistant grass weeds.https://www.teagasc.ie/news--events/daily/crops/the-challenges-of-herbicide-resistant-grass-weeds.php
7. Vijaya Bhaskar AV, Forristal D, Barth S & Hennessy M.(2021).Managing and preventing herbicide-resistant black-grass.TResearch Summer 2021. https://www.teagasc.ie/media/website/publications/2021/TR_Summer2021_ManagingPreventingWeeds.pdf
8. Vijaya Bhaskar AV, Forristal PD, Barth S & Hennessy M.(2020).Tackling grass weeds. Teagasc Research Impact Highlights, 2020. https://www.teagasc.ie/media/website/publications/2021/Research-impact-highlights-in-2020.pdf
9. Forristal D.(2021).Stop the spread of grass weeds.https://www.youtube.com/watch?v=VimX-96yY-w
10. Collins C.(2021).Black-grass – cultural control options https://www.teagasc.ie/news--events/daily/crops/blackgrass---cultural-control-options.php
11. Staples J.(2021).Weed screen trials.https://www.youtube.com/watch?v=VFEWAVcnBQA
12. Staples J.(2020).Grass weeds: preventing seed return.https://www.youtube.com/watch?v=YeTY-DVgRn0
13. Staples J.(2019).Stubble cultivations for grass-weed control https://www.youtube.com/results?search_query=teagasc+grass+weeds
14. Staples J.(2020).What is in your bag of seeds.Today's Farm.https://www.teagasc.ie/ media/website/publications/2020/Crops---Whats-in-your-bag-of-seed.pdf
15. Staples J.(2020).Stopping grass weeds in their tracks.Today's Farm. https://www.teagasc.ie/media/website/publications/2020/Crops---Beating-black-grass.pdf
16. Staples J.(2020).Wild oat control in spring cereals.https://www.youtube.com/watch?v=48RMmZy1zQQ

Fact sheet

1. Establishing arable grass margin (and controlling sterile brome).https://www.teagasc.ie/media/website/publications/2020/Establishing-Arable-Grass-Margins.pdf
2. Beware of wild flower mixes as you might get more than you paid for https://www.teagasc.ie/news--events/news/2021/blackgrass.php
3. Stopping the spread of grass weeds: cleaning harvest machines https://www.teagasc.ie/media/website/publications/2020/Machine-Hygiene-and-grass-weeds-web.pdf
4. Black-grass invading Ireland's tillage fields. https://www.farmersjournal.ie/blackgrass-invading-ireland-s-tillage-fields-601099
5. Nationwide grass weed survey launched.https://www.farmersjournal.ie/got-grassweeds-teagasc-needs-your-help-541002
6. Enable Conservation tillage (ECT) project featured in EU publication.https://ec.europa.eu/eip/agriculture/sites/default/files/eip-agri_brochure_climate-smart_agriculture_2021_en_web_final.pdf?fbclid=IwAR0ovbg-2OfwX_fS7ywg0GO3r7OkfoALYW22l1UCvJsi4qP6ZEo1A0W7cbg#page=7
7. Grass weed identification video launched. https://www.teagasc.ie/news--events/news/2021/teagasc-launch-grass-weed.php

Irish Farmers Journals and Other Farming Press

1. Vijaya Bhaskar AV & Mahon J.(2022).Growers help needed for black-grass and Italian ryegrass survey.Irish Farmers Journal. https://www.farmersjournal.ie/grower-help-needed-for-blackgrass-and-italian-ryegrass-survey-696221
2. Vijaya Bhaskar AV.(2022).The growing threat of Italian ryegrass.Crop Protection.Irish Farmers Journal. https://www.farmersjournal.ie/the-growing-threat-of-italian-ryegrass-herbicide-resistance-687965
3. Vijaya Bhaskar AV.(2021).Management of herbicide-resistant black-grass.Irish Farmers Journal. https://www.farmersjournal.ie/management-of-herbicide-resistant-blackgrass-655496
4. Vijaya Bhaskar AV.(2021).The challenges of herbicide-resistant grass weeds.Crop Protection.Irish Farmers Journal and Teagasc daily.https://www.farmersjournal.ie/the-challenges-of-herbicide-resistant-grass-weeds-610851
5. Vijaya Bhaskar AV.(2021).Grass weed challenges increase as resistance expands. Crops open day, Teagasc and Irish Farmers Journal.https://www.farmersjournal.ie/grass-weed-challenges-increase-as-resistance-expands- 630911 https://www.farmersjournal.ie/watch-grassweed-resistance-on-the-rise-what-can-i-do- 633618
6. Vijaya Bhaskar AV, Forristal D, Barth S and Hennessy M.(2020).Herbicide resistance confirmed in wild oats. Irish Farmers Journal. https://www.farmersjournal.ie/herbicide-resistance-confirmed-in-wild-oats-578319
7. Vijaya Bhaskar AV.(2019).Integrated weed management to tackle grass weed problems.Crops Open day.Teagasc and Irish Farmers Journal. https://www.teagasc.ie/media/website/publications/2019/Integrated-Weed-management-to-tackle-grass-weed-problems---Vijaya-Bhaskar.pdf
8. Hennessy M.(2021).Blackgrass – contrasting tale of farmers' response.Irish Farmers Journal https://www.farmersjournal.ie/blackgrass-contrasting-tales-of-farmers-responses-650017
9. Doyle A.& Robb S.(2021).Understanding dormancy in weeds and black-grass.Irish Farmers Journal. https://www.farmersjournal.ie/understanding-dormancy-in-weeds-and-blackgrass-638258
10. Cook S.& Mahon A.(2021).Black-grass lessons from the UK.Irish Farmers Journal https://www.farmersjournal.ie/blackgrass-lessons-from-the-uk-621955
11. Doyle A.(2021).Prevent black-grass seed return.Irish Farmers Journal. https://www.farmersjournal.ie/tillage/husbandry/prevent-blackgrass-seed-return-618894
12. Doyle A.(2021).Listen: the cost(s) of having black-grass.Irish Farmers Journal. https://www.farmersjournal.ie/tillage/crops/listen-the-costs-of-having-blackgrass-616311
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2. Tillage establishment systems and grass weed, from the South. https://www.youtube.com/watch?v=B1J98Aj6NOA
3. Tillage establishment systems and grass weed, from the South East https://www.youtube.com/watch?v=GJXMr9OvF-I

Tillage Edge podcast
(accessed via, https://www.teagasc.ie/crops/crops/the-tillage-edge-podcast/)

1. Black-grass: a UK expert's view to controlling the problem
2. John Mahon's view of conservation agriculture and grass weeds in Ireland
3. Andy Mahon on his UK 2021 harvest and prospects for 2022
4. Farmer Tom Tierney explains his direct drill system
5. Pre-emerge weed control in winter cereals
6. Machinery hygiene at harvest
7. Black-grass and no-till farmers
8. Grass weeds in non-plough systems
9. Weed control in winter cereals
10. The function and benefits of cover crops
11. Combine setup and the importance of stopping grass weed seeds spreading during harvest
12. How to deal with broad-leaf weed control and herbicide resistance issues
13. Dealing with tillage grass weeds including wild oats and black-grass
14. Weed control strategies in spring barley

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1. Vijaya Bhaskar AV, Forristal PD, Cook SK, Hennessy M & Barth S.Irish black-grass (*Alopecurus myosuroides*) populations carrying target-site resistance to ACCase/ALS herbicides also impact glyphosate efficacy. 19th European Weed Research Society (EWRS) symposium, Athens, Greece, June 20-23, 2022.
2. Vijaya Bhaskar AV, Forristal PD, Cook SK, Barth S & Hennessy M.Crop production systems and the evolving status of herbicide-resistant grass weeds in Ireland.19th European Weed Research Society (EWRS) symposium, Athens, Greece, June 20-23, 2022.
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