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Towards an assessment of low pesticide input cropping systems without pesticide seed treatments: an overview of the FAST project and key preliminary results

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Summary

The purported efficacy of many broad-spectrum pesticides in systemic control of seed-and soil-borne pathogens and pests has strongly encouraged the use of pesticide-treated seeds over the past five decades. While the use of seeds treated with insecticides such as neonicotinoids has come under scrutiny due to concerns about potential effects on non-target species, there are knowledge gaps about the potential negative effects due to the planting of fungicide-treated seeds on the health of operators (those applying, handling and using the treated seeds) and on non-target organisms (macro- and micro-organisms). In addition, it is not yet known whether the repeated use of pesticide-treated seeds in crop sequences offers economic and environmental benefits compared to the repeated use of untreated seeds. To fill this knowledge gap, a project called FAST (Feasibility and evaluation of low pesticide input cropping systems with repeated Absence of Treated Seeds), part of the DEPHY EXPE network, began in 2019. Arable cropping system experiments without chemical seed treatments are being compared with a control across an on-farm network in the Grand Est region, Northeast France. Preliminary results showed that in 89% of cases, the system without pesticide seed treatments achieves a yield at least equivalent to that of the system using pesticide-treated seeds.

Key words: Seed treatments, crop establishment, innovation, on-farm experiments, soil biodiversity, sustainability.

Introduction

In 2017, pesticides used for seed treatments has been included in the calculation of the treatment frequency index (TFI) in France, as in many other European Union (EU) member states, meaning that the use of pesticide-treated seeds counts as TFI = 1. On the other hand, the EU provide financial incentives to farmers who are able to reduce the TFI in their cropping systems within the frame of the agri-environmental and climate schemes. The latter are a contract providing farmers with financial support in return for adopting low-input and environmentally-friendly farming practices as an instrument of the EU's common agricultural policy. Following these changes, French farmers asked their advisors about the economic risks (yield losses) due to no longer planting pesticide-treated seeds, which has direct and indirect costs for farmers. Indeed, suppressing the planting of pesticide-treated seeds not only reduces production costs for farmers but also allows them to reduce the TFI of their crops with higher possibility of qualifying for such EU financial incentives. Nevertheless, there is a lack of knowledge about agronomic and environmental benefits vs. drawbacks of planting pesticide-treated seeds, especially on a crop-rotation scale. To fill this knowledge gap, a large-scale on-farm arable cropping system experiments was set up to answer these very pragmatic questions, exploring the impact of no pesticide seed treatments on economic viability (quantity and quality of harvests) of farms in the Grand Est region. In addition to yield impact, potential effect of no pesticide seed treatments on the build-up of soil biodiversity (micro- and macro-organism) was also considered.

FAST (Feasibility and Evaluation of low Pesticide input Cropping Systems in the Repeated Absence of Treated Seeds) is a DEPHY EXPE project under the Ecophyto Plan (https://ecophytopic.fr/dephy/concevoir-son-systeme/projet-fast) involving 6 development partners (the Grand Est Regional Chamber of Agriculture, the Vosges, Ardennes and Alsace Chambers of Agriculture, the Romilly CETA and the EMC2 cooperative) and one scientific partner (INRAE's UMR AGIR). It calls on the UMR Agroécologie (INRAE, Institut Agro Dijon, Université de Bourgogne) to carry out microbiological analyses of the soil and interpret the data in the light of farming practices as a whole.

Pesticide seed treatments consist in treating seeds with several chemical active ingredients, including insecticides, fungicides, nematicides, rodenticides or bird repellents, alone or in combination (Lamichhane et al., 2020). More specifically to field crops, on average, a seed carries three chemical molecules per treatment. The ultimate goal of using pesticide-treated seeds is to reduce damage due to biotic stresses, mainly soil-borne pests and pathogens, which can affect germinating seeds, as well as seedlings both pre- and post-emergence, and which can lead to crop establishment failure, stand and yield losses (Hitaj *et al.*, 2020; Lamichhane *et al.*, 2020). In addition, pesticide seed treatments help prevent the transmission of seed-borne pathogens (Khanzada *et al.*, 2002), protects above-ground plant parts from infection by airborne or insect vector-borne pathogens early in the season, reducing their sporulation levels, and slows the epidemic development of diseases (Sundin *et al.*, 1999). Other advantages of pesticide seed treatments include the reduction in the amount of active ingredient used compared to spraying (in situations where the absence of seed treatments results in aerial spray treatments), as well as lower user exposure and less dependence on weather conditions in terms of field access, compared to foliar spray applications (Munkvold *et al.*, 2014).

Marketing of systematically treated seeds leaves farmers with no choice

Seed companies supplying certified seeds market pesticide-treated seeds "by default" (Hitaj *et al.*, 2020; Lamichhane, 2020). This means that farmers willing to purchase certified seeds cannot freely choose between untreated and pesticide-treated seeds (except for seeds produced for organic farming, which are not treated with chemicals). For many crops, notably straw cereals, maize and sunflowers, farmers do not have access to personalised pesticide use based on their specific field situations (e.g. fields with a history of problems with soil-borne pathogens and pests). The marketing of pesticide-treated seeds in default packages is a major problem for farmers because, more often, they do not know the specific active ingredients contained in these packages nor the pests and pathogens that would be targeted (Hitaj *et al.*, 2020). In France, conventional farmers willing to plant untreated seeds have to order them several months in advance, particularly for crops such as sunflower and maize.

Low or very variable effectiveness of pesticide-treated seeds

Although pesticide seed treatments target specific pests and pathogens, the use of pesticide-treated seeds may not be effective due to the wide diversity of environmental conditions, cropping systems and soil pest and pathogen diversity around the world. A recent study, based on multi-year trials, analysed the efficacy of pesticide-treated seeds in controlling soilborne diseases of subterranean clover across contrasting soil and environmental conditions in Australia (You *et al.*, 2020). This study demonstrated that the use of pesticide-treated seeds provided effective control of a seed or seedling disease only when a single soilborne pathogen was associated with the disease, whereas this practice was ineffective when different soilborne pathogens were associated with the disease complex that resulted from synergistic interactions of different soilborne pathogens. Indeed, a growing body of information in the scientific literature shows that a given plant disease is often caused by synergistic interactions between different pests and soilborne pathogens that coexist in a given plant or parts of plants under field conditions (Harvey *et al*., 2008; Lamichhane and Venturi, 2015; Madriz-Ordeñana *et al*., 2019). The routine based use of pesticide-treated seeds for certain crops such as soybean has led farmers in the USA into a socio-economic impasse where they systematically bear the costs of pesticide seed treatments without any significant economic return (Mourtzinis *et al*., 2019; Rossman *et al*., 2018).

A little-known topic

For field crops, the use of pesticide-treated seeds is common practice, although the percentage of hectares planted with pesticide-treated seeds varies between crops and geographical areas. In the USA, almost 100% of maize and peanuts are treated, followed by cotton, potatoes, wheat and soybean (White and Hoppin, 2004). A recent study in the USA (Hitaj *et al*., 2020) indicates that the use of pesticide-treated seeds has increased in major field crops in recent decades, although farmers are less likely to know which pesticides are on their seed. This is mainly due to the fact that seed suppliers have increasingly standardised seeds, including multiple active ingredients of pesticides, and pesticide-treated seeds are most often marketed 'by default' (Hitaj *et al*., 2020; Lamichhane, 2020). In the USA, the lack of information on pesticides present on seeds is a major obstacle to adapting pesticide use to farmers' production objectives and the environment (Hitaj *et al*., 2020).

In the EU, no information is available on the share of agricultural land cultivated with pesticide-treated seeds for field crops (Lamichhane *et al*., 2020). Eurostat, the largest public database in Europe, does not report any information in this regard (Eurostat, 2020).

More specifically to France, the literature lacks information on the frequency of planting pesticide-treated seeds, farmers' knowledge of the pesticides used for seed treatments and their perception of the risks associated with the handling and use of the pesticide-treated seeds by French farmers. The reports published by the French Ministry of Agriculture and Food, based on farmer surveys on farming practices in 2017 (Agreste, 2019), provide information only on the share of farmland planted with pesticide-treated seeds for 14 major arable crops **(Figure 1)**. This survey shows that 93% of arable crops planted in France in 2017 were subjected to pesticide seed treatments and that the latter were almost systematic in sugar beet, wheat, barley, sunflower, maize, peas, and oilseed rape. However, it is unknown whether the seeds of these crops were treated with one or more pesticides. In almost 40% of cases, the farmers who responded to the questionnaire stressed that they did not know the type of treatment carried out on the seeds. Overall, no information is available on the type of pesticide used to treat seeds, the level of awareness among French farmers of the use of treated seeds, the potential targets of this practice, decision-making regarding where and how they use pesticide-treated seeds, and exposure to risks due to its handling.

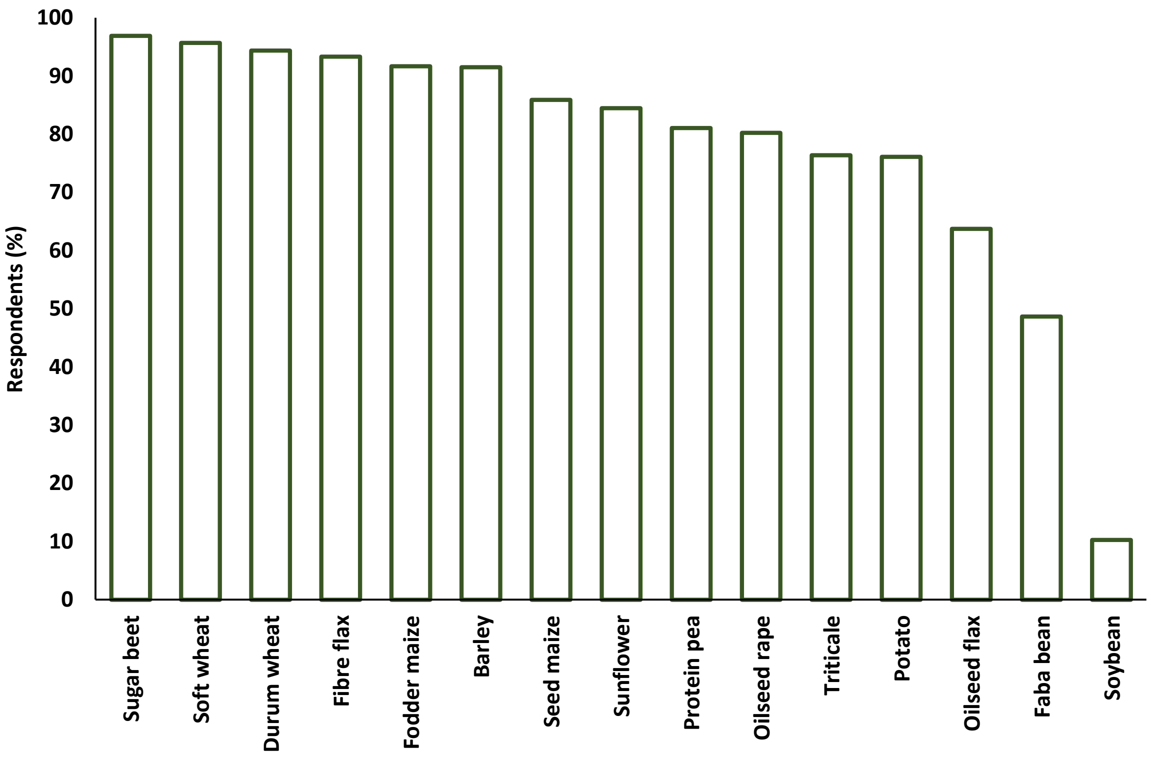

Figure 1: Percentage of main arable crops planted with pesticide-treated seeds in France (Source: Agreste - Survey of cultivation practices 2017).

To fill this knowledge gap, a recent study based on a questionnaire survey of French farmers practising conventional agriculture was carried out (Lamichhane and Laudinot, 2021). This study showed that the level of awareness among French farmers still needs to be improved, in terms of the real risks compared with the benefits of pesticide seed treatments and the use of treated seeds. Almost all (88%) of respondents confirmed that they had used pesticide-treated seeds, while only 24% had treated their own seeds. Most farmers (71%) were aware of the type of pesticides used on their seeds, but only 19% had a good knowledge of the active ingredients used. Only 59% of respondents systematically used protective equipment when treating seeds or handling pesticide-treated seeds. Only 50% of farmers thought that the planting of pesticide-treated seeds improved the quality of their crop establishment and yield.

Pesticide seed treatments and treatment frequency index

In most EU countries, pesticide use is generally measured by TFI, which is defined as the number of pesticide applications per hectare per calendar year or crop year, assuming the use of a standard dose for each authorised pesticide use. In France, as in most EU countries, seed treatments with pesticides was not taken into account in the calculation of the TFI until 2016, even though the data show that the TFI linked to seed treatments represents a significant proportion of the pesticides introduced into the environment **(Figure 2)**. The TFI due to seed treatments corresponds to 1 when all the seeds are treated. A TFI <1 means that either the farmer has only used treated seeds in certain areas of his field, or that he has mixed treated seeds with untreated seeds. Overall, the TFI due to seed treatments represents a significant proportion of chemical inputs for most arable crops and can amount to several thousand tons of active ingredients per growing season (Lamichhane *et al.*, 2020). Nevertheless, there is a lack of information on seed treatments, with such data being virtually inaccessible in many parts of the world, including Europe and North America (Hitaj *et al.*, 2020; Lamichhane *et al.*, 2020).

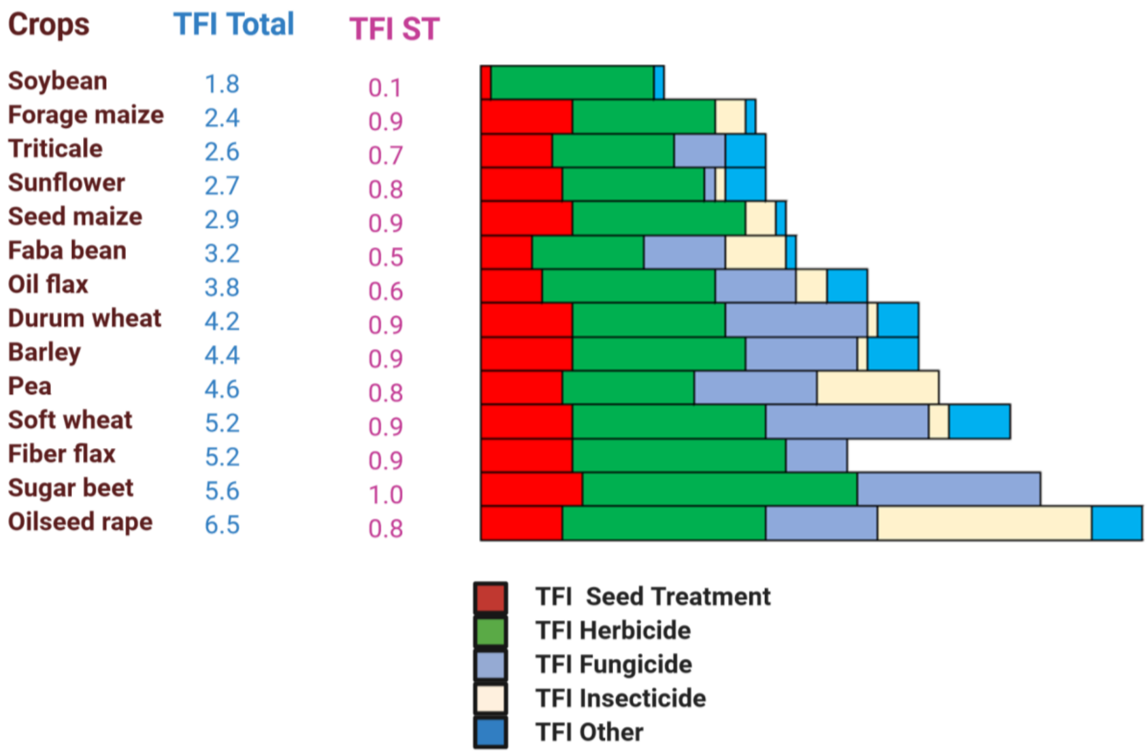

Figure 2: Treatment frequency index (TFI) for the main arable crops in France, including seed treatment (ST; from Lamichhane 2020). The calculation is based on the results of a questionnaire carried out in 2017 among 28,000 arable crop farmers. TFI other refers to seed treatments performed with pesticides other than fungicides, insecticides, and herbicides (e.g., rodenticides, bird repellents).

Exposure risks for operators

Primary exposure, due to the inhalation of dust contaminated by pesticides, and fungicides in particular, is a potential risk when chemicals are applied to seeds (Han *et al*., 2021). Employees of seed production stations and seed companies, who treat seeds on a regular basis, are the most exposed to this risk. Secondary exposure, due to the inhalation of dust during the pouring of treated seeds into seed drills or the handling of leftover seeds, is another major risk of exposure (White and Hoppin, 2004). In surveys conducted in France, farmers reported that they did not always wear personal protective equipment when handling pesticide-treated seeds (Lamichhane and Laudinot, 2021), and that they were not always aware of the health risks associated with exposure to pesticides (Agreste, 2014).

Risks to non-target organisms

Unlike many studies on the negative effects of insecticides such as neonicotinoids, there are relatively few studies that have demonstrated negative effects of fungicide seed treatments on non-target organisms. Examples are negative effects on beneficial soil organisms such as the fungus *Trichoderma* sp, (Tang *et al*., 2021) and the bacterium *Azospirillum* sp (Pereira *et al*., 2020). In addition to negative effects on soil microbial diversity, fungicide seed treatments have also shown negative effects on seed endophytes and plant endophytes with plant growth-promoting activities. Examples include reduced diversity of fungal communities on *Amaranthus retroflexsus* seed coats (Palmer, 2020), reduced prevalence of proteobacterial endophytes in *Nicotiana tabacum* (Chen *et al*., 2020) and negative effects on beneficial fungal endophytes in rice (Vasanthakumari *et al.*, 2019). Similarly, a recent study showed high exposure of wild birds to pesticides through consumption of winter wheat seeds treated with fludioxonil after autumn sowing (de Montaigu and Goulson, 2022). Overall, a growing body of literature reports the negative effects of fungicide seed treatments on the microbial community inhabiting soils, seeds and plants, although the persistence of these effects over time in crop rotation is completely unknown to date that requires further research.

In response to questions from farmers in 2017 about the risk they would be taking by no longer using pesticide-treated seeds, and due to poor knowledge available on this topic, an experimental project began in 2019. Three were the scientific questions we wanted to answer with this project: i) does the absence of fungicide seed treatments lead to systematic yield losses that are independent of crops and environmental conditions; ii) independent of the yield advantage, does the planting of pesticide-treated seeds, and in particular with chemical fungicides, affect soil microbial life, and iii) what are the risk factors that lead to significant yield losses in the absence of fungicide seed treatments?

The experimental set-up

Description of the methods and systems studied

The experimental set-up is of the controlled observatory type, involving farmer-experimenters. The main characteristics of the study sites used for the experiments are shown in **Table 1**. The network, created in 2019, comprises 32 sites (corresponding to plots). Each site comprises two treatments: REF (farming practices over a period of 5 to 6 seasons, including the use of fungicide-treated seeds) and DEP (all practices being equal to REF except the use of fungicide-treated seeds). The average surface of each treatment is 1.5 ha. All agricultural practices were recorded annually (fallow management, tillage, sowing, variety, fertilisation, plant protection, etc.). The variables monitored annually in each treatment are: emergence dynamics, emergence losses, yield explanatory factors (ears/m^2 in straw cereals, seed weight for rapeseed, etc.), harvest quality indicators (sugar content in sugar beet, bunt contamination in wheat, mycotoxins, etc.), yield and soil microbial abundance and diversity. An earthworm count was carried out at the start of the experiment across all sites and will be repeated at the end of the experiment (2024 campaign).

Table 1. Main characteristics of the 26 experimental sites representing the FAST project to date. Information on tillage, damping-off and risk of bunt is based on historical data from the sites, the last two refer to winter cereals only. FP: Frequent ploughing; DS: Direct seeding; MT: Minimum tillage; OP: Occasional ploughing.

Municipality	Area/treatment (ha)	Historical tillage	Texture (clay:silt:sand)	pH (water)	Organic matter (%)	Risk of damping-off	Bunt risk
Aingeville	1	FP	22:63:15	7.9	3.3	High	Low
Ambacourt	0.6	FP	36:46:18	8.1	3.6	High	Low
Auzainvillers	8	FP	22:68:10	6.6	2.7	Medium	Low
Balleville	0.6	DS	20:48:32	6.3	4	Medium	Low
Domèvre sur Durbion	0.6	DS	22:54:24	6.2	2.8	Medium	Low
Les Ableuvenettes	0.6	MT	22:63:20	8.2	5.3	High	Low
Offroicourt	0.9	FP	47:46:7	8.1	2.9	Medium	Low
Pompierre	1.4	OP	31:51:18	8.1	4.9	High	Low
Rebeuville	1.6	OP	30:66:4	7.4	3.1	High	Low
Removille	0.8	OP	33:41:26	7.2	3.4	High	Fort
Saint Gorgon	0.9	FP	19:50:31	6.1	3.2	Medium	Low
Valfroicourt	0.8	FP	37:51:12	7.9	4.6	Medium	Low
Valfroicourt	2.6	OP	36:55:9	8.2	4.1	Medium	Low
Vroville	1.8	OP	34:60:6	7.9	4.3	Medium	Low
Bras sur Meuse	1.6	MT	22:72:6	5.6	1.8	Low	Low
Pouilly sur Meuse	1	FP	26:56:18	7.8	9.7	Low	Low
Verdun-Regret	0.9	FP	28:47:25	8.2	4.6	Low	Low
Very	0.7	OP	25:67:8	7.2	2.3	Low	Low
Villegusien Le Lac	2	OP	30:61:9	7.9	5.3	Low	Low
Montuzain	1	MT	21:39:40	8.2	5	Medium	Medium
Montuzain	1.8	MT	24:48:28	8.2	3.9	Medium	Medium
Charbogne	1.7	MT	39:54:7	8	2.9	Low	Low
Sorbon	2.2	DS	29:65:6	8.1	3.7	Medium	Low
Pfettisheim	1.4	FP	25:70:5	8.2	2.2	Medium	Low
Schirrhein	2.4	FP	56:28:16	7.1	4.7	Medium	Low
Dessenheim	0.5	FP	22:33:45	8.4	2.6	Medium	Low
Mean ± SD	**2 ± 1**			**8 ± 1**	**4 ± 1**		

The cropping systems are all different, as they are individually designed by each farmer. The crop succession is not fixed in advance, but is adjusted annually according to the decision rules of each farmer, who adapts his crop rotation according to his objectives and the climatic conditions. A typology will be drawn up at the end of the project (2024) to determine whether the response differs according to the major characteristics of the systems.

The annual crop rotation within the FAST project is therefore variable. Until 2022, maize (grain or silage) and soft winter wheat were the main crops grown. In total, from 2019 to 2022, 28 sites were planted with soft winter wheat, 27 with maize and 11 with spring barley. Then 6 sites for oilseed rape and 5 sites for winter barley. The other crops were planted on fewer than 3 sites **(Figure 3)**. Various unforeseen events since 2019 have resulted in the abandonment of several sites and, consequently, the on-farm network of the FAST project now comprises only 26 sites **(Table 1)**.

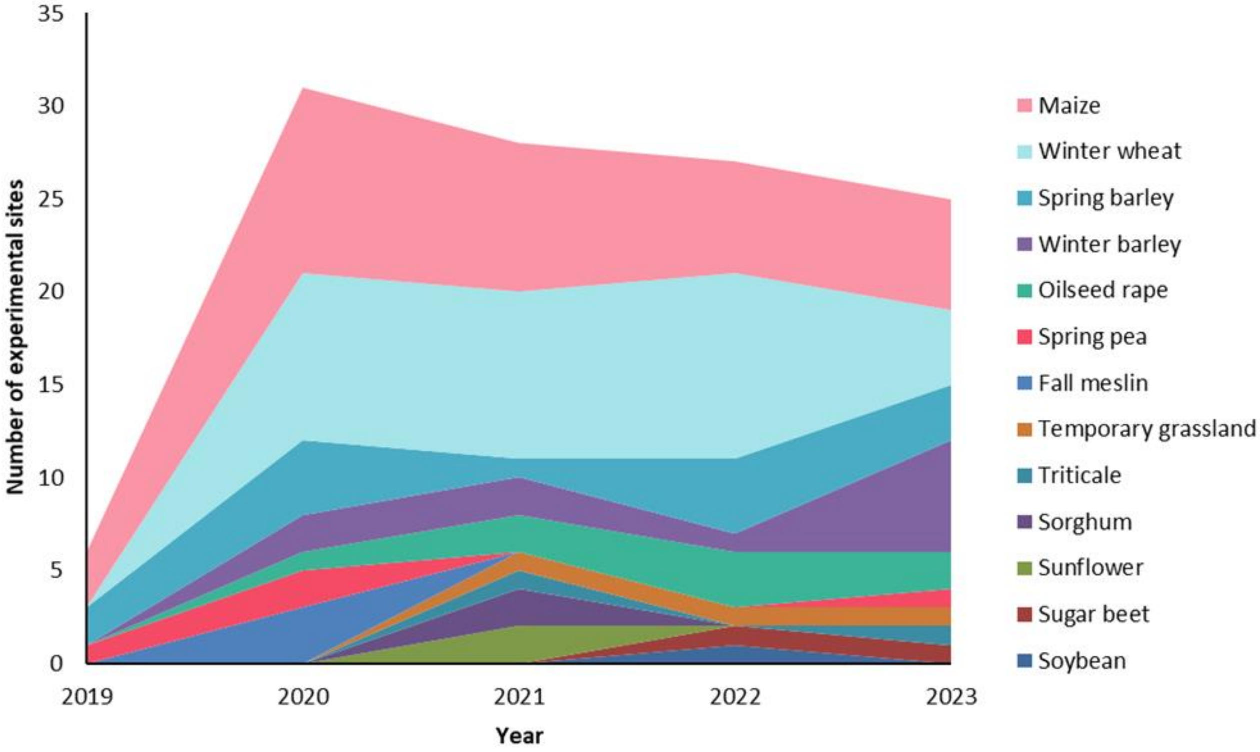

Figure 3: Crops monitored in the FAST project from 2019 to 2023.

Characterisation of systems according to the levers used

At the end of the project (2024), each system will be characterised by its crop succession, farming practices and the management levers used to combat pests and pathogens targeted by pesticide seed treatments. A typology of systems will thus be constructed and compared with the responses to the impasse of pesticide seed treatments (at the system and crop level). An example of the levers that can be used to control autumn insects on cereals, which are vectors of viruses, is shown in **Figure 4**.

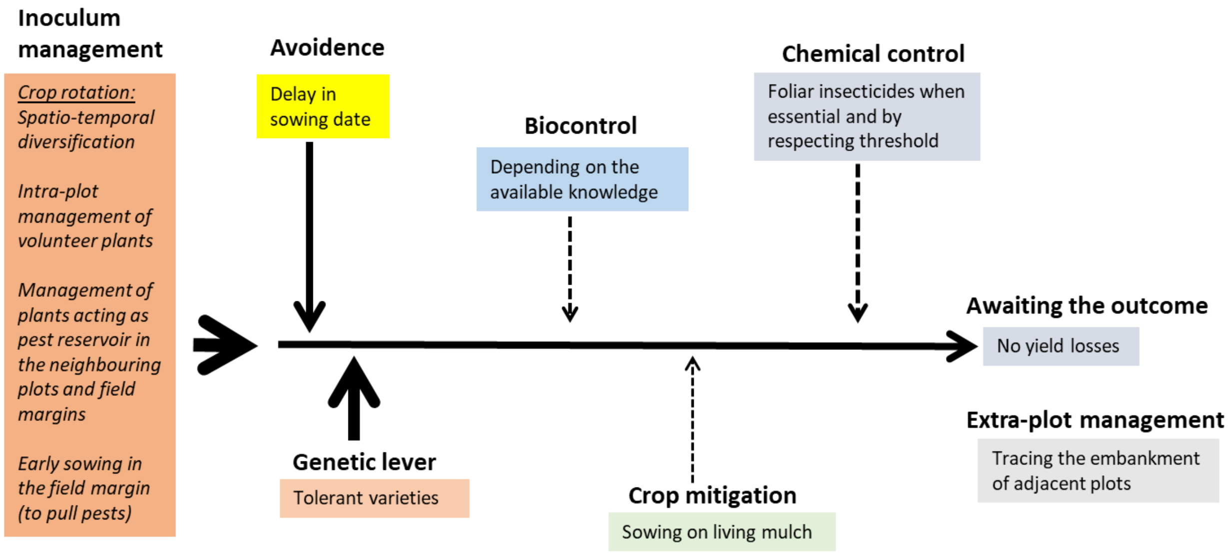

Figure 4. Ischikawa diagram showing management levers for limiting pest damage on straw cereals during autumn in the absence of pesticide seed treatments.

Preliminary results

Yields are rarely affected in the absence of pesticide-treated seeds

In the absence of intra-plot repetition, the difference in yield is estimated to be significant on the basis of a threshold defined for each crop. For example, for straw cereals, oilseed rape, sunflower and grain maize, where the harvest is measured over an area greater than or equal to 0.6 ha for each method, the threshold is 5 q/ha. In the case of silage maize, where harvesting is manual over an area of at least 30 m^2, a difference of more than 25% is deemed significant.

Over the last three seasons, yields were measured at 66 sites. In total, for all crops combined, in 89% of cases, the DEP treatment achieved a yield at least equivalent to the REF treatment **(Figure 5)**. This percentage is lower in 2022, where 23% of sites (5 out of 22) achieve a lower yield in the DEP treatment compared to the REF treatment.

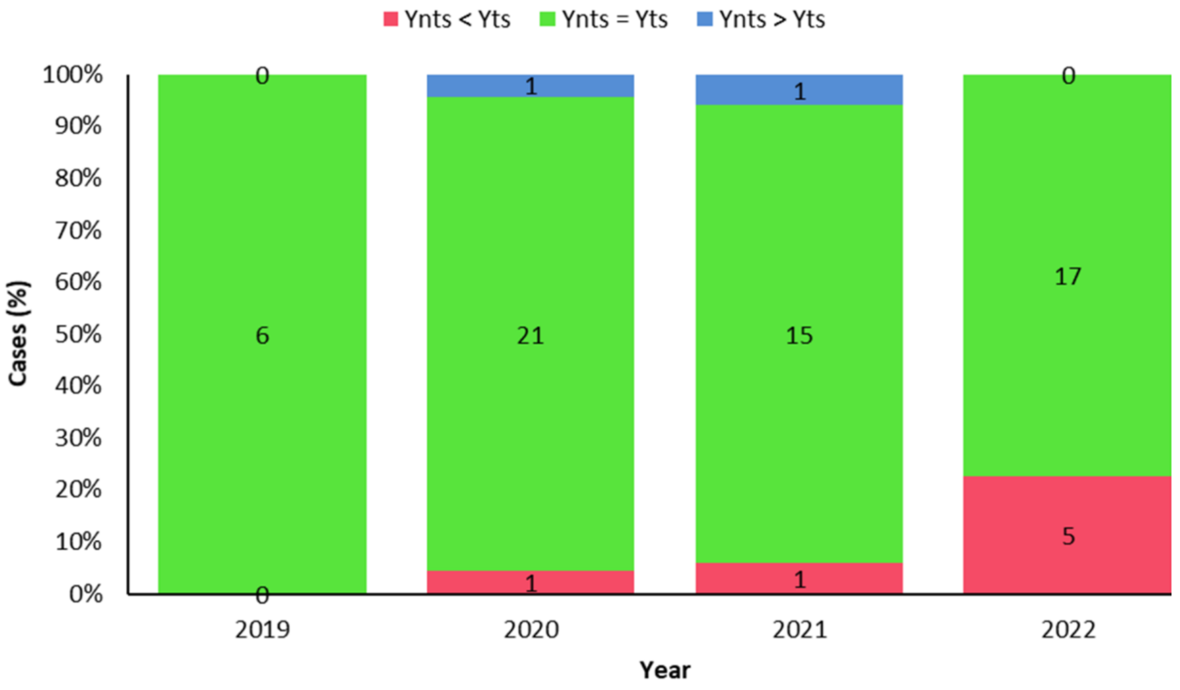

Figure 5: Share of cases reporting differences in yield obtained between non-treated seeds (Ynts) and treated seeds (Yts). The number in the histogram represents the number of experimental sites. The number in the histogram represents the number of experimental sites.

Over three seasons, 26 plots planted with soft winter wheat were monitored until harvest; four sites showed a yield difference in favour of pesticide-treated seeds **(Figure 6)**. For two of them, the impact was observed from the very first stages of emergence, with a high rate of emergence losses which were not compensated for during the 2022 campaign (the spike stands were significantly lower in DEP than in REF). In a third case, a specific pesticide seed treatments (based on silthiofam) was applied to prevent the risk of eyespot in a soft winter wheat following a soft winter wheat. This treatment resulted in a yield gain of 6 q/ha in 2020. No difference in virus symptoms was observed at any of the 26 sites. Above-ground management of insect vectors was identical in the two treatments (in most cases, no insecticides were applied).

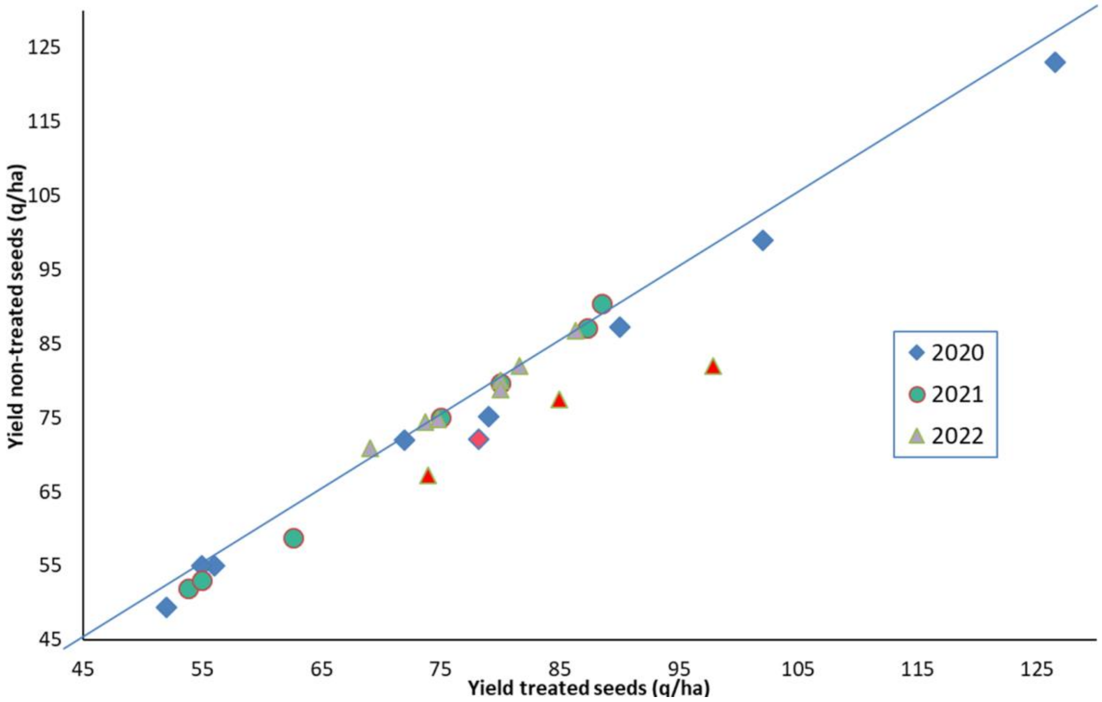

Figure 6. Effect of pesticide seed treatments on soft winter wheat yield. The red colour indicates that the difference in yield between the two treatments is considered significant with regard to the threshold of 5 q/ha.

Special cases of corvid damage to maize crops

Corvid damage rarely had an impact but, in two sites (out of 27 situations during the 2019 to 2022 campaigns), pesticide seed treatments with ziram enabled the crop to be maintained whereas the extent of the damage in the DEP treatment (without pesticide seed treatments) led to a resowing. The impossibility of obtaining untreated seeds as a matter of urgency led to the planting of pesticide-treated seeds in the DEP treatment, and, consequently, the experiment in these plots has been stopped.

Conclusions and outlook

- The FAST project is based on a network of farmer-experimenters, on a multi-annual and systemic scale. This originality requires a different approach to analytical trials, in particular because of the potential cumulative effect of the time factor. This network will explore the role of pesticide seed treatments in the technical, economic and environmental performance of cropping systems that are representative of the Grand Est region. The results obtained so far represent only a preliminary trend, which, however, already show that the systematic use of pesticide seed treatments for all crops is not justified.
- The possibility of not using pesticide seed treatments represents an opportunity for farmers not only to save on input costs, but also to reduce the risks associated with their potential effects on biodiversity and operators' health. This is especially true because their unfamiliarity with the active ingredients and reluctance to use protective equipments are factors that increase the exposure risk of operators.
- The FAST project plans to integrate analytical trials of non-chemical seed treatments to complement the study sites related to the system experimentation in order to detect possible solutions to situations in which the DEP treatment provides a lower yield than the REF treatment.

In particular, the predictability of risk, and therefore of the use of pesticide-treated seeds in at-risk situations, is a key element in the study, and this will require an in-depth analysis of the results incorporating variables related to weather, soil and cropping practices. The characterisation of these situations is one of the objectives of the project and will only be carried out at the end of the experiment. Another point to consider is whether, in high-risk situations, the use of pesticide-treated seeds can be replaced by seeds treated with biological products based on living organisms (mainly bacteria and fungi) and natural substances (such as plant extracts), although these products are not risk-free. An experiment comparing these two types of seed treatments in high-risk situations could help answer this question. A recent meta-analysis (Lamichhane et al., 2022) showed that biological seed treatments have the potential to replace chemical seed treatments and, as such, may represent a sustainable economic solution while reducing negative effects on human health and biodiversity. However, the same meta-analysis highlighted that while biological seed treatments reduce damping-off by up to 80% under controlled conditions (e.g. growth chamber and greenhouse), these measures are not very effective in controlling the disease under field conditions (between 0 and 10% disease control). This means that biological seed treatments need to be combined with other levers as part of agroecological crop protection (Deguine *et al*., 2023).

Ethics

The authors declare that the experiments were carried out in compliance with the applicable national regulations.

Declaration on the availability of data and models

The data supporting the results presented in this article are available on request from the author of the article.

Declaration on Generative Artificial Intelligence and Artificial Intelligence Assisted Technologies in the Drafting Process.

The authors have used artificial intelligence-assisted technologies to translate from French to English.

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Authors' contributions

Conceptualization: JRL, VL; Methodology: JRL, VL; Investigation: JRL, VL; Writing original draft: JRL; Final review: JRL, VL.

Declaration of interest

The authors declare that they do not work for, advise, own shares in, or receive funds from any organisation that could benefit from this article, and declare no affiliation other than those listed at the beginning of the article.

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