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Jay-Ram Lamichhane

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Jay Ram Lamichhane[1]*

[1]INRAE, Université Fédérale de Toulouse, UMR AGIR, F-31326 Castanet-Tolosan Cedex, France

*For correspondence: jay-ram.lamichhane@inrae.fr (J.R. Lamichhane)

Abstract:

Pesticide-treated seeds are usually supplied in "default" packages that leave farmers little choice for a tailor-made management of soil-borne pests and pathogens. This has led to a socio-economic impasse thereby questioning the sustainability of planting pesticide-treated seeds. Here the author proposes an Integrated Pest Management framework to overcome the current impasse.

Keywords: Seed germination; seedling emergence; crop establishment; seed treatment; soil biodiversity; sustainable agriculture

The rationale behind the pesticide seed treatment

Pesticide seed treatment (PST) is an old practice that consists of treating seeds with several synthetic pesticides including insecticides, fungicides, nematicides, rodenticides or bird repellents, alone or in combination [1]. The ultimate goal of planting pesticide-treated seeds (PTSs) is to reduce damage due to biotic stresses (mainly soil-borne pests and pathogens) that may affect germinating seeds, as well as emerging and emerged seedlings and can lead to crop establishment failure, stand and yield losses [2].

Pesticide seed treatment and treatment frequency index

The frequency of chemical pesticides applied via seed treatment is lower (i.e. only once per cropping season) compared with that applied via foliar applications. In most EU countries, pesticide use is generally measured as the treatment frequency index (TFI), which is defined as the number of pesticide applications per hectare per calendar year, assuming the use of a standard dose for each authorized use of pesticides [3]. In France, as in most EU countries, PST was not considered in the calculation of TFI until a few years ago, but now the TFI calculation takes PST into acount. The data show that TFI related to seed treatment represents an important portion of pesticides introduced into the environment (**Figure 1)**. Nevertheless, there is an acute lack of information on PST data which are mainly inaccesible in several parts of the world, including Europe and North America [2].

The current socio-economic impasse for farmers

A great majority of pesticide-seed treatment is performed by the seed suppliers, who market treated seeds in "default" packages. This means that farmers can not chose freely between untreated or treated seeds and do not have access to tailored pesticide use based on the specific field situations (e.g. fields with a history of post-planting problems). The marketing of pesticide-treated seeds in default packages constitutes an important problem for farmers as most often they are unaware of the specific active ingredients in these packages and the pests and pathogens that would be targeted [2]. This routine-based planting of PTSs for certain crops such as soybean has led farmers to a socio-economic impasse where farmers systematically bear seed treatment costs without important economic return [4,5]. This dilemma is further exacerbated by recent findings that the planting of PTSs does not, as thought previously, result in lower human-health and environmental impacts compared with foliar applications of pesticides, including potential non-target effects [6,7].

No, low or inconsistent effectiveness of pesticide treated seeds answered?

Even when targeted to the right pests and pathogens, the planting of PTSs may not be effective due to a high diversity of environmental conditions, cropping systems and the diversity of soil-borne pests and pathogens across the world. Sartori et al. [8] investigated the translocation pattern of three fungicides -- viz. pyraclostrobin, carbendazim, and metalaxyl -- with different modes of action and most often applied as a seed treatment, in interaction with soil type in soybean, the most important leguminuous crop worldwide. The authors showed that, following germination of PTSs, only a small fraction of the pesticides (i.e. 15%), compared with the quantity used for seed treatment, was translocated to plant parts that need protection (i.e. stem, roots and leaves) while a large proportion of these pesticides remained in cotyledons, independent of the fungicide type. This study also confirmed two key findings of previous studies: i) the rate of soil organic matter of a given soil affects the mobility of certain fungicides in the soil [9], and ii) the soil texture in general and the clay content in particular of a given soil affects absorbtion rate of such fungicides [10].

Another study by You et al. [11], based on multi-year trials, analyzed the effectiveness of planting PTSs in controlling seed and seedling diseases of subterranean clover across contrasted soil and environmental conditions of Australia. The authors, tested nine combinations of pesticides (i.e. thiram, metalaxyl, iprodione, phosphonic acid, propamocarb, fluquinconazole, difenoconazole + metalaxyl, ipconazole + metalaxyl, sedaxane + difenoconazole + metalaxyl), against four prevalent soil-borne pathogens -- viz. *Pythium irregulare*, *Aphanomyces trifolii*, *Phytophthora clandestina* and *Rhizoctonia solani* -- causing seed and seedling diseases worldwide on a large number of crops. This study demonstrated that planting PTSs provided effective control of a seed or seedling disease only when a single soil-borne pathogen was associated with the disease, whereas this practice was ineffective when different soil-borne pathogens were associated with the disease complex that resulted by synergistic interactions of different soil-borne pathogens. Indeed, increasing evidence in the literature shows that a given plant disease is often caused by synergistic interactions among different soil-borne pests and pathogens that co-occur in a given plant or plant-parts under field conditions [12–14].

The studies by Sartori et al. [8] and You et al [11] provide an important insight into lack of, low or inconsistent effectiveness of PTSs in controlling soil-borne pathogens that affect seeds and seedlings both pre-germination, pre- and post-emergence across various soil and environmental conditions. These studies, further emphasize the need for future studies on other crops, such as cereals, for which seed treatment is even more common compared with leguminuous crops [2]. In particular, a better focus on how pesticides used for seed treatments affect soil water regime, soil properties, plant biology, and the diversity of pests and pathogens of a given soil can provide important insights into the potential effectiveness of PTSs across environmental gradients.

An integrated pest management framework for a parsimonious use of PTSs in agriculture

Integrated Pest Management (IPM) is a dynamic and flexible approach that takes into account the diversity and the complexity of agro-ecosystems with the aim to improve the sustainability of cropping systems [15]. IPM encourages the use of non-chemical and sustainable cropping practices while also allowing a parsimonious use of synthetic chemicals, when indispensable.

More specifically to the sustainability issues related to the use of PTSs, an IPM framework **(Figure 2)** that combines all best management practices can significantly increase economic profitability of this practice while reducing environmental risks and health hazards. Such a framework is not dogmatic and can be tailored to specific contexts giving the highest priority to non-chemical measures while allowing the use of PTSs as the last option. Because decisions about the type of seed to be planted are made much earlier in the growing season (i.e. months before planting), a strict implementation of IPM is needed while making these decisions. This IPM framework takes into account diverse types of crops grown across very different areas of the world; multiplicity of soil types, environmental conditions, and production practices; diversity in seed- and soil-borne pests and pathogens to improve crop emergence, stand development and yield performance. This is fundamental to achieve the ultimate goal of increasing economic profitability due to planting of PTSs while reducing their negative effects to human health and the environment. However, key for an effective implementation of IPM is to provide farmers with diverse choices of treated vs. differently treated seeds and the detailed information on the type of active ingredients used for seed treatments. This will allow farmers to make better use of PTSs and help solve the curent dilemma of planting PTSs as a routine-based practice even when it is not needed.

Concluding remarks

The planting of PTSs remains an important practice for farmers to ensure economic profitability across areas characterized by a high pressure of soil-borne pests and pathogens. Nevertheless, there is a need to re-evaluate the routine-based planting of PTSs that is unsustainable from economic, environmental and social points of view. Therefore, farmers need market acess to a range of treated vs. untreated seeds, suitable for different crops and diverse field situations. Resolving the dilemma of marketing PTSs in "default" packages is the first step to get farmers out of the current socio-economic impasse of planting PTSs as a routine-based practice, and toward a proper adoption of IPM. I invite all stakeholders to re-think the current seed supply marketing policy, to re-assess the sustainability of planting PTSs as a routine-based practice, and propose an IPM framework for a judicious use of PTSs.

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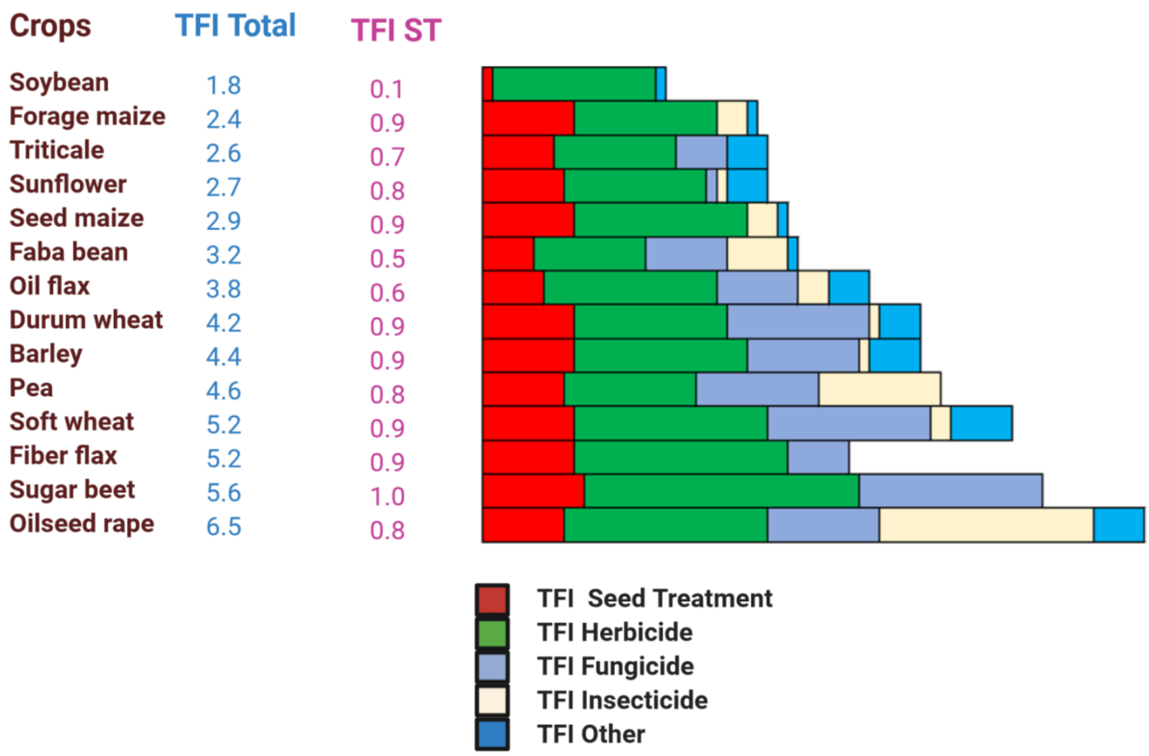

Figure 1. Treatment frequancy index (TFI) of major field crops in France, calculated as the number of pesticide applications per hectare per calendar year. The calculation is based on the results of a questionnaire survey in 2017 of 28 000 field crop farmers. The TFI due to seed treatment corresponds to 1 when all seeds are treated. A TFI <1 means that either the farmer planted treated seeds only in certain areas of his field or he mixed the treated seeds with the non treated ones. In these cases, the percentage of area planted or the quantity of treated seeds used over total provide the real value of TFI. Overall, TFI due to seed treatments represents a non-negligible part of chemical input for most of these crops and can reach several hundred thousand cubic meters of active ingredients per cropping season. ST: seed treatment, TFI Other: treatments performed with pesticides other than fungicides, insecticides and herbicides (e.g. rodenticides, bird repellents).

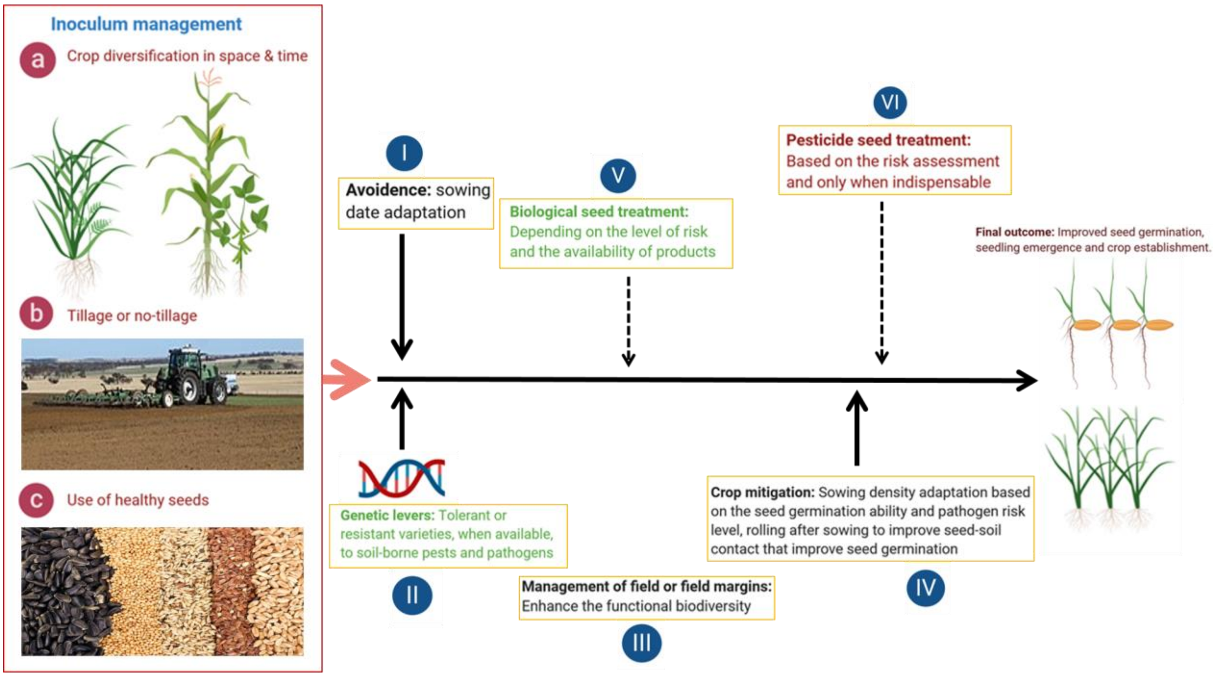

Figure 2. An Integrated Pest Management framework that combines all key crop management levers to improve seed germination, seedling emergence and thereby the quality of crop establishment. This framework prioritizes the non-chemical means of crop protection although the use of pesticide-treated seeds is allowed as the last option, based on *a priori* risk assessment of planting areas. The priority given to these measures decreases from left to right with the lever « inoculum management » and « chemical seed treatment » receiving the highest and lowest priority, respectively. More focus on crop diversification and, in general, on non-chemical measures, enhances soil microbial diversity that plays an important role in soil health. In this way, an increased level of beneficial soil microbial community helps to suppress soil-borne pests and pathogens and to reduce negative impact on seed and seedlings through biotic factors. Inoculation management refers both to the soil- and seed-borne inoculum and it is based on three key cropping practices : (a) crop diversification that includes crop rotation, inter- and cover-cropping; (b) tillage or no-tillage that comprise conventional, minimum or no-tillage, depending on specific situations; and (c) use of healthy seeds through using steps such as, testing seed sanitary quality before use, performing selective sorting of non-certified seeds, testing for good seed germination ability before planting, and applying biological seed treatments to manage seed-borne diseases when non-certified on-farm seeds have to be used. The horizontal arrow from left to right represents a set of IPM levers whereas the vertical arrows represent individual IPM levers. The order of the roman numerals indicate the increasing priority given to the individual IPM levers. The dotted arrows indicate that biological and chemical control should be applied for specific situations. The figure was partly created using BioRender (https://biorender.com/).