Indian Journal of Ecology (2023) 50(6): 1889-1894
DOI: https://doi.org/10.55362/IJE/2023/4152

Manuscript Number: 4152
NAAS Rating: 5.79

Integrated Pest Management: Innovations, Implementation and Impact in EU

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Abstract: Integrated Pest Management is one of the cornerstones of the EU pesticide legislation and viewed as vital for reaching the overall objective of reducing the risk and impact of pesticides. However, the uptake of IPM by EU farmers has been very slow. In this paper the causes for the slow uptake are discussed and examples are provided on EU supported activities intended to overcome the lack of uptake. Finally, the recent initiatives to reduce the use and potential impact of pesticides on human health and the environment are discussed.

Keywords: Sustainable use directive, IWMPRAISE, Green deal, IPM principles

The pesticide legislation in the European Union (EU) is generally considered to be the among the most rigorous in the world. This statement was recently substantiated by Donley (2019) who reported that 72 pesticides approved for outdoor agricultural use in the United States are banned or in the process of being phased-out in the EU. These pesticides are still widely used in the United States accounting for more than 25% of the total pesticide use. Nonetheless, pesticide authorities in the EU are under constant scrutiny for not providing a sufficient level of human and environmental safety.

Besides regulation setting the criteria for authorization of pesticides in the EU (Regulation (EC) No. 1107/2009), the EU pesticide legislation also includes a directive on the sustainable use of pesticides (Directive 2009/128/EC known as the Sustainable Use Directive (SUD)). The key objectives of the SUD are to reduce risk and impact, promote integrated pest management (IPM) and reduce the reliance on pesticides by promoting alternative approaches and technology. The directive stipulates several obligations for EU countries such as compulsory training for professional users of pesticides, distributors and advisors, regular inspection of spray equipment and raising public awareness. The SUD highlights the importance of IPM to reach the overall goals of the directive and by 1. January 2014 all professional users of pesticides were supposed to follow the eight principles of IPM laid out in Annex 3 of the directive (Barzman et al. 2015). All EU Member States are obliged to draw up National Action Plans to ensure the implementation of the SUD. More specifically, the Member States shall propose goals, targets and indicators to reduce the potential adverse effects on human health and the environment and take initiatives that stimulate the adoption of IPM and the use of alternative methods.

Bajwa and Kogan (2002) listed 67 definitions of IPM and since 2002 more definitions like 'true' and 'false' IPM reflecting the dependence on pesticides have been introduced (Ehler 2006). It has been argued that the many definitions of IPM focusing on different features of IPM has led to confusion and partly can explain the lack of uptake of IPM (Deguine et al 2021). The EU has largely adopted the FAO definition with one significant addition namely the word 'ecologically', i.e., the use of pesticides and other forms of intervention should be kept to levels that are economically and ecologically justified' highlighting the increasing emphasis on ecological processes in crop protection (Barzman et al 2015). The FAO/EU definition does not *per se* consider the hierarchy of different intervention technologies reflected in the 'IPM pyramid' but this is partly amended by the eight IPM principles. The eight principles and their numbering follow the passing of year in the field beginning with preventive and suppressive measures followed by monitoring/ forecasting, direct control and ending with evaluation with a view to improve the process (Table 1). Regarding direct interventions, it is clearly stated that non-chemical methods should be preferred to pesticides and that pesticide use, if required, should be kept at a minimum. Nonetheless, they are only principles and not guidelines and for farmers to successfully implement IPM strategies and giving up what most farmers consider to be a cost-effective approach based on a high reliance on pesticides, validated IPM control tactics and strategies are needed. Moreover, IPM

This paper was presented at the Indian Ecological Society International Conference 2022

emphasises a system approach building on agronomic, mechanical, physical, and ecological principles and only resorting to pesticide use when pests cannot be successfully managed with other tools. IPM is therefore a more knowledge-intensive approach than the traditional pesticide-based approach adopted by most European farmers.

In recent years the most important drivers for farmers to implement IPM have been the steadily increase in the number of cases of pesticide resistance and, in some crops, also the loss of key pesticides due to stricter regulations. This made many farmers realizing that heavy dependence on a constantly narrower supply of pesticides is not sustainable and led to changes in crop rotation and other farming practices focussing more on prevention and suppression. Not surprisingly, so far, all evaluations of the adoption of IPM among EU farmers have been negative whether conducted by the EU Commission (European Commission 2017) or third parties (Traon et al 2018, European Court of Auditors 2020). Studies conducted in individual EU countries add to this picture (Piwowar 2021). In a recent study, Helepciuc and Todor (2021) concluded that the lack of success could be attributed to very different approaches in the EU countries developing National Action Plans and proposing measures and timetables. It should, however, be stressed that because IPM is only defined by the eight principles and not rules, it is difficult to assess the degree of IPM implementation, as Matyjaszczyk (2019), conducting as assessment of IPM implementation in Poland, also concluded.

EU and national initiatives to promote the uptake of IPM: At EU member state level, many IPM activities were initiated. One initiative has been demonstration farms or farm networks where focus has been on reducing the use of pesticides by adopting IPM approaches and sharing the experiences among farmers. One example is the German project 'Demonstration Farms Integrated Plant Protection' which at one point included more than 60 farms covering most parts of Germany. The purpose of the demonstration farms was to demonstrate IPM tactics and strategies and to facilitate this; the farmers were supported by farm advisors and researchers. Another example is the DEPHY network created in France in 2010 now consisting of 3,000 farms who, supported by their advisors, are committed to adopt low pesticide use strategies. The network has seen farmers reducing pesticide use (expressed as the Treatment Frequency Index) but rather than adopting IPM this was achieved by substituting pesticides, reducing doses and more efficient pesticide application (Fouillet et al 2022). The project IPMWORKS was recently supported by the EU. The project builds on the principles of the DEPHY network but rather than building a French farm network, IPMWORKS will establish a pan-European farm network. The ambition is to promote a holistic IPM approach incorporating preventive and non-chemical control methods ('holistic IPM) (https://ipmworks.net/).

In recent years the EU has supported several IPM related research projects. The objective of many of the projects has

Table 1. IPM principles as laid out in ANNEX III of the SUD

1. The prevention and/or suppression of harmful organisms should be achieved or supported among other options especially by:
   - crop rotation,
   - use of adequate cultivation techniques (e.g., stale seedbed technique, sowing dates and densities, under-sowing, conservation tillage, pruning and direct sowing),
   - use, where appropriate, of resistant/tolerant cultivars and standard/certified seed and planting material,
   - use of balanced fertilisation, liming and irrigation/drainage practices,
   - preventing the spreading of harmful organisms by hygiene measures (e.g., by regular cleansing of machinery and equipment),
   - protection and enhancement of important beneficial organisms, e.g., by adequate plant protection measures or the utilisation of ecological infrastructures inside and outside production sites.
2. Harmful organisms must be monitored by adequate methods and tools, where available. Such adequate tools should include observations in the field as well as scientifically sound warning, forecasting and early diagnosis systems, where feasible, as well as the use of advice from professionally qualified advisors.
3. Based on the results of the monitoring the professional user has to decide whether and when to apply plant protection measures. Robust and scientifically sound threshold values are essential components for decision making. For harmful organisms, threshold levels defined for the region, specific areas, crops and particular climatic conditions must be considered before treatments, where feasible.
4. Sustainable biological, physical and other non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control.
5. The pesticides applied shall be as specific as possible for the target and shall have the least side effects on human health, non-target organisms and the environment.
6. The professional user should keep the use of pesticides and other forms of intervention to levels that are necessary, e.g., by reduced doses, reduced application frequency or partial applications, considering that the level of risk in vegetation is acceptable and they do not increase the risk for development of resistance in populations of harmful organisms.
7. Where the risk of resistance against a plant protection measure is known and where the level of harmful organisms requires repeated application of pesticides to the crops, available anti-resistance strategies should be applied to maintain the effectiveness of the products. This may include the use of multiple pesticides with different modes of action.
8. Based on the records on the use of pesticides and on the monitoring of harmful organisms the professional user should check the success of the applied plant protection measures.

been to develop novel IPM tools and assist the implementation of IPM through education and training of farmers and advisors. Earlier, most EU projects were developed and run mainly by researchers from universities and applied research institutes and dissemination and involvement of end-users was a minor activity in the last part of the project. Recently, the EU decided that research projects addressing IPM should adopt a 'multi-actor approach', i.e., that all stakeholders should be involved in the planning, execution and evaluation of the research activities thereby promoting a 'co-innovation' approach. One of the rationales behind the multi-actor approach is that it is more likely that farmers will adopt IPM tactics they were involved in developing, adjusting and evaluating than IPM tactics developed by researchers. In the following an example of an ongoing multi-actor project will be presented (Kudsk et al 2020).

Case study: IWMPRAISE

IWMPRAISE is addressing integrated weed management (IWM) in a broad range of crops (arable, horticultural and perennial herbaceous and woody crops). In contrast to the crop specificity of most herbicides, IWM tends to be more generic in the sense that IWM control tactics can often be applied in crops with similar growth habit, growing season and/or grown with the same spatial arrangement. This inspired us to adopt a categorical approach with four management scenarios: annually drilled crops in narrow rows (e.g., wheat and oilseed rape), annually drilled crops in wide rows (e.g., maize and field vegetables), perennial herbaceous crops (e.g., grassland and alfalfa) and perennial woody crops (e.g., pome fruit and olive). This allows for extrapolation of the eight IPM principles between regions of Europe with due consideration of differences in climatic and agronomic conditions. IWMPRAISE adopted the multi-actor approach, i.e., all stakeholders including end-users are involved in all steps of the project from the planning to the execution and evaluation. In each of the eight participating countries, 'national clusters' consisting of all stakeholders were formed. The national clusters were involved in the planning, execution and evaluation of the experimental trials. In the case of an unfavourable evaluation, the experimental design was adjusted for the following years. A similar approach was used in the second year prior to the third and last year of experimentation. By adopting this 'design-assessment-adjustment' approach it is anticipated that the IPM solutions developed will be more acceptable to the farmers and adopted faster. A range of dissemination activities were conducted to promote the visibility of the IWMPRAISE activities including a website in the local language in each of the eight countries.

The IWMPRAISE framework for IWM is built around the life cycle of weeds (Fig. 1). To manage weeds effectively farmers should either: 1) limit weed establishment in the crop from the soil seed bank or subterranean vegetative organs, 2) limit competition for resources such as light, nutrients and water by removing weeds or manipulating the weed flora to

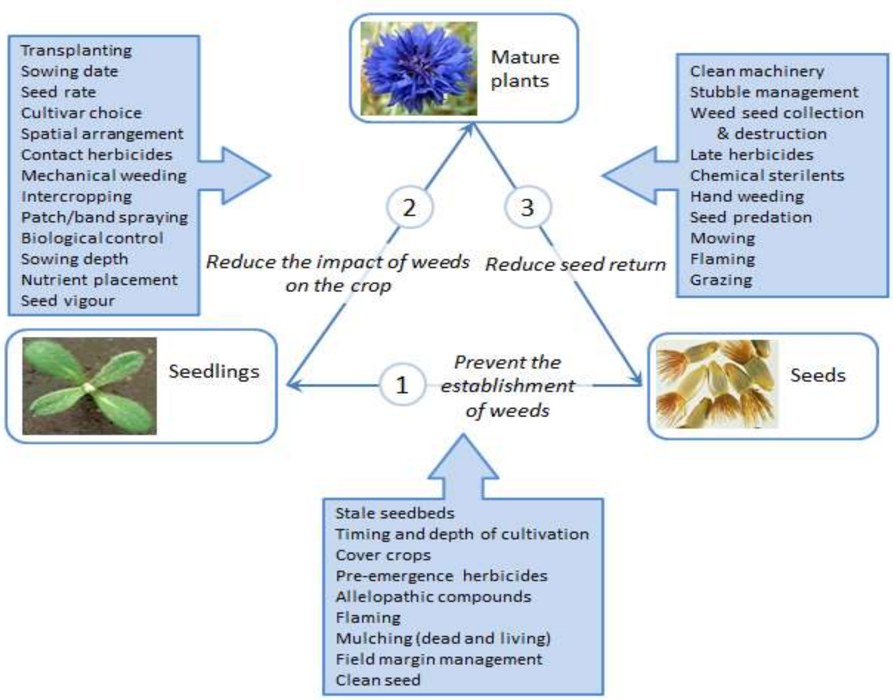

Fig. 1. Weed life cycle (Kudsk et al 2020)

reduce their competitive impact or 3) limit return of seeds or vegetative organs to the soil seed/vegetative organ bank. A sustainable approach should possibly combine control tactics impacting on different steps of the life cycle. Examples of tactics interfering at the three stages of the life cycle are shown in Figure 1.

One of the first activities in IWMPRAISE was a mental modelling exercise. Weed experts and end-users were interviewed to determine the knowledge, beliefs, perceptions and attitudes to IWM. The outcome of these interviews was used to develop an IWM framework. Based on the interviews, it was concluded that in the mindset of weed experts and end-users IPM control tactics could be allocated to one of the following five IPM pillars: 1) diverse cropping systems, 2) cultivar choice and establishment, 3) field/soil management, 4) direct control and 5) monitoring and evaluation. Combining the outcome of the interviews with the concept of categorising control tactics according to what stage of the life cycle they interfere with, led us to develop the general IWM framework shown in Figure 2 (Riemens et al 2022). Although the framework was developed in an European context, we believe it can be applied in other parts of the world in other cropping contexts but it may then be necessary to exclude or add control tactics.

The IWM framework is also available as an online version (https://framework.iwmtool.eu/). Using the online version, the first step is to select crop (annual narrow row, annual broad row or perennial) and weed (annual or perennial) groups. When pressing a hexagon, a factsheet will pop up providing further information on the use and experiences with that particular IWM control tactic.

DISCUSSION

Previous surveys have shown that there are a number of barriers constraining the uptake of IPM by farmers and advisors (Lefebvre et al 2015, Moss 2019). These barriers are based on both experiences and perceptions. An increased risk of inadequate pest control, higher costs, more labour intensive and investments in new equipment are among the reasons mentioned. Another issue, which is often mentioned, is limited evidence of the efficiency of IPM strategies. Although IPM is not a new invention, the focus on IPM in the EU is of recent date and there is little evidence that IPM strategies are cost-effective and as efficient as pesticide-based strategies.

Another constrain is lack of knowledge among farmers. IPM is more knowledge-intensive (Swanton et al 2008) and

Fig. 2. Framework for designing IWM strategies combining individual IWM control tactics from each of the 5 pillars of IWM. Colour codes refer to the weed life cycle shown in Figure 1 (Riemens et al 2022)

for IPM to be successful, a spatial and temporal scale has to be considered, which is different from the one crop – one pest approach that is currently practiced by most farmers. A spatial scale considering landscape instead of fields may be necessary to control insect pests without or with a minimum use of insecticides and a temporal scale considering, e.g., crop rotation is pivotal to manage weeds due to the close association between composition of the weed flora and the crop sequence. Hence, training of farmers and advisors is crucial to ensure that IPM becomes truly integrated pest management and not just 'Integrated Pesticide Management' (Peshin and Zhang 2014) or 'Intelligent Pesticide Management' (Nicholls and Altieri 2004). In this context, bringing groups of farmers together in hubs together with an advisor where farmers can share their experiences and receive advise on recent innovations seems to be one of the most promising ways forward. This approach was adopted in the ongoing EU project IPMWORKS and the ambition is that this project can serve as an inspiration in all EU countries. However, the success of this approach depends on the existence of an independent advisory service which is not the case in all European countries.

The development of IPM control tactics has unfortunately been lagging behind the political ambitions of implementing IPM. This is true for weeds, diseases and insect pests. For example, effective physical weed control methods are not available for all cropping situation but the use of cameras and other sensors for guiding machines will most likely promote the use of these methods. The EU project IWMPRAISE (see above) has provided numerous examples on how physical weed control methods can be part of an IWM strategy. The increased interest among farmers in precision farming including weed mapping may promote the use of integrated weed management approaches (Riemens et al 2022).

Biologicals have for many years been seen as a key component of IPM strategies (Lamichhane et al 2016) but the number of products available to European farmers are still limited (Helepciuc and Todor 2022). This has been attributed to a slow and rigoristic authorisation procedure in the EU (Sundh and Eilenberg 2020) and it is true that the time to authorise a biological in the EU is much longer than, e.g., in the United States or Canada (Gwynn, https://4458b165-2d60-4788-8442-b7e2057eceb6.usrfiles.com/ugd/4458b1_bc 95f91b705d41b889847504cd647290.pdf.). However, the efficiency of most of the commercially available biologicals is not comparable to that of synthetic pesticides and an increased use of biologicals will require that they are seen as one component of a an IPM strategy rather than a 'stand-alone' product. This change in perception has not been well communicated and the use of biologicals are a good example of how complexity increases when adopting IPM.

MacRae et al (1990) proposed the ESR (Efficiency, Substitution and Redesign) paradigm for describing the transition towards sustainability in farming. The development and implementation of IPM may benefit from leaning on this paradigm. 'Efficiency' is the improvement of the currently used methods such as optimising the application of pesticides thereby improving the performance and possibly allowing for dose reduction. Site-specific application of pesticides is another example. 'Substitution' is replacing the currently used methods by, e.g., environmental more benign methods. Examples are physical weed control methods and biologicals instead of pesticides. As mentioned, compared to pesticides many substitutes are not as effective and should not be regarded as a one-to-one substitution. This is where 'Redesign' comes in. To be successful with IPM and reduce/replace the use of pesticides with non-chemical methods, farmers will often have to apply more than one IPM tactic (referred to as 'the many little hammers' by Liebman and Gallandt (1997)). Often these tactics also involve a change in agronomic practices, i.e., in reality a redesign of the cropping system. Accepting that successful implementation of IPM may require redesign of the cropping system could provide a fresh start for the IPM concept. Recently, Jacquet et al (2022) took it a step further by suggesting that the agricultural research community in Europe need to adopt a pesticide-free paradigm to achieve a significant impact on pesticide use.

In 2020, the EU presented the European Green Deal (https://ec.europa.eu/info/strategy/ priorities-2019-2024/european-green-deal_en). One of the goals of the Green Deal is to create a sustainable food system and to achieve this the EU Commission recently launched the Farm to Fork strategy (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020D C0381&from=EN). Some EU countries have set targets for pesticide reductions but for the first time, the EU Commission is suggesting a pesticide reduction target of 50% before 2030.

Adoption by all farmers in the EU of 'true' or 'holistic' IPM is the current political goal but, so far, the adoption is progressing very slowly, as reflected in the overall pesticide use in EU which has not gone down since the implementation of the SUD (Buckwell et al 2020). It will require significant investments in research and establishment of independent advisory services in many EU countries to reach the goals of the SUD. Maybe economic incentives such as a restructuring of the EU subsidies to also focus on IPM implementation or pesticide taxes (Kudsk et al 2018) will be needed too.

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Received 05 August, 2022; Accepted 05 February, 2023

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