Benchmarking On-Farm Crop Protection Sustainability Using Pesticide Metrics

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This is the **final report** of a 6-month project that started in September 2021. The work was funded through an internal Harper Adams University call with a **£3,623** contract awarded for 7-days of staff time and associated overheads.

Background: Agronomic advances driven by a 'green revolution' during the 1950s and 1960s have facilitated significant crop production increases. Many of these agronomic advances rely on intensive synthetic chemical inputs, particularly with respect to crop protection against pests such as weeds, diseases and invertebrates. Conventional agricultural production systems depend on plant protection products, more commonly referred to as pesticides, to minimise crop losses to such organisms and secure profitable harvests for growers. Crop losses of up to 23 % can occur if pest organisms are not controlled. [1] It has, however, become increasingly clear that pesticides can negatively impact both human and environmental health.[2-3] Beyond these impacts it is also questionable as to how effective some pesticides are given increasing levels of target organism resistance to key active ingredients.[4] Greater awareness of these issues has led to widespread acknowledgment that crop protection practices must become more sustainable. This led to the creation of a European Union directive (2009/128/EC) promoting sustainable pesticide usage through adoption of integrated pest management (IPM) amongst farmers, which the United Kingdom remains committed to despite withdrawing from the European Union in 2021.

Integrated pest management is an environmentally and economically sustainable crop protection approach that seeks to reduce pesticide use within agricultural production systems. This is achieved by implementing a spectrum of pest control measures within a framework that emphasises prevention, monitoring and threshold use rather than eradication.[5] If pest populations grow above economic injury thresholds (*i.e.*, a level whereby a grower will incur financial losses) then control measures are used to reduce populations back below this threshold.[5] It should be highlighted that use of synthetic chemical pesticides is not excluded from IPM programmes, however alternative control measures such as natural enemies and biopesticides are usually given priority before their use. While metrics measuring IPM uptake are available and act as a measure of crop protection sustainability, they are not widely used within the United Kingdom.[6] Pesticide metrics are more widely used as a proxy for measuring crop protection sustainability. There are several different pesticide metric frameworks used globally (Table 1), however the United Kingdom currently relies on crude metrics to infer crop protection sustainability.[7] Implementing more comprehensive IPM and pesticide metrics is a key goal outlined in the updated UK National Action Plan for sustainable pesticide use.[7] With these improved metrics it will be possible to benchmark current crop protection practices and determine whether sustainability improves over time as these practices change.

Table 1 Frameworks used to measure sustainability (TFI = treatment frequency index; HRI = harmonised risk indicator; GHS = globally harmonised system; PL = pesticide load; EIQ = environmental impact quotient).

Framework	Country / Region	Classification	Description
Weight	UK	Quantitative	Total weight of pesticide applications
Treated hectares	UK	Quantitative	Total area of pesticide applications
TFI	France	Qualitative	Relative concentrations, efficacy and toxic effects of pesticides
HRI	EU	Weighted index	Categorisation based on quantity of pesticides sold
GHS	Global	Weighted index	Impact of a pesticide on human health
PL	Denmark	Multi-factor index	Impact of a pesticide on human and environmental health as well as toxicity
EIQ	USA	Multi-factor index	Impact on operators, the environment and consumers based on pesticide toxicity

Aim and Objectives: This project aimed to identify which existing pesticide metric framework is most suitable for UK arable crops and use this to benchmark crop protection sustainability on the Harper Adams University farm. Specific objectives (OX.) included:

- O1. Comparing pesticide metric frameworks using key pesticide products;
- O2. Using pesticide usage data from 2020 to calculate a sustainability value;
- O3. Developing a prototype web application for calculating pesticide metrics.

Although the project aim remained unchanged, project objectives were modified to enable the wider aim to be addressed. Updated objectives included:

- O1. **Comparing pesticide metric frameworks using a narrative review**. This objective was modified as there was insufficient information relating to how pesticide metrics were calculated. It was updated to be a narrative review. **COMPLETED**
- O2. **Using pesticide usage data from 2016 to 2019 to calculate a sustainability value.** This objective was modified as pesticide usage data for the Harper Adams University farm from 2020 was unavailable on the 'Online Farm' repository. It was updated to calculate sustainability values for arable crops produced between 2016 and 2019. **COMPLETED**

It was, unfortunately, not feasible to complete O3 as calculating pesticide metrics required access to a licensed version of the proprietary Pesticide Properties Database. There is extreme disparity in the quantity and quality of data relating to registered pesticide products and their active ingredients, making development of a web application to calculate pesticide metrics very challenging. Calculation of these metrics currently requires substantial effort to collect and prepare data from agrochemical companies, government databases and growers as there is no central repository.

O1 – Comparing Pesticide Metric Frameworks: To evidence improvements in the sustainability of pesticide use, the United Kingdom currently records weight of active ingredient applied and treated hectares. These measures are simple to calculate and quantify pesticide usage. However, there is a lack of comparative equivalence between products meaning that dose versus toxicity or frequency of application versus toxicity is not considered. Other available pesticide metrics qualify quantitative measurements through different criteria. At its simplest the Treatment Frequency Index (TFI) calculates the cumulative full rate equivalent applications of pesticide products to any individual crop or hectare and thus takes account of relative concentrations, efficacy and toxic effects. Whilst comparatively simple to apply, this approach does not consider differences between products. The Harmonised Risk Indicator (HRI) and Globally Harmonised System (GHS) are more sophisticated approaches but both focus on human health effects and provide little information about the wider environmental impacts of pesticides. Information to calculate the HRI is also not available for the UK. Measures of human health and environmental impacts of pesticides are provided by the Pesticide Load (PL) indicator and the Environmental Impact Quotient (EIQ). These metrics use weighted indexes for each product, which is then applied to the dose rate. The PL considers risk phrases, weight of application, formulation, degradation, mobility in soil, bioaccumulation and effects on non-target organisms. A significant challenge with these more comprehensive metrics is that they require data from several sources, which are poorly curated and often inaccessible (Table 2).

Table 2 Comparison of risks measure by the most commonly used pesticide frameworks and their ease of implementation / data capture.

Framework	**Indication of Comparative Risks**		**Implementation**	**Data Capture**
	Human	**Environment**		
Weight	Limited	Limited	Easy	Easy
Treated hectares	Limited	Limited	Easy	Easy
TFI	Moderate	Moderate	Easy	Easy
HRI	Good	Limited	Moderate	Moderate
GHS	Good	Limited	Moderate	Moderate
PL	Good	Good	Difficult	Difficult
EIQ	Good	Good	Difficult	Difficult

O2 – Calculating a Sustainability Value for Harper Adams University: Based on the review carried out during O1, the Danish Pesticide Load framework was applied to three arable crops (wheat, oilseed rape and winter barley) grown on the Harper Adams University farm between 2016 and 2019. This framework accounts for potential environmental and health effects at an individual pesticide product level, which can then be aggregated to calculate crop production sustainability values from field- to national-scale where data is available.

Using the Pesticide Load framework to calculate crop protection sustainability was not possible until the release of the *PesticideLoadIndicator* R package in 2021 as the underlying calculations are complex and poorly documented.[8] This R package facilitates calculation of the following sub-indicators within the wider Pesticide Load framework: Environmental Fate, Ecotoxicity and Human Health Load. Calculation of these sub-indicators requires data from several sources (Table 3), which was then integrated into an Excel database linked to the *PesticideLoadIndicator* package.

Table 3 Data required to calculate the metrics within the Pesticide Load framework and where this data is collated from (PPDB = Pesticide Properties Database; MSDS = Material Safety Data Sheet).

Data Type	Data Location
Crop	Farm records
Pesticide product used	Farm records
Application rate	Pesticide product label
Active ingredient concentration	Pesticide product label
Active ingredient fate	PPDB
Active ingredient ecotoxicity	PPDB
Human health risks	Pesticide product MSDSs

Collated data was used to calculate the Pesticide Load [load units per kg/l product] for each arable crop over three growing seasons on the Harper Adams University farm to act as a benchmark for future sustainability measurements. Pesticide Load was selected as a sustainability metric in this project as it encompasses the ecotoxicity, environmental fate and human health sub-indicators to provide a value per pesticide product that was aggregated into a single sustainability value (Fig.1).

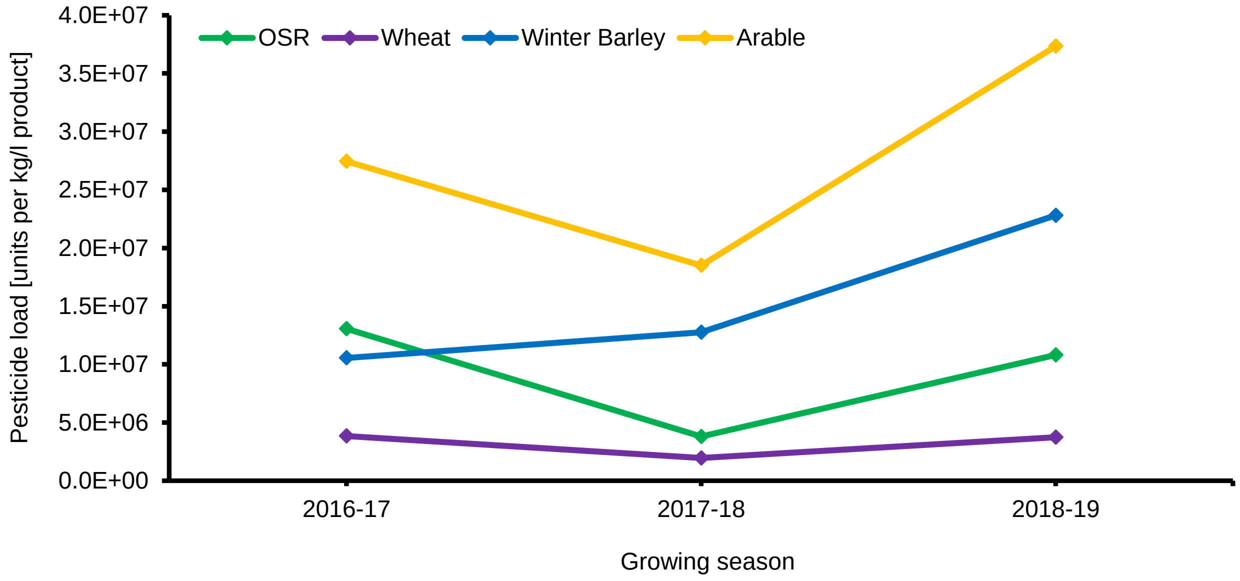

Figure 1 Pesticide Load values for oilseed rape (OSR), wheat and winter barley crops, as well as total arable production, across three growing seasons on the Harper Adams University farm.

Pesticide Load for Harper Adams University farm arable production is relatively stable across the three growing seasons, though it increases during the 2018-19 growing season (Fig. 1). This increase is driven by greater use of broad-spectrum pyrethroid insecticides in all three crops.

Outputs: O1 produced a succinct review of existing pesticide metrics, highlighting their respective advantages and disadvantages for benchmarking crop protection sustainability. It also provided justification for selecting the Pesticide Load framework to benchmark the Harper Adams University farm and its value for agriculture within the United Kingdom. O2 produced benchmark sustainability values for arable production across the Harper Adams University farm. A mid-term project progress meeting with Sophie Throup (Morrisons) introduced the project team to a pesticide consultant, Phil Gurney (Audax), who is also exploring pesticide metrics. This resulted in on-going discussions to identify opportunities to collaboratively develop pesticide metrics for the United Kingdom.

Further Work: This project provides a platform for further development of pesticide metrics to measure crop protection sustainability within the United Kingdom. At the farm level, further work should aim to calculate Pesticide Load values for additional growing seasons on the Harper Adams University farm to identify broader trends in crop protection sustainability for arable crops. While the Pesticide Load values calculated within this project provide some measure of crop protection sustainability, it is an incomplete picture as seed treatment data is unavailable at the farm level. This additional data would help identify clearer trends in crop protection sustainability as many recent pesticide product withdrawals have been seed treatments (*e.g.*, neonicotinoids) rather than foliar treatments. To enable growers to calculate their own crop protection sustainability values it is necessary to licence the Pesticide Properties Database for £720 / year. With this database a protype web application could be developed, which has scope to be deployed within existing farm management software packages (*e.g.*, Muddy Boots). Alongside access to the commercially available database, further work should focus on implementing tools that facilitate data collection from farm records and agrochemical companies.

References: [1] Savary et al. (2019) *Nature Ecology and Evolution* 3: 430-439; [2] Fantke *et al*. (2012) *Environment International* 49: 9-17; [3] Ollerton *et al*. (2014) *Science* 346: 1360-1362; [4] Sparks and Nauen (2015) *Pesticide Biochemistry and Physiology* 121: 122-128; [5] Kogan (1998) *Annual Review of Entomology* 43: 243-270; [6] Creissen (2019) *Pest Management Science* 75: 3144-3152; [7] DEFRA (2020) Sustainable Use of Pesticides: Draft National Action Plan; [8] Möhring *et al*. (2021) *Computers and Electronics in Agriculture* 191: 106498.