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Geomatic Techniques to Support Phytosanitary Products Tests whithin the EPPO Standard Framework

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Chapter 1

Introduction

1.1 EPPO

1.1.1 Phytosanitary Products

Phytosanitary products, commonly used as a synonym for ”Plant Protection Products” (PPPs), are a specific category of pesticides designed primarily to maintain crop health and prevent destruction by diseases and infestations. While the term ”pesticides” is broader and also includes biocidal products used to control harmful organisms and disease carriers not related to plant protection, phytosanitary products are specifically used to control harmful organisms affecting cultivated plants (such as insects, mites, fungi, bacteria, rodents, etc.), eliminate weeds, and regulate plant physiological processes. Fertilizers, which serve for plant nutrition and soil fertility improvement, are excluded from phytosanitary products.

Phytosanitary products contain at least one active substance, which can be either chemical compounds or microorganisms, including viruses, that enable the product to perform its intended function. These active substances undergo rigorous risk assessment processes, with EFSA (European Food Safety Authority) playing a central role in conducting peer reviews at the EU level to determine if these products, when used correctly, might produce harmful effects on human or animal health, either directly or indirectly through drinking water, food, or feed.

The main categories of phytosanitary products can be distinguished based on the type of organism they target or the function they perform, including:

- Fungicides
- Insecticides
- Acaricides
- Rodenticides
- Slimicides
- Nematicides
- Herbicides
- Plant growth regulators

The parameters identified through the risk assessment are compared with the values established by directive 97/57/EC [8], which indicates the acceptability limits for decision-making on the inclusion of active substances in the EU list (Annex I of directive 91/414/EEC [3]).

The Introduction of a product in the EU market is not only subject to audits on active substances and their safety for humans and environment but also to the evaluation of the product's efficacy and safety for the crop. World Trade Organization Sanitary and Phytosanitary Measures Agreement [11] recognizes the International Plant Protection Convention (IPPC) as the only international institution in charge of emitting standards for plant health [10]. IPPC is organized in regions. European Union (EU) countries refer to the European and Mediterranean Plant Protection Organization (EPPO). EPPO Standards are divided into Standards on Phytosanitary Measures and Standards on PPPs. PPPs standards describe the efficacy evaluation of PPPs (PP 1) and good plant protection practices. EU GEP units provide Biological Assessment Dossier (BAD) efficacy trials. GEP units are expected to follow EPPO PP 1 to assess PPPs selectivity detecting phytotoxicity effects, and efficacy in the complaint of Regulation (EC) No 1107/2009 of the European Parliament and Council [9].

1.1.2 Standard Experimental Design

Generics on efficacy assessments are reported in PP 1/181(5) [7], which describes herbicide, fungicide, bactericide, and insecticide efficacy on the target evaluation. PP 1/135(4) [5] describes the selectivity assessment procedures, in other words: the standard phytotoxicity assessments of PPPs. The PP 1/152 [4] standard describes the general principles for the efficacy and selectivity evaluation of PPPs, in describing the standard experimental design. Aside from: objectives of the study, description of treatments, controls, reference treatment, plot size, replications, randomization, sampling and assessment timing, the PP 1/152 outlined that a comprehensive experimental design should include: a description of the sampling and measurement procedures and the statistical analysis plan.

Target and crop-specific standards point out ”mode of assessment recording and measurements” fixing evaluation metrics in two ways: countable (discrete values) and measurable (continuous values) effects which must be expressed in absolute values, in other cases, frequency (incidence) and degree (severity) should be estimated and reported as affected percentage of the individual (ex. plant or plot) or as proportion within thesis and control expressed in percentage. As specified by PP 1/152 [4], classification by ranking (ordinal) and scoring (ordinal or nominal) is also contemplated. In the case of estimation, rather than count or measure, PP 1/152 reports ”The observer should be trained to make the estimations and his observations should be calibrated against a standard”. Calibration compliance with standards is ensured by GEP audits. Scoring and ranking scales examples are published on specific standards or the same PP 1/152. The lack of specific scales lets trial protocol authors define one inspired in range and intervals by the mentioned examples or other well-established ones. GEP units PP 1 assessments are produced by trained and experienced agronomists or biologists by visual inspection or laboratory analysis. The technician follows the trial protocol and related EPPO standards during assessment execution. The technician is critical for accuracy, precision, and repeatability. Sensitivity is determined by the trial protocol. It depends on expected differences and if a measure, a proportion, or a scale is used. For instance, in PP 1/93(3) [6] ”Efficacy evaluation of herbicides - Weeds in cereals - Observation on the crop”, phytotoxicity color modification could be measured, or estimated as proportion in respect to the untreated, or scored in EPPO scale as PP 1/135(4) reports, or a scientifically accepted score as the European Weed Research Society phytotoxicity damage score [2] and other ones. In general, data types must undergo the classification presented in Table 1.1

Table 1.1: Different modes of observation and types of variables

Type of Variable	**Measurement**	**Visual Estimation**	**Ranking**	**Scoring**
Binary				X
Nominal				X
Ordinal			X	X
Discrete	X	X		
Continuous limited	X	X		
Continuous not limited	X	X		

The statistical analysis of trials is equally critical, providing objective assessment of treatment effects. While PP 1/152 [4] doesn’t prescribe specific analyses for all situations, it emphasizes that analysis methods should align with the experimental design and data types collected. For qunatitative variables (continuous or discrete), parametric methods based on Generalized Linear Models (GLM) are recommended, including ANOVA and regression approaches. For qualitative variables (ordinal or nominal), non-parametric methods are more appropriate. Parametric analysis assumes additivity of effects, homogeneity of variance, and normally distributed errors—when these assumptions aren't met, data transformations or alternative approaches become necessary.

Statistical tests, particularly F-tests of orthogonal contrasts, should focus on biologically relevant comparisons specified during the design stage: untreated control versus treatments (establishing trial validity), reference products versus control (demonstrating coherence), test products versus reference (evaluating efficacy), and comparisons among test products (identifying superior treatments). For efficacy trials, EPPO suggests one-sided tests since the aim is comparing products against references or controls, with appropriate multiple comparison procedures when needed.

Through adherence to these rigorous design and analysis standards, researchers can generate reliable evidence to support phytosanitary product registration while ensuring that products demonstrate consistent efficacy across relevant agricultural conditions.

1.1.3 Digital Approaches

While the EPPO experimental design standards provide a solid foundation for conducting phytosanitary product trials, the increasing availability of digital tools and technologies offers new opportunities to enhance the efficiency and accuracy of these assessments. Digital approaches can streamline data collection, automate analysis, and improve the reproducibility of results, ultimately accelerating the development and registration of effective phytosanitary products.

In November 2024, the EPPO published a new standard, PP 1/333(1) [1], which filled the gap in the use of digital technologies in phytosanitary product efficacy and selectivity trials. This standard provides guidelines for incorporating digital tools into trial protocols, including the use of digital sensors and algorithms for data processing and analysis.

When implementing digital technologies in efficacy trials, it is essential to document how the technology was used in accordance with the verification report. In the final trial report, digital technologies used in assessment should be clearly specified, including:

- The type of digital technology used and its version number - Reference to the verification report - Confirmation that the digital technology was used within its verified scope and operating conditions - Any deviations from the standard operating procedure and their potential impact on the results - Calibration records showing the equipment was operating correctly at the time of assessment

The data generated through digital technologies should be stored in a manner that ensures traceability and allows for subsequent verification if required by regulatory authorities. Raw data, such as images used for analysis, should be archived according to GEP requirements.

Digital technologies offer significant potential to enhance the accuracy, efficiency, and reproducibility of efficacy evaluations for plant protection products. When properly validated, verified, and calibrated, these technologies can complement or potentially replace conventional assessment methods while maintaining compliance with GEP standards.

As digital technologies continue to evolve, this Standard will be periodically reviewed and updated to reflect advancements in hardware capabilities, algorithm development, and machine learning applications. Regulatory authorities, GEP facilities, and technology developers are encouraged to collaborate in the ongoing development of appropriate standards for digital technology implementation in efficacy evaluation trials.

The adoption of digital technology should prioritize data quality, reliability, and transparency while facilitating innovation that may improve the assessment of plant protection product performance. All parties involved should work to ensure that digital technologies are implemented in a manner that maintains the scientific integrity of efficacy evaluations while enabling more efficient and potentially more precise data collection methodologies.

1.2 Geomatic Technics

1.2.1 Photogrammetry

1.2.2 Geostatistics

1.3 Machine Learning

1.3.1 Approaches

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Chapter 2

Thesis Aims and Framework: A New Statistical Analysis Workflow

Chapter 3

Study Cases

3.1 Continuous Variables

3.1.1 Plant Count

3.2 Ordinal and Nominal Variables

3.2.1 Phytoxicity Score

3.3 Binary Variables

3.3.1 Embedding Spaces for Control Sample Anomaly Detection

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