Fostering soil management PRACtices and uptake and developing decision support TOols through LIVing labs in EU (PRAC2LIV)

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ABSTRACT

The overall objective of the EJP Soil project PRAC2LIV is to improve and promote the uptake of DSTs for sustainable soil management under changing climatic conditions, where soil quality, environmental impact and the farm economy are all considered. The focus is on DST covering soil organic matter (SOM), Nutrient Use Efficiency (NUE), and/or moisture retention (MOI) in the EJP SOIL Member States + Turkey. The aim of this report is to summarize the literature on DSTs and other relevant subjects that may be important for the execution of PRAC2LIV, e.g. the concept of soil quality and the implementation of living labs. For this purpose, an extensive literature search was carried out based on a grosslist of keywords at the beginning of the project. Conclusions were drawn for subsequent activities in PRAC2LIV, regarding the questionnaire (WP3), the validation of stocktake's outcome in workshops (WP4), and the evaluation of DSTs (WP5).

Table of contents

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1. Introduction

The project PRAC2LIV will make and evaluate a stock-take of Decision Support Tools (DSTs) that focus on soil organic matter (SOM), nutrient use efficiency (NUE), and water retention (MOI) as currently used by EJP Member States. Building on previous stocktakes, EU-projects and national reports, the overview will include DSTs from simple tools to the next generation level support systems. Both the scientific base of DSTs as well as their implementation and adoption at farm level will be assessed, with special attention for soil management practices, regional distance-to-target options, and data sharing for web-portal applications. Guidelines for development of DSTs and designs for (mock-up) web-portal and/or dashboards will be discussed in workshop exchanges with stakeholder groups, e.g., living labs and/or EU-lighthouse projects. Based on the results from the stocktake and these discussions, a tiered approach will be developed for future development of DSTs in agro-ecosystems across EJP Member States.

This literature review report aims to summarize the literature concerning DSTs on SOM, NUE and MOI, as well as other relevant subjects to demarcate the scope of the project PRAC2LIV. In addition, it reveals soil protection, soil quality and degradation problems in Europe and its related agri-environmental measures and agricultural sustainability indicators. Comprehension of decision support process includes decision problem and decision support systems, soil functional decision models and decision support tools, especially focusing on relevance of its use for water retention, nutrient use efficiency and soil organic matter as it is of high importance for different scales (local, regional, country) and different abstraction user levels (farmers, advisors, policy makers). The literature review introduces also future challenges in improving decision support tools and their application.

It has been established that there are no common indicators or algorithms for calculating ecosystem functions, as especially lack of information is related to soil formation factors, processes and soil properties. Impact assessment of DSTs is still an open question and remains unanswered due to used different approaches and input data. The interest of the most economically developed countries in improving their agricultural policy formulation processes using tools such is evident. DSTs developed so far aim mainly to improve agricultural production processes and reduce the negative impact of agricultural production on the environment; besides, they can help meet the sustainable development goals, but it is necessary to implement new features to these systems so that they take into account variables like poverty and food security. These latter aspects, however, are considered beyond the scope of PRAC2LIV.

There are many indicators in use for sustainable agriculture and these could be grouped into three dimensions: economics, environment, and social. Furthermore, different indicators are used in different countries and regions, so it is difficult to collect all of them in one study, and every year a new indicator is added to the sustainable agriculture field. Impact assessment of decision support tools is still open question and remains an unanswered due to used different approaches and input data. However, main indicators for impact assessment of decision support tools cover performance, ease of use, peer recommendation, trust, cost, habit, relevance to user, farmer-adviser compatibility, etc.

Living Labs

The European Commission promotes the concept of Living Labs, which, when effectively meeting the necessary ecosystem service requirements, can serve as influential "Lighthouses" for other land users, stakeholders, and policy-making entities. This approach is endorsed as it is only through the mobilization and application of bottom-up expertise and interests of land users, especially farmers who occupy vast land areas, that genuine success can be achieved. According to the EU Mission "A Soil Deal for Europe," a significant driver of soil degradation, impacting its ability to deliver ecosystem services, is the lack of knowledge and awareness regarding the vital importance of long-term soil health among various stakeholders including land managers, industries, consumers, and society as a whole. For this reason, the primary objective of this mission is to establish 100 living labs and lighthouses, serving as pioneers in driving the transition towards fostering healthy soils. It means co-creating and introducing tools and platforms for interaction, knowledge-sharing, and collaborative learning. Additionally, stocktaking and dialogue must be conducted to comprehend how regional assessments of soil requirements, coupled with harmonized monitoring mechanisms, can translate into actionable steps within living labs and lighthouses to promote soil health.

1.1. Scope and objectives of the literature review

The overall objective of WP2 Scope & Demarcation is to have a clear and refined understanding of the relevant literature for the project PRAC2LIV as well as to have a glossary of relevant terms.

Specifically, the objectives are:

- OB2.1 To review the literature and propose the 'scope & demarcation' of PRAC2LIV.
- OB2.2 To discuss and agree on the subjects to include in PRAC2LIV. OB2.2 is dealt with in T2.2.

Tasks are following:

- Task 2.1: Literature review, proposition and glossary.

A draft text including a literature review, a proposition and a glossary. The text is to serve as backbone of the topics to include in the stocktake and evaluation of responses. This will include e.g., definition of DST, selection of agricultural systems and agro-ecological conditions.

- Task 2.2: Team discussion on 'Scope & Demarcation' during KOM.

A session has been prepared and led during the KOM of PRAC2LIV (organised by WP1). This included presentation of the work to define scope & demarcation and subsequent discussion. Results of the discussion are used to finalise the description as chapter in the Final Report and will be used as input and background information for WP3 Stocktake.

Scope of the literature review is to summarise the relevant literature to formulate a solid questionnaire (WP3), to write a script for exchanging results in workshops (WP4), and to analyse and evaluate results from the questionnaire and formulate guidelines for future development of DSTs (WP5). For this purpose a grosslist of subjects was made:

1. **Defining** decision support tools (DST) by origin:
    - **support mechanisms** for society. Is the aim for soil fertility or for economic benefit for society? E.g. Greening Policy, Common Agricultural Policy etc.
    - **software** based tools
    - **monitoring** and related organizations
    - **classification** of DST by:
    - **input data**: remote sensing data, models, data of agrochemical analysis
    - **functions and aims**
    - **scale**: local, regional, national

- **impact**: direct, indirect
- **degree of approbation (validation)**: scientifically developed; validated in some etalon areas (farms etc.); widely used; conceptual, etc.

2. **Providing information on the DST** conceptualized and used in Europe concerning **soil organic carbon, water retention and nutrient use efficiency**
3. **Critical assessment of the DST** for soil organic carbon, water retention and nutrient use efficiency **including input data, performances, strengths and bottlenecks**
4. **Description of the Living labs concept, including:**
   - **an overview** of relevant farming groups
   - **major sources for relevant groups**, e.g. EU-initiatives for lighthouse farms, the mission board on Soil Health and Food, PREPSOIL. Also national projects and/or the European network of living labs (ENoLL)
   - **criteria for the selection of farming groups**, e.g. stakeholders, farms by tresholds of agrochemical indicators, soil organic matter, water retention, nutrient efficiency, climatic zones etc.
   - Relevant **European policies**, i.e. CAP.

2. Methodology for the literature review

A literature search was conducted in three stages to ensure the demarcation of literature to be as comprehensive and accurate as possible and to gather as much relevant literature as possible while minimizing the inclusion of irrelevant literature.
The SALSA (Search, Appraisal, Synthesis, and Analysis) and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) frameworks were used for literature search and analysis to minimize subjectivity. Figure 1 shows the framework for systematic literature search and review (Bathaei, Štreimikienė, 2023).

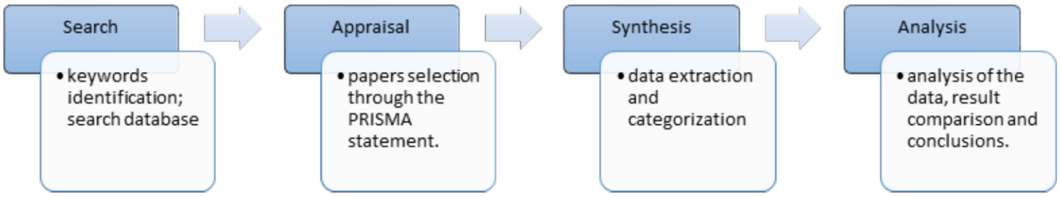

Figure 1. Framework for systematic literature search and review (Bathaei, Štreimikienė, 2023)

The first step to information demarcation - only peer-reviewed, published papers describing empirical, original research was included, and searches were carried out using the online scientific database SCOPUS for the period 2012–2023. The search was conducted only in the English language.

The next step of demarcation - the selection of a group of keywords provided understanding the size of the literature available (Annex I). It was concluded that available literature is too broad and therefore restriction of the search (mentioned above) included:

1. literature from SCOPUS for the period 2012–2023, and
2. the most used and updated information were obtained by the selection of a keyword combinations. E.g., the final search combinations for literature connected to soil water retention DSTs and DSTs were:

- (TITLE-ABS-KEY (decision AND support) AND TITLE-ABS-KEY (water AND retention) AND TITLE-ABS-KEY (agriculture));
- (TITLE-ABS-KEY (living AND labs) AND TITLE-ABS-KEY (water AND retention)); (TITLE-ABS-KEY (decision AND support) AND TITLE-ABS-KEY (water AND retention) AND TITLE-ABS-KEY (soil)).

All results from the search results were reviewed at title and abstract level to ensure they met a set of inclusion criteria by following aspects:
Key words were selected for exploratory analysis of the available literature including following criteria:
1) Type of DST:

- decision support system; decision support tool; decision support model; living labs

2) Scale:

- Europe; national/country scale; regional; local

3) Target groups:

- policy decision makers; stakeholders; farmers

4) Target objects:

- land quality; soil productivity; soil functions; soil properties; soil threats; soil degradation risks

- soil carbon, soil organic carbon, soil organic matter; soil water, water retention; soil nutrients, nitrogen, phosphorus, potassium, nutrient use efficiency

5) Agroecological conditions

6) Agricultural lands:

- croplands; arable lands; grasslands; abandoned lands

7) Agricultural systems

8) Agricultural management:

- intensive; extensive; conventional agriculture; organic farming.

Publications that passed the inclusion criteria were collected into the database and these were reviewed for suitability for inclusion and read in full to extract the relevant information to this project.

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3. Results of literature review

3.1. Glossary

We recommend to use terms, previously proposed by following projects:
https://landmark2020.eu/landmark-glossary/
https://vivagrass.eu/lessons/terms-used-in-the-theory/

3.2. Soil protection, soil quality and degradation problems in Europe

3.2.1. Soil protection and EU Common Agricultural Policy

The extent and causes of chemical, physical and biological degradation of soil, and of soil loss, vary greatly in different countries in Europe. Virto et al. (2015) reviewed and examined these issues and strategies for soil protection and future perspectives for soil quality evaluation, in light of present legislation aimed at soil protection. It was concluded that agriculture and forestry are the main causes of many of the above problems, especially physical degradation, erosion and organic matter loss. Land take and soil sealing have increased in recent decades, further enhancing the problems. In agricultural land, conservation farming, organic farming and other soil-friendly practices have been seen to have site-specific effects, depending on the soil characteristics and the particular types of land use and land users.

No single soil management strategy is suitable for all regions, soil types and soil uses. Except for soil contamination, specific legislation for soil protection is lacking in Europe. The Thematic Strategy for Soil Protection in the European Union has produced valuable information and has encouraged the development of networks and databases. However, soil degradation is addressed only indirectly in environmental policies and through the Common Agricultural Policy of the European Union, which promotes farming practices that support soil conservation. Despite these efforts, there remains a need for soil monitoring networks and decision-support systems aimed at optimization of soil quality in the region. The pressure on European soils will continue in the future, and a clearly defined regulatory framework is needed (Virto et al., 2015).

The countries that had joined the European Union (EU) have therefore implemented Common Agricultural Policy (CAP) regulations and other EU environmental directives affecting soils (i.e., Nitrates, Water and Pesticides Framework Directives) (Virto et al., 2015).

Unlike for air and water, environmental issues associated with soil degradation have been given marginal consideration in environmental regulations in WE. Soil protection has been addressed indirectly through measures aimed at the protection of air and water or developed within sectoral policies (EEA, 2003). The most important initiative that partly redresses the lack of explicit soil protection is, undoubtedly, the proposal for the development of a Thematic Strategy for Soil Protection.

Officially launched in 2002 (COM (2002) 179), this has led to a significant research effort and yielded an impressive amount of information on soil degradation in the EU. The final aim of these efforts was the implementation of a EU Directive for soil protection within the EU (i.e., in most WE countries) (Virto et al., 2015).

Unfortunately, after several years of discussion between different European institutions, the proposal for a Soil Framework Directive similar to those existing for Air and Water was finally withdrawn from the European Commission agenda in May 2014 (OJEU, 2014).

Although great efforts are being undertaken to recover this EU initiative, at present soil protection in WE mainly rely on national-level policies and indirect policies such as the Nitrates Directive and the Water Framework Directive

(Louwagie et al., 2009), and the agri-environmental measures included in the CAP regulations. As a result, many soil degradation issues are not completely covered by legislation at present. The only field in which soil protection is directly addressed in national laws is soil contamination and the management of contaminated sites (Virto et al., 2015).

Between 1980 and 2006, most WE countries developed specific laws to address issues related to soil contamination and contaminated sites (Rodrigues et al., 2009). For instance, in Germany, the Soil Protection Act acknowledges the ecosystem functions of soils and states that they should be preserved over time. However, the Act focuses on and limits the threats to these functions derived from chemical contamination (Römbke et al., 2005; Prager et al., 2011). In the Netherlands, the Soil Protection Act states the importance of prevention, reduction, and reversal of changes in the soil quality that imply a reduction or threat to the functional properties of soil has for humans, plants and animals (Römbke et al., 2005). The German Act mainly focuses on degradation risks associated with contamination of soil by toxic compounds (Virto et al., 2015).

Although there is a shift towards including the multi-functionality of soils into the legislation in many WE countries (e.g., The Netherlands (Boekhold, 2012), Belgium (Goidts, 2012) and France (Bodenez, 2012)), a specific legislative framework for unpolluted agricultural soils is so far lacking. However, as most countries in WE belong to the EU, they are affected by the CAP. The CAP is based on two groups of measures or pillars. Pilar one corresponds to the legislative framework in relation to agricultural production subsidies. Pillar two includes the support policies for rural development in the EU (Virto et al., 2015).

Since 1999, in the so-called Cardiff process, environmental protection measures have been integrated into the CAP. This implies that the successive reforms of the CAP established a list of statutory management requirements and a reference level of good agricultural practices that should be respected by European farmers being supported by the CAP. Different requirements and reference levels have been established for different local conditions by member states or competent regional or local authorities. The cross-compliance character of these measures implies that they are mandatory for farmers receiving CAP subsidies. From the perspective of soil conservation, cross-compliance links direct payments with compliance by farmers with the obligation of keeping land in good agricultural and environmental condition, including standards related to soil protection (namely protecting soil from erosion and the maintenance of soil organic matter and soil structure) (EU Council Regulation 73/2009).

Common Agricultural Policy (CAP)

The CAP has also encouraged sustainable soil management by funding the provision of environmental public goods and services beyond mandatory requirements to those farmers adopting the so-called agri-environmental measures (AEMs). In many cases, this implies adopting agricultural activities or levels of production intensity that deliver positive environmental outcomes, while not necessarily being the first choice from the point of view of profitability. Some of these measures are related to management systems that can promote SQ. As a result, throughout its successive reforms, soil protection measures have been reinforced in the CAP and expanded to encourage organic and integrated farming, extensification, maintenance of terraces, safer pesticide use, use of certified composts, and afforestation, among others (EEA, 2003). The flexibility of AEMs allowed WE countries in the EU to develop different measures or schemes to reflect different bio-physical, climatic, environmental, and agronomic conditions and therefore to tailor management options to suit the characteristics of their agricultural sector (Virto et al., 2015).

The development of agri-environmental indicators for monitoring the integration of environmental issues in the CAP was introduced in 2006 (COM 2006-508 final). Some of these indicators involve soil protection. These have been selected for monitoring farm management practices, agricultural production systems, pressures and risks to the environment and the state of natural resources. Their level of development differs greatly: while some are already operational, others are only defined and lack data (Virto et al., 2015).

The changes in CAP towards more environmentally oriented policies had different results in relation to SQ (Stoate et al., 2009). In most cases, measures included in AEMs, such as contour and reduced tillage, led to reduced erosion rates, higher biodiversity and generally improved SQ in arable land and grasslands across WE. However, promotion of set-aside, for example, may have the opposite effect in arid and semi-arid land. The difficulty in fulfilling the requirements of cross-compliance also stimulated land abandonment in some areas. The CAP has also encouraged the use of soil cover systems and crop rotations and has contributed to the dissemination of CF (Lahmar, 2010; Virto et al., 2015).

The latest reform of the CAP (for the period 2014–2020) includes significant changes in relation to environmental protection: a new policy instrument of the first pillar (greening) is directed to the provision of environmental public goods (EU Overview of CAP Reform, 2014). This instrument has been designed to reward farmers for respecting three obligatory agricultural practices:

- maintenance of permanent grassland;
- maintenance of ecological focus areas (land left fallow, terraces, landscape features, buffer strips and afforested areas);
- crop diversification (which includes having at least three crops on the same agricultural field, and/or including agronomic practices with minimum soil disturbance and green coverage of the soil surface in permanent crops). Implementation of these measures across the EU is expected to increase soil protection, as many of the measure directly involve soil.

For instance, in Spain, ecological focus areas include set-asides, N-fixing crops, afforested surfaces and land devoted to agroforestry. The aim of this reform is also to extend and reinforce the environmental component to Pillar 2, by including agri–environmental-climate measures, OF, forestry measures and investments that are beneficial for the environment or climate (amongst others) in rural development policies (Virto et al., 2015).

Nevertheless, the final net effect of the new CAP on SQ in WE will depend on multiple factors, both at local and national level, and it is possible that trade-offs between conflicting agricultural sector policies will appear. For example, a policy aimed at mitigating soil erosion (achievable through CF) may conflict with another policy discouraging the use of herbicides (often critical to the initial success of CF practices (Piorr, 2013)). Similarly, CAP measures designed to promote increased agricultural production may diverge from those developing environmental policy objectives (Schulte et al., 2014).

In addition to environmental issues affecting terrestrial and aquatic systems, CAP reforms included since 2010 support climate action. The reduction of GHG emissions from farmland, when including soil management strategies and the stabilization of organic C in soils, may affect SQ in WE. The efficiency of these strategies may differ both in terms of the abatement of GHG emissions and economic costs, as shown for ten possible measures in French farms (Pellerin et al., 2013). Among these measures, those directly affecting soil and soil management had positive (cover crops, hedges), very little (legume crops, agroforestry, reduced tillage) and negative (organic fertilizer application) effects in terms of net CO_2 abatement. Conversely, some agricultural practices that improve SQ have been observed to increase GHG emissions (Spiegel et al., 2014).

The new CAP structure offers the possibility of including climate action instruments in both Pillar 1 and Pillar 2; however, in some cases the impact of such measures is still uncertain. Nevertheless, according to (EU Agriculture, 2014), the new CAP will probably be one of the most important opportunities for the EU-28 to tackle the climate change issue. Implementation of CF and use of cover crops are included among the proposed measures to be adopted at farm level (Virto et al., 2015).

3.2.2. Strategies for soil quality

It can be concluded that SQ monitoring, assessment and protection are currently at different levels of development in Europe. Some promising strategies for increasing the awareness of SQ and improving its consideration in future policies include:

- the development of soil status and SQ monitoring networks at a continental scale;
- the inclusion of SQ and soil functionality issues in environmental and agricultural legislation;
- the research for accurate and, if possible, simple SQ monitoring tools;
- the implementation of multi-actor and multi-target strategies for promoting and increasing SQ awareness and the effective implementation of SQ-improving management practices.

The following has been based largely on (Virto et al., 2015) and some other authors. Monitoring SQ is essential to measure soil degradation and to develop appropriate strategies for soil protection. This includes the creation of international networks to address critical and crosscutting soil issues. In addition to national initiatives, Europe has several projects that address these issues. For example, the above-mentioned LUCAS survey and the recently launched (2013) European Soil Partnership (ESP) are added to previous initiatives under the support of the Joint Research Center of the EU, such as the European Soil Bureau and the European Soil Data Center, from which information on soils in the EU can be retrieved at the European Soil Portal (http://eusoils.jrc.ec.europa.eu/).

All these initiatives are supported by the JRC of the EU. The ESP is one of the regional partnerships of the Global Soil Partnership. The objective of this regional network is to bring together the various scattered networks and soil-related activities within a common framework, open to all institutions and stakeholders willing to actively contribute to sustainable soil management in Europe. The ESP has five main pillars of action, which include promoting sustainable management for soil protection, encouraging investment, technical cooperation, policy, educational awareness, and extension in soil, promoting soil research related to productive, environmental, and social development actions, enhancing the quantity and quality of soil data and information, and harmonizing methods, measurements and indicators for the sustainable management and protection of soil resources. These initiatives must account for the fact that sampling schemes suitable for inventory are not necessarily also suitable for monitoring (Lark, 2009)

Monitoring information on farm management practices, on how these practices affect the environment, and whether they correspond to recommended (or legislated) practices and standards may also contribute to early detection and assessment of SQ issues (Piorr, 2013). In relation to the inclusion of SQ issues in legislative and assessment tools (ii), the functional land management strategy recently proposed by Schulte and coworkers is a complete and promising model for developing policies that enable achievement of goal targets for productivity by considering and enhancing the capacity of soils to provide ecosystem services (Schulte et al., 2014). This strategy is based on optimizing five basic soil functions (biomass production, water purification, C sequestration, habitat for biodiversity and recycling of nutrients) by studying the potential of soils to supply these, as well the present and future demands by considering growth goals and environmental restrictions.

Although the study was proposed for Irish agricultural soils, it could be expanded to other European regions (including the EU). Another example of a decision tool that considers soil functions and that can be used to evaluate remediation alternatives for contaminated soils has been described by Volchko and coworkers (Volchko et al., 2014). This is based on the inclusion of selected ecological soil functions (basis for primary production, cycling of carbon, water, nitrogen, and phosphorus) in a multi-criteria decision analysis. The degree to which these functions are fulfilled in remediated sites is determined using a minimum data set of SQI (soil texture, coarse material, organic matter, available water, pH, potentially mineralizable nitrogen, and available phosphorus), which are scored and integrated in a SQ Index, in an approach very similar to that described in the SMAF (Wienhold et al., 2009).

A good example of the incorporation of soil functionality criteria in legislative frameworks is the ongoing process in the above-mentioned SSF in Scotland. This framework aspires to develop the EU Soil Thematic Strategy for Scottish soils, providing a legislative framework for soil protection that accounts for the inherent soil quality and the multi-functional roles. The declared aim of this SSF is to promote the sustainable management and protection of soils consistent with the economic, social, and environmental needs of Scotland. The framework identifies more than 35 actions in different fields (research, soil conservation, land management, etc.) linked to expected soil outcomes. Each action has a delivery date and designates the persons or bodies responsible for its accomplishment. These actions include the development of a Scottish soil-monitoring network and review of the land capacity for agriculture. The monitoring network focuses on the functions of soils related to ecosystem services.

This strategy will be included in the more general strategy for land use (Dobbie et al., 2014), which includes for instance, the rationale for woodland expansion. In this rationale, a soil-based evaluation of land is made to protect sensitive soils (such as peatland soils) or high-quality agricultural land, which provide essential services such as C sequestration and food production, from being converted into forest plantations. Another challenging aspect in many areas in the future is the development of adequate SQI (iii) (Panagos et al., 2013) and establishment of the relationship between their levels and soil functions for different areas and land uses across WE, as indicated for levels of soil organic matter (Hanegraaf et al., 2009). In this sense, although much work has been done in some aspects (for instance in relation to climate change mitigation and adaptation strategies), research for developing SQ assessment tools and SQI in other aspects is still pending in WE. For example, new methodological approaches for soil biodiversity measurement are being developed (Gardi et al., 2009), as well as new tools to assess land susceptibility to wind erosion (Borrelli et al., 2014). New techniques such as near-infrared reflectance spectroscopy are being considered for the evaluation of SQ and soil properties (Cécillon et al., 2009; Moreira et al., 2009).

Finally, attempts to broaden the participating agents (multi-actor) and the objectives (multi-target) of new soil management strategies that enable improved SQ (iv) also exist in WE. For example, the LIFE project series devoted to soil degradation problems and soil protection aims to translate science and policy into practice (Camarsa et al., 2014). These measures enable the involvement of stakeholders in the launching and demonstration of new techniques and systems for sustainable soil use in the EU. There is a special need for developing cost/benefit analysis, such as that recently developed for GHG abatement in French agriculture (Pellerin et al., 2013).

3.2.3. Soil quality

The formal concept of soil quality (SQ) was developed in the second half of the last century (Tóth et al., 2008a), in response to the need to assess soil degradation problems from a holistic perspective (Tóth et al., 2008b; Andrews et al., 2004; Karlen et al., 2003). Assessment of SQ is complicated by the fact that soil is a heterogeneous resource for which it is difficult to establish quality standards. Thus, SQ has not been defined by established universal criteria, but as the capacity of a given soil to function (Karlen et al., 199). Proper soil functioning is understood as the capacity of a soil to accomplish its natural (ecosystemic), social and economic functions in a sustained way over time (Blum, 2008). Defining soil functions was one of the goals of the European Thematic Strategy for Soil Protection (Virto et al., 2015). Five critical soil functions have been identified:

1. production of food and other biomass;
2. storage, filtration and transformation of minerals, water and other elements including C;
3. supply of habitat and gene pool for a variety of organisms;
4. acting as the physical and cultural environment for mankind (present and past);
5. as a source of raw materials.

The Commission's Communication (COM (2002) 179) states that most of these functions are inter-dependent and the development of some of them (raw materials, physical environment for mankind) may imply a reduction in the ability of soils to accomplish the others. Since this Communication was launched, some efforts have been made to develop SQ monitoring systems, mainly within the EU. At the continental level, the basis for SQ and sustainability evaluation was established via definition of a common framework to assess soil functions, degradation threats and soil-use options (Tóth et al., 2007). This framework proposed a three-step evaluation in which the capacity of a given soil to accomplish a selected function is first evaluated. The existing threats for the considered soil and soil function are then determined, and finally, the capacity of the soil to accomplish the function is evaluated for different levels of pressure from the threats identified in the second step. This approach acknowledges that the results of the three steps, and especially the sensitivity of a soil to different threats, is soil- and site-dependent. This implies that the soil functional ability (number of functions that a soil can accomplish) and the soil responses to different levels of human-induced or natural threats (soil response capacity) must be evaluated to define SQ for a given soil (Tóth, 2008).

The development of this framework requires detailed information on soil types, soil characteristics and threats to soil in each area studied. Its full development in detail therefore seems complicated. A first step is the identification of risk areas based on clearly described criteria (Eckelmann et al., 2006) for the identified threats to soil. Strategies for evaluating the risk of SOM decline, soil erosion, soil compaction, salinization, and landslides in WE have been suggested (Eckelmann et al., 2006). For each of these, the authors provided the information needed to evaluate the risk of soil degradation based upon soil/topography/climate parameters in each site. For most sites, it was concluded that determining quantitative scores or thresholds requires more accurate information than is currently available.

The ENVASSO project is another important pan-European attempt to advance towards the identification of SQ indicators (SQI) and baseline values. The main aim of this project was the creation of a comprehensive, harmonized soil information system in Europe via the design and testing of an integrated and operational set of indicators (Turbé et al., 2014; Pulleman et al., 2012). Its output (Kibblewhite et al., 2008; Hubert et al., 2008) includes selected indicators, threshold and baseline levels for the major soil threats identified in the European Thematic Strategy for Soil Protection (COM(2002) 179 final) and its subsequent evaluations (e.g., COM(2012)46). For each soil threat, three parameters were selected from an initial base of 290 indicators (Kibblewhite et al., 2008). Some of the selected soil parameters are measured values, and others are estimated through modelling. The indicators were selected by experts, following these criteria: relevance for assessing each soil threat, ease of application, link to policy aims and applicability in a pan-European context.

Baseline and threshold values were established for some of these indicators. However, it is recognized that such values may have to be established separately for different areas in Europe because of the variety of soil types and the variability in environmental conditions and land use. Table 1 summarizes the soil threats and properties suggested as indicators by the ENVASSO Project team, and which of those were finally selected as the best indicators for each threat. The performance of those indicators was tested in different pilot areas in Europe, and the results of these tests have been reported in detail (Micheli et al., 2008; Stephens et al., 2008). Complete descriptions of the protocols that should be used in each case have been published (Jones et al., 2008). The purpose of drawing up this list of indicators was to establish a monitoring network in which changes in soil characteristics can be periodically controlle (Morvan et al., 2008).

Development of the European Soil Data Centre provides additional mechanisms for reporting information on soil and SQ data and adequate definitions of SQ, SQI and monitoring networks (Panagos et al., 2014).
The spatial density of soil monitoring networks is very non-homogeneous in WE, with no or very few systematic sampling sites available for many of the indicators shown in Table 1 (Morvan et al., 2008). In fact, some of those SQI (e.g., those related to soil erosion or soil organic C) have been monitored with much higher intensity and frequency than others such as soil biodiversity (Turbé et al., 2014).

The LUCAS (Land Use/Land Cover Area Frame Survey) represents the first effort to build a consistent spatial database of the topsoil (0–30 cm) cover across Europe, based on standard sampling and analytical procedures (Tóth et al., 2013). The aim of LUCAS is to gather harmonized information on land use/land cover and several soil properties, such as soil texture, organic carbon, nitrogen content, pH and cation exchange capacity. The survey also provides territorial information for the analysis of the interactions between agriculture, environment, and countryside, such as irrigation and land management. LUCAS field surveys have been carried out every three years since 2006 (Virto et al., 2015).

Table 1. Proposed and selected soil properties for monitoring soil quality in the Environmental Assessment of Soil for Monitoring (ENVASSO) Project (Virto et al., 2015).

Soil Threat	Soil Indicator *	Source $	Baseline	Threshold
Soil contamination Diffuse and local	**Heavy metal content**	M	National background levels	National legislation
	Nutrient balance	M	Average national balance	Defined at a regional level
	Organic pollutant concentration	M	National background levels	National legislation
	Topsoil pH	M	Not defined	Not defined
Salinization	**Salt profile**	M	EC saturation extract < 2 dS/m	0.10% salt content or EC_e < 4 dS/m
	Exchangeable sodium percentage (ESP)	M	<5%	>15%
Soil compaction	**Density (bulk, packing and total density)**	M/E	Measured in non-compacted soils	Packing density: 1.75 g/cm^3
	Air-filled pore volume at a specified suction	M	Measured in non-compacted soils	Air-filled pore vol. at 5 KPa >10%
	Permeability	M	Not defined	Not defined
	Mechanical resistance	M	Dependent on soil structure status	Penetration resistance < 2–5 MPa
	Structure status	E	Not defined	Not defined
	Vulnerability to compaction	E	Not defined	Persistent (not recoverable)
	Drainage	E/M	Not defined	Not defined
	Precompression strength	E	Measured in non-compacted soils	<90–120 KPa
Decline in SOM	**Topsoil organic carbon content** §	M	Not defined	Not defined
	Soil organic carbon stock	M	Not defined	Not defined
	Peat stocks	E	Not defined	Not defined
	Topsoil C:N ratio	M	Not defined	Not defined
Soil biodiversity	Microbial and fungal diversity	M	Not defined	Not defined
	Earthworm diversity and fresh biomass	M	Not defined	Not defined
	Macrofauna diversity	M	Not defined	Not defined
	Collembola/Enchytraeid diversity	M	Not defined	Not defined
	Acari diversity	M	Not defined	Not defined
	Nematode diversity	M	Not defined	Not defined
	Microbial respiration	M	Not defined	Not defined
	Microbial activity (enzymes)	M	Not defined	Not defined
Erosion Water, wind and tillage erosion	**Estimated soil loss**	E	Water and tillage erosion: N Europe 0–3 ton/ha*year S Europe 0–5 ton/ha*year Wind: N&S Europe: 0–2 ton/ha*year	Water and tillage erosion: N Europe 1–2 ton/ha*year S Europe 1–2 ton/ha*year Wind: N&S Europe: 2 ton/ha*year
	Measured or observed soil loss	M	Water: 0.5 ton/ha*year	Water: 1–2 ton/ha*year
Soil sealing	No soil properties as indicators			
Landslides	No soil properties as indicators			

* Indicators shown in bold type are within the three selected for each threat; $ M: measured; E: estimated or calculated; § For desertification: SOM in desertified land, salt content in desertified land and soil biodiversity in desertified land; Sources: (Kibblewhite et al., 2008; Hubert et al., 2008; Morvan et al., 2008).

3.2.4. Soil degradation issues

The European Environment Agency (EEA) and the Joint Research Center (JRC) of the European Commission have published numerous papers and reports describing soil degradation problems in Europe, in some cases, with special emphasis on Western Europe (e.g., (Jones et al., 2012; EEA, 2000; EEA, 2003).

From a general perspective, soil degradation problems can be classified into four major groups:

1. chemical;
2. physical;

3. biological degradation (including soil organic matter decline);
4. soil loss.

Land-use changes can be considered as a cross-cutting factor that also affects soils (Virto et al., 2015).
The ENVASSO Project (Environmental Assessment of Soil for Monitoring), which involved 37 partners drawn from 25 EU Member States, represents a significant step in the identification of these problems and in the quantification of their spread and importance (Kibblewhite et al., 2008). The major problems of chemical degradation are soil contamination, soil salinization and acidification, and nutrient depletion (Tóth et al., 2008a). The causes of these problems are varied, as are their relationships with agricultural management (Virto et al., 2015). In general, agriculture and agricultural soil management are not related to contamination. Data on diffuse contamination, which is in many cases related to agriculture, are scarce and inaccurate owing to the lack of harmonized requirements for gathering this type of information in the different countries (Jones et al., 2012).

The overuse of plant protection products and fertilizers are usually highlighted as significant sources of diffuse soil contamination associated with agricultural production in Western Europe (EEA, 2012). Unlike in Eastern Europe, the use of fertilizers generally decreased in WE (in ton ha^{-1} and total ton) during the decade (2000–2012). Much of this decrease is due to the implementation of legislation to prevent contamination of fresh water due to agricultural activities in the EU (such as the Nitrate Directive 676/1991 and the Water Framework Directive 60/2000).
However, the rates of application of N and P vary widely between different regions. The highest average inputs of N and the highest share of manure to the total N fertilizer application have traditionally been observed in The Netherlands and Belgium (>300 kg/ha in 2008) (Eurostat, 2014). On the other hand, Spain and Portugal, while using only an average of 89 and 79 kg N ha^{-1}, respectively, in 2008, used less manure, although the amounts appear to be increasing. Differences in the way the data are reported by each country make straightforward comparisons difficult. The variability within countries is also high, with irrigated agriculture accounting for much higher N and P doses than dryland areas, especially in the Mediterranean region (Bouraoui et al., 2008; Virto et al., 2015).

Soil organic matter (SOM), in particular organic C (SOC), has been in the spotlight of soil research for decades. At the European level, an overwhelming amount of research on SOC storage, gains and losses in soils has been conducted on different scales. However, the high variability and diversity of data make comparisons difficult (Lugato et al., 2014). A general view on the average content in SOC of European soils is that most of South Europe is covered by soils with less than 2% SOC (Jones et al., 2005). This is related to both climate and historical land use. Many areas of France fall also below this threshold. The average SOC contents are higher in northern countries, the UK and Ireland (Virto et al., 2015). The reasons for the generally observed decline in SOC in agricultural soils in WE Europe have been summarized (Kibblewhite et al., 2008). These include conversion of grassland, forests and natural vegetation to arable land, deep ploughing of arable soils, intensive tillage operations, overfertilization (Jones et al., 2012), drainage, liming, fertilizer use and tillage of peat soils, crop rotations with reduced proportion of grasses, soil erosion, and wildfires. The latter two are of particular importance in Mediterranean countries (Shakesby, 2011; Virto et al., 2015).

At a national level, some long-term studies have reported changes in the SOC contents of agricultural soils. For instance, losses of 0.5–2 g SOC/kg soil per year were observed in England and Wales between 1973 and 2003 (Bellamy et al., 2005). A large-scale inventory in Austria revealed that croplands were losing 24 g C/m^2 annually (Capriel, 2013). In Southern Belgium, losses of 0.12 t/ha per year were reported for croplands, but with an increase 0.44 t/ha in grasslands between 1955 and 2005 (Goidts and van Wesemael, 2007). Grasslands on sandy soils in the

Netherlands displayed a non-homogeneous trend, with some gains and some losses of SOC between 1984 and 2004. Continuous maize crops on the same soils systematically lost SOC in the period mentioned (Hanegraaf et al., 2009). A slight average increment of 0.10 and 0.08 g SOC/kg soil in grasslands and arable land was reported for the same period (Reijneveld et al., 2009). In France, long-term observations (e.g., Saby et al., 2008) show decreasing stocks in many regions, because of deforestation, conversion of grassland into cropland, increasing cropping intensity or climate change. Vineyards and arable land display the lowest SOC contents overall (Micó et al., 2006). An overall decrease in SOC was also recently observed in Bavarian cropland, although the variability was high, with some plots showing no change or a net increase between 1986 and 2007 (Capriel, 2013). This was also reported in France, where some intensely cultivated areas showed stable or slightly higher SOC stocks over time (Micó et al., 2006; Virto et al., 2015).

Despite these regional-scale studies, consistent figures for SOC stocks and how they change at European level are still scarce (Jandl et al., 2014). The interaction between SOC and climate change is an important issue that complicates predictions about SOC changes in relation to future land-use changes in WE in (Lugato et al., 2014). Recent simulations predicted an overall increase in this pool in agricultural soils in Europe, with a non-homogeneous distribution (Lugato et al., 2014), including C losses in the South, which could be compensated by a gain in Central and Northern regions. This model also showed pastures in the UK, Ireland, the Netherlands and France as the dominant SOC reservoirs, while permanent crops (olives, vineyards and orchards) accounted for only 3% of the total SOC stock, despite being widespread in Southern Europe. Arable land was predicted as containing 43% of the total stock of C, while it represents 53% of the total agricultural surface. In forest soils, harvesting activities and site preparation may lead to the removal of the humus layer from more than 80% of the surface (Martínez de Arano et al., 2007; Virto et al., 2015).

3.3. Agri-environmental measures and agricultural sustainability indicators

Agri-environmental measures (AEM) are incentive-based instruments in the European Union (EU) that provide payments to farmers for voluntary environmental commitments related to preserving and enhancing the environment and maintaining the cultural landscape (Uthes and Matzdorf, 2012). The existing research by Uthes and Matzdorf (2012) is either biased toward ecological or economic perspectives and fails to provide a holistic picture of the problems and challenges within agri-environmental programming (e.g., multiple measures, multiple target areas, legal aspects, financial constraints, transaction costs). Most empirical studies provide detailed insights into selected individual measures but are incapable of providing results at a level relevant to decision-making, as they neglect the role of farmers and the available AEM budget (Uthes and Matzdorf, 2012).

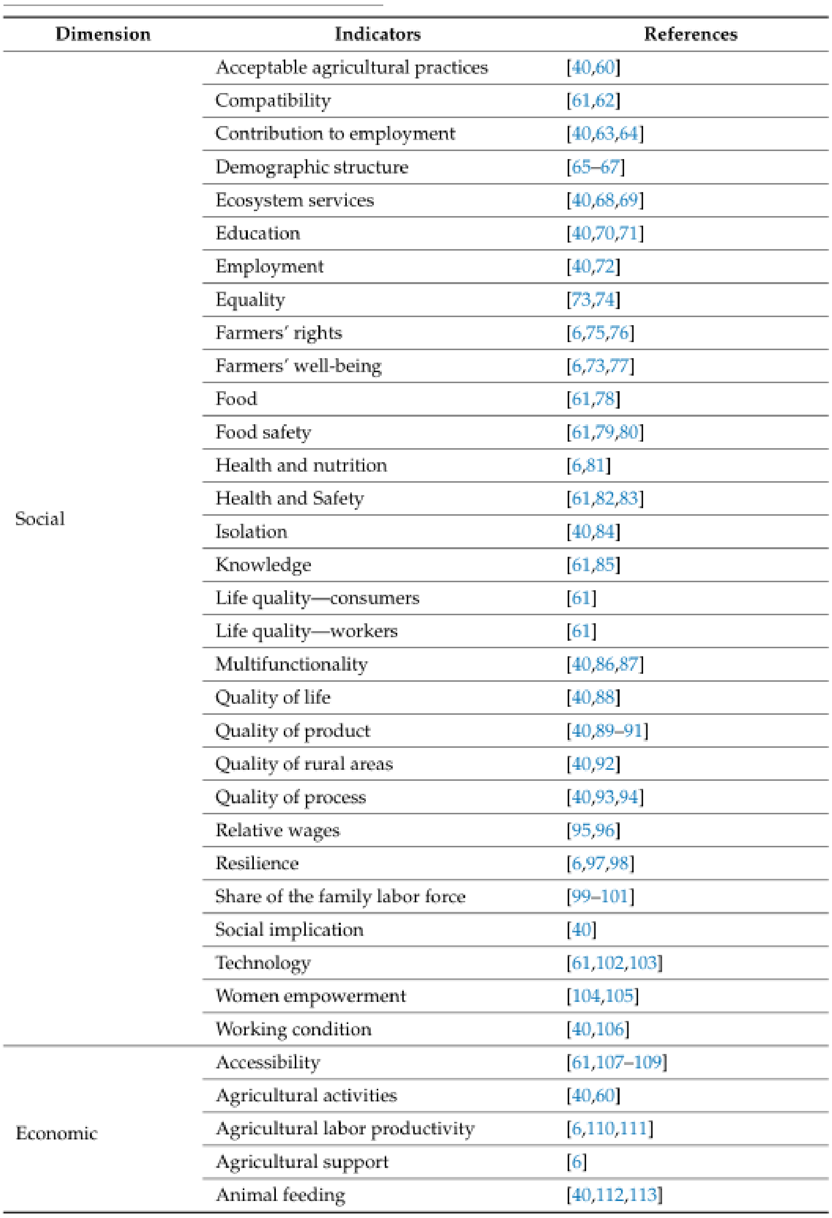
Predominantly Economic approaches often only consider rough assumptions of ecological and economic processes and are also not suitable for decision-making. Decision-support tools that build on these disciplinary results and simultaneously consider scheme factors and environmental conditions at high spatial resolution for application by the responsible authorities are rare and require further research (Uthes and Matzdorf, 2012).

A large pool of literature on agri-environmental measures (AEM) has become available in recent years as a result of their growing importance in terms of budgetary allocations and land area coverage since their inception in some EU member states during the 1980s. Since the Agenda 2000 reform of the Common Agricultural Policy (CAP)1 in 1999, AEM have become mandatory for all EU member states.

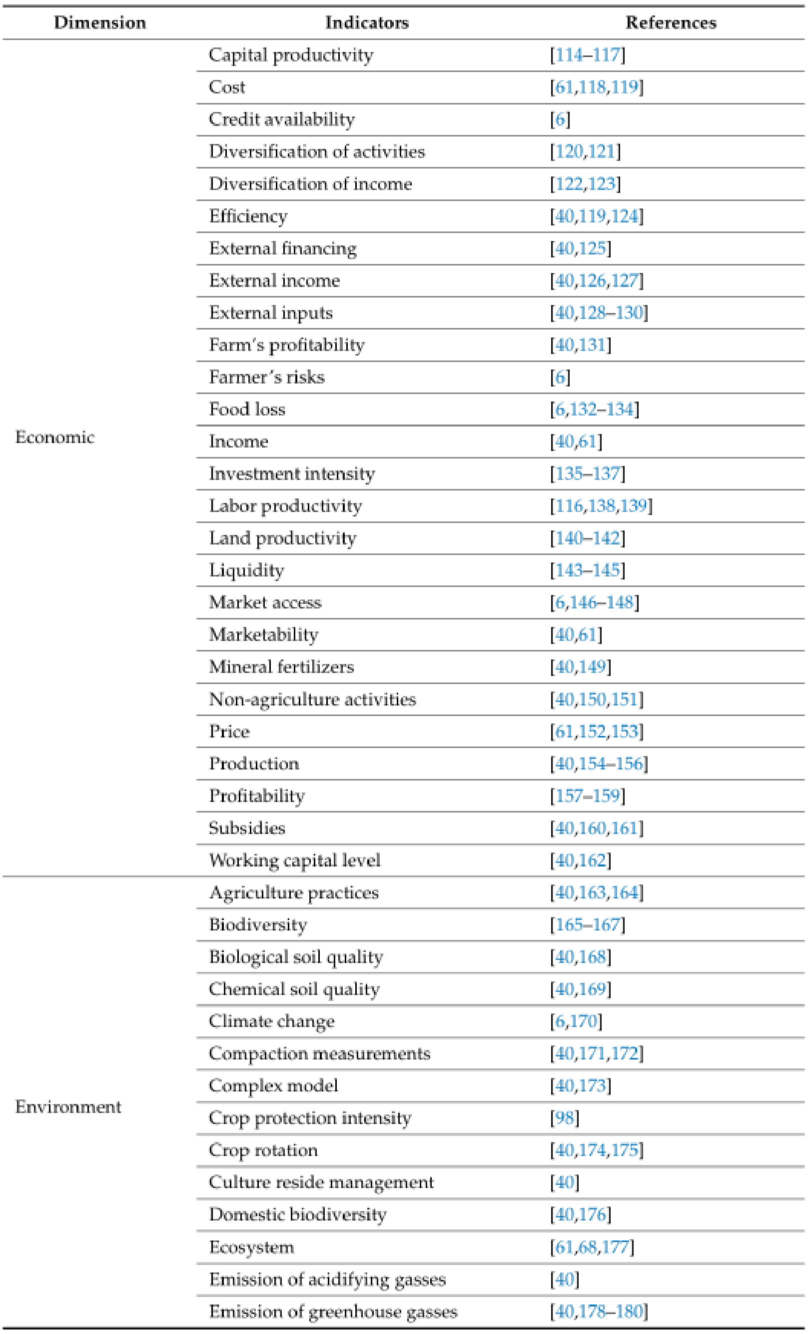
The majority of AEM are management agreements that provide compensation payments to farmers for the temporary adoption of input-reducing practices, such as adaptations to crop rotations, reduced fertilizer and pesticide application rates or organic farming, landscape and habitat measures as well as the raising of endangered domestic breeds of animals. The existence of AEM can be justified from an institutional economics perspective (Uthes and Matzdorf, 2012). The stated objectives of AEM are often vague, such as ‘‘to encourage farmers to protect and enhance the environment on their farmland by paying them for the provision of environmental services’’ while the definition of measurable normative objectives and indicators is uncommon (Prager and Nagel, 2008).

The analysis of extracting study of agricultural sustainability indicators by Bathaei, Štreimikienė (2023) reveals a total of 157 papers. Table 2 shows the indicators that are extracted from these papers. For the social dimension, 30 indicators were found from 49 papers; from 78 papers that related to the economic dimension, 31 indicators were found; for the environment, 40 indicators were found from 77 papers. Table 2 shows the obtained indicators from previous studies. These indicators grouped by the three dimensions (Bathaei, Štreimikienė, 2023).

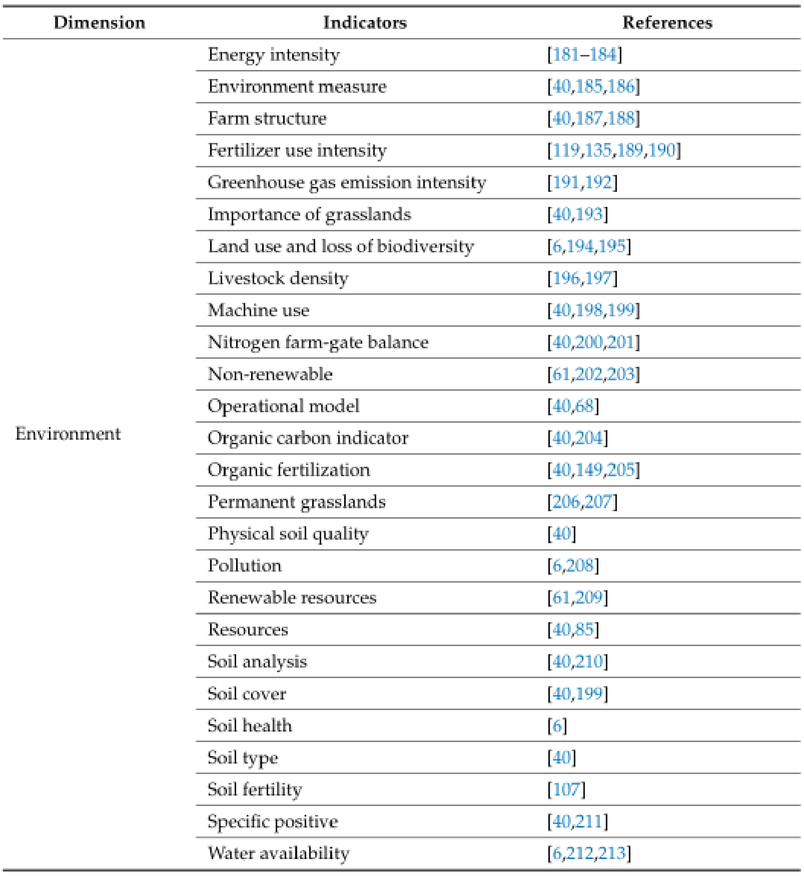
Table 2. Indicators of sustainable agriculture (Bathaei, Štreimikienė, 2023).



Dimension	Indicators	References
Social	Acceptable agricultural practices	[40,60]
	Compatibility	[61,62]
	Contribution to employment	[40,63,64]
	Demographic structure	[65–67]
	Ecosystem services	[40,68,69]
	Education	[40,70,71]
	Employment	[40,72]
	Equality	[73,74]
	Farmers' rights	[6,75,76]
	Farmers' well-being	[6,73,77]
	Food	[61,78]
	Food safety	[61,79,80]
	Health and nutrition	[6,81]
	Health and Safety	[61,82,83]
	Isolation	[40,84]
	Knowledge	[61,85]
	Life quality—consumers	[61]
	Life quality—workers	[61]
	Multifunctionality	[40,86,87]
	Quality of life	[40,88]
	Quality of product	[40,89–91]
	Quality of rural areas	[40,92]
	Quality of process	[40,93,94]
	Relative wages	[95,96]
	Resilience	[6,97,98]
	Share of the family labor force	[99–101]
	Social implication	[40]
	Technology	[61,102,103]
	Women empowerment	[104,105]
	Working condition	[40,106]
Economic	Accessibility	[61,107–109]
	Agricultural activities	[40,60]
	Agricultural labor productivity	[6,110,111]
	Agricultural support	[6]
	Animal feeding	[40,112,113]



Dimension	Indicators	References
Economic	Capital productivity	[114–117]
	Cost	[61,118,119]
	Credit availability	[6]
	Diversification of activities	[120,121]
	Diversification of income	[122,123]
	Efficiency	[40,119,124]
	External financing	[40,125]
	External income	[40,126,127]
	External inputs	[40,128–130]
	Farm's profitability	[40,131]
	Farmer's risks	[6]
	Food loss	[6,132–134]
	Income	[40,61]
	Investment intensity	[135–137]
	Labor productivity	[116,138,139]
	Land productivity	[140–142]
	Liquidity	[143–145]
	Market access	[6,146–148]
	Marketability	[40,61]
	Mineral fertilizers	[40,149]
	Non-agriculture activities	[40,150,151]
	Price	[61,152,153]
	Production	[40,154–156]
	Profitability	[157–159]
	Subsidies	[40,160,161]
	Working capital level	[40,162]
Environment	Agriculture practices	[40,163,164]
	Biodiversity	[165–167]
	Biological soil quality	[40,168]
	Chemical soil quality	[40,169]
	Climate change	[6,170]
	Compaction measurements	[40,171,172]
	Complex model	[40,173]
	Crop protection intensity	[98]
	Crop rotation	[40,174,175]
	Culture reside management	[40]
	Domestic biodiversity	[40,176]
	Ecosystem	[61,68,177]
	Emission of acidifying gasses	[40]
	Emission of greenhouse gasses	[40,178–180]



Dimension	Indicators	References
Environment	Energy intensity	[181–184]
	Environment measure	[40,185,186]
	Farm structure	[40,187,188]
	Fertilizer use intensity	[119,135,189,190]
	Greenhouse gas emission intensity	[191,192]
	Importance of grasslands	[40,193]
	Land use and loss of biodiversity	[6,194,195]
	Livestock density	[196,197]
	Machine use	[40,198,199]
	Nitrogen farm-gate balance	[40,200,201]
	Non-renewable	[61,202,203]
	Operational model	[40,68]
	Organic carbon indicator	[40,204]
	Organic fertilization	[40,149,205]
	Permanent grasslands	[206,207]
	Physical soil quality	[40]
	Pollution	[6,208]
	Renewable resources	[61,209]
	Resources	[40,85]
	Soil analysis	[40,210]
	Soil cover	[40,199]
	Soil health	[6]
	Soil type	[40]
	Soil fertility	[107]
	Specific positive	[40,211]
	Water availability	[6,212,213]

3.4. Decision support process

This paragraph is largely based on Sullivan (2002). Decision support methods codify expert knowledge and expertise into a "stored" method or process. The decision support methods use specific information for a particular problem; with the aim of providing a concise representation of the essential decision-making issues for that problem. Hence, decision support integrates information to produce usable knowledge, as illustrated in Figure 2. For example, consider the decision to select between two different remedial alternatives. The analyst would start with knowledge about the nature and extent of contamination. This information would be used to estimate the volume requiring treatment based on the "stored" knowledge (e.g., best practice, regulatory limits, cost data, data management and analysis techniques including interpolation, etc.). This information could then be used as the basis for the selection and/or design of the remedial options. For example, "stored" information on typical remediation costs could be used to estimate likely project costs.

Other knowledge such as the degree of uncertainty in the volume requiring remediation and the reliability of the different remedial options could also be evaluated. The decision maker would then be presented with information on costs, probability of success, and what is being treated for the money spent to support the decision on a course of action. Decision support methods help to make the decision-making process transparent, documented, reproducible, robust, and provide a coherent framework to explore the options available. Figure 2 illustrates the stages used to arrive at decision support knowledge for a typical site.
The stages of the decision support process are confined within the dotted lines of Figure 2. Taking the decision is illustrated as being supported by the process. The first stage in the decision support process is to use experience and

site-specific information (for example relating to the source terms, pathways, and receptors) and site-specific data (for example, soil properties and hydrology).

The second stage uses this information to develop simple conceptual models of the site behaviour. The conceptual model is the basis for the analysis (third stage in the process) which combines information on the technology being proposed (if any) and the information used to form the conceptual model. Often all this information is processed in computer software. There are several reasons for the use of software. First, the sheer amount of data in many problems favours electronic storage and manipulation. Second, the complexity of the analysis (e.g., geostatistics, groundwater flow and transport, human health risk assessment) requires many calculations, which can easily be done on a computer. Third, the use of computers permits rapid evaluation of the effects of changing parameters or scenarios. This may permit uncertainties to be addressed. For example, to determine the effectiveness of different remedial options, estimates of contaminant concentrations before and after remediation may be determined through a combination of data, geostatistical interpolation and flow and transport models. Usually, this information must be interpreted and analysed in terms of the decision variable (fourth stage in the process). In this example, the contaminant concentrations can be compared to regulatory thresholds and the region that exceeds the threshold can be defined for each remedial option.

The interpretation and analysis may be facilitated by the computer software, but it is the responsibility of the analyst to insure, that the analysis is accurate, and the output is in a form useful for decision making.
The knowledge supplied to the decision makers (fifth stage) should be transparent and readily understandable by different stakeholders, not just specialists. Indeed, even specialists might struggle with the sheer volume of detail that arises from many sites, and so require some form of rational abstraction of information into a more manageable volume and level of detail. These five stages form the basis for decision support, which uses information abstracted from other (and often more detailed) analyses.

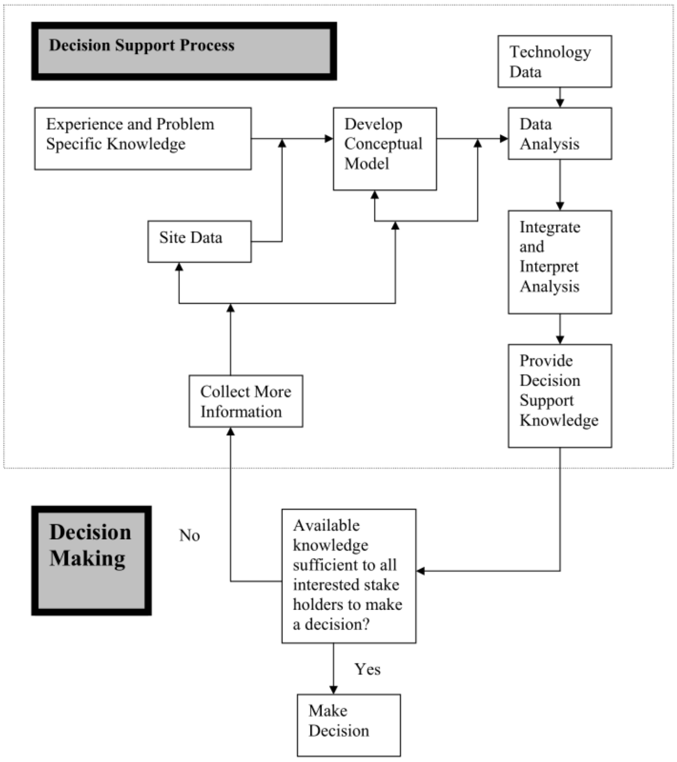


Figure 2. Flow chart containing the essential steps in the decision support process.

Decision knowledge is supplied to the decision makers, who then evaluate whether all stakeholders agree that the information provided is sufficient to support a decision. All environmental decisions are made with some degree of uncertainty. Complete knowledge is never available or attainable. If the stakeholders conclude that a decision can not be made, they may request additional data, improved conceptual models, consideration of different technologies or refined analysis. The process of providing decision support is repeated with the new information until a decision can be reached. In some cases, it may not be possible to get all stakeholders to agree to an approach. When this occurs, the process may be vulnerable to litigation.

Figure 2 also includes the idea that using models is not the same as decision support. Rather using models, and modeling techniques and software, is a step-in information collection that precedes decision making. It is the integration of model results and their interpretation in terms of the decision variable that supplies decision support. This is an important distinction and is made on the basis that decision support implies making usable information available to a variety of stakeholders. A variety of stakeholders may play a role in contaminated land decision making, for example: landowners/problem holders; regulators and planners; site users; those with a financial connection to a site; the neighbours to a site including the local community; the consultants, contractors, researchers and vendors involved in designing and implementing the remediation.

In some cases, campaigning organizations and pressure groups may also seek involvement. Clearly, it would be an unlucky site manager who had to defend his decision making against all of these stakeholders simultaneously, but any decision made should be clear to them. In particular the site owner and a busy regulator, dealing with a variety of issues, not just contaminated land, will want reliable information that can be easily and quickly understood.

Decision support exists within three broad sets of boundaries: the range of technical possibilities; the level of detail that is appropriate and the legislation and regulations pertinent to the decision.
An effective decision support tool needs to offer options that are both technically and economically feasible and permitted by regulators, the public and other stakeholders. In a practical sense, it is equally important that the level of detail is appropriate. The level of detail provided to the decision-makers must be sufficiently explanatory, but it must also be readily understood (as pointed out above). The implications of excess detail are not only reducing the helpfulness of the decision support, but also increasing the cost of the decision support knowledge.

3.5. Decision support systems

3.5.1. A brief history of decision support systems

The term ‘decision support systems’ first appeared in a paper by Gorry and Scott Morton (1971), although Andrew McCosh attributes the birth date of the field to 1965, when Michael Scott Morton’s PhD topic, ‘Using a computer to support the decision-making of a manager’ was accepted by the Harvard Business School (McCosh, 2004). Gorry and Scott Morton (1971) constructed a framework for improving management information systems using Anthony’s categories of managerial activity (Anthony, 1965) and Simon’s taxonomy of decision types (Simon, 1960/1977; Arnott and Pervan, 2005).

Gorry and Scott Morton conceived DST as systems that support any managerial activity in decisions that are semistructured or unstructured. Keen and Scott Morton (1978) later narrowed the definition, or scope of practice, to semistructured managerial decisions; a scope that survives to this day. The managerial nature of DST was axiomatic in Gorry and Scott Morton (1971), and this was reinforced in the field's four seminal books: Scott Morton (1971), McCosh and Scott Morton (1978), Keen and Scott Morton (1978), and Sprague and Carlson (1982), Arnott and Pervan (2005).

Much of the early work on DST was highly experimental, even radical (Alter, 1980; Keen and Gambino, 1983). The aim of early DST developers was to create an environment in which the human decision maker and the IT-based system worked together in an interactive fashion to solve problems; the human dealing with the complex unstructured parts of the problem, the information system providing assistance by automating the structured elements of the decision situation. The emphasis of this process was not to provide the user with a polished application program that efficiently solved the target problem. In fact, the problems addressed are impossible, or inappropriate, for an IT-based system to solve completely. Rather, the purpose of the development of a DST is an attempt to improve the effectiveness of the decision maker (Arnott and Pervan, 2005).

Sprague and Watson (1986) defined DST as a system that makes some contribution to decision making while Stuth and Lyons (1993) explained the term as contemporary jargon for an integrated approach to the age-old problem of helping people to make better decisions. Makowski (1994) proposed that DST are computerized tools to analyze large amounts of data and complex relations for making rational decisions. Klosterman (1997) explains the term 'DST' as a system or methodology that assists poorly or ill-structured decisions by facilitating interactive and participatory decision processes. Although the DST developed significantly in the following decades, no single definition is widely accepted (Claire, 1997; Huy, 2009).

A DST can be defined as an interactive computer-based system designed to support a decision-maker in a complex environment (Keen and Scott Morton, 1978). SDST are different from the ordinary DST in that they integrate GIS and model base management system capabilities. The common feature of GIS systems is their focus on the capture, storage, manipulation, analysis, and display of geographically referenced data (Malczewski, 2000; Huy, 2009).

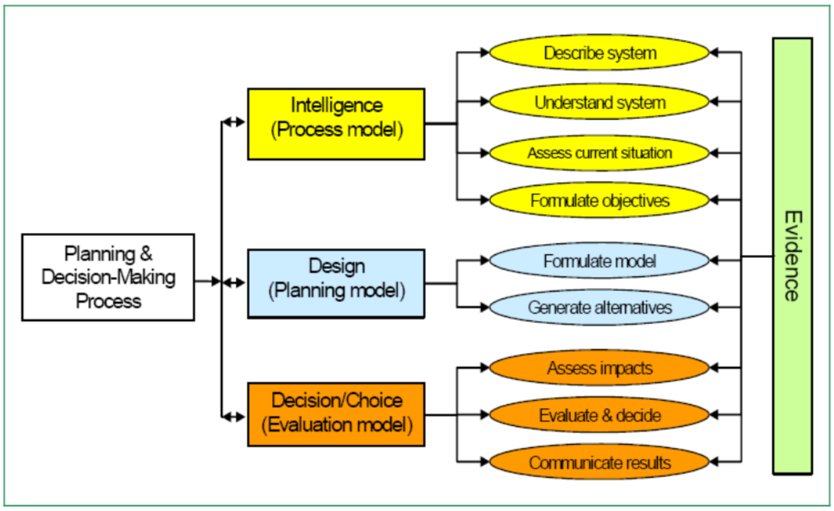


Figure 3. Planning and decision-making processes explained by Sharifi and Rodriguez (2002) based on Simon's model (1960)

Jozefowska and Zimniak (2008) has developed a DST for short-term production planning and scheduling. The system has two phases: In the first phase a rule-based expert system is used to reduce the space of feasible solutions in two ways. On one hand soft constraints are introduced in form of production rules.

On the other hand, the expert experience can be used to formulate rules eliminating solutions, which are very likely to be dominated by other solutions. In the second phase, a multiple criteria genetic algorithm is applied to find a set of potentially Pareto-optimal solutions (Jozefowska and Zimniak, 2008; Huy, 2009).

In a real sense, DST is a philosophy of information systems development and use and not a technology. DST is not a homogenous field. There are a number of fundamentally different approaches to DST and each has had a period of popularity in both research and practice. Each of these 'DST types' represents a different philosophy of support, system scale, level of investment, and potential organisational impact (Arnott and Pervan, 2005).

They can use quite different technologies and may support different managerial constituencies. Figure 4 extends the analysis of Silver (1991) and traces the evolution of the field from its radical beginnings to a complex disciplinary structure of partially connected sub-fields. In the figure, the emphasis is on the theoretical foundations of each DST type. The decades indicated on the left-hand side of the diagram refer only to the DST types and not to the reference disciplines (Arnott and Pervan, 2005).

Another dimension of the evolution of DST is improvement in technology (Figure 4), as the emergence of each of the DST types has usually been associated with the deployment of new information technologies. The nature and development of each DST type is discussed in detail below.

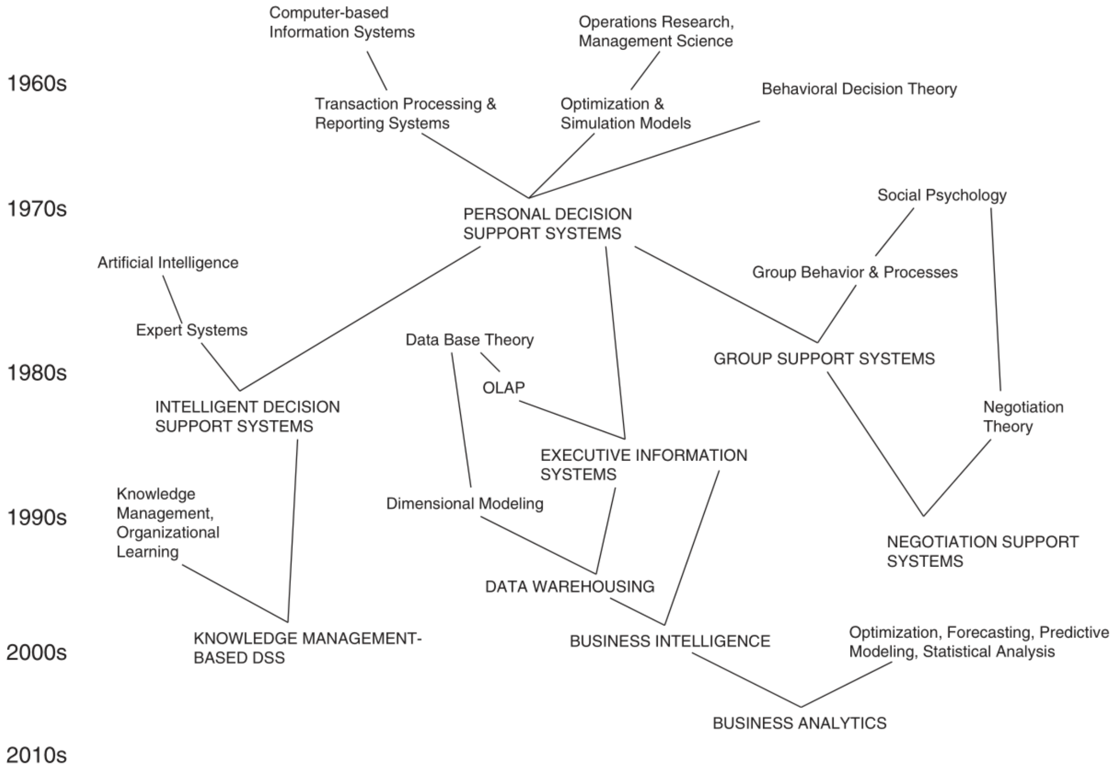


Figure 4. The genealogy of the DST field, 1960–2010 (Arnott and Pervan, 2014)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

Table 3. Alter's taxonomy of DST (Arnott and Pervan, 2005).

Technical orientation	*System types*	*Description*
Data-oriented	File drawer systems	Allow immediate access to data items
	Data analysis systems	Allow manipulation of data by tailored or general operators
	Analysis information systems	Provide access to a series of databases and small models
	Accounting models	Calculate the consequences of planned actions using accounting definitions
Model-oriented	Representational models	Estimate the consequences of actions without using or partially using accounting definitions
	Optimization models	Provide guidelines for action by generating an optimal solution
	Suggestion models	Provide processing support for a suggested decision for a relatively structured task

3.5.2. Characterization of Decision Support Systems

Decision Support System (DST) has been used and defined in various ways depending upon the author's point of view (Power, 2002; Druzdzel and Flynn, 1999; Power, 1997) defines it as "useful and inclusive term for many types of information systems that support decision making". For (Finlay et al., 1994), it is "a computer-based system that aids the decision-making process". Turban (1995) has defined it specifically as "an interactive, flexible, and adaptable computer-based information system, especially developed for supporting the solution of a non-structured management problem for improved decision making". Little (1970) define DST as "model-based set of procedures for processing data and judgments to assist a manager in decision-making". Keen and Scott-Morton (1978) define DST as "Computer-based support for management decision making". Moore and Chang (1980) define it as "extensible systems capable of supporting adhoc data analysis and decision modelling, used in future planning". Sprague and Carlson (1982) described DST as "interactive Computer-based systems that help decision makers to solve unstructured problems using data and/or models". Keen (1980) is not of the opinion to give DST a precise definition. For him "there can be no definition of DST". He further adds that DSTs have typically quantitative output and place emphasis on the end-user for final problem solution. Often ES is developed around very specific and highly detailed "Domains" and thus tends to be narrow in their range of knowledge (Luconi et al., 1993). To avoid exclusion of any of the existing types of DSTs, we define them roughly as interactive computer-based systems that aid in making a quality decision (Mir et al., 2015).

Systems that help make the decision-making process easier have been developed in recent decades. They are called Decision Support Systems (DST) and are computational solutions that can be used to support complex decision making and problem solving. The traditional design of a DST system is made up of three components. The first component consists of robust database management capabilities. The second component consists of powerful modeling functions that are accessed by a model management system. Finally, the third component consists of the system having a user-friendly graphical interface (Shim et al., 2002; Sánchez et al., 2020).

Therefore, DST propose an alternative to reduce the uncertainty that possible results can generatewhen implementing agricultural policies. For this reason, there have been several researches around the world that have developed DST for the formulation of agricultural public policies in order to foresee possible future results depending on the implementation of the policies formulated. This article reviews different DST applied to the formulation of agricultural public policies throughout the world during recent years (Sánchez et al., 2020).

Decision Support System comprises of vast set of characteristics and capabilities of DST. The key characteristics and capabilities of DST as reported by Turban (1995) are as follows (Mir et al., 2015):

- Ability to support in semi-structured and unstructured problems, including human judgment and computerized information.

- Ability to support managers at all levels.
- Ability to support individuals and groups.
- Ability to present knowledge on ad hoc basic in customized way.
- Ability to select any desired subset of stored knowledge for presentation or derivation during problem solving.
- Ability to support for interdependent or sequential decisions.
- Ability to support intelligence, design, choice, and implementation.
- Ability to support variety of decision processes and styles.
- Ability to support modelling and analysis.
- Ability to support data access.
- Benefits must exceed cost.
- Allow modification to suit needs of user & changing environment.
- Support quick decision-making using standalone, integration or web-based fashion DSTs having maximum number of these key characteristics and capabilities can be more useful and adoptable.

Major Fields of DST:

- Personal Decision Support Systems (PDST): usually smallscale systems that are developed for specified managers.
- Group Support Systems (GSS): they use combination of DST technologies to facilitate the effective decision process.
- Negotiation Support Systems (NSS): Here primary focus remains on negotiation between opposite perceptions.
- Intelligent Decision Support Systems (IDST): It uses artificial intelligence techniques to facilitate decision.
- Knowledge Management-Based DST (KMDST): They provide knowledge storage, retrieval, transfer using organizational memory and inter-group knowledge access.
- Data Warehousing (DW): systems that provides the large-scale data infrastructure in multiple formats for decision support.
- Enterprise Reporting and Analysis Systems: enterprise focused DST including executive information systems (EIS), business intelligence (BI), and corporate performance management systems (CPM). BI tools access and analyze data ware-house information using business intelligence software, query and analysis tools (Mir et al., 2015).

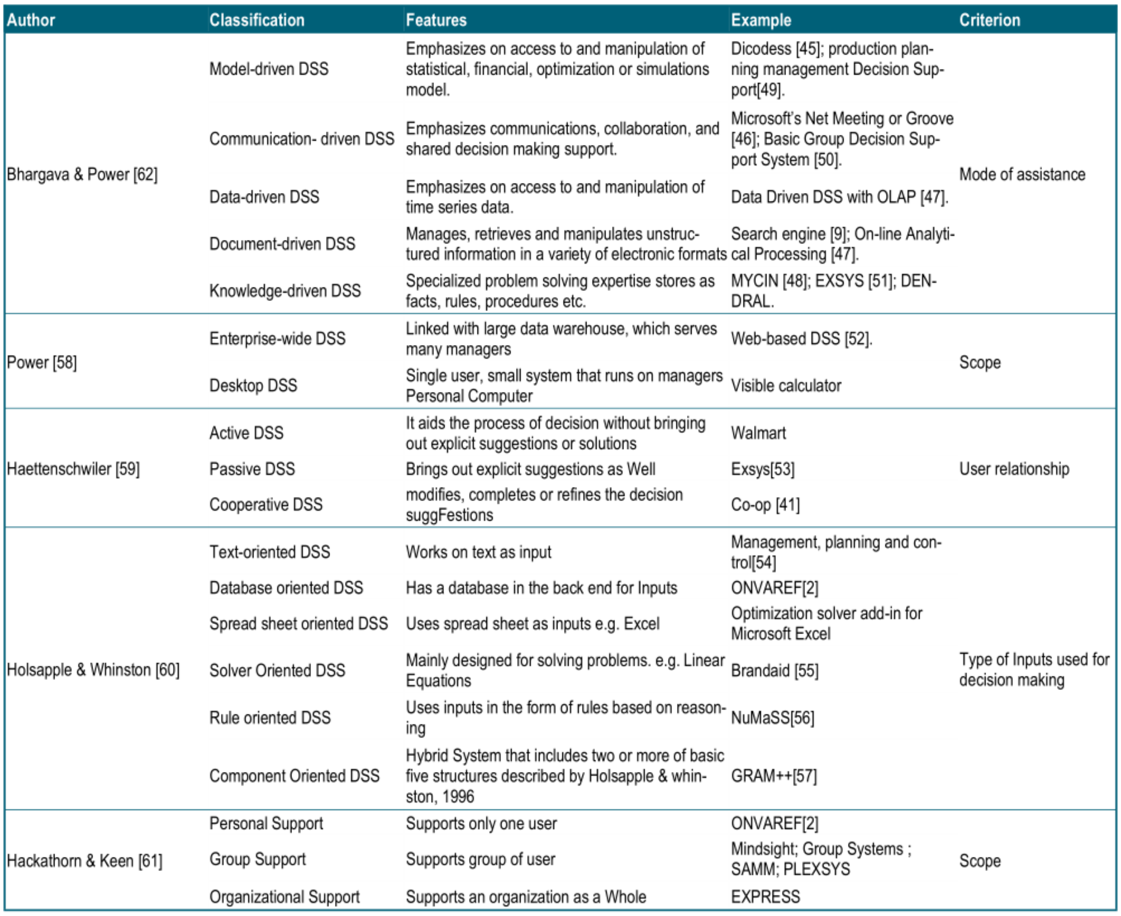
3.5.3. Classification of Decision Support Systems

There is no universally accepted taxonomy of DSTs, as different authors propose different classifications [Table 3]. However, important types of Decision Support Systems are:

- A Model-driven DST: Model-driven DST provides access to and manipulation of various underlying models by using data and parameters provided by users to assist decision making process. Dicodess (Gachet, 2004) is an example of an open-source model driven DST generator.
- A Communication-driven DST allows more than one person t o work on a one task. Microsoft's NetMeeting or Groove (Stanhope, 2002) is an example of communication driven DST.
- A Data-driven DST or data-oriented DST emphasizes access to and manipulation of internal or external data. Example of such DST is OLAP (Codd et al., 1993).
- A Document-driven DST utilizes unstructured information in a variety of electronic formats for manipulation, retrieval, and management; example includes Google Search Engine.

- A Knowledge-driven DST stores facts, rules, procedures, and structures for expertise problem solving purposes. Mycin (Buchanan and Shortliffe, 1984) is an example of knowledge driven DST (Mir et al., 2015).

Table 4. Classification of Decision Support Systems given by different authors (Mir et al., 2015).



Author	Classification	Features	Example	Criterion
Bhargava & Power [62]	Model-driven DSS	Emphasizes on access to and manipulation of statistical, financial, optimization or simulations model.	Dicodess [45]; production planning management Decision Support[49].	Mode of assistance
	Communication- driven DSS	Emphasizes communications, collaboration, and shared decision making support.	Microsoft's Net Meeting or Groove [46]; Basic Group Decision Support System [50].	
	Data-driven DSS	Emphasizes on access to and manipulation of time series data.	Data Driven DSS with OLAP [47].	
	Document-driven DSS	Manages, retrieves and manipulates unstructured information in a variety of electronic formats	Search engine [9]; On-line Analytical Processing [47].	
	Knowledge-driven DSS	Specialized problem solving expertise stores as facts, rules, procedures etc.	MYCIN [48]; EXSYS [51]; DENDRAL.	
Power [58]	Enterprise-wide DSS	Linked with large data warehouse, which serves many managers	Web-based DSS [52].	Scope
	Desktop DSS	Single user, small system that runs on managers Personal Computer	Visible calculator	
Haettenschwiler [59]	Active DSS	It aids the process of decision without bringing out explicit suggestions or solutions	Walmart	User relationship
	Passive DSS	Brings out explicit suggestions as Well	Exsys[53]	
	Cooperative DSS	modifies, completes or refines the decision suggFestions	Co-op [41]	
Holsapple & Whinston [60]	Text-oriented DSS	Works on text as input	Management, planning and control[54]	Type of Inputs used for decision making
	Database oriented DSS	Has a database in the back end for Inputs	ONVAREF[2]	
	Spread sheet oriented DSS	Uses spread sheet as inputs e.g. Excel	Optimization solver add-in for Microsoft Excel	
	Solver Oriented DSS	Mainly designed for solving problems. e.g. Linear Equations	Brandaid [55]	
	Rule oriented DSS	Uses inputs in the form of rules based on reasoning	NuMaSS[56]	
	Component Oriented DSS	Hybrid System that includes two or more of basic five structures described by Holsapple & whinston, 1996	GRAM++[57]	
Hackathorn & Keen [61]	Personal Support	Supports only one user	ONVAREF[2]	Scope
	Group Support	Supports group of user	Mindsight; Group Systems ; SAMM; PLEXSYS	
	Organizational Support	Supports an organization as a Whole	EXPRESS	

Table 5. Architectural components of DST given by different authors

Author	Architectural Component	Description of component
Sprague & Carlson [63]	Database Management System (DBMS) Model Base Management system (MBMS) Dialog generation and management system	Stores information Integrates models Provides user interfaces to manage system
Haag et. al. [64]	Same as above but describes them in detail	Stores information (that can be further sub divided into organizations traditional data repository, form external source such as internet or from experience of individual user Using various kinds of models it, handles representation of events, facts, or situations. Integrates models and provides user interface. Participates different roles or functions in the data management process
Haettenschwiler [59]	User Decision context Target system Knowledge base	Specifically defined decision rules Describes majority of the preferences External data sources, knowledge databases, working databases, data warehouse, metadata bases, models, methods, integrates search engines to responding system
Marakas [65]	Database Management System Memory Management System Knowledge Engine User Interface User	Stores, manages and provides access to the data Organizes memory efficiently Inference procedure or control structure for utilizing the knowledge Allows user to interact with the system One who uses the system
Power [9]	The user interactive The database interactive The model and analytical tool The DSS architect and network	Interacts with the user over a command line Interacts with a single or a group of users using a database for heuristics Model designed for analysis Interacts with the other DSS or database server.

3.5.4. Development of Decision Support Systems

Integrating GIS with the DST

Most of the agricultural data have geographic attributes while GIS is an important tool for agricultural analysis, so it is very important to include GIS into the DST for regional agricultural management. Nevertheless, it does not mean that the system should be developed on professional GIS. The pure second-time development capacity of professional GIS makes it difficult to develop attractive interfaces for users. Besides, the difficulty of operating attribute data with professional GIS is not helpful in meeting the various demands of users. Considering the demand of the management and the improvement of the function of various GIS components, GIS components will be a good choice (Yongzheng, 2002; Huy, 2009).

The geographic information system provides all the biophysical information for the DST; this includes climate, soils and topographic data and information on the farm infrastructure (Huy, 2009). Understanding the relationship between planning theory and methods and geospatial technologies is crucial for building and implementing tools that are suitable to planning practice. Esnard and MacDougall (1997) maintained that there is a common ground for integrating planning theory and GIS in data creation, analysis, and presentation. They suggest this integration as part of an educational experience (Huy, 2009). Guhathakurta (1999) also found that urban modeling and decision support tools could be developed to serve the practice and to link to its theoretical underpinnings. The author referred to a new form of rationality that encompasses both positivist and interpretative epistemology and promised to provide a framework for the development of planning technologies and tools (Batty, 1993; Huy, 2009).

According to Basnet et al. (2006), any DST needs to conform to the hierarchical nature of decision making. According to the research, compared to lower-level decisions, the top-level decisions are made with a longer planning horizon and the amount of detail is lesser at the higher echelons of decision making. As decisions are made further down the hierarchy, the lower-level decisions are subservient to the higher-level decisions (Huy, 2009).

Overview of Multi-Criteria Decision Making

Selene (1982) and Pitel (1990) defined Multi-Criteria Decision Making (MCDM) as methodology chosen to assess countermeasure suitability within the SDST. MCDM is a well-known branch of decision-making techniques that logically structure and evaluate problems with multiple attributes and objectives (Huy, 2009).

Multi-objective planning, where one decision maker seeks, within a single plan, to achieve more than one objective, is dominated, in a land-use context, by methods collectively known as multi-criteria decision making or MCDM (El-Swaify and Yakowitz, 1998). MCDM recognizes that there are often multiple, convicting criteria underlying a land-use decision (Huy, 2009). These connecting criteria are brought together using a variety of methods to derive a single recommended alternative, a reduced set of acceptable alternatives or a ranking of all possible alternatives (Jankowski, 1995; Huy, 2009).

Real estate and land management are characterised by a complex, elaborate combination of technical, regulatory and governmental factors. In Europe, Public Administrators must address the complex decision-making problems that need to be resolved, while also acting in consideration of the expectations of the different stakeholders involved in settlement transformation. In complex situations (e.g., with different aspects to be considered and multilevel actors involved), decision-making processes are often used to solve multidisciplinary and multidimensional analyses, which support the choices of those who are making the decision. Multi-Criteria Decision Analysis (MCDA) methods are included among the examination and evaluation techniques considered useful by the European Community. Such analyses and techniques are performed using methods, which aim to reach a synthesis of the various forms of input data needed to define decision-making problems of a similar complexity. Thus, one or more of the conclusions reached allow for informed, well thought-out, strategic decisions. According to the technical literature on MCDA, numerous methods are applicable in different decision-making situations, however, advice for selecting the most appropriate for the specific field of application and problem have not been thoroughly investigated. In land and real estate management, numerous queries regarding evaluations often arise. In brief, the objective of this paper is to outline a procedure with which to select the method best suited to the specific queries of evaluation, which commonly arise while addressing decision-making problems. Issues of land and real estate management, representing the so-called "settlement sector". The procedure will follow a theoretical-methodological approach by formulating a taxonomy of the endogenous and exogenous variables of the multi-criteria analysis methods (Guarini et al., 2018).

3.5.5. Area specific Decision Support Systems

Sustainable soil use and management must sustain biophysical soil potentiality and, at the same time, diversify the agricultural soil system, considering all the possible options to increase crop production: (i) expansion of the agricultural land surface; (ii) introduction of improved crop varieties; (iii) use of irrigation techniques; (iv) application of fertilizers and pesticides; and (v) rationalization of soil tillage practices (Robert et al., 1993).
For soil quality assessment, the development of relationships between all the soil quality indicators and the soil functions may be a monumental task. Therefore, land evaluation analysis may serve as a first step towards developing a soil physical/chemical quality assessment procedure. A short-term evaluation or monitoring procedure can then be considered mainly for the soil biological quality (Rosa et al., 2004).
Emerging technology in data and knowledge engineering provides excellent possibilities in land evaluation development and application processes. The application phase of land evaluation systems is a process of scaling-up from the representative areas of the development phase to implementation in unknown scenarios. The application phase—previously accomplished manually—can now be executed with computer-assisted procedures. This involves the development and linkage of integrated databases, computer programs, and spatialization tools, constituting decision support systems (De la Rosa and Van Diepen, 2002; Rosa et al., 2004).
Decision support systems are computerized technology that can be used to support complex decision-making and problem-solving (Shim et al., 2002). Opinions are wide-ranging as to what constitutes a decision support system. A

database management system could arguably be used as a decision support system for certain applications. Many people consider geographic information systems very useful decision support systems (Booty et al., 2001; Rosa et al., 2004).

Classic decision support system design comprises components for (i) sophisticated database management capabilities with access to internal and external data, information, and knowledge, (ii) powerful modeling functions accessed by a model management system, and (iii) simple user interface designs that enable interactive queries, reporting, and graphing functions (Shim et al., 2002; Rosa et al., 2004).

Nutrient Management

Fertilizers and lime are increasingly expensive but are commonly needed to grow high-yielding and good-quality crops. However, unnecessary use is wasteful, reduces farm profits and increases the risk of diffuse nutrient pollution. To maximize profits and avoid waste, farmers need to plan their use of nutrients for each field crop in each year. Organic manures (farmyard manure, sewage sludge, slurries, etc.) contain large quantities of nutrients which can often mean that large reductions are possible in the need for inorganic fertilizers. Nutrient management can play an important role in many of the regulatory and non-regulatory duties of farm-related management, and can protect, restore and enhance the status and diversity of all surface water ecosystems and ensure the progressive reduction of groundwater pollution (Mir et al., 2015).

For Nutrient management, different DSTs have been designed to recommend site-specific and need-based parameters that result in an optimized fertilizer management strategy. One example of such system is CERES, which simulates the whole soil crop system (Quemada and Cabreva, 1995). Another example is rice fertility DST, which provides recommendation on efficient utilization of fertilizer for the production of flooded rice in Arkansas (Chai et al., 1994). A DST for reduction in potential nitrogen (N) losses to the environment has been developed, which saves fertilizer expenditure (Lemberg et al., 1992).

There is an ongoing trend to develop Nutrition Management Decision support tools to make them available to the farmers through World Wide Web. These facilities are enabling farmers to use the service of these tools irrespective of computer ownership, which is being reported as one of the reasons for low adaptation of DST among farmers. Haifa Nutri-Net is an example of such system (Achilea et al., 2005). It is a comprehensive crop Nutrition DST, operated over the web, assisting growers to formulate their crop nutrition programs and irrigation schemes by integrating virtually all relevant cultivation parameters. It is based on comprehensive databases of crop nutrition, irrigation, soil and climate, covering all most every growth environment. FarmN is another web based DST providing INM recommendations (Jorgensen et al., 2005).

Most of the existing DSTs are based on very specific aspects, for example, Nutrient management. One system that addresses all the major manure management systems has been identified (Licklider et al., 2007). DST for Planning Land Applications of Nutrients for Efficiency and the Environment (PLANET) (Gibbons et al., 2005), provides best management practice tool for farmers and their advisors to adopt in the use of organic manure and fertilizers. Fertilizer recommendations for field are calculated based on the precious cropping fertilizer and organic manure application. To encourage maximum uptake of DST by the farming community, the logic to generate fertilizer recommendations based on input data was developed and made available to commercial agriculture software developers for integration within their systems, which are being widely used by farmers. In India number of DST have been designed mainly for nutrient and micronutrient management in field crops (Pal et al., 2009; Patil et al., 2002; Pal, 2007; Kumar, 1992; Mir et al., 2015).

Agricultural Land Use and Planning

With the rise in human population and their aspirations, land becomes an increasingly scarce resource – a scenario calling for land use planning. Land use planning is defined as a systematic assessment of land and water potential, alternative land use choices for better economic and social conditions. It has become essential to mitigate the negative effects of land use and to enhance the efficient use of resource with minimal impact on future generations. Land use planning is becoming complex and multidisciplinary as planners face multiple problems that need to be addressed within a single planning framework. These includes non-point-source deforestation, urbanization, pollution, ecosystem deterioration, water allocation, global warming, poverty and employment, deterioration of farmland and low economic growth. For land use planning it is increasingly necessary to recognize the complex trade-offs between the multiple objectives of stakeholders. This is particularly apparent where outcomes of scales above the land management unit are considered important (e.g., water quality, biodiversity, and land use planning). Many different DST tools for land use related decision-making have been designed for agricultural planning (Jeffrey et al., 1992), sustainable watershed management (Loi and Tangtham, 2004), forest planning (Riberir and Borges, 2005), environmental planning (Shim et al., 2002), site selection (Manos and Gavezos, 1995), species protection plans (Sandstorm, 1996) and conservation preserves planning (Klik, 2006). A conceptual framework and a spatial DST for rural land use planning have been developed for supporting decision making on selected area for different watershed management schemes for conservation planning (Adinarayana et al., 2000; Mir et al., 2015).

The system provides suggestions and warnings for land use. Linear programming approach-based decision support have been employed variously covering wide range of including land use planning. The first linear programming models applied to land use planning were single objective problems (Campbell et al., 1992; Chuvieco, 1993). However, because of the complexity of agricultural planning, multi-objective models are becoming increasingly more common. Within these models, goal programming is one of the techniques most frequently applied. Giupponi and Rosato (1998) developed a goal programming addressing land use and the cropping system, maximization of gross margin and the minimization of risk. Matthews and Buchan (2003) reported continuous development of the DST with multiobjective land use planning tools. Linear Programming model and Goal Programming-based DST for farm regions in Greece have been designed, having development possibilities of agricultural sector in relation with the agricultural processing industries of the region (Manos and Gavezos, 1995; Barnard and Nix, 1993; Bernardo et al., 1992; Hazell and Norton, 1986; Lee et al., 1995). It aims at the development of farm regions through a better utilization of available agricultural resources and agricultural industries (Mir et al., 2015).

Trends in modern land use planning increased with involvement of stakeholders in the planning process, which causes the need for interactive programming to exchange information between the decision-maker and the system. Interactive multiple objective learner programming has been successfully applied to agricultural development policy analysis (De Wit et al., 1988), land use strategy evaluation (Loi and Tangtham, 2004) and land resource utilization (Fischer et al., 1999). DST for sustainable land use planning to address conservation of land, improving soil quality and fertility, and local water balance with minimization of soil and nutrient translocation into surface water bodies and downstream fields have been designed keeping in view the optimized benefits for farmers as well as for the society (Klik, 2006; Mir et al., 2015).

Water and Drought Management

The central issue is how to manage water for all the different functions for which it is needed. With the advent of agronomic models that show how vegetation is likely to respond to climatic stress, with remote sensing to monitor vegetations conditions from airborne and space borne platforms, and with GIS to display spatial and temporal data in more comprehensible ways, it is now feasible to more accurately assess the impacts of drought (McVicar et al., 1992). Different DSTs have been developed to tackle with the problems related to water and drought management, Watkins and McKinney (1995), TEMPEST allows to model water flow both saline and fresh and predict the responses to each facet of the landscape to management (Sojda, 1994).

Aussie GRASS, developed by the Queensland Department of Natural Resources, provides timely estimation of the extent of severity of drought (EISA, 2001). A DST developed in Vietnam formulates the plans for sustainable watershed management, using a combined approach of linear programming, goal programming and GIS for deriving the sustainable watershed management plan (Loi and Tangtham, 2004); Mir et al., 2015).

In Thailand, the collaborative project between the Department of Geography, Faculty of Liberal Arts, Thammasat University, and the Remote Sensing and Geographic Information System field of study at the School of Engineering and Technology, Asian Institute of Technology, aims to assess the effects of climate variability (especially droughts or dry spells) on rice production in rainfed environments and to develop a DST tool that might help to properly anticipate and adapt farming to maximize agricultural production (Attachai et al., 2012; Mir et al., 2015).

3.5.6. Decision Support Systems in formulating agricultural public policies

Figure 5 presents the percentage distribution of the DST regarding the countries of origin. Several DST were developed in collaboration with researchers from different countries. The country that has developed most DST is the United States of America, followed by Spain, Netherlands, China, Germany, Australia, France, Italy, and Canada. It is worth noticing that most of the countries that developed these systems belong to Europe or North America, and all of them are considered developed countries, except for China; but China is the second largest economy in the world. It is also interesting that all these countries do not belong to the tropical zone (Sánchez et al., 2020). Therefore, there is an interest in developed countries and those with greater economies for improving their agrarian policy formulation processes using tools such as DST. Moreover, there is a need to develop these types of tools for countries located in the tropical zone, so that the characteristics of this region may be taken into consideration (Sánchez et al., 2020).

Currently one of the greatest concerns for developed and developing countries is the formulation of policies that promote sustainable development. Such is the concern that the United Nations promulgated the 17 sustainable development goals in 2015 (United Nations Development Program, 2019), and the policies that promote these goals become more relevant, and the agricultural sector becomes one of the fundamental axes for achieving these goals. The sustainable development goals related to agricultural public policies and the development of SSD systems are compared below.

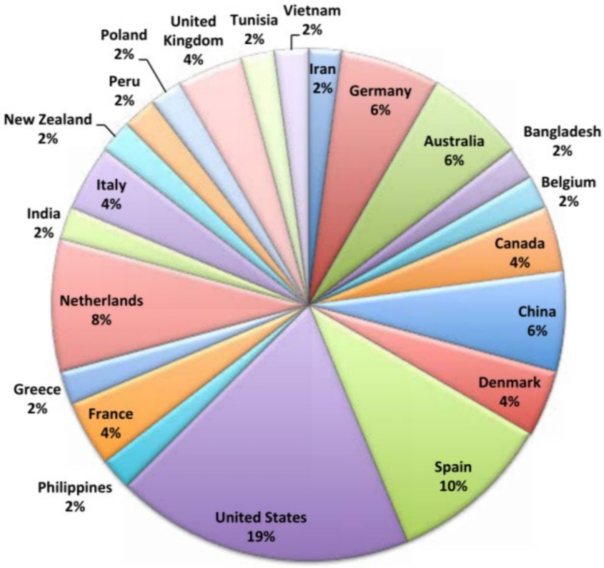
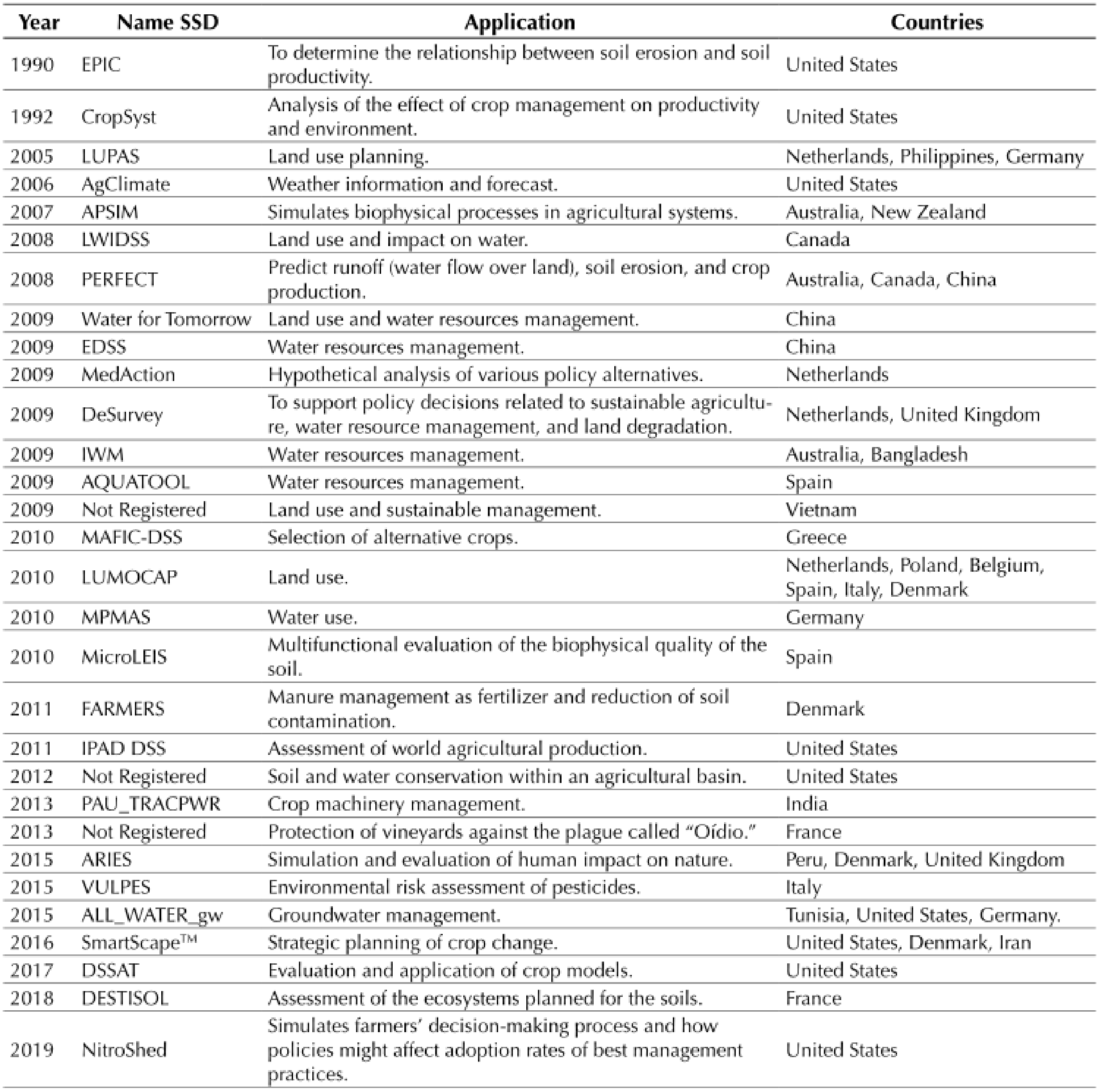


Figure 5. Percentage distribution of DST for the formulating of agricultural policies (Sánchez et al., 2020).

Table 5 presents the summary of the DST that were found after the search and debugging process. The first column shows the year of creation of the system (i.e., each system's first version) since several of the oldest systems have been continuously updated. The second column is the name the creators called each system. In some cases, there was no name assigned to the DST; in those cases, the indicative "Not Registered" was placed (Sánchez et al., 2020). The third column briefly describes the application of the DST when formulating agrarian public policy, although a deeper explanation of each system is better explained below Table 1. The fourth column refers to the country for which each system was design and implemented (Sánchez et al., 2020).

Table 5. Decision Support Systems in Formulating Agricultural Public Policies (Sánchez et al., 2020).



Year	Name SSD	Application	Countries
1990	EPIC	To determine the relationship between soil erosion and soil productivity.	United States
1992	CropSyst	Analysis of the effect of crop management on productivity and environment.	United States
2005	LUPAS	Land use planning.	Netherlands, Philippines, Germany
2006	AgClimate	Weather information and forecast.	United States
2007	APSIM	Simulates biophysical processes in agricultural systems.	Australia, New Zealand
2008	LWIDSS	Land use and impact on water.	Canada
2008	PERFECT	Predict runoff (water flow over land), soil erosion, and crop production.	Australia, Canada, China
2009	Water for Tomorrow	Land use and water resources management.	China
2009	EDSS	Water resources management.	China
2009	MedAction	Hypothetical analysis of various policy alternatives.	Netherlands
2009	DeSurvey	To support policy decisions related to sustainable agriculture, water resource management, and land degradation.	Netherlands, United Kingdom
2009	IWM	Water resources management.	Australia, Bangladesh
2009	AQUATOOL	Water resources management.	Spain
2009	Not Registered	Land use and sustainable management.	Vietnam
2010	MAFIC-DSS	Selection of alternative crops.	Greece
2010	LUMOCAP	Land use.	Netherlands, Poland, Belgium, Spain, Italy, Denmark
2010	MPMAS	Water use.	Germany
2010	MicroLEIS	Multifunctional evaluation of the biophysical quality of the soil.	Spain
2011	FARMERS	Manure management as fertilizer and reduction of soil contamination.	Denmark
2011	IPAD DSS	Assessment of world agricultural production.	United States
2012	Not Registered	Soil and water conservation within an agricultural basin.	United States
2013	PAU_TRACPWR	Crop machinery management.	India
2013	Not Registered	Protection of vineyards against the plague called "Oídio."	France
2015	ARIES	Simulation and evaluation of human impact on nature.	Peru, Denmark, United Kingdom
2015	VULPES	Environmental risk assessment of pesticides.	Italy
2015	ALL_WATER_gw	Groundwater management.	Tunisia, United States, Germany.
2016	SmartScape™	Strategic planning of crop change.	United States, Denmark, Iran
2017	DSSAT	Evaluation and application of crop models.	United States
2018	DESTISOL	Assessment of the ecosystems planned for the soils.	France
2019	NitroShed	Simulates farmers' decision-making process and how policies might affect adoption rates of best management practices.	United States

EPIC (Erosion/Productivity Impact Calculator) is a system that determines the relationship between soil erosion and soil productivity in the United States. It continuously simulates the processes associated with erosion. EPIC is made up of components based on hydrology, climate simulation, erosion-sedimentation, nutrient cycling, plant growth, tillage, and soil temperature. It also uses calculations to assess the economic cost of erosion, and to determine optimal management strategies (Sharpley and Williams, 1990).

CropSyst is a system written in C++, and its first version was developed in 1992. This System is used to analyze the effect of crop management on productivity and the environment. It simulates the use of water in the soil, the level of nitrogen in the soil plant, the growth of crops and roots, the production of dry matter, yield, the production and decomposition of residues, and the erosion. Management options include crop selection, crop rotation, irrigation, nitrogen fertilization, tillage operations, and residue management (Stöckle et al., 2019).

LUPAS (Land Use Planning and Analysis System) was designed as a DST for strategic land use planning. The system includes Crop Simulation Models, Expert Systems, SIG, and Multiple Objective Linear Programming (MGLP) models for land evaluation and optimization. LUPAS has three main parts: first, land assessment, which includes assessing resource availability, land suitability, and yield estimation; second, construction of scenarios based on policy opinions; and third, the optimization of land use (Roetter et al., 2005).

AgClimate is a web-based weather forecasting and information system. AgClimate was implemented in a Linux environment with specific applications and Perl modules installed. Dynamic tools were developed using the PHP web programming language that interacts with FLASH movies and MySQL databases. The system has two main components: the front-end interface and a set of dynamic tools. The main navigation menu includes weather forecast tools and management options for crops, forestry, pastures, and livestock. It also includes a section on climate and “El Niño” phenomenon with background information. The tools section contains two applications that allow the user to examine the weather forecast for individual counties based on the ENSO phase and assess the yield potentials for certain crops (Fraisse et al., 2006).

The APSIM (Agricultural Production Systems Simulator) is a system that simulates biophysical processes in agricultural systems, and specifically determines the possible economic and ecological results of management practices against climate risk. It also analyzes food security, and adaptation to climate change. APSIM is structured around plant, soil, and management modules. The creators, Queensland University (Australia), started developing it in 2007 (APSIM, 2019).

The LWIDST (Land and Water Integration Decision Support System) simulates land use scenarios characterized by different assumptions about management practices. The results are presented in the form of SIG spatial layers. These can be incorporated into other components, such as non-point source pollutant models to assess the impact of soil quality on water. Land use scenarios are integrated with watershed hydrology models to develop flow, sediment, and nutrient performance standards in streams to protect aquatic biodiversity (Wong et al., 2008).

PERFECT (Productivity Erosion and Runoff Functions to Evaluate Conservation Techniques) is a system that was designed to predict runoff (water flow over the land), erosion, and crop production to determine the sequences of planting, harvesting, and management of residues under different tillage practices. This model has been used widely in the agricultural areas of Australia, China, and India, among others (Li et al., 2008).

The “Water for Tomorrow” DST is designed to assist policymakers in making decisions about land use and water resource management, taking into account human use, preservation, and restoration of the ecosystem. Users can locate the watershed of interest, view summary data on that watershed, view and compare model results, and generate reports (Eckman et al., 2009).

They developed a web-based regional agricultural industry structure optimization tool in China, using AJAX (Asynchronous JavaScript and XML) technology and a suite of decision support tools for agricultural policymakers. The system provides a configuration method that allows applying sensitivity analysis, data use, and analysis results of comparative advantage, and a component that can solve the linear programming model and its double problem by the simplex method (Huang and Zhu, 2009).

The Integrated Environmental Decision Support System (EDST) was designed to help policymakers and other stakeholders gain a clearer understanding of key factors in water resource management. The system is made using MATLAB and a geographic information system (SIG). The model considers the social, economic, ecological, environmental system of water, and water resources as its interrelated subsystems, and integrates them into an organic whole to analyze. The system provides a visual simulation environment, and analysis and management capabilities of water resources for different scenarios (Leng and Haimid, 2009).

The MedAction Policy Support System (PSS) aims to support policymakers in arid and semi-arid regions in understanding the impacts of autonomous developments within a region, such as demographic and economic growth, or change climate. The system allows hypothetical analyzes of various policy alternatives; policy indicators can measure impact such as agricultural sector gains, forest area, water use and availability, land degradation, and changes in land use. The system is made up of several sub-modules, which are integrated into a single model that simulates regional developments up to thirty years in the future (Van Delden, 2009).

The DeSurvey Integrated Assessment Model (DeSurvey IAM) is a policy formulation support system. The system aims to support political decisions related to sustainable agriculture, water resource management, and land degradation. The system contains twenty models that include climate, hydrology, water management, erosion, salinization, vegetation growth, land use, macroeconomics, crop choice, and irrigation, among others, and they work with different spatial and temporal resolutions. Depending on the issue at hand and the data available, a region-specific application can be configured to contain a proper combination of built-in models (Van Delden et al., 2009).

Researchers from the Institute of Water Modeling (IWM) developed a Water Resources DST that uses mathematical models to simulate and predict likely impacts in sectors such as agriculture. The DST has been designed to be an educational tool for non-technical users and stakeholders. Thus, users can obtain information about the risks associated with climate change and also the effectiveness of different adaptation options (Zaman et al., 2009).

AQUATOOL is a DST for basins and water resource planning and management (Andreu et al., 2009). The system consists of several modules. The SIMGES module is a general model for the Simulation of Watershed Management, in which there are elements of regulation, storage, collection, transport, and consumption. The GESCAL module was developed to determine the quality of the water. The OPTIGES module defines the monthly distribution of water. The SIMRISK module is for watershed management and risk measurement. The EVALHID module (Evaluation of water resources) is used to develop Precipitation-Runoff Models (Andreu, 2019).

Researchers from Vietnam developed a decision support system for agricultural land use planning and sustainable management. The system is made up of the following components: the optimal problem-solving component helps the decision maker to solve the optimal problem; the expert opinion component helps the decision maker to establish the necessary requirements and expert data in order to combine it with expert opinions using the Delphi method; the reporting and Implementation Component helps to report the final option selected on the planning map. The system was developed using Microsoft Visual Studio together with MapInfo MapXtreme and was designed based on three main objectives: economic efficiency, land suitability, and sustainable environment (Huy, 2009).

The MAFIC-DST (Major Field Crops Decision Support System) is web-based and supports farmers in the selection procedure of appropriate alternative crops. The system provides the necessary information and supports the farmer throughout the growing period. The system has seven modules: The user profile module stores information for each farmer; the SIG module contains the necessary spatial information and stores data such as land use, cadastral information, soil characteristics, and climatic characteristics; the agricultural policy module contains all the national and EU agricultural policies and directives necessary for each crop of interest; the market profile module maintains the market information and the cultivation cost for each product, which refers mainly to market prices, national and international demand for each product, prices and specifications of fertilizers and pesticides, means of transportation, and energy costs; the interaction module is a chat-like application enriched with image upload facilities that allows farmers to send inquiries to experts using text and photos of their fields; and finally, the crop module, which consists of two submodules. The first sub-module contains different knowledge bases related to the main crops, such as soil and climate cultivation requirements and cultivation techniques, including needs for fertilization and irrigation. The second sub-module is a system for the chemical and organic management of pests and diseases (Antonopoulou et al., 2010).

The LUMOCAP System (dynamic land use change modeling for CAP impact assessment on the rural landscape) aims to assess how different political scenarios will affect land and landscape use in the 27 member States of the European Union. Due to the inherent complexity of land use change processes, agricultural policies at European level have their effect not only on the evolution of the agricultural sector, but also on the regional ecological coherence and socio-economic dynamics of rural areas. The system allows the following up of relationships between EU policies, agricultural economy, land suitability, and land use dynamics through simulation (Van Delden et al., 2010).

MPMAS (Mathematical Programming-based Multi-Agent Systems) is a system developed by the Hohenheim University. It was implemented using C++, and its user interface offers two modes. The first mode is the single agent mode, which simulates a decision problem for a single agent. The second mode is the complete agent, where decision making and actions of all agents like production, investment and consumption decisions, agent-agent interactions, and all relevant biophysical processes are simulated generally for several years. The system was used to predict the behavior of farmers in the use of water when building a dam (Berger et al., 2010).

The decision support system MicroLEIS (Mediterranean Land Evaluation Information System) was designed for the multifunctional evaluation of the biophysical quality of the soil, using the characteristics of the soil such as place, climate, and cultivation as input data, and it is particularly applied to the peculiarities of the Mediterranean region. This DST was designed to have a toolkit that integrates databases, statistical models, expert systems, neural networks, web and GIS applications, and other information technologies (De la Rosa and Anaya-Romero, 2010).

Fertilizing by Application and Reuse of Manure

Environmental Risk Software (FARMERS) is a decision-making system for the safe and sustainable management of livestock manure as a fertilizer to control and limit the accumulation of metals in the soil and to reduce metal bio-transference from the floor to other compartments. The system was developed based on a multi-compartment model for evaluating environmental risks. The tool was implemented in Visual C++ and is structured in a database (MS Access®) where all the required data is stored and the risk assessment model, a GIS module for the visualization of the scenario, and the results are obtained. The decision support system allows you to choose between three estimation options depending on the needs, which provide information to both farmers and policymakers. The first option is useful for evaluating the suitability of the current management practices of the different farms, and the others provide information on the measures that can be taken to carry out a fertilization plan without exceeding the risk to human health (Río et al., 2011).

The IPAD DST (International Production Assessment Division decision support system) was developed by NASA and aims to assess world agricultural production. The system takes global data, model input sources, and analysis tools to estimate crop production. The multiple data and results of the model are the basis for processing, analysing and visualization techniques that lead to an evidence convergence approach to the monthly estimates of production of specific products in each country (Van Leeuwen et al., 2011).

A decision support system for soil and water conservation within an agricultural basin was designed and used to generate alternative decision support scenarios to facilitate integrated watershed management concepts in an interactive and holistic way (Lal, 2012).

A decision support system called PAU_TRACP-WR for crop machinery management in India was developed. Detailed data information on the production parameters of the main crops, such as tractor prices, crop values, workloads, and the level of adoption of various agricultural technologies were used for designing the system (Bector and Singh Surendra, 2013).

A DST for the protection of vineyards against the plague called “Oídio” (“blanquilla” or “cenicilla”) because this plague must be treated before any symptoms appear. The system simulates the entire life cycle of the pathogen, including sexual and asexual reproduction modes, while estimating the area of the diseased leaf. The system is modeled after mathematical equations and expert knowledge (Garin et al., 2013).

A Decision Support System to identify land strategically located for the agrarian reform that developed in South Africa was developed in 2014. The system was built from geographic information systems (GIS), Earth Observation (EO) data, and multi-criteria decision making (MCDM). An index to identify the land was created, expert workshops to determine the criteria for land identification were conducted, and the analytical hierarchy process (AHP) was used to weight the criteria (Musakwa et al., 2014).

ARIES is a dynamic modeling platform that uses artificial intelligence techniques to simulate and evaluate the impact of human intervention on nature. The system integrates a set of process- and agent-based models to identify the changes in flows of ecosystem services as a response to changes in land use and weather, as well as the impact and scope of future land use scenarios in the region (Francesconi et al., 2015).

VULPES (“Vulnerability to Pesticide”) is a system based on GIS, client-server type designed for groundwater. The system aims to transfer scientific knowledge for evaluating environmental risks from pesticides, which allows to apply consolidated models and methodologies used in standardized scenarios for regulatory purposes and to identify vulnerable areas to pesticides. It is a system intended to help those responsible for public policies investigate sensitive areas to specific substances and propose limitations of use or mitigation measures (Di Guardo and Finizio, 2015).

ALL_WATER_gw was developed for groundwater management within the framework of the WEAP-MODFLOW DST. The system considers water demand, minimization of water cost, maximum reduction, and compliance with water salinity restrictions. The system uses a multi-objective genetic algorithm (MOGA) and PARETO optimization approaches to handle the formulated problem (Nouiri et al., 2015).
The SmartScapeTM DST is a system with an interactive web-based environment for strategic crop change planning, which allows users to create and evaluate a crop change scenario. This system has three main components: A terrain

selection panel; a scenario panel that allows stakeholders to make a crop change and run multiple environmental models; and a comparison scenario panel that allows users to compare the outcome of crop change scenarios in various ecosystem services using various visual analyzes and highlight the tradeoffs between multiple ecosystem services (Tayyebi et al., 2016).

The DSTAT is a comprehensive system that helps the evaluation and application of crop models for a variety of agricultural and environmental uses, such as yield predictions and water use (Salazar et al., 2012). This serves as support for agricultural planning and regional policy. The DST contains various crop and soil simulation models, as well as climate, soil and crop databases, and evaluation programs (Wolfe and Richard, 2017).

The DESTISOL DST is based on an integrative approach that links the indicators of soil characteristics: quality (i.e. physicochemical and biological characteristics, fertility, and contamination), functions, and ecosystem services. With this linking, the system also semi-quantitatively evaluates the ecosystem services that are provided by the soil as food production, air quality, flood mitigation, or climate regulation (Anne et al., 2018).

NitroShed is a system that was developed using agent-based modeling in Python. The system simulates the decision-making process of farmers in the Mississippi Basin and the Mexico Gulf. Additionally, it presents a simulation of how policies might affect adoption rates of best management practices also affecting the repercussions that farming activities may have on the soil. For example, the implementation of best practices could reduce the contamination produced by nutrients released by the farms located in the surrounding hydrographic basins. The system helps policymakers determine the most effective action plan to increase the adoption of best management practices by farmers (Zeman and Rodríguez, 2019).

After reviewing the functions for which the DST have been developed, it is worth noting that the main objective is focused on determining land use, managing water resources in agriculture, optimizing productivity, influencing the climate, and reduce the negative environmental impact of economic activity. In summary, all DST are focused on issues related to the agricultural production process and its relationship with the environment. Only two DST have a slightly different approach: the MPMAS developed in 2010, and the NitroShed developed in 2019. Both seek to predict the future behavior of farmers on different scenarios, proposing different possible public policies to establish which would be most advisable. These two DST were developed using Artificial Intelligence (AI) and agent-based models.

Decision Support System for Assessment and Management of Soil Functions

Agricultural decision support systems (DSTs) are mostly focused on increasing the supply of individual soil functions such as, e.g., primary productivity or nutrient cycling, while neglecting other important soil functions, such as, e.g., water purification and regulation, climate regulation and carbon sequestration, soil biodiversity, and habitat provision. Making right management decisions for long-term sustainability is therefore challenging, and farmers and farm advisors would greatly benefit from an evidence based DST targeted for assessing and improving the supply of several soil functions simultaneously (Debeljak et al., 2019).

To address this need, we designed the Soil Navigator DST by applying a qualitative approach to multi-criteria decision modeling using Decision Expert (DEX) integrative methodology. Multi-criteria decision models for the five main soil functions were developed, calibrated, and validated using knowledge of involved domain experts and knowledge extracted from existing datasets by data mining. Subsequently, the five DEX models were integrated into a DST to assess the soil functions simultaneously and to provide management advices for improving the performance of prioritized soil functions. To enable communication between the users and the DST, we developed a user-friendly computer-based graphical user interface, which enables users to provide the required data regarding their field to the DST and to get textual and graphical results about the performance of each of the five soil functions in a qualitative way. The final output from the DST is a list of soil mitigation measures that the end-users could easily apply in the field to achieve the desired soil function performance. The Soil Navigator DST has a great potential to complement the Farm Sustainability Tools for Nutrients included in the Common Agricultural Policy 2021–2027 proposal adopted by the European Commission. The Soil Navigator has also a potential to be spatially upgraded to assist decisions on which soil functions to prioritize in a specific region or member state. Furthermore, the Soil Navigator DST could be used as an educational tool for farmers, farm advisors, and students, and its potential should be further exploited for the benefit of farmers and the society (Debeljak et al., 2019).

Soil functions are fundamental for the provision of many ecosystem services, as soils contribute to the generation of goods and services beneficial to human society and the environment (Blum, 2005; Schulte et al., 2014; Adhikari and Hartemink, 2016; Baveye et al., 2016). The five main soil functions in agriculture and forestry are primary productivity, water purification and regulation, climate regulation and carbon sequestration, soil biodiversity and habitat provision, and provision and cycling of nutrients (Haygarth and Ritz, 2009; Creamer and Holden, 2010; Bouma et al., 2012; Rutgers et al., 2012; Schulte et al., 2014). If one or more soil functions are impeded, threats to soil functions may arise (e.g., soil sealing, compaction, erosion, loss of biodiversity, loss of organic matter, salinization, contamination, and desertification) (Blum et al., 2004; Creamer and Holden, 2010; Creamer et al., 2010; Stolte et al., 2016) and the rational use and protection of soil would fail (European Commission, 2006; Stankovics et al., 2018; Debeljak et al., 2019).

All soils can perform these functions simultaneously, but the extent and the relative composition of this functionality depend on soil characteristics (physical, chemical, and biological), environmental variables (regimes for temperature, humidity, hydrology, slope), land use (cropland, grassland, forestry), and soil management practices (e.g., drainage and irrigation, tillage, nutrient and pest management, crop choice, and rotation) that reflect the specific demands for soil functions (Schulte et al., 2015; Vogel et al., 2019; Debeljak et al., 2019).

Until now, research and corresponding soil-related policies have mostly focused on increasing the provision of individual soil functions. This has resulted in inconsistent and sometimes even conflicting recommendations (ten Berge et al., 2017). Making correct management decisions for soils is therefore challenging and farmers must make these decisions on their farm/land daily. Therefore, farmers and farm advisors would greatly benefit from evidence-based decision support systems (DSTs) to support their decision-making process. DST are web-based or app-based software systems and are designed to guide the end-users through different stages of decision making to reach a final decision (Dicks et al., 2014). DST targeted for optimizing the supply of soil functions could be used to provide farmers and farm advisors with information about the potential effects of external physiochemical, biological, and management factors (Debeljak et al., 2019).

In addition, DST could inform stakeholders about whether targets for selected soil functions have been reached, and if not, how management could enable them to reach those targets. The usefulness of DST has been confirmed in different agricultural domains like pest management, nutrient management planning, farm economy, livestock, and crop management (Jones et al., 2017a,b). The national farm advisory services in several European member states are offering access to DST as an integrated part of supporting their clients. Examples of such DST are MarkOnline in

Denmark (Bligaard, 2014), Mesp@rcelles in France (APCA, 2019), NMP Online in Ireland (Teagasc, 2016), AgrarCommander in Austria (AGES, 2019), and Web Module Düngung in Germany (LWK Niedersachsen, 2019; Debeljak et al., 2019).

Furthermore, in the new 2021–2027 Common Agricultural Policy (CAP) proposal (European Commission, 2018) adopted by the European Commission, member states are suggested to implement nutrient management plans, supported using Farm Sustainability Tools for Nutrients (FaST) (Debeljak et al., 2019).

This is specifically part of the new framework of standards for good agricultural and environmental condition of land (GAECs). A recent review of app based DST in agriculture concludes that there is a demand for and value in systems able to address individual farm management issues for achieving the sustainability goals (Eichler Inwood and Dale, 2019; Debeljak et al., 2019).

However, nearly all DST on the market can be characterized as “single solution” DST that provide limited data to improve only a specific aspect of farm management practices and lack an integration of sustainability aspects (Eichler Inwood and Dale, 2019). Evaluating several soil functions in the same DST would overcome this lack of integration. Furthermore, although agricultural DST are becoming increasingly advanced, the uptake and use of DST by farmers and farm advisors is still very low compared to the number available and accessible DST (Rose et al., 2016; Bampa et al., 2019). Several studies show that one of the main reasons for this is the lack of end-user involvement in the design and development of the DST since the beginning of the process (Rose et al., 2016; Lindblom et al., 2017; Rodela et al., 2017). Rose et al. (2016) argues that a successful uptake of DST requires end-users to be actively involved in the development of the DST. In addition, these tools should be designed in such a way that they are easy to use, fit the existing workflow of users, and are trustworthy. The main goal of the European-founded project LANDMARK (Land Management: Assessment, Research, Knowledge base) is to develop a scientific framework for the quantification and management of the five aforementioned soil functions (Debeljak et al., 2019).

Furthermore, it aims to provide guidelines for the optimization of these soil functions at the local, regional, and European scale. To quantify the soil functions at the local level, a web based DST, the Soil Navigator, was developed. It provides an integrated assessment of the five soil functions, which allows an assessment of trade-offs between soil functions for a specific agricultural management practice. In addition, the DST proposes a suite of management practices that foster an optimal balance among soil functions, recognizing the different function priorities and requirements across different European pedo-climatic zones (Metzger et al., 2005; Debeljak et al., 2019).

3.6. Decision problem and soil functional decision models

The initial step in the process of decision modeling and developing DST is to define the decision problem. For farmers and farm advisers, most existing decision models deal with primary productivity, which helps the farmer to achieve crop or livestock production targets and economic revenue. However, in the majority of cases, there are no strong drivers and limited legislation to enhance the multi-functionality of soils (Bünemann et al., 2018). Nevertheless, farmers and farm advisors often try to enhance the multi-functionality of their soils and are more likely to do so where they have observed reduction in crop yields, due to soil degradation, or due to climate change effects (Olesen et al., 2011). However, information on whether the applied agricultural management practices provide support to the multi-functional performance of their soils or how management needs to be modified to achieve better performance are not trivial to find or have access to. Hence, decisions on what agricultural management practices will need to be adopted to achieve better performances of all soil functions remains a complex decision problem (Debeljak et al., 2019).

Soil Function Decision Models

Since the decision models of soil functions should address both cropland and grassland soils, some of the decision models have been split into two separate decision models, one for cropland and one for grassland. By doing so, the sensitivity of the outputs for changes in the input data has been increased. The detailed descriptions of each model are provided in separate papers in this issue (Rutgers et al., 2019; Sandén et al., 2019; Delgado et al., unpublished2; Van de Broek et al., unpublished1). The model for nutrient cycling was developed earlier and published by Schröder et al. (2016) and Debeljak et al. (2019).

The primary productivity decision model consists of sub-models describing the environmental conditions (E), inherent soil conditions (S) (physical: structure, groundwater table depth; chemical: micro- and macro-elements; biological: pH, C/N ratio, soil organic matter), soil management (M), and crop properties (C). Primary productivity, as the top attribute, integrates the sub-models, which leads to an assessment of the capacity of a soil to produce biomass. A detailed description of the primary productivity model is given in Sandén et al. (2019).

The structure of the nutrient cycling decision model consists of three sub-models, integrated into the top attribute, describing the ability of a soil to provide and cycle nutrients. The first sub-model comprises nutrient fertilizer replacement value, which describes the extent to which nutrients, particularly those in left or applied organic residues, are as available to plants as manufactured mineral fertilizers. The second part of the model describes the extent to which plant-available nutrients are effectively taken up by crops and the last part addresses the harvest index describing the extent to which the nutrients taken up by crops are eventually leaving the field in the form of successful harvests (Schröder et al., 2018; Debeljak et al., 2019).

The climate regulation and carbon sequestration decision model integrates carbon sequestration, N_2O emissions and CH_4 emissions. The carbon sequestration sub-model is determined by the magnitude of carbon inputs, carbon losses, and the soil organic carbon concentration. The N_2O emissions sub-model makes a distinction between direct N_2O emissions occurring on agricultural fields, and indirect N_2O emissions, after reactive N species have been transported through the landscape. The part of the model addressing CH_4 emissions are determined by the extent to which artificial drainage is applied on organic soils (Debeljak et al., 2019).
The water regulation and purification soil function decision model integrates three sub-models describing the prevailing soil water pathways: water storage, water runoff, and water percolation. Water storage is determined by the attributes used for assessing the water holding capacity and soil moisture deficit (Debeljak et al., 2019).
Water runoff is determined by the attributes used for assessing the water-, sediment-, and nutrient-related runoff. The water percolation sub-model is determined by the attributes used for assessing the resulting drainage of excess of water above that potentially stored in the soil and the resulting nutrient leaching and losses (Wall et al., 2018; Debeljak et al., 2019).

The soil biodiversity and habitat provisioning decision model integrates four sub-models describing soil nutrients (status, trends, turnover, and nutrients availability), soil biology (available information on diversity, biomass, and activity of soil organisms), soil structure [structure and density, ranging from mesoscale (coarse fractions, soil particles, organic matter, air, and water-filled space) to macroscale (soil layers, terrain, slope)], and soil hydrology (soil humidity and the soil water flow pathways) (Rutgers et al., 2019; Debeljak et al., 2019).

All decision models have similar hierarchical structure (number of hierarchical levels), as well as the number of basic attributes. From the number of integration rules, it is evident that the water regulation and purification and the biodiversity and habitat models are more complex than the others, because of the total number of attributes and their scales of values. However, the decision models for all five soil functions use the same subset of basic attributes, so the total number of distinctive input attributes for all decisions models is 75 (Debeljak et al., 2019).

Jones et al. (2017a,b) highlighted the lack of integrated DST for farm system management. They envisioned a DST platform that connects various models, databases, analyses, and information synthesis tools in an easy-to-use interface to enable analyses and outputs to answer questions relating to the management of particular farming "systems" biophysical resources and/or socio-economic situations. Jones et al. (2017a,b) concluded that such DST are required, but still not developed.

The Soil Navigator DST encompasses the above-listed components, performs similar tasks, and communicates with the end-users through user-friendly graphical interface designed according to Rose et al. (2016). Furthermore, the Soil Navigator meets the documented needs for a DST that will assist farmers and advisors to achieve sustainability of the agricultural landscape (Eichler Inwood and Dale, 2019), by enabling field-specific assessment and the enhancement of five soil functions simultaneously while integrating sustainability concerns from multiple dimensions or themes. In addition, the Soil Navigator DST has the potential to complement the FaST tools required by the proposal on the 2021–2027 CAP (European Commission, 2018). As part of the GAESs framework, farmers will be required by Member States to use FaST tools in order to establish nutrient management plans and support the agronomic and the environmental performance on their farms. The tool should provide on-farm decision support featuring minimum nutrient management functionalities. However, the capacity of a soil to provide and recycle nutrients is determined not only by nutrient management practices but also by environmental or climatic/weather conditions and farm- or soil-related management practices (Debeljak et al., 2019).

This implies that for the same level of functioning, if attainable at all, soils will require different managements under different pedo-climatic conditions. Another consequence of the interplay of factors is that some environments are better suited to perform certain functions and deliver specific services than others, regardless of management efforts. Decisions favoring nutrient cycling may compromise one or more other functions, as for example increased cycling of phosphorus (P) nutrient may have negative consequences for the quality of water (water purification function) even if losses from the soil are relatively small. This complicates the decision-making process even further. Consequently, there is no such thing as a one size (or soil) fits all soil strategy, which is in line with the findings of Sandén et al. (2018). Decisions must therefore be based on careful considerations accounting for local demands, their soils' potential to deliver functions and even ecosystem services, as well as synergies and trade-offs between soil functions and the weightings of alternative options for achieving these services (Debeljak et al., 2019).

It is in this space that the Soil Navigator DST could support the objectives of the CAP post-2020. Based on the European Commission commitment to make FaST interoperable and modular, it should be possible to couple the Soil Navigator DST with FaST. Whereas, FaST is focusing on nutrients, the Soil Navigator DST could make it possible for the farmer to perform a combined assessment and optimization of nutrient cycling, primary productivity, biodiversity and habitat provisioning, water regulation and purification, and climate regulation and carbon sequestration. In addition, farmers will be able to assess the potential change in GHG emission because of the

management they apply, and to make them aware of trade-offs between, e.g., C sequestration and N2O emissions (Debeljak et al., 2019).
Obvious trade-offs occur, e.g., between application of fertilizer and manure, leading to increased carbon sequestration on one side and potentially leading to increased N2O emissions on the other side, if not managed correctly (Tubiello et al., 2015; Zhou et al., 2017; Lugato et al., 2018). Thus, the Soil Navigator could facilitate activities that will reduce the impact of agricultural sector on climate change and provide support actions to achieve the European Union commitments under the Paris Agreement (United Nations, Framework Convention on Climate Change, 2015; Debeljak et al., 2019).

Besides the potential to integrate the Soil Navigator in the CAP post-2020, there is also potential to use the DEX models at larger spatial scales (e.g., regional, or European) in order to improve the provision of soil functions in a spatially explicit context. Such an application of the developed DEX models could be used to indicate which soil functions should be prioritized by a specific region or member state. However, to produce reliable results, the different DEX models would have to be adjusted to match the specific scale. This can be handled easily, since the embedded DEX models can be improved upon request (e.g., for a higher tier assessment, other systems, such as forestry). By applying a set of harmonized models, it is possible to use the available data and knowledge as efficient as possible (Debeljak et al., 2019).

The Soil Navigator DST also has the potential to function as an educational tool for farmers, farm advisors, and students. The Soil Navigator DST presents an opportunity to gain knowledge about different soil functions and how they are affected by management strategies under certain soil and environmental conditions. The tool could potentially guide discussions between the farmers and farm advisors and demonstrate that primary productivity is closely linked with other soil functions. The stakeholders would be able to visualize the effect of the implementation of a specific management practice not only toward primary productivity but also toward the performance of other soil functions. Such demonstrations may incentivize farmers to obtain the data needed to run more specific Soil Navigator scenarios for particular farms or soil conditions in order to obtain more reliable results (e.g., soil pH, organic matter content, or soil texture). The Soil Navigator DST could also be linked to regional soil maps and thereby educate the farmers about new sources of information. Finally, it can be used as a tool to assess the influence of the global climatic changes on the soil functions, which will enable experts to perform risk assessment and risk management and to propose practical and effective climate adaptation measures for farmers and other stakeholders (Debeljak et al., 2019).

3.7. Decision support tools

In the broadest sense, a DST is any guidance, procedure, or analysis tool that can be used to help support a decision. Bardos, 2001 provides a literal definition of Decision Support as: “the assistance for, substantiation and corroboration of, an act or result of deciding; typically this deciding will be a determination of an optimal or best approach.” Although obvious, it is important to point out that decision support is NOT the same as making a decision. Another important point pertaining to decision support is that it can come in the form of written guidance or in the form of software. Written guidance is frequently provided by regulatory agencies as a means of obtaining a standardized, reproducible approach to reaching a decision (Sullivan, 2002).

An early description of Decision Support Systems states that a software DST has six characteristics (Geoffrion, 1983):
1) explicit design to solve ill-structured problems;

2) easy-to-use and powerful user interface;
3) ability to combine analytical models with data;
4) ability to explore the solution space by building alternatives;
5) capability of supporting a variety of decision-making styles;
6) allowing interactive and recursive problem-solving.

Advantages of Using a DST

The major advantages of using a computerized decision support tool is that it provides improved transparency of the decision process and permits the effects of uncertainty on the decision to be quantitatively addressed. A DST provides a structured process in which all assumptions, model parameters, and predicted outcomes can be reviewed and documented. Therefore, the steps in the decision process can be made transparent to those not directly involved in the process (Sullivan, 2002).

Uncertainties can be addressed through multiple use of the DST to examine the impact of model parameters and different scenarios on the decision variable. Uncertainties are also addressed through statistical analysis of the data. Incorporating uncertainties in the decision process can lead to better decision making (Sullivan, 2002).

Differences between a Computer Model and a DST

There is confusion over the difference between a DST and a model. The key difference is that a DST provides the information in terms of a decision variable. For example, if the decision was how much soil needs to be remediated, a DST would estimate the volume of soil in excess of a risk-based concentration limit. Computer models that produce output in terms of technical variables, e.g., flow rate, are not DST. For example, if the goal is to define an optimum sampling strategy, knowledge of the flow rate is insufficient to address this decision. However, computer models that produce output of technical variables may be incorporated into a DST. In the preceding example, the flow code could be coupled with knowledge about the source term, contaminant transport and geostatistical analysis to form a DST that calculated optimum sampling locations (Sullivan, 2002).

Suggested Taxonomy

Several papers have proposed categories to define decision support software tools (Powers, 2001, Pollard, 1999, Sullivan et al., 1997). The suggested categorizations all have substantial overlap, and their differences are primarily related to the degree of generality. Some define the taxonomy based on the solution technique (multi-attribute analysis, uncertainty analysis, etc.). While others define the taxonomy based on the application (sustainable land development, site characterization, etc.) (Sullivan, 2002).

Application of Decision Support Tools

The intent of a Decision Support Tool is to provide information in a form that readily supports the decision. Often there is a wide range of disparate data available to the decision-maker. For example, in environmental problems, it may include meteorological data (e.g., temperature, pressure, wind speed, precipitation, etc.), geologic data (soil structure, physical and chemical properties of the soil, etc.), hydrologic data (depth to the water table, groundwater elevation, groundwater flow rate and direction, hydraulic properties of the soil, etc), contamination data (source, distribution in the soil and groundwater over time, physical and chemical form of the contamination, etc.) and exposure pathway data (location of receptors, contamination uptake factors in plants, resuspension factors, etc.). It is essential for a decision support system to take the appropriate data from all the available data and synthesize this information to provide knowledge useful to the decision process (e.g., define likelihood of exceeding a risk threshold, identify uncertainties in the analysis and model parameters that could impact decisions) (Sullivan, 2002).

The theoretical basis for decision support tools and their applications are taught at many Universities, generally in management information sciences departments. These courses focus on decision making in the face of uncertainty and typically cover topics such as probability and Bayesian statistics as well as artificial intelligence concepts, case-based reasoning, expert systems, rule-based systems, machine learning methods, data mining, and neural networks (Sullivan, 2002).

Courses in decision support systems to improve medical diagnostics in the face of incomplete or ambiguous information are offered at some medical schools. In addition, several journals address both the theory and applications of decision support tools. These include Decision Support Systems, Decision Sciences, Journal of Data Intensive Decision Support, Journal of Decision Support, as well as journals that feature other topics but often have decision support articles (e.g., Journal of Management Information Systems) (Sullivan, 2002).

Key factors influencing use of a decision support tool

Figure 6 presents the key factors that were found to influence the uptake and use of DST in the interviews across the three study areas. All of these are relevant to varying degrees across all types of DST, whether computer-based, app-based, or paper-based.

For successful uptake of DST, researchers and designers should consider the following fifteen factors (∗ = mentioned most often) (Rose et al., 2016).

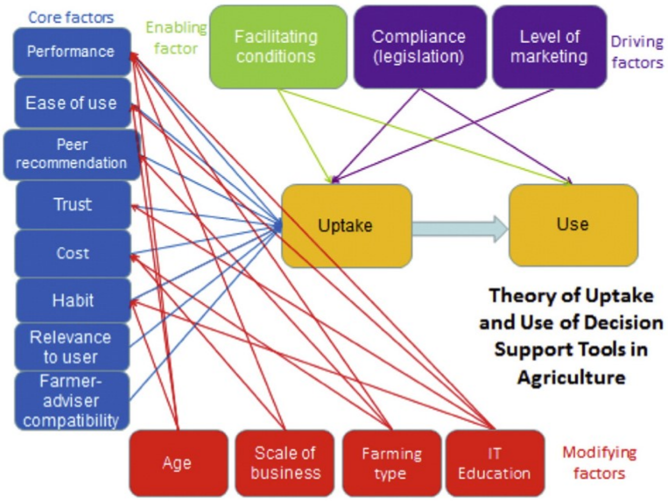


Figure 6. Theory of uptake and use of DST in agriculture

Core factors

The core factors presented in Fig. 2 directly influence behavioural intention to use a specific decision support tool. These factors are not mutually exclusive and the strength of each can be modified by other variables (Rose et al., 2016).

Future directions for the design and delivery of DST

In light of the findings, a number of suggestions can be made to guide the future design and delivery of DST. Firstly, designers could use the fifteen factors identified in this research as a checklist alongside which to measure the quality of new tools. This checklist is presented in Box 1 with a series of sample questions that designers could ask themselves throughout projects (Rose et al., 2016).

Table 6. Checklist for good design of decision support tools

1. Performance – does the tool perform a useful function and work well?
2. Ease of use – is the user interface easy to navigate?
3. Peer recommendation – how can we encourage peer-to-peer knowledge exchange?
4. Trust – is the tool evidence-based and do we have the trust of users?
5. Cost – is there a cost-benefit or is the initial cost too high?
6. Habit – does the tool match closely with existing habits of farmers?
7. Relevance to user – can the tool say something useful about individual farms?
8. Farmer-adviser compatibility – could the tool be targeted at advisers to encourage client uptake?
9. Age – does the tool match the skills and habits of different age groups?
10. Scale of business – how far is the tool applicable to all scales of farming?
11. Farming type – how far is the tool useful for different farming enterprises?
12. IT education – does the tool require good IT skills to use?
13. Facilitating conditions – can the tool be used effectively? i.e. is there internet access? Does it fit farmer workflows? Is there compatibility with use of existing devices?
14. Compliance – how can the tool help users to satisfy legislative and market requirements?
15. Level of marketing – how do we let users know about our tool?

Instead of focusing merely on designing sophisticated tools that are easy to use, some of the other important, but seldom highlighted, factors could be considered. Foremost amongst these, the ability to help users to satisfy legislative requirements via DST will encourage uptake, whilst delivery on the ground can be enhanced by working with existing trusted local networks. It may also be fruitful to target software and app-based systems at younger audiences with larger farms in the first instance. Then, once established amongst this group, manufacturers could work with government and the wider farming community to improve IT education (which may help in breaking embedded habits), as well as improving rural connectivity (Rose et al., 2016).

The findings also raise a tension between taking a ‘carrot’ or ‘stick’ approach to the use of DST. Quite clearly, farmers and advisers will use a decision support tool if they are required to by legislation or market requirements, such as complying with a quality assurance schemes. Thus, forcing them to use a specific tool by law would be the quickest route to uptake. Yet, such methods are draconian and risk alienating a set of end users already feeling the strain of administration and adhering to regulations. An alternative is to incentivise use, perhaps through market mechanisms, by showing how tools can add value to a business (e.g., saving time and making/saving money), or through financial incentives, such as grants or subsidies to help farmers recuperate the costs of purchasing DST. The results illustrated that this mechanism had been successful in encouraging some farmers, particularly upland livestock farmers with limited cashflow, to invest in such systems. However, the results illustrated that a large proportion of those farmers who had purchased DST with 80% or 100% grants were not actually using them regularly. Therefore, it raises the question as to whether the grant scheme was a cost-effective use of resources. Certainly, more work is needed to strike the right balance on this spectrum (Rose et al., 2016).

3.8. Relevance of DST use

3.8.1. Climate change and water retention

A large part of the world’s freshwater resources is contained in river basins and groundwater systems that are shared by two or more countries. As climate change essentially changes the hydrological situation in many basins, increasing the number of extreme situations of flooding and drought, transboundary management of these water resources in order to prevent negative effects of unilateral adaptation measures and in order to choose the most effective measures has become highly urgent (Timmerman et al., 2011).

Transboundary water management is in essence more complex than national water management because the water management regimes usually differ more between countries than within countries. Transboundary water management requires coordination over different political, legal and institutional settings as well as over different information management approaches and financial arrangements (Timmerman et al., 2011).

A Guidance on Water and Climate Adaptation has been developed under the UNECE Water Convention with the objective to support cooperation and decision making in transboundary basins, addressing adaptation to climate change impacts on water resources, such as flood and drought occurrences, water quality, and health related aspects, as well as practical ways to cope with the transboundary impacts (Timmerman et al., 2011).

In terms of climate change and extreme events, the role of the complex water systems and reservoirs management is increasing. Under these conditions the management of the built water reservoirs is of primary importance for both: responding to high-wave and for ensuring the ecological flow and water consumption during drought periods. In order to improve the complex and significant reservoir management, it has been initiated a phased development of a Decision support system (DST) with the appropriate modules. The used models provide the possibility of evaluating the current situation, impending needs and influx and relevant recommendations for solutions. Regardless of the diversity of the mentioned situations, the recommendations for solutions are concrete - from maintaining certain levels (operation at high water) to restricting individual water users (operation under conditions of drought and water shortage) (Yordanova and Ilcheva, 2019).

To prevent of flooding risk, it is needed free volume to be provided in reservoir timely to accommodate high inflow. This volume is different and varies considerably for different months, which requires a thorough analysis and especially determining of the monthly maximum runoff with a particular probability and related typical durations of their appearance (Yordanova and Ilcheva, 2019).

Floods are the most frequent and widespread natural disasters worldwide (WMO, 2013). In 2006 for instance, exceptionally high river levels caused loss of lives and considerable economic losses in Serbia, Bulgaria and Romania. Thus, risk prevention strategies were reconsidered and the need for common solutions for the Danubian countries was outlined. Non-structural measures to mitigate flood risk as is the improvement of forecasting capabilities on a basin-wide scale are known to be highly effective. The DAREFFORT project is a horizontal initiative to implement a flood risk mitigation measure in a joint and sustainable way on catchment level. The main output was the Danube Region Enhanced Flood Forecasting Cooperation that was a step towards creating the basis of ICPDR Danube Hydrologic Information System (HIS). This was only reached through a standardized data format utilized by the responsible national organizations and improved data exchange between the participating countries as reliable and comprehensive hydrologic data is the basis of sound forecasting in any country. In this paper the Bulgarian experience and contribution to the DAREFFORT project is presented. Balabanova et al. (2022) overviewed the present status of the national forecasting capabilities and main topics for the process of the hydrological forecasting, data flow, data processing and data exchange (Balabanova et al., 2022).

3.8.2. Soil water retention

Climate change will intensify water scarcity, and therefore irrigation must be adapted to save water. Operational tools that provide watering recommendations to end-users are needed (Mirás-Avalos et al., 2019).
Agriculture is the largest consumer of freshwater worldwide, accounting for 70% of water withdrawals, representing 2.7 Mhm^3 annually used to irrigate 324 Mha (8300 m^3 ha$^-$1) (FAO, 2017). It is noticeable that this water volume has multiplied by three since 1950 in order to provide food for the population, as irrigated agriculture produces 40% of the world's food while employing only 20% of cultivated land (AQUASTAT, S.a.). In addition, climate change is reducing the freshwater availability, increasing the competition for the available water resources among the different users (Turral et al., 2011). Therefore, an accurate determination of crop water requirements is essential to perform an optimal irrigation schedule and increase crop yields, water use efficiency and farm profits, while reducing costs and energy use and at the same time preventing surface and groundwater pollution (Ventura et al., 2001; Payero and Irmak, 2013).
In order to determine crop water requirements, most farmers and irrigation-advising websites have often used the one-layer methodology proposed by Allen et al. (1998), Food and Agriculture Organization of the United Nations (FAO) Irrigation and Drainage paper No. 56 (FAO-56), which is based on the multiplication of the reference evapotranspiration (ETo), calculated with the Penman–Monteith approach, by a crop coefficient (Kc) that represents the relative rate of evapotranspiration by a specific crop (ETc). This method can be considered as a reference due to its extensive use and reliable results, as reported for a great number of crops (Giménez et al., 2017; Hong et al., 2017; Paredes et al., 2018). However, the published Kc can result in poor estimates of crop water requirements (Dzikiti et al., 2018) due to several reasons.

First, the one-layer methodology considers the crop as a single big leaf and cases with partial vegetation cover, such as vegetable crops, might not satisfy completely such a hypothesis (Gharsallah et al., 2013); this could be solved by applying the dual-Kc approach that has been developed under FAO-56 (Allen et al., 1998).
Second, discrepancies exist between the actual crop characteristics (percentage of ground cover, crop height, phenological stage, etc.) and the published Kc (Cammalleri et al., 2013), which can be overcome by applying adjustment coefficients.

Third, the empirical Kc is site-specific (Villalobos et al., 2009), although many attempts for determining Kc at the local level have been reported for a great number of crops (Abrisqueta et al., 2013; López-Urrea et al., 2014; Ramírez-Cuesta et al., 2019). Finally, the single Kc methodology does not allow for the adaptation to different agricultural practices (e.g., mulching, cover crop) since it considers both evaporation and transpiration together. In order to take into account these issues, the dual-Kc approach (Allen et al., 1998) in which transpiration (T) is disconnected from the soil's physical conditions related to soil evaporation (E) might improve such estimations (Dzikiti et al., 2018). However, discrepancies between the actual crop characteristics and the published Kc and the specificity of the coefficients may still be present (Cammalleri et al., 2013). Therefore, modelling approaches overcoming these issues are needed.

Additionally, crop water requirements can be determined on-site by monitoring the energy exchange above the crop surface, as a residual term of the soil water balance (e.g., lysimeters and soil water budget; (Gharsallah et al., 2013; Rallo et al., 2017), or using soil and plant probes (e.g., soil water content, dendrometers, leaf temperature or sapflow probes) (Rana et al., 2000). Overall, these methodologies have been used for research purposes as they are expensive, complex, sometimes require the installation of sophisticated equipment and depend on qualified personnel to obtain reliable results (Soulis et al., 2018). Moreover, some of these methods provide specific point-based measurements that are often linked to uncertainties, requiring models for scaling up to the whole orchard (Ramírez-Cuesta et al., 2019; Rana et al., 2005). Consequently, they are not suitable for routine use in orchard water management (Dzikiti et al., 2018) and hence there is a need for more mechanistic models, which can provide reliable estimates of E and T under a wide range of climatic conditions and management practices.

Nowadays, a high number of tools and decision support systems (DST) intended for agro-system management exist. For instance, DSTAT, standing for Decision Support System for Agrotechnology Transfer, is a general crop model able to simulate growth, development and yield. There are also some more specific examples for water management such as: System of Participatory Information, Decision-support, and Expert knowledge for River-basin management (SPIDER) (Moreno-Rivera et al., 2009); AquaCrop (Steduto et al.,2009); Automated Radiative Transfer Models Operator (ARTMO) (Verrelst et al., 2012); AquaGIS (Lorite et al., 2013); VegSyst-DST (Gallardo et al., 2014) and ArcDualKc (Ramírez-Cuesta et al., 2019).

However, some of these DST provide information about aspects not directly related to crop water needs and, usually, they require a high number of inputs and parameters. Additionally, their complexity can limit their use by less specialized users, restricting them to scientific purposes. Furthermore, existent DST are restricted to herbaceous crops. In this sense, the VegSyst model, which initially was developed for its use in greenhouses, has been successfully adapted to outdoor conditions (Giménez et al., 2019). This model is able to estimate ETc for several vegetable crops; however, it is not capable of separating E from T since it uses the FAO-56 approach with a single Kc for calculating crop water requirements, with the particularity of providing Kc from a crop growth model.

One of the limitations of current DST (Steduto et al.,2009; Thysen and Detlefsen, 2006; Navarro-Hellín et al., 2016; Yang et al., 2017; Li et al., 2018) is that they do not consider the spatial heterogeneity within the plot, and estimations are referred to a specific point location. This spatial component is captured in other existent tools by the incorporation of remote sensing technology (Ramírez-Cuesta et al., 2019; Moreno-Rivera et al., 2009; Lorite et al., 2013). However, remotely sensed data can be easily incorporated into some of these models by calculating inputs from satellite or drone-acquired imagery, such as the vegetated fraction cover (Ormsby et al., 1987).

In this context, the aim of this work was to develop a simple and operational model, Irrigation-Advisor (IA), that overcomes the issue of depending on site-specific Kc, is able to provide a separate estimation of E and T, is easily adapted to different management situations, and avoids the use of on-the-ground sensors. The viability of IA was tested in six field experiments with four different crops (endive, lettuce, muskmelon and potato) carried out in Southeast Spain (Mirás-Avalos et al., 2019).

There are no direct DST or DST explicitly designed for soil water retention except for irrigation system control. Several GIS–based models approved in local research and remote sensing data combined with agronomic models can be used as a support tool in decision-making related to soil drainage and irrigation. Geographic heterogeneity of the environmental growth conditions is an advantage for locally approved models (Todoroff et al., 2010). Soil workability evaluation can be used as DST. Modelling of soil water retention and potential is connected to the planning and scheduling of tillage operations allowing farmers to maintain soil quality and improve crop outcomes. These models use soil texture, SOM and soil water potential as main factors as SOM improves soil stability with its binding capacity which affects soil strength and structural porosity (Obour et al., 2017; 2019). Wall and colleagues (Wall et al., 2020) suggest DSM for primary productivity that uses water storage sub-model. By integrating the factors that affect soil moisture and the soil's ability to hold and store water, this model simulates the current water storage potential. It provides farmers and farm advisors with assessment based on qualitative factors regarding the soil's current ability to regulate water storage, reduce phosphorus and sediment losses in water runoff, and limit nitrogen leaching that occurs as water infiltrates below the root zone. This approach resulted in an accurate, reliable, and useful decision support model for the assessment of the WR soil function at the field level. This water retention model can be used to help inform choices related to farm management practices toward enhancing the water retention function provision of agricultural soils (Wall et al., 2020).

Erosion control with the proper agricultural soil management methods can be connected to water retention. Research in Italy (Giambastiani et.al. 2023) suggests that modelling the effects of cultivation practice on soil water retention capacity can constitute a real DST for the design of keylines and for agricultural hydraulic arrangements in general.

German research involving qualitative system dynamics models (QSDMs) (Egerer et al., 2021) shows that identification and analysis of leverage points on farm level can be a useful DST for regional policy makers.
DST in agriculture and water retention can be defined as monitoring systems as well. Soil water sensor experiments has proved to be a useful tool for optimizing agricultural irrigation (Nolz et al., 2012). Different algorithms are used to process the data collected from sensor experiments. Evapotranspiration, precipitation and irrigation rates are taken into consideration when processing the results and making predictions models based on the data collected. The fractional differential models have proven their ability of performing short- and medium-term water demand forecasts for and serve as a DST for further economic planning (Romashchenko et al., 2021). Sensors and wireless monitoring are used to reduce the waste of water and to maximize the crop yield according to the weather conditions and the real water needs. Experiment in Italy (Viani et al., 2017) shows that exploitation of the irrigated water can be improved thanks to the reduction of the percolation phenomenon without affecting the quality of the crops. Wireless sensor network and wireless sensor and actuation network technologies have proved to be useful DST to acquire heterogeneous environmental parameters and to control the functioning of the irrigation system. A completely autonomous wireless system that has high practical value of the suggestions given to the farmers, directly support the daily irrigation schedule without any specific input or calibration required by the proposed methodology.

DSTs for assisting with irrigation management of vegetable crops (open field and greenhouse) are the most widely used DSTs in agriculture. Web interface, SMS messages and a Tablet App can be used as tools to provide users with irrigation scheduling advice (Gallardo et al., 2020). Recently developed irrigation advisor DST in Spain uses weather forecast to determine near-future conditions and optimize water applications for vegetable crops in the Mediterranean coast (Mirás-Avalos et al., 2019).

Models used as DSTs do not always have to be mathematically complicated. Total available water capacity of the soil can be modelled using cheaper and more robust methods. Todoroff (2010) used already established crop growth model (in their case MOSICAS) and remote sensing data (ortho-images), proving that even with limited resources this model can be applied to field farming (not only experimental) cropping conditions. It provides an easy way to map the total available water capacity of soils on a wide geographical scale provided that the climate and crop description are available.

3.8.3. Synergies and trade-offs between soil functions

Soil properties or management decisions with a positive effect on a specific function may enhance other functions ('synergies') or reduce them ('trade-offs') (Power, 2010). One of the most obvious examples of a conflict between soil functions is the demand for the production of fresh water with a low concentration of nutrients, which is probably best served by set-aside land, and the demand for nutrient cycling through fertilized and transpiring crops which have received fertilizer applications. Figure 7a and b give more examples of synergies and trade-offs between nutrient cycling and other soil functions (Schröder et al., 2016).

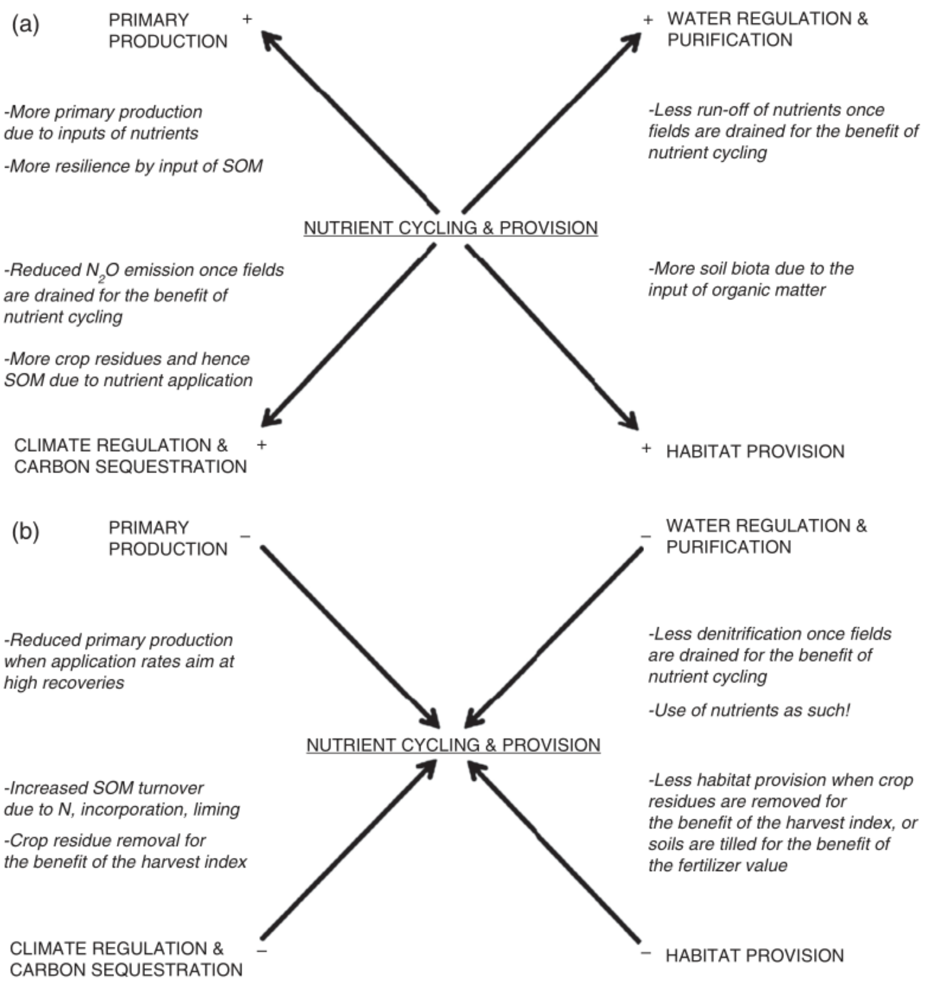


Figure 7 (a) Examples of situations where conditions or measures with a positive effect on nutrient cycling are supportive of the other four major soil functions.
(b) Examples of situations where conditions or measures with a positive effect on nutrient cycling have a trade-off in terms of the other four major soil functions (Schröder et al., 2016)

As far as management decisions are concerned, not removing cereal straw, for instance, provides a substrate for soil organisms (Fraser and Piercy, 1998), contributes to short-term sequestration of carbon, increases the water retention capacity of soils (Hudson, 1994) and may support primary production by soil organic matter (SOM)-induced disease suppression (Stone et al., 2004). At the same time, however, it slightly reduces the total amount of nutrients harvested and, hence, their potential for nutrient cycling according to the present definition. Tillage often increases yield and thus the amount of nutrients harvested (Palma et al., 1997; Rasmussen, 1999; Alvarez and Steinbach, 2009; Giller et al., 2009). The positive effects of reduced or no-till on biological and physical soil properties, including the retention of plant-available water (e.g., Spiegel et al., 2007; Hobbs et al., 2008; Lehtinen et al., 2014), is apparently not always reflected in increased yields and shows that what is beneficial for one soil function is not necessarily beneficial for all functions.

As far as soil properties are concerned, well-drained light textured soils have a high potential for nutrient cycling in Atlantic climatic conditions. They allow field traffic all year round, allow incorporation of residues, are conducive to rapid mineralization and have relatively small denitrification losses. They also facilitate deep rooting and thus avoid nutrients moving beyond reach, provided that suitable crops are grown. In addition, their infiltration capacity can contribute to the recharge of groundwater and its purification via increased residence times compared to soil types that are conducive to surface run-off (Rivett et al., 2008). However, the same kind of soils may have a smaller carbon sequestration potential due to ample aeration and limited protection of SOM, are less able to buffer nutrients and water, less able to decrease the bioavailability of contaminants and less productive under dry conditions due to their smaller water retention capacity (Coyle et al., 2016).
As for biodiversity, there are as many dilemmas. Soil quality, soil health and soil life are often presented as a trinity (e.g., Doran and Zeiss, 2000; Brussaard et al., 2007; Kibblewhite et al., 2008), and, indeed, the presence of soil biota is instrumental in nutrient cycling (e.g., Caldwell, 2005; Coleman, 2008).

Mineralization of organically bound nutrients would be limited without the support of soil biota; that is, FV of residues would be greatly reduced. Moreover, rhizospheric microorganisms can have a demonstrable effect on the size and effectiveness of roots and thus increase the RV of plant-available nutrients (Lynch, 2007). Due to their effects on soil structure and the consequential drainage capacity (Bronick and Lal, 2005; Blouin et al., 2013), soil biota may also affect the suitability of fields to accommodate the reception of residues (AV). Laboratory experiments have further shown reduced mineralization rates when specific groups of soil biota were deliberately removed (Griffiths et al., 2000; Wagg et al., 2014). Field experiments have demonstrated an intricate interaction between specific types of residues and the kind of soil biota required for their decomposition (Rashid et al., 2013) or yield depressions in leguminous crops if the appropriate Rhizobium strain is lacking (Keyser and Li, 1992).
Giller et al. (1997) posed the question of which and how much soil biota is truly needed for nutrient cycling. This question is legitimate as the actions required to maintain soil biota in terms of diversity and abundance, carry a price, either because of the cost of the actions themselves or because of yield penalties. Tillage operations can have a negative effect on earthworm populations but, depending on the environment, crop yields can benefit from the positive effect of tillage on the accessibility of a soil to roots, on weed control and on the conservation of ammonium-N in manures.

Likewise, refraining from pesticide use will undoubtedly have a positive effect on the on-farm biodiversity including soil organisms, but there is convincing evidence that it carries a price in terms of nutrient use efficiency, productivity and thus land consumption and off-farm biodiversity (De Ponti et al., 2012; Grau et al., 2013). It is evident that the use of pesticides can undermine the inherent capacity of soils to suppress pests and diseases.
However, in general, there are no indications that the collateral damage to soil biota hampers the decomposition of organic residues in a significant way. Although some species have a key role in determining soil processes, soil organisms generally show strong functional redundancy (Setälä et al., 2005).
Giller et al. (1997) acknowledge that these 'unemployed' organisms probably play a role in the resilience of production systems to perturbations. However, without more evidence of a broad applicability of this utility across many environments, there is as yet no reason to refrain from every activity that may potentially be harmful to soil biota.

The generally observed positive relationships between the abundance of soil biota, N mineralization and crop yield are sometimes interpreted as an indication for a causal positive relationship between soil biota and yield, implying that soil organisms need to be cherished for the sake of yield formation. The enhanced mineralization is not necessarily the result of promoting soil biota, however. Instead, both mineralization and abundance of soil biota may simply be the consequence of improved conditions for microbial activity such as rewetting a soil after droughts (López-Bellido and López-Bellido, 2001) or resulting from greater inputs of organic matter, that is a substrate for soil biota. In line with this, a long-term experiment comparing conventional and organic cropping systems, differing in terms of soil organic matter inputs, has indicated that the recovery of both organic N and mineral N by crops is not significantly affected by the abundance of soil biota (Langmeier et al., 2002; Bosshard et al., 2009). Differences in mineralization rate are hence not per se indicative of the capacity of soils to sustain the FV or RV, let alone 'the soil quality', if differences between systems in terms of weather or of earlier organic material inputs cannot be excluded. Attribution of ecosystem service credits to systems with greater mineralization (e.g., Sandhu et al., 2015) becomes questionable.

3.8.4. Nutrient use efficiency

Cycling of nutrients, including nitrogen and phosphorus, is one of the ecosystem services we expect agricultural soils to deliver. Nutrient cycling incorporates the reuse of agricultural, industrial and municipal organic residues that, misleadingly, are often referred to as 'wastes'. The present review disentangles the processes underlying the cycling of nutrients to better understand which soil properties determine the performance of that function. Four processes are identified:

- the capacity to receive nutrients,
- the capacity to make and keep nutrients available to crops,
- the capacity to support the uptake of nutrients by crops,
- the capacity to support their successful removal in harvested crop.

Soil properties matter but it is imperative that, as constituents of 'soil quality', they should be evaluated in the context of management options and climate and not as ends in their own right. The effect of a soil property may vary depending on the prevailing climatic and hydrologic conditions and on other soil properties. Schröder et al. (2016) recognized that individual soil properties may be enhancing one of the processes underlying the cycling of nutrients but simultaneously weakening others.

Competing demands on soil properties are even more obvious when considering other soil functions such as primary production, purification and flow regulation of water, climate modification and habitat provision, as shown by examples. Consequently, evaluations of soil properties and management actions need to be site-specific, taking account of local aspects of their suitability and potential challenges (Schröder et al., 2016).
Land application is the most cost-effective outlet for recycling farm manures and other organic materials (e.g. biosolids, composts, digestates), enabling plant available nutrients and organic matter to be utilized to contribute to crop nutrient demands and maintain soil fertility. However, in many countries, farmers do not always make adequate allowance for the contribution of organic materials to crop nutrient requirements, potentially resulting in nutrient oversupply and subsequent environmental pollution.

Increasing the contribution of organic materials to crop nutrient requirements is essential in reducing nitrate (NO_3) and phosphorus (P) losses to water systems, and ammonia (NH_3) and nitrous oxide (N_2O) emissions to air from agriculture, to comply with existing and forthcoming EU Directives and International agreements (e.g. Nitrates Directive, Water Framework Directive, National Emission Ceilings Directive, Kyoto Protocol etc.).
The ADAS MANure Nitrogen Evaluation Routine (MANNER version 3.0) decision support system was originally developed to predict crop available N supply following farm manure (and other organic material) applications to land, taking into account manure N analysis, NH_3 volatilization and NO_3 leaching losses, and the mineralization of organic N (Chambers et al., 1999). Over 10 000 copies have been distributed following its launch in August 2000. A new version of the software (MANNER-NPK) was developed to enhance the N loss and crop available N supply predictions by utilizing more recent scientific information. In response to user and stakeholder feedback, the software functionality was also extended to include predictions of phosphorus (as P_2O_5), potassium (as K_2O), sulphur (as SO_3) and magnesium (as MgO) supply to crops, and to enable users to view the results in terms of both the fertilizer replacement value (kg/ha) and the economic value (£/ha) of manure applications (Nicholson et al., 2013). The MANNER conceptual model was enhanced to incorporate new modules to estimate N_2O (via nitrification and denitrification) and di-nitrogen (N_2) losses (via denitrification), and to take into account autumn crop N uptake (Figure 8).

Some changes were also made to the inter-relationships between modules to better represent the N flow pathways and transformations that occur following manure application to land. In particular, MANNER-NPK now estimates the quantity of N available to following crops (i.e. in the cropping year after manure application) through the release of manure organic N.

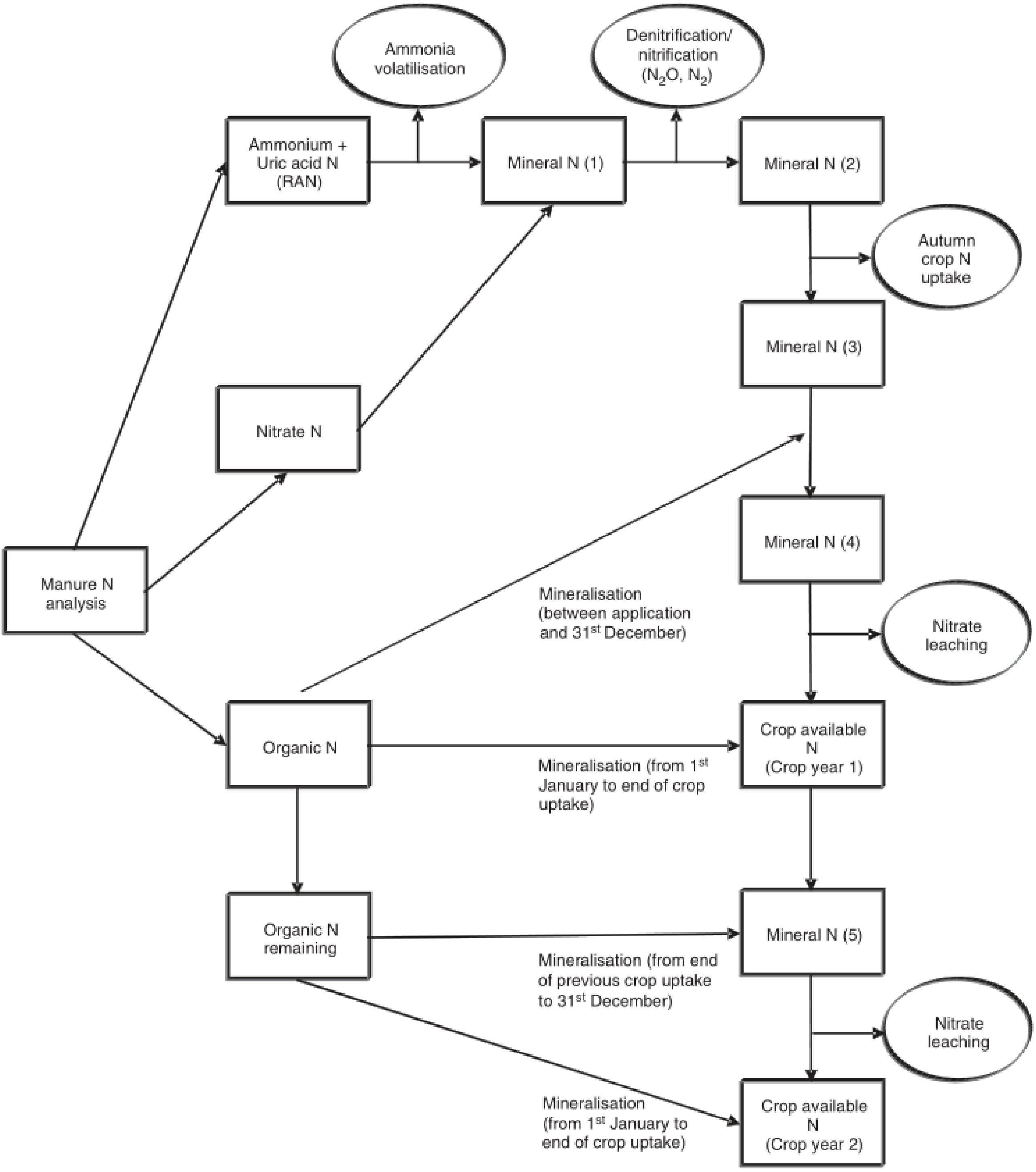


Figure 8. The MANNER-NPK conceptual model

3.8.5. Phosphorus management decision support

The evolution of phosphorus (P) management decision support tools (DSTs) and systems (DST), in support of food and environmental security has been most strongly affected in developed regions by national strategies:

- to optimize levels of plant available P in agricultural soils;
- to mitigate P runoff to water bodies.

In the United States, Western Europe, and New Zealand, combinations of regulatory and voluntary strategies, sometimes backed by economic incentives, have often been driven by reactive legislation to protect water bodies. Farmer-specific DSTs, either based on modeling of P transfer source and transport mechanisms, or when coupled with farm-specific information or local knowledge, have typically guided best practices, education, and implementation, yet applying DSTs in data poor catchments and/or where user adoption is poor hampers the effectiveness of these systems. Recent developments focused on integrated digital mapping of hydrologically sensitive areas and critical source areas, sometimes using real-time data and weather forecasting, have rapidly advanced runoff modeling and education. Advances in technology related to monitoring, imaging, sensors, remote sensing, and analytical instrumentation will facilitate the development of DSTs that can predict heterogeneity over wider geographical areas. However, significant challenges remain in developing DSTs that incorporate "big data" in a format that is acceptable to users, and that adequately accounts for catchment variability, farming systems, and farmer behavior. Future efforts will undoubtedly focus on improving efficiency and conserving phosphate rock reserves in the face of future scarcity or prohibitive cost. Most importantly, the principles reviewed here are critical for sustainable agriculture (Drohan et al., 2019).

350 years after Hennig Brandt's discovery of phosphorus (P), the sustainable management of P is at the center of global food and water security agendas (Withers et al., 2015), challenged by a myriad of factors tied to mining, application to agricultural lands for crop production, industrial use, and recovery from waste streams (Jarvie et al., 2015; Sharpley et al., 2018). Given that >90% of the P used by society is in the production and processing of food, enhancing P use efficiency throughout the whole food system is central to achieving sustainable P management (van Dijk et al., 2016). Within the food system, the farmer is at the forefront of daily decision making in P management, ensuring that mined P efficiently reaches crops while preventing excess P from entering water bodies where it can result in eutrophication (Sharpley et al., 2018; Withers et al., 2014). From the standpoint of water quality protection, it is essential that applied P reach the target plant without being inadvertently lost to surface waters, but this objective can be difficult to achieve in practice due to incomplete scientific understanding of P cycling and movement through the soil–plant system (Sharpley et al., 2018), a lack of awareness of the environmental impact of P loss in runoff (Kleinman et al., 2015), insufficient funding to support sustainable P management strategies by farmers (Kleinman et al., 2015), commodity prices that do not include externalities (Sharpley et al., 2015), situations beyond the farmer's control, low implementation rates of conservation practices that reduce diffuse P transport to waterways, and a lack of legislative mandates to enforce P management (Kleinman et al., 2015; Sharpley et al., 2018).

Decision support (DS) is a strategic mechanism used in many disciplines to help apply specialized knowledge and bring about evidence-based decision making. Agricultural applications using DS generally strive to improve agricultural productivity and profitability, as well as to lessen environmental damage (Rose et al., 2016). Decision support has become an integral part of modern agricultural management and plays an especially critical role in regulating agricultural nutrients like P (Sharpley et al., 2017).

Decision support for agriculture can come in the form of a DS tool (DST) with a specific purpose (e.g., P Index in either the United States or European Union [EU] to identify fields in need of remedial management), whereas a DS system (DST) is a multicomponent framework that may integrate several DSTs (e.g., farmer conservation plans or nutrient calculator spreadsheet), external computer models, independent databases, weather forecasts, or user submitted data (Rose et al., 2016). The site-specific nature of P loss makes the development and implementation of both DSTs and DSTs very challenging for scales larger than a field, since P loss occurs from a number of different point and nonpoint sources, along a number of different hydrological pathways, and often in response to highly variable episodic rainfall events (Withers and Bowes, 2018). A diverse array of P management strategies, from field to national scale, have been developed (Fig. 9), which rely on DS to help farmers and catchment managers sustainably manage P.

Drohan et al., (2019) first reviewed national applications of DS in agricultural P management across several OECD (Organization for Economic Cooperation and Development) countries, including New Zealand, the United States, the United Kingdom (UK), RoI, and the Nordic countries of Norway, Sweden, and Finland. We present short histories from each country on the evolution of P agricultural management with the aid of DSTs or DSTs, which relay the local context of P use and legislation (a primary driver of DST and DST development), followed by examples of DST and DST progression. We then reflect on the lessons learned from our collective experiences and identify a path forward for future development and application of DSTs or DSTs for P management. Through documenting the similarities and differences in approaches to P management across the globe, we hope to identify common needs for future work and mutual areas of success where current efforts should continue to be supported or enhanced.

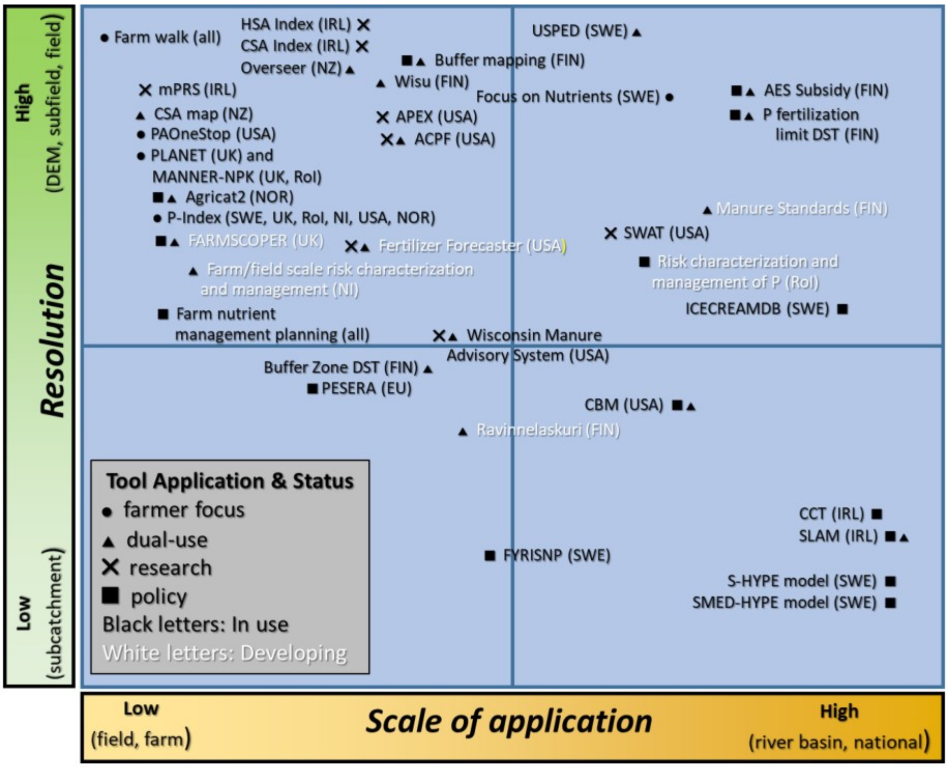


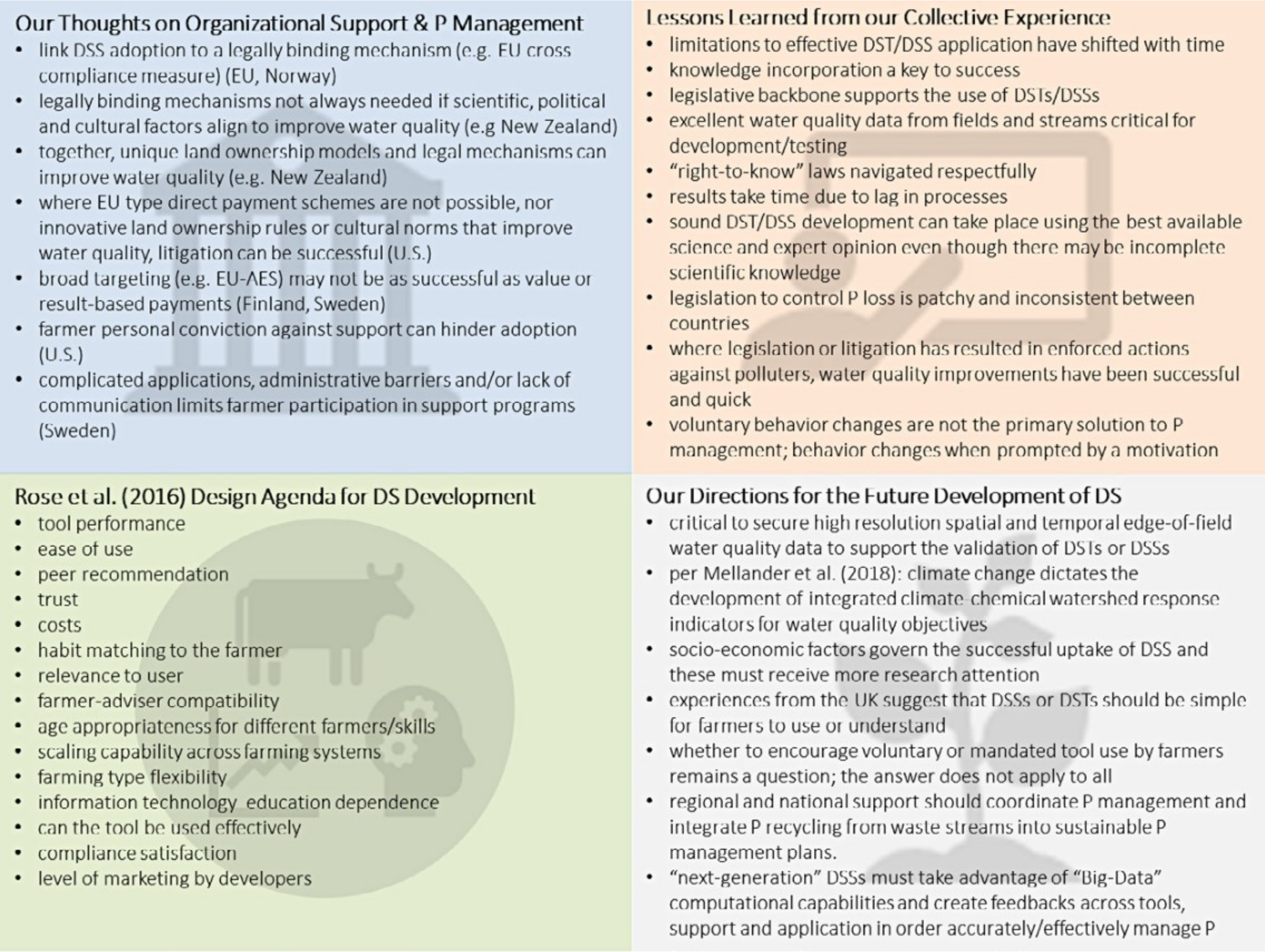
Figure 9. Decision support tools (DSTs) and decision support systems (DSTs) used throughout this manuscript with their respective country of use noted, the scale and resolution of application, and whether the tool's purpose is dominantly farmer focused (e.g., farm planning assistance like MANNER-NPK), dual-use research and decision making (e.g., Fertilizer Forecaster runoff forecasting tool), research driven (e.g., external computer model), or predominantly policy assistance (e.g., Chesapeake Bay Model) (Drohan et al., 2019).

Abbreviations: ACPF, Agricultural Conservation Planning Framework; AES, Agri-Environmental Scheme; APEX, Agricultural Policy Environmental eXtender; CBM, Chesapeake Bay Model; CCT, Catchment Characterization Tool; CSA, critical source area; DEM, digital elevation model; DST, decisiuom support system; DST, decision support tool; EU, European Union; FIN, Finland; FYRISNP, River Fyris catchment, Nitrogen, Phosphorus (Widén-Nilsson et al., 2012); HSA, hydrologically sensitive area; ICECREAMDB, ICE refers to the frozen state of water given the applicable model countries are Finland and Sweden, CREAMS refers to the Chemicals, Runoff, and Erosion from Agricultural Management Systems model, and DB refers to database (Larsson et al., 2007); IRL, Ireland; MANNER, Manure Nutrient Evaluation Routine; mPRS, modified P ranking scheme; NI, Northern Ireland; NOR, Norway; NPK, nitrogen–phosphorus–potassium; NZ, New Zealand; PAOneSTop, Pennsylvania One Stop; PESERA, Pan-European Soil Erosion Risk Assessment; PLANET, Planning Land Applications of Nutrients for Efficiency and the environmenT; RoI, Republic of Ireland; S-HYPE, Sweden-Hydrological Predictions for the Environment model (Lindström et al., 2010; Strömqvist et al., 2012);SLAM, source load apportionment model; SMED-HYPE,Swedish Environmental Emissions Data-Hydrological Predictions for the Environment model (Ejhed et al., 2009); SWAT, Soil and Water Assessment Tool; SWE, Sweden; UK, United Kingdom; USA, United States; UPSED, Unit Stream Power Erosion and Deposition model (Mitasova et al., 1996; Djodjic and Markensten, 2018); Wisu, Wisu viljelysuunnitteluohjelma (Wisu cultivation of design software)

Drohan et al. (2019) review of P management across different political systems with unique legal, economic, and support capabilities and structures has identified potential organizational mechanisms for future adoption by land managers or political representatives (Fig. 10). Review of P management across a select group of countries resulted in our realization of commonalities in DS for P management, which include:
qualitative guidance on best practices,

- quantitative nutrient accounting tools to support management of P inputs,
- quantitative risk assessment tools for P transfer and its mitigation.

In reflecting on how tools were developed and applied while writing this manuscript, Drohan et al. (2019) noted that the design principles of Rose et al. (2016) (Fig. 10, upper left box) were often important points captured purposely, or by accident. Additionally, had better tool development occurred that more closely aligned the tool in question with the farmer’s habit, or information on whether the farmer’s action resulted in compliance, tool use might have increased, or water quality goals might have been met (or been met more quickly).



Our Thoughts on Organizational Support & P Management

- link DSS adoption to a legally binding mechanism (e.g. EU cross compliance measure) (EU, Norway)
- legally binding mechanisms not always needed if scientific, political and cultural factors align to improve water quality (e.g New Zealand)
- together, unique land ownership models and legal mechanisms can improve water quality (e.g. New Zealand)
- where EU type direct payment schemes are not possible, nor innovative land ownership rules or cultural norms that improve water quality, litigation can be successful (U.S.)
- broad targeting (e.g. EU-AES) may not be as successful as value or result-based payments (Finland, Sweden)
- farmer personal conviction against support can hinder adoption (U.S.)
- complicated applications, administrative barriers and/or lack of communication limits farmer participation in support programs (Sweden)

Lessons Learned from our Collective Experience

- limitations to effective DST/DSS application have shifted with time
- knowledge incorporation a key to success
- legislative backbone supports the use of DSTs/DSSs
- excellent water quality data from fields and streams critical for development/testing
- "right-to-know" laws navigated respectfully
- results take time due to lag in processes
- sound DST/DSS development can take place using the best available science and expert opinion even though there may be incomplete scientific knowledge
- legislation to control P loss is patchy and inconsistent between countries
- where legislation or litigation has resulted in enforced actions against polluters, water quality improvements have been successful and quick
- voluntary behavior changes are not the primary solution to P management; behavior changes when prompted by a motivation

Rose et al. (2016) Design Agenda for DS Development

- tool performance
- ease of use
- peer recommendation
- trust
- costs
- habit matching to the farmer
- relevance to user
- farmer-adviser compatibility
- age appropriateness for different farmers/skills
- scaling capability across farming systems
- farming type flexibility
- information technology education dependence
- can the tool be used effectively
- compliance satisfaction
- level of marketing by developers

Our Directions for the Future Development of DS

- critical to secure high resolution spatial and temporal edge-of-field water quality data to support the validation of DSTs or DSSs
- per Mellander et al. (2018): climate change dictates the development of integrated climate chemical watershed response indicators for water quality objectives
- socio-economic factors govern the successful uptake of DSS and these must receive more research attention
- experiences from the UK suggest that DSSs or DSTs should be simple for farmers to use or understand
- whether to encourage voluntary or mandated tool use by farmers remains a question; the answer does not apply to all
- regional and national support should coordinate P management and integrate P recycling from waste streams into sustainable P management plans.
- "next-generation" DSSs must take advantage of "Big-Data" computational capabilities and create feedbacks across tools, support and application in order accurately/effectively manage P

Figure. 10. This paper's summary take-home points on organizational support, lessons learned from our collective experience, a decision support (DS) development framework to follow as proposed by Rose et al. (2016), and directions for future development of DS tools (DSTs) and DS systems (Drohan et al., 2019).

United Kingdom and Republic of Ireland

The UK and RoI policies have largely focused on P mitigation strategies that address the "source" and "mobilization" components of the Phosphorus Transfer Continuum (PTC) proposed by Haygarth et al. (2005). In both countries, large investments have been made through grant schemes for storage facilities and other infrastructure (winter housing) to reduce farmyard P pressures. These strategies have been predominantly driven by total territory, top-down approaches (Kleinman et al., 2015; Withers et al., 2014), largely following the assumption that the reduction of source pressures to optimum agronomic levels, and adoption of best management practices to reduce P losses in runoff and erosion, will be sufficient to achieve the targets of the EU Water Framework Directive (WFD) (2000/60/EC). As a result, DS approaches have focused on optimizing levels of plant available P in agricultural soils, based on the RB209 fertilizer manual (AHDB, 2019) in the UK and the Teagasc "green book" (Wall and Plunkett, 2016) in RoI, in which a soil P Index classification system is delivered through advisory services on farms to make recommendations.

Note that the soil P Index system in this context differs from the P Index in the United States and is rather a soil property based on the bioavailability of soil P as defined by soil test P. In this context, in the UK, an Olsen soil test P level of between 16 and 25 mg L^{-1} falls in Index 2, which is identified as the agronomic optimum for grassland and most arable crops. In RoI, a Morgan P soil test is similarly used where an Index 3 is considered optimum (5.1–8 mg L^{-1} for grassland and 6.1–10 mg L^{-1} for arable crops).

The UK and RoI soil P Index systems have been incorporated within a number of online nutrient management calculators (e.g., DAERA, 2019) that are used to inform the efficient management of P on farms (e.g., Teagasc Nutrient Management Planning Online [Teagasc, 2017]; PLANET and MANNER-NPK nutrient management software run by ADAS [Wall and Plunkett, 2016]). Freely available, these calculators are for use by all farmers but on a voluntary basis. The requirement to avoid higher soil P Indices and avoid gross water pollution is written into regulatory programs that differ slightly between countries.

For example, in Northern Ireland (NI) and RoI, the need to limit soil P accumulation is written into the EU Nitrates Action Programs (European Commission, 2019d), although a requirement to soil test is not mandatory on farms operating up to the equivalent of 170 kg organic N ha L^{-1} but is strongly encouraged through extension services. In England, new regulations came into force in April 2018 with a specific regulatory requirement for farmers to test their soils every 5 yr if applying P to agricultural crops (Statutory Instruments, 2018). These regulations also require that P inputs meet but do not exceed crop and soil needs, and that farmers take steps to avoid diffuse water pollution from applying fertilizers and manures, or due to soil erosion. Guidance on the preparation of farm-scale soil erosion risk maps, manure management plans, and nutrient budgeting provide examples of general existing DSTs available to farmers to help enact good practice, but their adoption has been voluntary. A Microsoft Excel-based DST (FARMSCOPER, http://www.adas.uk/Service/farm-scoper) has been developed in the UK to compare and prioritize mitigation measures that span the source–mobilization–delivery continuum based on an analysis of assessment of their costs and efficacy (Zhang et al., 2012; Gooday et al., 2014).

Although the reactive P concentrations in many UK and RoI rivers has improved significantly since 1990 due mainly to the success of point source controls, in many cases, river P concentrations have reached a plateau above what is required to achieve the targets of the WFD or have increased (Barry and Foy, 2016). In England, P is still the main cause of failure to achieve good ecological status in rivers, which has prompted the introduction of new regulations (Statutory Instruments, 2018). In NI and RoI, this has raised concern that the current “source”-focused mitigation measures do not go far enough and has resulted in a renewed interest in the development of a risk-based DST for P management loss. A recognition that transport, or pathway, factors need to be incorporated into UK and RoI DS has been acknowledged for some time (e.g., Heathwaite et al., 2005; Hughes et al., 2005) and more recently was summarized by Daly et al. (2016) and Deakin et al. (2016). Recent technological advances in landscape modeling, coupled with field-scale hydrologic monitoring, have led to the development of field-scale risk-based approaches to P management. “Risk-based” implies generating risk scores of P loss risk from the (sub)field, which include source, mobilization, transport, and connectivity factors. An example in the UK and RoI is the generation of high-resolution, hydrologic risk maps developed with light detection and ranging (LiDAR) elevation data (Thomas et al., 2016a, 2017) and combined with field and farm soil P information to provide fine scale CSA maps (Thomas et al., 2016b). Despite adding an important farm-scale element to compliment the catchment scale DST approach reported by Daly et al. (2016) in RoI, the impact of this finer scale research was until recently limited, although it is now being applied nation-wide using 5-m digital elevation models (Thomas et al., 2019) but within the micro-topographic limitations highlighted by Thomas et al. (2017).

The implementation of a risk-based approach to P management and the farm P surplus limit on NI and RoI farms could have significant implications for the farm, inter-farm, catchment, and regional management of slurry, as there would be an excess of P in many farms, catchments, or regions. Although there are existing farm-scale P governance structures that could be adapted to incorporate a risk-based approach, no framework for the catchment or regional governance of P exists in either country beyond the identification of eutrophic sensitive catchments and quantification of the P load reduction gap required for compliance with the EU WFD. An interesting state-of-knowledge (and governance) juxtaposition in both Irish jurisdictions at present is that RoI is focused on developing the catchment- and regional-scale risk characterization and management of P, whereas NI is developing finer farm- and field-scale risk characterization and management. Both have advantages but, clearly, approaching the development of P-based DST from both scales is likely to provide improvements of both governance and problem ownership.

Norway

Demand for DSTs has evolved in Norway from a focus on building soil fertility to a modern emphasis on water quality. Like in most Western European countries, Norway's use of inorganic fertilizers between 1950 and 1980 was extensive and manure applications sometimes resulted in field agronomic P imbalances (Ulén et al., 2007). Nutrient excess led to lake eutrophication, and the concentration of P, rather than N, was recognized as limiting for algal growth in lakes (Berge, 1987; Faafeng and Hessen, 1993). Phosphorus transfer from agricultural areas has therefore been a focus of Norwegian water quality management since the early 1980s (Lundekvam et al., 2003; Miljødirektoratet, 2019).

Norwegian regulations to improve P management consist of subsidies or direct payment for changed tillage, placement of grassed buffers along open water, grassed waterways, and sedimentation ponds. Norway requires that all farms have nutrient management plans, although there are no specific rules guiding the development of these plans. In 1985, Norway introduced the National Action Plan against Agricultural Pollution (1985–1988) (Rognerud et al., 1989), which resulted in practical measures and increased political interest (Lundekvam et al., 2003). Mitigation of diffuse P sources was targeted using economic incentives to encourage farmers to implement measures to reduce soil loss and P transfer. A main component of mitigation strategies was an integrated package of legislative, regulatory, and economic instruments that were used together with targeted information campaigns and individual support through the extension services. Targeted information campaigns and individual support through extension services were related to P application in fertilizer and manure, and measures related to the transport of P (e.g., reduced autumn tillage) (Ulén et al., 2010).

Norwegian subsidies to farmers are determined, in part, by detailed soil mapping of the erosion risk with autumn plowing (NIBIO, 2019b) in regions with the highest watershed P losses (Norwegian Agriculture Agency, 2019). To encourage compliance, Norway provides among the highest subsidies to farmers in Europe, with a 2016 annual average being €62,000 per farmer (OECD Ecoscope, 2019). Subsidies to farms increase with the erosion risk of the area to motivate more spring tillage on areas with higher erosion risk (e.g., steeper slopes). An erosion risk map DST was developed and first based on a modified Universal Soil Loss Equation (USLE) approach, but starting in 2018, erosion risk is now calculated using the Pan-European Soil Erosion Risk Assessment (PESERA) (Kirkby et al., 2008). Erosion risk mapping is but one component of an emerging DST to improve P mitigation in Norway. To be able to include soil P status in the overarching P management DST, investigations of approaches like the US P Index were initiated to create a Norwegian P Index (Heathwaite, 2002). In addition to this Norwegian P Index, Agricat2 (a DST)

(NIBIO, 2019a) has been used in the Norwegian DST to help water managers decide on the most efficient mitigation measures to implement.

Like the US P Index (Sharpley et al., 2001), Agricat2 is based on data input of erosion risk and soil P status; soil P status data are owned by farmers but provided voluntarily to the government and applied in analysis at the watershed level. Information on crop type and soil tillage methods are included in Agricat2 calculations and derived from national production statistics. Agricat2 also includes changes in soil tillage, soil P status, and grassed buffer zones. However, only the effect on total P loss is estimated. A future challenge is to include the effect of soil P status on dissolved reactive P. Effects of mitigation measures used in Agricat2 are based on results from plot study sites (Bechmann et al., 2011) and are upscaled to exemplify effects at the catchment scale. However, upscaling does not consider differences in scale, and therefore the estimated effect of changing soil tillage methods is relative. The relative effect of mitigation measures is used by water managers to prioritize mitigation measures and combinations of measures for different areas. Agricat2 also helps identify the most cost-efficient implementation of mitigation measures for P. Agricat2 can
be coupled to calculations of cost effectiveness based on information on yield loss given by farmers.

Sweden

Across Sweden, several national, EU, and Baltic Sea-specific programs aim at improving water quality through significant reductions in P losses:

- national environmental goals and specifically the Swedish “zero eutrophication” goal,
- the EU WFD,
- the ambitious Country Allocated Reduction Targets (CARTs) for the Baltic Sea agreed to at the Baltic Marine Environment Protection Commission–Helsinki Commission (HELCOM) Copenhagen Ministerial Meeting (HELCOM, 2013).

Even with this array of initiatives, P management across Sweden still results in some water quality degradation, especially diffuse nutrient losses from Sweden to the Baltic Sea (Ejhed et al., 2016).
After World War II, large amounts of inorganic fertilizers were applied across Sweden to increase crop yields (Morell, 2011). Mineral fertilizer applications continued to grow until the start of the 1970s but have since decreased; P manure application has been constant during this period. Approximately 700 kg P ha−1 has accumulated in Swedish arable soils since the 1950s (Andersson et al., 1998). Since the 1970s, improvement in Sweden’s P balance came about largely from rapid declines in mineral fertilizer application and national limitations on the allowed number of animals per manure spreading area. A balance between P inputs and P outputs was established in Sweden by 2011 (Bergström et al., 2015); however, regional differences in P balances are still quite large, and several regions have a negative balance (Statistics Sweden, 2018). A recent survey of southern Swedish soils based on >12,500 soil samples (Djodjic, 2015; Paulsson et al., 2015) show that arable soils have a range of low (31% of soils), optimum (35%), and above optimum (34%) soil P content.

Legislation in Sweden covers a wide number of regulatory measures. These measures include establishing the minimum capacity and rules for manure storage on a farm; restrictions on applied quantities of manure and fertilizer, timing, and incorporation of manure applications; recommendations regarding spreading of liquid manure in growing crops; recommended soil surveys to determine soil P status; and rules concerning land under vegetative cover in the autumn and winter. Limitations on manure application (to 22 kg ha−1 in Sweden) are arguably the most discussed part of the legislation and have resulted in some cases in litigation setting standards. Financial instruments used in DSTs, and available via rural development programs, include:

- nonproductive investments such as structural liming and tile drainage, as well as support for environmental investments (construction of wetlands and P ponds, two-step ditches, or lime-filter ditches),
- agrienvironmental payments such as environment protection measures (development of crop production plan, nutrient balances, soil mapping, and determination of N content in liquid manure), measures to reduce N leaching (catch crops and spring tillage), riparian buffer strips and place-specific adjusted buffer strips, maintenance of existing wetlands, and support for cultivated grasslands, among others.

Additionally, the Swedish government has co-financed local water management projects through the so-called lokala vattenhanteringsinitiativ (local water management initiatives, or LOVA) program (Swedish Ministry of Environment and Energy, 2009). Extension service education and information in Sweden, provided for example through the Focus on Nutrients program, is aimed at reducing nutrient losses from agriculture. Focus on Nutrients is a joint venture between the Swedish board of agriculture, Swedish county administration boards, the Federation of Swedish farmers (LRF), and several agribusiness companies. The core of the project is farmers' education and individual on-farm advisory visits. The Development of the Farm P Management Strategy DST is one of the DST modules offered to farmers free of charge. An extension worker and farmer review existing maps of soil P content, the farm level nutrient balance, and the crop rotation and fertilization plan and agree on a P management strategy for the farm. Additionally, topographic and soil distribution maps are used to identify risk areas for P losses and most suitable countermeasures. There are also other modules to help reduce P losses, such as modules regarding improved drainage, wetland construction, and soil compaction. Farmers' participation is free of charge and has been strong, with 960 and 778 P-related farm visits in 2016 and 2017, respectively (Greppa Näringen, 2017).
An environmental effects evaluation of the Focus on Nutrients program (Nilsson and Olofsson, 2015) shows improvements in many indicators reflecting P management and P loss reduction. However, there are no direct measurements showing reduced P concentrations in the receiving waters connected to the Focus on Nutrients program.

Like Norway, Sweden has explored application of the US P Index concept (Djodjic et al., 2002). To account for some of the unique conditions in Sweden that contribute to P loss (e.g., snow cover and melting, soil freezing and thawing, relatively low precipitation intensity, flat relief, and a high proportion of tile-drained fields), a specific Swedish DST P Index was developed (Djodjic and Bergström, 2005). However, the index did not gain broader use due to high data input demands (Buczko and Kuchenbuch, 2007) and due to the belief that existing regulation of animal density and Sweden's flat-rate P application (the above-mentioned 22 kg ha−1 yr−1) was already enough to avoid high P surpluses (Foged, 2011).

Subsidies and direct payments are used in Sweden to incentivize farmer behavioral changes, but P management strategies are still not fully implemented by farmers, in part due to complicated application rules, administrative barriers, and/or lack of communication between policymakers and end users (farmers). Evaluation of the success of P management DST and DST strategies to improve water quality is contradictory and difficult to interpret. In general, expected trends with decreasing P concentrations in water recipients are still rather limited. Fölster et al. (2012) show decreasing trends of total P for the 20-yr period (1991–2011), but no significant trends could be found for the shorter 10-yr period (2001–2011).

To further increase farmer participation, Sweden is considering an evaluation of alternative payment models that are results, or value-based, to increase cost efficiency (Hasund and Johansson, 2015). Farmers are now paid a compensation for lost income due to countermeasure implementation regardless of the effect of countermeasures. Sidemo-Holm et al. (2018) suggest that result-based payment schemes, based on modeled outcomes of pollution abatement, are feasible and will considerably improve cost effectiveness via relocation of riparian buffer strips to the most sensitive parts of the watershed. Recently, Djodjic and Markensten (2018) produced widely available and extensive risk maps (90% of arable land, 2-m ´ 2-m resolution) identifying CSAs for erosion and P losses. Although risk mapping may help with the identification of CSAs for overland flow and erosion, corresponding maps for leaching subsurface losses are still lacking.

Finland

Finnish agriculture has a history of P use like other developed countries and a variety of DSTs have emerged that, collectively, contribute to an emerging, national DST for P mitigation. After World War II, national goals to increase agricultural productivity were supported by fertility programs to build soil P levels. Use of mineral fertilizers increased from 10 kg ha^{-1} in 1950 to their peak in 1975 at 34 kg ha^{-1}, and average concentrations of available P in the soil solution increased from 5 to 15 mg L^{-1} over the same timeframe (Mäkitie, 1960; Yli-Halla et al., 2001). Nutrient losses from agricultural lands were an insignificant issue until the late 1980s (Jokinen, 2000). Since 1992, efficiency in point-source pollution abatement has continued to increase (HELCOM, 2018). Finnish small catchment network data from the 1980s to present suggest that there has been a slight decrease in total P load from agricultural catchments. However, this has been associated with a similarly slight increase in dissolved reactive P loads (Vuorenmaa et al., 2002; Tattari et al., 2017). Nevertheless, soil P values have decreased on average ~10% since the late 1990s (Lemola et al., 2018), and the slight increase in dissolved reactive P loading may be associated with the increased use of no-till and other conservation tillage practices (Uusitalo et al., 2007; Tattari et al., 2017).

Most Finnish environmental protection policies are top-down with little emphasis on incentives to implement desired actions, contrasting with point source related abatement laws and regulations. Policies for DST include EU (e.g., marine strategy framework or water framework directives) and state-level strategies and programs (e.g., HELCOM, 2007: Ministry of the Environment of Finland, 1998, 2002). These programs set goals and list measures that should be performed to curtail nonpoint source loading from agriculture but rely entirely on the EU AgriEnvironmental Scheme (AES) to incentivize the desired actions or EU Agricultural Environment Measures (AEM). The EU AES is thus at the heart of Finland's DST to curtail P loading from agriculture. Current farmer participation in the program has been extremely high, with ~90% of the farmland and 86% of Common Agricultural Policy (CAP) eligible farmers participating. Finnish farms receive about €340 million annually from AES compensations (including about €110 million for animal welfare and organic farming). The share of Finnish agrienvironmental support has been ~25% of the total CAP-based support (European Commission, 2019a, 2019b).

Distribution of these funds to address P mitigation is supported by several types of DST, including those targeting riparian buffers, those aimed at improving the management of soil P, and those guiding sustainable manure management. Two separate DSTs drive the establishment of buffer zones:

- a location planning procedure,
- the AES subsidy established via the EU Agricultural Environment Program (AEP).

The placement of a buffer zone is guided by a site-specific mapping DST, which has the objective of locating field parcels most susceptible to erosion. This DST results in a region-specific map of desired buffer locations that regional environmental centers then use to develop farm-specific buffer implementation plans from information on topography, soil types, and onsite visits.

The effectiveness of the location planning DST is substantially influenced by the EU AEP subsidy paid to establish and maintain buffers. Across the EU, most agroenvironmental payments go through EU rural development programs in each member country. Member states draw up their specific rural development programs based on needs. These programs need to target some common goals and priorities, but the tools and practical solutions can be, and mostly are, country specific. Finland's payment scheme is unfortunately somewhat decoupled from plans set by the location planning DST.

Subsidies for buffer strips in Finland exist, like in Sweden, but the conditions and requirements are not the same. As a result, in 2015, there were nearly 60,000 ha of buffer zones in Finland with 30% specifically in southern and western Finland located in planned areas. However, of this 30%, £20% of the mapped, optimal locations had a buffer (ELY-keskus, 2016; Yli-Viikari and Aakkula, 2017). Thus, most buffer zones have been placed on fields not posing a significant erosion risk suggesting there is room for increasing the environmental and economic efficiency by effective targeting. The incoherence of the tools that plan the measures, and those incentivizing them, is detrimental for the efficiency of the overall system of managing P loading from agriculture.

In contrast with the buffer location planning DST and subsidy DST, P fertilization limits based on soil P levels are a coherent and well-functioning DST in Finland. The objective of the P fertilization limit DST is to prevent unnecessarily high P applications and to gradually lower soil P levels. The tool's adoption and needed data are supported by the linkage to the AES subsidy, which requires that soil samples be taken on a regular basis. Initial AES periods had fixed maximum P application amounts set for each crop, but a more precise additional measure could be chosen that allowed for higher application rates for lower soil P values and lower application rates for higher. In the most recent programs, soil P limits were made mandatory for all participants and application rates have been tightened gradually.

Average soil P concentration values have continued to decrease, and Laukkanen and Nauges (2014) estimate that as a net effect, participating in AEP has reduced fertilizer applications by 1.5%. Wider utilization of manure in crop production regions is being promoted by a nutrient calculator DST (Ravinnelaskuri) (LUKE, 2019b) that is currently being adopted by the Regional Environment Centers. The objective of the tool is to quantify all flows of organic nutrients including manure, side streams of forest industry, urban wastewater treatment plants, etc., as well as crop uptake. Quantification is accomplished at the rural district level with assistance by a DST calculator being developed by the Natural Resources Institute Finland. The Ministry of Agriculture and Forestry is promoting adoption of the tool by making it compulsory for regional authorities to be able to somehow quantify the flows of nutrients in organic materials. However, like the site-specific mapping buffer placement DST, there is no initial link to farm-level decision making with Ravinnelaskuri. Given that the Ravinnelaskuri DST is in the adoption phase, it could be linked in the future to a more specific farm-scale environmental permitting process.

A related Baltic Sea region-wide DST has been developed for the Manure Standards project, which is developing and standardizing tools to determine the quantity and plant availability of manure nutrients (LUKE, 2019a). Lack of such information is one of the reasons for crop farms not being willing to substitute chemical fertilizers with manure (Case et al., 2017). Providing data and tools for more precise assessment would help alleviate the manure nutrient pressure of the most intensive animal production regions. From the farm perspective, the most widely adopted DST to support decision making is the Wisu planning platform, operated by the ProAgria extension service, which is a private association consisting of a dozen of regional ProAgria units (Mtech, 2019). Most of ProAgria's revenues come from various extension services and some government support (Mtech, 2019). The objective of the tool is to improve the economic performance of farms but also to improve the efficiency of the extension services in meeting farmer needs. The latter is promoted by the ability of extension experts to assist decision making remotely (via mobile devices), with access to the farm-level database and farming history. The P application choices, which are optimized based on soil P values and restricted by the AES limits if the farm participates in the program, are one feature of the tool. During 2019, various precision farming features will be added to the platform.

Serbia

The combined PROMETHEE and GAIA analysis done by Mladenovi´c-Ranisavljevi´c et al. (2022) included indicators of nutrients in the water (total nitrogen, nitrite, nitrate, ammonium ion, total phosphorus, and orthophosphates) to rank and evaluate significant sites along the Danube River flow through Serbia. Furthermore, the ecological quality status of the water was determined which places the Danube River into the category of “good” to “moderate” water quality. The results represent a detailed evaluation of the sites with increased nutrient content, associated with the most dominant parameters of nutrient indicators affecting water pollution at each site. The main sources of nonpoint pollution are of anthropogenic origin reflected in agricultural applications of pesticides and fertilizers, together with natural contamination of ground and water sources, while pollution from point sources arises from industrial waste waters as well as from domestic activities. Minimizing the application of fertilizers and pesticides is a way to control pollution from agricultural activities while, at the same time, a proper wastewater treatment is needed to reduce point sources, although financial aspects and lack of funds are limiting factors of this control in Serbia. Therefore, the findings by Mladenovi´c-Ranisavljevi´c et al. (2022) could serve environmental scientists and water resources managers as a starting point in identifying key sources of nutrient pollution in water, as well as industry experts and national authorities in expanding strategies and taking long-term measures to reduce the input of nutrients into the valuable Danube River.

In accordance with the Danube River Basin Management Plan, one of the four major problems related to the quality of water and its chemical and ecological conditions along the Danube basin is nutrient pollution. The three other problems are related to organic pollution, pollution with dangerous substances, and hydro-morphological changes in rivers. Nutrients are compounds of nitrogen and phosphorus that are normally found in water, but whose increased content in water leads to a pollution, as a result of which the water then becomes an unhealthy environment due to the flora and fauna in it, and becomes unsuitable for drinking purposes. Namely, these compounds potentiate the faster growth of algae and contribute to the process of eutrophication, which jeopardizes the supply of some of the substantial water purposes.

Soil erosion and leaching of the arable land increases the content of nitrogen and phosphate compounds in water and leads to nutrient pollution of water. Moreover, the concentration of nutrients in water is affected by various detergents from households or industry, excess herbicides, insecticides, oils, fats, and numerous toxic chemicals from the urban environment, as well as salt deposition during irrigation, acids from abandoned mines or sediments from construction sites, crops and forest land. Nevertheless, changes in climate conditions affect the amount of precipitation leading to floods, which then enhance soil washing and erosion and therefore increase the risk of nutrient pollution.

Recent published data of the Republic of Serbia and the Green Network of Vojvodina estimate that Serbia releases 7200 tons of nitrogen and 7000 tons of phosphorus annually, which represents 13% of the total nitrogen pollution of the Danube and 14% of its total phosphorus pollution. It places Serbia in the third place in regard to the amount of nitrogen, and in second place in terms of the amount of phosphorus flowing into the waters of the Danube from all the countries within the basin. Nevertheless, the problem of the increased content of nutrients in the water is not specific only to the Danube basin, but related to many other water bodies, as well [7]. In its official annual Report on

Water Quality and Pollution Indicators in Ireland, the EPA (Environmental Protection Agency) suggests that the main problem in the damaging of waters in Ireland is in fact the presence of excessive nutrient contents, primarily phosphorus and nitrogen, arising from agriculture and waste waters.

In general, sources of water pollution can be divided into concentrated (point) and scattered (nonpoint) sources. Point sources of pollution are commonly associated with urban areas and industry. Among the industries, the chemical and petrochemical industry, paper industry, food industry, metallurgy, and textile industry are among the biggest consumers of water. Pollution from agriculture can be of a concentrated (point) nature, if it is collected and released in one place, but more significant are scattered (nonpoint) pollutions that come from the use of fertilizers and chemical agents, which dissolve and flow into watercourses and other water ecosystems via surface or underground water.

Number of researchers in the field refers to the nonpoint sources of water pollution as a “wicked” ongoing problem that needs to be addressed thoroughly. The circulation of substances in nature causes other forms of nonpoint pollution to appear, especially those originating from exhaust gases from traffic, emissions from industrial plants, landfills, etc. Uncontrolled and increased concentrations of nutrients in water bodies may cause a significant deterioration of water, which reflects back on both humans and all aquatic life, leading to increased health risks, water treatment costs, and ecological damage.

According to The International Commission for the Protection of the Danube River (ICPDR) and recent calculations, nonpoint sources of pollution dominate nitrogen emissions in the entire basin with approximately 80% of the total load. The remaining 20% of the total load is related to emissions from point sources, such as wastewater treatment plants and industrial discharges. The total nitrogen emissions in the Danube River Basin are estimated to be about 600,000 tons per year. Although wastewater discharges and combined sewer overflows are significant source areas, some recent investigations suggest that the main emission sources are agricultural fields representing 40% of the total load.

Based on all the above, it is certain that excessive nutrient pollution represents a great source of concern to water resources management around the world. However, there are still a few up-to-date papers that deal with this issue, especially in regard to the Danube Basin. Therefore, the aim of this work is to carry out the analysis on the content of nutrients in the water of the Danube in Serbia. Given that the problem of water pollution with nutrients is a demanding and multicriteria problem, a multicriteria decision making analysis (MCDA) was used in this work to reveal more information about the mutual dependence between certain parameters of the nutrient indicators and the exact locations where nutrient content is exceeded.

The application of MCDA methods in water resources management has to date provided significant results. Although there are many different MCDA methods applicable to water allocation issues, it is acknowledged in the literature that no single approach is superior. In fact, the selection of a specific method depends on the type of information that is provided within the problem, the preferences of a decision-maker, as well as the preferred final outcome of the decision process. Some require ranking of different alternatives, others search for a single optimal alternative, while some focus on discrepancy between acceptable alternatives.
The use of PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluation) and GAIA (Geometric Analysis for Interactive Assistance) methods in water quality analysis makes it possible to rank locations on the Danube to the desired criteria, as well as to determine consent or conflict between the individual criteria. Therefore,

a better and more comprehensive insight into a water quality parameters' correlation leading to a more thorough evaluation on the actual state of the water quality of the Danube can be obtained. Indicators of nutrients in the water (total nitrogen, nitrite, nitrate, ammonium ion, total phosphorus, and orthophosphates) were used as ranking criteria to investigate selected sites along the river flow through Serbia. Nutrient content values were therein compared with the limit values of the water quality classes, prescribed by the Regulation on limit values of pollutants [28] and the deviations are discussed.

To the best of our knowledge, none of the previous researches has dealt with nutrient pollution of the Danube River from a multicriteria analysis point of view providing the interdependences of locations and specific sources of pollution while, at the same time, exploring deviations from the prescribed limit values to determine the ecological quality status of water. The opinions of experts involved in water resources management were used as a guideline in defining the weights of criteria. Therefore, this paper can serve as a valuable contribution in providing an in-depth approach to the case of the matter. Furthermore, it can contribute to future investigations on improving the Danube River water quality, not only in Serbia, but also in the entire basin (Mladenovi´c-Ranisavljevi´c et al., 2022).

3.8.6. Soil organic matter

Stock takes and literature review on DST on soil organic matter (SOM) revealed, that soil organic matter usually are one of the key components of soil health indication, therefore majority of DST on SOM content are parts of tools with broader aim. One of the recent studies have developed decision support framework that links management practices on sustainability indicators with environmental targets (Young et al., 2021). In this study soil organic carbon is used as soil quality indicator, that is used in assessment of management practice impacts. This framework is based on meta – analysis data and long-term experimental sites across several European regions, therefore it could be used in different climatic and soil regions for management production mapping to achieve, for example, soil organic carbon targets.

From the regional perspective - Mediterranean region – is region where wider range of support tools and systems are available. In Spain in Sevilla province MicroLEISS decision support system that is based on empirical models. DST designs most sustainable land use and management practices for different indicators. Soil organic matter is set as soil quality goal for management planning at the farm level, different management practices (residue treatment, tillage direction, row spacing) is proposed for SOM restoration.

For the Mediterranean region soils are designed other DST that allows evaluate agro ecological measures (AEM) impact on soil quality and soil threat avoidance. Soil organic matter is calculated rather as soil quality indicator then soil target parameter. The GIS based DST, that uses spatial data on soil management, fertilizer application, meteorological data, and soil profiles, calculates and generated maps on agri – environmental benefits. This DST demonstrates the AEM positive impact on SOC accumulation in Veneto region soils in Italy (Dal Ferro et al., 2016).

There are also set of papers on methods, systems, or tools, that uses soil organic matter (or carbon) content to identify degradation risks or evaluate restoration practices. Evaluation of indicators in several European, African, Latin American, and Asian countries shows the necessity to include SOM information in monitoring sites in territories with high soil degradation risk (Kosmas et al., 2014). Developed vision by Schroder et al. (Schröder et al., 2018) may also serve as the DST on soil productivity restoration in poor, marginal agricultural lands. Paper provides information on most suitable amendments or biochar applications to obtain sufficient SOM content in marginal or degraded soils. These recommendations are based on expert knowledge and literature studies.

Some DSTs on soil organic matter improvement are very site or practice specific. Model for vineyards, that calculates the emergence of 18 different plant species, that have potential to be used as decision support tool for best cover crop establishment, that may lead to higher SOM in vineyard soils (Cabrera-Pérez et al., 2022).

Study in Swiss provided the tool for spatial planners, where several soil functions and function fulfilment were mapped. Soil organic matter and soil carbon content was mapped to show soil carbon sequestration function (Greiner et al., 2018).

The future of DST on soil organic matter and soil carbon management will be related to different remote sensing data and models. For now, several studies provide insight in SOM prediction based on remote sensing, especially in bare soil conditions. As studies may continue, more precise, fast predictions for wide areas will be available that will serve as DST for soil management and soil carbon target fulfilment (Vaudour et al., 2022).

3.9. Future challenges in improving DST and their application

A major part of current DST is based on soil productivity, soil overall quality and health. At lesser extent DST for soil organic matter, soil water retention or nutrient balance are developed. From the technical aspects current tools are model based tools, that is more suited for scientific community rather than policy makers.

With the rapid development of information and communication technology, the technical sophistication of DSTs has advanced quickly. Previously, DSTs were created using simple spreadsheets that required significant manual data entry, but now, with the aid of smartphone apps, web-based programs can obtain climate and other data from various online databases automatically. One notable characteristic of this evolution is the significant improvement in user-friendliness and overall appeal to users. However, many DSTs have not been widely adopted as practical tools. The reasons for this include the complexity of earlier computer-operated spreadsheets and programs, extensive manual data entry requirements, insufficient ongoing funding to maintain the DSTs, and inadequate training and technical support for users (Gallardo et al., 2020).

Research (Rose et al., 2016) shows that farmers and advisers will utilize a decision support tool if it becomes mandatory by law or market demands, such as meeting quality assurance standards. Hence, making it obligatory to use a particular tool through legislation would be the most efficient way to encourage adoption. This may result in isolating a group of end users who are already struggling with administrative tasks and complying with regulations, further adding to their burden.

Market mechanisms should be used to show end user how DST can add value to the business. Another option is to offer financial incentives, such as subsidies or grants, to assist farmers in recovering the expenses associated with acquiring a DST (Rose et al., 2016).

Future Trends

Researchers are optimistic about the future of DST. This optimism continues to produce products and contributions to literature. A host of new tools and technologies are adding new capabilities to DST. They include hardware and mathematical software development, artificial intelligence techniques, data warehousing and mining, OLAP enterprise resource planning, ERP, intelligent agents, and World Wide Web (WWW) (Berners-Lee, 1996). Separated from operational databases and optimized for decision support, data warehousing is an integrated, time-variant, and non -volatile collection of a relational or multidimensional database (MDDB). It organizes data as an n-dimensional cube so that users deal with multidimensional data views such as crop, region, yield, and area, with speedy query response time. Also known as knowledge Data Discovery, Data Mining refers to discovering hidden pattern from data, not known before. It attempts automatic extraction of knowledge from the large databases like data warehouse, spreadsheets, weather observatories, text documents etc. (Mir et al., 2015).

Intelligent agents research is an emerging interdisciplinary research area involving researches from such fields as ESs, DST, cognitive science, psychology and databases. Intelligent agent’s research has contributed to the emergence of a new generation of active and intelligent DST. This approach will enable us to integrate simulation models, GIS and multimedia with ESs, giving DST a dominant role to play in modern agriculture. Development of domain-specific tasks will help in knowledge sharing and reuse (Mir et al., 2015).

Sophisticated user interfaces for different media types are expected to be designed based on the users expertise and need. World Wide Web (WWW) is becoming an infrastructure for the next generation of DSTs and groupware applications. There is also a trend to develop tools and techniques that could facilitate the dissemination of ESs through WWW. High bandwidth, reliable internet connectivity and carefully prepared underlying data will be keys to the future success of web-based decision tools. ERP, a new generation of information system, is integrating information and information-based processes within and across functional areas in an organization. The extensive databases created by the ERP system provide the platform for decision support using data warehouse, data mining and executive support systems. Global DSTs are emerging as the new frontiers in MIS area. Over the next decade, DST will focus on large scale decision making involving groups, teams within distributed and decentralized structures (King, 1993). In future, DST will be a small tool for aiding farmer's tactical decisions, a versatile simulator as a consultant's tool, a core of a facilitated learning & training and a formal framework that supports regulatory objectives in constraining and documenting farming practice (Hammer et al., 2002). DST integrated with precision agricultural equipments, GIS and site-specific farming are changing the realm of modern agri cultural practices. Future developments may include the possibility of implementing several DST models into a GIS, which will support precision agriculture by providing adjusted spraying advice based on plot-specific characteristics (Bouma, 2007; Mir et al., 2015).

In future, design, and development of DST is expected to get advantage from promising technologies like data warehousing and mining, agent-based approach, intelligent agents, and enterprise resource planning besides advancement in hardware and software technologies. These technologies shall facilitate easier design of more complex DSTs. Agricultural is expected to get maximum benefits out of these as well as new milestones laid by the technologies like modelling, hypothesis, simulations, and projections.
Continued progress in system modelling combined with increasing growth in computer power, improvements in Remote Sensing, Geographical Information Systems, Precision Agriculture, new developments in the data extraction like data warehousing and date mining with new concepts of data exchange over the Internet should all contribute to expanded use of DST for cropping systems in the future. Also there has been renewed interest in search strategies that can exploit the rapidly expanding information base on the Internet. These strategies may make qualitative information much more accessible to computer-based reasoning systems to give new spin in DST research and development (Mir et al., 2015).

3.10. Living labs

In the late 1990s, the concept of living labs emerged, initially in the United States. Subsequently, it gained prominence as a research concept, particularly in European settings, emphasizing the context of innovation and placing a strong emphasis on co-creation (Schuurman and Tõnurist, 2017). With the emergence of living labs in Europe during the early 2000s, it became evident that the prevailing concept of living labs in Europe, which drew from prior experiences in participatory design, social experiments, and digital cities, presented a significant reinterpretation of the home labs originating from the United States. In November 2006, during the Finnish Presidency of the Council of the European Union (EU), the European Network of Living Labs (ENoLL) was established. Helsinki Manifesto (2006) characterized ENoLL as a platform dedicated to knowledge sharing and collaboration, aiming to establish common methodologies and tools across Europe that facilitate, encourage, and expedite co-creative innovation processes through user involvement. While living labs predominantly exist within Europe, their membership in ENoLL has steadily expanded to include labs from other continents, such as Brazil, Colombia, Canada, Mexico, Australia, China, and Egypt. Alongside geographical diversity, there is also an increasing variety of topics and approaches embraced by living labs in their practice and research. Early living labs research focused on defining and describing the concept, highlighting best practices and contextual factors. Present-day research encompasses a wider range of aspects, exploring different implementations of living lab activities and conceptualizations of innovation within living labs. Since 2006, ENoLL has positively evaluated over 300 living labs; however, not all of these initiatives have endured. Many living labs are established solely for the purpose of executing a single innovation project (Ballon and Schuurman, 2015; McPhee et al., 2017).

Living labs function as both practical entities that facilitate and promote open, collaborative innovation, and as real-life settings where open and user innovation processes can be observed and experimented with, leading to the development of new solutions. This distinctive capability allows living labs to create tangible innovations by actively involving users and communities, while also contributing to the academic understanding of open and user innovation principles and processes (Schuurman and Tõnurist, 2017). Living labs also serve as a platform for research groups to actively engage with highly relevant practical cases. Through the participation of researchers, inter-organizational knowledge sharing occurs within the community of practice established by living labs. This knowledge exchange takes place through various means, including events and publications (Dutilleul et al., 2010). Knowledge obtained in Living Labs can be interpreted in various ways and given farmers' inherent individualistic nature, they are likely to selectively embrace certain aspects of these narratives. The scientific community should acknowledge and embrace this approach as a valid and scientifically robust means of bridging the gap between science and society (Bouma et al., 2021). Both innovation scholars and business managers, along with other stakeholders interested in utilizing living labs for innovation development, must take into account the principles of open innovation and the underlying assumptions. It is crucial to grasp the various tools available, particularly the distinctions between different types of tools used to facilitate innovation (Leminen and Westerlund, 2017).

The European Commission promotes the concept of Living Labs, which, when effectively meeting the necessary ecosystem service requirements, can serve as influential "Lighthouses" for other land users, stakeholders, and policy-making entities. This approach is endorsed as it is only through the mobilization and application of bottom-up expertise and interests of land users, especially farmers who occupy vast land areas, that genuine success can be achieved (Bouma and Veerman, 2022). Soil scientists, particularly soil surveyors and fertility specialists, have a long-standing history of collaborating with farmers. However, in many countries, conventional soil surveys have concluded, and automated soil fertility procedures have reduced direct interaction between farmers and specialists. Revisiting the fundamental principles of the profession and reestablishing meaningful interactions with farmers becomes essential (Bouma et al., 2021). Effective communication processes play a vital role not only within living labs and farmers but also when engaging with the general public, especially once successful lighthouses have been established. The establishment of living labs with the goal of creating lighthouses presents a challenge to the scientific community, demanding the implementation of transdisciplinary approaches in real-world contexts. As lighthouses likely already exist, promptly documenting their experiences would significantly contribute to the ongoing discourse surrounding living labs and lighthouses (Bouma, 2022).

According to the EU Mission "A Soil Deal for Europe," a significant driver of soil degradation, impacting its ability to deliver ecosystem services, is the lack of knowledge and awareness regarding the vital importance of long-term soil health among various stakeholders including land managers, industries, consumers, and society as a whole. For this reason, the primary objective of this mission is to establish 100 living labs and lighthouses, serving as pioneers in driving the transition towards fostering healthy soils. To achieve the goal the PREPSOIL (Preparing for the "Soil Deal for Europe" Mission) project was initiated within ENoLL. The project plays a crucial role in enabling the implementation of the Mission in European regions. This objective will be accomplished by co-creating and introducing tools and platforms for interaction, knowledge-sharing, and collaborative learning. Additionally, stocktaking and dialogue will be conducted to comprehend how regional assessments of soil requirements, coupled with harmonized monitoring mechanisms, can translate into actionable steps within living labs and lighthouses to promote soil health (The PREPSOIL, S.a.). Similar project within ENoLL ''The European Agroecology Living Lab and Research Infrastructure Network'' (ALL-READY) will create AgroEcoLLNet, an innovative framework for the future European network of Living Labs and Research Infrastructures. It will establish the foundations and undertake essential preparatory measures and activities. Through rigorous testing, the project will validate and enhance its outcomes, which will subsequently be disseminated extensively throughout Europe (Schuurman and Tõnurist, 2017). Other ENoLL project (the NATI00NS project) is actively supporting the Mission by mobilizing and strengthening the capabilities of stakeholders in 43 Member States and Associated Countries. Its objective is to facilitate their participation in regional soil health Living Labs (LLs) Open Calls, promoting engagement and collaboration in the pursuit of soil health improvement using matchmaking platform, national mentors and capacity building webinars and e-learning materials (NATI00NS, S.a.).

4. Conclusions and recommendations

Based on the literature review conclusions and recommendations are given for subsequent activities in PRAC2LIV:

Relevant for the questionnaire (WP3):

- Many different calculation tools exist that could qualify as DST, and these may differ in type, format and potential use. Stakeholders may evaluate DSTs differently depending on their need for them, e.g. agricultural advice and/or monitoring.

It is recommended to introduce the concept of DSTs in the questionnaire and give some examples for SOM, NUE and/or MOI.

It is recommended to not only have the viewpoints from and/or collected by the national coordinators, but also directly from farmers and other stakeholders from the agricultural community. It should be taken into account, however, that this may require a different set of questions.

Relevant for the exchange in workshops (WP4)

- The concepts of sustainability and soil quality are generally well known by the various types of stakeholders though viewpoints may vary.

It is recommended that the workshop programme spends some time in giving relevant description of e.g., soil quality and participants viewpoints and interests, before engaging in more in-depth discussions regarding SOM, NUE and/or MOI.

- Agricultural soil management is to some extent governed by prevailing regional environmental conditions (soil type, hydrology, climate). This may be of consequence to the selection and use of DSTs.

It is recommended that the exchange on results of the questionnaire will focus on farmers and/or stakeholdergroups at the regional level, sharing the environmental conditions (as opposed to, e.g. national level).

This previous recommendation would also match with the endeavour to have ‘Living Labs’ established. If possible, workshops could take place with the stakeholders in a living lab.

Evaluation and synthesis (WP5)

- For the evaluation of DSTs several classification schemes are available.
- For the development of new DSTs checklists are available.

It is recommended to make use of existing schemes and checklists, and also adding to them based on the outcomes of the questionnaires.

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Annex I

Number of publications in SCOPUS database

	Number of publications in SCOPUS	**Number of publications in SCOPUS (last 10 years)**	**Number of publications in SCOPUS**	**Number of publications in SCOPUS (last 10 years)**	**Number of publications in SCOPUS**	**Number of publications in SCOPUS (last 10 years)**	**Number of publications in SCOPUS**	**Number of publications in SCOPUS (last 10 years)**
List of decision support tools for:	**Decision support tool**	**Decision support tool**	**Decision support system**	**Decision support system**	**Decision support model**	**Decision support model**	**Living Labs**	**Living Labs**
	69983	47434	222569	137867	141729	96464	4839	3826
Europe	1409	840	3128	1766	1879	1081	159	140
National / country scale	4470	3199	12000	7919	7050	4887	176	132
Regional	699	495	1504	1044	1260	934	14	13
Local	952	730	1983	1452	1383	1038	52	48
Policy decision makers	2153	1578	4434	3172	3028	2209	10	10
Stakeholders	4741	3716	8935	6854	5274	4114	402	370
Farmers	1225	940	2965	2189	1979	1497	26	24
Land quality	635	394	1203	763	949	615	8	8
Soil productivity	201	157	467	371	322	255	4	4
Soil functions	225	140	527	321	488	320	6	5
Soil properties	226	157	507	354	526	401	7	5
Soil threats	60	46	117	91	89	73	4	4
Soil degradation risks	33	22	71	46	44	28	0	0
Agroecological conditions	9	9	14	12	11	8	1	1
Soil carbon	168	135	377	307	372	318	13	12
Soil organic carbon	71	60	165	140	188	167	4	4
Soil organic matter	63	59	180	136	185	151	7	6
Soil water	1111	767	2255	1491	1897	1306	36	29
Water retention	81	60	140	92	122	92	6	3
Soil nutrients (nitrogen,	281	206	583	401	415	276	14	12

phosphorus, potassium)								
Nitrogen	571	410	1311	917	1202	879	57	37
Phosphorus	236	168	462	312	400	281	15	12
Potassium	133	116	415	325	272	236	23	16
Nutrient use efficiency	106	84	216	171	122	96	10	8
Agricultural lands	810	590	1783	1275	1357	996	13	11
· Croplands	69	56	195	167	159	136	0	0
· Arable lands	46	34	106	74	100	74	1	1
· Grasslands	153	115	331	249	338	273	2	2
· Abandoned lands	16	10	51	32	35	26	3	3
Agricultural systems	1948	1374	6214	4405	3324	2298	40	32
Agricultural management:	1583	1126	3573	2441	2424	1692	23	19
· Intensive	2097	1540	6457	4288	3700	2652	57	48
· Extensive	1469	991	4234	2748	2888	2059	89	74
· Conventional agriculture	80	62	199	155	125	96	3	3
· Organic farming	74	53	192	137	121	91	4	3