Towards climate-smart sustainable management of agricultural soils

Deliverable 2.13
Stocktake study and recommendations for harmonizing methodologies for fertilization guidelines

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ABSTRACT

A stocktake study and recommendations for harmonizing methodologies for fertilization guidelines across regions was carried out as part of EJP SOIL WP 2 'Developing a Roadmap for EU Agricultural Soil Management'. The stocktake revealed substantial differences in the content, format and delivery of current fertilization guidelines across members of the EJP SOIL. Fertilization guidelines are developed within individual countries according to the agronomic requirements of the agricultural crops grown. The stocktake study revealed that numerous soil tests are used to analyse plant available nutrients and these are very different between one country to the next, and between neighbouring countries within the same environmental zone. Larger countries even have variation in soil analysis methods regionally within the same jurisdiction. Fertilization guidelines are largely developed by a committee of representative stakeholders within each country, who meet on a regular or in some cases infrequent basis. The general consensus from EJP SOIL participants was that harmonization across the EU could be increased in terms of shared learning in the delivery and format of fertilization guidelines, best practice and mechanisms to adhere to environmental legislation. However, it would be difficult, if not impossible, to harmonize soil test data and agronomic requirements at an EU-wide level due to differences in soil type and agro-ecosystem variations. Nevertheless, increased future collaboration between neighbouring countries within the same environmental zone was seen as potentially very beneficial.

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List of acronyms and abbreviations

ALN - Alpine North

ALS - Alpine South

ANA - Anatolian

ATC - Atlantic Central

ATN - Atlantic North

BOR - Boral

CON - Continental

ER - European region

ENZ - Environmental Zone

LUS - Lusitanian

MDM - Mediterranean Mountains

MDN - Mediterranean North

MDS - Mediterranean South

NEM - Nemoral

PAN - Pannonian

SOC - Soil organic carbon

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1. Executive summary

This synthesis delivers the findings of Task 2.4.5 ‘A stocktake study and recommendations for harmonizing methodologies for fertilization guidelines across regions’. Task 2.4.5 is part of the EJP SOIL WP 2 ‘Developing a Roadmap for EU Agricultural Soil Management’. The synthesis involved a stocktake questionnaire which was sent to representatives within each participating country of the EJP SOIL. In total, twenty three of the twenty four countries completed the questionnaire. The questionnaire sought information around six main sub-objectives: (1) To complete a stocktake of current fertilization guidelines across regions within the EJP SOIL. (2) To identify key variables in directing these guidelines, e.g. climate, soil, cropping system, nutrient loss. (3) To identify synergies, similarities and differences between systems. (4) To assess the potential for harmonization of methodologies and barriers to harmonization. (5) To identify stakeholders involved in formulating fertilization guidelines. (6) To evaluate the importance of knowledge transfer and community engagement. The stocktake revealed substantial differences in the content, format and delivery of current fertilization guidelines across members of the EJP SOIL. Fertilization guidelines are developed within individual countries according to the agronomic requirements of the agricultural crops grown. The stocktake study revealed that numerous soil tests are used to analyse plant available nutrients and these are very different between one country to the next, and between neighbouring countries within the same environmental zone. Larger countries even have variation in soil analysis methods regionally within the same jurisdiction. Fertilization guidelines are largely developed by a committee of representative stakeholders within each country, who meet on a regular or in some cases infrequent basis. The general consensus from EJP SOIL participants was that harmonization across the EU could be increased in terms of shared learning in the delivery and format of fertilization guidelines and mechanisms to adhere to environmental legislation. However, it would be difficult, if not impossible, to harmonize soil test data and agronomic requirements at an EU-wide level due to differences in soil type and agro-ecosystem variations. Nevertheless, increased future collaboration between neighbouring countries within the same environmental zone was seen as potentially very beneficial. It is also essential that countries base fertilizer recommendations on robust scientific data such as crop-specific agronomic trials. This data should be updated regularly as knowledge increases, crop varieties change, and also in response to climate change. Precision technologies are playing an increasingly greater role in managing crops and soil nutrient inputs. Fertilizer guidelines should harness the advances in precision technologies, and mutual benefit could be achieved from collaborative research across a number of countries, with the sharing of methods, learning and understanding. Precision technologies have great potential for tailoring nutrient inputs at farm, field and landscape scale, which would contribute to the overall vision of the EJP SOIL research domains. The result of Task 2.4.5 has been the generation of knowledge on existing regional fertilization guidelines. This will be further disseminated through a workshop to be organised in EJP SOIL year 3, where selected members of the National Hub will be invited to participate. The workshop will evaluate the outcomes of stocktake 2.4.5 and will identify knowledge gaps and tools to enable improvements in region specific fertilization guidelines and updates to the EJP SOIL roadmap.

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2. Introduction

EJP SOIL - Towards climate-smart sustainable management of agricultural soils, is a European Joint Programme aimed at enhancing the contribution of agricultural soils to key societal challenges, such as climate change adaptation and mitigation, sustainable agricultural production, ecosystem services provision, prevention and restoration of land and soil degradation, and biodiversity maintenance. The EJP SOIL consortium is composed of 26 European research institutes and universities in 24 countries.

This report analyses the inputs given by 23 participating countries for Task 2.4.5 "Stocktake study and recommendations for harmonizing methodologies for fertilization guidelines across regions" which, along with four other stocktakes and synthesis, is part of task 2.4 "Synthesis of key soil related issues in the EJP SOIL countries in order to identify gaps and design region relevant research", included in Work Package 2 "A roadmap for Agricultural Soil Management research in Europe".

The main activities involved in achieving the aim of the synthesis were the collection of systematic information from all countries in the EJP SOIL on current soil fertilization guidelines, how these are formulated and managed, along with methods of communication and dissemination. The potential for harmonizing methodologies between neighbouring countries and across regions was assessed. The output of the stocktake is the provision of input and guidance into the development of a roadmap describing the current state and knowledge gaps in agricultural soil management in Europe and will form the base to develop calls in the 2nd year of the EJP SOIL and beyond.

The aim of fertilization is to optimise crop production in order to sustain a growing global population. At the same time, this needs to be balanced with meeting environmental legislation associated with the EU Nitrates Directive (91/676/EEC) and the EU Water Framework Directive (2000/60/EC) in particular.

The report presents the methodology used to collect and analyse the information (section 3), and details the results in the form of a summary of the responses from the questionnaires (section 4). Finally, the limitations and conclusions of the synthesis are presented in sections 5 and 6.

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3. Methodology and data source

3.1 Data Collection

Activity 1: The information for this report was collected through a questionnaire sent to the twenty four countries participating in the EJP SOIL. It was recommended that the questionnaire should be completed by a person or team within each country who are responsible for or involved in compiling and disseminating current fertilization guidelines within their country.

The questionnaire explained the overall objective of Task 2.4.5 and was followed by a series of questions within six main sub-objectives. The sub-objectives and questions are detailed below:

Overall Objective of Task 2.4.5: To complete a stocktake study and recommendations for harmonizing methodologies for fertilization guidelines across regions.

1. **Sub-Objective 1: To complete a stocktake of current fertilization guidelines across regions within the EJP SOIL**

   Q1. Does your country have fertilization guidelines?

   Q2. Are these fertilization guidelines specific to your country or are they shared guidelines across a number of countries?

   Q3. Did your country develop these guidelines?

   Q4. If the answer to Q3 is No, then please state who developed the fertilizer guidelines to which your country adhere to.

   Q5. Is your country involved in making changes or recommendations to the fertilization guidelines used in your region?

   Q6. How often are the fertilization guidelines updated?

   Q7. What organization(s) / institute(s) / stakeholders are in charge of managing fertilization guidelines in your country?

   * Each country was also asked to attach a copy of the fertilization guidelines or provide a short description of N, P, K, pH advice for the most important crops grown in their country

2. **Sub-Objective 2: To identify key variables in directing these guidelines e.g. climatic, soil, cropping system, nutrient loss**

   Q1. What environmental zone is your country in? (Environmental Zones were addressed using the classification by Metzer *et al.*, 2005[1], see Figure 1)

   Q2. What are the main crops grown in your country?

   Q3. Do you have a dominant soil type in your country?

[1] Metzger, M.J., Bunce, R.G.H., Jongman, R.H.G., Mücher, C.A. and Watkins, J.W. (2005). A climatic stratification of the environment of Europe. *Global Ecology and Biogeography*, 14, pp. 549–563.

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Q4. What soil phosphorus test is used in your country e.g. Olsen, Morgans, Mehlich?

Q5. Are fertilizer guidelines based solely on agronomic requirement in your country?

Q6. Are nutrient loss and environment important considerations in your fertilizer recommendations?

Q7. Have adjustments been made to fertilizer recommendations in order to minimise nutrient loss to the environment?

Q8. Are there crop-specific fertilizer guidelines?

Q9. Are there a single set of fertilizer recommendations for your country (per crop) or are there variations within-country?

Q10. What soil organic carbon test is used in your country?

Q11. Are soil physical attributes (texture, water retention, soil profile differentiation) a distinguisher in directing fertilization advice?

Q12. Are fertilizer guidelines considered on particular soil type and terrain (relief) in your country?

Q13. Is the soil pH (acidity/alkalinity) an important factor for agricultural soils and fertilization guidelines in your country?

Q14: Is soil liming used in practical farming in your country?

Q15: Are soil conditioners used in your country?

Q16: What soil K, Mg & Ca tests are used in your country?

Q17. What soil N tests are used?

3. **Sub-Objective 3: To identify synergies, similarities and differences between systems**

Q1. Are there differences in fertilization guidelines between you and your neighbouring countries?

Q2. Are there differences in soil tests used in your country and a neighbouring country separated by a land border?

Q3. For farmers living in border regions, do you feel that there are differences in fertilization regimes operating within close proximity?

Q4. Are there differences in fertilization regimes that may impact on cross border river catchments and nutrient loss for example?

Q5. Can you identify any similarities in fertilization guidelines within your region and neighbouring countries?

Q6. Are there restrictions of fertilization in conservation areas (nature reserves, eroded areas) in your country? Please describe

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Q7. Are there different guidelines for mineral and organic fertilizer use in your country? Please describe

Q8. Are there restrictions /limits on the use of specific kinds of organic fertilisers (digestate, sapropel, other organic waste)?

4. **Sub-Objective 4: To assess the potential for harmonization of methodologies and barriers to harmonization**

Q1. Do you feel that fertilization guidelines should be harmonized between neighbouring countries? This implies discussions between countries on common practice and sharing of knowledge

Q2. Should there be a centralised EU approach to fertilization management?

Q3. What do you think the main barriers are to harmonizing fertilization regimes across countries and environmental zones?

Q4. Can you identify any similarities in fertilization guidelines within your country and neighbouring countries? This includes the format of the guidelines (booklet, advice tables and nutrient index systems), how often they are updated and how the knowledge is shared with farmers. Also includes shared rules on organic waste products. Please describe

Q5. Do farmers in your country actively use any precision technology to identify soil or crop nutrient requirements e.g. ground sensors, remote sensing and satellite imagery?

Q6. Does your country consider that precision agriculture using soil and crop sensors and site specific land management is important in future farming?

Q7. Could precision agriculture techniques (shared principles) and apps be a way of harmonizing nutrient management and fertilization practices across EU countries?

5. **Sub-Objective 5: To identify stakeholders involved in formulating fertilization guidelines**

Q1. Please list the stakeholders currently involved in formulating fertilizer guidelines in your country.

Q2. Should other additional stakeholders be consulted that currently are not? Please list.

6. **Sub-Objective 6: To evaluate the importance of knowledge transfer and community engagement**

Q1. How are fertilization guidelines delivered to communities? Booklet / Website / App / Events / Farm Advisors?

Q2. Does the effectiveness of the communication vary between stakeholders?

Q3. What form of communication do farmers prefer?

Q4. How often do stakeholders meet to discuss fertilization strategies?

Q5. How often do knowledge transfer events take place?

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3.2 Country Response

Twenty three of the twenty four of the EJP SOIL participating countries provided information for the synthesis (Czech Republic did not participate). Each country was asked to indicate their environmental zone. This enabled any similarities and differences in response within and between environmental zones to be identified. The Environmental Zones (ENZ) displayed in Figure 1, and according to European regions, are as follows:

- Northern Europe (Denmark, Norway, Sweden, and Finland)
- Central Europe (Austria, Czech Republic, Estonia, Germany, Hungary, Slovakia, Slovenia, Poland, Lithuania, Latvia, and Switzerland)
- Western Europe (Belgium, France, Netherlands, Ireland and United Kingdom)
- Southern Europe (Portugal, Spain, Italy, and Turkey)

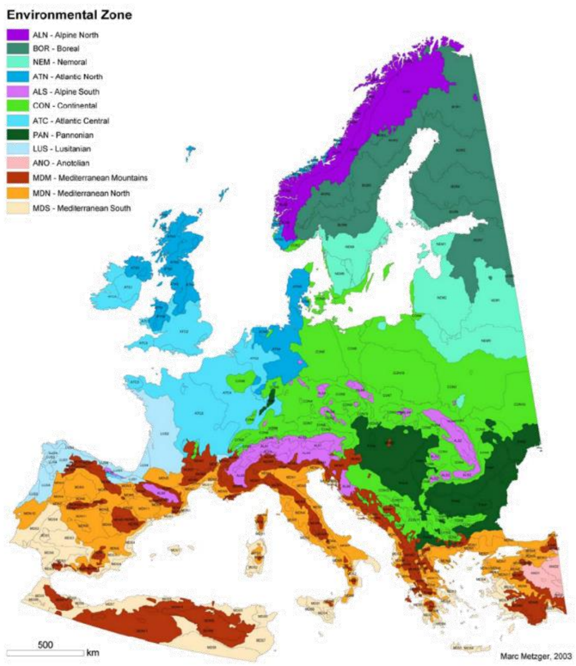

Figure 1. Environmental zones (ENZ) of Europe according to Metzger et al. (2005). In this synthesis the following ENZ are represented: Alpine North (ALN); Boral (BOR); Nemoral (NEM); Atlantic North (ATN); Alpine South (ALS); Continental (CON); Atlantic Central (ATC); Pannonian (PAN); Lusitanian (LUS); Anatolian (ANA); Mediterranean Mountains (MDM); Mediterranean North (MDN); Mediterranean South (MDS).

3.3 Data harmonization

Activity 2: Responses to questions within each sub-objective were assessed individually on a per-country basis. In some cases, individual countries identified similarities in fertilization guidelines between their neighbouring countries, and there were specific questions asking countries to identify similarities and differences. This enabled an assessment of the importance (or otherwise) of environmental zone in current fertilization guidelines.

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4. Results

4.1 Sub-Objective 1: Stocktake of current fertilization guidelines across regions within the EJP SOIL

Activity 3: Summary of Results: All twenty three countries stated that their country has fertilization guidelines specific to their country and developed by their country. The frequency by which these guidelines are updated is highly variable. The mean frequency of updates is every 10 years (Figure 2). Some countries make small amendments regularly in accordance with the latest research findings and particularly in relation to environmental legislation (France, Netherlands, UK, Ireland and Finland). For a small number of countries (Estonia, Hungary, Latvia, Lithuanian), fertilization guidelines are seldom updated (> 10 years between updates). Three countries make annual revisions to their guidelines (UK, Italy, Sweden).

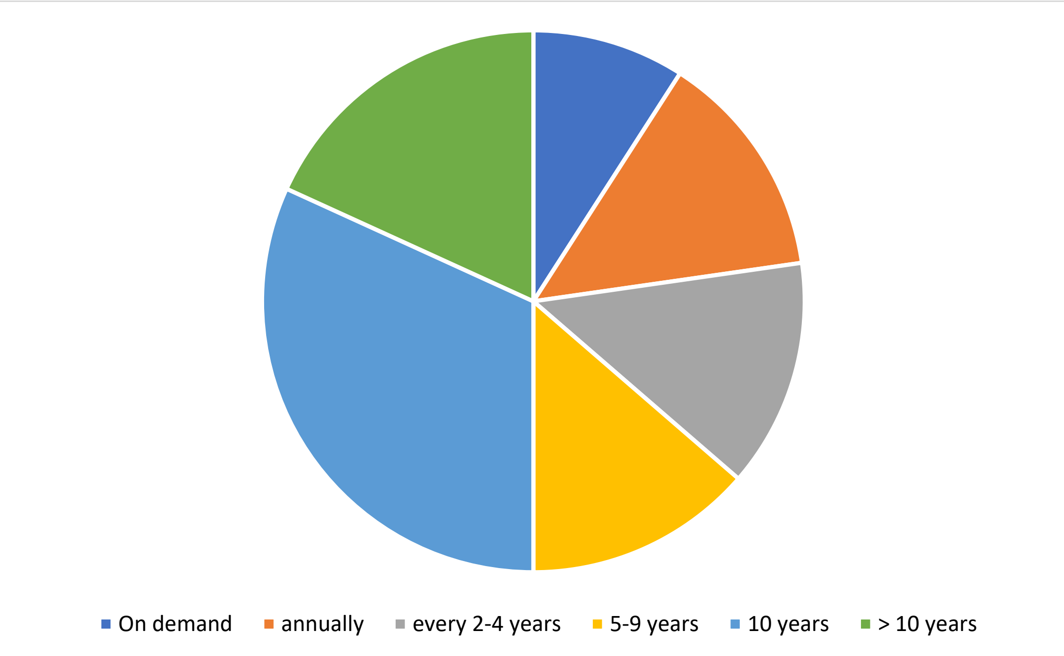

Figure 2. Frequency of updates to fertilization guidelines per country

While in some countries fertilization guidelines are developed solely by universities, research institutes or through government advisory service, in the majority of countries there is a designated committee responsible for the formulation of fertilization guidelines. This comprises representatives from research, economic actors, government bodies, public authorities, education and farmers organizations and involves collective decision making. In some countries soil laboratories and commercial fertilizer companies also have a role.

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4.2 Sub-Objective 2: Identification of key variables in directing fertilization guidelines

Across the EJP SOIL participating countries there are a large range of crops grown and enormous spatial variability in soil properties within and between countries. The classification of soil types also varies and is country-specific. In addition, the soil test methods used to analyse soils varies widely (Table 1), even with neighbouring countries in the same environmental zone. For example, Ireland analyses soil phosphorus via the Morgan's soil P test, while the neighbouring UK uses the Olsen P method. Some countries, such as France, use more than one soil phosphorus test, managed regionally within France.

Table 1. List of soil phosphorus analyses methods recorded by participating countries

Country	Soil Phosphorus Test / Analysis Method
France	Three soil phosphorus tests are used in France : - Dyer (standardised NF X 31-160), a rather aggressive extraction method used for acidic soils, which can lead to an overestimation of bioavailable phosphorus. - Joret-Hébert (standardised NFX 31-161), a French method, developed for neutral or calcareous soils. - Olsen (standardised NFISO 11263), a gentle extraction method also suitable for neutral or calcareous soils. It extracts a smaller quantity of phosphorus than the two previous methods. The value obtained is probably more representative of bioavailable phosphorus. The Olsen method is used more and more, the others are in marked decrease but remain sometimes at the region scale used because of an abundant experimental frame of reference.
Netherlands	Arable farming: P-water up to now, change expected in short term to combination of P ammonium lactate P-Al and P-CaCl2 Dairy farming (grassland and maize): combination of P ammonium lactate P-Al and P-CaCl2
Austria	ÖNORM L 1087 (Calcium Acetate Lactate extract according to Schüller)
Flanders	The soil phosphorus test in Flanders is based on 1:5 extraction with ammonium lactate and measurement with ICP-OES (P-AL). Accordingly, Amery et al. (2019) found in their study that P-AL is the most suitable test to estimate both plant availability of soil phosphorus and risk of phosphorus leaching.
Denmark	Olsen P
Estonia	"Official" method by state lab is Mehlich-3.
Finland	Acid (pH 4.65) ammonium acetate
Germany	in calcium lactate // electro ultra-filtration (EUF)
Hungary	AL (ammonium-lactate, Egner - Riehm - Domingo method)
Ireland	Morgan's P
Italy	The reference analytical procedure for soil available phosphorus are the Olsen method, actually the most widely used, and the Bray-Kurtz method, more specifically recommended for the determination of P labile pool associated with iron and aluminium. DTPA extraction is also suggested to quantify soil labile P ("Methods of Soil Chemical Analysis", T. Miano and C. Colombo Eds. 2015; Italian Official Gazette n. 248 21/109/1999).
Latvia	Egner-Riehm
Lithuania	Available P by A-L method
Norway	The AL method of Egner et al. (1960). This is the ammonium-lactate method at pH 3,75, soil:solution ratio 1:20, shaking time 90 minutes.

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Portugal	72% labs use P-AL; 20% use Olsen. P-AL is extracted by a solution of ammonium lactate 0.1 N and acetic acid 0.4 N buffered at pH 3.65-3.75, in a soil-to-solution ratio of 1:20 (m/v) and shaking for 2h.
Slovakia	Mehlich III
Slovenia	ammonium-lactate; AL (Egner, Riehm, Domingo) - technical documentation in preparation (SLOVENIAN INSTITUTE FOR STANDARDIZATION; SIST)
Spain	Mostly Olsen (pH usually above 7)
Sweden	For plant available P the P-AL (Ammonium Lactate) method is standard in labs and is what national recommendations, including extensive field trials, are based on. Olsen is used by some farmers in Southern Sweden. P-HCl is sometimes used for storage P.
Switzerland	CO2-saturated water water AAE10 (ammonium acetate EDTA)
Turkey	Olsen, Bray Kurtz (in low pH Soil)
UK	Olsen P

Soil fertilization guidelines are primarily based on the agronomic requirement for specific crops. However, within this there is adherence to environmental regulations for nitrogen and phosphorus in order to meet the requirements of the Nitrates Directive and Water Framework Directive. Countries also take into consideration factors such as recent fertilisation history, previous crop and organic manure management. Many countries such as Denmark, UK and Ireland base their fertilization guidelines on local scientific research trials, generating nitrogen response curves and calculating economic optimal nitrogen requirement. An essential outcome of this stocktake would be to ensure that all fertilizer guidelines are based on robust scientific data in order to validate fertiliser recommendation procedures as they vary between and within countries. Essentially these should be country-specific, soil-type-specific, and crop-specific agronomic response to applied nutrients.

All participating countries stated that nutrient loss and the environment are important considerations in the fertilizer guidelines for their country. Adjustments have been made to fertilization guidelines and best management practices in order to minimise nutrient loss to the environment.

In all countries there are crop-specific recommendations. Fertilization advice frequently varies locally and regionally within some countries depending on soil type, climate etc. (for example France, Netherlands, Austria, Denmark, Germany, Hungary, Ireland, UK, Italy, Norway, Portugal, Sweden and Turkey) whereas in other countries the entire territory follows the same guidelines (Estonia, Finland, Slovakia, Slovenia) but there may be local farm-specific advice if individual farm nutrient management plans are in place (for example Flanders and Switzerland).

In addition to variation in soil phosphorus tests used, soil analysis methods for carbon, potassium, magnesium and calcium also vary widely between countries (Table 2).

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Table 2. List of soil carbon. Potassium (K), magnesium (Mg) and calcium (Ca) and nitrogen (N) analyses methods recorded by participating countries

Country	Soil carbon test	Soil K, Mg and Ca tests	Soil N tests
France	Difference between total C and mineral C, or measurement by dry combustion after decarbonation, or wet oxidation " Anne method " (standard NF ISO 14235)	The contents of exchangeable cations are measured after extraction with a normal and neutral ammonium acetate solution (AFNOR X 31-108), by ICP spectrometry. In the case of calcareous soils, a normal sodium acetate solution is used.	For total N : dry combustion (NF ISO 13878) or N Kjeldahl (NF ISO 11261)
Netherlands	Loss on ignition (but mainly measured with NIRS)	K: a) extraction with 0.1 M HCl and 0.4 M oxacalic acid (this is the formal adviced test, however not practiced by the major laboratories) or b) extraction with 0.01 M CaCl2 and determination of the amount of K at the absorption complex (mainly measured with NIRS).	No information provided
Austria	ÖNORM L 1080	ÖNORM L 1087 (K), ÖNORM L 1093 (Mg), ÖNORM L 1086-1 (Ca)	ÖNORM EN 15936 (Ntot), ÖNORM L 1204 (potentially mineralisable N), ÖNORM L 1091 (Nmin)
Flanders	Determination of organic and total carbon after dry combustion (ISO 10694).	The soil K, Mg and Ca tests used in Flanders are based on 1:5 extraction with ammonium lactate (method also used for Fe, Mn and Na tests).	Both NO3-N and NH4-N tests in Flanders are based on 1:5 extraction in 1M KCL (ISO 14256-2).
Denmark	High temperate dry combustion, i.e. dry combustion at 950°C using a Vario Max Cube (Elementar Analysensysteme GmbH, Hanau, Germany).	Soil K: Extraction with NH4OAc, and determination by flame photometry. Soil Mg test: Extraction with NH4OAc, and determination by atomic absorption spectrophotometry. Soil Ca test: Extraction with NH4OAc, and determination by atomic absorption spectrophotometry.	NH4-N and NO3-N in soil is determined using flow colorimetry after shaking fresh soil immediately after sampling with 2 M KCl for 30 min. Total soil N is determined by high temperature dry combustion as for total SOC.
Estonia	For routine testing of agricultural soils wet chemistry (potassium di-chromate) method.	Mehlich-3	not used for routine analysis
Finland	Most results to farmers are based on manual/visual soil type estimation by commercial laboratories. Laboratories also provide loss on ignition and Dumas method, if farmers are interested.	Acid (pH 4.65) ammonium acetate	No information provided
Germany	elementary analysis after dry combustion	K in calcium lactate, Mg in calcium chloride // electro ultra filtration (EUF)	plant available mineral N extracted from soil (for agricultural soils mostly by 0.0125 M CaCl2)

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Hungary	Tyurin method (wet combustion)	K: Ammonium-lactete(Egner - Riehm - Domingo method), Mg, Ca: KCl	Humus content (Tyurin-method, wet combustion, mineral nitrogen (KCl)
Ireland	Officially a soil organic matter (OM%) test using Loss on Ignition method is used when soil organic C is measured. However, more recently a dry combustion for C and N (LECO or equivalent) has been proposed	Morgan's extractable K and Mg is used as standard. Calcium is not routinely tested.	There are no official N tests used for routine soil analysis. Beyond SOM testing, mineral N (NO3 and NH4) is sometimes conducted using KCl extraction to assess residual N in soils in spring or after harvest in autumn.
Italy	Determination of soil total organic carbon (TOC%) is performed with the Springer and Klee, Walkley-Black and dry combustion methods (Italian Official Gazette n. 248 21/109/1999). Among them, dry combustion technique by elemental analyzer is being increasingly used by laboratories, replacing chemical methods.	Determination of soil total K, Ca and Mg by "acidic digestion", "alkaline fusion" or "microwave digestion"; Exchangeable K by Melich III; Exchangeable K, Ca, Mg and Na by pH-7 buffered Ammonium Acetate or pH 8.2 buffered BaCl2 -Triethanolamine (Italian Official Gazette n. 248 21/109/1999).	Soil total N by the Kjeldhal method or dry combustion (elemental analyzer); Soil mineral N in KCl (as nitrate and ammonium by distillation, specific electrode or colorimetric determination); Organic N as the difference between total and mineral N (Italian Official Gazette n. 248 21/109/1999).
Latvia	Carbon analyser	atomic absorption spectroscopy	spectrophotometric method, Kjeldahl method, dry combustion method, determination by segmented flow analysis
Lithuania	Spectrophotometrical method according to oxidation capability	Available K by A-L method; Mg and Ca - both by Atom Absorbtion Spectrometry method	No information provided
Norway	Loss on ignition is routine analysis for cultivated soil. If soil C is measured, total C is used as organic C if pH is less than 6.5.	AL-method of Egner et al. (1960). This is the ammonium-lactate method at pH 3,75, soil:solution ratio 1:20, shaking time 90 minutes.	No method is used for practical farming except indirect method by using organic matter content to indicate the amount of mineralized N release during the growing season. Norway has, however, a good method available, but it is not recommended to analyze on soil samples from only the top layer in soil which is the most sampled layer (0-20 cm) on cultivated land. It is recommended that if available, N is to be analyzed in soil samples to a depth of 60 cm. This is not routine and very time consuming. It is also recommended to analyze

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			N on fresh samples because of nitrate change (increase) by drying and storage. Leaching of available N during wintertime is also high in Norway and available N on autumn sampled soil does not reflect the N content in soil for the next growing season.
Portugal	Wet_Dichromate oxidation (around 55% of labs); Dry combustion (25%)	K (ammonium lactate/acetic acid); Mg and Ca (ammonium acetate 1M pH7)	Around 50 % of the labs determine total N (mainly Kjeldahl); Some labs (15 %) determine mineral N (mainly KCl)
Slovakia	Method by Walkey-Black or method by Tjurin	Mehlich III.	Total nitrogen by Kjeldahl method; mineral nitrogen by flow segmented analyzer SKALAR SUN+ with colorimetric method
Slovenia	Total soil organic carbon: total C (Ignition at 900°C*) minus carbonate C	AL-K; 0,01 M CaCl2 for Mg and Ca; in pedological analyses we use also ammoniu-acetate extraction of soil bases (Ca, Mg, K, Na)	0.01 M CaCl2 extraction for soil mineral N forms; combustion at 900°C for N total.
Spain	Soil organic carbon is usually determined by the method of oxidation with potassium chromate based on Nelson, D.W., Sommers, L.E., 1996. Total carbon, organic carbon, and organic matter. In: Methods of Soil Analysis Part 3—Chemical Methods. SSSA Book Series No. 5. Madison, WI, pp. 961–1010. However, sometimes it is estimated as the difference between the total soil C content obtained by combustion in a LECO (or similar) and the C as CaCO3, measured by the HClO4 method (https://www.boe.es/doue/2016/054/L00001-00446.pdf)	Usually obtained with an optical emission spectrometry with an ICP-OES plasma spectrometer or similar	NH4 and NO3 are determined by pectrophotometry methods (NO3 after a reduction in a Cd column), based on the classical: Solorzano, L., 1969. Determination of ammonia in natural waters by the phenolhypoclorite method. Limnol. Oceanogr. 14, 799–801. Keenney, D.R., Nelson, D.W., 1982. Nitrogen-inorganic forms. In: Page, A.L. (Ed.), Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. ASA and SSSA, Madison, WI, US, pp. 643–698.
Sweden	In farm soil mapping usually loss of ignition corrected for clay content. For research purposes often LECO	Same extractions as P (ammonium-lactate soluble P)	To some extent, at a regional scale, mineral N (nitrate and ammonium) is analysed as a rough estimate of N remaining and mineralized during winter. Recent years this is

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			largely replaced by zero N plots (plots of 20-25 m2 treated as the field at large apart from nitrogen that is excluded) and the NBA use a hand held Nitrogen sensor (Yara N-sensor) to weekly estimate the N-uptake in Winter wheat from spring until flowering. The estimation is done in several zero-N plots distributed on farms and also in the surrounding crop, fertilized at normal rates. Yara publish similar results from their own field trials. It has become increasingly popular among farmers to by this as a service from their advisory organisation. This is also recommended in the NBA guidelines. Preferably in combination with a Max N-plot deliberately fertilized with a surplus of N.
Switzerland	currently under revision old: wet oxidation with dichromate new: stepwise combustion + mass spectrometry	K: CO2-saturated water; water; AAE10 (ammonium acetate EDTA) Mg: CaCl2; water; AAE10 Ca: water; AAE10	Nmin
Turkey	SOC Device or calculation from soil organic matter content.	K- Flame photometer, Mg+Ca titrimetric, ICP	N calculation from organic matter, Total Kjeldahl N, Ammonium-N, Nitrate-N
UK	Loss on Ignition and LECO	1M ammonium acetate	Total N by LECO, Mineral N by KCl extraction

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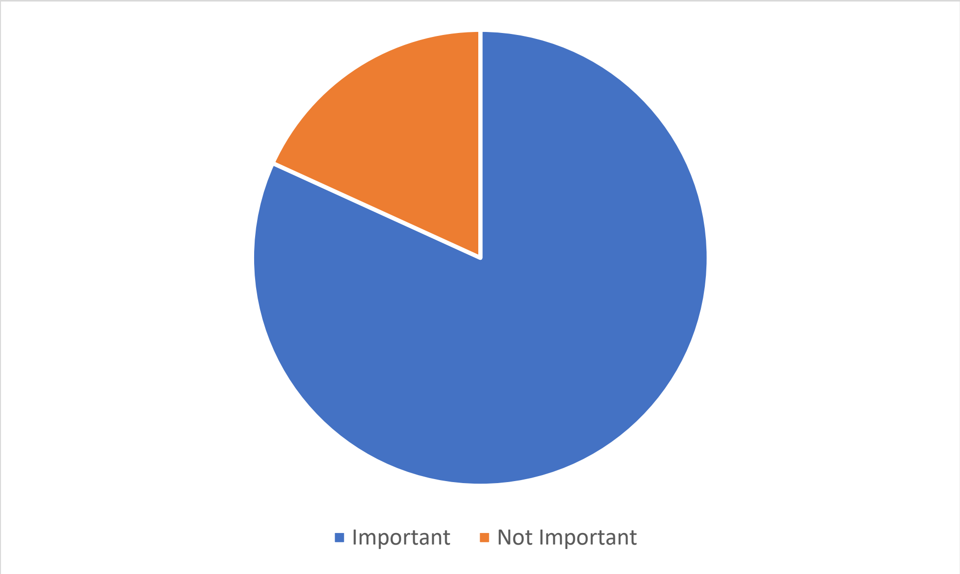

Figure 3. Countries in which soil pH is an important factor for agricultural soils and fertilization guidelines

The majority of countries (82%) consider soil pH to be a very important factor for agricultural soils and would include soil pH management within their fertilization guidelines. A smaller number of countries (18%) consider soil pH to be important or recognise its importance but pH management is not included within fertilization guidelines. In some cases it may be a separate document. All countries use liming within practical farming, apart from a small number of countries where calcareous soils are prevalent and liming does not need to be carried out regularly. Soil conditioners were stated as being used within all countries surveyed, but the definition of a soil conditioner and the type and frequency of soil conditioners used varies considerably between countries.

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4.3 Sub-Objective 3 : Identification of synergies, similarities and differences between systems

It is widely recognised that there are differences in fertilization guidelines between countries and their neighbouring countries. Methods of soil analysis are different between countries, and even within regions of the same country. There have been a small number of peer-reviewed publications analysing some of these differences, for example:

Klages, S., Heidecke, C., Osterburg, B., Bailey, J., Calciu, I., Casey, C., Dalgaard, T., Frick, H., Glavan, M., D'Haene, K., et al. 2020. Nitrogen surplus—A unified indicator for water pollution in Europe? Water, 12, 1197.

Wim van Dijk en Hein ten Berge (Eds) 2009 "Agricultural nitrogen use in selected EU countries", where N recommendations are compared across Belgium, Germany, France, Denmark and Netherlands (Report)

Variability in fertilization guidelines between neighbouring countries occur due to a wide range of factors including:

- Climate
- crops grown
- different target crop yields
- crop varieties
- animal production systems (confined feeding vs pasture grazing etc)
- whether a country treats its whole territory similarly
- whether factors such as NVZ's are used to regionalise or differentiate fertilisation limits and recommendations
- other regional differences such as fertiliser application season opening dates in spring and closing dates for nutrient applications in autumn/winter
- Differences in soil testing methods and soil tests used, along with corresponding soil test indices/soil nutrient fertility ranges as a basis for differentiating fertilization rates etc.
- Differences in agronomic optimum soil pH ranges for different crops etc.

In general, common across all countries is the completion of an analysis of the soil, the nutritional needs of crops, interpretation of soil test results and formulation of a fertilization plan in relation to the pedo-climatic conditions. The format of communication of fertilization guidelines varies greatly between countries with some countries, such as France (for P, K and Mg), Switzerland and Austria (P, K, Mg, S, micronutrients), providing great detail in how to build the fertilization plan. Other countries, such as Slovenia, use a similar conceptual approach, but the communication is simplified, for example into three soil classification: low, medium or high nutrient content.

Many countries are aware of the methods used to formulate fertilization guidelines in their neighbouring countries, and the format in which they are published. Other countries in this study reported that they are aware that differences exist but are not familiar with the detail, and there is a lack of shared information available (for example Latvia, Lithuania, Slovakia, Turkey). It is unclear whether this information is unavailable or simply unknown to the person completing the questionnaire detail.

Another factor is the types of farming system and their management. For example, Sweden is mostly forested, while Denmark is largely agriculture. Compared to Sweden, the farm animal density and presence of manure is much higher in Denmark in agricultural districts along the Baltic coast line. Spain and Portugal reported being similar in their fertilization guidelines, while differences with France are more apparent, mainly driven by differences in the type of agro-ecosystems between the countries.

For farmers living in border regions between countries, it is recognised that there are likely to be differences in fertilization regimes operating within close proximity. However, this has been under-reported and while many countries expect that **differences exist along border regions, they have not been quantified and the implications have not been reported**. ***This is one of the important results of this stocktake.*** Flanders reported that there may be farmers who own land parcels across border areas and they must comply with different fertilization guidelines for different land parcels. In Ireland there are different soil tests used between Ireland and Northern Ireland (UK) but the guidelines in general are similar between these countries, with shared environmental concerns and agronomic crop requirements. There would be good collaboration, understanding and knowledge exchange between Ireland and the UK and so while soil tests may be different, the fertilization guidelines are generally quite well aligned. In Portugal near the border with the south of the country there are intensive olive groves that are managed by Spanish technicians, using the fertilization guidelines developed in Spain. The border areas between Norway and Sweden are mainly forest and in the north there is no farming between northern Finland and Russia. Fertilization differences in these border areas are therefore not an issue.

Differences in fertilization regimes may impact on cross border river catchments and nutrient loss. This is a recognised issue, and all countries completing the questionnaire reported that this is likely but they have *limited knowledge of the detailed magnitude of this issue*. Cross border traffic of manure was also reported. Ireland operates on the basis of zero P balance (P inputs= P outputs, excluding soil fertility build-up) whereas in Northern Ireland (UK) a small P surplus (5kg/ha) has been permitted to accommodate increased slurry production in confined feeding production systems that are more dominant in this region. There may be implications of Farm P management on the eutrophication of cross border lakes and river systems.

There is huge variety of soil test procedures, and often poor correlation among those tests. To date there is no unified legislation at European level defining the maximum P amount applicable to agricultural soils. Generally, the applied amounts go from 60 kg ha^{-1} up to 120 kg ha^{-1}. In Italy they range between 120 and 250 kg ha^{-1}, influenced by the widespread occurrence of alkaline and calcareous soils in Italy. Slovenia has superimposed restrictions on fertilization close to the water bodies (Law of Waters OJ RS 67/02, 110/02, art. 15, which prohibits fertilizer use in the band 15 m from the shore of 1st order water bodies, and 5 m from the shore of 2nd order water bodies).

In all countries there are restrictions in fertilization within conservation areas and nature reserves, and there are regulations for organic materials, particularly sewage sludge.

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4.4 Sub-Objective 4 : Assessing the potential for harmonization of methodologies and barriers to harmonization

Overall, there is support amongst countries for the harmonization of fertilization guidelines between neighbouring countries. However, it is emphasised that this should only be where soil type, growing conditions and crop rotations are comparable. Cooperation between countries can lead to improved fertilization guidelines. However, harmonization should not be a goal in itself. It is recognized that harmonisation and alignment of fertilisation guidelines between neighbouring countries and regions will be difficult, if not impossible, and should be evaluated case by case. Rather than aiming to harmonise advice, sharing of knowledge is very valuable and should be strengthened. Full harmonization may not be necessary. Due to differences in soil tests and fertilization guidelines, comparison of short and long-term data sets between countries is very difficult.

The development of more harmonized fertilization guidelines, which at least overcome discrepancies linked to overly empirical evaluations and implement an agreed selection of scientifically based methods, would be extremely important to allow truly balanced mineral and organic fertilizer inputs and provide more reliable information on the long term effects of national and EU environmental measures and policies.

Sharing knowledge represents a value that should be exploited to consolidate agronomic practices based on the agroecological approach all over the Europe. Currently, Italy, France, Austria propose similar fertilization guidelines which are based on the evaluation of the soil characteristics, climate, crop and the way in which nutrients are released by different fertilizers. Other countries such as Slovenia, simplify this approach: in these cases, sharing experiences could represent an excellent opportunity to align fertilization plans between cross-border countries.

The Scandinavian countries, especially Norway, Sweden and Finland, have young soils compared to the rest of Europe with some differences in origin and mineralogy. A cold climate and high precipitation influences the amount and quality of soil organic matter, and the pH in soils are in general low. A harmonization and interpretation of methods should be discussed. Today, with a few exceptions, the four countries have different methods both for pH and macro and micro nutrients. Guidelines should be harmonized as long as they are flexible enough to account for specialties (climate, soil, geography) of each individual country.

Should there be a centralised EU approach to fertilization management?

It is felt that reflections could begin in this direction, but probably in the long term the situations seem to be very different between countries. European harmonization would lead to a change in practical references, which must be considered over a generation. An evolution too rapid would lead to a distortion of competition between countries, depending on their initial situation and the new standards they would have to share.

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There is little common EU-wide knowledge on the nitrogen budgeting and its comparability at the farm level for the detection of ground and surface water pollution caused by nitrates and the monitoring of mitigation measures (Klages *et al.,* 2020). The Nitrates Directive leaves the Member States some freedom which can be considered as positive. There could be an integrated approach of nutrient management (with extensive exchange on scientific knowledge and with a unified system of registration, monitoring and inspection) for wider areas in Europe, e.g. for all regions and Member States with intensive agriculture.

Some countries felt that for detailed guidelines and regulations there should not be a centralised EU approach because conditions are too different. Best management practices for both production and environment are those adapted to local conditions. Analytical methods, purpose and possible gains must be carefully evaluated. The local adaptation needed at the farm and field scale for efficient use of resources should be considered. There are indications that the optimal N rate in some countries may be substantially higher for the same crop and the same harvest than in other countries. To establish such circumstances and to investigate plausible reasons and environmental and economic consequences may be of considerable interest. Ideally there would need to be fertilizer response trials in contrasting crops, environments and soil types. However, crops and their growing period differ widely from south to north. ***Comparisons in nutrient dynamics may not be possible***.

The form in which fertilization guidelines are delivered and disseminated to farmers and stakeholders, for example as a booklet, advice tables or nutrient index systems is country-specific and there is generally a lack of awareness about the detailed differences between neighbouring countries and across Europe. ***One of the outcomes of this stocktake in the longer-term may be a development of a common method of delivering and disseminating fertilization guidelines across MSs, along with a common approach to basing fertilization guidelines on the best, most robust available scientific data.***

Precision Agriculture

To some level, precision agriculture is implemented by farmers within all countries surveyed, but generally the percentage of farmers implementing precision technology is quite low. In the Netherlands it is estimated that approximately 15% of the farmers use satellite imagery, soil scans and place-specific fertiliser application. Though an increase may be expected when the techniques become cheaper, and accuracy improves, and when technology becomes easier-to-use and when legislation becomes more customized. There is currently much active ongoing research in this area. In Estonia less than 5%, and in Italy and Hungary only 1- 2% of the farmers use precision agriculture techniques, but the value and potential benefit of adopting such techniques is recognised.

In Norway and Sweden, N sensors for nitrogen are used in grain farming. The N sensor on the tractor communicates with the fertilizer distributor for optimal dosing of N. Precision technology is also used in lime application where the lime distributor add lime according to information on pH and the soil buffer capacity (organic matter and soil type) mapped by coordinates and based on soil analysis. The lime application is controlled by a computer on the tractor.

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Most countries, while current adoption rates are minimal on the whole, consider that precision agriculture using soil and crop sensors and site specific land management is important in future farming. However much research and development is still required in integrating these methods on farms. The use of apps, nutrient management planning computer programmes, and precision agriculture principals could possibly be used as the basis for harmonising management practices across EU countries and more specifically within discrete environmental zones.

Precision technologies have great potential for tailoring nutrient inputs at field, farm and landscape scale. A collaborative approach to investigating precision technologies across regions and climatic zones would be desirable and highly beneficial. Using precision technology to tailor nutrient inputs to agricultural systems would be an important mechanism for improving environmental conditions in terms of soil, water and air quality, along with influencing biodiversity and productivity.

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4.5 Sub-Objective 5: Identification of stakeholders involved in formulating fertilization guidelines

Countries generally have a committee of representatives involved in formulating fertilization guidelines. The representatives on this committee varies widely between countries. Examples include Public administrations, state research centres, educational institutions, learned societies, professional agricultural organisations, industries producing fertilizing materials, distribution and service companies. In some countries the committee is confined to researchers, advisors, farmer organizations, laboratories and nutrient management policy representatives. In larger countries there should be representatives from different regions within the country. In a small number of countries, fertilization guidelines are formulated by the Ministry of Agriculture for the country, and there is less representation from a wider body of stakeholders, particularly farmer representatives.

There is currently no harmonized EU structure of stakeholders per country involved in the formulation of fertilization guidelines.

4.6 Sub-Objective 6: Evaluation of the importance of knowledge transfer and community engagement

Similar to the structure of fertilization committees, there is currently no harmonized approach to how fertilization guidelines are delivered to communities. Guidelines are generally delivered in booklet form, but the degree of dissemination through websites and other publications such as education material, apps and computer software, and presence of farm advisors varies widely between countries.

Some countries have recently developed individual farm nutrient management calculators for online use. Advice is often delivered through sales reps from fertiliser companies. Research organisations and government bodies also hold open days and information days once a year (but the frequency varies between countries). Open days often accommodate small focus groups of 40-50 farmers, but there can be up to 500 farmers at some events. Discussion groups on specific topics with a small number of maybe 10-15 farmers are often held. Ireland hosts an annual soil fertility conference for a mainly farmer audience.

Regular and updated training for farm advisors and stakeholders is essential as new research and changes to policy emerge. In some countries the fertilization guidelines are currently only in booklet form but plans exist to produce online and digital versions. Many farmers prefer paper copies, but new, younger farmers are moving to more digital applications.

The effectiveness of the form of communication varies between stakeholders, but general awareness of this and in-depth knowledge or experience was not available amongst the colleagues completing the questionnaire detailing specific country experiences.
The frequency by which fertilization committees meet, and also the frequency by which farm advisors meet with farmers, varies significantly between countries. In some countries it is irregular, infrequent

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or with no planned schedule. In other countries there is an annual meeting and in some countries the fertilization committee (made up of representatives specific to that country) meet three or four times a year.

Currently there is no harmonized EU approach to the frequency of meetings by fertilization advisory groups or communication strategies.

5. Limitations of the Synthesis

This synthesis is a stocktake study and recommendations for harmonizing methodologies for fertilization guidelines across regions:

- Specific expertise was required to complete the synthesis questionnaire. We asked participants to ideally send the questionnaire to a representative within their country who has expertise in fertilization management and guidelines.
- The detail of the information provided by the participating countries was not always uniform. Some participants were quite extensive answering all the questions while other provided incomplete answers.
- It is apparent that more detail could possibly be obtained for some answers if further questions and discussions took place with some of the participants. This would be beyond the scope of this task, but could be conducted in future if desired.
- There are also publications in the literature that may have addressed some of the aspects of the questionnaire such as differences in soil tests and strategies amongst a small group of neighbouring countries. These publications could possibly add more detail to the attached synthesis however there was limited time and resources available to enable this within the current synthesis.

6. Conclusions

This synthesis presents the responses of 23 EJP Soil participating countries on recommendations for harmonizing methodologies for fertilization guidelines across regions.

All participating countries have fertilization guidelines which are produced by their country and specific to their country. The form of these guidelines varies between countries, along with the frequency by which they are updated. In most countries the fertilization guidelines are managed by a committee of stakeholders such as researchers, government representatives, farm advisors and farming representatives.

Of great importance is the variation in soil tests used between countries. This applies to soil phosphorus tests along with nitrogen, potassium, magnesium and carbon. Differences in soil tests are necessary due to the huge spatial variation in soil types and soil properties both within an individual country and between countries. Harmonizing data between soil types, different analysis methods, different crop types, climate and management will be extremely challenging and perhaps impossible.

There is general agreement that a more centralised approach to fertilization guidelines across the EU would be advantageous, particularly in terms of knowledge exchange and sharing of common principles. The difficulties of this however are acknowledged. A more achievable desire would be to have greater harmonization between neighbouring countries with shared agro-environmental ecosystems, such as within environmental zones.

Knowledge of the specific detail of fertilization guidelines between neighbouring countries tends to be low, although there are some exceptions, particularly in northern European countries where there are perhaps shared challenges such as the phosphorus limits associated with grassland livestock farming and the need to manage organic manures. Overall across the EU there is inadequate knowledge of fertilization guidelines practiced between different environmental zones for example, such as N limits for different soils and crop types etc. but this is just based on the responses of the questionnaires. As is recognised, it may not be necessary to have a detailed knowledge of practices outside ones immediate region. However, some awareness of general practices and knowledge exchange for tackling environmental issues would be desirable. The sharing of ideas and knowledge around precision agriculture technology was widely specified as an area through which shared learning would be beneficial for future farming.

It may also perhaps be useful to re-assess the soil analytical methods currently used. While fertilization guidelines are based primarily on agronomic need per crop and are specific to each soil type, the growing importance of environmental issues and the need to minimise nutrient loss may necessitate soil tests which quantify the risk of nutrient loss within particularly sensitive zones, along with maintaining agronomic performance.

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Wim van Dijk en Hein ten Berge (Eds) 2009 "Agricultural nitrogen use in selected EU countries", where N recommendations are compared across Belgium, Germany, France, Denmark and Netherlands (Report).

Annex I

A folder with the complete information provided by the participating countries is available in the EJP SOIL SharePoint (https://sites.inra.fr/site/ejp-soil/WP2/SitePages/Home.aspx) and available upon request to ana.paz@iniav.pt.

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