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Organische stof wordt algemeen beschouwd als een belangrijke factor om de kwaliteit van de bodem van landbouwgrond te handhaven en te verbeteren. Er bestaat echter vooralsnog geen systemisch kader om de bodemchemische, -fysische, -biologische en economische aspecten te evalueren met betrekking tot de toepassing van organische bemestingsproducten. Mede als gevolg van de transitie van een lineaire economie naar een circulaire economie zullen veel nieuwe organische producten op de markt komen die voortkomen uit de be- en verwerking van verschillende organische reststromen, zoals slib van afvalwater, mestoverschot en voedselresten. Dit rapport geeft een overzicht voor de karakterisering van zowel de organische meststoffen, alsmede de impact op de bodemkwaliteit met daaraan gekoppeld de agronomische, milieukundige, gezondheid en economische aspecten. Ten slotte worden de belangrijkste kennislacunes en ontbrekende methoden vermeld om de duurzaamheidsaspecten van nieuwe organische meststoffen in kaart te brengen. Dergelijke informatie is relevant zowel voor agrariërs ten aanzien van gebruik van organisch meststoffen als voor financiers en grondeigenaren ten aanzien van de kwaliteit van de bodem als voor beleidsmakers ten aanzien van wet- en regelgeving ten aanzien van toelating.

Organic matter is widely recognised as an important factor in maintaining and improving soil quality in agricultural land. However, there is no systemic framework or approach to quantify soil’s chemical-, physical-, biological- and economic aspects. Furthermore, due to the introduction of the circular economy, many new organic fertiliser products are becoming available. These products are derived from several organic waste streams, such as sewage-sludge, surplus manure and food-waste. This report describes an approach that can be used to evaluate the effect of applying organic fertilisers on the impact on soil quality, agronomy, the environment and human-health. Finally, the main knowledge gaps and missing methods to assess sustainability aspects of new organic fertilisers are mentioned. Such information is relevant both for farmers (who might ask: “what will I get?”), financers and landlords (who might ask: “what is the effect on land value?”), as well as for policy makers (who might ask: “how could legislation aspects be dealt with?”).

Keywords: organic biobased fertilisers, impact, soil quality, agronomy, environment, human-health, economy, evaluation framework

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Contents

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Preface

Assessment of the value of organic fertilisers in terms of soil quality, agronomy, environment and human-health is complex, but needs more attention because of valuable biomass streams for food production will come on the market as a result of Europe's Circular Economy strategy. Therefore, Wageningen Research has started a project called: "Development of an evaluation framework for organic fertilisers". In the first phase (July 2018 – July 2019), the activities were focused on setting-up a framework for the evaluation, including the determination of important parameters and their measurement protocol.

This preliminary study was carried out by Wageningen Environmental Research, Wageningen Plant Research, Wageningen Livestock Research, Wageningen Economic Research, and Wageningen Food Safety Research. The research was funded by the Dutch Ministry of Agriculture, Nature and Food Quality (project numbers KB-33-003-003 (2018) and KB-34-001-002 (2019)).

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Summary

The implementation and enforcement of the European Circular Economy Action Plan (CE Package, December 2015) has led into an increased interest in using organic waste streams as a source for production of different types of organic fertilisers. Furthermore, the 4 promille initiative, as presented by France during the COP21, promotes the use of organic products towards increasing the organic matter content of soil with 4 promille each year.

Organic-rich waste streams, such as sewage-sludge, food- and feed-waste and surplus manure in areas with intensive animal husbandry, differ in composition. Consequently, the organic fertilisers produced from them differ in composition, and, therefore, also in agronomic value, impact on soil quality and environmental losses.

This study focuses on the development of a framework to evaluate organic fertilisers that are known, as well as new ones. In the report, the conceptual approach is described. It will be followed up by other studies for testing the derived concept.

Within the framework, four major aspects regarding the use of organic fertilisers were discussed and evaluated in order to bring forward a first concept or approach: (1) Characterisation of the organic fertilisers, (2) Soil quality from an agronomic point of view, (3) Environmental- and health aspects and (4) Economic aspects. Although there is a lot of information already published on each of these aspects, as well as some combined aspects, an integrated methodology to evaluate different types of organic fertiliser is lacking. Starting from peer reviewed literature, literature available in reports, and expert knowledge (internal and external), a general methodology was set up.

Regarding the characterisation of organic fertilisers and the product quality, a listing of chemical-, physical- and biological parameters is shown for different types of reasonably well-known organic fertilisers (manure, compost, digestate, biochar and growing media). From an agronomic point of view, the focus is often on parameters that are relevant to assess the plant availability of nutrients (nutritional value), the organic matter content and the biodegradability of the organic matter. Although the listing of relevant chemical-, physical- and biological parameters can be defined, there are a wide variety of analytical methods and protocols to determine the value; sometimes even within well-known groups of organic fertilisers (standards for manure/digestate, compost, biochar and growing media; resp. Annexes 8-11). For each new organic fertiliser, the group it belongs needs to be decided. If this is not possible, a proposed set of standard analysis will be used (that require definition in the next stage). This is also the case for the biodegradability / stability of the organic matter, since several approaches are available and the outcome is very relevant for the assessment of the short- and long-term impacts on soil quality in terms of agronomic- and environmental aspects.

Regarding the characterisation of soil quality, a large number of potential indicators have been extensively studied. Literature research was also carried out to determine the parameter values that correspond to the different analytical procedures that have been published, or are currently in use by international laboratories to determine fertiliser recommendations for the farmer. In this study, a list of proposed standard analyses was selected taking into account fertilisation aspects and parameters used in regulation and permissions in the Netherlands.

Alongside the determination of the current quality of the soil, the long-term impact of applied organic fertilisers on soil quality (and the environment) requires quantification. This has to be done by means of model calculations, because the time-span of the decomposition of applied organic matter and release of minerals vary from a few to many decades. Based on a literature study, the model, MITERRA, was selected as it can be used to describe the carbon-, nitrogen- and phosphorus turnovers in soils, and the associated emissions to air and water. In this model, the well-known ROTHC description was used to describe organic carbon pools. Furthermore, the fate of heavy metals can be directly linked to this selected model.

An important follow up activity of the underlying study was to translate the organic fertiliser characterisation parameters and measured biodegradability into the model parameters. Within this integrated characterisation – biodegradability - model approach, the most recent insights regarding the decomposition and role of organic carbon pools were taken into account. This can lead to additional parameters to characterisation organic fertilisers that are highly relevant in determining the long-term impact of organic fertilisers in soils.

In this study, a pre-defined selection of crop rotations based upon specific soil types were defined that can be used to predict the impact of different organic fertilisers on the soil quality and the agronomic aspects. The organic fertilisers will be applied up to the limits of the application standards as defined for Manure / Fertiliser Act of the Netherlands, which are in line with the Nitrate Directive for vulnerable zones. The amount of mineral N, P and K fertilisers required for application can be calculated to meet at least with crop requirements and to maintain a sufficient P- and K soil status. Furthermore, the impact on the development of soil organic matter (SOM) content can be calculated. This approach clarifies the nutritional value of the organic fertiliser, together with the additional need and costs of required mineral fertilisers. Furthermore, the long-term increase or decrease in soil organic matter can be estimated, including the CO_2 and N-emissions to the air and N, P emissions to water. This approach will not only be used for new organic fertilisers that become available on the market, but also for the main, currently used organic fertilisers (manure, compost etc). These products can be used for 'benchmarking' purposes.

In this study, a systemic approach was set up for the environmental- and health risk assessment of organic fertiliser applications. Regarding the impact of organic fertilisers on the fate of available heavy metals in organic fertilisers, long-term model scenario analyses are also needed, because of the often strong chemical reactions in the soils (high buffer capacity) that cause long-term delays through changes in uptake by crops and emissions to water. Comparable to the modelling of the fates of C, N, P and K, and also the fate of heavy metals; these can be predicted. Long-term negative aspects of specific heavy metals can be addressed as part of the overall evaluation scheme.

A workshop with experts was held (in November 2018) to derive an initial list of potentially unwanted substances, organisms or diseases that might be present in organic fertilisers. Three main categories together with subcategories were defined:

1. Microorganisms: zoonosis, infectious diseases, ARM (= antibiotic resistant microorganisms)
2. Medical drugs: antibiotics, antiparasitics, other drugs
3. Other chemicals and substances: nanoparticles, dioxins, biocides, emerging contaminants.

There is not much information available of the fate of such substances in soil ecosystems (sorption / degradation – uptake by crops and animals - transport to water). Therefore, a matrix was created, with these (sub)categories scored for their environmental impact (Annex 12).

A pass / fail approach was developed to evaluate priority substances in organic fertilisers (Figure 4.5). In this pass / fail risk assessment approach, the following aspects were taken into account: detected in matrix, tolerable, criteria available, end points + risk indicator + transfer model available, impact assessment. In the next phase for each of the steps of the pass / fail approach, more detailed information that is relevant for the overall evaluation of the organic fertilisers will be collected.

The economic aspects of the evaluation framework were focussed on the economic value of organic fertilisers in terms of nutrients supplier and in relation to soil quality. By using organic fertilisers, a part of the mineral fertilisers can be substituted. This can be directly evaluated by pricing in terms of kg N, P and K. Insight into the benefits of these fertilisers for the farmer is needed for the assessment of the total economic value of organic fertilisers. It concerns not only the possible cost reductions for fertilisation, but also the cost reduction in pest management and possible yield increases due to the organic matter in the products. These effects will be different per crop and farm type.

In some European regions with an excess of manure, farmers get paid if they accept manure/digestate from other farmers, intermediaries or manure processors, which is a direct benefit for those farms and often a relevant part of their income. In these situations, the value of the manure is not based on the fertilisation and organic matter value, but on the opportunity for manure disposal.

The use of organic fertilisers also contributes to the maintenance of the soil organic matter content. The maintenance of the organic matter content of the soil is recognised by farmers as an important soil quality factor, because it highly determines crop yields and crop quality, as well as the costs for pest control. However, there is no system or approach to determine the economic value of a certain soil quality. The current pricing of agricultural land is partly determined by the strategic value of the land and partly by its agricultural value. The agricultural value is based on the crops that can be cultivated, the number of animals that can be additionally kept at the farm and the location of fields in relation to the location of the farm. The soil quality is a minor aspect.

Nevertheless, there is an upcoming interest of several stakeholders (financers, landlords and companies in the drinking-water industry) in soil quality and sustainability aspects of agricultural land. An initial conceptual model was developed for the development of the economic framework of organic fertilisers and soil quality aspects. Furthermore, interviews were set up with several stakeholders including chain partners in the production, processing and sales, and a bank and institutional landowner, to retrieve economic key performance indicators that should be taken into account in the economic framework.

Farmers, landowners, investors and banks find the indicators related to the productivity of land to be the most important ones. As a consequence, there is an interest among all these stakeholders to further explore the relation between organic matter in the soil, crop management and yield levels, because this insight is needed to assess the economic effects of organic fertilisers. However, the knowledge of the relations between soil organic matter, crop management and yield levels are often poor. Therefore, it was concluded that the assessment of the economic value of organic fertilisers would be based upon: 1) The value of the nutrients (N, P and K) in the products, 2) The costs needed to maintain the soil organic matter balance and 3) The effects of an improvement of the organic matter content in the soil on crop management and yield levels.

1 Introduction

Organic matter is widely recognised as an important factor in maintaining soil fertility, soil biological activity and soil structure. Different organic materials and fertilisers are used to improve soil quality. In current conventional farming systems, the most important sources of organic matter are crop residues, different types of manure or co-digestates, compost, and also in some countries, sewage sludge. However, in the near-future, additional types of organic sources will become available on the agricultural market, because the current European policy strongly focuses on the transition from a linear economy towards a circular economy (CE Package 2015). The main goal of this policy is to achieve 'economic sustainable growth by increasing the value of products, materials and raw materials as long as possible in the economy'. The three main strategies are to: (a) Reduce waste to a minimum, (b) Promote re-use and recycling of materials & products, and (c) Create value: from waste to valuable raw material.

The European Commission proposes a large package of measures to set product requirements regarding reparability, sustainability and recyclability, mainly to prevent the production of waste. One of these measures is the recycling of waste materials and by-products as fertilising products.

As part of this whole process, the European Commission is working on the introduction of a new Fertiliser Regulation (a regulation on fertilising products). The regulation focuses on the production of fertilisers from renewable raw materials, which are classified into different categories. There is much attention on the organic fertilisers and organo-mineral fertilisers. New in this regulation is that criteria will be set for protection of the environment. If a waste meets these criteria, then an end-of-waste status is obtained and fertiliser products derived from those materials can be freely traded within the European Union.

Another major development is that the European Commission will set up criteria for nitrogen fertiliser derived from manure, which may be applied above the nitrogen application standard for manure as a substitute for (synthesized) mineral nitrogen fertilisers.

Furthermore, there is an European initiative to increase the soil organic carbon stock in the soil with 4 promille (the so called '4 promille initiative', https://www.4p1000.org/).

As a result of this European policy change, more different types of mineral, organo-mineral and organic fertilisers will be produced to be applied on agricultural land. To date, there is no general systemic framework for the evaluation of such new materials in terms of quality of the product, fate in the soil system and expected agronomic- and environmental impact. This is information that farmers typically want to know: 'What do I get and what can I expect?'. Furthermore, this type of information is also required from legislation and regulation perspectives.

A framework for the evaluation of organic materials should focus on the required soil quality for different 'People, Planet and Profit' functions, such as building areas, roads, nature development, drinking-water- and agricultural production (Figure 1.1). Within this study, however, the focus is on agricultural production systems with open cultivation. The impact of organic fertilisers on agricultural production mainly depends initially on the chemical, physical, biological and hygienic characteristics of the organic matter, and the amount applied. However, the chemical, physical, biological and hygienic characteristics of the soil itself and the processes in the soil (sorption/desorption, biological decomposition, …) are also relevant. As a result, the associated changes of soil properties (fertility and quality) and the consequences on the emissions (e.g. environmental losses to water and air) need to be taken into account, as visualised in Figure 1.1.

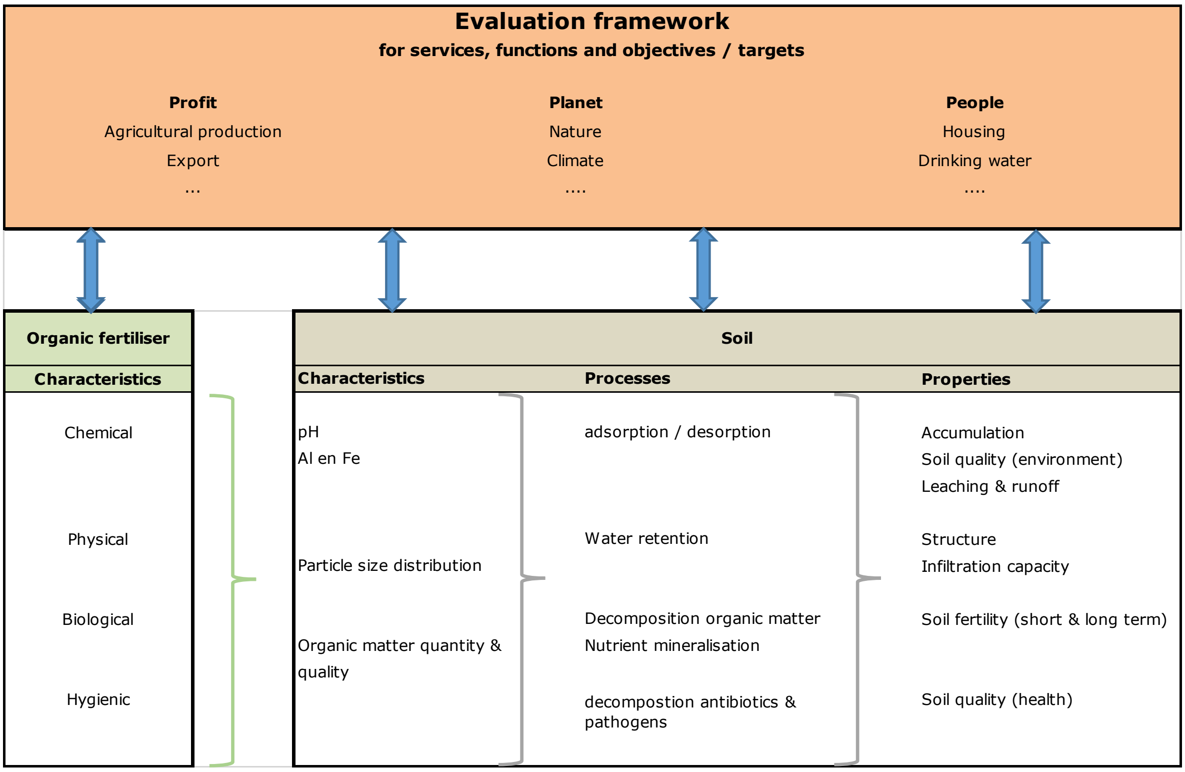

Figure 1.1 *Proposed general approach for the evaluation framework for organic fertilisers.*

Several other initiatives that evaluate organic fertilising products have been, or are being developed, e.g. within the EIP-AGRI Focus Group - Nutrient recycling (Veeken et al., 2018), the KB WUR-programme 'Mestkwaliteit' (Galama et al., in prep), and the BVOR/VVA (Van Geel et al., 2019). The approaches and results of these studies will be taken into account, because there are differences in sources of organic materials (mestkwaliteit and BVO/VVA study) and in specific aspects (nutrient cycling). Within our study, the focus is on the use of analytical methods, scientifically approved protocols, and mechanistic model approaches to estimate long-term effects on agriculture, which include emissions to air and water. The proposed steps in the development of an evaluation are:

1. Selection of different reference types of organic fertilising products
2. Characterisation methods for organic fertilising products
3. Selection of soil quality parameters that are influenced
4. Description of the short-term and long-term C- and N-dynamics in soil
5. Selection of methods to quantify short-term and long-term agronomical (CNP) and environmental (emissions of CNP, heavy metals, ...) effects
6. Scenario-studies to quantify the impact
7. Procedure for normalisation and weighting of effects.

The use of organic fertilisers within agricultural production systems is focused on plant nutrition, abilities to maintain or increase the soil organic carbon content and acid neutralisation value (liming materials). ECOFI[1], the European representative for producers of organic fertilisers, organo-mineral fertilisers and organic soil improvers, addresses more (specific) functional uses for agricultural systems, such as:

- To boost both nutrient efficiency and organic matter content in the soil;
- nurture the soil with organic matter that reduces dependency on chemical inputs;
- restore and maintain soil fertility to nurture plant growth;
- enhance the biological activity and biodiversity of soils;
- enhance the quality attributes of produce, as well as yield;
- improve the efficiency of nutrient use to produce more robust crops;
- facilitate the slow release of nutrients in response to the dynamic needs of plants;

[1] European Consortium of the Organic-Based Fertiliser Industry (ECOFI), Consulted on 29 November 2018 via http://www.ecofi.info/benefits-of-organic-based-fertilisers/.

- boost the efficiency of water use to render crops more resilient and drought-resistant;
- reduce the impact of farming and safeguard ecosystems by minimising leaching.
- enhance crop resistance to erosion by improving the soil's organic matter content.
- improve the efficiency of resource use by incorporating natural raw materials.

The multiple uses of organic fertilisers on agricultural land and the complex interactions with the soil systems require a clear (more narrowed) scope regarding an evaluation framework for assessing the quality of organic fertilisers. However, from a sustainability perspective (sustainable development goals; SDGs), environmental targets (soil, water, air) and European Union and national policy developments regarding circular economy and climate change, an even broader evaluation is needed.

Initially, the development of the evaluation framework for organic fertilisers will mainly focus on the long-term effects that organic fertilisers may have on soil fertility (carbon, nitrogen, phosphorus and potassium), soil quality aspects (heavy metals), emissions to the air (N_2O, NH_3) and water (NO_3, P), health aspects (antibiotics, pathogens) and economic value of the soil and agricultural production. Many of these aspects must be based on a mechanistic understanding of the fate of the components from organic fertilisers in the soil.

Objectives
The aim of this study is to develop a fundamental, science-based framework to evaluate (new) organic materials intended for use in agricultural practice (organic fertilisers).

This approach is developed to be transparent, as simple as possible, well-defined in terms of measurement protocols (organic fertiliser and soil characterisation), and in model description for the assessment of long-term effects.

A key issue addressed here is the development of a framework that allows for benchmarking of positive (increase soil organic matter, supply nutrients) versus potentially negative impact (crop quality, ecosystem health, water quality, ….) as the basis for a decision on acceptable levels for specific elements and priority substances.

The framework is developed with the following potential uses in mind for the users (farmers) the producers, and the national government, respectively in:
- Certification of organic fertilising products, and
- Component of regulation scheme Product selection.

The derived evaluation framework for organic fertiliser products will be used in the forthcoming years to test selected commonly used organic fertilisers as benchmark products, and to apply the approach on new organic fertilisers becoming available on the market. The outcome of this study will be used to improve the evaluation framework approach.

Methodology
As a first step for the evaluation of the organic materials, a quick, efficient and cheap approach is required to predict the effectiveness of nutrients, the decomposition of the organic matter, the effect on soil and environmental quality, health aspects and finally economic aspects. Models were selected that could quantify the long-term impact and the fate of organic fertilisers.

The next step focused on establishing a reference framework with well-known materials to be used to benchmark the value of other / new products in terms of agronomic-, environmental- and economic aspects. This fundamental approach, and the knowledge and data gained, was necessary to develop a sustainable agricultural practice with the goal of applying only those organic materials that have an overall added value.

Approach
The framework was based on a survey of literature and models. The approach started with the characterisation of organic fertilisers that can be used for the inter-comparison of products in a standard way. Mechanistic models were used to quantify the major effects of both the short-term and long-term (nutrient availability, soil fertility, nutrient emissions). A systemic risk approach was developed to determine short-term and long-term risks of application of organic fertilisers on soil quality (heavy metals) and health aspects (antibiotics, pathogens, …). The survey included a cross examination of potential suitable parameters of organic fertilising products and data demand of selected models to predict the impacts both from an agronomic (positive impact) and environmental (negative impact) point of view. The survey will be extended to analytical methods to measure these potential suitable parameters.

Reader
In Chapter 2 the characterisation of organic fertilisers in terms of chemical-, physical- and biological parameters, and measurements and protocols, are discussed. The methods and protocols to quantify soil fertility aspects are discussed in Chapter 3, together with the methods to determine the decomposition of organic matter and the mineralisation and immobilisation of nitrogen, which are relevant for the resilience of the soil. In Chapter 4, methods to describe and quantify environmental and health aspects are discussed, and in Chapter 5 parameters to quantify the economic value of organic fertilisers and a healthy soils are evaluated. Finally, in Chapter 6, the main conclusions are summarised.

2 Characterisation of organic fertilisers

2.1 Type designation and demarcation

In this report, we follow the type designation of the new facultative European Fertilising Products Regulation[2] (FPR). FPR serves free trade of fertilising products within the European Union. The new European Union Regulation for fertilising products designates organic fertilisers, organo-mineral fertilisers, organic soil improvers based on compost and digestate (energy crops digestate and digestate from other organic resources), plant bio-stimulant, and organic growing media (next to inorganic growing media) and blends thereof. These are all fertilising products categorised in the so-called 'product-function categories (PFC)'. Annex 1 gives the descriptions of the PFC's. All fertilising products are generalised under the denominator 'organic fertilisers'. Quite often a contrast between manure and other organic fertilisers (sewage sludge, compost and other fertilisers for organic resources) is used (e.g. for statistical purposes by Eurostat[3]). This designation is broader than e.g. FAO has proposed (Annex 2). Another definition used in agriculture with biological production methods is derived from the origin: all fertilising products that originate from vegetative and/or animal origin can be referred to as organic fertilisers, even if the product consists of mineral salts only (e.g. ammonium sulphate produced by stripping of ammonia from animal manure). Type designation is, however, important when addressing agronomic characteristics of organic fertilisers focused on fertiliser values and tools to assess these values. Some demarcations are needed to sharpen this focus.

The new European Union regulation for the free trade of fertilising products will regulate on the value-giving components: nutrients, acid neutralising value, organic carbon, beneficial microorganisms, inhibitors (nitrification, urease and denitrification) and other product characteristics, such as stability of organic carbon, electro-conductivity and pH. The regulation will also set standards for designated contaminants. Fertilising products produced for free trade may be produced only from designate component materials. For this, specific categories are given (component material categories (CMC)). The Regulation also sets standards to CMC e.g. requirements for sanitation and designated organic contaminants. Sewage sludge will not be regulated by FPR, exemptions are phosphate salts (struvite), biochar and ashes of incineration of sewage sludge. Biochar of sewage sludge is currently the only organic fertilising product that will be able to, in due course, enter free-trade of fertilising products within the EU.

The concept 'organic fertiliser' is also used in another context. This concept bears significance when addressing designated fertilising products allowed in agriculture with organic production methods. This report will not focus on fertilising products that are allowed in agriculture with organic production methods only. This leads to an initial demarcation: characterisation of the fertilising products used in agriculture with organic production methods will follow the characterisation of similar products used in all types of agriculture. This report, however, does not cover the protocols[4] currently under development, for assessing adulteration of organic fertilisers designated for use in agriculture following organic production methods[5].

A second demarcation is that this report also does not cover diagnostic protocols for enforcement of adulteration of regulatory requirements to control manure surpluses. Adulteration or fraud occurs by amendments (blends) based on prohibited synthetic fertilisers or other chemical nutrient sources.

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2 REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation https://data.consilium.europa.eu/doc/document/PE-76-2018-INIT/en/pdf (EC) No 2003/2003.

3 https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Fertiliser, consulted on 29 November 2018.

4 These protocols are e.g. based on a combination of methods following a decision tree. Methods used are ammonium nitrogen content, C/N ratio and stable isotopes of N (δ^{15}N=ratio N15/N14) and (Attenuated Total Reflectance) Fourier transform infrared (ATR)-FTIR) spectroscopy methods (Horwath and Parikh 2012; Mukome et al., 2013).

5 Biological production methods follow EC Regulation No 834/2007 and EC Regulation 889/2008. Fraud occurs by mixing inorganic synthetic fertilisers with organic fertilisers designated by 889/2008, consulted on 29 November 2018.

Organic fertilising products have different agronomic functions (Annex 3). The function depends upon their use to support the soil fertility and crop yield and quality (Chapter 3). Soil fertility refers to the ability of a soil to sustain agricultural plant growth. Furthermore, toxic substances can inhibit plant growth. Traditionally, physical-, chemical- and biological aspects of soil fertility are distinguished, and criterions have been developed and continue to be developed.

Definitions and descriptions of organic fertilisers, thus, vary. Annex 1 gives an overview of the descriptions of the new European Regulation for fertilising products that will be implemented within the relative short-term (2022). The criterions for the value-giving components, contaminants and pathogens are given in Annexes 4, 5 and 6.

2.2 Selection of organic fertilising products

The circular economy has led to the developments of new organic fertilising products. The range of organic fertilisers is much wider than processed animal manures and includes a range of fertilising products that is freely traded worldwide and can be divided into the following origins:

I) *Vegetative sources:*
  - (Processed) agricultural crops (alfalfa meal, cotton seed meal, corn gluten meal etc.;
  - (Processed) grain & other agricultural crop residues;
  - Peat, bark, wood, humic acids;
  - Algae;
  - Seaweed;
  - Oil press cakes (soy, sunflower, rapeseed, line seed...);
  - Cacao shells;
  - Or products based thereof and industrial by-products (amino acids, protamylasse, vinasse, biochars...).

II) *Animal sources:*
  - (processed) animal by-products: manure, as well as by-products from industrial processing (blood-meal, bone-meal, fish-meal, leather-meal, feather-meal, hair/horn/hoof-meal etc.);
  - Their processed derivates (amino acids, uric acid, urea's, biochars).

III) *Microorganisms:*
  - Yeast, bacteria, fungi…

IV) *Fossil resources:*
  - Coal;
  - Guano (seabird, bats);
  - Leonardite (fossilised peat, source of humic acids).

V) *(Thermo-)chemical synthesis:*
  - Urea formaldehydes (slow-release fertilisers);
  - Chelates;
  - Biochars.

Existing organic fertilisers of known-origin, composition, and plant nutrition value, will be used as reference material and benchmark for other/new organic fertilisers on the market. This study includes the following types of references:

- Animal slurry (dairy cattle, pig, poultry);
- Farm-yard manure (mainly dairy cattle);
- Digested animal slurry (dairy and pig, ….);
- Separated liquid and solid fractions of above products;
- Composts (manure, vegetable-fruit-garden compost, green compost, spent mushroom-compost).

This comparison follows the importance of these organic fertilisers on the market, expressed in terms of phosphorus (Annex 7). In principle, we focused on manure and processed manure (digestate) being the most relevant ones. Sludge is excluded as a source material in the Fertiliser Decree and compost is considered a specific product (organic fertiliser/soil improver) with clearly established quality guidelines. Evaluation frameworks for compost[6] and growing media[7] have been established and are evaluated on a regular basis to keep pace with new developments. Evaluation frameworks for bio-stimulants are currently heavily debated due to the new European Fertiliser Regulation.

Recently Veeken et al. (2018) provided an overview of many of these and other relevant organic fertilisers or soil improvers, including the main average nutritional characteristics.

Table 2.1 *Composition of several organic sources with respect to organic matter, nitrogen and phosphate (all values in g/kg fresh material or otherwise mentioned).*

Organic sources	Dry matter	Org. matter	HC[8] (% M)	EOM[9]	N-total	C/N[10] kg kg^{-1}	N-min	N-org.	P_2O_5
Data Netherlands									
Pig slurry	57	43	0.33	14	7.1	3.5	4.6	2.5	4.6
Digested pig slurry	82	32	0.34	11	7.1	2.6	5.2	1.9	4.6
Cattle slurry	86	64	0.75	48	4.1	8.9	2	2.1	1.5
Digested cattle slurry	69	48	0.67	32	4.1	6.7	2.6	1.5	1.5
Solid pig manure	260	153	0.33	51	7.9	11	2.6	5.3	7.9
Solid cow manure	267	152	0.75	114	5.3	16.3	0.9	4.4	2.8
Bio-waste compost	661	217	0.9	195	7.6	16.3	0.8	6.8	4.2
Green waste compost	594	185	0.9	166	5.3	19.9	0.5	4.8	3.4

2.3 Characterisation methods

2.3.1 Protocols

Agronomic functions determine the parameters to assess agronomic performance and quality. This is part of the 4R stewardship[11] when choosing and using a fertilisation product to steer agronomic production and product quality.

Agronomic functions of organic fertilisers are (Annex 3):
1. Source of organic matter: Organic carbon (EOM) that effectively contributes to soil organic content (SOM). In this report, 'effectively contributes' is defined by the quantity that remains after a year in soil; (this is equal to HC * OM, see Table 2.1);
2. Source of nutrients: Nutrients that effectively are available to plants in time and space;
3. Source of acid neutralising value;
4. Aid to restore and ameliorate soil physical status;
5. Aid to restore and ameliorate soil biological quality;
6. Plant enforcer, plant bio-stimulant: an enhancing function not attributable to the addition of organic carbon and/or nutrients but to other, still to be defined, components;
7. Substrate for root development, to grow plants in.

Traditionally, organic carbon that effectively contributes to the soil organic matter content (SOM) was made from stabilised organic fertilisers or organic soil improver (compost, digestate and recently also

[6] http://keurcompost.nl/.
[7] http://www.biostimulants.eu/ebic-code-of-conduct/.
[8] HC: the remaining percentage of organic matter after one year of incorporation in the soil.
[9] EOM: the remaining percentage of organic matter after one year of incorporation in the soil. EOM=HC*Org. matter.
[10] Assuming a C content of 57% for OM.
[11] The Fertiliser Institute (https://www.tfi.org/our-industry/state-of-industry/fertiliser-on-the-farm), consulted 19 November 2018
4R stewardship:
Right fertiliser source at the
Right rate, at the
Right time and in the
Right place

biochar). A stabilised product characteristically features organic matter that is hardly- or slowly biodegraded. Different terminology is in use to define biodegradation (ISO 11266:1994 biodegradation of organic chemicals in soil under aerobic conditions):

a. Biodegradation: The molecular degradation of an organic substance resulting from the complex actions of living organisms;
b. Primary biodegradation: The degradation of a substance to an extent sufficient to remove some chrematistic property of the parent molecule;
c. Ultimate biodegradation: The breakdown of an organic compound to carbon dioxide, water, the oxides, or mineral salts of any other elements present, and products associated with the normal metabolic processes of microorganisms;
d. Mineralisation: The complete degradation of an organic substance to inorganic products.

Biodegradation of organic matter in soil (SOM) has been and continues to be (extensively) studied (e.g. Alvarenga et al. (2007); Branco de Freitas Maia et al. (2013); Durgait et al. (2010); Gholzadeh et al. (2013); Gregorich et al. (1994); Lützow et al. (2007); Manlay et al. (2007); Santolemma (2018); Thevenot et al. (2010); Wadman and De Haan (1997); Wiesmeijer et al. (2019)).

The study of the stability of fertilising products resultant from composting (compost), (biogas) digestion (digestate) and pyrolyses (biochar) has led to proposals for criteria to improve product quality through influencing these production processes (Martin Mata et al. (2016); Matheri et al. (2018); Ohemen Ntiamoah et al. (2018).

The characterisation of the nature and stability of organic carbon in (processed) manures has been limited, and is in the literature usually linked to nutrient availability (Table 2.2).

Table 2.2 *Overview of parameters to assess product quality of organic fertilisers focused on organic carbon- and nitrogen availability (Bernal et al. 2009, Chanyasak and Kubota (1981), Mathur et al. 1993, Bernal 1998, Cooperband et al. 2003, Zmora-Nahum et al. 2005, RHP/RAG, 2018, EBN, 2018, TMECC, 2002).*

Parameter		Parameter scope	Organic fertiliser				
			Manure	Compost (RHP/RAG marks[12])	Digestate	Biochar	Growing media (RHP/RAG marks)
All	Sampling		X	X	X	X	X
	Sample preparation		X	X	X	X	X
Chemical	pH		(X)(1)	X	(X)	X	X
	EC			X			X
	Chloride			X			X
	Dry matter		(X)		(X)		
	Water contents			X		X	X
	Organic carbon					(X)	
	Organic matter		X	X	X		X
	Ash					X	X
	Bulk density			X			X
	Total N		X	X	X	X	X
	Mineral N (NH_4-N)		X		X		X
	Organic N		X		X		(X)
	C/N		X		X	X	X
	P and K.		X	X	X	X	X
	Ca, Mg, S and Na.		(X)	X	(X)	X	X
	B, Co, Cu, Fe, Mn, Mo and Zn.		(X)	(X)	(X)	X	X

[12] RHP/RAG: European Knowledge Centre for growing media. RHP certificates serve quality of substrates, RHP certificates serve quality of soil and structure improvers. https://www.rhp.nl/en/home, consulted 23rd November 2018.

Parameter		Parameter scope	Organic fertiliser				
			Manure	**Compost (RHP/RAG marks[13])**	**Digestate**	**Biochar**	**Growing media (RHP/RAG marks)**
Chemical	Calcium carbonate	Acid neutralising value		X			(x)
		Inorganic carbon					
	Cation exchange capacity				X		X
	Water solubility extract				X		X
	Humification indices (2)				(x)		X
	Organic matter quality(3)				(X)		X
	Inorganic contaminants (Cd, Cr^{III}, Cr^{VI}, Hg, Ni, Pb, Zn and As)			X	X	X	X
	Organic contaminants	PAHs,			X	x	
		PCBs,			X		
		Dioxins			X		
		Residues of other organic contaminants			X		X
		Volatile matter				X	
Physical	Water holding capacity					X	X
	Gross calorific value/net calorific value					X	
	Particle size						X
	Inert materials (glass, plastics)			X	X		X
Biological	Microbial activity indicator (4)	Oxygen consumption (e.g. Oxitop, mmol O_2/kg OM/hour))		X	X		X
	Phytotoxicity (plant test)				(X)		X
	Weed seed and propagules			X	(X)		X
	Pathogens, ecotoxicity tests)	*Enterococcaceae*, *E. coli*, *Samonella*		X	X		X

1) (X) Not standard, facultative/voluntary basis.

2) Humification indices or parameter for the assessment of the stability of an organic fertilising product, based upon chemical analyses: Elemental- and functional group analysis, molecular weight distribution, E4/E6 ration[14], pyrolysis GC-MS, spectroscopic analyses (NMR, RTIR, Fluorescence etc.) e.g. humification ratio, humification index, percentage humic acid, polymerisation index).

3) Lignin, complex carbohydrates, lipids, sugars etc.

4) Humification indices or parameters for the assessment of the stability of an organic fertilising product based on biological (eco) tests: respiration (O_2 uptake/consumption, CO_2 production, self-heating test, biodegradable constituents, enzyme activity (phosphatases, dehydrogenases, proteases, etc., ATP content, nitrogen mineralisation-immobilisation potential, nitrification, etc., microbial biomass.

[13] RHP/RAG: European Knowledge Centre for growing media. RHP certificates serve quality of substrates, RHP certificates serve quality of soil and structure improvers. https://www.rhp.nl/en/home, consulted 23rd November 2018.

[14] *E4/E6 ratio* is a measure which is inversely related to the degree of condensation and aromaticity of the humic substances and to their degree of humification.

Selected manures and products have been extensively studied with regard to (long-term) effects of application of agricultural crops (grassland, arable land). However, the characterisation of manure and products, thereof, in combination with the agronomic performance in the short- and long-term is a topic that has received much less scientific attention. Standard analyses on total contents on organic carbon and nutrients, however, have been widely published.

2.3.2 Current analytical research methods

For the characterisation of organic fertiliser products, a wide variety of analytical methods and protocols exist that focus on chemical, physical and/or biological composition and stability. Given the focus of the framework, our main interest is in methods that characterise: 1) As a source of plant nutrients and a source of organic matter, and 2) The degradability of the organic matter. The biodegradability of organic residues may be evaluated using biological (biotic), as well as abiotic methods. Tables 2.4, 2.5 and 2.6 give an overview of research methods currently in use.
Major indicators to express the kinetics of the decomposition (also called: degradation) process are:

- Respirometry Activity, calculated from the Biological Oxygen Demand (BOD) / Total Oxygen Demand (CODtot);
- Biochemical Methane Potential (BMP), Standard method ISO 11734; and
- O_2-consumption during aerobic respiration;
- CO_2-emission from aerobic respiration.

Respiratory Quotient (RQ)

Carbohydrates are oxidised through aerobic respiration using RER, resulting in an equal ratio of CO_2 release and oxygen consumption; this implies that 100% of carbohydrates are consumed to produce ATP.

$C_6H_{12}O_2$ + 6 O2 -> 6 CO_2 + 6 H_2O + Energy
RQ= 6 CO_2 /6 O_2 = 1.0

When fat is oxidised the outcome is reduced CO_2 production for every oxygen molecule consumed.

$C_{16}H_{32}O_2$ + 23 O_2 -> 16 CO_2 + 16 H_2O + Energy
RQ= 16 CO_2 / 23 O_2 = 0.7

When protein is oxidised the outcome is also a reduced CO_2 production for every oxygen molecule consumed.

$C_{72}H_{112}N_{18}O_{22}$ + 77 O_2 -> 63 CO_2 + 38 H_2O + Energy
RQ= 63 CO_2 / 77 O_2= 0.9

For each principle, a variety of methods are in use (Tables 2.4, 2.5 and 2.6). Not surprisingly, most methods originate from research focused on the fate of organic residues in waste-dumps and during the composting process. Maturity of compost is a well-studied subject and has led to a variety of methods for determination (Lü et al., 2018) and a variety of respiratory quotients.

When respiration is measured, often a ratio (respiratory quotient, RQ) is used to assess the stability or the maturity of organic matter. This RQ differs between substrate (see Textbox). This difference is a reason why O_2 consumption during aerobic respiration is preferred above measurements of CO_2 emission, as O_2 consumption is seen as a direct measurement of biological activity in an aerobic environment and CO_2 emission as an indirect measurement (Adani et al., 2001; Gomez et al., 2005; Wagland et al., 2009). Measurement of CO_2 emission is seen as a simple method compared to the measurement of O_2 consumption, as the latter method has more bias.

Respiration methods can be static or dynamic in nature. With dynamic methods, the sample is aerated during measurement, with static methods, they are not. A dynamic method minimises O_2 diffusion limitations and is, therefore, preferred (Wagland et al., 2009).

To assess the effects of a product when applied to agricultural soil, other parameters are also of interest, e.g. pH, electrical conductivity (EC), bacterial- and fungal biomass, as well as kinetics of the C- and/or N- mineralisation processes.

A quick scan was conducted to identify the major analytical methods used to characterise organic fertiliser products and/or that describe the decomposition process.

Several statistical methods can be used for the evaluation of possible relationships between product characteristic and decomposition rate, e.g. principle component analysis, correlation analysis, and multivariate analysis.

Table 2.3 *Overview of research methods for biotic response: aerobic test methods.*

Method principle	Test method	Reporting units	Test purpose/ common use	Reference
Static respiration index (without continuous aeration, equilibration for about one day)	AT_4 ('Atmungsaktivität') or RA_4 (Respiration Aktivity) for four days (Sapromat E)	mg O_2/ g DS	Describe the biological activity of waste with respect to landfill regulations	Binner and Zach (1999a), Binner et al. (1999b), Barrena et al. (2005, 2006, 2013)
	(Specific-) Oxygen Uptake Rate (OUR or (SOUR); solid samples are immersed in water	mg O_2/ g DS/d	Compost stability/composting process	Iannotti et al. (1993), Lasaridi and Stentiford (1998), Adani et al. (2001, 2002, 2006)
	Respiration Index (RI_{24}): A mean of the SOUR values during the 24 h maximum activity period	mg O_2/ g DS/d	Compost stability/composting process	Scaglia et al. (2000)
	Dewar self-heating test	Temperature (°C) rise above ambient	Compost stability/composting process	Jourdan (1982, 1988), Britton (1994)
	Solvita® headspace CO_2	Solvita® maturity scale (1-8, with 1 being very active, and 8 being very mature), colour code	Compost stability/composting process	Solvita (2019)
Dynamic Respiration	Without inoculum and nutrients added	mg O_2/h/g DS	Compost stability/composting process	Paletski an d Young (1995), ASTM (1996), Barrena et al. (2005, 2006, 2013)
Dynamic Respiration Index (with continuous aeration, DRI)	ORG0020 in PAS100 test: equilibration; Inoculum and nutrients are added	mg O_2/h/ g DS or CO_2/h/g DS	Compost stability/composting process	Adani et al. (2001, 2002, 2006), Barrena et al. (2005, 2006, 2013)
	DR_4 unnecessary for equilibration: Inoculum and nutrients are added	mg O_2/kg LOI or CO_2/h/g DS	Monitoring performance of mechanical biological treatment (MBT) and other treatment processes	Godley et al. (2005)
	Respiration Quotient (RQ): the mole ratio between CO_2 produced and O_2 consumed		Monitoring performance of composting process, compost stability	Gea et al. (2004), Barrena et al. (2005, 2006, 2013)

Table 2.4 *Overview of research methods for biotic response: anaerobic test methods, phytotoxicity tests, and alternative microbial activity tests.*

Class of methods	Method principle	Test method	Reporting units	Test purpose/	Reference
Anaerobic test methods	Biochemical Methane Potential (BMP) test	Gas Generation Sum (GS) for 21 days (GS_{21}) or 60 days (GS_{60}); 100% material water retention capacity, 800-1500 g samples	ml CH_4/g DS	Biodegradability of substrate	Binner et al. (1999)
		Gas evolution ('Gasbildung') for 21 days (GB_{21}) or 60 days (GB_{60}): 8%-16% TS, 50 g samples	ml CH_4/g DS	Biodegradability of substrate	Bockreis et al. (2007)
Alternative microbial tests	Measurement of microbial activity relating to the in-situ metabolic activity of microorganisms in tested materials	Activity of hydrolytic enzymes (alkaline phosphatase, acid phosphatase, endo-cellulase, glucosidase, β-glucosaminidase, proteases and lipases, fluorecein di-acetat (FDA) hydrolytic enzyme and dyhydrogenase	mmol-substrate/g/h		Hermann and Shann (1993)
		ATP content			Tiquia et al. (2002)
		Biomass amount			Garcia et al. (1992), Horiuchi et al. (2003) and Hermann and Shann (1993)
Phytotoxicity tests	Germination test	Germination Index	%		Komilis et al. (2011), Oviedo-Ocaňa et al. (2015)
		Plant growth tests	[-]		

Table 2.5 *Conventional test methods, based on abiotic physico-chemical characteristics of organic matter.*

Focus	Test method	Reporting units	Reference
Degradation (Mineralisation) of biodegradable organic matter	Total organic content (OS)	% DS	
	Volatile solids (VS)	% DS	Zheng et al. (2015)
	Chemical Oxygen Demand (COD)	g/L	Zheng et al. (2015)
	Biodegradable dry matter (BDM)	% DS	Zheng et al. (2015)
	Oxidizable Organic Matter (OOM)	% DS	Zheng et al. (2015)
	C/N mass ratio	g/g	
	Content of easily biodegradable biochemical components (starch, sugars, proteins, lipids).	% DS	
	Content of recalcitrant biodegradable biochemical components (cellulose, lignin, cellulose+hemicellulose, cellulose+hemicellulose+lignin, mass ration of cellulose to lignin (C/L).	% DS	
Humification that produces humus-like organic matter	Humification Ratio (HR), content of humic substances (alkali-extractable organics).	% DS	Lü et al. (2018)
	Humification index (HI), content humic acid (HA).	% DS	Lü et al. (2018)
	Percent humic acids (PHA) mass ratio of HA to humic substances.	%	Lü et al. (2018)
	Polymerisation Index (PI), mass ratio of humic acid to fulvic acid.	g/g	Lü et al. (2018)
	Cation Exchange Capacity (CEC): production of functional groups influenced by the increased oxidation of organic matter during humification process.	Cmol/kg	Lü et al. (2018)
	Colour, appearance, the material becomes dark due to humification.	-	
Production of intermediate metabolites	Water extractable organic matter (WEOM).		Lü et al. (2018)
	Dissolved Organic Carbon (DOC), water-soluble organic C.	g/kg	Lü et al. (2018)
	Volatile Fatty Acids (VFAs).	g/kg	Lü et al. (2018)
	C/N ratio in WEOM.	g/g	Lü et al. (2018)
	NH_4^+-N.	g/kg	Lü et al. (2018)
	Mass ratio of NH_4^+-N to NO_3^-N.	g/g	Lü et al. (2018)
	pH.	[-]	Lü et al. (2018)
	Electro-conductivity.	mS/cm	Lü et al. (2018)
	Gaseous pollutants (NH_3, VFAs, FOCs, TVOC).	ppm	Lü et al. (2018)

2.4 Analytical methods in protocols and regulation

Current European Union regulation for fertilisers 2003/2003 regulates exclusively free-trade of mineral (chemical or synthetic) fertilisers. This regulation excludes nutrients or acid neutralising value from vegetable- or animal origin. Harmonised conformity methods are available for these mineral fertilisers. The new European Union regulation for fertilising products (FPR) will also include organic fertilisers, for which analytical standards still need to be designated. Current research methods for fertilising products focus primarily on the effectiveness of nutrients and acid neutralising value. This assessment is based on empirical research in laboratory- and field trials, in connection with physical-chemical analysis methods. The matrix of these mineral fertilisers differs considerably from that of new fertilising products based on renewable raw materials. Therefore, current methods of conformity must be modified or newly developed to provide information about the effectiveness of the nutrients in these new fertilisation products, both in the short- as well as in the long-terms. The characterisation of the organic matter (fractions) into organic fertilising products and organic soil improvers will be based on a standard for organic carbon. Characterisation of the different organic components is not foreseen, or is a standard for humification coefficient. Standards on the stability of organic matter in compost (oxygen uptake rate, self-heating factor) or digestate (oxygen uptake rate, self-heating factor, residual biogas potential) will be designated. These methods characterise bulk parameters of organic fertilising products, but will not provide information on their potential to maintain and/or increase soil organic matter and/or on the release of crop-available nitrogen. This information is needed to support the use of current- and new organic fertilisers for soil- and crop production. Also, information on the effect of their use on other ecosystem services remains unclear. Methods to characterise agronomic performance are required. These standard methods should be assessed. A condition is that these methods can be performed by test laboratories. Therefore, they should support fast, cheap and efficient characterisation of agronomic performance and environmental risk.

The new FPR was published[15] on June 25th, 2019, effectively, this Regulation will come into force on July 17, 2022. In this period, notifying authorities, notifying bodies, committee procedures and delegated powers will be organised. Also, the European Commission has mandated the European Committee for Standardization (CEN[16]) to develop standards for fertilising products. The CEN has a variety of standards for key parameters of organic fertilisers and organo-mineral fertilisers available already. These have been developed by different Technical Committees (TCs). Currently TC 260 WG-8 works on standards for organic and organo-mineral fertilisers. Alongside this, the AOAC, ISO and ASTM are other notifying bodies that have developed and continue to develop standards (Table 2.6).

Table 2.6 *Overview of notifying bodies that develop standards for fertilising products.*

CEN European Committee for Standardization (1961, 34 countries)	Technical bodies (n=395, Working Groups n=1653)	Standards, number
	CEN TC 223 - Soil improvers and growing media	22
	CEN TC 260 - Fertilisers and liming materials	97
	CEN TC 292 - Characterisation of waste	15
	CEN TC 308 - Characterization and management of sludge	35
	CEN/TC 411 - Bio-based products	12
	CEN/TC 455 – Plant bio-stimulants	0
AOAC (1884, governmental chemists (1987))		**
ASTM international (1902, 1105 members)		**
ISO (1946, 162 national bodies)		**

[15] FPR published on June25th 2019: REGULATION (EU) 2019/1009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003;https://eur-lex.europa.eu/legal-content/en/TXT/PDF/?uri=CELEX:32019R1009&from=EN.

[16] European Committee of Standardization (CEN) https://www.cen.eu/Pages/resultsearch.aspx?k=mandate%20european%20commission.

The state-of-the-art for standards for manure for the Netherlands is given in Annex 8, for compost in Annex 9, for biochar in Annex 10 and for growing media in Annex 11. Standards for digestate are similar to those for manure or for compost. Digestate is often composted in the Netherlands.

2.5 A framework for assessing the quality of organic fertilisers

Information given in the previous paragraph can be summarised in a decision tree, upon which parameters of an organic fertiliser can be analysed to assess its agronomic potential value and exclude potential environmental risks. This decision tree uses current type designation of organic fertilisers, including organic soil improvers and growing media, as is proposed by the new European Fertilising Product Regulation (Figure 2.1). Bio-stimulants are not yet included, as quality assessment requires new harmonised standards that still require development. Included are also standards for sewage sludge, although its use as a fertilising product in the Netherlands bears no significance (i.e. less than 1% of the volume is legally used as a fertilising product) and are not included in the FPR. The decision tree is a 'work in progress', as matrices of fertilising products still require an evaluation. In addition, the information in the annexes does not distinguish standards for legal requirements from standards from meeting requirements used in certification. The exemptions are the standards for animal manure (Annex 8); these are only used to meet legal requirements. Annex 8 must be elaborated to required standards that meet certification requirements. Standards to meet certification requirements are currently being developed. In the Netherlands, digestates are co-digested manures. Co-digestion points to the substrates (co-materials) that are added to manure to increase biogas-production. In the decision tree, the same methods are proposed for digestates, as they also are for animal manures. If materials are composted, the resultant product is a compost.

The framework begins by assessing the type designation of the fertilising product: Is the type designation known or unknown? If the type designation is known, there are packages of standards available. These packages are given in the annexes. Organic fertilisers are often blends (mixtures of different fertilising products). If the quality of a blend requires assessment, the main constituent determines the package of standards.

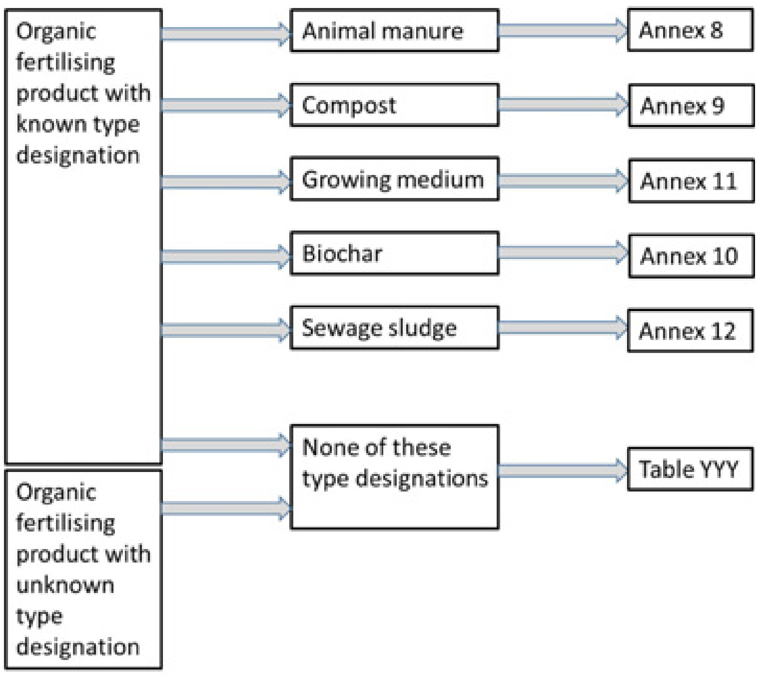

Figure 2.1 *Proposed decision tree for assessing (minimal) standards required to verify product quality. This decision tree is a first approximation and will be elaborated during this project.*
If the type designation is not known, a reference to a known type designation can currently be made.

If, however, the type designation is not known, standards have to be appointed. Table 2.7 (‘work in progress’) proposes standards for materials that are assumed to have an agronomic effectivity as an organic fertilising product or organic soil amendment.

Table 2.7 *Proposed parameters for organic materials with an unknown type designation.*

Proposed	Reference to fertilising products of the decision tree	
	Solid material	Liquid material
Sampling	Nature of the material determines if the sampling method is referenced as manure, digestate, compost, biochar or **inorganic** fertiliser	Nature of the material determines if the sampling method is referenced as liquid manure, digestate or **inorganic** liquid fertiliser
Sample preparation	See sampling	See sampling
pH	compost	Sewage sludge
EC	compost	manure
Chloride	To be determined	To be determined
Dry matter	compost	Manure
Water content	compost	Manure
Organic carbon	Compost	Sewage sludge
Organic matter	Compost	Sewage sludge
Ash	Compost	Sewage sludge
Bulk density	Compost	Sewage sludge
Total N	Compost	Sewage sludge
Mineral N (NH_4-N)	Compost	Sewage sludge
Organic N	Compost	Sewage sludge
C/N	Compost	Sewage sludge
Other primary minerals P and K.	Compost	Sewage sludge
Secondary minerals Ca, Mg, S and Na.	Compost	Sewage sludge
Micronutrients B, Co, Cu, Fe, Mn, Mo and Zn.	Compost	Sewage sludge
Inorganic contaminants (Cd, Cr^{III}, Cr^{VI}, Hg, Ni, Pb, Zn and As)	Compost	Sewage sludge
Organic contaminants (PAH’s, PCB’s, dioxins)	Compost	Sewage sludge
Pathogens (indicators; microorganisms *E. coli, Salmonella*	Sewage sludge (solids)	Sewage sludge
Glass, plastic and other non- fertilising materials	Compost	Compost

2.6 Main knowledge gaps and missing methods

The European Regulation on fertilising products (FPR) will appoint standards for organic fertiliser, compost, digestate, plant-bio-stimulant, (organic) growing media, and blends thereof. With the exception of plant-bio-stimulants, it is foreseen that standards will be determined by the Summer of 2022. Validation and ring-testing might, however, still be required. Also, new standards will be developed for certain parameters (e.g. organic nitrogen and phosphonates). As plant-bio-stimulants are new entries on the EU market, all standards still require development, and it is anticipated that this work will not be finalised by the Summer of 2022. A review of the methods given in Annexes 8-12 must still be conducted. The bulk parameters of organic fertilising products are well known and CEN expects to finalise the standards well before 2022. New standards (e.g. oxygen uptake rate, self-heating factor, residual biogas potential and bioassays (germination)) require validation and testing. Thus, the interconnection of current classical quality standards for bulk parameters of organic fertiliser, with new quality standards for biotic- and abiotic test methods for evaluating organic fertilisers is a ‘work in progress’ This will possibly lead to an insight into knowledge gaps and missing methods.

A previous comparison of organic products by Van Geel et al. (2019) may serve as the basis for the development of a classification scheme for organic products. The purpose of the scheme is to be able to distinguish between products that, primarily, build up SOM, and products that, primarily, add nutrients. This is convenient in view of a new regulation as part of the 6th Action Programme for the Nitrates Directive, that allows the use of an extra 5 kg phosphate when soil improvers are used in case soil phosphorus status is classified as high (from 2020 onwards). In a study of 23 products, comparison was made using data on the HC of the products and SOC-models (Minip, RothC) over 20-, 50- and 100-year timescales. It was found that criteria for the contents in terms of organic matter and nitrogen alone are not sufficient to indicate the risk for nitrate leaching. In addition, a criterion that includes the P-content is required (EOM / kg N-total, addition EOM / kg P_2O_5 and EOM / kg N-total per kg phosphate).

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3 Methods to quantify effects on soil quality

3.1 Soil quality and chemical, physical and biological soil parameters

In literature, both soil quality and soil health are used to describe the capacity of a soil for agricultural production, with differences in the focus depending upon the actual research group. Both terms refer to the definition of Doran & Zeiss (2000), i.e.: i) the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries; ii) to sustain plant and animal productivity, maintain or enhance water and air quality; and iii) to promote plant and animal-health. A large number (>80) of potential indicators to assess soil quality have been studied extensively. For practical purposes, several selections have been proposed e.g. Andrews et al. (2002), Bünemann et al. (2018), and Spiegel et al. (2015). The latter has been developed within the EU-project 'Catch-C' and is focused on the evaluation of management practices e.g. through including the organic fertilisers; slurry, FYM, and composts.

For agriculture in The Netherlands, several sets of indicators are available to evaluate soil quality. Through an initiative of the Dutch Ministry of Agriculture, two sets, both developed by WUR (Haan et al., 2019; Van den Elsen et al., 2019) are currently being combined into one. The selection of indicators and analytical methods is based upon an overview of possible relations between soil functions and indicators (see Figure 3.1 for an example regarding soil organic matter).

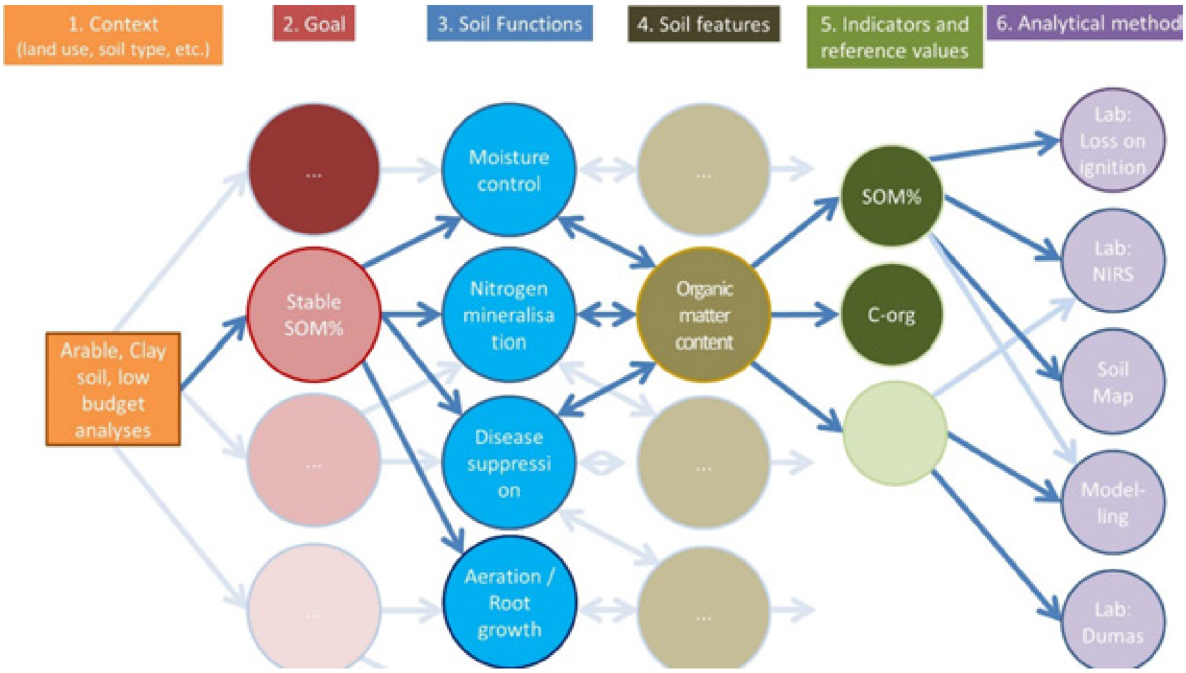

Figure 3.1 *Elaboration of the scheme of functional relations to evaluate soil quality (Hanegraaf et al., 2019) for soil organic matter.*

Integration in the framework

Many indicators in the full scheme are relevant for the short-term (within a year), although some are specifically indicative to ensure long-term soil quality, e.g. total nutrient contents. For the evaluation of the effects of organic products on soil quality, we will focus on indicators with relations to soil organic carbon, with regard to the dynamics of SOC and/or the emissions from soil, related to nitrogen, phosphorus, micronutrients, or the heavy metal contents of organic amendments (see Annex X for an overview).

3.2 Carbon- and nitrogen dynamics in soil

Carbon-cycling - current knowledge
Mineralisation processes of carbon and nitrogen have been studied widely, for reasons of nutrient availability, and/or of the prevention of nitrate leaching, and/or sequestration of carbon. It is a generally accepted view that the quality of organic matter determines the rate of decomposition, with quality indicated by several variables, e.g. the C/N-ratio. Easily decomposable organic matter mineralises first, rendering the remainder less decomposable. During the process, CO_2 and, in some cases, CH_4, is emitted, while at the same time, the stable fraction of SOM increases. Effective organic matter (e.o.m.) is defined as the amount of organic matter that is distinguishably present in the soil one year after its addition (Kolenbrander, 1963). Expressed as fraction of initial C-content, EOM after one year gives the humification coefficient (h.c.). The current view is that the more stable additions of organic matter, as indicated by the humification coefficient, the more they lead to an increase in SOM. The humification coefficient and the concept of 'effective organic matter' for organic inputs are widely used in accounting for the soil organic matter balance, that may be seen as the simplest model carbon cycling currently in use.

In addition to the quality of SOM, conditioning factors play a role as well, e.g. soil temperature, moisture, nitrogen content, clay content, pH and presence and activity of soil (micro-)organisms. Furthermore, soil C- and N-dynamics are also influenced by additions of organic material from plant- (e.g. vegetative waste, compost) or animal origin (e.g. manure). Several models have been developed that distinguish one or more carbon pools of different decomposability (Figure 3.2, traditional view).

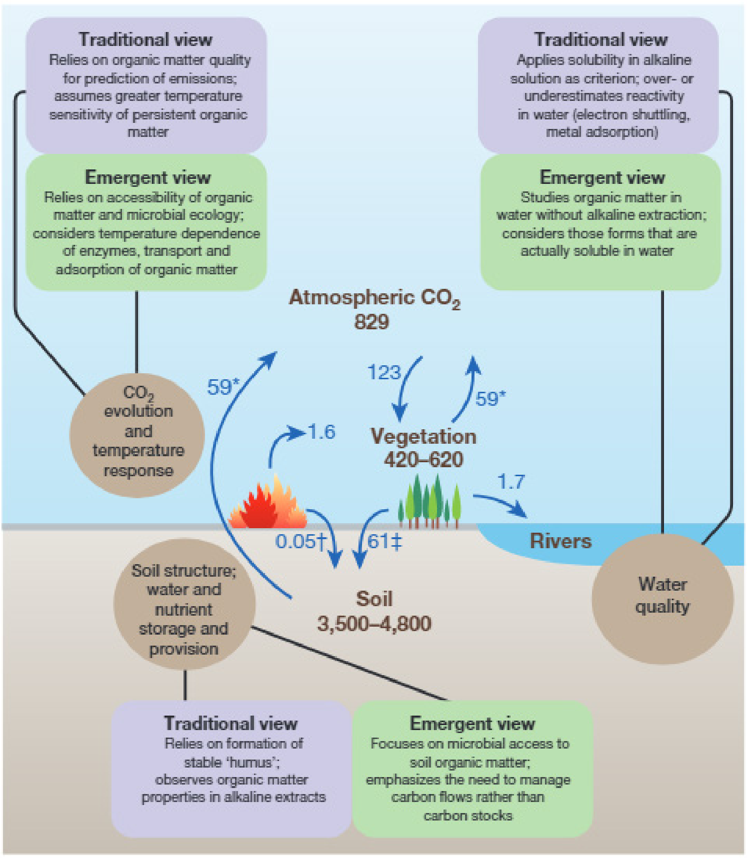

Figure 3.2 *Traditional- and emergent views on SOC dynamics (Lehmann & Kleber, 2015).*

The new theory stresses the importance of the phenomenon that, during decomposition, the solubility of carbon compounds increases, which would in turn, ease protection by the mineral soil fraction, thereby, rendering carbon less accessible to organisms.

Carbon cycling - emerging knowledge
Recent advances in SOC dynamics include the development of a new theory (Figure 3.2, emerging view) that explains how easily decomposable organic matter may appear more quickly in the stable SOC fraction (mineral associated SOM) than slowly decomposing organic matter (Lehmann & Kleber, 2015). The solubility aspect of carbon compounds itself is not new, but the consequences that solubility gives for protection have, so far, not been included in mechanistic thinking about stabilisation of SOC.
The absence of the mechanistic view may explain poor validation of many models currently in use, in particular, when they are used for predictions over large timescales. Future models may regard the mineralisation process as a continuum, and take into account: 1) Possible protection of substrates, 2) Possible preference by the microbial community for substrate of specific quality, and 3) Mobility of organic decomposition fragments in soil solutions.

Nitrogen cycling
Mineralisation of nitrogen occurs during the decomposition of organic matter present in the soil fractions and/or in the added organic material. The fate of mineral nitrogen in soil may be diverse, i.e. uptake by plant roots, immobilisation in newly formed intermediate organic products, leaching, denitrification etc.. It is generally assumed that soil C/N-ratio remains constant, and that priming with nitrogen may stimulate the mineralisation-immobilisation turnover (MIT) (Jenkinson, 1985). Thus, carbon sequestration and build-up of SOM in general requires nitrogen.

Integration in the framework
For the agricultural evaluation of organic fertilising products, both short-term (e.g. N) and long-term effects on soil quality are relevant (e.g. build-up of carbon). As the development and validation of models based on the emerging theory is beyond the scope of this project, the framework is based on current knowledge and models.

3.3 Emissions from soil

Nitrogen and phosphorus
Nitrogen may be present in mineral- and organic form, both in the soil and in organic fertilising products. Specifically for animal manure, three fractions are commonly distinguished (NMI, 2000): Nm, the mineral fraction added with application (mainly NH_4); N_e, the fraction mineralised N in the first year after application; N_r, the fraction mineralised in later years. For other organic products, e.g. compost, the available N is approximately 10%. Based on such data and coefficients, policy regulations indicate the percentage N available in the year after application per manure type.

Major nitrogen emissions from soil are:
- Ammonia (NH_3) volatilisation, mainly occurring during application of animal manures;
- Nitrate (NO_3^-) leaching, occurring year-round with peaks in rain period;
- Emission of dinitrogen-oxide (N_2O), occurring in wet, anaerobic soil conditions following denitrification from nitrate to nitrite (NO_2^-), and subsequently, N_2O and/or N_2.

Phosphates in agricultural soil are mainly present in the form of definite phosphate compounds and surface films of phosphate that surround inorganic particles. They may also be adsorbed to soil organic matter. Phosphates are subject to adsorption and desorption processes and only slowly released into the soil solution. Phosphate that is bound into soil organic matter may become available following mineralisation. Either way, the fraction in the soil solution, available to plant roots, is the smallest phosphate fraction. Phosphate fixation to the clay-humus complex, resulting from decades-long, high additions of animal manure, and is widespread in Dutch agricultural soils. Following drastic events, e.g. waterlogging, a change in redox reactions may result in significant P-leaching. Emissions from phosphate out of the soil compartment are run-off from the field to surface-waters and leach phosphate.

Integration in the framework
For the quantification of N- and P-emissions, and P-fixation, complex models have been developed that include emission factors relative to, e.g. soil type, land-use, management practices, and weather conditions.
The most important features of organic fertilising products in terms of possible N- and P-emissions are:

- Total N- and P-content;
- N-mineral content;
- Plant availability; and
- Field-specific loading of P in soils.

In addition, the regulations concerning allowable amounts of N and P added at farm-level should be taken into account.

3.4 Methods to quantify effects

3.4.1 Options

Use of data from long-term field experiments (LTE)
Short-term effects of organic fertilising products are often quantified using incubation procedures, pot experiments and/or field experiments. Results may be interpreted in terms of effective organic matter and/or N-mineralisation, and/or N- and P-uptake. As such, these trials allow for making an initial distinction between products. However, in order to fully comprehend the possible effects of products on soil quality, additional parameters are needed, also for the long-term timescale.

Data from long-term field experiments are frequently used for additional and re-analysis of relationships between soils, field management, crops, and weather conditions. It is expected that for existing organic products, such as slurry and farm-yard manure, data of one or more long-term experiments may be available. In the past decades, however, many long-term experiments have been discontinued. Also, coverage of soils and crops may be insufficient for using these data for an evaluation. Perhaps more important is that, for recent organic products such as digestates, as well as for future products, no data from long-term experiments will be available, at least not in the near-future. For these reasons, data from long-term experiments cannot be considered suitable for use in the evaluation framework. Their use is restricted to those products that are currently known, and may serve as a source of reference for the calibration and validation of models.

Use of the humification coefficient for characterisation and modelling
A comparison of 23 organic products was made as a base for the development of a classification scheme for organic products to distinguish between products that build up SOM and products that add nutrients (Van Geel et al., 2019). This distinction was deemed necessary in view of a new regulation as part of the 6th Action Programme for the Nitrates Directive, that enables an extra allowance of 5 kg phosphate when products that add organic matter are used. In the study of 23 products, comparison was made using data on the EOM of the products and SOC-models (Minip, RothC) over 20-, 50- and 100-year timescales (Figure 3.3.). It was found that criteria for the contents in terms of organic matter and nitrogen alone are not sufficient. In addition, a criterion that includes phosphate was required, e.g. the addition of EOM per kg N-total, addition of EOM per kg P_2O_5, and addition of EOM per kg N-total per kg phosphate. These criteria were found to be in agreement with those suggested by the Commission Experts Fertilisers regarding effects from nitrogen additions and organic matter by organic fertilising products (CDM, 2017ab).

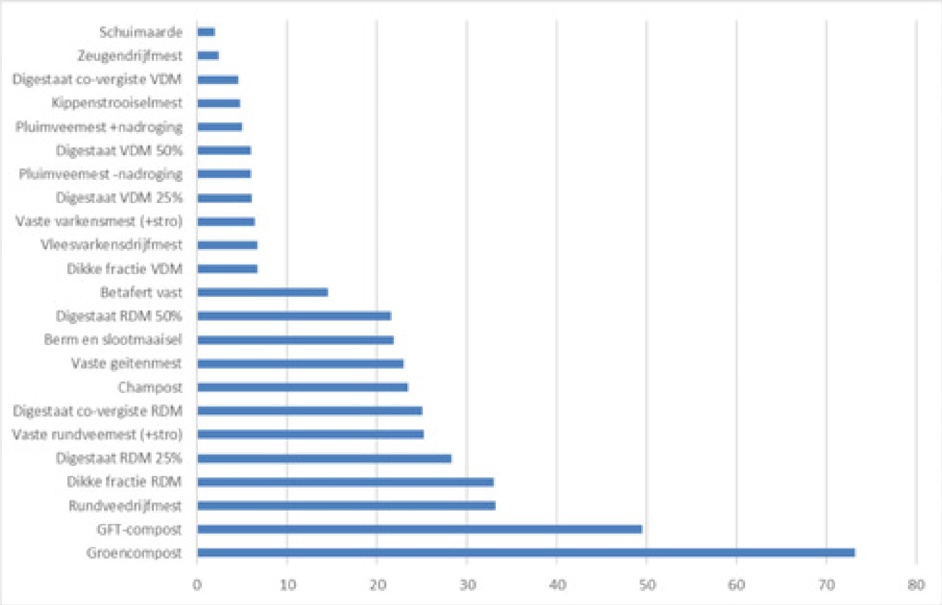

Figure 3.3 *Addition in EOM per unit phosphate (kg per kg P) (Van Geel et al., 2019).*

The study by Van Geel et al. (2019) also showed that for EOM, various figures are available and are indeed in use (e.g. Handboek Bodem en Bemesting, CDM 2017b). Further research has indicated that the method of determining the C-mineralisation rate may differ substantially at the international-level as well (Table 3.1). The length of incubation, continuous measurement or measurement moments and conditioning period differ between studies. The moment/type of measurement has a big influence on the results. However, also variables like pre-treatment of samples, fresh or dry samples used, differed among the studies. Only some studies mentioned that they worked with a kinetic function (mineralisation model), to interpret the results.

These different methods of determining mineralisation make it difficult to compare the organic fertilisers with each other. Protocol and/or standardised methods are needed to be able to make a comparison of mineralisation rates. In addition, the characterisation of products does not suffice to fully evaluate the products, taking into account their agricultural- and environmental effects when used. Complete evaluation of all relevant aspects requires extended modelling of a suitable selection of scenario analyses. Above all, it requires a better mechanistic understanding of what is going on in the soil after (organic) fertiliser application.

Integration in the framework
The use of the humification coefficient offers perspective for making a first distinction between organic products. As the procedure for required aerobic incubation is time consuming, and the analytical procedures in use may vary significantly, development of a standardised protocol is necessary. Current research by WUR colleagues to assess the humification coefficient of organic fertilisers provides a standardised dataset and may serve as protocol. This protocol may be further refined during the development phase of the framework, and may also serve as a prerequisite for potential producers in submitting data for the evaluation of their products.

In addition, work is necessary on the characterisation of organic fertilisation products to the humification coefficient. This will shorten the time needed to obtain the necessary data for an organic product for its evaluation. Further literature research will be carried out to identify suitable product characteristics. A different approach is to find a kinetic parameter that requires little time to assess, and that may serve as a proxy for the humification coefficient. An initial exploration may be made using the following kinetic indicators: BOD/COD-ratio, O_2 –consumption, CO_2-emission after three days, and the Microresp. Method.

Table 3.1 *Overview of variations in incubation experiments with organic fertilisers.*

Nr.	Product	Fresh / Dry product	Amounts substrate and soil	Length aerobe incubation (days)	Temperature (C)	WHC (%)	Conditioning period (days)	Continuous measurement (C) or time intervals (T)	Mineralisation model	Reference
1	manures, sludges, composts	dry	200 g soil (24 or 48 ton/ha in 10 cm of top soil)	several periods	30	80	0	T	NCSOIL (first-order kinetic)	Antil 2011
2	mixture of sludge and olive waste	dry	200 mg per 10 g soil	28	70	60	1	T	combined first- and zero-order	Bernal 1998
3	manures, composts	dry	n.a.	168	25	n.a.	28	T	n.a.	Harz 2000
4	biochar , digestates	fresh	25 g (20 cm top soil)	133	22	60	16	T	n.a.	Hewage 2016
5	various	dry	2.5 g C / kg soil for 0.5 kg soil / pot	several periods	several	n.a.	7	T	n.a.	Hossain 2017
6	compost, biogas waste		120 g soil. 31 mg Nt manure per incubation vessel. (equal to 60 kg N / ha)	53	20	40	12 + 3	T	n.a.	Jager 2012
7	manure, sludge	dry	100 g (top 20 cm) soil	60	22	60	n.a.	C	several non-linear models	Saviozzi 1999
8	manure, composts, ver	dry	500 g soil, 12 g dry manure	142	15	75	3	C	n.a.	Flavel 2006
9	cattle slurry and digestate fractions	dry	100 g dry soil, 4 ml slurry and/or 100g dry soil, 2 g manure	56	26	60	2	T	n.a.	Fuente 2013
10	digestates cattle slurry and maize	dry	0-30 cm	181	25	n.a.	1	T	n.a.	Cavalli 2017
11	bio- and solid wastes	dry	100 kg	60	35	n.a.	n.a.	T	n.a.	Bayard 2015
12	sludges, wastes	wet		n.a.	n.a.	n.a.	n.a.	T	n.a.	Maynaud 2017
13	compost	fresh	0-15 cm, 250 g	28	25	n.a.	7	T	n.a.	Griffin 2007
14	greenwastes, composts, manures	dry	25 g	60	several	30	0	T	n.a.	Reddy 2019
15	mushroom compost	fresh	10 g compost	180	37	n.a.	0	C	n.a.	Semple 1997
16	liquid and solid fractions of pig slurry	dry	60 g dry soil, 250 kg total N/ha	171	25	65	1	T	kinetic models	Fangueiro 2010

3.4.2 Extended modelling

The effects of additions of organic matter on the soil-plant system can be predicted by modelling. A wide range of tools and models are available that can be used to assess the effect of additions of organic matter on the SOC status in soil. They range from static calculation (e.g. organic matter balance) to process-based models (e.g. with rate parameters for temperature and moisture).

Following the goal of the framework for the evaluation of organic fertilisers, ultimately a dynamic SOIL-CROP model is required that accounts for interactions between organic fertilising product and soil. Therefore, available SOC and Soil-Crop models have been screened for a number of desired properties. The model should include:

- an indicator for the decomposability of the product (in addition to its C-content);
- relevant soil features;
- weather conditions;
- nitrogen mineralisation from product and soil;
- relevant management practices;
- yield and/or net primary production (NPP);
- emission of ammonia, nitrate, and/or greenhouse gases (GHG), and
- leaching of P.

The models were screened for the above-mentioned features only; No statistical evaluation of model performance was made. Two types of models were screened, i.e. models that assess changes in SOC, e.g. MINIP, and models that assess crop yield and/or emissions to the environment, e.g. Daycent (MANURE) and STICS (CLIMATE CAFE). The required information was extracted from scientific papers.

Table 3.2 *Screening of SOC and SOIL-CROP Models.*

Model	Product input parameter					Soil variables		Weather /climate conditions	Management practices	NPP	N-cycling			Dynamic C/N-ratio	GHG	P	Water balance	Time-scale	Used for policy	Comments	Ref
	N-total, P-total	Nmin	Norg	C	Measurable	C	Add.		other than input substrate		minerali-sation	Nitrate	Ammonia								
SOC model																					
MINIP	yes	no	no	TOC, eos	aer. inc.	TOC, age	no	temp, rainfall		no	yes	no	no	no	no	no		month		no interaction C and N	Janssen, 1984; Janssen 1986
Yang	no	no	no	TOC, R^9, S	aer. inc.	TOC, R^9, S	no	temp, rainfall		no	yes	no	no	no	no	no		month		no interaction C and N	Yang 1996, Yang & Janssen, 2000
ROTHC	no	no	no	TOC, DPM, RPM	proposed	TOC, 5 SOC-pools	clay	temp, rainfall, evapotr.	soil cover	no	no	no	no	no	no	no		month			Coleman & Jenkinson, 2014
SOIL-CROP model																					
NDICEA	yes	no	no	--------------------as MINIP --			pH						yes					month			Van der Burgt, 2006
NUTMATCH				----------as Yang --------------		TOC	no		application method	yes			yes	no	yes			year		no interaction product - soil	Bos et al., 2017
INITIATOR				---------------------- based on 2 C-pools from RothC --------------------------------------									yes		yes			year			De Vries et al., 2006
MITERRA				---------------------- based on 5 C-pools from RothC --------------------------------------									yes		yes			year	IPCC		Lesschen & Kuikman
Landscape				------------------------------as RothC --									yes		yes			year			Coleman et al., 2017
ROTOR				yes	aerobic incubation								yes		yes			year			Bachinger et al., 2007
DAYCENT				decomposabilit	lignin/N		clay, pH		tillage	yes			yes		yes			year	JRC		Necpalova et al., 2015; Chang et al., 2013
STICS				TOC	C/N-ratio	TOC, 3 SOC-pools	clay, limestone	temp, rainfall		yes	yes	flow per cr	yes	yes	yes		yes	year		2/3 N uit fert nr humus; 2T-functions for HUM and RES	Brisson et al., 1998; Tribouillois et al., 2018; Plaza-Bonilla et al., 2018
SWAP/WOFOST				--------------------as MINIP --		------------ as RothC ----------------					yes	yes	yes				yes	year			Groenendijk et al., 2016

Table 3.2 shows that models may differ in the number of SOC-pools they use, e.g. from 1 (MINIP) up to 5 (ROTHC). Some SOIL-CROP models are also based on SOC-models (NDICEA, NUTMATCH, Landscape). None of the models are currently being used for policy purposes in the Netherlands or the European Union. However, regarding future use of the framework by other European Union Member States, the DAYCENT and MITERRA models offer the advantage of already being accepted for policy purposes, e.g. JRC and IPCC, respectively.

From Table 3.2, it follows that none of the models offers a crop response module in relation to changes in SOC and N- and/or P-status of the soil. Also, the possible impact of soil management and/or method of product application are almost absent, as is the impact of soil compaction and/or waterlogging on SOC-changes. The results featured in Table 3.2 have been used to identify the models that meet all of the following three criteria:

- Allow for distinction between products with regard to their decomposition; for the framework, the single most important feature of the selected model is to distinguish organic fertilisers with regard to SOC accumulation. This implies that the model should make use of input characteristics in terms of degradability of the organic products. These characteristics must be measurable by a fast and cost-effective method.
- Indicate N- and P-availability and –losses. Next to decomposition, changes in N and P are considered the most important features for the evaluation of organic fertilising products;
- Is available within the WUR-organisation; this criterion was chosen to save time and make best use of available experience within WUR.

Distinction between products
The Daycent and STIC-model have a different basis and use the lignin/N-ratio and the C/N-ratio, respectively. In Daycent, the lignin/N-ratio is used to assess decomposition of manure. It is not clear if/how this method is used for other organic products, for which two levels of decomposability are included in the model. In STIC, no distinction between organic products seems possible. Regarding the criterium, the RothC-model is the preferred model.

Indication N- and P-emissions
For N- and P-emissions the choice is between the available Soil-Crop models only, as the SOC-models do not include N and P. A common feature of the Soil-Crop models is the timescale of the output, which is at annual level for N- and P-emissions. For evaluating emissions from organic products, this is adequate. Based on this criterion, several Soil-Crop models are suitable.

Availability within WUR
The SOC models included in the model screening are commonly used within the WUR-organisation, as a software programme, MS Excel file, and/or interface. For complex soil-crop models, WUR offers a selection of models, including the Miterra model (https://www.wur.nl/en/Research-Results/Research-Institutes/Environmental-Research/Facilities-Products/Software-and-models.htm), but not the other soil-crop models listed in our inventory. Thus, regarding this criterion, the score for both RothC and Miterra is positive.

RothC and the RothC-based model Miterra match all three criteria and, therefore, offer potential for use in the evaluation framework. A major difference in the RothC-part is that the stand-alone model includes a monthly base, whereas in Miterra, algorithms are aggregated to an annual base. This difference in timescale is important, since for agricultural production, e.g. nitrogen availability, estimation would be undertaken on a monthly base (even on a daily base), while for environmental issues, evaluation on the basis of a yearly estimate would suffice.

We propose to make optimal use of the available models, by 1) extending the RothC-model with a module for nitrogen mineralisation, and use the model for testing the effect of organic fertiliser products during the growing season, in terms of changes in SOC-, and N-mineralisation; 2) use Miterra for assessing N- and P-emissions on an annual level.

Proposed use of the RothC model (stand-alone)
Before actually using the RothC model, an initialisation step is required to assess pool sizes. The parameterised model should be tested on a time series of known SOC-data. It is then ready to ascertain the effect of organic products in soil.

The initialisation step may be done via modelling. For a field-specific assessment of the carbon pools in ROTHC, a set of analytical procedures has been proposed (Table 3.3, (Zimmermann, 2007) and refined (Poeplau et al., 2013).

Table 3.3 *Fractionation methods corresponding to C-pools in ROTHC (Zimmermann, 2007).*

Three fractions by wet sieving bulk soil sample	Method	Result	Calculations	ROTHC-pool
> 63 µm	density separation	light fraction POM (part. OM)	POM + DOC	DPM + RPM
		heavy fraction (S + A)	(s + c) - rSOC + (S + A)	BIO + HUM
< 0.45 µm		DOC (diss. OC)		
< 63 µm (s + c)	oxidation 6% NaOCL	rSOC (residual)	rSOC	IOM

It should be noted that the initialisation of the RothC-model only needs to be carried out at the start of the scenario-analyses involving standardised soil – crop – fertilisation scenarios. Once the model is calibrated, it can be run to quantify the effects of current- and new organic products.

The RothC model uses for the decomposability of organic products the ratio between two decomposition parameters, i.e. the DPM (Decomposable Plant Material) and the RPM (Resistant Plant Material). According to a Flemish carbon accounting tool (Anonymous, 2008), this ratio may be assessed from the humification coefficient following aerobic incubation.

The model will be used in scenario-analyses to assess, on a monthly base, the change in SOC.

3.4.3 Outlook on scenario-analyses

The modelling with RothC (standalone version) and Miterra will be done for a selection of scenario-analyses (Table 3.4) concerning arable crops (including grassland) and specific soil types (Schröder & Van Dijk, 2017). The selection will be used in an analysis of the impact of different organic fertilisers on soil quality and agronomic aspects. The initial soil status will be set as sufficient in terms of C, N, P and K. Also initial other parameters will be set e.g. regarding heavy metal contents. The organic fertilisers will be applied up to the limits of the application standards, as given by the for Manure / Fertiliser Act, which are in line with the Nitrate Directive for zones vulnerable to nitrate leaching. For each type of organic fertiliser, calculations will be made of the quantity of mineral N, P and K fertilisers needed to the meet crop requirements and to maintain a sufficient P and K soil status.

The objective of the scenario-analyses is two-fold: 1) To assess the impact of a product on the development of SOC; and 2) To assess losses of N and P to the environment after application (thus, including interaction with the soil). The use of this approach results in an overview of the nutrient value of the organic fertilisers, together with the additional requirement and costs of mineral fertilisers. In addition, the long-term increase or decrease in SOC will be estimated, including the CO_2 and N-emissions to the air and N, P emissions to water. This approach will not only be used for new organic fertilisers on the market but also for commonly used organic fertilisers (manure, compost etc.). These products will be used for 'benchmarking' purposes.

Table 3.4 *Selection of scenario-analyses for the evaluation.*

	Arable crops			Ornamental bulb		Horticulture	
Crop	**A**	**B**	**C**	**Crop**	**A**	**Crop**	**A**
ware potato	25		25	hyacinth	2.5	strawberry	
seed potato				lely		ware potato	15
starch potato		33		narcisus	2.5	seed potato	
set aside		4		tulip	2.5	starch potato	
peas, beans				other	2.5	endive	
cereals	25	33				asparagus	
grass seed			12.5			ornamental bulbs	
maize	12.5	4	12.5			cauliflower	
schorseneer			12.5			carrot, sandy soil	
spinach (double)						broccoli	
tulip						carrot, clay soil	7.5
sugar beet	25	20	25			Leek	
carrot		6	12.5			iceberg lettuce	
winter carrot						lettuce	
onion	12.5					head cabbage	
						spinach	
						Brussels sprouts	55
						winter wheat	15
						chicory, clay soil	7.5
Part (%)	100	100	100	Part (%)	100	Part (%)	100

3.5 Relevance of organic matter dynamics in soil in relation to environmental risk assessment

Dynamics of organic matter in soil are relevant in view of, among others, the carbon storage potential of the soil. Therefore, this Chapter describes how modelling of soil carbon balances can be improved by taking into account different ‘pools’ of organic carbon. Such pools reflect differences in stability, nutrient supply and –ideally- can be related to the potential long-term built up of a stable carbon pool in soil. In addition to these aspects, the build-up of a stable organic carbon pool, or dynamics thereof, is also relevant in view of the so-called buffer function of the soil to store contaminants (NRCS, 2011; Stolte et al., 2016).
This refers to the capacity of a soil to retain contaminants once added to the soil and, thus, prevent the substance of concern to be transported to ground- and surface-waters. Clearly retention of chemicals by organic matter thereby can also lead to a build-up of those contaminants in the topsoil. This is, for example, reflected by natural background levels of most trace metals, which tend to be higher in organic matter rich soils (e.g. peat soils) compared to sandy soils (Mol et al., 2012). Retention of contaminants of course is not regulated entirely by the soil carbon content; additional relevant soil properties include pH, texture, content of amorphous (hydr)oxides and redox potential. However, for metals like copper, lead, cadmium and organic micropollutants (PAH’s, medicinal products), binding to soil organic carbon is one of the dominant buffering processes in control of the solubility of such contaminants.

Not surprisingly, the soil carbon content both in the solid- and solution phases is a key property in numerous models to predict the fate, bioavailability and risks of both metals, organic micropollutants and emerging contaminants including substances, like PFAS, nanoparticles and veterinary products present in soil (e.g. Vitale and Di Guardo, 2019; Li et al., 2019).
In most cases, such models still rely on the total carbon content as proxy for the buffering capacity of the soil, even though binding of most contaminants is related to specific physico-chemical characteristics of organic carbon. Metals like copper and lead, but also persistent pesticides like DDT in solution tend to have a higher affinity for high molecular weight structures, such as humic acid type carbon compared to smaller, low molecular weight fulvic acid type components (Römkens and Dolfing, 1998, Haarstad and Fresvig, 2000). Also metal binding to smaller organic matter size fractions in the

soil solid phase is stronger compared to larger size fractions (Quenea et al., 2008), even though this difference depends on soil type and carbon content. In the same study, it was also shown that this size fractionation corresponded to the age of the aggregates with increasing C14 levels recorded for the smaller fractions (Quenea et al., 2008). Recent work from Wiatrowska and Komisarek (2019) has shown that binding on metals to the light fraction of fresh organic matter added to soil via manure or straw does not differ substantially from that of the original soil carbon pool, which would facilitate a single model concept to describe binding on metals to soil carbon in soil. On the other-hand, Li et al. (2018) have reported that copper binding to different size fractions on soil carbon (cf. the < 2µm and 20 – 63 µm fractions) occurs on different reactive groups. Whereas copper tends to bind to carboxyl-C in the finest fractions, it is preferentially bound to alky-C in larger size fractions. Also, the pre-treatment of organic carbon added to soil affects the sorption capacity. Especially, products produced at high temperature ('char' or black carbon) have been shown to retain organic contaminants more than non-treated soil organic carbon, which is related to the higher aromaticity of black carbon type materials (Cornelissen et al., 2004). Already in 1990, Gratwohl (1990) showed that by correcting for the degree or aromaticity, the sorption behaviour to various organic materials using the K-OC concept could be improved substantially.

In addition, for veterinary products, such as ivermectins, the complex nature of the compounds, including both hydrophobicity-related sorption characteristics, the nature of binding to soil carbon depends on the hydrophobicity of the specific compound (Krogh et al., 2008). Whereas the more hydrophobic abamectin tends to be regulated primarily by interaction with hydrophobic pockets on soil carbon, the more hydrophilic ivermectin can bind to soil inorganic compounds (oxides, clays).

These examples show on one-hand information on the speciation of organic matter (size, stability, chemical characteristics, such as aromaticity) and that relevant contaminant can improve the understanding of their fate. On the other-hand, however, the understanding of the interaction of especially emerging organic pollutants in relation to organic matter dynamics is still insufficient, or requires further study. In Chapter 4, several of the required aspects related to the modelling of contaminants in soil will, therefore, be further explored, so as to evaluate what information on soil organic carbon currently available and used in this Chapter can be used to improve the prediction of fate of pollutants in the soil-water-air continuum.

3.6 Main knowledge gaps and further steps

The approach described in this Chapter may be further developed by filling in knowledge gaps and subsequent modelling. The most important issues are deemed to be:

- Development of a protocol for the aerobic incubation method, from which to derive a standardised humification coefficient.
- Extension of the RothC-model with a module for N-mineralisation during the growing season, taking into account C/N-ratios for the SOC-pools.
- Testing of the methods for field-specific parameterisation of the model with physical-chemical fractionation methods for the Dutch situation.
- Development of a decision tree for the evaluation (normalisation, weighing, min-max values, etc.).
- Development of an interface for the overall system comprising the stand-alone RothC model (incl. N-module) and Miterra model.

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4 Risk assessment of organic fertilisers: towards a systems approach

4.1 Introduction

The potential introduction of new or additional fertilisers and (organic) soil improvers derived from (animal) manure, processed sewage sludge, compost or other (e.g. ashes, biochar or struvite) calls for a balanced evaluation of the quality of such organic fertilisers. This related to both beneficial impact (nutrient supply, source of organic matter; see Chapter 1) and possible unwanted effects. The latter is largely related to the presence of unwanted substances in organic fertilisers, of which the potential risks can vary substantially.

Currently there are largely three classes of substances that are or can be of concern:

1. Those substance currently banned (zero tolerance) due to unwanted effects on human-health or the environment. Examples of such compounds include zoonoses among others.
2. Substances tolerated in fertilisers and soil improvers up to a certain maximum level. Examples of such substances include heavy metals among others, PAH’s that are regulated either at the national- or EU-levels.
3. Substances not yet regulated. This group contains both known substances, such as medicinal products, as well as ‘emerging’ pollutants, like microplastics, nanoparticles or heavy metals currently excluded from regulation. To a large extent, it is unclear at what levels such compounds are actually present in organic fertilisers, and if so, what the effect in the environment is or will be, if these are to be added to the soil for longer periods of time.

Depending upon the biochemical behaviour of unwanted substances that belong to this third group, levels present in manure and in soil, such substances can enter the soil plant system and, thus, enter the food- and feed chain. Alternatively, depending upon the mobility of the compound of interest, they can be transferred to surface- and/or groundwater, or emitted to air. Ultimately, depending upon the risk such non-regulated substances can pose to the environment, they can be classified as Group 1 (non-tolerable) or Group 2 (tolerable up to a specific level depending upon the impact that they have in soil, crops or water), but to assess and evaluate this, a framework is needed.

Aside from the need to evaluate the risk of such new contaminants that are not yet regulated, various shortcomings of current risk evaluation approaches used to evaluate the risk of organic fertilisers can be explained by the following:

- Current evaluation approaches are largely based on static assessments based upon levels of priority substances in products, partly based on –scientifically- outdated risk assessment principles. A much-needed improvement, therefore, would be a systems approach that is able to focus on where (soil/water/product), to what extent, and when (time) risks occur.

- Usually the risk assessment performed does not (or only for a few substances) consider multiple environmental compartments (i.e. soil – water – air – product) and their interactions; based on the systems approach, benefits (in soil) can, for example, be assessed against adverse effects and consequences thereof elsewhere. This calls for an integrated risk assessment framework that takes into consideration multiple end-points (e.g. de Vries et al., 2007). Such integrated risk assessment frameworks, however, as of now are scarce and not available for an array of substances present in organic fertilisers. This is relevant, as generic standards developed so far may not be protective enough to provide a relevant level of protection, either in soil or in surface-waters, depending upon local soil, land use and climatic conditions. An additional aspect in this context is that often risk limits or target loads are specifically related to the soil compartment, but do not consider the impact further down the environmental chain (i.e. emission to water) or development in time (dynamic approach).

- Current risk assessment frameworks largely refer to a limited number of heavy metals, residues of pesticides and biocides, PAHs, PCBs and dioxins but do not include 'emerging' contaminants, such as nano-particles (NPs), medicinal waste materials used by humans and in intensive animal husbandry, or industrial contaminants, for example, flame retardants like PFAS, (micro)plastics, pharmaceuticals, personal care products (PCPs) and endocrine disrupting compounds (EDCs). Currently, no adequate established risk assessment approach exists for several of these new emerging contaminants.

- An important issue in this context is to realise that the approach discussed here targets the quality of finalised products and not so much the quality of source materials from which organic fertiliser can be prepared. This is relevant, as processing of source materials can possibly alter the levels of potentially harmful substances, thereby reducing the levels in the finalised products.

To evaluate the merits of organic fertilisers considering potential adverse environmental effects due to the presence of priority substances, we aim to provide an overview of the following:
1. The principle of the overall risk assessment framework used here including currently banned or regulated substances extended with the approach to evaluate (as of now) non-regulated substances (par. 4.2.1).
2. Information on current Dutch and EU regulation of either banned or regulated (par. 4.2.2).
3. A summary of the need to include assessment of other substances as well (par. 4.2.3).
4. The general principles and backgrounds of the risk assessment approach targeting non-regulated compounds (par. 4.2.4 to 4.2.6).

This approach will be developed and tested for a number of selected substances. To select these an expert workshop at Wageningen Food Safety Research (WFSR, November 2018) was organised. During this workshop several main groups of substances were identified and characterised using a number of relevant properties related to expected levels in fertilisers, toxicity, mobility etc. (see par. 4.3). Ultimately, a selection of these will be used to evaluate the approach described in the preceding paragraphs.

4.2 Essential aspects of the risk assessment approach

4.2.1 General principles of risk assessment: from non-tolerated compounds to non-regulated compounds

Risk assessment procedures have been developed to avoid unwanted effects of chemicals (and microbiological hazards) in the environment, including both the terrestrial and aquatic environments. Within this context, a range in 'acceptability' can be defined ranging from 'unacceptable' (or non-tolerable) for substances that cause immediate or chronic effects on either health of organisms or humans (via food or intake of water) to 'acceptable' up to a certain level. Such acceptable levels depend upon the expected impact that the substance has in the environmental compartment of concern (soil, water, air, crops).

At present, substances present in fertilisers are either classified as non-tolerable and, therefore, their presence at any level is prohibited, or as tolerable up to a specific level. For this, existing legal frameworks have been put in place (see par. 4.2.3). For a large group of either new-, or as of now, non-regulated substances, no systematic framework has been developed. Here (see also Figure 4.1), we propose to develop such a framework based upon a combination of expected effects of such substances (risks) and information on the transfer of such substances in the environment once entering the soil-crop-water compartment.

Figure 4.1 *Proposed approach on the environmental and health risk assessment of organic fertilisers. In green, Group 1 (non-tolerated substances) and Group 2 (currently regulated substances) are shown. In red, the framework discussed in the Chapter is shown targeting –as of now- non-regulated substances (note that non-regulated substances can end up as 'non-tolerable' as well following assessment).*

The first step should be to check if a substance is tolerable at all (Step 1). If not, the product fails the risk assessment. Currently a number of substances, notably several with microbiological parameters, are classified as non-tolerable, largely due to the fact that they cause immediate health effects for animals and humans alike (e.g. Salmonella). If the substance is tolerable, the question is if quality criteria are in place. If such criteria are available in the legal framework, the product must be tested for the presence of this substance and depending on the contents will fail or pass the assessment (Step 2). This approach is currently being used for a number of substances, both chemical and microbiological. Potentially some of the 'new' non-regulated substances may be classified as non-tolerable as well, but this must be evaluated using scientific knowledge (e.g. toxicity data, chemical characteristics that determine mobility and uptake, see also par. 4.3).

For new and currently unregulated substances, a question that remains is if it is possible to analyse these substances at the relevant levels? This aspect, however, is not the major focus of this study, but will be evaluated for a selected number of substances (see par. 4.3).

For those substances that are present in detectable quantities in organic fertilisers, the approach in the red box in Figure 4.1 is proposed. Here, available scientific data should be evaluated that can be used to assess whether or not substances present in fertilisers can pose a risk for the environment. If sufficient reliable toxicity and transfer models are available, these can be used to develop a risk assessment framework to evaluate if a substance can be tolerated, and if so, at what level? (system approach, Step 3, see also par. 4.2.4). If too little information is available, expert judgement of the potential risks is required to evaluate if the substance can be tolerated and at what level ? (Step 4).

4.2.2 Current legal instruments to evaluate the quality of fertilisers (Group 1 and 2 substances)

For the first two groups of substances (non-tolerated and regulated), both national (The Netherlands) as well as EU legal frameworks exist that regulate the quality of fertilisers and materials used to produce fertiliser. In the Netherlands, regulations for organic fertilisers are laid down in the 'Meststoffenwet'. European Union legislation on fertilisers is currently under revision.

The Netherlands
Within the Dutch legal framework, a distinction exists between products and wastes. Products must meet designated criterions for contaminants. Waste materials may be used to produce fertilisers (source materials) and the fertilisers themselves provided that they are listed in Annex Aa of the Implementation Regulation of the Fertiliser Act.

To be listed in Annex Aa, potential materials are judged according the 'protocol for assessing the risk of using waste as fertiliser, version 3.2[17].Criterions for inorganic- and organic contaminants designated by the Fertiliser Act and the corresponding Fertiliser Decree and Implementation Act, Annexes 2 and 4 give the criteria. Annex 3 gives designated analytical method. For other contaminants, the protocol for evaluation of an environmental risk is given in Annex 5. The standards of criterion for fertilising products or secondary raw material from waste are identical to those for other inorganic fertilisers or other organic fertilisers. These standards are given in Annex II of the Fertiliser Decree (for N, P, K, NV or OM) and Annex Ab of the Implementation Regelation (for Ca, Mg, Na, S). These standards limit heavy metals, PAH's, PCB's, dioxins, mineral oil and designated residues of plant protection chemicals.

Other contaminants that may be present in the fertilisers must comply to the criterion of not being harmful for human, animal, crop and the environment (Article 6 Section 3 of the Fertiliser Decree). This does not refer to actual specified limits of potential contaminants in fertiliser, but rather the approach to evaluate risks.

EU
In the European Union, only mineral contents and neutralising value (liming materials) were regulated for free-trade within EU27. This year (2019), a revision of EU2003/2003 was published, which includes quality criteria for the seven Product Function Categories (PFC) marked as CE fertilising products, including both mineral and organic fertilisers, as well as additional products, such as micronutrient fertilisers, organic soil improvers, growing media and plant bio-stimulants[18]. The new facultative European Regulation for free trade of fertilising products 2019/1009 will also regulate the quality of fertilising products by setting standards for contaminants. Here we shortly summarise the main principles for contaminants of both the legal framework of the Netherlands and the new EU framework. One reason for the revision of the EU regulation for free-trade of fertilisers is the focus on a more effective re-use of existing wastes in view of the circular economy. The source materials must meet quality criteria of:
- EU regulation on animal by-products (1069/2009 and 142/2011). Only after an animal by-product has reached an end-point in this regulation can it be used as a source for fertiliser production.
- EU regulation on plant protection products (ppp) 1107/2009, the product or waste may not be a designated ppp.
- Next there are a number of EC regulations which will not be affected by the new regulation on fertilising products[19].

The new EU regulation for fertilising products takes into account:
- European Council Regulation (EEC) No 315/93 on Community procedures for contaminants in food.
- Regulation (EC) No 396/2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin.
- Regulation (EC) No 470/2009 on residue limits of pharmacologically active substances in foodstuffs of animal origin).
- European Union Directive 2002/32/EC on undesirable substances in animal feed.

[17] http://edepot.wur.nl/394876.
[18] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL laying down rules on the making available on the market of CE marked fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009.
[19] 86/278/EEC, 89/391/EEC, 91/676/EEC, 2000/60/EC, 1907/2006/EC, 1272/2008/EC, 1881/2006/EC, EU 2016/2031/, EU 98/2013/, EU 1143/2014, EU 852/2004/ 2016/2284/EC, EC 882/2004, EU 2017/625 (FROM 15 December 2019 on), EC 2017/625, EC 834/2007/EC.

Once these criteria are met, fertilisers are classified according to seven PFC's (Product Function Categories ranging from fertilisers (PFC 1) to fertilising product blends (PFC 7), Annex I COM(2016) 157 Final. These can be prepared from a list of 11 CMC's (component material categories, Annex II, COM(2016) 157 final). Waste that meets the criteria of both PFC and CMC has reached an end-of-waste status. End-of-waste status is only valid on PFC-level. A waste that meets criteria of CMC remains a waste.

Both the Dutch and EU frameworks exclude a wide array of unwanted substances or place limits on various grouped of contaminants. Nevertheless, there are some issues that need to be addressed. A number of emerging contaminants (e.g. nano particles, residues from veterinary or human medicines) are not considered in any of the listings or protocols for fertilising products.

4.2.3 Current non-regulated substances and emerging contaminants: reason for concern?

The quality of organic fertilisers is, obviously, related to the source materials used to produce such fertilisers. Hence, farm management, waste processing and field application of fertilisers has resulted in an increased concern about the presence of various substances in animal manure, compost and processed sewage sludge, among others.
A few examples of 'emerging' or known (but non-regulated) priority substances detected in organic fertilisers include:

- Copper and zinc in animal manure that originates either from illegal waste disposal (copper in food bath solutions) or from additions to drinking-water (zinc in pig breeding).
- The presence of antibiotics and other medicinal drugs used in animal husbandry present in animal manure, which is due to comparatively low absorption by the animal relative to the dose given.
- Nanoparticles and rare earth metals in processed sewage sludge.
- Micro-plastics in compost derived from household waste.
- Presence of waste from (illegal) preparation of drugs in animal manure.

The awareness of the potential risk or risk of priority substances and pathogens in organic source materials has been recognised for a few decades and has resulted in the development of risk assessment frameworks.
The most common way to avoid risks from entering the soil is to limit the amounts of priority substances in the source materials or products derived thereof or excluding its use (Example: cat. 1 animal by-products[20]). Examples of such approaches include quality guidelines for sewage sludge (both at EU[21] and, e.g. in the Netherlands at national-level[22]), compost (national[23] and EU-level) and animal manure (national-level). For sludge and compost quality criteria for heavy metals and organic micropollutants used in the Netherlands (UBM[24]) and EU (Sludge Directive[25], compost[26]), simply relate to the maximum allowed levels in the product itself. Compost must also fulfil the requirements of the application standards. The use of sewage sludge is limited to regulatory application standards and an obligation for soil testing on heavy metals. For manure, the maximum levels of priority substances are related to the nitrogen and phosphate content and their application standards. The risk assessment frameworks focuses on heavy metals and pathogens. Aside from generic EU-wide risk-based quality criteria, such as those listed in the sewage sludge directive, national risk assessment frameworks as used by individual EU Member States are still based on different principles and methods, which leads to widely different soil quality standards, as well as acceptable levels for organic soil improvers or fertilisers.

[20] Animal by-products and derived products not intended for human consumption (Regulation (EC) No 1069/2009).
[21] Sludge Directive (86 / 278 / EEC).
[22] Heavy metals and organic compounds from wastes used as organic fertilisers ENV.A.2./ETU/2001/0024.
[23] Table 1 (Compost) and 2 (Sludge) Appendix II Uitvoeringsbesluit Meststoffenwet.
[24] Fertilser Decree (in Dutch: Uitvoeringsbesluit Meststoffenwet).
[25] COUNCIL DIRECTIVE of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC).
[26] Revision EU 2003_2003.

4.2.4 Basic principle of systems approach to be applied to non-regulated substances

A system approach can be applied for those substances for which sufficient data or models are available to predict their transfer within the relevant environmental compartments (soil, water, crop). Key aspects include the (transfer) processes considered and relevant risk limits to be applied. Clearly the choice of relevant risk limits, is related to the pathways along which priority substances (and nutrients alike) are translocated across the chain from production to target end-points (water/soil/food). This chain from source material to impact on specific end-points is summarised in Figure 4.2.

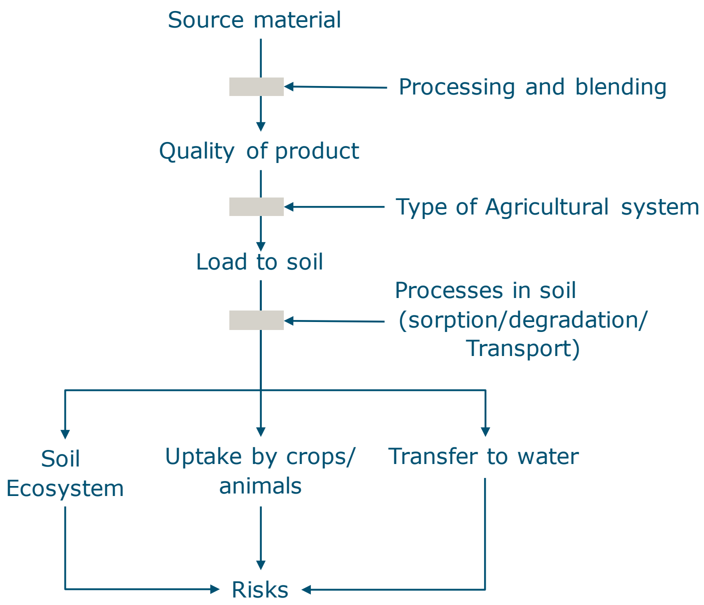

Figure 4.2 *Schematic overview of aspects relevant to evaluate environmental and health risks of unwanted substances in organic fertilising products.*

The final stage of this scheme, indicated with 'risk' textbox, refers to the potential impact the presence of a substance has on either the terrestrial and/or the aquatic ecosystem, and consequently on animal- or human-health. Here, we define 'risk' as the likelihood that -given a specific type of land use - (here related specifically to the application of fertilisers) concentrations of substances exceed current, or yet to be developed, legislative thresholds values related to the protection of the end-points. Such threshold values include, for example, drinking water standards to limit human exposure, or NOEC (No Observed Effect Concentration) in soil related to ecosystem functioning.

This framework is largely in-line with the ones proposed by Spijker and Van der Grinten (2014), who describe the need to evaluate waste materials (waste-water and building materials) to be used in a circular economy (Spijker and Van de Grinten, 2014). This approach is also based on source-path-receptor approach, but the end-points are explicitly linked to either ecological- or human toxicological criteria.

4.2.5 Development of Risk Assessment Protocol for non-regulated substances: systems approach

Any chemical introduced into soil will affect the concentration of the compound, either directly in soil (in case of accumulation), or in another environmental compartment, such as adjacent surface-waters in the case of mobile compounds. Whether or not this increase in concentrations will lead to an effect depends upon a large array of factors, the main ones are:

a. Levels of priority substances in raw- or processed source materials itself and amounts of products applied to soil. What is the relevance of the amounts of products used in Dutch agriculture? The focus is on:
   i. Likelihood of contaminant being present in the product.
   ii. Likelihood of the contaminant being detected in the soil after application.

b. Processes in the soil-water-air continuum that may cause alteration, retention or degradation effecting soil quality in the short- and long-term. The degree to which a contaminant poses a risk in soil, water, air or the product depends upon an array of processes. Here, we will include:
   i. Assessment of stability and mobility (transport to water) of contaminant under relevant conditions prevalent in the soil.
   ii. Assessment of uptake of the contaminant in the food chain (crops/animals).
   iii. Potential availability of priority substances for soil organisms.
   iv. Assessment of emission to air (volatilisation).

c. The actual toxicity of specific priority substances and pathogens which determine the actual risk. Ultimately, the impact of specific substance (in Dutch 'Milieubezwaarlijkheid') is the crucial factor to evaluate: is there reason for concern for the selected compound and if so, in what context? Here, we consider on the following relevant end-points for risk assessment:
   i. Impact in soil (ecosystem health).
   ii. Impact on water quality considering both drinking-water (human-health) and surface-water (ecology).
   iii. Transfer of priority substances into the food chain, more specifically the impact on crop and animal product quality (human-health and animal welfare/health).

d. The potential toxicity of specific priority substances on the long-term. This calls for a dynamic approach to assess such long-term changes either assuming unchanged conditions or, where possible, accounting for such changes in soil conditions like organic matter or acidity.

Clearly the assessment of the actual (and future) quality calls for relevant risk limits in all compartments considered. For the compartments and targets listed here, this includes threshold in soil for ecosystem health (NOEC, LOEC, or other relevant indicators), human-health (e.g. food- and feed quality standards, drinking-water standards, Tolerable Daily Intake (TDI) of soil itself in view of children), and animal-health (TDI).

Here, we propose as overall methodology for the risk assessment a four-step evaluation approach corresponding to the 'red box' in Figure 4.1. This approach includes the aspects listed under a to d above, but, in addition, includes an assessment related to the analytical issues that specifically target emerging pollutants. For some contaminants that are assessed to be relevant, e.g. medicines used in animal husbandry or metabolites thereof, it is essential to evaluate to what extent these can be detected, and if so, at what level? The eventual approach is performed along the following four steps provided that sufficient information is available to perform the assessments listed under each of these steps. If this information is not available or of insufficient quality, expert judgement will be used to assess the substance of interest (lower-part of Figure 4.1).

There are four basic steps required to perform the system approach for risk assessment of non-regulated substances:
1. Identification of potential risks based on existing information (quantity and quality, total load to the soil).
2. Assessment of detection issues (can we measure the substance).
3. Risk assessment based on detected levels and know processes.
4. Dynamic risk assessment to identify potential risks within 0 to 50 years.

This is schematically illustrated in Figure 4.3 below. It should be noted that this approach is relevant for priority substances that are tolerated in fertilisers or source materials for the production thereof.

Contaminants that are not tolerated according to existing regulations do not need to be evaluated and products that contain such non-tolerable priority substances will fail to pass the final evaluation (see Figure 4.1).

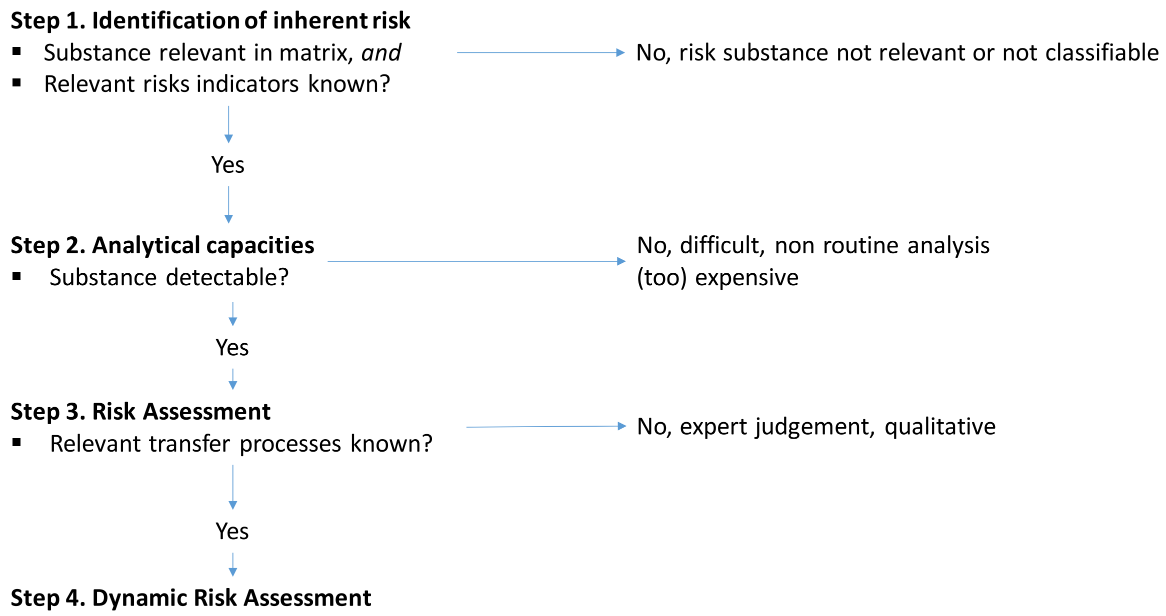

Figure 4.3 *Four step approach to identify risks of substances in (organic) fertilisers (note: Steps 3 and 4 correspond to the steps marked in red in Figure 4.1).*

The assessment flow as depicted in Figure 4.3 is an extension of the one described by Ehlert et al. (2013). In the study of Ehlert et al. (2013), a two-step procedure is described, which is followed sequentially for three groups of compounds (metals, organic micro-pollutants, other organic pollutants):

1. Determination of levels in the compound of interest.
2. Evaluation of levels of priority substances against existing quality standards at product-level.

If a product fails to meet one of the standards for each of the three groups of priority substances, the product is qualified as unsuitable for use as source materials for co-digestion.

The approach described in the underlying study goes beyond the approach by Ehlert et al. (2013). Here, a systems approach is used to quantify the impact of using a product of specific quality on specific environmental compartments (soil, water), both for a given moment in time (actual risk) and in the near-future. The criteria used to assess the quality of products, therefore, are not product criteria but rather criteria related to human and animal-health in terrestrial- and aquatic environments.

A framework is needed to evaluate the impact of organic fertilising products on the environment, including soil and water quality, animal- and human-health, due to the presence of unwanted substances in fertilisers according to the flows as depicted in Figure 4.2. Such a framework should include all relevant aspects ranging from levels of the selected potential risk substances in the fertiliser itself, via the load to soils, and subsequent transfer from soil to either crops, including food and fodder crops, as well as transfer to the groundwater and surface-water.

The essential information that is needed to perform this analysis was summarised earlier, and the main part of the project will focus on how to establish the links between, on one end of the chain, the presence of priority substances in various fertilisers and, on the other end, the impact these levels have on selected end-points (cf. Figure 4.2).

For some relevant priority substances present in organic fertilisers, such as heavy metals or PAHs, maximum limits have been set or are currently proposed (e.g. in view of the revision of the Fertiliser Regulation), which can be used as starting point in a dynamic assessment. Note that for regulated substances, such a dynamic assessment (cf. Steps 3 and 4 in Figure 4.3, or the steps marked in the red square in Figure 4.1) is not strictly needed, as the acceptance (or reflection) of a fertiliser is simply characterised by the detected level of the relevant compound as such (the green box in Figure 4.1). However, one of the shortcomings of the current risk assessment, also for regulated substances, is that it does not account for long-term changes in soil or water, or to a small extent only. Application of a dynamic approach can quantify such long-term changes in environmental quality, as demonstrated by Regelink et al. (2018) in cases of application of sludge and sludge-derived products, or for cadmium in phosphate fertilisers (Römkens et al., 2019).

As shown in Figure 4.2, relevant end-points are selected, for which relevant quality criteria are needed to serve as benchmarks for the evaluation of substances assessed. In this assessment, we will use existing Dutch quality criteria for soil (Regeling Bodemkwaliteit[27]), which cover both food quality, ecology and human-health protection, current food quality criteria set at EU-level (Regulation (EC) No. 1881/2006[28]), and, where relevant, quality criteria in adjacent environmental compartments with a focus (here) on groundwater and surface-water, for which quality criteria have been also been derived both for the Netherlands (Besluit kwaliteit drinkwater BES[29]), as well as the EU (WFD[30], Drinking Water Directive[31]).

4.2.6 Towards an integrated risk assessment of priority substances in organic fertilisers

The main added value of an improved evaluation system for priority substances in organic fertilisers is its capacity to eliminate those products that contain priority substances that are not tolerated in fertilisers in view of food safety, human-health, or any other relevant target end-points. Critical requirements for such an approach to function include the following:

- Relevant risk indicators that identify the maximum acceptable level of a specific substance in all end-points to be protected.
- Reliable transfer models to quantify the levels of priority substances in the targets.
- Analytical techniques to detect such priority substances at levels that can be expected or are relevant in view of the risk assessment.

So-far, the end-point of the assessment of risks related to the presence of priority substances in organic fertilisers has not been defined. Based on current risk assessment approaches, as outlined in Figure 4.1, various assessments apply:

1. *A product is disqualified for use based on the presence of specific priority substances regardless the level ('zero-tolerance')*. This can be suitable for those priority substances that are absolutely unwanted in fertilisers. In fact, this is similar to a quality standard equal to the detection limit. The product is accepted for use only if detection limits are not exceeded,
2. *A product is disqualified for use if current quality standards are exceeded*. This approach basically depends on the availability of quality standards that have been developed with a generic protection of the environment or human-health, in general. Examples of this include currently proposed standards in the Fertiliser Regulation.
3. *A product is disqualified for use if - within a specific time-frame- available risk indicators (e.g. standards in soil, water, animals or agricultural products) are exceeded*. For some priority substances present in fertiliser currently produced, current levels do not impose immediate risks for the environment or agricultural products. If supplied in sufficient amounts for a period of time, however, levels may exceed threshold levels, at which the end-points are considered at risk.

[27] https://wetten.overheid.nl/BWBR0023085/2018-11-30.
[28] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006R1881&from=EN.
[29] https://wetten.overheid.nl/BWBR0028642/2010-10-10.
[30] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008L0105-20130913&from=EN.
[31] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31998L0083&from=EN.

4. *Critical maximum levels for the specific contaminant and product are derived based upon pre-defined risk levels,* and shall not be exceeded to avoid short- or long-term effects on the environmental- or agricultural end-points considered.

A crucial difference between Approaches 1 to 3 versus Approach 4 is that in Approach 4, one (or more) risk-indicator(s) in defined end-points are taken as the starting point and critical levels in products are then back-calculated from this. Clearly this approach only can function if transfer processes from target end-points (e.g. groundwater) back to a contaminant level in manure (for example) are known.

Rather than seeing the above mentioned four approaches as different options, these can also be integrated, since it is likely that the way that a contaminant is evaluated depends upon the nature, relevance, detection capacities or toxicity of this contaminant. For example, some priority substances, either organic, inorganic or biological, e.g. specific zoönoses are absolutely unwanted in fertilisers, and Approach 1 (disqualified once present) applies.

For other priority substances with inevitable presence in fertiliser, by nature or deliberate addition, the source material (e.g. most micronutrients, present in either raw feed materials or added to feed), Approaches 2 and/or 3 apply. In this scenario, existing generic standards (Approach 2) if based on sound scientific risk-based principles can be referred to as the guiding quality standards. In this instance, the recently updated list for several metals in the Fertiliser Regulation can be used as a guideline.

For a number of priority substances, however, including, but not limited to emerging contaminants, such as nano-particles, micro-plastics, and several anti-parasitic drugs used in animal husbandry, such generic quality standards are not (yet) available. This then calls for Approach 3, in which the presence of the substance, based on its known (or yet to be established) pathways to relevant end-points must be evaluated. This requires the use of transfer models to predict the fate and concentration in these relevant end-points, for which risk indicators (standards) are available. Also, for this category of priority substances, not all risk-indicators in all end-points are available. Especially, critical levels in agricultural crops or animals used for human food-production are still scarce, and the relevant end-point in that case would be the calculation of exposure through intake of food. On the other-hand, critical levels in (drinking- or surface-) water are more abundant, which would allow for a risk assessment for these environmental end-points.

This approach is schematically illustrated in Figure 4.4.

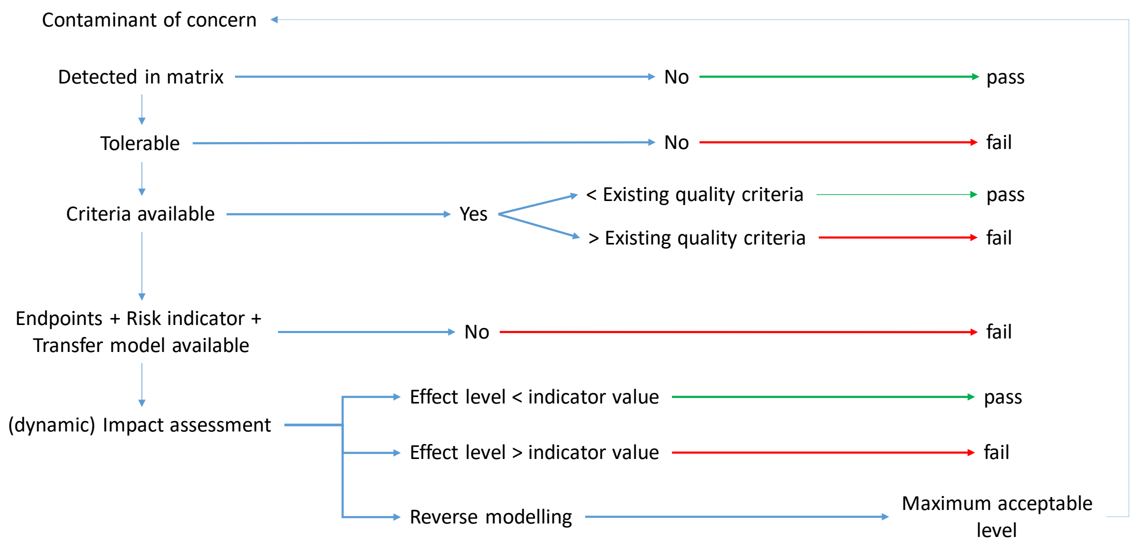

Figure 4.4 *Approach to evaluate priority substances present in organic fertilisers.*

In the approach described here, we focus on end-products derived from a wide array of source materials. The assessment of the source materials in view of expected impact can differ substantially from that of the end-product, depending upon the type of processing of the source materials. For some priority substances, both organic ones including zoonoses, medical drug processing, and inorganic ones, such as metals, the level in the end product can be reduced (in some cases to zero) depending upon the technology used. Especially in case of thermal treatment of organic materials, (e.g. HTC) the absolute concentrations, or the bioavailability of priority substances, can be reduced. Considering the large array of methods currently developed to produce new fertilising materials from various source materials, an in-depth assessment of the potential role of processing on the levels and availability of priority substances is beyond the scope of this project. So we have focused on the assessment of the product to be applied to soil, whether processed (compost, digestate) or not (manure). If such a product fails to pass the scheme shown in Figure 4.4, (additional) processing of source materials can be a way to improve product quality. This, however, is also not addressed here.

Based on the approach shown in Figure 4.4, a number of activities can be described to complete each of the consecutive steps. These steps are outlined in Annex 14 in a number of follow-up actions.

4.3 Assessment of relevant contaminants present in organic fertilisers: identification of priority substances

The first step in the assessment of relevant contaminants is to ascertain if contaminants are regulated and can already be analysed. This is because the presence of these contaminants is already a reason not to continue their further assessment. This is, for example, the case for certain heavy metals, PAH’s, dioxins and mineral oil in manure products.

For the other contaminants, which are not yet regulated, we start the assessment with an inventory of the products listed here, in which the specific priority substances are relevant, since not all priority substances are present in all products. For each combination of products and relevant substances present therein, the following criteria will be evaluated (note that this is relevant for tolerable substances only):

1. Relevance in matrix: in which product can the substance be detected considering source materials and/or processing thereof?
2. Levels in matrix, if possible with data.
3. Levels in soil, if possible with data.
4. Regionally- or nationally present in soil?
5. Mobility in soil based on process knowledge: Transfer to water likely?
6. Availability of process models to predict soil to water transfer.
7. Effects in soil (ecosystem): known? If so, magnitude at present?
8. Effects in water system.
9. Effects on crop production.
10. Effects on crop quality.
11. Effects on product from animals.
12. Potential impact on human-health.
13. Potential impact on animal-health.
14. Other (specific).

4.3.1 Substances to be included in this analysis

In the overview below, a listing of potentially relevant substances is given (Table 4.1). The selection is based on expert judgement and compiled during a workshop held at Wageningen Food Safety Research (former RIKILT) in November 2018. Several WUR researchers with different backgrounds, who are all experts in this field, attended this workshop. The aim of the workshop was to make an initial inventory of the most relevant aspects in the risk assessment of biofertilisers. Different categories of potentially unwanted substances, organisms or diseases that could be present in biofertilisers were identified. These categories and subcategories are:

- Microorganisms: zoonosis, infectious diseases, ARM (= antibiotic resistant microorganisms),
- Medical drugs: antibiotics, antiparasitics, other drugs,
- Other chemicals and substances: nanoparticles, heavy metals, dioxins, biocides, emerging contaminants.

Table 4.1 *Overview of selected priority substances to be evaluated: longlist.*

Type of priority substances	Substance/compound
Zoonosis	Salmonella, Influenza, Hepatitis E, STEC, Campylobacter Coxiella brunetii, Listeria, *Cryptosporidium parvum*
Contagious animal diseases	Bird flu, pathogenic coli's (speendiarree, baccilosis), PRRS, Lawsonia intracellularis, *Brachyspira hyodysenteriae,* Partuberculose, Bovine virus diarree virus, Coccidiose
ARM	MRSA, ESBL, CPE
Antibiotics	Tetracyclins, Macrolides/lincosamides, Trimethoprim, Sulfonamides, Penicillin, Fluoroquinolones, Amphenicols Polymyxins, Aminoglycosides, Pleuromutilins
Antiparasitics, incl. coccodiostatica	Ivermectin, Flubendazol (+metabolites), Toltrazuril + ponazuril
Pain relievers, hormonal substances, other pharmaceuticals	NSAID's
	Natural and synthetic hormonal substances
Nano particles	Metallic Nano Particles (Zn, Ag)
Heavy metals	Classic: Zn, Cu, Cr, Cd, As, Pb, Hg, Ni
	New: Ba, Co, Mo, Sb, Se, V, U
Other substances from 'Bijlage AA meststoffenwet'	Dioxins, PCB's, PAH's, mineral Oil
Biocides	Fipronil, Glyphosate, Diazinon
Emerging contaminants	PFAS, V, Tl, Flame retardants
Physical impurities	Glass, stone

A matrix was set up, with these (sub)categories to be scored for their environmental impact. The participants were asked to fill in the matrix. The workshop aimed to answer the following questions:

1. Which substances are most important for each category? The aim was to select a top three priority substances per category.
2. What is the relevant matrix? The focus for now was on manure (1) and sewage sludge (2).
3. What levels of a specific substances are expected in the matrix? And is that a problem for the quality of the fertiliser?
4. Is this substance present in measurable amounts in soil? If yes, at what levels? How stable is the substance?
5. How mobile is this substance once it is present in the soil? Do models exist to predict the process of emission to water?
6. What effect does the presence of a substance/organism/disease have on:
   a. Soil (ecosystem)?
   b. Water (ecosystem)?
   c. Quantitative production and product quality (aimed at the right quality of consumption of the crop by humans and animals).
   d. Is the presence of the substance in the soil a threat to humans? Specifically aimed at direct work with the soil or substance.

Not all detailed information was directly available at the workshop. Therefore, participants were asked to review the literature database and send in relevant information for the completion of the matrix. The result of this workshop is presented in Annex 12. This output can be used to prioritise subjects, in which more research is required to derive to a simple table of priority substances for analysis in new biofertilisers, and, where appropriate, an amount for their maximum levels allowed in the bio fertiliser. A potential result could be tabulated, as shown in Table 4.2.

Table 4.2 *Shortlist of selected clusters of priority substances and representative compounds thereof.*

Cluster	Specific groups within cluster	Representative contaminants
Microorganisms	Zoonosis	Salmonella, STEC
	Infectious Animal Diseases	
	Antibiotic Resistant Microorganisms	
Medical drugs	Antibiotics	Tetracyclins, Sulfonamides, Fluoroquinolones
	Antiparasitic drugs	Ivermectin
	Other medical drugs	
Other chemicals and substances	Nanoparticles	Microplastics
	Heavy metals	Copper, zinc, cadmium
	Dioxins	
	Biocides	
	Emerging contaminants	PFOS

4.4 Conclusions and future work

So far, a conceptual systems approach for the health and environmental risk assessment of organic fertilisers has been established. A long-list of possible harmful substances was presented. During workshops with experts from WUR and RIVM, per category priority substances were selected (as mentioned in Table 4.2).

In the forthcoming year(s), these priority substances will be evaluated according to the steps suggested in Figure 4.4. This will be achieved through a more intensive literature research and further workshops with experts in the field from WUR and from RIVM. These results will be summarised in a table with the priority substances as rows and the steps suggested in Figure 4.4 as columns. It will probably not be possible to fill the whole table after the literature study and workshops. The remaining gaps provide insight into where best future experimental work could be performed.

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5 Parameters that quantify the economic value

5.1 Introduction

This Chapter presents a framework for the assessment of the economic value of organic fertilisers. The use of organic fertilisers is an important, cutting-edge topic, insofar as it enhances the soil quality, which is crucial to circular agriculture, water quality and the reduction of climate issues.

Through the development of the Dutch Soil Strategy, the Dutch Government strives for 'good quality agricultural soils, which form the basis and a condition for realising the major challenging condition in the areas of climate, food security and safety, and biodiversity' (DGAN-PAV / 18081747; 23 May 2018). In this strategy, the key role of the use of organic fertilisers is recognised. The use of high-quality organic fertilisers is an important part of sustainable soil management, because it contributes to:

a. improved soil fertility.
b. improved organic matter quantity and quality management for the purposes of:
   i. crop growth;
   ii. a better soil structure for better moisture retention and a better permeability with a lower risk of runoff and leaching;
   iii. a healthy soil life, and a resilient arable and horticultural system;
   iv. carbon storage.
c. a reduction in the use of chemical inputs.
d. lower application risks of contamination of the soil with pollutants and pathogens.

However, although the use of organic fertilisers might be beneficial for climate-, environmental- and agricultural reasons, the question is if the use of organic fertilisers is also profitable for farmers? If the organic fertilisers are profitable, farmers will be happy to apply them. However, if these organic fertilisers are not profitable, other incentives have to be considered in order to stimulate farmers to apply them. Due to their contribution to environmental and climate issues, the use of organic fertilisers is not only a concern of the farmers, but also of society, in general.

Furthermore, soil quality is of concern to financers, landlords and drinking-water production companies. A good soil quality is of concern to financers and landlords insofar as it determines the economic value of the land and contributes to sustainability. Landlords are mainly concerned about maintenance of soil quality by the farmers to guarantee the economic value of the land. They are, therefore, interested in a tool to assess the economic value of their land.
The use of organic fertilisers that enhance the quality of the soil is also of concern to drinking-water companies, as good water quality correlates with high soil quality.

As so many stakeholders have an interest in high soil quality, it is in the interest of many to stimulate farmers' use of organic fertilisers. The question is, however, if farmers need extra incentives, and to what extent can the involved parties contribute to such incentives. In order to gain this insight, the benefits and costs of the use of organic fertiliser must be quantified for each party.

5.1.1 Research aspects of the economic value assessment

The effect of organic fertilisers on soil quality is a crucial element in the assessment of their economic value, as this might result in positive economic effects, such as higher crop yields and/or more efficient nutrient use, and a reduction of costs for the control of pests. Based on the net effect of benefits and costs, farmers will decide whether to apply organic fertilisers or not. If chain partners consider the use of organic fertilisers valuable, it might also improve the price of the agricultural products, which is also an incentive for the use of organic fertilisers. In this way, the intrinsic economic value of organic fertilisers is established. This value provides the maximum price that, based on economic principles, can be paid. However, whether this price will be paid or not, depends also upon the prices of alternative options. In European regions with an excess of manure, like the Netherlands, the economic value of manure is not based on its fertilisation value, but on the opportunity for manure disposal. This results in negative prices for manure. As manure forms an alternative source of organic matter for the farmer, the value of organic fertiliser depends also on negative prices of manure, which will affect the economic value of organic fertilisers negatively.

Financers, landlords and the drinking-water industry work together to develop a Dynamic Soil Index based on key performance indicators for soil quality. Organic matter in the soil is an important indicator of soil quality. Therefore, soil quality and the value of organic fertilisers are linked. As to if the Dynamic Soil index is an interesting starting point for the development of the economic framework will be analysed.

5.1.2 Approach

Three steps were distinguished for the development of the economic framework of organic fertilisers:
1. The development of a conceptual model in which the relations between the use of organic fertiliser and their effects on sustainability goals and economic value is described. The relevant stakeholders and their interaction as chain partners in relation to the use of organic fertilisers are also described.
2. Based on the conceptual model and identified relevant stakeholders, an interview scheme was developed to operationalise the conceptual model into a framework for the quantification of the economic value of organic fertilisers. Interviews were, therefore, conducted with different stakeholders, including chain partners in the production, processing and sales of dairy-, flower-bulb- and arable products:
   a. 3 from the primary sector: 1 dairy farmer, 1 flower bulb grower and 1 arable farmer;
   b. 2 processors, both in the arable sector;
   c. 1 flower bulb exporter;
   d. 1 retailer;
   e. 1 bank; and
   f. 1 institutional landowner/insurance company.
3. An analyses of the interview results.

The possible harmonisation between the Dynamic Soil Index and the economic assessment framework of organic fertilisers was investigated separately.

Section 5.2 presents the first step – the conceptual model. Steps two and three are presented in Section 5.3, as well as the possible linkages with the Dynamic Soil Index. Section 5.4 presents a synthesis and recommendations for further research.

5.2 Conceptual model for economic assessment of organic fertilisers

The focus in this Chapter is on the economic assessment of high-quality organic fertilisers. The relations among the use of organic fertilisers, their effects on soil quality and sustainability goals are presented in Figure 5.1. High-quality organic fertilisers contribute to a vital and well-functioning agricultural soil. Soils that are in good condition supply the crop with water and nutrients in a reliable, customised way, and contribute to the crop’s resistance against diseases and plagues. Overall, through these mechanisms, high-quality organic fertilisers have good effects on the climate, biodiversity and food security/safety. A customised supply of water and nutrients contributes to optimal plant growth and decreased emissions of nitrogen. An increased level of resistance contributes to lower pesticide inputs and to lower risks for food safety (residues). Lower emissions of nutrients and pesticides are also favourable for preserving or restoring biodiversity. Finally, livestock feed that grows on good soils contributes to high-quality manure.

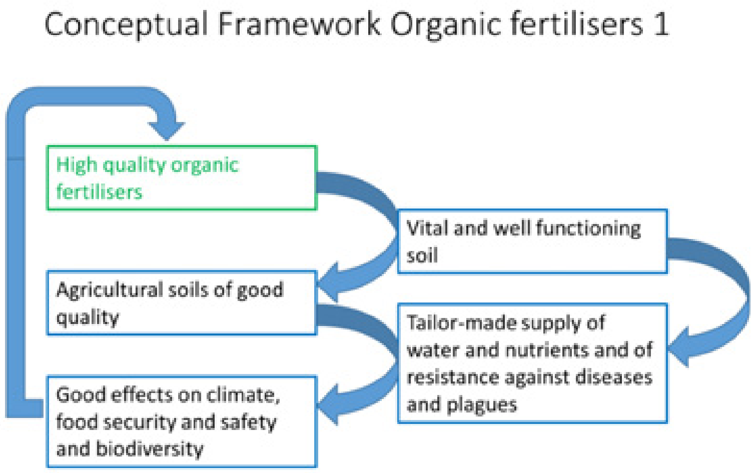

Figure 5.1 *Conceptual Framework and the relation with soil quality and sustainability goals.*

For the assessment of the economic value of such fertilisers, a number of questions need to be answered (Figure 5.2). Initially, we need to ascertain the effects of organic fertilisers on sustainable soil management, i.e. effects on soil fertility and organic matter quantity and quality. We need to select key indicators to quantify those characteristics, which are needed for the economic evaluation. Secondly, the economic value of these effects must be assessed, i.e. the effects on yield level and quality of crops/products, on costs of fertilisation, crop protection and tillage and on risks of yield loss.

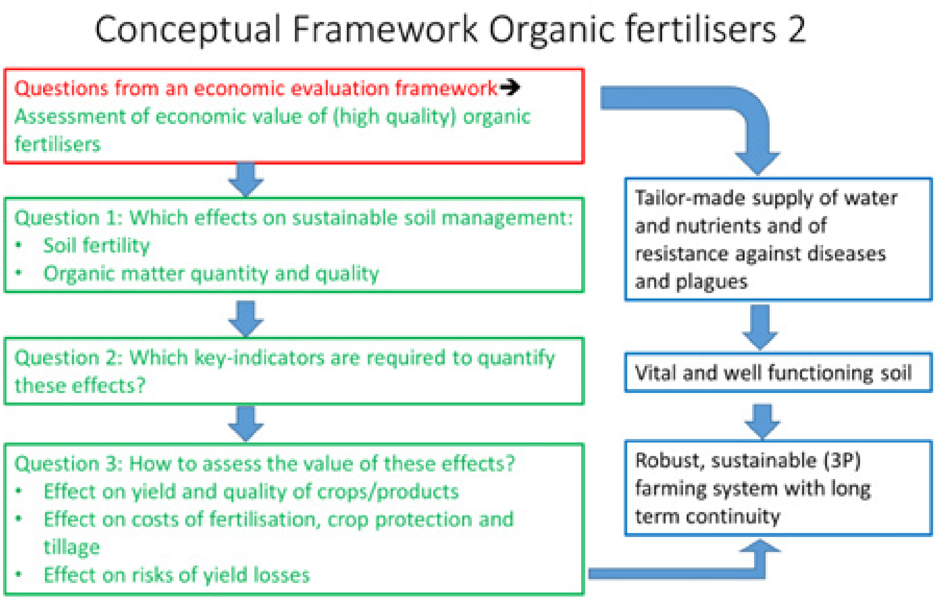

Figure 5.2 *Conceptual framework on the relation between the sustainability goals and research questions for the development of an economic evaluation framework.*

To be able to assess the effects listed, the idea was that the value of such effects is not only determined by the farmers (in the sense of direct costs and benefits), but also by other chain partners, who determine to a certain extent the required quality and the price of agricultural products, on one-hand (government, the end-user, consumer or, effectively, the retail), but also the price and the financing of land (land owners, banks, real estate companies) on the other-hand. These chain partners were all interviewed (Figure 5.3).

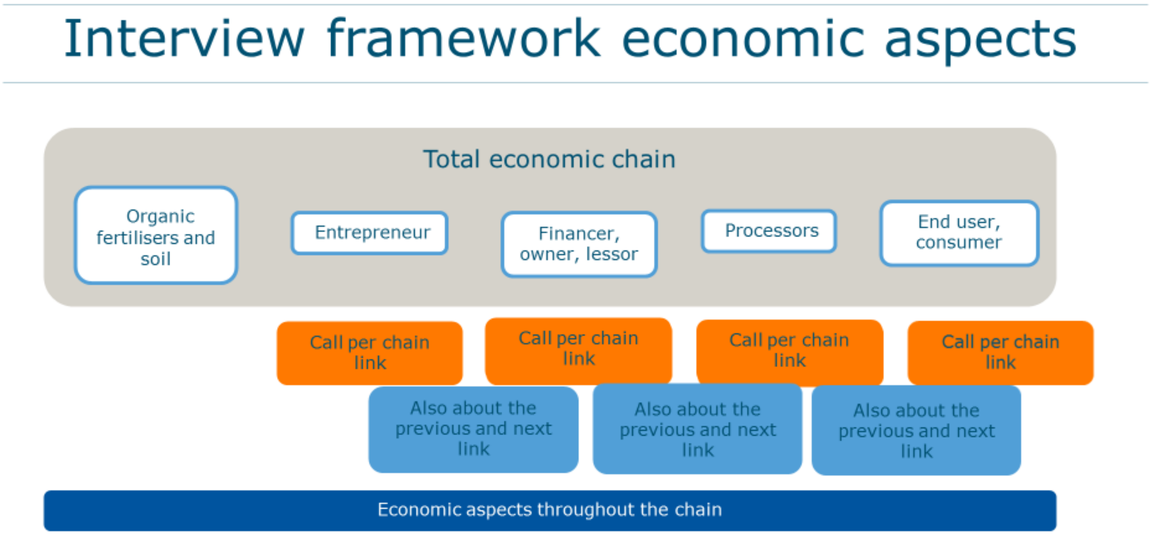

Figure 5.3 *Conceptual framework, the interview set-up.*

5.3 Results

5.3.1 Interview results

The interview results are presented in Table 5.1, including the results for the Dutch Government, which was not interviewed, but submitted its opinion via policy letters. The table is divided into an upper- and a lower-half, presenting the synthesis from two approaches: 1) From the perspective of organic fertilisers, and 2) From the point of view of soil quality. The first three columns give the entities that stakeholders mentioned in the interviews, the key performance indicators that they could derive from these, and the units of measurement involved. The indicators were given the typology 'profit', when the production process, the costs and benefits were involved; 'planet' when the environment and the climate were the focus; and 'people', when e.g. food safety was an issue.

Organic fertilisers
For organic fertilisers, many indicators were listed by farmers, mainly dealing with productivity of the soil expressed in high-yields and high-quality and, as a consequence, the profit of the farm (Table 5.1, upper part). The emission of ammonia and nitrate were mentioned as planet indicators, which were mainly determined by government policies. Most other indicators were not of interest for the other stakeholders, except for indicators that could affect their profit, such as chemical- and physical contaminations that could harm the equipment of the processors and/or human consumer health. The latter is also an important people indicator for the Government.

5.3.2 Soil quality

Organic fertilisers are applied to improve the soil quality and its fertilisation status (Table 5.1, lower-part). An improved soil quality is a way to reduce risks, e.g. in stabilising yields and quality, but also in improving more 'planet-like' indicators, like saving inputs and limitation of emissions. For farmers, all these indicators deal with profit aspects of their farm, including saving costs and maintaining the licensing necessary to produce. Processors are also interested in a decrease of variation of yields and quality, making their processing campaign more stable and efficient. That is a matter of profit for them and a ‘people aspect’ (constant quality) for retail and consumers.

The quality of the soil is important for farmers, but also for banks, other financing companies, and land owners, as this is an important determining factor for the productivity of the land. That is the basis for profitable crop margins for the farmers and, hence, also for the agricultural value of the land. For banks and land owners, it is of great importance that the agricultural value of the land is at least maintained and increased, if possible. Such an increase improves the value of their possessions and decreases the risks of farmers not being able to pay back their loans. Improved soil quality could stimulate land owners to decrease the lease price of land, as the farmers invest in that and the owner receives the premium. The owner could reward the farmers for their investment with a lower lease price and, thus, stimulate him or her to further improve the soil quality. However, drinking-water companies, like Vitens, also benefit from improved soil quality, as the soil will better absorb pesticides, so that such chemicals do not reach the drinking-water reservoirs so easily. This results in a reduction of purification costs. The last line (Table 5.1) deals with a landlord, who is willing to process grass that is harvested along the roadside, thus, reducing a municipality’s costs for the processing of that material as waste.

Dynamic Soil Index

In an interview with Rabobank, the relevance of the dynamic soil index as proposed by Rabobank, a.s.r. and Vitens for the development of the economic evaluation framework of organic fertilisers was discussed. Rabobank saw the relevance of the economic evaluation framework for this index; however, the dynamic soil index was started through focus on the environmental- and agricultural issues and indicators. The operationalisation of the economic indicators must be started, and this project might contribute to that process. Therefore, it was agreed that both projects will inform each other and work together where possible.

Land value

It is assumed that soil quality is important for land value, however, it is important to realise that approximately 50% of land value is based on its strategic value (Silvis, 2018). Whereas, the agricultural value of the land is determined by its agricultural productivity, the strategic value is largely determined by land supply and demand in the marketplace. In the market, the competition between building companies, municipalities and governments, drives the land prices up beyond their agricultural value.

Soil quality is only of concern for the agronomic value of the land. It has no effect on the strategic value of the land, which is mainly determined by the values of buildings and infrastructure. This means that the economic value of soil quality is only partly relevant for the economic value of the land.

Table 5.1 *Performance Indicators of application of organic fertilisers.*

Entity	Indicator	Unit	Farmers	Financers, land owners, banks, water company	Processors	Retail/consumer	Government
Approach from the point of view of organic fertilisers							
Nutrients	Known nutrient contents		**Profit**				
	- N, P, K	kg/tonne	**Profit**				
	- micro nutrients	kg/tonne	**Profit**				
	Ratio between nutrients		**Profit**				
	Share of availability of N, P, K for crop	%	**Profit**				
	Availability timing after application	months	**Profit**				
Conditions for application	Homogeneity/uniformity		**Profit**				
	Application precision		**Profit**				
Contaminants	Weeds, nematodes, fungi		**Profit**				
	Antibiotics, medicines		**Profit**		**Profit**	**People**	**People**
	Glass, plastics and other non-natural issues		**Profit**		**Profit**	**People**	
Organic matter content	Content	%, kg/tonne	**Profit**				
	C/N-ratio		**Profit**				
Costs of application	Costs of organic fertiliser	Euro/tonne	**Profit**				
	Costs of organic fertiliser application	Euro/tonne	**Profit**				
	Soil structure damage		**Profit**				
	Emission of NH3 and NO3	kg/tonne	**Planet**				**Planet**
Approach from the point of view of soil quality							
Effects on soil	Improving soil quality	% SOM	**Profit**	**Profit**			
Risk management	Quality of products		**Profit**		**Profit**	**People**	
	Yield variation		**Profit**		**Profit**		
	Saving inputs		**Profit**				**Planet**
	Limitation of emissions		**Planet**				**Planet**
Agricultural value of soil	Productivity, in margin	Euro/ha	**Profit**	**Profit**			
(excluding strategic value)							
Public costs	Purification costs of drinking water	euro/m3		**Profit**			**People**
	Recycling of waste by Municipality	euro/tonne		**Profit**			**Profit**

5.4 Synthesis and recommendations

5.4.1 Synthesis

Farmers know which indicators are important for the application of organic fertilisers, but the combined effects of these indicators on the economic importance is still unknown. This means that the economic value of organic fertilisers cannot yet be assessed by farmers.

Farmers and land-owners, investors and banks find the productivity of land an important indicator. As a consequence, there is an interest among all these stakeholders to further explore the relationship between organic matter in the soil and crop production. If these relations are quantified, and if the possible effects on product prices can be charted, both the effects on the farmers' income and on the agricultural value of the land can be determined. These effects will further determine the demand and accompanying prices that farmers are prepared to pay for organic fertilisers.
All other values aside, considering the economic value, the relationship between organic fertilisers and organic matter in the soil is only of concern for the farmers, as for other parties the strategic value of the land is more economically relevant.

5.4.2 Recommendations

The following recommendations are made for the analysis of the relationship between the use of organic fertilisers and their economic effects.

Economic value of organic fertilisers
For the assessment of the economic value of organic fertilisers, insight is needed into the benefits of these fertilisers for the farmer. It concerns the possible reductions in costs for fertilisation and pest management, the costs of application and possible yield increases, which will be different per crop, farm type, soil and groundwater table. Besides this intrinsic value of the organic fertilisers, the economic value depends of the prices of alternative options, like manure.
By synthesising the relations among organic fertilisers, organic matter in the soil, the effects on crop yield and alternative options into a bio-economic farm model, the trade-offs between agronomic- and economic goals could be analysed, providing insights into the current incentives for farmers to apply organic fertilisers.
For this, the quantification of the indicators in the scheme is required. This includes cooperation with soil- and plant scientists (see Chapter 3). The model will explore the effect of organic fertilisation on the farming system and the accompanying agronomic and economic aspects.
Insight into the economic effect of the use of organic fertiliser also provides the data needed to calculate the effects on the agronomic value of the land.
If, in the bio-economic model, the effects of organic fertiliser on the nitrate concentration in groundwater were also incorporated, the model would also provide insight into the effect of the use of organic fertiliser on the nitrate concentration in the groundwater. With these results, the economic benefits of organic fertilisers for the drinking-water industry could also be assessed. The nitrate concentration can be calculated based on N-surplus and soil- and farming system-specific leaching fractions (Groenendijk et al., 2016).

Land value and lease prices
Our second recommendation is to (further) develop and fine-tune the bio-economic model and test it with stakeholders in the field concerning its contribution to the assessment of the effects on land value, lease prices and costs for the improvement of the drinking water quality. One of them is the discussion as to whether the proposed indicators are useful for the Dynamic Soil Index or not. For this, a workshop will be organised with some of the people interviewed.
If the model works out well, it could serve as an independent and robust instrument to assess land sales and lease prices from the point of view of soil quality and the reward of farmers' soil improving activities.

Link with in-depth studies

A PhD-project was begun in February 2019, entitled: "The economic value of soil quality in arable and dairy farms in The Netherlands". This project can contribute to the KB-project, although its focus is not specifically on organic fertilisers. The PhD-project includes different soil quality measures including organic fertilisers, but also a cropping plan, the application of green manures, the type of tillage, etc. The economic value of soil quality (EVsq) represents the accumulated (future) discounted gross margins over a certain time-span. The aim of this PhD-project is to optimise current- and future soil and crop management, assuming that this results in long-term soil quality with the highest EVsq levels. Therefore, we investigate (1) the development of EVsq, (2) its assessment and (3) its application in decision-making. This holds for both arable- and dairy farms, while taking into account issues, such as; soil type, cropping plan, farming intensity, and impacts on business and financial risks. The methodology consists of developing a conceptual framework, the development of modules for soil, crop rotation, and economic aspects, as well as an optimisation model based on stochastic and robust optimisation techniques. This could be a good project to link-up with.

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6 Conclusions

In this study, a conceptual framework for the evaluation of organic fertilisers was developed to characterise organic fertilisers and to assess the agronomic-, environmental- and health aspects, as well as the economic aspects. The following conclusions were drawn:

- The determination of the biodegradability of organic matter from organic fertilisers in soils requires additional attention. Different available methods focus on different characteristics of organic matter, and the differences in derived parameters highly determines both the short- and long-term effects in soils, and, therefore, the agronomical- and environmental impacts.

- As the decomposition of applied organic matter and release of minerals often vary from a few to many decades, a model approach is needed to assess the impact on soil quality and the associated agronomic-, economic- and environmental aspects (both for the short- and long- term). The focus of agronomic- and economic aspects is on yield and the nutritional value of the organic fertiliser and the soil. The environmental aspects focus on CO_2 and N-emissions to the air, the N, P emissions to water and heavy metals accumulation in soil and crops.
- A selection of crop rotations on specific soil types was specified and will be used to predict the impact of different organic fertilisers on the soil quality and the agronomic aspects.
- An approach was developed to assess the costs of applying organic fertilisers and the costs of required additional mineral fertilisers to maintain a good nutritional status in the soil.

- A first listing of potentially unwanted substances, organisms or diseases that could be present in organic fertilisers was made, together with a short list of priority substances for three main categories and their subcategories, which are: (1) Microorganisms (zoonosis, infectious diseases, antibiotic resistant microorganisms (ARM); (2) Medical drugs (antibiotics, antiparasitics, other drugs); and (3) Other chemicals and substances (nanoparticles, dioxins, biocides, heavy metals and emerging contaminants).
- A preliminary matrix was set up to score the environmental- and health aspects of substances, which requires further extrapolation.
- A decision tree (pass/fail) approach was developed to evaluate priority substances in organic fertilisers. In the next phase for each of the steps in the decision tree, more detailed information must be collected.

- The economic value of organic fertilisers is mainly determined by the plant nutritional value of the organic fertiliser, the price of the organic fertiliser, the cost of application, the impact on the soil quality and yield and reduction in costs for pest management.
- Interviews with important stakeholders (farmers, financers, landlords and drinking-water industry organisations) showed that there is no practical approach to quantify the economic value of soil quality as yet.
- An economic approach is needed that combines the effects of applying organic fertilisers on the nutritional value and soil organic matter content of the soil, which requires further calculation in the next stage.

Annex 1 Description of fertilising products, new regulation

Product function category	Product function category	Description
1	Fertiliser	A fertiliser shall be an EU fertilising product, the function of which is to provide nutrients to plants or mushrooms.
1A	Organic fertiliser	An organic fertiliser shall contain - Organic carbon (Corg), and - Nutrients, of solely biological origin. Organic fertiliser may contain peat, Leonardite and lignite, but no other material which is fossilised or embedded in geological formations.
1B	Organo-mineral fertiliser	1. An organo-mineral fertiliser shall be a co-formulation of: (a) one or more inorganic fertilisers, as specified in PFC 1(C), and (b) one or more materials containing: — organic carbon (C org); and — nutrients of solely biological origin. An organo-mineral fertiliser may contain peat, leonardite and lignite, but no other material which is fossilized or embedded in geological formations. An organo-mineral fertiliser may contain peat, Leonardite and lignite, but no other material which is fossilized or embedded in geological formations.
1C	Inorganic fertiliser	An inorganic fertiliser shall be a fertiliser containing or releasing nutrients in a mineral form, other than an organic or organo-mineral fertiliser. In addition to the requirements of either PFC 1 (C) I or PFC 1 (C) II below; an inorganic fertiliser which contains more than 1% by mass of organic carbon (Corg), other than organic carbon (Corg) from: - chelating of complexing agents referred to in point 2a of CMC 1, from - nitrification inhibitor, urease inhibitors or denitrification inhibitors referred to in point 2b of CMC 1, from - coating agents referred to in point 1(a) of CMC 10, from - urea, or from - calcium cyanamide - shall meet the requirement that pathogens in an inorganic fertiliser must not exceed the limits set out in a table.
2	Liming material	A liming material shall be an EU fertilising product the function of which is to correct soil acidity. It shall contain oxides, hydroxides, carbonates or silicates of the nutrients calcium (Ca) or magnesium (Mg).
3	Soil improver	A soil improver shall be an EU fertilising product, the function of which is to maintain, improve or protect the
4	Growing medium	A growing medium shall be an EU fertilising product other than soil in situ, the function of which is for plants or mushrooms to grow in.
5	Inhibitor	An inhibitor shall be an EU fertilising product, the function of which is to improve the nutrient release patterns of a product, providing plants with nutrients by delaying or stopping the activity of specific groups of microorganisms or enzymes. A plant bio-stimulant shall be an EU fertilising product, the function of which is to stimulate plant nutrition processes independently of the product's nutrient content with the sole aim of improving one or more of the following characteristics of the plant and the plant rhizosphere: a nutrient use efficiency, b tolerance to abiotic stress, c quality traits, ca availability of confined nutrients in the soil and rhizosphere.
6	Plant bio-stimulant	A microbial plant bio-stimulant shall consist of a micro-organism or a consortium of microorganisms referred to in Component Material Category 7 of Annex II.
7	Blend	A fertilising product blend shall be an EU fertilising product composed of two of more EU fertilising products of Categories 1 – 6, for which the compliance with the requirements of this Regulation of each component fertilising product in the blend has been demonstrated in accordance with the conformity assessment procedure applicable to that component fertilising product.

Annex 2 Description of organic fertilisers, FAO term portal

Source: FAO term portal[32]

Biofertiliser: a substance containing live microorganism which, when used for plant production, increase the supply or availability of primary nutrients to plants through nitrogen fixation, phosphorus solubilisation and the stimulation of plant growth through the synthesis of growth-promoting substances (http://www.fao.org/3/a-a0443e.pdf).

Biosolid: Sludge and other residue deposits obtained from residual water treatment plants and from treatment applied to urban and industrial wastes (food industries or other types of industry), or Nutrient-rich organic materials resulting from the treatment of sewage sludge (the name for the solid, semisolid or liquid residue generated during the treatment of domestic sewage in a treatment facility). CAC/RCP 53-2003, FAO, 2017 (MU833).

Bio-stimulant: product that stimulates plant nutrition processes independently of nutrient content, with the aim of improving one or more of: the plants' nutrient use efficiency or uptake; tolerance to abiotic stress; or, crop quality traits COAG/2018/12, FAO, 2018 (MX544).

Digestate: solid material remaining after various digestion processes have been used on waste products, such as livestock manures COAG/2018/12, FAO, 2018 (MX544).

Inorganic fertiliser: a fertiliser produced industrially by chemical processes or mineral extraction. Note that though urea is technically an organic material, it is referred to within this Fertiliser Code as an inorganic fertiliser[33].

Organic fertiliser: a carbon-rich fertiliser derived from organic materials, including treated or untreated livestock manures, compost, sewage sludge and other organic materials used to supply nutrients to soils[34].

Organo-mineral fertiliser: Material obtained through blending or processing organic materials with mineral fertilisers to enhance their nutrient content and fertilising value (World Programme for the Census of Agriculture (WCA 2010), FAO Statistics Division, 2005).

[32] FAO Term Portal, http://www.fao.org/faoterm/news/en/, consulted on 23rd January 2019.
[33] http://www.fao.org/fileadmin/user_upload/bodies/COAG_Sessions/COAG_26/MX544_12/MX544_COAG_2018_12_en.pdf: consulted on 23rd January 2019.
[34] http://www.fao.org/fileadmin/user_upload/bodies/COAG_Sessions/COAG_26/MX544_12/MX544_COAG_2018_12_en.pdf: consulted on 23rd January 2019.

Annex 3 Agronomic function of organic fertilising products

Table A3.1 *Agronomic functions of organic fertilisers.*

Type designation of organic fertilising products	Main agronomic function	Main characteristic	Other functions and characteristics
Organic fertiliser	Maintenance of soil organic matter (SOM)	Organic carbon that effectively contributes to SOM	Source of nutrients and/or acid neutralising value and/or amelioration of soil physical condition and/or amelioration of biological soil quality
Organo-mineral fertiliser	Maintenance chemical soil fertility	Nutrients that effectively are plant available	Source of organic matter and/or amelioration of soil physical condition and/or amelioration of biological soil quality
Organic soil improver	Restoration and/or maintenance SOM and/or to prevent the loss of moisture, control weed growth, and reduce soil erosion (mulch)	Organic carbon that effectively contributes to SOM	Source of nutrients and/or acid neutralising value and/or amelioration of soil physical condition and/or amelioration of biological soil quality
Digestate	Maintenance chemical soil fertility	Nutrients that effectively are plant available	Source of nutrients, and/or acid neutralising value and/or amelioration of soil physical condition and/or amelioration of biological soil quality
Compost	Restoration and/or maintenance SOM	Organic carbon that effectively contributes to SOM	Source of nutrients, and/or acid neutralising value and/or amelioration of soil physical condition and/or amelioration of biological soil quality
Bio-stimulant	Enhancer of nutrient use efficiency	An enhancing function that cannot be contributed to organic carbon and/or nutrients but to other, still to be defined, components.	[-][35] Plant strength-enhancing microorganisms
Growing media	Support of root growth	Substrate for root development, in which plants are grown.	Source of nutrients and/or amelioration of substrate physical condition and/or amelioration of biological substrate quality
Blends	Maintenance SOM and/or maintenance of chemical soil fertility and/or Restoration and/or maintenance SOM and/or Enhancer of nutrient use efficiency and/or (support of root growth)	Depending of the blend, any of the above given characteristics. In general blends serve organo-mineral fertiliser production.	Source of organic carbon, nutrients and/or acid neutralising values and/or amelioration of soil/substrate physical condition and/or amelioration of biological soil/substrate quality

[35] Rate of application is too low to bear significance as a source of organic carbon or nutrients.

Annex 4 Standards for value giving components according to the new European regulation for organic fertilising products

PFC no	PFC sub-category	Dry matter	C_{org}	N	N from NH_4NO_3	N organic	P_2O_5	K_2O	N+ P_2O_5+ K_2O
1A	***Organic fertiliser***								
1(A)(I)	Solid organic fertiliser, straight		15	2.5			2	2	*
1(A)(I)	Solid organic fertiliser, compound		15	1			1	1	4
1(A)(II)	Liquid organic fertiliser, straight		5	2			1	2	*
1(A)(II)	Liquid organic fertiliser, compound		5	1			1	1	3
1B	***Organo-mineral fertiliser***								
1(B)(I)	Solid organo-mineral fertiliser, straight		7.5	2.5	<16	1	2	2	*
1(B)(I)	Solid organo-mineral fertiliser, compound		7.5	2	<16	0.5	2	2	8
1(B)(II)	Liquid organo-mineral fertiliser, straight		3	2	<16	0.5	2	2	
1(B)(II)	Liquid organo-mineral fertiliser, compound		3	2	<16	0.5	2	2	6
3	***Soil improver***								
3A	Organic soil improver	20	7.5						

Annex 5 Standards for contaminants according to the new European regulation for organic fertilising products

PFC No	PFC category	PFC sub-category	mg/kg DM							
			Inorganic As	Cd	Cu	CrVI	Hg	N	Pb	Zn
1A	***Organic fertiliser***		40	1.5	300	2	1	50	120	800
1B	***Organo-mineral fertiliser***	< 5%P_2O_5	40	3	600	2	1	50	120	1500
		≥ 5%P_2O_5	40	60	600	2	1	50	120	1500
3	***Soil improver***									
3A	Organic soil improver		40	2	300	2	1	50	120	800

Annex 6 Standards for pathogens according to the new European regulation for organic fertilising products

Micro-organisms to be tested	Sampling plans			Limit
	n	C	m	M
Samonella spp.	5	0	0	Absence in 25 g or 25 ml
Escherichia coli or *Enterococcaceae*	5	5	0	1000 in 1g or 1 ml

where n = number of samples to be tested.
c = number of samples where the number of bacteria expressed in CFU may be between m and M.
m = threshold value for the number of bacteria expressed in CFU that is considered satisfactory.
M = maximum value of the number of bacteria expressed in CFU.

Annex 7 Volume of manure production in the Netherlands and the estimated processed manure thereof

Table A7.1 *Volume of manure production in the Netherlands and the estimated processed manure thereof (CBS, 2018; BMA, 2018).*

Treatment	**Type designation**	**Manure production**		**Phosphate**
		Liquid	**Solid**	
		10^3 kton	10^3 kton	10^6 kg P_2O_5
Non processed (CBS, 2018)	Cattle,	60.4	0.5	
	Beef cattle	3.2	0.0	
	Pig	10.1	0.0	
	Poultry	0.0	1.4	
	Sheep & goat	1.1	0.5	
	Fur-bearing animal & rabbit	0.2	0.0	
	Horse & pony	0.2	0.4	
	Total manure	75.2	2.7	168
Processed (CBS, 2014)	Compost (green compost, vegetable-fruit-garden compost)			3
Processed (BMA, 2018)	Pelletised manure 90% dry matter			7.6
	Sanitised thick-fraction manure			0.1
	Sanitised animal slurry			1.3
	Sanitised digestate			0.5
	Sanitised thick-fraction digestate			2.4
	Sanitised thick-fraction manure			0.4
	Dried manure			0.01
	Dried digestate			1.1
	Composted manure			10.2
	Other (poultry litter, ash, etc.)			9.3
	Total			33

Annex 8 Standards for manure

Analytical requirements for analyses of animal manure according to the Fertiliser Act of the Netherlands.

Source: Implementing regulation of the Fertiliser Act, Annex H.

Requirements for the test laboratory:
NEN-EN-ISO/IEC 17025:2018 en: General requirements for the competence of testing and calibration laboratories

Designated analytical methods:

- NEN 7430: Manure and derivatives - Sample pre-treatment by homogenisation – Slurries. *Dierlijke mest en mestproducten. Monstervoorbehandeling door homogeniseren. Drijfmest (in Dutch);*

- NEN 7431: Manure and derivatives - Sample pre-treatment by mixing, drying and milling – Manure. *Dierlijke mest en mestproducten. Monstervoorbehandeling door mengen, drogen en malen. Stapelbare mest (in Dutch);*

- NEN 7433: Manure and derivatives - Sample pre-treatment for the determination of nitrogen, phosphorus, and potassium - Destruction with sulphuric acid, hydrogen peroxide and copper sulphate. *Dierlijke mest en mestproducten. Monstervoorbehandeling voor de bepaling van stikstof, fosfor en kalium. Ontsluiting met zwavelzuur, waterstofperoxyde en kopersulfaat (in Dutch);*

- NEN-EN 14672:2005: Characterisation of sludges - Determination of total phosphorus. This standard applies within the Fertiliser Act only on mineral concentrates i.e. fertilising products process of manure separation into a liquid and solid fraction followed by an inverse osmosis treatment of the liquid fraction.

Designated reference methods:

- NEN 7434: Manure and derivatives - Determination of the nitrogen content in digests. *Dierlijke mest en mestproducten. Bepaling van het gehalte aan stikstof in destruaten (in Dutch);*

- NEN 7435 (under draft, *2^e draft*): Manure and derivatives - Determination of the phosphorus content in digests (). *Dierlijke mest en mestproducten. Bepaling van het gehalte aan fosfor in destruaten (in Dutch);*

- NEN 7437: Manure and derivatives - Determination of the total nitrogen content. *Dierlijke mest en mestproducten. Bepaling van het gehalte aan totaal stikstof (in Dutch).* Mineralconcentrate.

Annex 9 Standards for compost

NTA 8777:2011 en - Validation of processes in facilities transforming manure and/or other animal by-products into biogas or compost - Method including material spiked with *Enterococcus faecalis.*

NEN-EN 16087-2:2011 en - Soil improvers and growing media - Determination of the aerobic biological activity - Part 2: Self heating test for compost.

NEN-ISO 16929:2013 en - Plastics - Determination of the degree of disintegration of plastic materials under defined composting conditions in a pilot-scale test.

NEN-EN 14045:2003 en - Packaging - Evaluation of the disintegration of packaging materials in practical oriented tests under defined composting conditions.

NEN-EN 13432:2000 en - Packaging - Requirements for packaging recoverable through composting and biodegradation - Test scheme and evaluation criteria for the final acceptance of packaging.

NEN-EN-ISO 20200:2015 en - Plastics - Determination of the degree of disintegration of plastic materials under simulated composting conditions in a laboratory-scale test.

NEN-EN-ISO 14855-1:2012 en - Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions - Method by analysis of evolved carbon dioxide – Part 1: General method.

NEN-EN-ISO 14855-2:2018 en - Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions - Method by analysis of evolved carbon dioxide – Part 2: Gravimetric measurement of carbon dioxide evolved in a laboratory-scale test.

NEN-ISO 17088:2012 en - Specifications for compostable plastics.

NEN-ISO 17126:2005 en - Soil quality - Determination of the effects of pollutants on soil flora - Screening test for emergence of lettuce seedlings (Lectuca sativa L.).

NEN-ISO 21501-1:2009 en - Determination of particle size distribution - Single particle light interaction methods - Part 1: Light scattering aerosol spectrometer.

NEN-EN 14995:2007 en - Plastics - Evaluation of compostability - Test scheme and specifications.

NEN-EN 13592:2017 en - Plastics sacks for household waste collection - Types, requirements and test methods.

NEN-EN 16171:2016 en - Sludge, treated biowaste and soil - Determination of elements using inductively coupled plasma mass spectrometry (ICP-MS).

NEN-EN-ISO 11269-1:2012 en - Soil quality - Determination of the effects of pollutants on soil flora - Part 1: Method for the measurement of inhibition of root growth.

NEN-EN-ISO 10210:2018 en - Plastics - Methods for the preparation of samples for biodegradation testing of plastic materials.

NEN-EN-ISO 14851:2004 en - Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium - Method by measuring the oxygen demand in a closed respirometer.

NEN-EN-ISO 14852:2018 en - Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium - Method by analysis of evolved carbon dioxide.

NEN-EN-ISO 16198:2015 en - Soil quality - Plant-based test to assess the environmental bioavailability of trace elements to plants.

ASTM D5929 - 18 en - Standard Test Method for Determining Biodegradability of Materials Exposed to Source-Separated Organic Municipal Solid Waste Mesophilic Composting Conditions by Respirometry.

ASTM D5975 - 17 en - Standard Test Method for Determining the Stability of Compost by Measuring Oxygen Consumption.

ASTM D5338 - 15 en - Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions, Incorporating Thermophilic Temperatures.

ASTM D6340 - 98(2007) en - Standard Test Methods for Determining Aerobic Biodegradation of Radiolabeled Plastic Materials in an Aqueous or Compost Environment.

ISO 18763:2016 en - Soil quality - Determination of the toxic effects of pollutants on germination and early growth of higher plants.

ISO 18606:2013 en - Packaging and the environment - Organic recycling.

ISO 29200:2013 en - Soil quality - Assessment of genotoxic effects on higher plants - Vicia faba micronucleus test.

ASTM D6400 - 12 en - Standard Specification for Labelling of Plastics Designed to be Aerobically Composted in Municipal or Industrial Facilities.

ASTM D6868 - 17 en - Standard Specification for Labelling of End Items that Incorporate Plastics and Polymers as Coatings or Additives with Paper and Other Substrates Designed to be Aerobically Composted in Municipal or Industrial Facilities.

ASTM D7444 - 18a en - Standard Practice for Heat and Humidity Aging of Oxidatively Degradable Plastics.

ASTM D6954 - 18 en - Standard Guide for Exposing and Testing Plastics that Degrade in the Environment by a Combination of Oxidation and Biodegradation.

ASTM E3073 - 17 en - Standard Guide for Development of Waste Management Plan for Construction, Deconstruction, or Demolition Projects.

CEN/TR 15463:2007 en - Characterisation of sludge - Physical consistency - Thixotropic behaviour and piling behaviour.

Annex 10 Standards for biochar

Analytical methods European Biochar Certificate[36]

Sample preparation, DIN 51701-3:2006-09, Testing of solid fuels - Sampling and sample preparation - Part 3: Sample preparation (in German).

Bulk density, analogue VDLUFA-Method A 13.2.1, *Bestimmung der Rohdichte (Volumengewicht) von gärtnerischen Erden und Substraten ohne sperrige Komponenten* (in German).

Electrical conductivity (salt content), Method of the BGK (Federal quality community compost), volume 1, method III. C2 – in analogy to DIN ISO 11265: ISO 11265:1994 Soil quality -- Determination of the specific electrical conductivity.

pH-value, DIN ISO 10390 ($CaCl_2$): ISO 10390:2005 Soil quality -- Determination of pH.

Water content, DIN 51718: 2002 testing of solid fuels - determination of the water content and the moisture of analysis sample.

Thermogravimetry, (TGA laboratory standard Eurofins Umwelt Ost GmbH).

Carbonate CO_2 analogue (inorganic C), DIN 51726: Testing of solid fuels - Determination of the carbonate carbon dioxide content (in German).

CHN, according to DIN 51732: 2014 Testing of solid mineral fuels - determination of total carbon, hydrogen and nitrogen - instrumental methods (in German).

Sulfur, according to DIN 51724-3: DIN 51724-3:2012-07 Solid mineral fuels - Determination of sulfur content - Part 3: Instrumental methods (in German).

Oxygen, (calculation) according to DIN 51733: DIN 51733:2016-04 Testing of solid mineral fuels - Ultimate analysis and calculation of oxygen content C_{org}, H/C und O/C (calculation).

PAH, analogue to DIN EN 15527 (extraction with Toluol) GC-MS (DIN CEN/TS 16181):

> DIN EN 15527:2008-09 Characterization of waste - Determination of polycyclic aromatic hydrocarbons (PAH) in waste using gas chromatography mass spectrometry (GC/MS); German version EN 15527:2008.
>
> DIN CEN/TS 16181:2013-12;DIN SPEC 91243:2013-12 DIN SPEC 91243:2013-12. Sludge, treated bio-waste and soil - Determination of polycyclic aromatic hydrocarbons (PAH) by gas chromatography (GC) and high performance liquid chromatography (HPLC); German version CEN/TS 16181:2013.

[36] European Biochar Certificate, http://www.european-biochar.org/en/analytical%20methods, consulted 23rd November 2018.

Trace metals, after microwave-assisted digestion according to DIN 22022-2, DIN 22022-7, DIN EN ISO 17294-2 / DIN EN 1483:

DIN 22022-2:1999-10 - Draft Solid fuels - Determination of contents of trace elements – Part 2: ICP-OES.

DIN 22022-1:2014-07 Solid fuels - Determination of contents of trace elements - Part 1: General rules, sampling and sample preparation - Preparation of samples for the analyses (dissolution method).

ISO 17294-2:2016 Water quality -- Application of inductively coupled plasma mass spectrometry (ICP-MS) -- Part 2: Determination of selected elements including uranium isotopes.

DIN EN 1483:2007-07 Water quality - Determination of mercury - Method using atomic absorption spectrometry; German version EN 1483:2007.

Main elements after melting digestion DIN 51729-11, DIN EN ISO 11885 / DIN EN ISO 17294-2:

DIN 51729-11: 1998. Testing of solid fuels - determination of chemical composition of fuel ash - part 11: determination by inductively coupled plasma emission spectrometry (icp-oes);

ISO 11885:2007. Water quality -- Determination of selected elements by inductively coupled plasma optical emission spectrometry (ICP-OES);

ISO 17294-2:2016 Water quality -- Application of inductively coupled plasma mass spectrometry (ICP-MS) -- Part 2: Determination of selected elements including uranium isotopes.

Gross calorific value / net calorific value according to DIN 51900:

DIN 51900-1 Determining the gross calorific value of solid and liquid fuels using the bomb calorimeter, and calculation of net calorific value - Part 1: General information.

DIN 51900-2 Testing of solid and liquid fuels - Determination of the gross calorific value by the bomb calorimeter and calculation of the net calorific value - Part 2: Method using isoperibol ot static, jacket calorimeter.

Ash content (815 °C) DIN 51719:

DIN 51719 Determination of ash in solid mineral fuels.

Volatile matter according to DIN 51720:

DIN 51720 Testing of solid fuels - Determination of volatile matter content.

Water holding capacity (WHC) according to DIN ISO 14238-2011:

ISO 14238 Soil quality — Biological methods — Determination of nitrogen mineralization and nitrification in soils and the influence of chemicals on these processes. Annex A Determination of water-holding capacity of soil.

Annex 11 Standards for growing media

NEN-EN 12579:2013 en - Soil improvers and growing media – Sampling.

NEN-EN 12580:2013 en - Soil improvers and growing media - Determination of a quantity (in Dutch volumebepaling).

NEN-EN 13037:2011 en - Soil improvers and growing media - Determination of pH.

NEN-EN 13038:2011 en - Soil improvers and growing media - Determination of electrical conductivity.

NEN-EN 15428:2007 en - Soil improvers and growing media - Determination of particle size distribution.

NEN-EN 13650:2001 en - Soil improvers and growing media - Extraction of aqua regia soluble elements.

NEN-EN 16086-1:2011 en - Soil improvers and growing media - Determination of plant response - Part 1: Pot growth test with Chinese cabbage.

NEN-EN 15761:2009 en -Pre-shaped growing media - Determination of length, width, height, volume and bulk density.

NEN-EN 13652:2001 en - Soil improvers and growing media - Extraction of water soluble nutrients and elements.

NEN-EN 16086-2:2011 en - Soil improvers and growing media - Determination of plant response - Part 2: Petri dish test using cress.

NEN-EN 13654-1:2001 en - Soil improvers and growing media - Determination of nitrogen - Part 1: Modified Kjeldahl method.

NEN-EN 13651:2001 en - Soil improvers and growing media - Extraction of calcium chloride/DTPA (CAT) soluble nutrients.

NEN-EN 13654-2:2001 en - Soil improvers and growing media - Determination of nitrogen - Part 2: Dumas method.

NEN-EN 16087-1:2011 en - Soil improvers and growing media - Determination of the aerobic biological activity - Part 1: Oxygen uptake rate (OUR).

NEN-EN 13039:2011 en - Soil improvers and growing media - Determination of organic matter content and ash.

NEN-EN 15238:2007 en - Soil improvers and growing media - Determination of quantity for materials with particle size greater than 60 mm.

NEN-EN 13041:2011 en - Soil improvers and growing media - Determination of physical properties - Dry bulk density, air volume, water volume, shrinkage value and total pore space.

NEN-EN 16087-2:2011 en - Soil improvers and growing media - Determination of the aerobic biological activity - Part 2: Self heating test for compost.

NEN-EN 13040:2007 en - Soil improvers and growing media - Sample preparation for chemical and physical tests, determination of dry matter content, moisture content and laboratory compacted bulk density.

NPR-CR 13456:1999 en - Soil improvers and growing media - Labelling, specifications and product schedules.

ASTM E2788/E2788M - 18 en - Standard Specification for Use of Expanded Shale, Clay and Slate (ESCS) as a Mineral Component in the Growing Media and the Drainage Layer for Vegetative (Green) Roof Systems.

NPR-CR 13455:1999 en - Soil improvers and growing media - Guidelines for the safety of users, the environment and plants.

NPR-CEN/TR 15214-2:2006 en - Characterization of sludges - Detection and enumeration of Escherichia coli in sludges, soils, soil improvers, growing media and biowastes - Part 2: Miniaturised method (Most Probable Number) by inoculation in liquid medium.

NPR-CEN/TR 15214-3:2006 en - Characterization of sludges - Detection and enumeration of Escherichia coli in sludges, soils, soil improvers, growing media and biowastes - Part 3: Macromethod (Most Probable Number) in liquid medium.

NPR-CEN/TR 15214-1:2006 en - Characterization of sludges - Detection and enumeration of Escherichia coli in sludges, soils, soil improvers, growing media and biowastes - Part 1: Membrane filtration method for quantification.

ASTM E3161 - 18 en - Standard Practice for Preparing a Pseudomonas aeruginosa or Staphylococcus aureus Biofilm using the CDC Biofilm Reactor.

CEN/TR 15215-2:2006 en - Characterization of sludges - Detection and enumeration of Salmonella spp. in sludges, soils, soil improvers, growing media and bio-wastes - Part 2: Liquid enrichment method in selenite-cystine medium followed by Rapport-Vassiliadis for semi-quantitative Most Probable Number (MPN) determination.

CEN/TR 15215-1:2006 en - Characterization of sludges - Detection and enumeration of Salmonella spp. in sludges, soils, soil improvers, growing media and biowastes - Part 1: Membrane filtration method for quantitative resuscitation of sub-lethally stressed bacteria (to confirm efficacy of log drop treatment procedures).

CEN/TR 15215-3:2006 en - Characterization of sludges - Detection and enumeration of Salmonella spp. in sludges, soils, soil improvers, growing media and biowastes - Part 3: Presence/absence method by liquid enrichment in peptone-novobiocin medium followed by Rapport Vassiliadis.

NPR-CEN/TS 16201:2013 en - Sludge, treated biowaste and soil - Determination of viable plant seeds and propagules.

Annex 12 Annex Characterization of sludges

CEN/TR 13097:2010 (WI=00308091) Characterization of sludges - Good practice for sludge utilisation in agriculture.

CEN/TR 13983:2003 (WI=00308033) Characterization of sludges - Good practice for sludge utilisation in land reclamation.

CEN/TR 15126:2005 (WI=00308044) Characterization of sludges - Good practice for landfilling of sludges and sludge treatment residues.

CEN/TR 15175:2006 (WI=00308057) Characterization of sludges - Protocol for organizing and conducting inter-laboratory tests of methods for chemical and microbiological analysis of sludges.

CEN/TR 15214-1:2006 (WI=00308061) Characterization of sludges - Detection and enumeration of Escherichia coli in sludges, soils, soil improvers, growing media and biowastes - Part 1: Membrane filtration method for quantification.

CEN/TR 15214-2:2006 (WI=00308062) Characterization of sludges - Detection and enumeration of Escherichia coli in sludges, soils, soil improvers, growing media and biowastes - Part 2: Miniaturised method (Most Probable Number) by inoculation in liquid medium.

CEN/TR 15214-3:2006 (WI=00308063) Characterization of sludges - Detection and enumeration of Escherichia coli in sludges, soils, soil improvers, growing media and biowastes - Part 3: Macromethod (Most Probable Number) in liquid medium.

CEN/TR 15215-1:2006 (WI=00308064) Characterization of sludges - Detection and enumeration of Salmonella spp. in sludges, soils, soil improvers, growing media and biowastes - Part 1: Membrane filtration method for quantitative resuscitation of sub-lethally stressed bacteria (to confirm efficacy of log drop treatment procedures).

CEN/TR 15215-2:2006 (WI=00308065) Characterization of sludges - Detection and enumeration of Salmonella spp. in sludges, soils, soil improvers, growing media and biowastes - Part 2: Liquid enrichment method in selenite-cystine medium followed by Rapport-Vassiliadis for semi-quantitative Most Probable Number (MPN) determination.

CEN/TR 15215-3:2006 (WI=00308066) Characterization of sludges - Detection and enumeration of Salmonella spp. in sludges, soils, soil improvers, growing media and biowastes - Part 3: Presence/absence method by liquid enrichment in peptone-novobiocin medium followed by Rapport-Vassiliadis.

CEN/TR 15252:2006 (WI=00308067) Characterization of sludges - Protocol for validating methods for physical properties of sludges.

CEN/TR 15463:2007 (WI=00308075) Characterization of sludges - Physical consistency - Thixotropic behaviour and piling behaviour.

CEN/TR 15473:2007 (WI=00308068) Characterization of sludges - Good practice for sludges drying.

CEN/TR 15584:2007 (WI=00308076) Characterisation of sludges - Guide to risk assessment especially in relation to use and disposal of sludges.

CEN/TR 15809:2008 (WI=00308089) Characterization of sludges - Hygienic aspects – Treatments.

CEN/TR 16394:2014 (WI=00308096) Characterization of sludges - Protocol for preparing synthetic suspensions.

CEN/TR 16394:2014/AC:2015 (WI=00308C01) Characterization of sludges - Protocol for preparing synthetic suspensions.

CEN/TR 16456:2013 (WI=00308069) Characterization of sludges - Good practice of sludge dewatering.

CEN/TR 16788:2014 (WI=00308108) Characterization of sludges - Guideline of good practice for thermal processes.

CEN/TS 13714:2013 (WI=00308107) Characterization of sludges - Sludge management in relation to use or disposal.

CR 13846:2000 (WI=00308008) Recommendations to preserve and extend sludge utilization and disposal routes.

EN 12880:2000 (WI=00308009) Characterization of sludges - Determination of dry residue and water content.

EN 13342:2000 (WI=00308011) Characterization of sludges - Determination of Kjeldahl nitrogen.

EN 14671:2006 (WI=00308012) Characterization of sludges - Pre-treatment for the determination of extractable ammonia using 2 mol/l potassium chloride.

EN 14672:2005 (WI=00308034) Characterization of sludges - Determination of total phosphorus.

EN 14701-1:2006 (WI=00308037) Characterisation of sludges - Filtration properties - Part 1: Capillary suction time (CST).

EN 14701-2:2013 (WI=00308106) Characterisation of sludges - Filtration properties - Part 2: Determination of the specific resistance to filtration.

EN 14701-3:2006 (WI=00308041) Characterization of sludges - Filtration properties - Part 3: Determination of the compressibility.

EN 14701-4:2018 (WI=00308111) Characterization of sludges - Filtration properties - Part 4: Determination of the drainability of flocculated sludge.

EN 14702-1:2006 (WI=00308039) Characterisation of sludges - Settling properties - Part 1: Determination of settleability (Determination of the proportion of sludge volume and sludge volume index).

EN 14702-2:2006 (WI=00308054) Characterisation of sludges - Settling properties - Part 2: Determination of thickenability.

EN 14702-3:2019 (WI=00308110) Characterisation of sludges - Settling properties - Part 3: Determination of zone settling velocity (ZSV).

EN 14742:2015 (WI=00308100) Characterization of sludges - Laboratory chemical conditioning procedure.

EN 15170:2008 (WI=00308038) Characterization of sludges - Determination of calorific value.

EN 16720-1:2016 (WI=00308102) Characterization of sludges - Physical consistency - Part 1: Determination of flowability - Method by extrusion tube apparatus.

EN 17183:2018 (WI=00308112) Characterization of sludge - Evaluation of sludge density.

EN ISO 16720:2007 (WI=00308078) Soil quality - Pre-treatment of samples by freeze-drying for subsequent analysis (ISO 16720:2005).

EN ISO 5667-13:2011 (WI=00308090) Water quality - Sampling - Part 13: Guidance on sampling of sludges (ISO 5667-13:2011).

EN ISO 5667-15:2009 (WI=00308088) Water quality - Sampling - Part 15: Guidance on the preservation and handling of sludge and sediment samples (ISO 5667-15:2009).

Annex 13 Overview of soil indicators for the evaluation

	Nr	Indicator	Unit	Classical method	Cheaper/Faster method [2]
Organic Matter	1	Organic matter / carbon content	%	Loss on Ignition / Dumas	NIRS
	2	Stable fraction organic matter	%	Oxidation permanganate (POXC)	n.a.
	3	Labile fraction organic matter	mg kg^{-1}, g ha^{-1}	Hot Water-extractable carbon (HWC)	n.a.
Fysical	4	Water Holding Capacity	%, mm	water column method and pressure plates method	assessed from texture + SOM
	5	Aggregate stability	-	Wet sieving	n.b.
	6	Texture	%	Pipette	NIRS
	7	Penetration resistance	MPa	Penetrometer	
	8	Bulk Density (dry)	kg m^{-3}	Mass after drying at 105° C	Assessed from SOM
Chemical	9	Acidity (pH)	-	Extraction in $CaCl_2$	
	10	N-total	g kg^{-1}, kg ha^{-1}	Kjeldahl	NIRS
	11	Potential Mineralisation of Nitrogen (PMN)	mg kg^{-1}, g ha^{-1}	Anaerobic incubation	NIRS
	12	Phosphate status[3]	mg 100 g^{-1}, g kg^{-1}, kg ha^{-1} mg 100 ml^{-1}	Extraction in ammonium lactate-acid, $CaCl_2$ resp. water	
	13	Kalistatus[3]	mg 100 g^{-1}, $mmol^{+}$/kg, g kg^{-1}, kg ha^{-1}	Extraction in HCl en oxalic acid	NIRS + Extraction in $CaCl_2$
Biological	14	Nematode number and diversity (incl. plant parasitic)	# taxa # 100 ml^{-1} soil	Microscopy	PCR
	15	Bacterial- and fungal biomass	μg kg^{-1}	PLFA	NIRS
	16	Earthworm number and diversity	# m^{-2}, kg m^{-2}	Visual	n.a.
General	17	Visual assessment (physical-chemical-biological)	Several	Visual	n.a.

1 From a soil quality / fertilisation approach.

2 N.a. means currently unavailable, but desired. If empty, the classical method is cheap and fast.

3 The nature of the indicator may differ per agricultural sector.

Annex 14 Results from inventory workshop on substances and their relevance and risks

Column	**Relevant question/aspect**
Specific compound	What are the most important examples in this category; top 3
Relevant in product	Focus on animal manure and sludge WWTP
Level in matrix	Which levels are expected vor the specific substances in the matrix? Is that a problem? --> If yes, red. If not: fill in the other columns (in case it is applied).
Measurable in soil/ranges	Is the substance measurable in soil and what are the ranges
Emission to water	Mobility in soil. High / Low
Effects on:	What are the effects of he substance / organism etc on:
- product	
- soil	
- water	
- crops - does it grow?	
- crop - does it comply (for animal/human consumption)?	
- animal and animal products	
- humans (via food/contact)	
Abbreviations	
ARM	Antibiotica Resistente Microorganismen
CPE	carbapenemase-producing Enterobacteriaceae
ESBL	Extended Spectrum Beta-Lactamase. This is an enzyme that certain antibiotic species can degrade (penicillines and cefalosporines). This term is sometimes used for the bacteria who produce this enzyme.
MRSA	Meticilline-resistant Staphylococcus aureus
PAH's	polycyclic aromatic hydrocarbons
PCB	polychloorbifenyl
PFAS	PerFluor-Alkyl Substances (o.a. gen-X)
PFOS	perfluorooctane sulfonate
PRRS	Porcine reproductive and respiratory syndrome
(red)	Category and substance/organism: highest priority to test
(yellow)	follow in the nackground, lower priority, incidental measurements

Categories	Specific substance/organism/disease	Relevant in matrix (1= animal manure; 2= sewage sludge)	Level in matrix fresh product	Measurable in matrix/soil (incl ranges)	national - incidental
Zoönoses	Salmonella	1, 2	1 high; 2 low	Yes: 0 - >1000/g	national
	Influenza				
	Hepatitis E	1 (mainly pig)	1 high; 2 low	Yes, log 3 - 5 (g pig manure)	National
	STEC	1,2 (mainly cow)	1 low; 2 low	Yes: 0 - >1000/g	Incidental
	Campylobacter	1, 2	Low	Yes: 0 - >1000/g	National
	Coxiella brunetii	1 (goat, cow)	1 low; 2 low	Present or not (detection limit?)	Incidental
	Listeria	n.a.			
	Cryptosporidium parvum	1, 2?	1 high; 2 low	Present or not (detection limit?)	National
	?				
Contagious animal diseases	avian Influenza	1			
	pathogenic coli's (weening diarrhoea, baccilosis)	1, 2	1 low; 2 low	Present or not (detection limit?)	Incidental
	PRRS	1			
	Lawsonia intracellularis	1	Low		
	Brachyspira hyodysenteriae	1	Low		
	Partuberculose	1	Low		
	Bovine virus diarrhoea virus	1	Low		
	Coccidiosis	1			
Antibiotica (now focus on animal, human could be added)	Tetracyclines	1	++++	++++	National
	Macrolides/lincosamides	1 and 2	+++	+++	National
	Trimethoprim	1	0	0	National
	Sulfonamides	1	+++	+	National
	Penicillins	1	0	-	
	Fluoroquinolones	1	+++	+++	National
	Amphenicols	1	+	+	Incidental
	Polymyxins	1	+		Incidental
	Aminoglycosides	1	+		Incidental
	Pleuromutilins	1	0		Incidental
	?				
Antiparasitics, incl coccodiostatica	Ivermectin	1, 2?	+	-	National
	Flubendazol (+metbolites)	1	++++	++++	National
	Toltrazuril + ponazuril	1	++	+	National
	?				
Pijnkillers, hormones, other (human) pharmaceutics	NSAID's		+++		National
	Natural hormones	1	+++	+	National
	Synthetic hormones		+	+	National
Nanopaticles	Microplastics	2	yea, 1500 - 24000 parts/kg	yes	Limited in NL, use of sludge is limited
	Metallic nanoparticles	2	yes, but extremely variable (level/type)	partly (Ag, Au), very low levels, partly conversion (ao Zn and Cu NP's)	Incidental
	3				
	?				
ARM	MRSA	no	1 low; 2 low	Present or not (detection limit?)	National
	ESBL	1, 2	1 high; 2 low	0-1000/g	National
	CPE	2 (for now absent in animal manure)	Low	0-1000/g	National
	?				
Emerging contaminants	PFAS	2	PFOS phasing out, others coming up	Yes, local (sludge), low levels	Incidental
	V	2	ly in processed sludge (ash), high conc possi	yes, background levels	National
	Tl	mainly ashes (vooral via assen (coals/woo	ly in processed sludge (ash), high conc possi	yes, background levels	Incidental
	Flame retardant, brominated substances	2	s, highly variable, related to industry (e-wast	yes, when sludge is applied	Incidental
	?				
Heavy metals	Zn	1, 2	s: 978/300	Yes (20 - 121 mg kg^{-1})	National
	Cu	1, 2	s: 409/75	Yes (7 - 29 mg kg^{-1})	National
	Cd	(1), 2	s: 1.2/1.25	Yes (0.2 - 0.8 mg kg^{-1})	National
	As	(1), 2	s: 11/15	Yes (3 - 15 mg kg^{-1})	National
	Pb	(1), 2	s: 107/100	Yes (17-62 mg kg^{-1})	National
	Hg	(1), 2	s: 0.70/0.75	Yes (0.04 - 0.16 mg kg^{-1})	National
	Cr	(1), 2	s: 41/75	Yes (21 - 77 mg kg^{-1})	National
	Ni	(1), 2	s: 28/30	Yes (2 - 32 mg kg^{-1})	National
Appendix AA meststoffenwet	Dioxins	hrough co-material --> harmful to the environment		Yes	
	PCB's	hrough co-material --> harmful to the environment		Yes	
	PAH's	hrough co-material --> harmful to the environment		Yes	
	Mineral oil	hrough co-material --> harmful to the environment			
Pesticides/biocides	Fipronil	2 (in manure???)			
	Glyphosphate	2 (in manure???)			
	Diazinon				

Categories	Specific substance/organism/disease	Emission to water		Effects (extent and which organisms)	
		mobility (high-low)	process models available	Soil	Water
Zoönoses	Salmonella	low	Yes, thermofilic fermentation/separation/composting/RO	no	
	Influenza				
	Hepatitis E	low	Yes, thermofilic fermentation/separation/composting/RO	no	yes
	STEC	?	Yes, thermofilic fermentation/separation/composting/RO	no	
	Campylobacter	low, dependant on con in product	Yes, thermofilic fermentation	no	no
	Coxiella brunetii	?	?	no	
	Listeria				
	Cryptosporidium parvum	low	Yes, thermofilic fermentation	no	
	?				
Contagious animal diseases	avian Influenza				
	pathogenic coli's (weening diarrhoea, baccilosis)	low	Yes, thermofilic fermentation	no	no
	PRRS				
	Lawsonia intracellularis				
	Brachyspira hyodysenteriae				
	Partuberculose				
	Bovine virus diarrhoea virus				
	Coccidiosis				
Antibiotica (now focus on animal, human could be added)	Tetracyclines	+		mainly unknown	mainly unknown
	Macrolides/lincosamides	+		mainly unknown	Evolutionary pressure, besides mainly unknown
	Trimethoprim	++++		mainly unknown	Evolutionary pressure, besides mainly unknown
	Sulfonamides	++++		mainly unknown	Evolutionary pressure, besides mainly unknown
	Penicillins				
	Fluoroquinolones	+		mainly unknown	mainly unknown
	Amphenicols	++		mainly unknown	mainly unknown
	Polymyxins			mainly unknown	mainly unknown
	Aminoglycosides	++++		mainly unknown	mainly unknown
	Pleuromutilins	++		mainly unknown	mainly unknown
	?				
Antiparasitics, incl coccodiostatica	Ivermectin	++		Clear effects on manure insects when fresh manure applied routinely	Very toxic to water animals
	Flubendazol (+metbolites)	+		mainly unknown	mainly unknown
	Toltrazuril + ponazuril	+		mainly unknown	mainly unknown
	?				
Pijnkillers, hormones, other (human) pharmaceutics	NSAID's	+++			Diclofenac high risk to water organisms
	Natural hormones	+++			Oestrogenic hormones cause effects in male fish in surface [illegible]
	Synthetic hormones	+++			Oestrogenic hormones cause effects in male fish in surface [illegible]
Nanopaticles	Microplastics	strongly dependant on physical particle size	no, experimental work	uptake noticed, effects still unclear (matrix effect vs compound in matrix)	yes, uptake by fish/plants
	Metallic nanoparticles	low	no/under development	effects micro- and mesofauna noticed, but at extreme levels	?
	3				
	?				
ARM	MRSA	no	Yes, thermofilic fermentation	no	no
	ESBL	yes	Yes, thermofilic fermentation	no	no
	CPE	yes	Yes, thermofilic fermentation	no	no
	?				
Emerging contaminants	PFAS	high (dependant on compound)	partly, high level of uncertainty	limited	medium - high
	V	low, mainly colloidal	partitioning models available	?	low
	Tl	medium - high (relative to other metals)	partitioning models available	very toxic	high
	Flame retardant, brominated substances	mainly low (high K-OC)	no	uptake noticed (ao by worms), variable toxicity	established at waste dumps (e-waste)
	?				
Heavy metals	Zn	medium-high	yes, fair-good	not national, very local (polluted grass lands ao by horses)	yes, norm exceedence
	Cu	low-medium	yes, fair-good	poor (sheep, peatland areas)	yes, norm exceedence
	Cd	medium-high	yes, fair-good	limited	no
	As	medium	yes, but moderately evaluated	limited, seepage zones	no
	Pb	low	yes, but moderately evaluated	low	no
	Hg	low	no	high	no
	Cr	low	No (not according to similar system)	low	no
	Ni	medium	yes, but moderately evaluated	limited	regional norm exceedence
Appendix AA meststoffenwet	Dioxins				
	PCB's				
	PAH's				
	Mineral oil				
Pesticides/biocides	Fipronil				
	Glyphosphate				
	Diazinon				

Categories	Specific substance/organism/disease	Effects (extent and which organisms)				
		Production (yield)	vegetable products	animal products	Human	Evolutionary
Zoönoses	Salmonella	no	Yes, contamination in open soil	yes	yes, frequently	
	Influenza					
	Hepatitis E	no	Yes, contamination in open soil	yes	yes, contaminated soil	
	STEC	no	Yes, contamination in open soil	yes		
	Campylobacter	no	Yes, contamination in open soil	yes	yes, frequently	
	Coxiella brunetii	no	?	no	yes,mainly via air	
	Listeria					
	Cryptosporidium parvum	no	?	?	yes, mainly via water	
	?					
Contagious animal diseases	avian Influenza					
	pathogenic coli's (weening diarrhoea, baccilosis)	no	Yes, contamination in open soil	no	n.a.	
	PRRS					
	Lawsonia intracellularis					
	Brachyspira hyodysenteriae					
	Partuberculose					
	Bovine virus diarrhoea virus					
	Coccidiosis					
Antibiotica (now focus on animal, human could be added)	Tetracyclines	not at realistic concs			Risk most likely limited	Yes, possibly evolutionary pressure
	Macrolides/lincosamides	not at realistic concs	Uptake and circulation to animal feed	evolutionary pressure	Risk most likely limited	Yes, possibly evolutionary pressure
	Trimethoprim	not at realistic concs	Uptake and circulation to animal feed	evolutionary pressure	Risk most likely limited	Yes, possibly evolutionary pressure
	Sulfonamides	not at realistic concs	Uptake and circulation to animal feed	evolutionary pressure	Risk most likely limited	Yes, possibly evolutionary pressure
	Penicillins	not at realistic concs			Risk most likely limited	Yes, possibly evolutionary pressure
	Fluoroquinolones	not at realistic concs			Risk most likely limited	Yes, possibly evolutionary pressure
	Amphenicols	not at realistic concs			Risk most likely limited	Yes, possibly evolutionary pressure
	Polymyxins	not at realistic concs			Risk most likely limited	Yes, possibly evolutionary pressure
	Aminoglycosides	not at realistic concs			Risk most likely limited	Yes, possibly evolutionary pressure
	Pleuromutilins	not at realistic concs			Risk most likely limited	Yes, possibly evolutionary pressure
	?					
Antiparasitics, incl coccodiostatica	Ivermectin				Risk most likely limited	
	Flubendazol (+metbolites)				Risk most likely limited	
	Toltrazuril + ponazuril				Risk most likely limited	
	?					
Pijnkillers, hormones, other (human) pharmaceutics	NSAID's				Risk most likely limited	Ecotoxicologic effects
	Natural hormones				Risk most likely limited	Ecotoxicologic effects
	Synthetic hormones				Risk most likely limited	From human use, ecotoxicological effects
						We have less knowledge on other human farma
Nanopaticles	Microplastics	yes, experimental	unknown, uptake by terrestial plants limited	partly uptake (chicken)	unknown, but suggested	
	Metallic nanoparticles	no	no	no	?	
	3					
	?					
ARM	MRSA	no	no		yes, mainly via contact	Yes, resistence-evolution taking place when man
	ESBL	no	Yes, contamination in open soil	yes, but indirect through gene transfer	limited, via contact, food and environment	Yes, resistence-evolution taking place when man
	CPE	no	Yes, contamination in open soil	yes, but indirect through gene transfer	limited, via contact, food and environment	Yes, resistence-evolution taking place when man
	?					
Emerging contaminants	PFAS	no (only at extremes)	Limited	yes (milk, meat)	k assessment under discussion, possibly serieously decreased norm	
	V	no	uptake by cereals higher than other products	partly transferred to milk	yes, but less important than other categories	
	Tl	yes	mainly through fruit and vegetables	dly known, but potential uptake (analogous to	toxic, but exposure in NL limited	
	Flame retardant, brominated substances	?	ake limited, sometimes related to soil/crop vari	via uptake soil (chicken/cows)	yes, but exposure mainly not via plant food chain	
	?					
Heavy metals	Zn	no	no	no	no	
	Cu	no	no	no	no	
	Cd	no	yes (regional)	yes, offal (regional)	regional, via food not via drinking water	
	As	no	no	no	no, discussion on exposure ongoing (uptake soil)	
	Pb	no	only very incidental	regional	no, discussion on exposure ongoing (uptake soil)	
	Hg	no	no	no	no	
	Cr	no	no	no	no	
	Ni	no	no	no	no	
Appendix AA meststoffenwet	Dioxins					
	PCB's					
	PAH's					
	Mineral oil					
Pesticides/biocides	Fipronil					
	Glyphosphate					
	Diazinon					

Annex 15 Risk assessment for heavy metals: overview of relevant exposure pathways and transfer models (example)

For a number of priority substances (here focused on metals as an example), relevant pathways that contribute to exposure, as well as availability of transfer models to predict fate of priority substances are listed in Tables A15.1 and A15.2
In the remainder of the project, this will be elaborated on for other priority substances and used to perform the impact assessment, as referred to in Figure 4.1.

Table A15.1 *Potential Impact (Milieubezwaarlijkheid) and relevant pathways of substances considered here (example: metals).*

Substance	relevance	target	scale	Pathway
As	0/+	H[1]	L[2]	largely via drinking-water, intake soil (playgrounds)
Cd	+	H	N	Intake food (crops)
Cr	-	E	L	Impact in soil
Cu	++ (E)	E	N	Impact surface-water, animal-health (sheep)
Hg	-	-	-	Not relevant
Ni	0/+	E	R	Surface-water quality
Pb	+	H	L	Intake food/soil (allotments)
Zn	++ (E)	E/A	N	Impact surface-water, regional issues animal-health
Mo	-	?	?	?
Se	-	?	?	?
Ba	-?	?	?	?
Tl	-	-		Not relevant
V	-	-		Not relevant

[1]H: human, E: Ecology, A: Aquatic

[2]L: local, R: regional, N: national

Availability of relevant risk indicators – limit values

In contrast to the largely absent regulatory framework for a large array of products, there are soil- and water quality criteria available in various EU Member States, including the Netherlands, for the majority of compounds with the exception of micro-plastics, nano-particles, polymers and drug waste. These risk limits for soil and water are either based on human-health criteria or ecological impact. The minimum of both aspects is chosen as the ultimate criterium. Current soil- and water criteria are listed in Bijlage 1 Streefwaarden grondwater, interventiewaarden bodemsanering, indicatieve niveaus voor ernstige verontreiniging, bodemtypecorrectie en meetvoorschriften from 'Circulaire Bodemsanering'.

Description of available models to predict processes in soil (notably transfer to food chain and to water).

Table A15.2 shows also the model availability to predict transfer of contaminants once introduced to the soil. Here we focus on both the transfer into the food chain (uptake by crops), translocation of compounds to animals (organs and products) and ground- and surface-water.

Availability is classified as follow:

Available and applicable/validated at field scale: +
Available but largely experimental and not validated at field scale: 0
Not available: -

Table A15.2 *Overview of availability and quality of models to predict transfer of compounds into the food chain or water.*

Substance	Transfer model		
	Uptake crop	Transfer animal organs	Transfer to water
As	0	0	+
Cd	+	+	+
Cr	0	0	0
Cu	+	+	+
Hg	0	0	0
Ni	0	0	+
Pb	+	+	+
Zn	+	+	+
Mo	0	0	+
Se			+
Ba			0
Tl			0
V			0
Emerging/Industrial			
PBDE’s	0	0	0
PFAS	+	+	+
Micro-plastics	-	0	0
Nano-particles	-	-	0
Polymers	-	-	-
Drug waste	-	-	-

Annex 16 Overview of required actions related to risk assessment

Action 1: *Identification of potentially harmful substances with a distinction between non-tolerable and tolerable substances*
Who: WFSR – RIVM - WENR.
Output: Summary table with priority substances clustered in categories and approximate risk level (tolerable -> non-tolerable) also in view of the most critical end-point (water/crops etc). In 2019 a workshop with project team members and scientists from RIVM will be organised. The workshop aimed to discuss current methods used in risk assessment for specific substances, as well as criteria used to mark substances as non-tolerable. This is essential to avoid that risk assessment concepts developed within this project will result in conflicting interpretation - or the degree- of risk compared to methods used by RIVM (planning: end of February 2019). In addition current national (o.a bijlage Aa Uitvoeringsregeling Meststoffenwetor) EU regulations or proposals (e.g. STRUBIAS full 'Pre-Final Report and Appendix & Annexes', circulated 13/8/18) developed as part of the End of Waste Strategy or will be consulted.

Action 2*: Listing of detection capacity for each substance or group of substance (accuracy/costs)*
Who: WFSR – WENR (RIVM).
Output: Overview of (groups) of priority substances that can be detected routinely and at what cost versus those that require further development of analytical tools (or cannot be detected at relevant levels). This action includes the evaluation of methods used in the Netherlands and abroad and if these methods are suitable to detect priority substances in organic fertilisers, as targeted in this project.

Action 3: *Listing of existing quality criteria (standards) for selected substances and evaluation thereof (scientific basis/which end-point considered).*
Output: Overview, per priority substance, or clusters thereof (e.g. metals) of existing quality criteria and scientific assessment thereof. This includes standards developed and used in the Netherlands and abroad.
Who: WENR – RIVM (WFSR).

Action 4: *Listing of relevant end-points (and risk indicators/standards) for non-regulated* priority substances *(acceptable levels in end-points as identified, e.g. in water, TDI (in case of human exposure).*
Who: WENR – RIVM (WFSR).
Output: Overview of end-points considered to be the most relevant to consider in view of protection of human-health or environment and existing (or lack thereof) of relevant risk indicators.

Action 5: *identification of knowledge on relevant pathways to link the presence of priority substances in product to that in end-points (water/crops/animals/humans).*
Who: WENR – RIVM (WFSR).
Output: Overview of transfer models to be used to quantify the link between the prevalence of priority substances in the matrix of fertiliser and end-points identified.

Action 6: *Risk evaluation of detected levels of* priority substances *using the target end-points*
Who: WENR – RIVM (WFSR).
Output: Quantitative assessment of selected cases (land use/fertiliser) to compare the impact of various fertilisers in view of environmental impact.

Action 7: *Reverse model calculation using risk indicators in end-points (e.g. food quality criteria) to derive new maximum limits to be used.*
Who: WENR – RIVM (WFSR).
Output: Calculation of a selected number of maximum acceptable levels for specific priority substances.

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