Application of organic wastes to soils and legislative intricacies in a circular economy context

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Abstract
Currently, the absence of specific regulations on soil fertilization gives rise to sectorial normative with different regional approaches regarding application conditions, quality and other conditions that reused materials must meet. The purpose of this case study in Galicia (NW Spain) is to analyse the coherence of legal texts in the application of organic waste in soils regarding a more circular economy. The context of the case study is characterized by several Directives such as the Nitrates Directive or the "out of date" Directive on sewage sludge, among others, the lack of soil quality protection regulations and the existence of different administrative levels (European Union, Member State and Region). Manures and other agriculture wastes represent the main source of wastes being vastly applied to soils without previous treatment. Other waste streams (i.e. industrial biowaste, municipal biowaste and sewage sludge) undergo treatment generating commercial fertilizers, bio-stabilized wastes, technosols and waste-treated products that are subject to different standards. The screening of regulations and scientific literature detected limiting situations in the recycling of organic wastes due to natural or legal issues. On the other hand, risky applications are identified due to the lack of quality requirements for waste-treated products under regional legislation, or no mandatory compliance with codes of good agricultural practices for manures and waste-treated products. Contradictory situations of legal regulations and other issues were outlined and discussed. Final considerations were outlined to promote a more effective recycling of organic wastes and the design of a suitable legislation adapted to the natural conditions of the region.

Graphical abstract

Keywords Regulations · Fertilization · Normative · Soil · Recycling · Nutrients

Abbreviations
CGAP Code of good agricultural practices
CE Circular economy
EC European Commission

Extended author information available on the last page of the article
Introduction

Under an expected demographic scenario of nearly 10 billion in 2050, human activities are susceptible to cause unacceptable environmental change with the risk of crossing and, with uncertain consequences, various planet boundaries (Rockström et al. 2009).

In the last decades, a broad range of environmental policies and normative documents were developed in Europe aiming to protect nature and prevent human activities from crossing these biophysical boundaries highlighted by Rockström et al. (2009). Within the framework of the 7th EU Environmental Action Programme, the concept of CE has emerged strongly (Geissdoerfer et al. 2017). Although the term remains ambiguous, it could be defined as “a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops” (Geissdoerfer et al. 2017). CE has also gained traction with policymakers, influencing governments and intergovernmental agencies at the local, regional, national, and international level (Geissdoerfer et al. 2017). Among these, the regions take on importance as appropriate areas for the implementation, monitoring and evaluation of the different CE action plans considering their resource potential. In fact, research on practical cases at the regional level remains underexplored and deeper discussions are required on the challenges that circularity presents to enable CE to be performed in real-world systems (Vanhamäki et al. 2020). Recently, different authors provided an overview of this regional circular transition, case of Emilia-Romagna in Italy (Sani et al. 2021) or Päijät-Häme in Finland (Sani et al. 2021; Vanhamäki et al. 2020).

The CE notion can be referred to multiple topics (Araujo Galvão et al. 2018). Among these topics, wastes constitute a large source of biomass that can be, if properly managed, turned into valuable resources on which their nutrients can be returned to soils.

Whereas management of organic waste is a well-established research matter, the links with CE were less frequent so far (Paes et al. 2019). Under different approaches and scales, this gap was filled very recently. Puntillo et al. (2021) outlined the possibility of recycling absorbent hygiene products at the very local level. Pličanić et al. (2020) addressed the particular case of mining wastes in North Macedonia. The links between CE and the management of organic wastes as fertilizers were previously reviewed (Chojnacka et al. 2020; Antoniou et al. 2019) but not the legal terms that these fertilizers must meet before their application to soil.

Connections between wastes and legislation have also been established by different authors. De Clercq (2001) compared sectorial normative for different fertilizers on soil nutrient management in Europe aiming to come up with proposals for more harmonization legislation among countries. Bauer et al. (2020) reported the different implementation of legislation relating to sewage sludge disposal comparing the situations in Netherlands, Germany and Sweden. Micha et al. (2020) studied the influence of regulations on organic fertiliser allocation in pasture based systems. Agovino et al. (2021) investigated the effectiveness of a Legislative Decree in promoting the separate waste collection among various Italian regions.

The necessity of legal–regulatory instruments at European, National and Regional levels to launch a circular economy model was pointed out previously by Sany et al. (2021) in Italy, or Smol, Marcinek and Koda in Poland (2021). Literature reveals case studies that, under a regional scope and with regard to wastes, current regulations don’t always lead to a shift towards CE. In this manner, legislation (or the absence of) was identified as one of the obstacles in this transition as in the sugarcane ethanol sector in Brazil (Jesus et al. 2021), mining waste in north Macedonia (Pličanić et al. 2020), or from all over the EU (Kirchherr et al. 2018). In the Emilia-Romagna Region, it was demanded a practical one legislation that favours the use of waste (Sani et al. 2021). In rural Denmark and for household waste, normative obstructs the transition to the circular model (Zacho et al. 2018). In the case of Flanders, Viane et al. (2016) remarked the complex regulations about the use of compost due to the diverse policy areas and topics at different policy levels (Flemish, Belgian and European), resulting in contradictory situations where compost application was stimulated and at the same time limited by different policy and regulatory documents under a defined as “complex, confusing, and often contradictory legislative landscape”. Similar situations are mentioned for other waste streams such as bakelite, asphalt, products recovered from wastewater (Kirchherr et al. 2018), or mining wastes (Pličanić et al. 2020). In other occasions, legislation limits are eluded by parallel administrative incentives, and thus, it is reported manure transport from livestock intensive to arable farming in order to lower the environmental burden of regional livestock concentration (Kuhn et al. 2020). In the concrete case of Spain, Barral and Paradelo (2011) detected paradoxical situations when evaluating the content of legislation related to commercial fertilizers. These authors
outlined that sometimes, due to heavy metals limitations, SS might be directly spread on soil but not after composting, despite the beneficial effects of composting. While raw sludge met the MPLs for soil application, final HM concentrations in the same material after composting would exceed limits for class C composts (corresponding with commercial composts with the MPLs of HM). These authors also evaluated the total annual HM loads for SS and its derivative composted according to MPLs defined in legislation: Comparison resulted in a substantial higher amount of HM load for SS than from composted SS, varying by a factor of 2 to 15, depending on the HM considered.

Under this general framework, in Spain there is currently no specific legislation regarding soil protection or fertilization. The topic is tangentially governed through other environmental legislation, and nutrient management goes hand in hand with control of pollution (or in other words, with offsite nutrient losses reduction). In fact, nutrients overload from agriculture remains the predominant source of N discharged into the environment and this occurs despite recovery of nutrients from wastes becomes a priority in the EU CE Strategy. Regarding normative connected with soil fertilization, Spanish legislation imposes quantitative limits to nitrates pollution from agrarian sources (BOE 1996) and commercial fertilizers (BOE 2013). Another document involved with the application of wastes to soil is related to biostabilized materials (MAGRAMA 2013).

Due to the model of territorial organization, regions, among them Galicia autonomous region (NW Spain) may develop and execute basic Spanish state legislation. In Galicia, main regulation affecting the application of waste-derived materials on soils is Decree 125/2012 that regulates the usage of sewage sludge (DOG 2012). It is noteworthy outstanding that Galician Decree 125/2012 prohibits direct recovery of not only sludge but any organic raw materials in agricultural soils, requiring various treatments. In practice, enacting this normative implied a sharp decline in the disposal of SS to soil with agricultural purposes. In the 5-year period before and after the appearance of Decree 125/2012, the total amount of sewage sludge used in agricultures roughly varied from 15,000 to 1,000 t (d.m. basis) (Xunta de Galicia 2018). In addition to Decree 125/2012, voluntary guidelines concerning fertilization affect agrarian and forestry productive models in the region as well as a Technical Instruction for the elaboration of technosols from wastes not aimed to fertilization purposes.

As exposed previously for other European regions, this legislative spectrum often results confusing for farmers (Ortolano et al. 2009) and in the common thought that fertilization strongly correlates with the crop yield, organic and inorganic fertilization is carried out following their own criteria. In Galicia, annual doses of 40 m3 ha⁻¹ of poultry manure were addressed by Conde-Cid et al. (2018) in agriculture areas, 100 m³ ha⁻¹ for cattle slurry and 1000 kg ha⁻¹ for mineral fertilizer NPK 8:24:16 were reported in pasturelands (Seco-Reigosa et al. 2015), and over 200 kg N ha⁻¹ and 50 kg P kg⁻¹ for grasslands (Paz-Ferreiro et al. 2010). On the other hand, the addition of organic materials different from manures on Galician soils was widely studied by different authors (Santalla et al. 2011; Paz-Ferreiro et al. 2012; Pousada-Ferradás et al. 2011) before and after the appearance of Decree 125/2012 that regulates the usage of organic wastes in Galicia.

Legal barriers, outlined as one of the most important in the implementation of circular models (Araujo Galvão et al. 2018), are supposed to be overcome by the different CE strategies throughout the diverse governmental jurisdictions. The Galician CE strategy contains general references to the necessary revision of normative on wastes, as well as specific mentions about the revision of the normative in matters of fisheries and food health in relation to the uses of waste products, new law on waste and contaminated soils as well as the prediction of a future new law that will aim to regulate the production and management of livestock manure (Xunta de Galicia 2019). Thus, in the near future it is not predictable changes on the current normative involving waste application on soils.

Despite the large number of studies on the CE, as far as we are aware, little research was carried out about the implications and relations among regulations concerning the recirculation of wastes in soil. This guides the research hypothesis of this paper: Do current regulations promote the recycling of wastes on soils? To solve the question, this work is aimed at: (a) filling this gap and increase understanding of the links of sectorial normative with waste land application; (b) identifying and analysing the main normative involved in the practical application of wastes on soils; (c) determining to what extent the current regulatory frame promotes CE by impelling the recirculation of wastes in the soil, avoiding other harmful routes such as landfilling or incineration.

Identifying these items will help policymakers define discussion baselines to consolidate or redirect current legislative spectrum involving the recycling of wastes on soils. Results also can serve as a point of reference for future comparative framework with other jurisdictions and/or regions in the way through an effective CE implementation.

Materials and methods

Characteristics of the study site

Administrative contextualization

This case study is circumscribed in Galicia (northwestern Spain). Regulations are applied from four hierarchical levels,
similarly to other EU countries (Liu et al. 2020). The European Union is a legislative primary source that frequently binds, through Regulations and Directives, the appearance of environmental normative in EU Member States. Spanish state constitutionally establishes the basic legislation on the protection of the environment and the Autonomous Communities are responsible for its execution and may issue additional or more stringent standards on the environment. The bottom level of government are Municipalities (313 municipalities in the study region), which might establish restrictions through local by-laws or ordinances. Nevertheless, these were not compiled as the evaluation at the very local scale was not under the scope of this study.

Synoptic overview on climate and soils

Galicia occupies around 3 million ha where nearly 2 million represent forest land. With 2.7 MM inhabitants, mostly concentrated in the coastal area, forests and water are significant natural resources. Annual precipitation ranges from 700 to 2000 mm (1400 mm as average), while annual temperature varies from 8 to 15 °C with an average value of 12 °C. Soils are characterized by low chemical fertility and 5.0 average pH values (Macías and Calvo de Anta 2009).

It is noteworthy referencing the concentration of HMs in soils as they influence legal fertilization practices. Main lithological formations lay in granitic and metamorphic rocks (slates, schists and phyllites), and to a lower extent, basic (and ultrabasic) rocks, as well as sedimentary deposits. Geological parent material influences natural HMs content in soils with large differences depending on the type of substrate (Table 1).

With the exception of Ni and Cr, for which the concentrations are markedly higher in Galicia, particularly in ultrabasic rocks, values could be considered in the range of worldwide values (Kabata-Pendias and Mukherjee 2007) and in general terms, higher than mean concentrations of European soils.

Research methodology

The study was mainly based on qualitative methods throughout three different steps (Fig. 1). The two first focussed on data collection about regulations and waste (steps 1 and 2, respectively). Step 3 was based on the analysis, evaluation and interpretation of data gathered in the previous steps.

The scope was limited to Galicia as the present work was designed at regional level and some of its intrinsic

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**Table 1** Comparison of soil HMs mean levels in Galicia (Macías and Calvo de Anta 2009) with European (Tóth et al. 2016) and worldwide references (Kabata-Pendias and Mukherjee 2007)

| Metal | Granite | Slates | Schists | Basic rocks | Sediments | Ultrabasic rocks | Limestone | Quartzites | Mean values | Europe | Worldwide |
|-------|---------|--------|---------|-------------|-----------|------------------|-----------|------------|-------------|--------|-----------|
| Cd    | 0.08    | 0.13   | 0.11    | 0.16 | 0.10 | 0.11 | 0.50 | 0.08 | 0.11 | 0.11 | 0.11 | 0.5 |
| Cu    | 9.8     | 24.9   | 23.9    | 49.9 | 14.7 | 205.1 | 36.6 | 16.8 | 20.61 | 9.40 | 20–30 |
| Ni    | 23.7    | 43.2   | 40.7    | 65.7 | 29.2 | 2155.9 | 74.4 | 34.9 | 55.83 | 18.15 | 19–22 |
| Pb    | 29.8    | 26.1   | 31.0    | 32.0 | 21.0 | 18.3 | 58.6 | 19.2 | 29.32 | 8.33 | 25 |
| Zn    | 50.9    | 69.1   | 65.8    | 66.3 | 48.3 | 81.7 | 176.5 | 47.0 | 60.29 | n.a | 64 |
| Hg    | 0.07    | 0.07   | 0.08    | 0.12 | 0.06 | 0.08 | 0.18 | 0.07 | 0.07 | 0.04 | <1 |
| Cr    | 20.2    | 43.7   | 48.8    | 128.7 | 22.9 | 4268.4 | 58.2 | 28.3 | 80.25 | 15.70 | 54 |

Italicized numbers indicate situations where natural HM concentrations exceed the threshold for SS legislation in acidic soils. Values expressed in mg kg\(^{-1}\)

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**Fig. 1** Research method steps

- **REVIEW OF REGULATIONS INVOLVED IN ORGANIC WASTE APPLICATION ON SOILS.**
- **ANALYSIS OF THE LEGISLATION SUITABILITY TO PROMOTE THE RECYCLING OF WASTE ON SOILS.**
- **POTENTIAL FOR WASTE RECYCLING IN A CIRCULAR ECONOMY SCENARIO.**
- **BARRIERS FROM CURRENT NORMATIVE FRAMEWORK TO CIRCULAR ECONOMY.**
- **MAIN PROPOSALS FOR IMPROVEMENT.**
properties, the natural and administrative the most relevant, must be considered.

In the first step, the different normative directly involved with the practical application of organic wastes to soils was reviewed on the Galician context. A desk research method was carried out based on the different texts accessed through the various official web pages (EC, Spanish and Galician government). Regulations with any reference to soil were selected after a first screening. Secondly, legislation regarding fertilization and/or waste management practices were revised. Documents imposing final product properties or conditions of application on soils were positively discriminated from those with vague, tangential, or imprecise references. Other references with legal background and direct incidence in this paper were also included. Supplementary data relative to the content of Decree 125/2012 was also obtained from a primary source after formal request to the Regional Agriculture Agency (Xunta de Galicia 2018).

The second step focussed on the collection of information, from two sources, about wastes or waste-derived materials. First, Scopus® databases were searched (2000–2020) aiming to gather as much information as possible relative to waste materials produced in Galicia, treatments and assessment of their application to the soil. Keywords used (contained in the article title, abstract or keywords) were “manure”, “slurry”, “waste”, “fertilizer”, “sewage sludge”, “amendment”, “compost”, “Galicia”, “northwest Spain”, “NW Spain” with different combinations of the logical operators “AND” and “OR”. The output results, including abstract, were exported for subsequent external review and organization with the reference management software Zotero (Corporation for Digital Scholarship, 2009). Different queries resulted in a total 446 documents and after removing duplicates, 314 remained. From 314 and after reading the article or abstract title, 263 were discarded as they were not aligned with the objectives of the review. As a result, 51 articles were left to which another 18 were added after reading related citing and cited articles. Among the 69 selected papers, 35% of papers focussed on abundant regional wastes (mussel shells, ash, dairy-industry sludge, seaweed and others). The addition of different materials (technosols, SS, biochar, composts, etc.) for the recovering of degraded mine soils was the scope of another 25% of articles, and 17% of reviewed papers dealt with SS. Inorganic fertilizers, composts, manures and other materials represented the remaining fraction. Second, the properties of commercial fertilizers based on organic wastes produced in Galicia were obtained from the database of the Spanish Agricultural Ministry website (MAPA 2018). Data, only available at national level, corresponded to those, defined by state legislation as, organic fertilizers (products whose main function is to provide nutrients, which are derived from carbonaceous materials of animal or vegetable origin), mineral organic fertilizers (products whose main function is to provide nutrients for plants, which are of organic and mineral origin, and obtained by mixing or chemical combination of inorganic fertilizers with carbonated materials of animal or vegetable origin or organic fertilizers) and organic amendments (products from carbonaceous materials of vegetable or animal origin, mainly used to maintain or increase the OM content of soil). Finally, gathered information from selected sources, both legal (step 1) and scientific or technical (step 2), was analysed and interpreted, searching for coherence, links or mismatches between them.

In the third step, and under an inductive approach (Thomas 2006), imperative legal requirements established by current normative were associated with the limits of the resource potential of the region and the main streams of wastes generated in it. This assessment, under the main topics of this paper (wastes, legislation and CE) and the planned objective, led to the elaboration of the results and conclusions.

Results and discussion

Regulations

The regulations currently in force were developed, at different administrative scales, on several products: SS and nitrates were regulated at the three levels for more than 30 years, fertilizers within the European and Spanish scope, and finally, the biostabilized material and technosols have, respectively, specifications at the state and regional level (Fig. 2).

Sewage sludge

Directive 86/278/EEC (SS Directive) regulated the use of SS in agriculture, aiming to protect soil and human health against HMs (Cd, Cr, Cu, Hg, Ni, Pb and Zn) contained in sludge. EU States differently approached the scope of the Directive. Some countries added limits for new contaminants, established stricter values or even banned its use in agriculture, whereas others used sludge widely (EC 2014).

In Spain, SS Directive was transposed by R.D. 1310/1990 (BOE 1990) and Galician Government, by Decree 125/2012 (DOG 2012), relating organic waste to be applied to soil, adapted the content of both SS Directive and Spanish R.D. 1310/1990 to the conditions of Galicia. This Decree comprises SS from urban wastewater treatment plants, domestic septic tanks and from certain types of agricultural industries. It also includes other organic materials expressly included in the Spanish list of biodegradable organic waste (BOE 2013) under the condition that such waste becomes part of a compost or digestate. Any other waste will need the
authorization from the Galician government. Furthermore, Decree specifies treatments (composting, lime stabilization, digestion, thermal drying) and respective technical requirements for these wastes resulting the so-called sewage sludge treated products (SSTP), global term that includes the also defined treated SS, digestates and composts.

Nitrates from agricultural sources

Council Directive 91/676/EEC (Nitrates Directive) aimed to protect waters against pollution caused by nitrates used in agriculture. The Directive instructs the EU Member States to designate the Nitrate Vulnerable Zones (NVZs) and the design of compulsory Action Programmes in these with mandatory measures to reduce the concentration of nitrates. The EU States should establish a voluntary CGAP as a reference for farmers in the country. Nitrates Directive (1990) was transposed into the Spanish legal system by R.D. 261/1996 (BOE 1996). According to this R.D., in the NVZs the total amount of N contained in manure applied to soils must be lower than 170 kg ha\(^{-1}\) year\(^{-1}\). In Galicia, the implementation concluded with the publication of the Galician CGAP (DOG 1999) and the declaration of absence of NVZs (DOG 2000). That implied: (a) the no existence of Action Programmes in the whole Autonomous Community and the non-applicability of the mandatory N limit of 170 kg ha\(^{-1}\) year\(^{-1}\); (b) the optional application of the Galician CGAP, non-binding policy instrument that does not impose compulsory requirements.

Commercial fertilizers

The new Regulation (EU) 2019/1009 (EC 2019) intends to create harmonized conditions to promote and make use of recycled or organic materials for fertilising purposes. It established seven Product Function Categories for EU fertilising products (fertilisers, liming materials, soil improvers, growing medium, agronomic additives, plant biostimulants and fertilising product blends). EU fertilising products shall consist solely of component materials listed in an eleven Component Material Categories. For both, Product Function and Component Material Categories, requirements were established regarding quality and safety limits. All producers must respect defined criteria to commercialize their fertilizers in the EU, but at the same time they are still allowed to sell their products within the national markets, under the national fertilizer regulations conditions and therefore not obliged within their national boundaries to respect the Regulation (EU) 2019/1009 (Marini et al. 2020).

At the level of Spain, legislation currently in force is Spanish R.D. 506/2013 (BOE 2013) which regulates fertilizers to be used in agriculture, gardening, and degraded soils. It establishes seven groups of fertilizer products which must be part of the Register of Fertilizer Products. Particular attention was paid to these groups that use organic wastes (necessarily included in the Spanish list of biodegradable organic waste (BOE 2013)) in its formulation: organic fertilizers, mineral organic fertilizers and organic amendments. The fertilizers of these three groups are classified in three classes (A, B and C) according to their HMs content, being required a set of common minimum conditions for all of them. Amount limits for soil application were only fixed for Class C fertilizers, 5 t ha\(^{-1}\) year\(^{-1}\), whereas the three mentioned groups will be applied following the CGAP. Besides, in those regions with NVZs declared, fertilization should be adjusted to the respective Action Programmes.
Biostabilized material

Spanish waste law (Law 22/2011 on wastes and contaminated soils) differentiates compost (fertilizer included in the group of organic amendments) and biostabilized material (from mixed wastes treated in mechanical–biological treatment plants). While advancing in separate waste collection, in 2013 Spanish government launched the Decalogue for the use of biostabilized material and composts not included in the Register of Fertilizer Products through the operation R10 (MGRAMA 2013).

Under operation R10, the application to soil must produce a benefit to agriculture or an ecological improvement of the soil, aspects that must be justified in the authorization request to the Galician Agency. Possible destinies of biostabilized materials, must meet specific requirements, include agriculture, slope revegetation, coverage of landfills, restoration of quarries and mines and public gardening. In all cases, dosages must be justified case by case.

In the agricultural application, doses exceeding 5 t d.w. ha\(^{-1}\) year\(^{-1}\) (and provided that the average annual value in a five-year period does not exceed 5 t d.w. ha\(^{-1}\) year\(^{-1}\)) will require a Fertilization Plan which will justify agronomically and environmentally these loads. Same criteria apply for public gardening. Different criteria apply for slope revegetation, coverage of closed landfills and restoration of quarries and mines, in which dosages must be under 50 t d.w. ha\(^{-1}\) year\(^{-1}\) (unless specific justification).

Technosols

The Galician Waste Technical Instruction ITR/01/08 regulates the elaboration of technosols derived from non-hazardous waste, including SS, aiming to fulfil the natural soils functionality, likely to evolve through soil formation processes and achieve efficient carbon stabilization. These technosols should be used in soil and water recovery processes, rock outcrops, landfill cover, areas affected by urban and infrastructures works, industrialized areas, mines and quarries, degraded silvicultural soils from erosion, fire or loss of production capacity, intensive forestry soils and non-food biomass crops (DOG 2008).

Under the ITR/01/08 a technosol, which can be formulated from different wastes, free of ecotoxicity and some of them with specific limitations, must have structural and nutritional properties that guarantee their quality. A procedure is established for the admission of wastes as well as the characteristics of the technosols created. As with bioestabilized materials, the application of technosols will require a case-by-case study and an administrative authorization of the Galician government.

Flows of organic wastes

The legal application of organic wastes in soils can be possible following different routes in Galicia. Although available information at regional level about quantities of wastes often presents difficulties (Virtanen et al. 2019), Fig. 3 presents an estimation of the main flows produced in Galicia.

Broadly speaking, major quantities come from agricultural activities, mainly manures, with nearly 15.24 Mt year\(^{-1}\), recycled almost entirely as fertilizers by direct application. Manures account for 94.6% of the total organic waste (wet basis), as well as 82.9% of the total dry matter. The remaining fraction, alongside with industrial biowastes, municipal solid (bio)wastes and sewage sludge are transformed into waste treatment facilities.

The recovery rate of organic matter is estimated to be close to 48% in the waste treatment facilities, being produced commercial fertilizers, biostabilized material, SSTP or technosols (Fig. 3). Commercial fertilizers have the highest added value and can largely relieve the pressure on the extraction of non-renewable resources from nature.

For the elaboration of commercial fertilizers with an organic base (organic fertilizers, mineral organic fertilizers and organic amendments), 50 types of waste are used, being the most frequent those indicated in Table 2, present in some proportion, in more than 59% of commercial fertilizers. In correspondence with Fig. 3, manures, sludges and agroforestry wastes account for the higher presence.

In the management of organic wastes, an important question to solve is if these treated wastes reach the minimum standards for commercial fertilizers required in the Spanish R.D. 506/2013. This is relevant as these fertilizers are excluded from the scope of the Galician Decree 125/2012 and will determine different application practices.

Required properties of treated wastes

Before the application to soil, final products made from organic wastes must reach different legal requirements, variable according to the normative they are influenced (Tables 3, 4).

In terms of the recirculation of nutrients, CE promotes closed loops of organic wastes as sources of amendments or fertilizers. Considering this, regulations directly related to this topic are Galician Decree 125/2012 and Spanish R.D. 506/2013. Unlike commercial fertilizers, legal requirements of SSTP are much laxer than those of the other products. Important qualitative parameters such as nutrients content, C/N ratios or impurities are irrelevant and, even for technosols a minimum organic matter content is required.

Thus, it can be inferred that Galician Decree 125/2012 is not finally aimed to obtain an amendment or fertilizer but a
material intended to be spread on the soils. At this respect, no biological properties are required for SSTS, and the presence of microorganisms, stability or toxicity are omitted by Decree 125/2012. The final safety conditions rest on mandatory treatments as methods to achieve the hygienization. However, treatments not always ensure fertilization in safety conditions (Zhang et al. 2019). Analogous normative in other regions of Europe (e.g., Lombardy, Veneto or Emilia Romagna in Italy) establishes well-defined quality parameters, including microbiological (Collivignarelli et al. 2019).

With respect to the HMs content and considering acidic soils as the most abundant in Galicia, limits are considerable

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**Table 2** Organic wastes used for the preparation of commercial fertilizers in Galicia. Source MAPA (2018). *n*, number of commercial fertilizers in which the described waste is present; EWC, European Waste Catalogue.

| EWC code | Waste | Presence |
|----------|--------|----------|
|          | Sinoptic description | n | % |
| 020106   | Manures | 24 | 40.7 |
| 190805   | Sludges from treatment of urban wastewater | 22 | 37.3 |
| 020204   | Sludges from processing of meat, fish and other foods of animal origin | 17 | 28.8 |
| 020103   | Plant-tissue waste | 16 | 27.1 |
| 020107   | Wastes from forestry | 12 | 20.3 |
| 020502   | Sludges from on-site effluent treatment (dairy products industry) | 9 | 15.3 |
| 020305   | Sludges from on-site effluent treatment (wastes from fruit, vegetables and similar) | 8 | 13.6 |
| 020203   | Materials unsuitable for consumption or processing (foods of animal origin) | 7 | 11.9 |
| 020702   | Wastes from spirits distillation (alcoholic and non-alcoholic beverage industry) | 6 | 10.2 |
| 200201   | Biodegradable waste (garden and park wastes -including cemetery waste-) | 5 | 8.5 |
| 020202   | Animal-tissue waste (processing of meat, fish and other foods of animal origin) | 5 | 8.5 |
| 020304   | Unsuitable for consumption or processing (wastes from fruit, vegetables, etc.) | 5 | 8.5 |
| Others   | Various | 1–4 | 2–7 |
Table 3 Comparison between different legal requirements for waste products before their application to soil in Galicia

| Properties                  | Parameter                      | Spanish R.D. 506/2013 Commercial fertilizers | Galician Decree 125/2012 SSTP | Spanish R10 Decalogue Biostabilized material | Galician ITR/01/08 Technosols | EU Regulation 2019/1009 Solid organic fertiliser | Organic soil improver |
|-----------------------------|--------------------------------|---------------------------------------------|-------------------------------|-----------------------------------------------|--------------------------------|-------------------------------------------------|----------------------|
| Physical–chemical           | Organic matter                | > 35%                                       | N.n                          | ≥ 25%                                         | ≥4%                             | Corg and nutrients of biological origin          | 95% of biological origin |
|                            | Moisture content              | <40%                                        | <40% (compost)<10% (thermic drying)<80% (digestates) | 20 – 40%                                | N.n                             | N.n                                             | <80%                 |
|                            | C/N                           | <20                                         | N.n                          | <20                                          | >12                             | Corg ≥ 15%                                      | Corg ≥ 7,5%           |
|                            | Inerts/impurities             | Absence                                    | N.n                          | Impurities higher than 2 mm ≤ 3%             | N.n                             | N.n                                             | N.n                  |
|                            | N total                       | >1%                                         | N.n                          | N.n                                          | N.n                             | Variable                                        | N.n                  |
|                            | N organic                     | ≥ 0.85 N total                             | N.n                          | N.n                                          | N.n                             | N.n                                             | N.n                  |
|                            | Macronutrients                | >1%                                         | N.n                          | N.n                                          | N.n                             | Variable                                        | N.n                  |
|                            | Granulometry                  | > 90% through 25 mm sieve                  | N.n                          | ≥ 90% through 25 mm sieve Stones and gravels higher than 5 mm < 5% | N.n                             | Stones and gravels ≤ 10% and < 50 mm            | N.n                  |
|                            | Texture                       | N.n                                         | N.n                          | N.n                                          | Silt loam or sandy loam         | N.n                                             | N.n                  |
|                            | Odours                        | N.n                                         | N.n                          | N.n                                          | Absence                         | N.n                                             | N.n                  |
|                            | Limits for specific contaminants | N.n                                      | N.n                          | N.n                                          | Defined                          | N.n                                             | N.n                  |
|                            | Limits for HMs lixiviation   | N.n                                         | N.n                          | N.n                                          | Defined                          | N.n                                             | N.n                  |
|                            | Presence of microorganisms    | Salmonella (in 25 gr)                      | Absence                      | N.n                                          | Absence                         | Absence                                         | Absence              |
|                            | E. coli                       | <1000 MPN/gr                                | N.n                          | <1000 MPN/gr                                  | <1000 MPN/gr Variable, depending on the type of raw material | <1000 MPN/gr              | <1000 MPN/gr |
|                            | Furfural                      | 0.05%                                       | N.n                          | N.n                                          | N.n                             | N.n                                             | N.n                  |
|                            | Polyphenols                   | 0.8%                                        | N.n                          | N.n                                          | N.n                             | N.n                                             | N.n                  |
|                            | Benzo-(a)-pyrene              | <1 (mg/kg)                                  | N.n                          | N.n                                          | N.n                             | N.n                                             | N.n                  |
|                            | PAH<sub>16</sub>              | N.n                                         | N.n                          | N.n                                          | N.n                             | N.n                                             | N.n                  |
|                            | Size (inert materials)        | <25 mm                                      | N.n                          | N.n                                          | N.n                             | N.n                                             | N.n                  |
|                            | Stability                     | Self-heating test                           | N.n                          | N.n                                          | Class III (or higher)           | N.n                                             | N.n                  |
|                            | O<sub>2</sub> consumption index | N.n                                      | N.n                          | N.n                                          | N.n                             | N.n                                             | N.n                  |
|                            | Toxicity                      | Acute toxicity test                         | N.n                          | N.n                                          | Fulfilment                      | N.n                                             | N.n                  |
|                            | Terrestrial plants growth test | N.n                                         | N.n                          | N.n                                          | N.n                             | N.n                                             | N.n                  |
higher, and hence more permissive, for SSTP than for any other product, even for these of class C commercial fertilizers.

In the case of manures, there is no current legal limitation about their HMs content (or other considerations beyond voluntary CGAP compliance) with fertilization purposes despite it can be considerably high. Finally, the recent Regulation 2019/1009 establishes more stringent limits and the upcoming EU fertilizers will establish more restrictive thresholds than current class B Spanish fertilizers. This will lead to a more careful selection of those raw materials intended to be used, alone or in combination, as fertilizers. Therefore under a CE perspective it will be necessary to introduce selective waste collection, increase the efficiency of nutrient recovery and obtain a more concentrated form with good bioavailability.

Biostabilized materials, and more clearly technosols, are not primarily intended for fertilization or agronomic purposes. In the first case, materials are non-quality biotransformed products that in other Autonomous Communities (e.g. Valencia in SE Spain) regional laws that allowed their use as fertilizers were judicially denounced against the Spanish Constitutional Court by environmental organizations.

### Required application practices for treated wastes

The addition of organic materials to soil must be carried out under certain conditions established by the normative and grouped in Table 5.

Approaches of Galician Decree 125/2012 for SSTP and Spanish R.D. 506/2013 for commercial fertilizers are markedly different. Commercial fertilizers must be applied under the CGAP requirements, similar to other national and regional codes of practice with a compendium of agronomic techniques, and MPLs are only specified for class C fertilizers, up to 5 t ha\(^{-1}\) year\(^{-1}\). On the other hand, the application of SSTP must respect regional particularities regarding buffer application distances (extended from those contained in the CGAP), prohibitions of spreading in certain cases (Table 5) and MPLs. Maximum loading rates of SSTP are determined by the lowest value of the following three calculations: HMs load (kg ha\(^{-1}\) year\(^{-1}\), same tabulated values than SS Spanish normative), maximum N or P loads (kg ha\(^{-1}\) year\(^{-1}\), tabulated values depending on theoretical nutritional demands of classified groups of crops). As a result, considering that the total amount of SSTP applied to soil is partially determined by their N and/or P content and that no minimum content of these nutrients is required, it could be possible that soils could receive great amounts of SSTP with low HMs, nutrients, and organic matter content.

Comparatively with commercial fertilizers, the total soil target surface for SSTP application is increased by raising
Table 5  Conditions to be considered prior to soil application of products according to legislation

| Parameter                        | Details                                      | Spanish R.D. 506/2013 Commercial fertilizers | Galician Decree 125/2012 Treated wastes | Spanish R10 Decalogue Biostabilized | Galician ITR/01/08 Technosols |
|----------------------------------|----------------------------------------------|---------------------------------------------|----------------------------------------|-------------------------------------|-------------------------------|
| Distances (m)                    | Water bodies<br>a. Public supply<br>No<br>Traditional bathing areas<br>Water tanks and closed conduits<br>Buildings<br>Residential, industrial, sport or recreational areas<br>Agricultural<br>Elements of cultural interest<br>The Way of Saint James<br>Terrain requirements<br>Slope<br>Forestland conditions<br>Land uses<br>Agricultural or forest land<br>Quantitative limits (kg/ha year)<br>Nitrogen<br>Phosphorous<br>Limits of HMs in soils<br>Agronomic techniques<br>Consideration of periods of appropriate fertilization<br>Considerations for fertilization near water courses, steeply sloping, water saturated, flooded, frozen or snow-covered soils<br>Guidelines on crop rotation and minimum quantity of vegetation cover during certain periods<br>Recommendations to control nutrient losses to water bodies<br>Consideration of pollution prevention with irrigation systems<br>Mandatory fertilization plans | Yes<br>No<br>Not considered<br>Not considered<br>Not considered<br>Not considered<br>Not considered<br>Not considered<br>Not considered<br>Not considered<br>Not considered<br>Not considered<br>Not considered<br>Not established<br>Not established<br>Yes<br>Yes<br>Yes<br>Yes<br>Yes | > 30—50<br>2 - 10<br>≤ 25%<br>≥ 100<br>N or P are not considered. Limit is 5.000 d.m. basis (Class C fertilizers)<br>50 — 100 b<br>≤ 25%<br>N or P, not considered. Need to justify if higher than 5.000 d.m. basis (agricultural use)<br>Established<br>50 — 100 b<br>Prohibited periods after SSTP application<br>No<br>No<br>No | > 200<br>50<br>≥ 250<br>≥ 100<br>N and P, not considered. Need to justify if higher than 5.000 d.m. basis (agricultural use)<br>Established<br>≥ 50<br>No<br>No<br>No<br>No | No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established<br>No buffering distances established| Prohibited for groundwaters, header and river banks | Prohibited for groundwaters, header and river banks | Prohibited for groundwaters, header and river banks | Prohibited for groundwaters, header and river banks | Prohibited for groundwaters, header and river banks |

aMandatory and binding report from Hydraulic Agencies needed. bRanges dependent on different crop cultivation (animal and woody crops, natural or non-planted forage utilization areas, forest areas). In italics for R.D. 506/2013, direct consideration in the legal text. cAgricultural Plots Geographical Information System (https://sixpac.xunta.es)
Circular economy barriers of regional regulation

Treatments and organic matter cycles loops

SS is a waste characterized by its high levels of HMs, usually higher than materials from other sources. In Europe, the question regarding whether the extension of SS Directive onto other organic wastes, when sufficiently justified, was discussed in Sludge and Biowaste Working Document (EC 2010). In Galicia, with the publication of Decree 125/2012, such doubts were elucidated by making extensible the rules for SS to other organic waste intended to be applied to soil as fertilizers. Thus, Galician Decree fixes the same mandatory conditions for any organic raw material, whatever their properties might be. Consequently, these mandatory conditions could represent an obstacle to CE in two ways. First, the multiple beneficial effects derived from the addition of organic amendments on soil (Diacono and Montemurro 2010) are inhibited. Second, the waste of chance that represents this option versus others less desirable in the model hierarchy in waste management like landfill disposal or incineration, as in the case of debarking residue in Finland (Pöykiö et al. 2019), which is recommended for forest fertilization or landscaping purposes. The review of the literature revealed multiple cases about the recycling of organic wastes of the region with no previous treatment and positive effects on soil properties. Mussel shell can act as a substitutive of lime, avoiding environmental effects arising from lime extraction (Álvarez et al. 2012), or can be used as pollution control agent in the copper-enriched vineyards soils (Garrido-Rodríguez et al. 2013). Mussel shell was also added to soils in combination with cattle slurry, enhancing their biological and chemical properties with no adverse effects (Paz-Ferreiro et al. 2012). Similarly, ash with charcoal from biomass plants (Santalla et al. 2011) and mixtures with other organic wastes (Pousada-Ferradás et al. 2011) can act positively as fertilizers and liming agents for agricultural and forestry use. Lowering solubility of HMs, alkaline wastes reduce the risks of water pollution (Pousada-Ferradás et al. 2012). Scientific literature contains other additional references to the recovering of organic wastes with beneficial agronomic purposes in Galicia. These practices are no longer feasible after the promulgation of Decree 125/2012, since it required mandatory treatment before their application as a fertilizer in agricultural soils. The costs of these treatments suppose additional drawbacks that could discourage the recovery of the nutrients and OM contained in wastes. At this respect and as outlined by Overtuf et al. (2020), many CE projects can be compromised because of economical drives and it can become more profitable to make less environmentally sustainable choices. At this point, regulations become exceedingly important in the implementation of the CE. (Overtuf et al. 2020).

On the other hand, some allowable treatments may not be technically necessary with certain streams of wastes, as thermal drying in the case of ashes, an organic residue broadly studied in the region as fertilizer or amendment. While in other European countries, the application of ash in forest soils is permitted or even recommended, current regional normative did not define any guideline in this regard. The role of this same product was recently brought into question since despite its potential recycling in soils it is still not properly framed by the EU regulatory framework (Silva et al. 2019).

Organic matter may influence the chemical properties of the soil by reducing Al toxicity and increasing the retention of cations in the soil exchange complex of soils of the region. If the addition of organic matter favours a non-acidic pH in the soils, it also reduces HM solubility, and therefore reduces their bioavailability, especially important in Galicia, location characterized by acidic soils and high rainfall. Regional legislation on the recirculation of wastes should be adapted to main groups of soils (Macías et al. 2006) and related main climatic areas as they might positively influence biochemical soil properties (Paz-Ferreiro et al. 2010). Suggestions of Barral...
and Paradelo (2011) on the Spanish State commercial fertilizers legislation can be extended to other organic materials in Galicia. Current regional regulation might blur the limits between fertilization and disposal (of treated wastes) as neither quality standards for SSTP nor tests of its agronomic efficiency are required. For this reason, it could be possible to get rid of important amounts of those (treated) wastes with low HMs content and scarce agronomic interest. This creates an undesirable scenario, where linearity prevails over circularity, that must be avoided preventing soils from becoming mere receptors of (treated) wastes through the requirement of the legislation to obtain high-quality amendments or fertilizers.

The analysis also shows that legislation should make profit of the scientific evidence carried out in the region with positive results in the recycling of wastes with no previous treatment on soils, promoting their recycling. At this respect, disconnection between scientific evidence and its translation to environmental policy was previously reported (Margalida et al. 2015). The question that emerges is whether the legislation should adapt to science or science to legislation. European Commission efforts in providing the best available scientific knowledge to EU policymaking to make sense of and use knowledge to inform policymaking across Europe (EC 2021). In accordance, the Spanish CE strategy outlines as one of the primary objectives to promote mechanisms to enhance the exchange of information and coordination among public administrations, the scientific and technological community, and economic and social agents to favour the transition to a more circular model (MAPAMA 2019). Efforts should be renewed to strengthen mechanisms of information flows between policymakers and stakeholders to boost the recycling of organic wastes in soils as secondary raw materials considering soils as natural capital.

Legal limits of soil heavy metals

When analysing nutrient management legislation, De Clercq (2001) exposed that bordering countries may face environmental concerns in a different manner from a legislative approach. In this sense, although the North Portuguese and Galician soils, both adjacent territories, present great similarities, respective legislation established differences in legal HM soil limits (Table 6).

Whereas Galician and Spanish legislation only distinguished between acidic and basic soils, Portuguese normative (Diário da República 2009) introduced an intermediate 5.5–7.0 pH range for moderate acidic soils with more tolerant limits. Such soils could be assimilated to those of Galicia where agriculture practices, as liming, led to a raise in pH (Conde-Cid et al. 2018). This means that in Portugal, the possibility of recovering organic waste, because of the natural HMs concentration in soils, is expanded. The limits fixed in Portugal for moderate acidic soils would be above the natural Galician HMs (Table 6). In the end, Portuguese normative considered a strongly acidic range (pH < 5.5), representative of Galician forestland soils. In this last case, Portuguese legislation presents the same values (except for Cr) than Galician/ Spanish legislation (Table 6). For pH > 7, limits in Portugal are less restrictive than in Galicia/Spain, but as in Galicia, Portuguese soils are mainly acidic.

As a result of comparing the reference values of HMs content in Galicia natural soils with the legal thresholds established in the normative (Table 6), it becomes apparent that the own nature of these soils may constitute an obstacle in the recycling of the SSTP as the natural levels are close (Hg, Cr) or higher (Ni) than the established limits to allow the SSTP application. Even thresholds for Cu, Pb, and Zn can be achieved in natural soils when settled under determinate rocks (see italicized bold values in Table 1). Only soils settled on sediments and granites would be plenty appropriate for the recovery of organic amendments as fertilizers (Barral and Paradelo 2011). This legal approach can limit

| Normative       | Soil pH | Cd  | Cu  | Ni  | Pb  | Zn  | Hg  | Cr  |
|-----------------|---------|-----|-----|-----|-----|-----|-----|-----|
| Europe*         | 6–7     | 1–3 | 50–140 | 30–75 | 50–300 | 150–300 | 1–1,5 | –   |
| Galicia/Spain   | <7      | 1   | 50  | 30  | 50  | 150 | 1   | 100 |
|                 | >7      | 3   | 210 | 112 | 300 | 450 | 1,5 | 150 |
| Portugal        | ≤5,5    | 1   | 50  | 30  | 50  | 150 | 1   | 50  |
|                 | 5,5 < pH ≤7 | 3   | 100 | 75  | 300 | 450 | 1,5 | 200 |
|                 | >7      | 4   | 200 | 110 | 450 | 450 | 2   | 300 |
| Galician soils reference values*b | 0,11 | 20,61 | 55,83 | 29,32 | 60,29 | 0,07 | 80,25 |

*aIf sludge were applied in soils with pH < 6, EU Member States should take into account the increased mobility of HMs and, where necessary, reduce the limit values they have fixed in accordance with Annex I A (EC 1986)

*bReference values (Macías and Calvo de Anta 2009)
the recovery of organic wastes as fertilizers, compromising the action proposal of reusing organic wastes that can be returned to the soil as fertilizers included in the Galician CE Strategy (Xunta de Galicia 2019). Of course, this limitation do not work in the absence of controls on the compliance of the established rules or if controls result inefficient.

In line with this argument, the literature search exposed the existence of unnatural levels of HMs. In the main wine production areas of Galicia, covering a 33.273 ha of land, Fernández-Calviño et al. (2009) found total Cu concentrations that largely exceeded (from a factor of 2 to up to 5) the 50 mg kg⁻¹ threshold (Table 6) and, again, the recovery of regional treated wastes would be restricted in these vineyard soils. This is a key consideration as these soils are characterized by a low OM content (Fernández-Calviño et al. 2009) and on the other hand, Cu immobilization by OM is a common technique that results in reducing Cu soil solution and subsequently, the toxic effects on microbiota (Kabata-Pendias and Mukherjee 2007). In this case, it was demonstrated that the direct application of another abundant waste in the region, the crushed mussel shell, has shown beneficial effects in reducing Cu bioavailability and promoting plants growth (Fernández-Calviño et al. 2017), or enhancing soil properties by diminishing the risks of environmental damage related to Cu (Garrido-Rodríguez et al. 2013).

In relation to this and after the analysis of the current legislation, to circumvent this inconvenient, a legal shortcut would invite to increase the SSTP quality in the physical–chemical and biological terms expressed in Tables 3, 4 for commercial fertilizers. In this way, the natural HMs content in soils would not be a barrier because, as exposed previously, SSTP reaching the before-mentioned quality requirements are excluded from the scope of the regional normative, and thus, the consideration of HMs content in soils is not necessary for the application of commercial fertilizers on soils.

Moreover and conversely, from a legal point of view, soils in areas with high levels of HMs (vineyards or others) would admit inorganic fertilizers, commercial amendments or manures, despite HMs accumulation in soil can be caused by municipal solid waste composts (Domínguez et al. 2019) or manures (Feng et al. 2018), or even result in toxicity for cattle manure as reported by López Alonso et al. (2000) in Galicia. In the same manner, inorganic fertilizers might content HMs in upper concentrations to those marked in regional legislation for treated wastes, as in Cd. For this element, Cd, the so recent Regulation (EU) 2019/1009 on fertilizers has already been questioned as its dispositions are considered insufficient alone in reducing the Cd accumulation in EU soils (Marini et al. 2020). In the meantime, in Galicia there are no restrictive limits for the use of inorganic fertilizers although some European countries have developed legislative restrictions in their heavy metal content, for both agriculture and forestry application.

At a supranational scale, the implementation of EU legislation may differ widely (EC 2014) as most Directives and Regulations are legislative documents that need to be applicable throughout the wide range of climates, soils, ecosystems and agricultural practices present in the EU (Vrebos et al. 2017). In what SS is concerned and regarding the restrictions because of HMs limits in soils, SS Galician Decree 125/2012 took the same values than the Spanish R.D. 261/1996 although soils as well as climates in Galicia are very dissimilar from those in other parts of Spain, especially in the southeast areas, the driest in Europe. At this respect, the convenience of considering regional differences in the implementation of a national regulation was previously reported when referring to separate waste collection in Italy, and aiming to achieve a similar convergence and avoid discrimination (Agovino et al. 2021). Similarly in Spain, and as regional regulation may stablish stricter but not more permissive limits to a national legislation, RD 1310/1990 on SS should consider the significant disparities among regions in terms of their natural conditions regarding the HMs content thresholds in soils.

Conclusions

In this paper, the influence of legislation on the promotion of organic wastes recycling on soils was evaluated and to what extent the principles of circular economy are overlooked, exploring a practical case at the regional level.

It can be concluded that current normative, only in a partial manner, promotes a transition to CE at the recycling of organic matter and nutrients in the region. The regulations tend towards a more lenient approach to manures and inorganic fertilizers, thus favouring their application to soils. No legal restrictions are established on the content in HM (nor in the target soils) and other physico-chemical and biological properties of manures and inorganic fertilizers, unlike what happens for commercial organic fertilizers obtained from waste or for SSTPs. This is contrary to EC expectations aimed to progressively replace the use of inorganic fertilizers in the near future.

The findings also indicate that regional normative on sewage sludge and other organic waste does promote their addition on soils but on low-quality recycling schemes, which mainly maintain the undesired linearity using the soil as a waste sink. This is so due to the lack of agronomic quality requirements of the current regulation, as it does not require a minimum content of N or organic matter, or other basic parameters, which gives way free to get rid of important amounts of treated waste in soils.
Current regional regulation on SSTP can be improved in two key aspects. First and according to CE fundamentals about nutrient recovery, the requirement of quality standards to prevent soils from being a second-class landfill option for organic wastes with scarce agronomic interest. Second, it is advisable the reconsideration of mandatory treatments for these significant regional streams of wastes (e.g. ashes, mussel shells and others), for which scientific literature showed beneficial effects on soil properties after their direct application. The latter exemplifies the need for information exchange and coordination between lawmakers and the scientific community, as well as other actors, to promote the transition to circular models.

As long as the regulations remain unaltered, the regional natural soils properties (or others with antrophic heavy loads of HMs) can represent an obstacle pursuing these circular models, which leads, again, to the obtention of high-quality natural soils properties (or others with antrophic heavy loads). This time, it is aimed to overcome a legal barrier. The contradiction arises because limits must be respected for waste treated according to regional regulation but exempt for commercial fertilizers according to Spanish State normative.

The analysis also revealed some particular insights as the observance of good agricultural practices. These practices, primary intended for prevention from pollution from agrarian sources, become voluntary for manures, whereas they are mandatory for organic-based commercial fertilizers, characterized by stability and medium mineralization rates (in opposite to liquid manures).

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