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Using bone char as phosphate recycling fertiliser: an analysis of the new EU Fertilising Products Regulation

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Abstract

Background Phosphorus recycling is an important cornerstone of sustainable phosphorus management and required to establish a circular economy in line with the EU Green Deal. Animal bones contain phosphate which can be recovered and processed into bone char. Animal bone char has a fertiliser potential. In the past, the EU lacked measures to market these fertilisers on the internal market. With the adoption of the Fertilising Products Regulation in 2019, the EU sought to incentivise recycling fertiliser production. Against this backdrop, the aim of this paper is to first provide the key elements of the new regulation and to second assess the extent to which it enables marketing bone chars as fertilisers. To this end, a qualitative governance analysis is applied.

Results Results show that the Fertilising Products Regulation closes an important regulatory gap by establishing the legal framework for diverse recycling fertilisers, including bone char fertilisers. However, a lengthy adoption process hinders the marketing of bone char fertilisers and contaminant limits require improvement.

Conclusions Ultimately, the promotion and use of recycling fertilisers is a necessary but complementary approach for the circular economy. A comprehensive transformation of the sector is needed to align it with global environmental goals.

Keywords Fertilising products regulation, Bone char, Recycling fertilisers, Phosphorus, Phosphorus governance, Circular economy

Background

Phosphorus (P) is essential for food production [1–5]. However, most states are highly dependent on P imports from a few supplier countries, including Marocco/Western Sahara and Russia, thus facing the risk of supply shortages [4, 6–10]. In the EU, 92% of phosphate is imported from third countries [11], which makes rock phosphate a critical raw material [12–14]. Currently, as a result of the Russian invasion of Ukraine, the import dependency of the EU from fertilisers and inputs for fertiliser production adds further pressure on the EU agricultural sector [15, 16]. Apart from that, the predominantly sedimentary rock phosphate deposits are increasingly contaminated with heavy metals and radioactive substances, bearing environmental and health risks [17–21]. Although there is a high potential for substituting rock phosphate with recovered P [22–24], P use in the EU is mostly linear and a considerable amount of P-rich waste remains unused for fertilisation [25].

To reduce short-term supply shortages and ensure long-term availability of P for future generations, efficient P fertilisation and increased P recycling are necessary [26–28]. Improving P efficiency and circularity would

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also counteract the environmental issues of unsustainable P management. The agriculturally used P is a major driver of eutrophication and exceeds planetary boundaries (oceans) [29–32]. Eutrophication causes dead zones with (very) little or no biodiversity [33, 34]. Intensive animal husbandry in particular causes high P surpluses and disturbed P cycles [24, 35–37]. Hence, unsustainable P management has negative implications for biodiversity. At the same time, climate change is expected to be a major driver of soil erosion [38] which will likely increase P transfers from arable fields into freshwater and marine ecosystems [39]. Thus, these environmental issues (P, biodiversity, climate) must be analysed together and addressed comprehensively [36, 40]. More sustainable P management, including P recycling, and an agricultural sector which is in line with the legally binding goals of the Paris Agreement [41, 42] and the Convention on Biological Diversity (since 2022 concretised by the Montreal–Kunming targets [43]) are necessary. Sustainability is understood as 'extending the idea of justice, i.e., the normative question of the right society […], in spatio-temporal terms, i.e., towards intertemporal and global cross-border justice' [44].

The EU acknowledges these challenges for the agricultural sector and P management. The Farm to Fork Strategy [45, 46] at the heart of the European Green Deal [47] seeks to redesign the EU's agri-food sector towards sustainability, inter alia by aiming more sustainable nutrient management especially for phosphate and nitrate. One objective of the Farm to Fork Strategy requires the reduction of nutrient losses by at least 50% resulting in at least 20% less fertiliser use by 2030. Another building block of the Green Deal is the Circular Economy Action Plan which promotes food-waste reduction, more sustainable nutrient application and market stimulation for recovered nutrients through a yet to be published Integrated Nutrient Management Plan [48]. In accordance with these measures, the EU's updated Bioeconomy Strategy aims at promoting sustainable food and farming systems, including nutrient recycling [49, 50].

Against the backdrop of the current global mineral fertiliser crisis caused by disrupted supply chains due to the COVID-19 pandemic and the Russian invasion of Ukraine, P recycling has once again moved upwards on the EU's political agenda. In November 2022, the EU Commissions published a Fertiliser Communication. The Communication aims at ensuring availability and affordability of fertilisers in the EU through production diversification and reliable fertiliser supply chains. For the medium and long terms, the Commission emphasises the need to substitute rock phosphate-based fertilisers with more sustainable alternatives, such as organic fertilisers and recycling fertilisers. Moreover, the Commission highlights that the current fertiliser crisis is 'an opportunity to accelerate the transition to a sustainable agriculture […] system' [15]. Yet, the targets of the Commissions' Communications are not legally binding. They have to be implemented through binding legislation, i.e., regulations or directives according to Article 288 TFEU. One such legislation is the Fertilising Products Regulation (FPR). As little research has so far discussed the new EU FPR, this article first aims to present the key elements of the new regulation. To this end, the article introduces one phosphate recycling fertiliser, bone char, which it uses as an example throughout the analysis. On this basis, the article second aims to assess the extent to which the new FPR enables the placing on the market of bone char fertilisers and thereby contributes to sustainable P management [37, 51] and the goal of the Convention on Biological Diversity.

Materials and methods

This article assesses EU fertilising legislation. The research scope covers the legal provisions for the placing on the market of recycling fertilisers and in particular bone char fertilisers. The scope does not extend to, e.g., the construction and operation of P recycling facilities or the application of these fertilisers on the land. For each of these areas, different legal measures such as the Industrial Emissions Directive[1] or the CAP Strategic Plan Regulation[2] are relevant. Hence, the present analysis assesses provisions of the new Fertilising Products Regulation[3] and the preceding Fertiliser Regulation,[4] the Mutual Recognition Regulation[5] and the Animal by-products Regulation.[6]

[1] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).

[2] Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013.

[3] 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.

[4] Regulation (EC) No 2003/2003 of the European Parliament and of the Council of 13 October 2003 relating to fertilisers.

[5] Regulation (EU) 2019/515 of the European Parliament and of the Council of 19 March 2019 on the mutual recognition of goods lawfully marketed in another Member State and repealing Regulation (EC) No 764/2008.

[6] Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation).

For this assessment, a qualitative governance analysis is applied. The qualitative governance analysis aims to identify effective policy instruments to achieve a policy goal. Relevant for the analysis of this article is in particular the goal of the Convention on Biological Diversity. The legally binding goal requires stopping and reversing global biodiversity loss [52]. While new biodiversity goals have been adopted recently (Sect. "Background"), their legal status is still unclear which is why this analysis excludes them and instead focuses on the Convention on Biological Diversity.

The qualitative governance analysis is built on findings from behavioural studies and findings from natural sciences. Results from natural sciences can highlight issues that need to be addressed by policy instruments, such as, e.g., contamination levels of recycling fertilisers and the energy intensity of manufacturing. Against this backdrop, we reviewed literature on bone char fertilisers. Being part of an interdisciplinary project on sustainable P management, where research on bone char fertilisers has been undertaken (https://www.innosoilphos.de/), we primarily used the project findings to underpin our analysis. We supplemented these studies with recent as well as relevant older international scientific publications on (bone) char-based fertilisers. The results of this review can be found in the section hereafter.

Alongside findings from natural sciences, insights from behavioural studies forms a basis of the qualitative governance analysis. In contrast to the research on bone char fertilisers, we have not performed a review on behavioural studies as we have extensively discussed this topic in earlier publications [44, 53]. In short, studies show that typical barriers that policy instruments need to overcome include emotional factors such as convenience and habits, concepts of normality and self-interest [e.g., 54–56]. (Lacking) knowledge, awareness and values frequently play a subordinate role [e.g., 57–59]. These barriers have not only direct implications for designing policy instruments, e.g., the indication that purely voluntary and educational instruments such as fertilising guidelines are (predominantly) of limited effectiveness effective, but can also point to some typical governance problems. Alongside geographical and sectoral shifting effects, the effectiveness of policy instrument can be limited by enforcement problems, rebound effects and issues of depicting. The latter is a typical challenge of policy instruments which target very complex (environmental) compartments, such as peatlands, greenhouse gas fluxes and biodiversity [60–62]. When qualitatively assessing fertilising policies, these results are factored in, i.e., in the discussion, we assess the FPR with regard to potential governance problems and in light of the Convention on Biological Diversity. In doing so, the qualitative analysis offers a comprehensive assessment of the FPR, including how it can be improved, potentially supplemented by alternative/additional instruments and the extent to which it contributes to global environmental goals.

The following section introduces recycling fertilisers and in particular bone char fertilisers. Thereafter, the new FPR is introduced and a potential legal pathway for putting bone char fertilisers on the EU internal market assessed. Discussion and conclusions follow.

Recycling P fertilisers and bone char

Recycling fertilisers play a crucial role in making the agricultural sector more sustainable and resilient. Recycling P fertilisers can substitute rock phosphate-based, chemically industrially processed fertilisers and, thereby, improve circularity and close the supply gap for P fertilisers due to import dependency and rising energy prices (Sect. "Background").

Fertiliser based on 'secondary raw materials', i.e., materials that can be recycled and send back into the production processes as new raw materials [63], can be derived from various wastewater and waste streams, such as animal and human excreta, and food processing and food waste [6, 22, 64, 65]. Recovery precedes recycling and creates intermediates, so-called recyclates [66]. Source materials, processing, P content (as well as other elements, especially N and C, and their ratio), plant availability of P, pollutant levels, cost intensity, energy input, and transport requirements vary between recyclates. Hence, different products may be recommended for different soil parameters, farm characteristics and regions [22, 67].

Since the largest P losses are found in the wastewater sector of the EU [68], research and development focus on P recovery from wastewater. The technical requirements for P recovery from sewage sludge and/or sewage sludge ashes are well-developed. Still, up to now, industrial-scale P recovery is implemented sparsely and many processes for P recovery not only from sewage sludge but also from other waste and wastewater are not yet ready for the market—including animal bones. Similarly, many P recyclates are not yet economically competitive with conventional fertilisers [2, 3, 9, 22].

Using the diversity of potential secondary raw materials will help to establish the circular economy for P. The heterogeneity of soils, P fluxes and P losses, as well as the different P requirements and P availabilities of different agricultural systems mean that P recovery strategies and fertiliser products should be as diverse as possible. In fact, P recovery is conceivable from all waste streams along the value chain. Following the waste water sector, the food processing sector, in particular the slaughter of animals and removal of P-rich waste materials, such as meat and bones, accounts for the second largest amount of P losses [68, 69]. At least part of these losses is not necessarily lost forever, but could be avoided and materials used for fertilisation when properly treated. For instance, animal bones, which have a very high P content compared to other animal waste, have been used as fertilisers in the eighteenth and nineteenth century [69, 70]. Especially in organic farming, meat and bone meal has been used as a major source for P in the past. However, as a result of the bovine spongiform encephalopathy (BSE) crisis in 1999, the use of meat and bone meal has been largely prohibited [71].

Nowadays, pyrolysis of animal by-products—not only meat and bone meals but bone chips and grist—has been established to eliminate pathogens while retaining C and P content [69, 72]. Pyrolysis is process of heating organic substances in the absence of oxygen, which transforms the material into three components, i.e., solid, gas and liquid. The properties of the output charred products, i.e., biochars, depend on (the plant) or animal-derived source material and the pyrolysis technology and conditions [25, 69, 73]. While plant biochar has high C contents but no or low nutrient contents, animal bone chars have high P and calcium contents and low C content [69]. The agronomic efficiency[7] of pyrolysis materials derived from slaughter by-products varies depending on input material, production process, and soil and plant characteristics. Hence, a direct comparison between bone char fertilisers and mined and synthetic P fertilisers is difficult [25]. Depending on the soil characteristics, the P solubility of bone char is between those of rock phosphates and triple super phosphate, with the P solubility of the sulfur-enriched bone char being enhanced [74, 75]. Bone chars can be produced from defatted, optionally gelatinized, bones by pyrolysis at about 800 °C [76–78]. Further processing is feasible, such as surface-modification and sulfur-enrichment to create small-scale local hotspots of acidity from microbial S^0-oxidation to SO_4^{2-} which enhances the dissolution of bone char particles and the release of nutrients, such as P and S, resulting in a "Bone Char^{plus}" [79, 80]. Bone chars have several environmental and economic advantages, making them a promising recycling fertiliser. The porosity of bone char particles provides a good habitat for microorganisms, including beneficial microorganisms, such as P-mobilising or antipathogenic bacteria and fungi [81]. Furthermore, since porosity affects water retention, bone char application to soil can improve the soil moisture status for cropping by retaining more soil water from percolating and holding it in the root zone [69, 76, 77]. Besides that, bone char is free from organic contaminants, such as pharmaceuticals and contains—in contrast to rock phosphate-based fertilisers—no heavy metals [80].

When developing and using recycling fertilisers from various residual materials, it is also necessary to consider properties, such as interactions with other substances in the soil. For instance, bone char and sulfur-enriched bone char have different soil cadmium (Cd) mobilisation properties, depending on soil pH and P content [76]. Cd is a heavy metal that harms human health when, e.g., taken up with contaminated food [82]. By nature, Cd is a relatively mobile element. Bone char leads to increasing pH values and the formation of Cd phosphates, thus favouring Cd immobilization and reducing Cd uptake of plants. Hence, bone char immobilises Cd in soil while having a positive effect on P mobilisation for plant nutrition [72, 76, 79, 83]. In contrast, sulfur-enriched bone char tends to increase Cd solubility and hence plant uptake. Therefore, this bone char can only be recommended for slightly Cd-contaminated soils [76, 79, 83].

Another crucial factor for the successful establishment of recycling fertilisers is their applicability. One important element of applicability is particle size. The particle size, in turn, influences the effectiveness of fertiliser products. Bone char particle size affects P release, distribution in the soil and reactivity with other soil compounds. In an experiment, bone chars achieved the highest P release with relatively low Cd release into the soil solution at particle sizes of 0.5 mm to 1 mm, i.e., not necessarily at the smallest particle sizes. Fertilisers with particles of this size can be applied by common agricultural machinery, while smaller particles require palletisation, also to comply with health and safety precautions established in fertiliser legislation [79]. Besides applicability, nutrients in substitutes for rock phosphate-based fertilisers need to be available to plants, both in the long term and the short term [25, 67, 71, 80]. Likewise, P losses to the aquatic environment have to be low, even in the case of recycling fertilisers, which makes efficient, site-adapted and needs-based fertilisation necessary. In addition, when using P recyclates, soil protection needs be taken into account, e.g., maintaining or increasing soil organic matter. Finally, other environmental protection concerns must be considered, especially climate protection concerns. This implies that the production of recycling fertilisers has to be as energy-efficient as possible and undertaken using renewable energies. In fact, zero greenhouse gas emission pyrolysis for P recovery already exists [69, 84]. Hence, the development and application of recycling fertilisers alone will not suffice to combat environmental issues and establish the circular economy. Instead, sustainable P and soil management as well

[7] Agronomic efficiency describes yield changes in relation to nutrient application (Fixen et al. 2015).

as comprehensive transitions in the agricultural sector are needed. Still, one step towards creating the circular economy is the replacement of rock phosphate-based fertilisers with recycling fertilisers. Against this backdrop and as bone chars are still in the research stage and not (yet) sold on the market, the following section investigates if the EU FPR establishes a pathway to market these products.

Results: the EU fertilising products regulation

The results are divided into two parts. The first part discusses the key elements of the FPR. The second part investigates a (potential) regulatory pathway to market bone char fertilisers through the FPR in the EU.

Aims and general provisions

The EU establishes harmonised rules for placing fertilisers on the internal market. Where a fertiliser complies with these rules, it is eligible for the CE marking and free movement between the member states of the EU. Until 2022, the EU Fertiliser Regulation (EC) 2003/2003 determined the legal framework for EU fertilisers. It was repealed by the EU Fertilising Products Regulation (EU) 2019/1009 in July 2022. Fertilisers which have been placed on the market before the entering into force of the new FPR can continue to be marketed after the repeal of the fertiliser regulation 2003/2003 (Art. 52 FPR). In general, applying for CE marking is optional. Fertiliser manufacturers can also put fertilisers on the national market of a member state when complying with national rules. Yet, this article focusses on the EU provisions.

The previous Fertiliser Regulation (EC) 2003/2003 hindered the introduction of innovative fertilisers. To be marketed as EC fertiliser, a fertiliser had to belong to a fertiliser type listed in Annex I of the regulation. However, this annex it did not cover organic fertilisers and recycling fertilisers and hence excluded their placing on the internal market. Besides, threshold values for heavy metals such as Cd in fertilisers were missing [66, 85, 86]. To address these issues, the Commission published its first Circular Action Plan in 2015. The Circular Action Plan included a revision of the EU Fertiliser Regulation with measures to facilitate the EU wide recognition of organic and waste-based fertilisers [63]. In preparation of the revised regulation, an impact assessment was performed. This assessment states that "[t]he general objective [of the new fertiliser regulation] is to incentivise large scale fertilising products production in the EU from domestic organic or secondary raw materials by creating a regulatory framework granting such fertilisers access to the internal market and to address the well-recognised issue of soil contamination by contaminants present in fertilisers" [11]. Ultimately, the new regulation was adopted in June 2019. It applies to EU fertilising products which are defined as "a substance, mixture, microorganism or any other material, applied or intended to be applied on plants or their rhizosphere or on mushrooms or their mycosphere, or intended to constitute the rhizosphere or mycosphere, either on its own or mixed with another material, for the purpose of providing the plants or mushrooms with nutrient or improving their nutrition efficiency" (Art. 2 (1) FPR).

The regulation establishes obligations for economic operators which include manufacturers (Arts. 6–7 FPR), importers (Art. 8 FPR) and distributors (Art. 9 FPR). For example, manufacturers have to ensure that fertilising products comply with the requirements of the product function and component material categories (see below). They do also have to perform the conformity assessment (Art. 6 (1) and (2) FPR). Importers have to ensure that, before placing a fertilising product on the EU market, products from third countries comply with the regulation, i.e., that the manufacturer in the third country has done the prescribed conformity assessment procedure (Art. 8 (2) FPR). Distributors have to ensure that the fertilising products are equipped with the required documentation (Art. 9 (2) FPR). Penalties for infringements with this regulation are established by the member states (Art. 48 FPR). Besides, surveillance, control and safeguarding procedures for dealing with potentially harmful EU fertilising products are established (Art. 37–41 FPR).

If the fertilising products comply with the requirements of the regulation, they can be placed on the internal market of the EU (Art. 5 FPR) and the CE marking indicates the conformity with the regulation (recital 41 FPR). The regulation enables the marketing of products with different functions and components (Fig. 1). To this end, product function categories with individual product safety and quality requirements (Annex I FPR), and different component categories with individual process requirements and control mechanisms are established (Annex II FPR). An EU fertilising product has one product function and can be composed of several component materials. Each material has to comply with the requirements of the corresponding component material category/categories. For fertilising products with multiple functions, a separate product function category 'fertilising product blend' is created (Annex I FPR). In addition to these requirements, an EU fertilising product must comply with labelling requirements (Art. 4 (1) lit. (c) FPR).

Where a fertilising product complies with other standards of EU regulation, it is assumed to also comply with the FPR (Art. 13 (1) FPR). For all other fertilising products, conformity assessment procedures are established in Annex IV. Depending on the product function category and the component material category, different

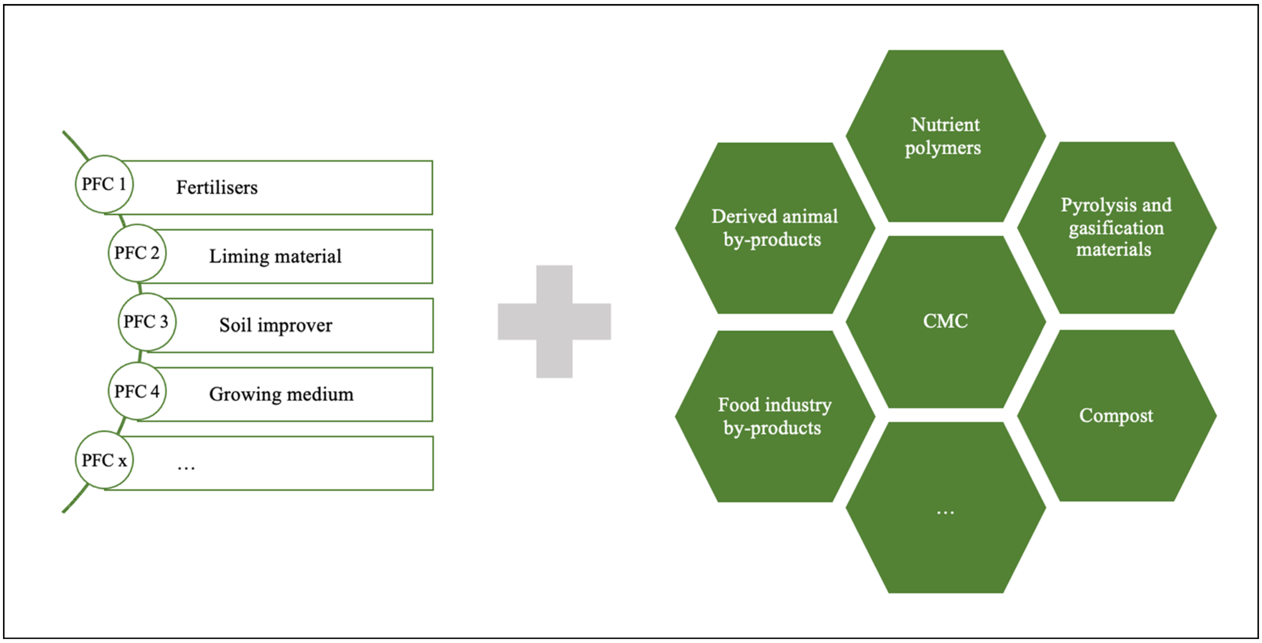

Fig. 1 EU fertilising products are a combination of one product function category (PFC) and one or multiple component material category/categories (CMC)

procedures—called 'modules'—have to be applied. These modules are adopted from EU Decision No 768/2008/EC. Some modules require a third-party conformity assessment body; others can be performed internally by the manufacturer (Art. 32 and Annex IV FPR). Conformity assessment bodies have to be notified by the member states to the Commission (Art. 20 FPR). To ensure a level playing field, the regulation establishes mandatory requirements for all assessment bodies (Art. 24 and recital 43 FPR). This includes having to have a legal personality and employees with sound technical training and being independent of the assessed fertilising product [Art. 24 (1)–(11) FPR]. Ultimately, where a fertilising product contains waste material and is compliant with the requirements of the FPR, that material is no longer considered waste material ('end of waste status') (Art. 19 FPR).

To keep up with technological process and to enable market access for new fertilising products, the Commission can adopt delegated acts to amend the annexes of the regulation. National authorities and stakeholders can submit proposals for new fertilising products [87]. The proposed fertilising products (1) must have the potential to be widely traded on the internal market, and come with scientific evidence that they (b) do not cause a risk to human, animal or plant health, to safety or to the environment, and that shows their agronomic efficiency (Art. 42 (1) FPR). Exempted from the Commission's empowerment is a change in Cd limit values (Art. 42 FPR).

Bone char fertilisers under the EU Fertilising Products Regulation

This section assesses if the FPR contains a legal pathway to put bone char fertilisers on the internal market of the EU. Research on bone char primarily focusses on its fertilising characteristics, but an application as soil improver also appears feasible (Sect. 3.2). Still, this article focusses on bone char as recycling fertiliser.

Annex I of the FPR establishes the product function category 'fertiliser' (Fig. 2) (Annex I Part II pp. 33–43 FPR).

A fertiliser has to provide nutrients to plants or mushrooms. Fertilisers are distinguished into (1) organic fertilisers, (2) organo-mineral fertilisers and (3) inorganic fertilisers. Bone char can be categorised as inorganic fertiliser that supplies P to plants. According to the FPR, an inorganic fertiliser has to contain or release nutrients in a mineral form. Bone char contains calcium phosphate which is a mineral form. The FPR further distinguishes between inorganic macronutrient fertilisers and inorganic micronutrient fertilisers. As a P (and S) supplying fertiliser, bone char is an inorganic macronutrient fertiliser. For this fertiliser category, the FPR establishes contaminant limit values, including Cd. The Cd limit value depends on the total P content of the fertiliser. If the total P content is below 5% phosphorus pentoxide (P_2O_5)-equivalent by mass, Cd content must be below 3 mg/kg dry matter. If P content exceeds the 5% threshold value, Cd content must be below 60 mg/kg phosphorus

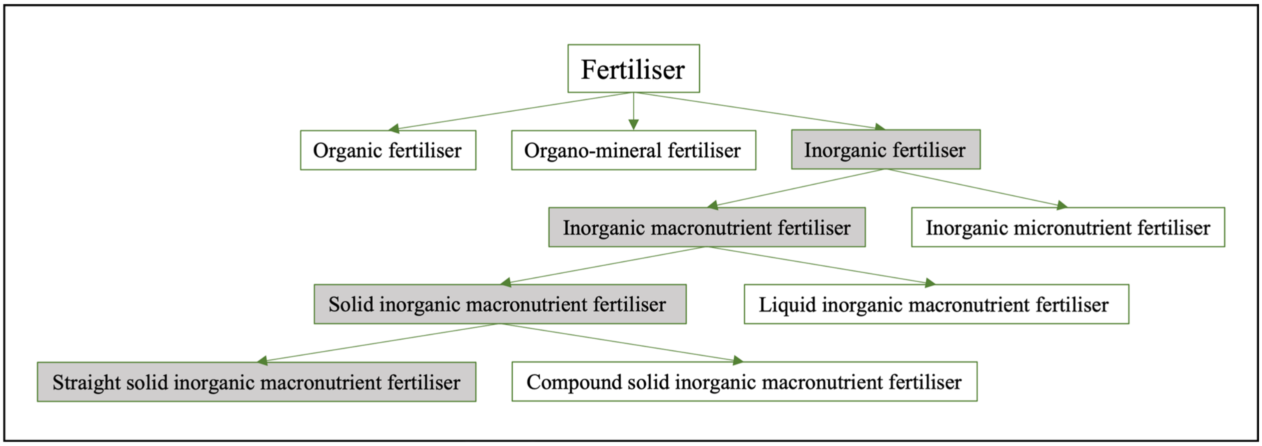

Fig. 2 Overview of PFC fertiliser. Dark fields show relevant bone char categories

pentoxide (P_2O_5). Bone char does not contain heavy metals, such as Cd and no organic contaminants (Sect. "Recycling P fertilisers and bone char"). The Regulation then distinguishes between solid and liquid inorganic macronutrient fertilisers. Bone char is solid (Sect. "Recycling P fertilisers and bone char"). Finally, solid inorganic macronutrient fertilisers are divided into straight solid inorganic macronutrient fertilisers and compound solid inorganic macronutrient fertilisers. The allocation of a fertilising product towards either category depends on the declared nutrient content (Fig. 3). It appears feasible that bone char could be allocated towards straight solid inorganic macronutrient fertilisers: declared nutrient could either be only one macronutrient (P) or one primary macronutrient (P) with one secondary macronutrient (S).

Annex II currently establishes 15 different component material categories (CMC) which can be used for fertilising products. To be included in the FPR, animal by-products or derived products such as bone chars have to leave the scope of the Animal by-products (ABP) Regulation: Art. 1 FPR states that the regulation applies to EU fertilising products and not to animal by-products or derived products which are subject to the requirements of the ABP Regulation (Art. 1 (1) lit. a FPR). To leave the scope of the ABP Regulation, animal by-products or derived products have to reach an end point in the manufacturing chain (Art. 5 (2) ABPR). Against this backdrop, the FPR contains an obligation for the Commission to determine end points for certain animal by-products and hence amend the ABP Regulation. Once this has been accomplished, these materials will be included in the FPR (Art. 42 (5) FPR). While the Commission has recently adopted a (delayed) delegated regulation,[8] which determines end points for meat-and-bone meal under certain conditions (Art. 4 (1) lit d Delegated Regulation), the final inclusion of these materials still requires an amendment of the FPR. Thus, currently, animal by-products and derived products such as bone chars cannot be included in fertilising products.

Still, as the Commission is working to include these materials into the FPR, we will discuss two CMCs which could be relevant for bone char fertilisers once they have been incorporated into the FPR. The first potential candidate is CMC 10. CMC 10 covers derived products as covered by the ABP Regulation. The second potential candidate is CMC 14 which covers pyrolysis and gasification materials. CMC 10 requires derived products to have reached an end point in the manufacturing chain and be listed in a table in Annex II of the FPR. However, that table has not been included into the Annex so far (see above). Hence, up to this point, legal provisions for CMC 10 are not established and cannot be used as pathway for placing bone char fertilisers on the market.

As an alternative to CMC 10, CMC 14 enables the input of animal by-products or derived products upon the condition that (1) again, an end point in the manufacturing chain has been determined and (2) they comply with certain manufacturing and material requirements. CMC 14 limits input material to Category 2 and Category 3 material as defined by the ABP Regulation. The ABP Regulation establishes three categories with increasing

[8] Commission Delegated Regulation (EU) 2023/1605 of 22 May 2023 supplementing Regulation (EC) No 1069/2009 of the European Parliament and of the Council as regards the determination of end points in the manufacturing chain of certain organic fertilisers and soil improvers (Delegated Regulation).

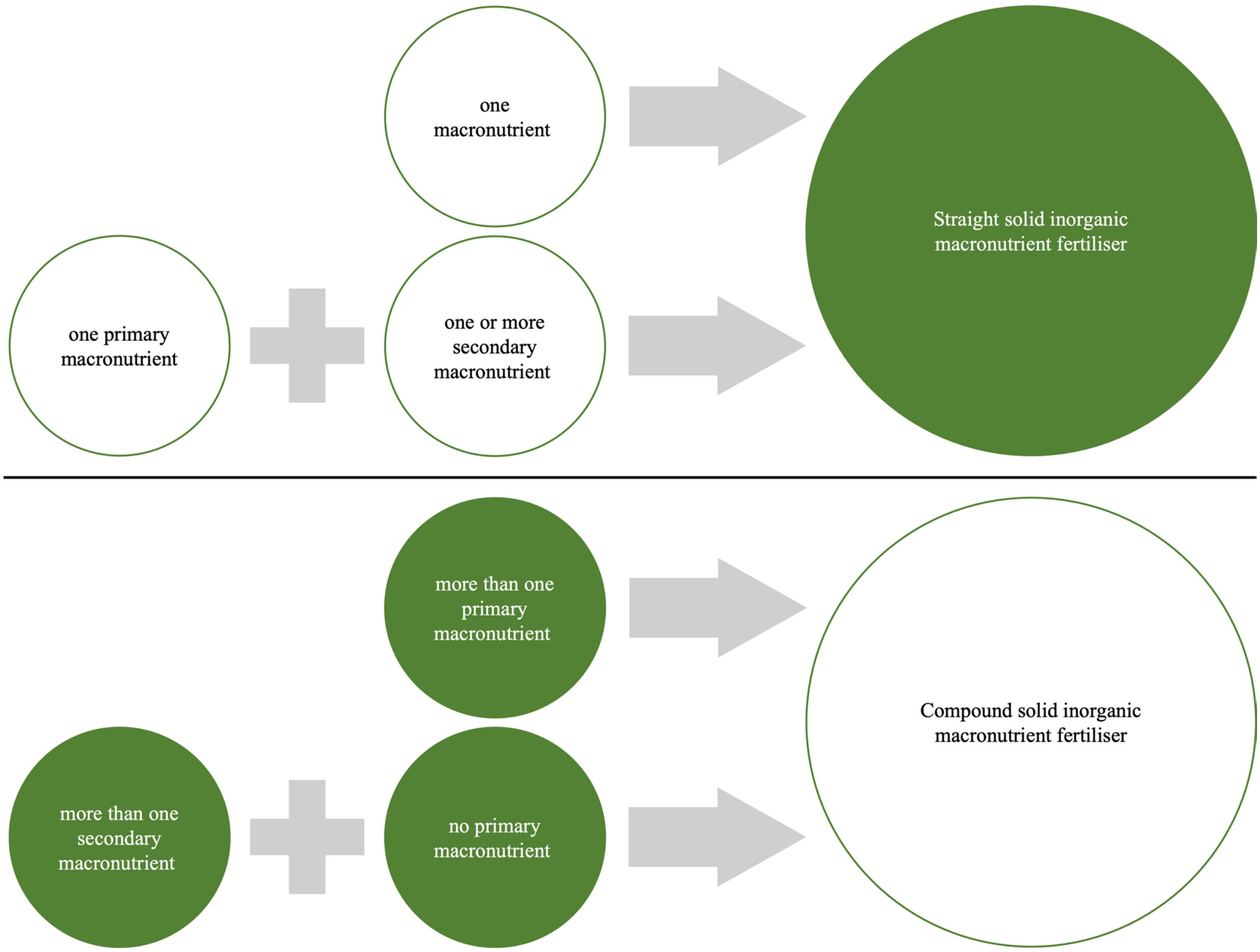

Fig. 3 Declared nutrient content of straight solid inorganic macronutrient fertilisers and compound solid inorganic macronutrient fertilisers

public and animal health risk levels (Arts. 7–10 APBR). Category 1 material covers material with the highest risk level. This includes, e.g., entire animal bodies and all body parts which are suspected of or confirmed to be infected with a transmissible spongiform encephalopathy (TSE), contaminated animal by-products, catering waste from international transport and mixtures of Category 1 material with either Category 2 material or Category 3 material or both (Art. 8 ABPR). Category 2 material covers, e.g., manure, Category 3 carcases and parts of animals slaughtered for human consumption but removed for commercial reasons (Arts. 9–10 ABPR). Manufacturing requirements of CMC 14 include, for example, a reactor temperature of at least 180 °C for a minimum of 2 s and prohibition of physical contact of input and output material. Besides, pyrolysis materials, i.e., the bone meal/chips/grist, have to be registered under the REACH Regulation.[9] Despite containing more details than CMC 10, CMC 14 also currently does not provide a legal pathway to put bone char fertilisers on the market for the same reason as CMC 10. Still, principally, the FPR contains the legal frame to market bone char fertilisers on the internal market of the EU. However, the incorporation into the FPR of animal by-products and derived products is a bottle neck that urgently needs to be addressed.

[9] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.

Discussion

Critical review of the Fertilising Products Regulation

This subsection begins with a discussion on the strengths and benefits of the FPR and proceeds with its limitations, including the lengthy policy process, restrictions of the input material and contamination issues.

Replacing finite resources with recycling and alternative materials is urgent to achieve the goal of the Convention on Biological Diversity. Still, it took 10 years from a Parliament resolution calling for nutrient recycling from waste streams to the entering into force of the FPR [88]. Despite the lengthy policy process, the FPR now finally closes an important regulatory gap for the marketing of organic and recycling P fertilisers in the EU. The FPR removes legal barriers for using recycled materials by granting an end of waste status. Besides, the adoption of the FPR is expected contribute to replace non-renewable resources, such as rock phosphate in fertiliser production [89]. In doing so, an important step towards operationalising the circular economy for P [90] and achieving the goal of the Convention on Biological Diversity is taken. Finally, in the past, researchers have called for harmonised procedures to assess potentials risks of recycling fertilisers when applied on soils, so that costs for fertiliser producers, farmers and public administration could be decreased [86]. The FPR now establishes such harmonised procedures and hence simplifies market access and observation and thereby policy enforcement.

These promising developments are dampened by several outstanding policy issues. The long process of integrating animal by-products and derived products such as bone char into the FPR hinders their use in recycling fertilisers—an issue that has repeatedly been picked up by the industry and other stakeholders [91, 92]. Quick legislation adoption is needed. Still, in the meantime, a fertiliser producer could access the internal market of the EU through a national market application and the Mutual Recognition Regulation. The Mutual Recognition Regulation enables the marketing of a product that is marketed in one member state to be also marketed in another member state. Benefits include a shorter application process in comparison with the application process under the past fertiliser regulation. Besides, authorities have more decision flexibility and the burden of proof in case of non-approval lies with them. Shortfalls include that the (additional) application procedure increases the administrative burden for fertiliser producers [66]. In addition, shifting effects which counteract achieving the goal of the Convention on Biological Diversity appear likely. For example, poor quality fertilisers may be approved in a national market with little legal requirements but would fail approval in a member state with higher legal requirements. These fertilisers could still enter the market with higher legal requirements through the Mutual Recognition Regulation [66]. Hence, again, fast adoption of outstanding legislation to enable marketing of bone char through the FPR is needed.

Once the FPR enables the use of animal by-products and derived products in fertilising products, input material is limited to Category 2 and Category 3 materials (Sect. "Bone char fertilisers under the EU Fertilising Products Regulation"). The exclusion of Category 1 material is a wasted opportunity. In its report, that serves as a basis to include new materials into the FPR, the Joint Research Centre of the Commission quotes numbers of the European Fat Processors and Renderers Association. According to these numbers, approximately one quarter of the material that is annually processed, is classified as Category 1 material [93]. Hence, one quarter of potential bone feedstock cannot be used for fertiliser production. It would thus be useful if the Commission mandated a risk assessment of Category 1 material also with a view to animal diseases, such as TSE—a step it did not do in the past [93, 94]. In addition, in fact, it seems that the Commission is considering such an assessment but cautions that this process is going to be lengthy [95].

Another risk of (recycling) fertilisers pose contaminants, such as Cd. In this context, the proposal of the FPR established that one of the two policy objectives of the proposal aims at the introduction of harmonised Cd limits [96]. However, no comprehensive Cd limit has been established (Sect. "Bone char fertilisers under the EU Fertilising Products Regulation"). Hence, while nearly closing an important regulatory gap—the previous fertiliser regulation did not contain any threshold value for Cd [see also 9, 66]—current provisions still offer a substantial shortcoming. In doing so, the FPR fails to exercise an effective steering effect and to adopt the precautionary principle as established in EU primary law [97, 98 instead argues for risk assessment-based requirements]. These inadequacies also counteract achieving the goal of the Convention on Biological Diversity as soil contamination is not adequately addressed.

Finally, the FPR misses an opportunity to enhance the competitive position of recycling fertilisers, such as bone char, by not increasing the cost of mineral fertilisers due to Cd-removal. In fact, low prices for (fossil-based) P raw materials are a primary market barrier for recycling products [98–100]. Still, the fertiliser industry lobby and the EU farmers association were opposed to the Cd threshold limits [101]. To enhance the economic viability of P recycling outside the FPR, different proposals have been made. For example, Jupp et al. [9] propose to implement a ban on all routes which do not recycle P, such as landfilling and incineration of meat and bone meal in cement works (p. 98). Others propose recycling quotas and targets [66, 98, 99] as, for example, established in the reformed German sewage sludge ordinance (AbfKlärV). Besides that, a supportive effect could be achieved if voluntary industry certificates included bone chars into their certification schemes (see, e.g., positive list of the European Biochar Certificate) [102]. Finally, including biochars from animal materials into the scope of organic farming could increase their application. To date, organic farming only allows the application of biochar from plant materials (Annex II Regulation EU 2021/1165 i.c.w. Art. 24 (1) lit. b Regulation EU 2018/848). All of these measures could provide incentives establish bone char production in the EU, which is currently non-existent.

Taking a step back to the impact assessment of the FPR which established two general objectives, namely, pushing large scale recycling fertiliser production and addressing soil contamination (Sect. "Aims and general provisions"), the assessment of this article finds that first important steps have been made to achieve these objectives but further regulatory action is needed as soon as possible.

P recycling in a greater context

Promoting recycling fertilisers such as bone char contributes to close P cycles and, in doing so, to achieve the objectives of the Circular Economy Action Plan and the Convention on Biological Diversity. However, this push—as done through the FPR—alone does not solve the issues of unsustainable fertilisation practices, P losses into the environment through, e.g., soil erosion and waste accumulation through mining [103, 104]. Consequently, P recycling is just one element in the transition to a circular economy and the adoption of the FPR does not replace the necessity to (1) promote site-adapted and efficient fertilisation, (2) target regional P surpluses, (3) minimise mined P fertilisers and (4) transform the entire agricultural sector to be in line with global environmental goals. For example, the agricultural sector of the EU is characterised by regionally very high livestock densities [105]. If these densities remained high, large P import dependency, inefficient P use and regional nutrient surpluses would continue to exist. The FPR exercises no steering effect on these issues. Hence, a comprehensive transformation is needed and it is the interlinkage of the environmental problems that makes this comprehensive transformation essential.

The example above indicates that a comprehensive transformation for P management (including P recycling) and the entire agricultural sectors cannot be achieved by solely addressing P. Instead, the major drivers of global environmental issues, namely, livestock farming and fossil fuels, have to be targeted [36, 37, different argument by 106]. Yet, aligning livestock farming with global environmental goals such as those of the Convention on Biological Diversity and the Paris Agreement would directly impact the production of bone char fertilisers as animal numbers would have to decline and hence the supply of animal bones. In addition, even without more ambitious climate policies, beef and pig meat production are expected to shrink in the EU [107]. This highlights again the necessity to make best use of all available resources, including Category 1 of the ABP regulation. Finally, recycling fertilisers have to be produced with renewable energy. This includes bone char fertiliser production. Pyrolysis of biomass can have a positive energy balance [Sect. "Recycling P fertilisers and bone char" and 73] but an expansion of renewable energy and technological efficiency as well as frugality will play a key role in the transformation [40, 44]. Overall, this article finds that the promotion and use of recycling fertilisers is a necessary but complementary approach for the circular economy.

Conclusions

Recycling P fertilisers such as bone char fertilisers contribute to close P circles and establish a circular economy. Hence, in creating a legal pathway to market these fertilisers on the internal market of the EU, the FPR is an important measure to not only achieve global environmental goals of the Convention on Biological Diversity and Paris Agreement but also to contribute to the objectives of the Green Deal, the Circular Economy Action Plan and the Farm to Fork Strategy. However, outstanding legislation hinders the marketing of bone char fertilisers and inadequate Cd threshold values endanger soil health and biodiversity. Quick adoption of outstanding legislative acts and stricter threshold limits are, therefore, warranted. A bird's-eye view finally finds that, to achieve comprehensive changes in the agricultural sector, replacing mineral P fertilisers with recycling fertilisers is just one element amongst many.

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