EIP-AGRI Focus Group - Nutrient recycling

The value of recycling organic matter to soils

Classification as organic fertiliser or organic soil improver

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1. Introduction

Nutrient recycling mainly involves the recycling of organic waste or residual sources from agricultural, industrial and communal activities. Relevant organic sources are animal manures and organic wastes from urban and industrial activities (Möller, 2016). In the European Waste Framework directive, organic waste is legally defined by the term bio-waste: biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants. Bio-waste does not include forestry or agricultural residues, manure, sewage sludge, or other biodegradable waste such as natural textiles, paper or processed wood; it also excludes those by-products of food production that never become waste (European Commission, 2008).

Nutrient recycling is mainly focussed on nitrogen (N) and phosphate (P) as these components can replace chemical fertilisers to minimise extraction of fossil P resources and to reduce the environmental impacts of mineral nitrogen fertiliser production. Additionally, when not properly managed, nutrient recycling may result in negative environmental impacts as nitrogen and phosphate can pollute groundwater and surface waters and ammonia and nitrous oxide may be released to the atmosphere, contributing to eutrophication, acidification and climate change. The Nitrate directive, Water Framework directive and NEC directives are the regulatory instruments that prevent and control these negative impacts.

In the discussion related to nutrient recycling of organic sources a relevant aspect is often overlooked: the value of organic matter for sustaining soil quality. Agriculture is not only about nutrient application, for an economically viable agricultural production system soil quality and production (soil fertility) are of key importance. In this, soil organic matter (SOM) plays a crucial role as it is directly related to chemical, physical and biological properties of the soil (Murphy, 2014):

- Soil organic matter has clear effects on water holding capacity, cation exchange capacity, aggregate stability and buffering capacity to acidification.
- Soil organic matter also has a definite effect on the compaction and strength characteristics of soils which in combination with friability can determine how the soil responds to traffic and tillage.
- Soil organic matter is an important factor in providing a nutrient supply and in nutrient cycling, especially of nitrogen, but also of significant proportions of phosphorus and sulphur and other micronutrients.

Besides organic matter, organic sources can also deliver compounds such as lime, K and Mg and trace elements. These aspects are not covered in this mini-paper.

Farmers acknowledge the importance of soil organic matter as they use exogenous sources of organic matter and apply management practices to minimise SOM decay (Soilservice, 2012; EIP-AGRI, 2015). But despite this awareness, intensive agricultural practices have resulted in a decline in soil fertility and SOM across European regions. Decreases in SOM appear mainly as a consequence of intensive arable cropping systems and an underestimation of the relevance of soil organic matter (European Commission, 2011).

Based on these arguments, nutrient recycling by organic sources should not only focus on nutrient recycling but also on the value of organic matter in the organic sources. As such, organic sources can both serve as nutrient fertiliser and/or as soil improver. On the other hand, the nutrient efficiency of organic sources is variable and can be hard to predict. Moreover, when organic sources are applied as soil improver, care should be taken to avoid excess N and P dosing, resulting in soil and water pollution.

Therefore we consider it important to make a distinction between organic sources that mainly contribute to nutrient fertilisation and organic sources that mainly contribute to soil organic matter. In this way, organic sources can be applied in a dedicated way and negative environmental impacts can be prevented. In this chapter the idea of distinguishing organic sources in an organic fertiliser or an organic soil improver is further elaborated. For this, we first focus on composition and features of the various organic sources. Next, we present parameters that can be used to best represent the properties of a fertiliser and a soil improver. Based on these parameters a classification scheme is proposed to distinguish between an organic fertiliser and an organic soil improver. The mini-paper ends with conclusions and recommendations for research and policies.

2. Pros and cons of the application of organic sources in agriculture

As discussed before, organic sources can have a positive effect on the soil quality and supply nutrients. However, negative aspects of the application of these organic sources should not be ignored. As discussed in the mini-paper by Eory et al. (2016), assessing the environmental effects of recycled organic fertilisers is a complex task where the whole life cycle of the products needs to be considered. Instead of applying the comprehensive assessment methodology of the life cycle assessment (LCA), we limit ourselves here to addressing the most relevant aspects that need to be considered when assessing organic sources, as shown in Table 1.

This mini-paper will only focus on the effective organic matter in relation to nutrient supply resulting in a classification scheme for organic fertilisers and soil improvers. The other aspects are not within the scope of this paper but are partly addressed by other mini-papers of this EIP-AGRI Focus Group on Nutrient Recycling.

Table 1. Main aspects to be considered in the assessment of organic sources when applied in agriculture

Positive effects	Negative effects
Soil fertility and quality. Organic sources can increase soil organic matter (SOM). Soil organic matter plays a key role in maintaining soil aggregation and aeration, hydraulic conductivity and water availability, cation exchange and buffer capacity and the supply of mineralisable nutrients.	*Nutrient leaching*. Mineral nitrogen and phosphate and mineralisation of organic matter may result in emissions of N and P to ground and surface water when the nutrients are not used by plants.
	Gaseous emissions. Presence of mineral nitrogen (ammonium) may result in NH_3 emissions (acidification and particulate matter formation) and anaerobic degradation and transformations process may lead to emissions of CH_4 and N_2O (greenhouse gases).
Carbon storage. Degradation of organic matter can be reduced in soil and in this ways carbon can be sequestered for longer periods. The net carbon sequestration may reduce CO_2 emissions and mitigates global warming. It is still under debate what the magnitude of this carbon cycle–climate feedback is (He et al. 2016)	*Inorganic and organic pollutants*. Organic sources may contain unwanted substances that may harm the flora, fauna and humans. Examples are heavy metals, PAH's, dioxins, pesticides, residues of medicines, etc.
	Safety/hygienic aspects. Presence of human and plant pathogens, animal by-products, weeds and seeds, etc.
Disease suppression. Organic soil amendments can reduce the impact of soil-borne diseases (Bonanomi et al. 2010).	*Macroscopic impurities*. Presence of materials such as stones, glass, metals and plastics can be harmful and also decrease the market value of the product.

Criteria for safe use of organic sources such as compost and digestate are established in the upcoming revision of the Fertiliser Regulation (European Commission, 2016). These criteria are based on the study elaborated by the Joint Research Centre's Institute for Prospective Technological Studies (JRC-IPTS) to establish end-of-waste criteria, i.e. criteria that a given waste stream has to fulfil in order to cease to be waste (Saveyn and Eder, 2014). To prevent the presence of contaminants in compost/digestate and guarantee the safe use in agriculture, a restrictive list of input materials can be used and prevents the use of the organic fraction of mixed municipal household waste, sewage sludge, industrial sludge, dredging sludge, and animal by-products of category 1 (according to Regulation (EC) No 1069/2009). Also, quality assurance schemes (QAS) for compost and digestate have been introduced in several European Member States in the last 20 years. On the basis of these experiences the European Compost Network developed a European Quality Assurance Scheme (ECN-QAS) for compost and digestate (European Compost Network, 2016).

3. Organic sources to increase soil organic matter

Organic matter has a positive impact on the physical, chemical and biological characteristics of the soil (Diacono and Montemurro, 2010). Different organic matter pools affect different soil functions. There are many possible organic sources of fresh organic matter that can be added to the soil for the creation of soil organic matter; examples are crop residues, forest litter, manure, compost and digestate. Some types of organic matter break down quickly and some take longer to degrade. In contrast to fresh plant residues or animal manure, composted or digested organic materials decompose slowly when added to soil because they have already undergone a significant amount of decomposition during the biological treatment, concentrating the more recalcitrant fraction.

Effective organic matter (EOM)

When organic matter is applied to soils, decomposition by soil microbes starts. Part of the organic matter is used for growth of the microbes whereas another part is emitted as CO_2 through respiration. After some time, the more stable less easily degradable organic matter remains and contributes to the existing soil organic matter. The part of the input that remains one year after addition is called "effective organic matter".

To express the rate of decomposition (or degradation), the term effective organic matter (EOM) is introduced. EOM is defined as the organic matter that is still available after one year after incorporation in the soil. The remaining percentage of organic matter is also referred to as humified (residual) organic matter. Table 3 in the appendix shows the effective organic matter content of several organic sources together with the nutrient composition. EOM is calculated from the organic matter content and the humification coefficient (HC), where HC is defined as the fraction of effective organic matter to total organic matter. During composting, organic matter is degraded and water is evaporated resulting in compost with a high organic matter content and humification coefficient. Therefore, EOM values of compost can be a factor 10 higher compared to fresh manures.

4. Classification of organic sources as fertiliser or soil improver

Based on the discussion above we propose a classification for organic fertilisers and organic soil improvers. Whether an organic source can be considered a "fertiliser" or a "soil improver" depends on its effect on plant nutrition. Fertilisers are a source of readily available nutrients and have a direct, short-term effect on plant growth. Soil improvers affect plant growth indirectly by improving the physical and biological properties of the soil, such as water retention, aeration and microbial activity and diversity. A suitable definition for both categories is given in the proposal of the revised Fertiliser Regulation (European Commission, 2016) as listed in Table 2.

Table 2 shows that the revised Fertiliser Regulation does not give a clear distinction between the two categories. Neither the nutrient content nor the organic matter content reflect the differences between a fertiliser and a soil improver:

- Minimum nutrient contents are given for an organic fertiliser but no maximum contents are given for a soil improver.
- Comparing the values of Table 3Table 3 with the legal definition in Table 2 shows that none of the solid organic sources can qualify as an organic fertiliser as the nutrient content is too low.
- Only total organic matter content (expressed as organic carbon) is given in Table 2 ignoring the concept of EOM that is directly related to the soil improving quality and not the total organic matter content.
- Remarkable to observe in Table 2 that the organic matter carbon of an organic fertiliser has to be higher than the organic matter content of an organic soil improver, 15% organic carbon vs. 7,5% by mass.

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Table 2 Definitions of solid organic fertiliser and organic soil improvers according to the draft version of the revised Fertiliser Regulation (European Commission COM(2016) 157 final)

Solid organic fertiliser	Organic soil improver
A fertiliser shall be a CE marked fertilising product aimed at providing nutrients to plants.	A soil improver shall be a CE marked fertilising product aimed at being added to the soil for the purpose of maintaining, improving or protecting the physical or chemical properties, the structure or the biological activity of soil.
An organic fertiliser shall contain carbon (C) and nutrients of solely biological origin, excluding material that is fossilized or embedded in geological formations.	An organic soil improver shall consist exclusively of material of solely biological origin, excluding material that is fossilized or embedded in geological formations.
A solid organic fertiliser shall contain 40% or more dry matter by mass.	The CE marked fertilising product shall contain 40% or more dry matter.
The CE marked fertilising product shall contain at least one of the following declared nutrients in the minimum quantities stated: 2,5% by mass of total nitrogen (N), 2% by mass of total phosphorus pentoxide (P_2O_5), or 2% by mass of total potassium oxide (K_2O).	No declaration and minimum quantities of N, P_2O_5 and K_2O.
Organic carbon (C) shall be present in the CE marked fertilising product by at least 15% by mass.	Organic carbon (C) shall be present in the CE marked fertilising product by at least 7.5% by mass.

We propose the following parameters to best reflect the difference between an organic fertiliser and an organic soil improver:

- The effective organic matter content (EOM): EOM gives good indication of the part of the organic matter that contributes to soil organic matter and soil quality. EOM can be determined by measuring the organic matter content and multiplying by the humification coefficient (HC of most organic sources are well documented).
- The mineral nitrogen content (N-mineral): gives good indication of nitrogen that is directly available to plant. N-mineral (ammonia and nitrate) determination is a standard routine analysis.
- The total phosphate content (P_2O_5): gives a good approximation of the P availability. Determination of total P_2O_5 is a standard routine analysis.

The availability of N-organic and P_2O_5 can also be measured by incubation tests but we have chosen here to select parameters that are relevant, readily available in literature for many organic sources and are easy to determine by standard chemical analysis (cheap and accessible).

For the classification, we use the intrinsic characteristics of both categories:

- an organic soil improver should contain a high level of EOM to contribute to soil organic matter and should be low in nutrients as it is not a fertiliser;
- for an organic fertiliser it is the other way around: high in nutrients and low in EOM.

Based on this concept, we introduce the ratios EOM/N-mineral and EOM/P_2O_5 as parameters to distinguish between fertiliser and soil improver shown in Figure 1 for the organic sources of Table 3.

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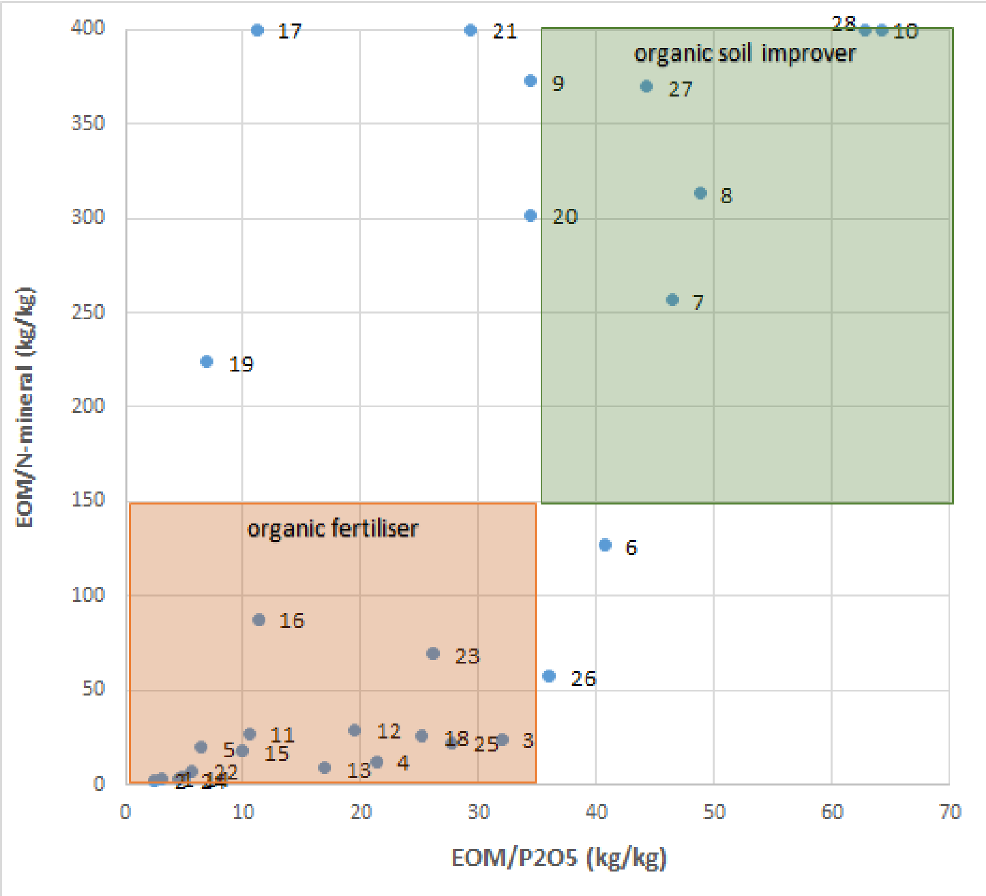

Figure 1 Classification of organic fertilisers and organic soil improvers on basis of EOM/N-mineral and EOM/P_2O_5 (numbers correspond to the numbers of the 2nd column in Table 3); EOM/N-mineral of 3 organic sources (#10, #17, #21 and #28) are set at 400 as they have values >400 and would fall outside the graph

Figure 1 shows that almost all the organic sources congregate in two quadrants in the lower-left and upper-right corners. There is a clear distinction between products having a high EOM/N-mineral and EOM/P_2O_5 ratio and products with low EOM/N and/or EOM/P_2O_5. This also reflects common agricultural practices: animal manures are mainly used as fertiliser value, they supply N and P needs of many crops because greater than 25% of their total N and P contents are in forms readily available for crop uptake. Compost is a good example of a soil improver, it is generally not considered a fertiliser substitute, and mainly used by farmers to build up soil organic matter and improve soil fertility.

Based on the results in Figure 1 we propose to complement the definitions of organic fertiliser and soil improver in the revised Fertiliser Regulation (see Table 2) to make the differences between both categories more evident:

- Conditions to qualify as organic fertiliser: EOM/N-mineral<150 and EOM/P2O5<35
- Conditions to qualify as organic soil improver: EOM/N-mineral>150 and EOM/P2O5>35

There are only few organic sources that do not fulfil both conditions and/or fall in between.

This is a first proposal to classify organic sources that needs further elaboration and fine-tuning in collaboration with other stakeholders.

5. Conclusions

This mini-paper has the objective to make clear that recycling organic resources is more than just nutrients (N and P). Organic sources contain effective organic matter (EOM) that is essential to maintain soil fertility. Some organic sources like fresh animal manures mainly supply nutrients and only contain low levels of EOM. Other sources like green compost contains high levels of EOM and the amount of directly plant-available nutrients is low. Therefore, it makes sense to distinguish between these properties and establish two categories of organic sources for agriculture, i.e. fertiliser and soil improver. Moreover, via organic sources it is often not possible to supply EOM, without at the same time also supplying N and P that may leach to ground- and surface waters.

To make farmers and policy makers more aware of the various organic sources, the differences between an organic fertiliser and an organic soil amendment were discussed. The draft revision of the Fertiliser Regulation already anticipates on this difference by introducing different product categories. However, in the definitions no clear distinction is made between the two categories. In this paper, a classification scheme is introduced to distinct between organic fertiliser and organic soil improver based on the rations of EOM/N-mineral and EOM/P2O5. Both parameters can be calculated from readily available data and are easy to determine by routine analysis. Also some discriminatory values are proposed to classify organic sources between organic fertiliser and organic soil improver.

Based on the classification scheme it may be of help to:

- Farmers: to choose the best organic sources for their specific need, fertiliser or soil improver
- Policy makers: to take into account the differences in properties between organic fertilisers and organic soil improvers when drafting new legislation.

In a recent study, D'Hose et al. (2016) have shown that farmers can use compost to increase organic matter in the top soil without inducing higher N and P leaching. In this way, soil quality can be improved without negative effects on groundwater and surface waters. Another positive aspect of soil improvers is the fact that EOM can possibly accumulated in the top soil increasing the total organic matter content, depending by pedoclimatic condition. In this way, EOM may contribute to carbon sequestration and reduction of greenhouse gas emissions. However, there is still debate about the effect of carbon stabilization processes and the turnover time of slow and passive reservoirs on the mitigation of global warming (He et al., 2016).

These positive effects of soil improvers could be an argument to give organic soil improvers a special status in European or national fertiliser legislation. For example:

- allow organic sources that classify as organic soil improver to be used outside the growing season
- nitrogen and phosphate in organic soil improvers could get a partial exemption in relation to the legal constraints for N and P as laid down in the Nitrate and Water Framework directive.

6. Research questions and needs

What type of external organic matter is needed to improve soil fertility? It is presumed that not the total pool of organic matter affects soil fertility but specific fractions of organic matter. How can we describe and assess the organic matter quality? Is Effective Organic Matter the proper indicator?

Elaborate further on the proposed classification of organic fertiliser and soil improver. Are the criteria EOM/N-mineral and EOM/P_2O_5 suitable or do we need other criteria? What values do we need to adopt for the classification?

What are the mechanisms that determine the N and P leaching to soils in organic soil improvers? How can we improve soil fertility (soil organic matter) and at the same time minimise harmful N and P emission to soil and water?

Long-term field trials are needed to demonstrate the value of organic matter in organic sources for soil fertility and quality. Also, more information is needed to get more information on the leaching behaviour of N and P in organic sources. Several examples of field trials are:

- BOPACT. Soil organic matter management within the legal constraints of the fertilization laws. Institute for Agricultural and Fisheries Research (ILVO, Flanders); **http://pure.ilvo.vlaanderen.be/portal/nl/publications/soil-organic-matter-management-within-the-legal-constraints-of-the-fertilization-laws--bopact-field-trial(271dcd4b-5174-4944-af4d-00a621555ed1).html**.
- FERTIPLUS. Fertiplus will take up the challenge to identify innovative processing technologies and strategies to convert urban and farm organic waste to valuable and safe products for agriculture and allow industries to develop projects and provide adequate information on use and quality of the products; **http://www.fertiplus.eu/**.
- REFERTIL. Reducing mineral fertilisers & chemicals use in agriculture by recycling treated organic waste as compost and bio-char products; **http://www.refertil.info/**.
- SmartSOIL. A research project which aim has been to contribute to reversing the current degradation trend of European agricultural soils by improving soil carbon management in European arable and mixed farming systems covering intensive to low-input and organic farming systems; **http://smartsoil.eu/**.

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Table 3 Composition of several organic sources with respect to organic matter, nitrogen and phosphate (all values in g/kg fresh matter or otherwise mentioned)

Organic sources	Number[1]	Dry matter	Organic matter	HC[2] (% OM)	EOM	N-total	C/N[3] (kg/kg)	N-mineral	N-organic	P2O5	EOM/N-mineral (kg/kg)	EOM/P2O5 (kg/kg)
Data Netherlands												
Pig slurry	1	57	43	0,33	14	7,1	3,5	4,6	2,5	4,6	3	3
Digested pig slurry	2	82	32	0,34	11	7,1	2,6	5,2	1,9	4,6	2	2
Cattle slurry	3	86	64	0,75	48	4,1	8,9	2,0	2,1	1,5	24	32
Digested cattle slurry	4	69	48	0,67	32	4,1	6,7	2,6	1,5	1,5	12	21
Solid pig manure	5	260	153	0,33	51	7,9	11,0	2,6	5,3	7,9	20	6
Solid cow manure	6	267	152	0,75	114	5,3	16,3	0,9	4,4	2,8	127	41
Bio-waste compost	7	661	217	0,90	195	7,6	16,3	0,8	6,8	4,2	257	46
Green waste compost	8	594	185	0,90	166	5,3	19,9	0,5	4,8	3,4	313	49
Data Flanders												
bio-waste compost	9	667	249	0,90	224	12,7	11,5	0,5	12,2	6,5	373	34
green waste compost	10	578	194	0,96	186	7,2	15,9	0,1	7,1	2,9	1695[5]	64
solid pig manure	11	299	230	0,42	97	10,7	12,7	3,6	7,1	9,2	27	11
solid cattle manure	12	242	184	0,42	78	8,5	12,8	2,7	5,8	4	29	19
cattle slurry	13	86	64	0,40	25	5,2	7,2	2,9	2,3	1,5	9	17
pig slurry	14	83	56	0,36	20	8,6	3,8	5,5	3,1	4,2	4	5
digestate manure-energy crops	15	88	54	0,72	39	4,6	6,9	2,2	2,4	3,9	18	10
solids of digestate manure-energy crops	16	253	170	1,23	209	8,0	12,5	1,5	6,5	11,3	87	11
dried digestate manure-energy crops	17	839	522	0,79	411	22,3	13,8	0,8	21,6	37	549[5]	11
Data Denmark												
digestate household waste	18	15	9,8	0,8[4]	8	0,5	11,0	0,3	0,2	0,31	25	25
sewage sludge	19	160	112	0,4[4]	45	5,6	11,8	0,02	5,6	6,4	224	7
bio-waste compost	20	575	302	0,9[4]	272	10,1	17,7	0,04	10,0	7,9	302	34
green waste compost	21	625	188	0,95[4]	178	7,2	15,4	0,02	7,2	6,1	445[5]	29
pig slurry	22	45	38	0,35[4]	13	5,1	4,5	1,9	3,2	2,4	7	6
cattle slurry	23	85	68	0,75[4]	51	4,5	8,8	0,7	3,8	2,0	69	26
Data Germany												
pig slurry	24	5	38,2	0,33[4]	13	5,6	3,96	4,2	1,4	2,8	3	5
cattle slurry	25	8	63	0,75[4]	47	3,9	9,34	2,1	1,8	1,7	22	28
solid cattle manure	26	233	186	0,75[4]	140	8,06	13,38	2,4	5,6	3,9	57	36
bio-waste compost*	27	638	247	0,9[4]	222	9,44	15,86	0,6	8,8	5,0	370	44
green waste compost*	28	623	234	0,9[4]	211	7,35	19,50	0,25	7,1	3,4	842[5]	63

[1]correspond to the numbers in Figure 1; [2]Humification coefficient (HC): the remaining percentage of organic matter after one year of incorporation in the soil; [3]assuming a C content of 57% for OM; [4]HC values of Denmark and Germany are derived from measured values of data from Netherlands and Flanders; [5]EOM/N-mineral values higher than 400 are capped to 400 in Figure 1