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Towards an exergy methodology to assess the fertility of topsoil

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Abstract:

Feeding a growing world population is threatened by soil degradation, which currently affects around 38% of the world´s cropland. Soils are complex systems constituted by physical, chemical and biological properties. Due to the soil's complexity, the measure of degradation or fertility represents an unsolved problem. The degradation of soils is an important issue currently faced by humanity that can be accounted for using exergy.

A methodology to calculate the exergy value enclosed in a fertile soil due to its inorganic, organic and biological components is developed in this study and will be used to assess soil fertility, degradation and quality. As a starting point, the exergy of an ideal topsoil with optimal attributes called "OPT soil" is established. The "OPT soil" is based on agronomic knowledge and will allow to establish a theoretical general line useful to perform exergy evaluations of the soil and compare the degradation degree of any soil with respect to the optimum. This paper establishes the factors that define the inorganic part of "OPT soil" and the methodology to calculate its exergy from Thanatia. Accordingly, we establish the first steps in order to allow the quantification of the quality of any soil and its degradation.

Keywords:
Exergy, soil fertility, soil degradation, Thanatia, optimum soil.

1. Introduction

In previous studies, Valero and Valero [1] developed a reference baseline to evaluate the abiotic resources of the planet. This reference baseline was called Thanatia and represents a degraded planet where all resources would have been extracted and dispersed throughout the Earth's crust. It is composed of a degraded atmosphere, hydrosphere and upper continental crust, in terms of the inorganic species of each of the aforementioned layers of the Earth. Thanatia's model is the basis for evaluating the exergy of natural resources. Particularly, for the upper continental crust, it represents the starting point to evaluate the exergy of mineral capital on Earth because it provides the concentration of the around 300 most abundant elements found in the Earth's crust.

The degradation of the mineral capital is an important source of concern since the transition to low carbon technologies will require a huge amount and variety of raw materials, some of which scarce and with serious supply problems. Yet the sustainability of agroecosystems is also an important issue considering that global population is expected to continue growing reaching almost 13 billion in 2100 [2]. By 2050, the an increase of about 49 percent in the agricultural production would be required to satisfy demand [3]. Crop production yield has been increased by means of intensive agriculture which is based on the use of high inputs of inorganic fertilizers and pesticides, resulting in severe environmental impacts, erosion and loss of soil quality, among other problems. In fact, the agricultural sector causes approximately 25 percent of the global greenhouse gases [3]. In addition, degradation caused in soils threatens around 40 per cent of the land area and, in Europe, it is estimated that there are 12 million hectares affected by erosion which currently generates losses of 1.250 million euros per year [4].

As it has been done for the mineral capital, one can assess soil fertility through exergy. However, for an exergy evaluation of soil, the Thanatia model is not enough, since it does not consider the specific attributes that make a given soil fertile. Therefore, it is necessary to establish an adequate methodology that serves as a starting point to evaluate soil fertility.

Soil fertility is defined by FAO as “the capacity of the soil to support the growth of plants on a sustained basis, yielding quantities of expected products that are close to the known potential” [5]. Soil Science Society of America defines soil quality as “the ability of a soil to work within the limits of the soil manage and ecosystem to maintain biological productivity and promote animal and plant health” [6]. Soil quality can be considered for both agricultural and natural ecosystems where main objectives are to maintain environmental quality and biodiversity conservation.

This study is focused on agricultural soils. Agricultural soils are complex systems formed by physical, chemical and biological properties interacting among them. Due to this complexity a unified approach about the evaluation of soil fertility or soil quality does not exit, even if there are a high number of studies performed on the topic [7].

One of the main disadvantages in the evaluation and characterization of the soil is the inability to use a single indicator or parameter for its determination [8]. Due to the wide number of factors and properties that influence and alter the composition of the system, most of the studies found in the literature focus on determining a "minimum data set" (MDS) of soil characteristics with the greatest influence on quality [9–12].

The aim of this study is to use exergy as a unifying tool to assess quality and degradation of soil using Thanatia as a reference environment and laying the foundations of the fourth dimension of Thanatia: fertile soils. Firstly, the inorganic part of the soil will be tackled. The inorganic part is essential in soil systems because it determines its physical properties such as structure or texture, and its chemical properties, such as nutrients or pH, among others.

2. Definition of an optimum soil

In any exergy assessment, a reference state needs to be first established. Normally, a reference state is considered a dead state, the most degraded state with the minimum exergy. In the case of soil our first attempt was to define the minimum characteristics required under which the growth of a plant is not possible [13]. However, the establishment of an optimum level is more adequate in the case of fertile soils.

The establishment of the “OPT soil” will provide an ideal top level by the quantification of the exergy level of the optimal fertile soil selected according to the chemical, concentration and comminution exergy from the dispersed state of Thanatia. This level which is the total exergy of the “OPT soil”, allows to calculate the difference between it and a soil under study, as replacement exergy. The replacement exergy accounts for the minimum exergy required to return a substance from the state of a soil less fertile and with poorer quality to the physical and chemical conditions of the “OPT soil” selected [14] (Fig. 1).

Thus, in this work the called “OPT soil” will be established for the inorganic part of the soil. This “OPT soil” will be based on agronomic knowledge. That said, its aim is not to provide agronomic recommendations about soil management, but to establish a theoretical general baseline that will allow for an exergy evaluation of the degradation of a soil.

Firstly, the main characteristics that define the inorganic part of a soil and the selection of appropriate levels for each of them is conducted. Furthermore, the methodology necessary to calculate the exergy of the OPT soil is assessed.

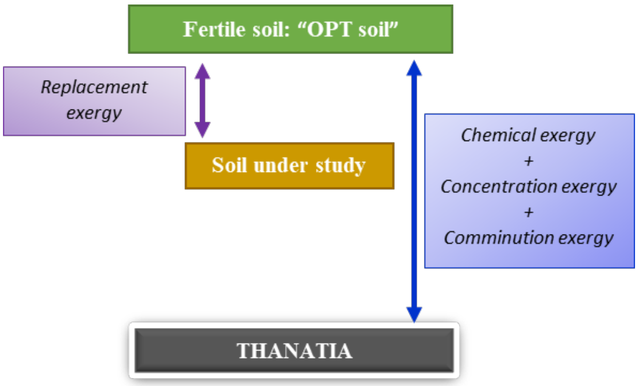

Figure 1. Representation of the reference state chosen, the dead state as Thanatia and a soil under study.

But before that, it is important to state that as is well known, there is a wide range of soils and a lot of factors that influence them. Agricultural soil quality not only depends on physical, chemical and biological properties, but also on factors such as the type of the crop, management, climate conditions, vehicle traffic among others. Thus, an optimum soil does not exist from an agronomical point of view, as the preferred characteristics depend on external variables as type of crop or climate. That said, this reference will serve us as an indication of soil quality by comparison.

3. Assessment of the inorganic part of soil

Soil is a very complex system in which many parameters interact with each other. The properties of the soil system can be classified into physical, chemical and biological. In this paper, the research is focused on the inorganic soil aspect.

Among these aspects texture is essential because it determines the porosity of a soil, thus it influences in the rest of the physical properties of the soil. Available water capacity, aeration and the soil ability to retain water are affected by the type of soil texture, which in turn also affects soil chemical properties like the nutrients holding capacity, permeability (flooding, risk of leaching of water and nitrogen, etc.) and its ability to decompose organic matter. Due to all the interactions and influences of texture on the physical, chemical, and biological properties of the soil, texture is indirectly involved in the biogeochemical processes that happen in a soil system. That is why, texture has been selected as a factor to be evaluated.

The second factor selected are nutrients. Nutrients found in soils are required by plants to perform most of their functions and growth, thus they are essential in fertile soils.

3.1. Texture

Texture is determined by the size distribution of the three elemental particles: sand, silt and clay. Each of these components have a different particle size. According with the classification of the U.S. Department of Agriculture (USDA) sand is formed by particles smaller and larger than 2mm and 0.05mm, respectively. Silt particles are smaller than 0.05mm and larger than 0.002mm. Clay is constituted by particles smaller than 0.002mm. The different textures are defined by the proportion of the elemental particles in soil. According to different distributions, soils can be classified into 12 different types: sand, loamy sand, sandy loam, sandy clay loam, sandy clay, silt, silt loam, silty clay loam, silty clay, loam, clay loam and clay.

There is not only an ideal and optimal soil texture as this will depend on the type of crop and meteorological conditions. Yet loam texture, located approximately in the central of USDA-NRCS texture triangle [15], is considered to own optimum properties between sandy, silty and clay soils. Commonly, loam soils combine the three elemental soil particles with approximately same amounts of silt and sand and less proportion of clay particles. This is because a small fraction of clay is enough to provide properties such as cation exchange capacity and/or water retention in soil. In loam soils water retention capacity and nutrients are more favourable than in sandy soils whereas its aeration, drainage and manage characteristics are more beneficial than in clay soils [16]. In addition, loams are soils potentially fertile and can be used for a wide variety of farming types, like cereals, potatoes, oilseed rape and sugar beet among others [17].

According to Jaja (2016) [18], the composition of loams, considered as one of the best soil texture, is about 40 %, 40 % and 20 % of sand, silt and clay, respectively. It should be said, however, that soil degradation and soil management will not be accompanied by a change in texture in the short term. It can be considered stable over a period of decades [19]. That said, texture is an important factor when classifying the fertility of soils.

3.1.1. Mineral composition of the texture

In order to determinate the mineral composition of the different textural fractions, the mineral composition proposed by Weil and Brady [19] was followed as it is shown in Table 1.

Table 1. Estimations of the soil particles composition (in percentage) obtained through the information and graphics. Source [19].

	Quartz (%)	Primary Silicate Minerals (%)	Secondary Silicate Minerals (%)	Other Secondary Silicate Minerals (%)
Sand Particles	77	17.8	0	5.2
Silt Particles	59	14.2	7	19.8
Clay Particles	16.8	0.9	62.5	19.8

As can be observed in table 1 there are four main mineral groups in soil: quartz, primary silicate minerals, secondary silicate minerals and other secondary minerals. Sand and silt particles are predominantly composed of quartz. In the case of clay particles, they have mainly secondary silicate minerals, and less quartz fraction. The components found in each group of minerals have been determined by means of literature review [16,20,21].

In order to know the relative abundance of each mineral in each group it has been assumed that this is proportional to the abundance of the minerals in the Earth´s crust, which was determined by Valero and Valero [1], derived from a model developed in Valero [22]. Thus, the following equation is applied (Eq. (1)).

$$R.Abund_{mineral}\ (mass\%) = \frac{Earth's\ crust\ mineral\ abund.(mass\ \%)}{\sum Mineral\ abund.of\ the\ group} \cdot 100, \quad (1)$$

3.1.2. Texture chemical exergy

The relative abundance determined was used to calculate the chemical exergy per unit of mass, together with the exergy values of the minerals in the Earth´s crust [1].

$$Ex_{ab,ch}\left(\frac{kJ}{kg}\right)=\frac{\left[\frac{Ex_{ch,mineral}(kJ/mol)}{Molecular\ Weight(g/mol)}\right]\cdot Rel\ Abund_{mineral}(mass\%)\cdot 1000}{100}, \quad (2)$$

This procedure has been followed for every single mineral of each group of minerals.

Once the input of each mineral of the different groups have been obtained, the chemical exergy generated with Szargut's reference environment [23], per unit of mass values of quartz, primary silicate, secondary silicate and other secondary minerals are calculated. It can be observed that the secondary silicate minerals have the largest specific chemical exergy and quartz has the lowest specific chemical exergy value (Table 2).

Table 2. Chemical exergy of the main soil minerals composition.

Mineral groups	Exergy (kJ/kg)
Quartz	13.65
Primary silicate minerals	93.80
Secondary silicate minerals	138.54
Other secondary minerals	386.86

Using the data obtained in Table 3 and the amount of each group of minerals in sand, silt and clay fractions (Table 1) the specific chemical exergy of each of the textural fractions is obtained (Table 3).

Table 3. Chemical exergy of sand, silt and clay as the three components of soil texture.

Elemental Particles	Exergy (kJ/kg)
Sand	47.32
Silt	107.67
Clay	166.33

Each particle size has a characteristic chemical exergy per unit of mass value. The data shows the major influence and predomination of clay in the specific chemical exergy of the soil texture. This is so because clay fraction has the three mineral groups with the highest exergy values, whereas, sand and silt fraction have quartz, an abundant and stable mineral, thus the one with the lowest chemical exergy value.

Subsequently, considering the values of the three particles sizes that form soil texture (Table 3) and Eq. (3), the chemical exergy per unit of mass of the texture of any soil can be calculated.

$$Ex_{ch,text}\left(\frac{kJ}{kg}\right)=\frac{Sand(\%)\cdot Ex_{ch,sand}}{100}+\frac{Silt(\%)\cdot Ex_{ch,silt}}{100}+$$
$$+\frac{Clay(\%)\cdot Ex_{ch,clay}}{100} \quad (3)$$

In the case of the loam texture corresponding to the OPT soil" texture chemical exergy per unit of mass will have a value of 95.26kJkg^{-1}.

$$Ex_{ch,text}\left(\frac{kJ}{kg}\right) = \left[\frac{40\% \cdot 47.32\,\frac{kJ}{kg}}{100}\right]_{sand} + \left[\frac{40\% \cdot 107.67\,\frac{kJ}{kg}}{100}\right]_{silt}$$

$$+ \left[\frac{20\% \cdot 166.33\,\frac{kJ}{kg}}{100}\right]_{clay} \cong [18.93]_{sand} + [43.07]_{silt} + [33.26]_{clay} \cong 95.26\ {}^{kJ}/_{kg}$$

3.1.3. Texture concentration exergy

In addition to the chemical exergy, a substance has concentration exergy due to its specific structure. When a substance is more concentrated than in the reference state, it has the potential to do work and hence it has concentration exergy. The concentration exergy associated to texture is calculated using the relative abundance.

Therefore, the concentration exergy per unit of mol of one of the minerals that form soil is calculated as the difference between the mineral concentration in the state as "OPT soil" and the average concentration in the Earth´s crust obtained through the abundance in mass percentage in Thanatia [1,24].

$$Ex_c(kJ/mol) = -RT_0\left[lnx_i + \frac{(1-x_i)}{x_i}\cdot ln(1-x_i)\right], \qquad (4)$$

Where R is the universal gas constant ($8.314\cdot10^{-3}$kJmol^{-1}K^{-1}). T_0 is the standard ambient temperature (298.15K), x_i is the mass concentration of a mineral or substance.

Every mineral or substance has a specific concentration exergy. The difference between the concentration of the mineral in the Earth's crust with the average mass concentration of x_c (g.g^{-1}) and the concentration of the mineral in the "OPT soil" chosen, with a mass concentration of x_m (g.g^{-1}), is the concentration exergy per unit of mol of the mineral. This difference shows the lowest exergy necessary to form and concentrate the mineral from the Earth's average crust to the "OPT soil" or the opposite [1,24].

$$\Delta Ex_c = Ex_c(x_i = x_c) - Ex_c(x_i = x_m), \qquad (5)$$

Table 4 shows x_m, the molar concentration of each group of soil minerals for the reference state selected. With this information, we are able to calculate the value of x_m for every mineral included in each mineral group.

Table 4. Contribution of every group of minerals in the "OPT soil". The contribution is based on the amount of sand, silt and clay in the reference state.

Mineral groups	"OPT soil" x_m (g.g^{-1})
Quartz	0.5776
All Primary silicate mineral	0.1298
All Other secondary minerals	0.1396
All Secondary silicate minerals	0.1530

Therefore, the concentration exergy per unit of mol, and then per unit of mass, is calculated for all the soil minerals (quartz, primary silicate minerals, secondary silicate minerals and other secondary minerals). In the case of the "OPT soil" the total concentration exergy value is equal to 492.10 kJkg^{-1}.

3.1.4. Texture comminution exergy

Following the procedure described in [1,25] the specific comminution exergy for the texture components has been calculated. As an example, the comminution exergy per unit of mass of clay fraction in hematite is $2.45\cdot10^{-1}$ kJkg^{-1}, which is a small value in contrast with concentration exergy per unit of mass, 23.07 kJkg^{-1}. Therefore, due to the small contribution of the comminution exergy, only chemical and concentration exergy is going to be considered in the estimation of the total texture exergy. This is in line with what Valero et al. [25] demonstrated, stating that the comminution exergy is insignificant in comparison with chemical and concentration exergy values.

3.2. Nutrients

Nutrients needed by plants are typically classified into two groups: the macronutrients which are required in high concentrations, and the micronutrients required in lower concentrations but not less important. Macronutrients are nitrogen (N), sulphur (S), phosphorus (P), magnesium (Mg), calcium (Ca) and potassium (K). Micronutrients are iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), nickel (Ni), molybdenum (Mo), boron (B) and chlorine (Cl). Furthermore, sodium (Na), silicon (Si), cobalt (Co), selenium (Se) and aluminium (Al) are considered beneficial elements. Beneficial elements stimulate growth but are only essential for certain species or under specific conditions [26]. One study [13] exposed more information in the role of each essential nutrient.

In general, the availability of a nutrient depends on their physicochemical forms, being free ions, the forms normally taken up by plants. Nutrients may be chelated, absorbed, or precipitated onto mineral or organic surfaces or be part of soil biomass or organic forms. All these forms have different ranges of availability to plants and are normally in continuous exchange forming cycles. Soil pH, redox conditions, cations exchange capacity, microorganisms, soil structure and water determine these exchanges and cycles [27]. Furthermore, different types of plants may have different requirement of the different elements.

Our scope in this work is far removed from evaluating all the processes and factors involved in the acquisition of each nutrient or from giving recommendations suitable for crop managements. Instead, our aim is a theoretical establishment of an “optimum soil” necessary to perform an exergy evaluation. Optimal values are considered according to different sources, in most of the cases the selected value correspond to the average value among the different sources cited.

The negative value of the anion’s exergy makes difficult the estimation of the nutrients chemical exergy per unit of mol. Also, the different ranges of magnitudes could generate a contradiction because the exergy value is not representing the importance of some nutrients over others. For example, the specific exergy value of 267.88 kJ/mol for the manganese cation (Mn^{2+}) could mask the specific exergy value of the hydrogen phosphate (HPO_4^{2-}), 14.38 kJ/mol, despite the relevant phosphorus function in soil reactions and processes. Furthermore, the chemical exergy should only be considered when nutrients are not present in the soil. This is because while all the nutrients are in the soil, regardless of the concentration they are in, the chemical exergy will be the same for “OPT soil” as for the soil under study. That is why, only the concentration exergy of nutrients is going to be assessed.

3.2.1. Nutrients concentration exergy

Optimal level of concentration of the different nutrients has been established through a bibliographic research. The selected values and the cations or anions considered for each nutrient are shown in Table 5.

The concentration exergy of nutrients is going to be supported by the composition in cations and anions of the soil. Then, the concentration exergy is going to be estimated through the concentration of the nutrients selected (Table 5). The difference between the concentration of the nutrient in a reference state with an average mass concentration of x_c (gg^{-1}) and the concentration of the nutrient in the “OPT soil” chosen, with a mass concentration of x_m (gg^{-1}), is the specific concentration exergy of the nutrient (Eq. (4),Eq. (5)). This difference shows the lowest exergy necessary to form and concentrate the nutrient to the “OPT soil” or the contrary [1,24].

The optimal concentration chosen has been used to calculate the value of the mass fractions (x_m) of every nutrient in the “OPT soil”. These mass fractions are used to calculate the specific concentration exergy (Table 5).

Table 5. Optimal concentration selected form literature and the molar fraction for nutrients in the “OPT soil” state (x_m).

	Form uptake by plants	C_{opt} (kg/ha)	REFERENCES	x_m (gg^{-1})
Nitrogen	NH_4^+/NO_3^-	8400	[28,29]	$1.27\cdot10^{-3}$
Phosphorus	$HPO_4^{2-}/H_2PO_4^-$	70.0	[30,31]	$2.50\cdot10^{-4}$
Sulphur	SO_4^{2-}	40.0	[30,31]	$2.50\cdot10^{-5}$
Magnesium	Mg^{2+}	840.0	[31]	$4.00\cdot10^{-3}$
Calcium	Ca^{2+}	11206	[30,32]	$3.00\cdot10^{-4}$
Potassium	K^+	700.0	[30]	$2.30\cdot10^{-5}$
Iron	Fe^{2+}/Fe^{3+}	7.0	[30]	$2.00\cdot10^{-6}$
Manganese	Mn^{2+}	14.0	[30]	$2.50\cdot10^{-6}$
Cupper	Cu^+/Cu^{2+}	5.6	[30,31,33]	$5.00\cdot10^{-6}$
Zinc	Zn^{2+}	4.2	[30,31,34]	$1.50\cdot10^{-6}$
Nickel	Ni^{2+}	1.1	[35]	$1.43\cdot10^{-5}$
Molybdenum	MoO_4^{2-}	0.6	[30]	$3.93\cdot10^{-7}$
Boron	$B(OH)_3$	2.8	[31,36]	$2.14\cdot10^{-7}$
Chlorine	Cl^-	56.0	[31,34]	$1.00\cdot10^{-6}$
Sodium	Na^+	64.3	[30]	$2.00\cdot10^{-5}$
Silicon	$Si(OH)_4$	294.0	[37]	$1.05\cdot10^{-4}$
Cobalt	Co^{2+}/Co^{3+}	4.2	[38]	$1.50\cdot10^{-6}$
Selenium	SeO^{2-}/SeO_3^{2-}	0.3	[39]	$1.07\cdot10^{-7}$
Aluminium	Al^{3+}	3831	[40,41]	$1.37\cdot10^{-3}$

In the case of the texture, the Earth’s crust has been chosen as reference state in the concentration exergy. However, nutrients available for plants are anions and cations in solution and not minerals as it happens in the texture. Therefore, the hydrosphere is chosen as reference state for nutrients. The hydrosphere comprise oceans, seas, rivers, rain, ice and even the atmospheric water vapour. The major component of the hydrosphere are oceans which involve more than 97% of all Earth’s water. In this research, the composition of minor elements in seawater, also present in Thanatia and described in [42] will be used in the estimation of the mass fraction in the reference state (x_c).

For some elements, the concentration in the reference state (seawater) is lower than in the “OPT soil”, thus the value of specific concentration exergy is positive. On the contrary, if the concentration is higher in the reference state (seawater) than in the "OPT soil" state, then, the specific concentration exergy value of the nutrient is negative.

The total concentration exergy per unit of mass calculated for the nutrients results in a value of 3684.13 $kJkg^{-1}$. As it is shown, it is a great contribution to the total soil exergy in the “OPT soil”.

For a rigorous exergy analysis of a given soil, ideally, all nutrients should be considered. However, in practice the determination of all 19 nutrients is usually unfeasible. Thus, only nitrogen, phosphorus, potassium, calcium, magnesium, copper, sodium, iron, manganese and zinc, the substances that are normally analysed are going to be used in the calculations. The specific concentration exergy calculated for the selected nutrients results in 1626.37 kJkg^{-1}.

4. Results and discussion

The methodology to calculate the textural exergy of a soil is explained in detail in section 3.1. As justified above, loam texture is selected as reference for the "OPT soil". Accordingly, the specific chemical and concentration exergy of the texture selected has been calculated. Considering a density of 1400 kg m^{-3} and a depth of 20 cm, the exergy contribution of topsoil can be estimated, as shown in Table 6.

Table 6. Exergy values of the ideal texture chosen.

	kJ kg^{-1}	kJ ha^{-1}	toe ha^{-1}
Chemical Exergy	95.26	$2.67 \cdot 10^8$	6.38
Concentration Exergy	492.10	$1.38 \cdot 10^9$	32.96
Total texture exergy	587.36	$1.645 \cdot 10^9$	39.34

The total texture specific exergy estimated is about $1.64 \cdot 10^9$ kJha^{-1} (Table 6), or in other words, 39.34 toe/ha (tonne of oil equivalent/ha). As it is shown, the concentration exergy contribution is higher than the chemical.

Selected nutrients are also considered for the calculation of the exergy of the inorganic part of the soil. The exergy contribution of the two inorganic fractions considered for the evaluation of soil fertility as "OPT soil" is shown in Table 7.

Table 7. Exergy values of the texture and nutrients.

	kJ kg^{-1}	kJ ha^{-1}	toe ha^{-1}
Texture	587.36	$1.645 \cdot 10^9$	39.34
Nutrients	1626.37	$4.55 \cdot 10^9$	108.77

Nutrients are the ones that show the greatest contribution. However, it should be noted that the texture influences and affects the soil nutrients due to the interactions between the minerals which form the elemental particles of the texture and the nutrient ions.

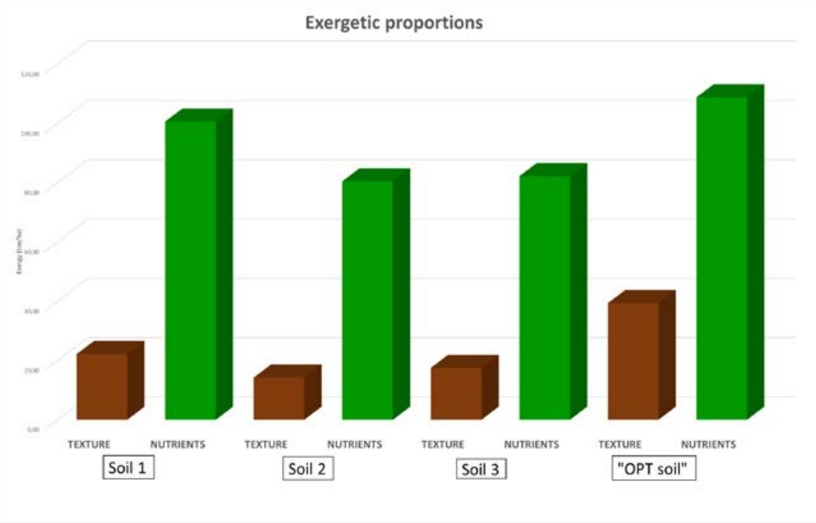

Figure 2. Representation of the inorganic contribution to exergy value in different systems soils.

In Figure 2 the comparison of the specific exergy values obtained for different soils under analysis and the "OPT soil" can be observed. In all the cases the OPT soil shows higher values than the studied soils. Furthermore, the values found in the studied soils maintain a relationship with its agronomic performance, showing that at least for the analysed soils, the methodology is suitable.

5. Conclusions

Exergy is a useful tool to assess the complex problem of the evaluation of the fertility or quality of a soil. In order to do that, the establishment of an "OPT soil" is proposed, using Szargut and Thanatia as references. In this work the inorganic part of the soil is analysed, concluding that texture and nutrients are the most important parameters to be determined. A methodology to calculate the specific exergy of the OPT soil is proposed. As a result, it can be observed that the nutrients specific exergy is higher, however, the value of the texture is not negligible. Exergy shows the quality and quantity of energy contained in soil nutrients and texture but does not value and consider the interactions between both factors or in general the influences that have on the rest of parameters and processes that occur in the soil. Despite that, exergy is able to assess the inorganic parameters selected to determine the quality of a soil and the values obtained when analysing different soils are in accordance with their agronomic performance. However, more factors need to be considered in order to accomplish an overall evaluation of fertile soils. The PhD thesis developed by Atares [43] deals with the evaluation of the biotic part of the soil using ecoexergy methodology [44]. In an ongoing PhD, abiotic and biotic parameters will be merged in an overall OPT soil that will be validated using real experimental results. This will lay the foundations of the fourth dimension of Thanatia.

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