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INFLUENCE OF THE AGRICULTURAL EXPLOITATION PROCESSES ON THE PRODUCTIVITY CAPACITY CONTROL OF SOILS
Design of an experimental procedure

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Soil productivity and health were analyzed using an experimental procedure designed for this kind of studies. The continuous loss of fertile soil obliged the Food and Agriculture Organization (FAO) to declare soil as an item to be protected as a support of the world society welfare. The procedure here described is in accordance with the premises necessary for a rational and sustainable development of soil and the resources it contains and can be used to study any soil all over the world.

The study was carried out using soil microbial population as a bioindicator of soil health. Microbial activity was followed using the microcalorimetric technique. The microcalorimetric study can be complemented through a deep analysis of soil physical, chemical and biological properties together with a study of the environmental properties that have a strong influence on the afore mentioned properties and, thus on the microbial activity in soil. The different properties follow different ASTM, ISS/FAO, USDA, etc. well defined standards.

The experimental procedure reported in this work could be very helpful to create a data basis that could be useful to quantify and control soil potentiality or design soil decontamination and recovery systems.

Keywords: *microbial activity, microcalorimetry, productive capacity, rational and sustainable exploitation*

Introduction

In the last 100 years, as a consequence of the fast development of the present technological society, about one third of the world agriculture cultivable land was lost. This process is a direct consequence of the joint action of many factors going from the population boom in the developing countries to the erosion caused by deforestation. This alarm situation made the world society to react through the development of rational and sustainable processes of different resources as a survival unavoidable strategy. One of the vital resources is soil, that from the 1960's was included as priority task as one item to be protected as a support of the world society welfare. Soil is not only a physical mean in which our communities build houses, but also the direct or indirect origin of the most part of the products used in our daily diet, and also a highly complex system for storage and purification of water [1].

In this work we report the evolution of the design of an experimental procedure capable of both to evaluate the soil productive capacity and its health state as a function of the microbial load. For this reason, the main objective of this study was to develop a procedure capable of being applied to every type of soil in every part of the world, providing the performance of the protocols pointed out in the procedure. With this purpose, samples of the different kinds of soils existing in Galicia (NW Spain) were collected and analysed during the last 12 years.

Microbial growth, in a highly heterogeneous medium [2, 3] such as soil was studied by microcalorimetry [4–6]. This technique was confirmed to be valid as an alternative method in the study of metabolism and microbial growth in soils, as it permits the continuous monitoring of the activity of a living process in situ for a prolonged period without disturbing the system [3, 7]. It is a useful tool for evaluating the metabolism of microbial biomass in soils because the heat produced in the various processes depends solely on the initial and final energy states of the system, and is independent of the type of microorganisms and their form of evolution. The study follows a 3-stage scheme based on the following assumptions [8]:

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- the soil productive potentiality directly depends on its living phase. In this way, microbial growth is related to the productive capacity of soil
- microorganisms are real bioindicators of soil quality
- soil living phase evolution, and thus the study of microbial activity in soils, can be quantified by using microcalorimetry

The microcalorimetric study can be complemented through a deep analysis of soil physical, chemical and biological properties together with a study of the environmental properties that have a strong influence on the aforementioned properties and, thus on the microbial activity in soil [9, 10].

Experimental

Materials and methods

For a better understanding, this study was divided into three very well differentiated parts: sampling phase, microcalorimetric study, and analysis of physical, chemical, biological and physical environmental properties.

Sampling phase

From the ecological point of view, the study of a soil begins with a precise and detailed examination of it as a whole and also of the special characteristics of its surroundings. Samples were collected in four different seasonal periods with the objective of analysing the influence of all the properties on the yearly evolution of the microbial population activity in the soil.

The study was focused on a soil with an original vegetation of *P. pinaster Aiton*, that was subjected to two reforestations with *P. sylvestris L.* in the last years. The zone corresponds to a hillside zone situated in the north of Lugo (Galicia). This soil was designated as 1. A second soil situated 200 m far from this soil was named as 2, and have similar characteristics as regard as origin, composition and climate. The second soil keeps its original vegetation, *P. pinaster Aiton*, as it was not subjected to changes in the last 50 years. At a first stage, samples were collected in the same zone but from plots with different agriculture exploitation with the objective of analyzing the possible influence of different soil cultures on the soil microbial population. At the beginning, the sampling was made from about 10 randomly chosen points from each plot. After the removal of the very top layer of soil, samples were collected to a depth of about 15 cm. All samples from each were mixed and sieved. In the course of the study, it was checked that sampling should follow the procedure next described. Two different kinds of sample were taken, one for microcalorimetric measurements, and the other for determination of physical, chemical and biological parameters. For collection of the first sample, 100 m^2 of soil were chosen that then were divided into 1 m^2 sites, 6 of which were randomly chosen after eliminating those situated in the borders. Before collecting samples, the vegetal cover on every site was removed, and then 1 kg of soil was taken from a depth of 5–15 cm. The sample was reduced through a coning and quartering procedure to a final size of about 400 g. By doing so, the sample was highly homogenized, thus allowing to obtain reproducible and representative [11] results and showing the diversity and the density of the microorganisms existing in the environment where the sample was collected. The samples were introduced into polyethylene bags, to avoid contamination and loss of moisture and then sent to the laboratory in less than 10 h. To collect the second sample, 10 kg of soil were taken following the procedure previously described.

Calorimetric phase

Once in the laboratory, it was found that, to obtain a good reproducibility, samples should be stored in a refrigerator at 4ºC for up to three months [12]. After this time, calorimetric experiments were performed using a microcalorimeter 2277 thermal activity monitor (TAM) Thermometric AB [13]. Measurements were carried out in hermetically sealed 5 mL stainless steel ampoules. Microcalorimetric measurements were made using a closed ampoule method which causes a decrease in the available O_2 with a corresponding CO_2 enrichment. Consequently, the environmental conditions inside the closed ampoule change. Soil samples of 1 g size at water-holding capacity were treated with 1.25 mg of glucose g^{-1} soil. This glucose concentration value was determined after trying different concentrations [6]. Experiments were repeated five times. The reference ampoule was filled with 1 mL of distilled water. It was found that the results obtained by doing this agree reasonably well with those obtained using a soil as reference. Calorimetric results showing soil behavior were reported in the form of power-time curves as shown in Fig. 1. In this plot, 4 different phases can be observed: latency phase, exponential growth phase, steady phase, and dead phase. The first 3 phases could be perfectly explained, but the fourth (dead phase) originated a doubt, because microbial death could be caused either by carbon source (glucose) exhaustion or by CO_2 accumulation, thus poisoning the ampoule environment. This doubt was solved by opening the ampoule in the course of the dead phase to allow the renewal of the ampoule atmosphere with income of new oxygen [14]. After closing the ampoule, the calorimetric experiment was let to continue. It was found that a continuous curve was recorded, thus showing that the dead phase was originated by exhaustion of the carbon source.

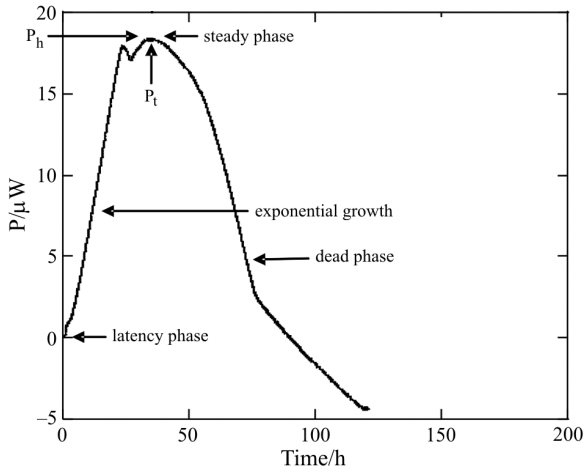

Fig. 1 Typical *P–t* curve for microbial growth in soils

These calorimetric experiments were carried out over some years using different types of soils. It was observed that as a consequence of the different microbial load caused either by soil own origin or by the different types of soil exploitation [9] independently of soil origin, these phases follow a similar behavior pattern for soils with same use. As a control system of the results obtained by microcalorimetry, these same soils were studied using the fumigation method. The results obtained by this last method corroborated the reliability of microcalorimetry to assess microbial growth studies and thus soil health [15, 16].

Other properties

Parallel to the evolution of the microcalorimetric technique, and for a better understanding of the results obtained, new parameters were introduced in our studies. With this purpose, to water-holding capacity determination, C/N ratio, pH, most probable number of microorganisms (MPN), glucose consumption per microbe, sample moisture that were used in our first studies, some other parameters were added. All these parameters when considered together give a more comprehensive understanding of soil behavior before different productive stress processes or pollution, thus allowing a more adequate evaluation of soil potentiality or health state through convenient tables of properties. These parameters such as environmental temperature, soil temperature, chemical elemental composition, apparent and actual densities, plasticity, texture or soil structure [17–19], were considered together with those previously mentioned.

Table 1 shows the most important physical, chemical and biological characteristics corresponding to soil 1.

All the parameters necessary for our study were recorded in a special form designed for this kind of research. The following data recorded in this form must be pointed out:

- type and characteristics of the vegetation existing in the zone
- orientation, topography and slope of the sampling zone
- surface description of the soil sampling zone and surroundings, stone presence, surface water presence, springs presence, man activities, apparent structure, etc.
- data and time of sampling, necessary to repit same time for all samplings
- environmental characteristics of the zone, wind intensity, solar radiation intensity, clouds, etc. These data were corroborated with those supplied by the Spanish National Meteorology Institute
- soil color through Munsell charts, thus to infer particular characteristics of soil and possible problems related with aeration and/or drain in situ

These values were used to construct a bioclimatic diagram of the zone. This diagram is very helpful for the understanding of the influence of climatological parameters on the soil living phase and the soil productive capacity as a function of the vegetative activity of vegetals growing in a particular zone. Figure 2 shows a bioclimatic diagram of the sampling zone. It was constructed using data contained in Table 2 [20, 21].

Analysis of all soil properties as a whole gives a very important partial information about soil present physical state, and can be used as a basic reference for understanding of soil potentiality or health state when the study is complemented through microcalorimetric data.

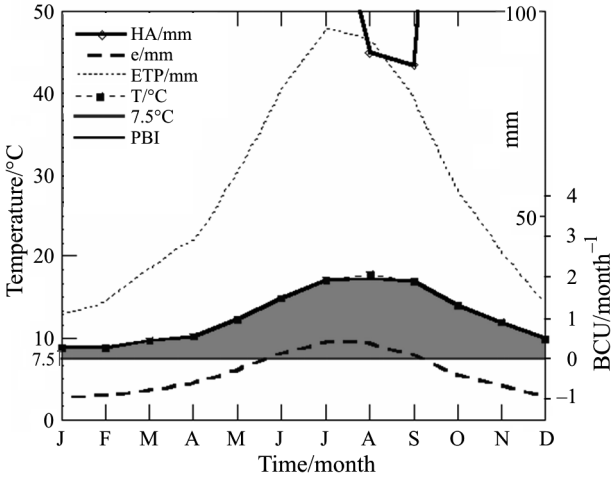

Fig. 2 Bioclimatic diagram of the sampling zone; 7.5 – minimum temperature for vegetal activity, *ETP* – evapotranspiration in mm, *e* – residual evapotranspiration in mm, *HA* – hydric availability in mm and *PBI* – potential bioclimatic intensity in bcu

Table 1 Physical, chemical and biological properties corresponding to soil 1

	Soil 1			
	spring	summer	autumn	winter
pH	4.3 extremely acid	4.2 extremely acid	4.2 extremely acid	4.5 extremely acid
temperature/°C	14.9	16.2	14.6	11.1
moisture/%	28.9	23.9	22.9	37.4
MPN	$0.130 \cdot 10^8$	$0.018 \cdot 10^8$	$0.035 \cdot 10^8$	$0.035 \cdot 10^8$
texture	sandy loam			
actual density/kg m^{-3}	1490			
apparent density/kg m^{-3}	337, sponger organic type			
residual moisture/%	7.52			
total porosity/%	77.38, excessive			
air porosity/%	65.42			
water porosity/%	11.96			
plasticity index	little plastic, ML-OL (silt organic silt)			
adherence	grain			
proctor/%	30.4			
hydraulic conductivity constant, K/m s^{-1}	$8.10 \cdot 10^{-3}$, excessive			
infiltration rate/m s^{-1}	$0.81 \cdot 10^{-4}$			
C/N	22			
organic matter	extremely rich			
field capacity/%	35.50			
structure	very good			
other characteristics	low depth soil with high slate presence			

In general, analysis of these properties gives information about:

- pH and organic matter content, depend mainly on soil origin [22, 23] and they limit soil productivity because pH values less than 4.5 or greater than 10 are not favorable for soil microorganisms. For this reason, for Galician soils, liming was a traditional treatment that was performed by addition of lime, algae and seafood shells to help agriculture exploitation of soil. It must be taking into account that an extremely acid pH originates solubility of Al and Mn, that are toxic for soil micoorganisms, also P precipitates and so Fe or Al phosphates that are not favorable for microbial growing
- temperature is one other limiting factor for soil microbial biomass. Soil acts as a 'thermal absorber' of environmental temperature changes as a consequence of its porosity and structure that create a suitable habitat for microorganisms. For Galician soils the optimum temperature range for microorganisms activity is between 20 and 25ºC, temperatures that correspond with the ideal range for soil organic matter decomposition processes and subsequent release of nutrients [24, 25]
- density: actual and apparent densities have a direct influence on the thermal and hydraulic conductions and on porosity that have an important influence on soil aeration
- structure, compaction index, plasticity, porosity, field capacity, moisture, residual moisture, hydraulic conductivity and infiltration rate, directly related to density, are key for the soil aeration processes, because in zones with high pluviometry can generate flooding anaerobic processes. At the same time, these properties give information for the study of soil erosion susceptibility and the possibility of crust formation
- C/N ratio, organic matter and elemental composition: give an idea about soil potentiality to generate macronutrients to support the sustainable productivity of soil [23, 24]. The most suitable ratio values are in the range from 10 to 15. A lower value is indicative of a poor content in organic matter and the possibility of a seriously damage because of soil mineralization processes. The organic matter content gives information about the capacity of a soil to supply nutrients to the living phase in it for a correct development
- MPN: it is assumed that the higher MPN, the higher the soil potentiality. This property varies as a function of some of the parameters above mentioned, especially temperature, pH and moisture content [26]

Table 2 Main weather properties of the zone where the study was made. The different data were measured in situ and compared with those supplied by the weather station Penedo do Galo, Viveiro, Galicia, NW Spain

	Months					
	January	February	March	April	May	June
MT/°C	8.8	8.8	9.7	10.3	12.3	14.9
rainfall/mm	140	101	85	131	71	63
HA/mm	240	201	185	231	171	163
moisture/%	71.8	66.7	71.0	72.5	74.7	73.2
insolation/%	36.4	39.8	43.9	36.9	44.3	44.7
sun/h	106.2	117.8	162.1	149.1	202.2	205.6
wind/days	9.7	10.5	9.5	7.8	7.6	5.9
ETP/mm	26	29	37	44	61	81
e/mm	5.3	5.9	7.4	8.9	12.2	16.2
IPBI/bcu	0.26	0.26	0.44	0.56	0.96	1.48
	July	August	September	October	November	December
MT/°C	17.2	17.8	16.9	14.0	12.0	9.9
rainfall/mm	49	55	87	142	104	151
HA/mm	131	90	87	204	204	215
moisture/%	73.5	71.4	68.9	71.3	70.6	71.4
insolation/%	47.0	50.3	45.4	39.4	35.4	31.1
sun/h	218.7	217.3	171.2	134.9	103.6	87.3
wind/days	5.0	5.5	5.8	7.8	8.9	9.9
ETP/mm	96	93	79	56	41	28
e/mm	19.1	18.7	15.8	11.1	8.2	5.7
IPBI/bcu	1.94	2.06	1.88	1.30	0.90	0.48
FBI/bcu		1.97				

MT – mean temperature in °C, *ETP* – evapotranspiration in mm, *e* – residual evapotranspiration in mm, *HA* – hydric availability in mm, *PBI* – potential bioclimatic intensity in bcu and *FBI* – free bioclimatic intensity in bcu

Table 3 Characteristic microcalorimetric parameters corresponding to soil 1

Parameters	Soil 1			
	spring	summer	autumn	winter
P_t/h	15.795±0.623 (3.95%)	17.880±0.335 (1.87%)	19.621±0.322 (1.64%)	18.663±0.341 (1.83%)
P_h/μW	146.015±2.935 (2.01%)	127.443±3.444 (2.70%)	144.031±1.101 (0.76%)	106.911±2.906 (2.72%)
Q_t/J g^{-1}	829.351±12.970 (1.56%)	805.925±16.992 (2.11%)	885.015±1.878 (0.21%)	730.810±4.980 (0.68%)
μ/h^{-1}	0.1361±0.0021 (1.58%)	0.1252±0.003 (2.41%)	0.0936±0.0020 (2.15%)	0.1040±0.0012 (1.20%)

Peak time (P_t/h) is the time to reach the maximum of the peak, peak height (P_h/μW) is the power at the maximum of the peak, Q_t/J g^{-1} is the total heat evolved up to the maximum of the power–time curve, μ/h^{-1} is the microbial growth rate constant

Results and discussion

Table 3 shows soil 1 mean values of: peak time, P_t (h), peak height, P_h (μW), total heat, Q_t (J g^{-1}), and the growth rate constant, μ (h^{-1}). Values shown are the mean of 4 experiments carried out on each sample and season. From these values it follows:

- P_t value corresponding to spring is the lowest of the year. This means that P_h is reached faster than in the other seasons. This could be originated by a temperature effect (higher or lower than in spring) that influence in negative on microbial population growth capacity. P_t shows the highest value in autumn what could be a consequence of this fact. Autumn is the driest season in Galicia, being moisture a parameter with an important influence on microbial growth. This agrees the evolution of μ over the year. The value of μ in spring could be a consequence of the joint influence of temperature and moisture on microorganisms growth
- this same reasoning could be applied on P_h, because in summer (high) and in winter (low), temperature directly controls soil microbial growth and because of this, P_h shows its maximum value in spring

Table 4 Characteristic microcalorimetric parameters corresponding to soil 2 in autumn

Parameters	Soil 2				
	P_t/h	P_h/μW	Q_t/J g^{-1}	μ/h^{-1}	MPN
Autumn	10.7510±2.2509 (0.65%)	71.6523±0.5233 (0.73%)	345.0446±2.2509 (0.65%)	0.0106±0.0004 (3.57%)	$0.007 \cdot 10^8$

Peak time (P_t/h) is the time to reach the maximum of the peak, peak height (P_h/μW) is the power at the maximum of the peak, Q_t/J g^{-1} is the total heat evolved up to the maximum of the power–time curve, μ/h^{-1} is the microbial growth rate constant, MPN – most probable number of microorganisms

- Q_t is maximum in autumn. This could be a consequence of the increase in organic matter originated by the death of the vegetable cover during this season
- MPN is a direct indicator of soil potentiality. The joint analysis of Tables 1 and 2 and Fig. 4 shows that soils with poor microbial load correspond with those generating low heat. As an example, soil 1 MPN in autumn is $0.035 \cdot 10^8$ and generates 885.015 J g^{-1}, while soil 2 has a MPN of $0.007 \cdot 10^8$ and generates only 345.045 J g^{-1}

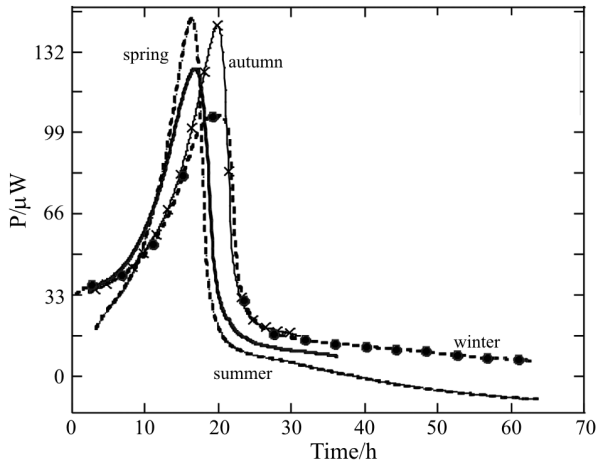

Fig. 3 *P–t* curves corresponding to seasonal evolution for soil 1. In this plot the evolution of peak time (P_t) and peak height (P_h) over the year can be followed

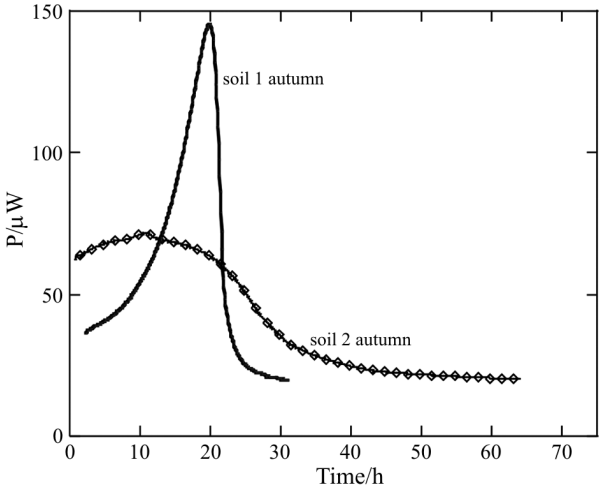

Fig. 4 *P–t* curves corresponding to soils 1 and 2

Figure 3 helps to a better understanding of the data shown in Table 3. In this figure, the year evolution of soil 1 microbial population can be followed through a *P–t* plot.

Figure 4 allows comparison of soils 1 and 2 through *P–t* curves corresponding to each of them. The different shape of both curves is related to the different uses of both soils with regard to their agriculture exploitations. This fact makes the shape of the *P–t* curves to become a very useful tool for studies of soil productivity and state of health [10]. From analysis of data in Table 4, it follows:

- value of μ corresponding to soil 2 is a consequence of the low microbial growth potentiality of this soil (acid and without treatment) compared to values corresponding to soil 1 treated with amendments (fertilizers and lime) to improve forest exploitation. Microbial population is limited by the low pH (4.2). This pH, in rain periods, decreases as a consequence of the dragging of substances originated by degradation of pine leaves situated on the cover surface to a depth of 3 cm
- P_t is reached in a shorter time as a consequence of a lesser microbial load with lesser diversity of microorganisms. Microorganisms in this soil are those perfectly suitable to the environmental conditions, as the soil population was not changed in many years
- both P_h and Q_t are much lower for soil 2. This gives a direct information on soil potentiality because the low generated heat values are related either to low productivities or to soils deteriorated by different phenomena going from pollution to soil overexploitation, as a direct consequence of a very low microbial load

Conclusions

Microcalorimetry shows as a very reliable method to assess microbial activity in soils. Results obtained by the microcalorimetric method are in very good agreement with those obtained through different physical, chemical and biological tests.

A comparative study of similar soils subjected to different man activities could be the basis for campaigns designed either to recover degraded soils or to avoid soil

degradation. The experimental procedure reported in this work could be very helpful to create a data basis that could be useful to quantify and control soil potentiality for a rational and sustainable exploitation.

The procedure here proposed has been successfully checked using different kinds of soils, both in origin and use, situated in different zones of Galicia. In our opinion, this procedure could be used on any soil everywhere, providing the determination of the own parameters of soil and zones.

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