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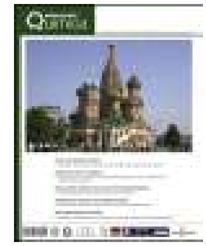

CHEMISTRY DIDACTICS

Studying the importance of soil organic matter: An educational proposal for secondary education

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Abstract Although the importance of including in the curriculum of all educational levels issues related to soil science has been strongly highlighted, the fact is that the importance that the quality and availability of organic matter in the quality of soil have received very little attention when it comes to considering educational practices in classrooms. This paper brings an educational proposal for teaching the transcendence of organic matter in soil at secondary level. The learning unit presented is based on essential chromatography techniques and allows the qualitative study of soil organic matter. The ultimate purpose is to offer basic educational tools for reflection on the implication that soil has in order to maintain biodiversity and food production.

PALABRAS CLAVE
Métodos de enseñanza;
Educación de pregrado;
Ciencia del suelo;
Educación secundaria

Estudiando la importancia de la materia orgánica del suelo: una propuesta educativa para educación secundaria

Resumen Aunque la importancia de incluir en el plan de estudios de todos los niveles educativos cuestiones relacionadas con la ciencia del suelo ha sido fuertemente resaltada, el hecho es que la importancia de la calidad y la disponibilidad de la materia orgánica en el suelo han recibido muy poca atención cuando se consideraran las prácticas educativas en las aulas. Este documento aporta una propuesta educativa para la enseñanza de la trascendencia de la materia orgánica en el suelo en el nivel secundario. La unidad de aprendizaje presentada se basa en las técnicas esenciales de la cromatografía y permite el estudio cualitativo de la materia orgánica

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del suelo. El objetivo final es ofrecer herramientas educativas básicas para la reflexión sobre la implicación que tiene el suelo a la hora de mantener la biodiversidad y la producción de alimentos.

Introduction

Soil is a complex, non-renewable and essential natural resource in the maintenance of ecosystems and it is also key to ensuring the food, energy and fibre supply to humans.

Soil organic matter comes from either the remains of living things which were once alive or their waste products in a natural environment. Once on the ground, organic matter undergoes a set of complex chemical transformations conducted by living beings in soil (Trevors, 1998). Thanks to these chemical changes, organic matter gradually achieves a quasi-equilibrium state known as *humus* which can remain stable over time (Schmidt et al., 2011; Tan, 2014).

What makes humus so important for plant life is that it is rich in humic and fulvic acids. These substances produce organo-mineral associations with ions such as Mg^{2+}, Ca^{2+}, Fe^{2+} y Fe^{3+} (Tang et al., 2014) resulting in an increase in the availability of micronutrients to plants which is an essential feature of healthy and fertile soils.

However, secondary and high school level educational programs have paid little attention to this crucial factor closely tied to soil productivity (Bertha & Leslie, 2002; Megonigal et al., 2010; Vila, Contreras, Fernández, Roscales, & Santamaría, 2001).

Objective

On the basis of the above, this paper presents a practical proposal specially targeted for the laboratory of secondary education with the purpose of encouraging a vision of soil organic matter as a finite and vulnerable resource which is essential to sustain plant life, the environment and to the foodstuffs industry.

Procedure

The following is the teaching sequence proposed to achieve the previously highlighted objective. To this end, and as a form of an example, this paper presents a real study carried out with five soil samples.

First step: sampling and sample preparation

The five soil samples analysed in this study were collected using a metal trowel to a depth of 10 cm.

First of all, the samples are left to air dry for three days on a white blank sheet of paper. Then, 150 g of each soil sample is taken, without stones or plant debris and are sieved and ground with a mortar until a homogeneous powder is achieved. The final samples, duly sieved and ground, are stored in clearly labelled paper bags.

Second step: the impregnation of the stationary phase with light-sensitive substance

To continue with the experiment Whatman qualitative filter papers (grade 4) are required. In this case, 5 circular filters are to be used, one for each sample. With a pencil, two points will be marked on each filter, 4 and 6 cm respectively from the centre of the circle.

On another development, five small pieces of filter paper are cut (2 cm × 2 cm) and these filter pieces are rolled up to form small cylinders as a cannula or tiny tube. Finally, a hole is drilled into the centre of each filter and each of the previously created cannula is inserted perpendicularly through the holes in the centre of each filter.

The filter with the cannula lodged in the centre is placed on a Petri dish in which previously a 0.5% silver nitrate ($AgNO_3$) solution is poured (see Fig. 1).

The dissolution will rise by capillarity through the cannula, soaking into the filter paper. When the dissolution reaches the previously marked point (4 cm from the centre of the filter), the filter is removed from the Petri dish. Finally the cannulas are removed from the filters and these are left to dry. To this end, the filters are kept separately between sheets of paper and inside a dark box so that the silver cannot be reduced by light.

Figure 1 The impregnation process of the filters with $AgNO_3$.

Figure 2 A plastic shallow container with the dissolution.

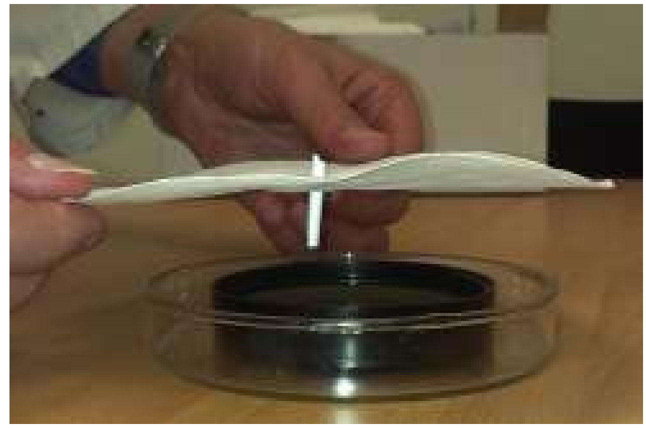

Figure 3 The infiltration process of dissolution into the filters.

Third step: the extraction of organic matter

The procedure to extract the organic matter of the soil samples should be carried out as follows. Firstly, 5 g of each of the soil samples previously sieved and ground are weighed inside a 100 mL Erlenmeyer flask. Subsequently, 50 mL of a 1% solution of sodium hydroxide ($NaOH$) should be added to the Erlenmeyer flask. Finally, the mixture is rocked gently for about 10 min and then left to stand for at least 12 h so that the organic matter can be extracted.

Fourth step: chromatography

After the extraction of the organic matter, 10 mL of the dissolution contained in each of the Erlenmeyer flasks are collected with a syringe and poured into a plastic shallow container. After that, the container with the dissolution inside is placed in a Petri dish as Fig. 2 shows.

In this regard, it is important to avoid disturbing the mixture and also to use different syringes for each sample (or to flush with distilled water in the case of reusing the same syringe).

The dry filters which were previously impregnated with silver nitrate, are now placed on each of the containers and a new cannula made with a paper filter should be inserted vertically into the centre of each filter (see Fig. 3). It is very important to be sure that the central part of the filters is not touched by hand to avoid damaging the photosensitive substance.

In this way, the fluid that carries the dissolved organic matter soaks the filters by capillarity. At this point in time, the different compounds of the dissolution start to separate and one can see how some coloured stains start to become evident on the surface of the filters (see Fig. 4). The filter paper is taken off from the cap once the soaking area reaches the point of 6 cm from the centre of the filter.

The final step is to leave the filters to air dry for about 8 h in a well lit place but avoiding direct sun light. The silver that the photosensitive substance has is reduced by light, which yields a chromatogram with clear colours and crisp lines. Photographic illustration 4 presents the results of the chromatography process, just before the drying period.

Fifth step: the qualitative assessment of the chromatography

In line with previous studies related to the use of radial chromatography to qualitatively assess the condition of the soil organic matter (Quintanilla, Yane, & Monge, 2013; Restrepo & Pinheiro, 2011; Senthil Kumar, Satheesh Kumar, Rajendran, Uthaya Kumar, & Anbuganapathi, 2014), the following criteria are proposed to be used to analyse the chromatograms:

- The first criterion: the colours that appear on the chromatogram. The presence of colours like brown, yellow and ochre are related to a greater amount of organic matter. However, grey, violet and black colours mean lower content.
- The second criterion: The presence or absence of a well-defined radial structure, made up of radial streaks. If this structure appears, instead of a dense, lumpy and blurred

Figure 4 The initial results of the chromatography process.

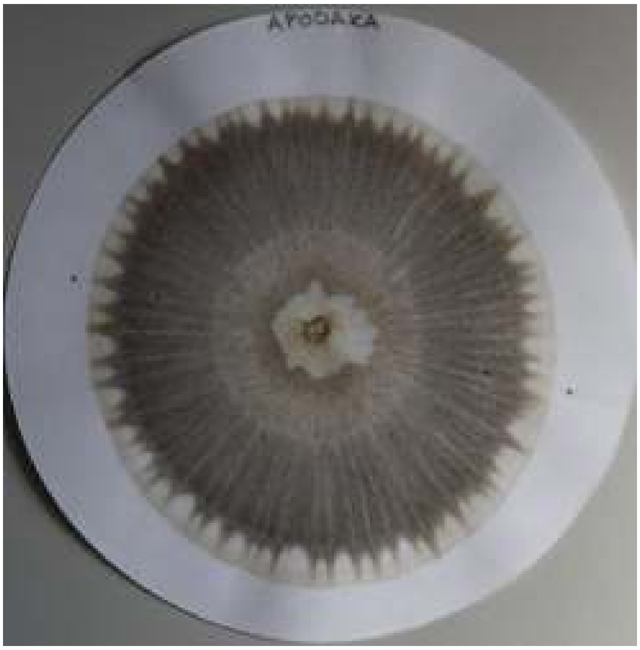

Figure 5 The chromatogram of the sample from a cereal crop field.

area, this feature indicates good availability of organic matter in the sample.

- The third criterion: The presence or absence of up to four different ring-like concentric areas on the chromatogram:
  - o In the case of healthy soils, the inner area of the chromatogram often has a white to off-white or light cream colour. However, this area could appear dark or even black in the case of soils that have suffered a severe mechanization process and intensive exposure to plant protection products. If a pale white colour is very apparent in this zone, this usually means a significant use of organic fertilisers.
  - o Above the inner area a zone linked to the mineral substrate in the sample can appear, and just above this, a ring-shaped zone which is related to the presence of organic matter.
  - o Finally, an outer zone can appear which is linked to soil enzyme activity. The chromatogram of healthy soils usually displays undulating and wavy lines in this external area.

Results

The first sample was collected from a cereal crop field near the municipality of Apodaka (Basque Country, Spain). Fig. 5 shows details of the chromatogram obtained with the sample of this soil.

This soil sample comes from a single-crop cultivation from which a high production is needed resulting in intensive farming and the utilization of chemical fertilizers, pesticides and others.

Concerning the chromatogram, a well-marked radial structure and, also, ring-like concentric areas are displayed

Figure 6 The chromatogram of the soil from a holm-oak wood.

(the second and third criteria). Grey, however, is the main colour with some minor areas displaying muted brown tones.

The next sample was collected from a well-preserved holm-oak wood in Gorliz (Basque Country, Spain). Fig. 6 presents the chromatogram achieved with the sample of this soil.

With regard to the soil characteristics, the sample comes from a zone of high environmental and scenic interest with soils rich in organic matter (Aguirre, Prieto, & Rodrigo, 2010).

Figure 7 The chromatogram of the sample from a wetland soil.

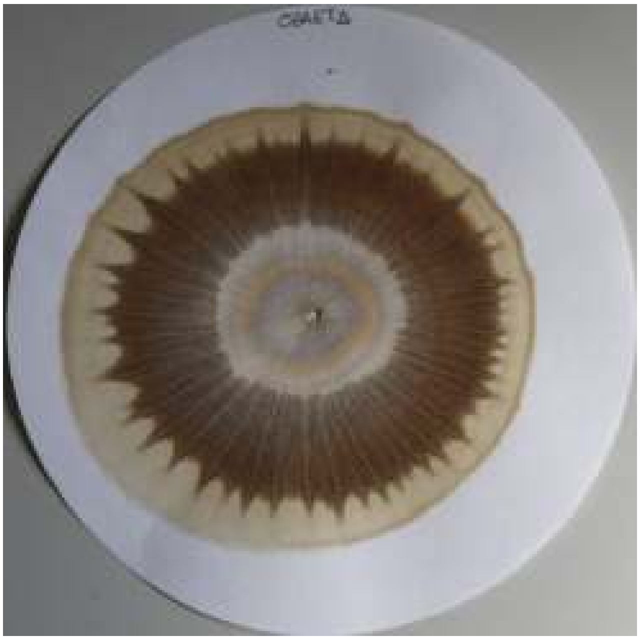

Figure 8 The chromatogram of the soil from an ecological vegetable garden.

Figure 9 The chromatogram of the soil from an urban garden.

The result of the chromatography displays brown and yellow colours and also ring-like concentric zones. However, the chromatogram shows an unclear radial structure.

Fig. 7 shows the chromatogram of the sample from a wetland zone located in the outskirts of the city of Vitoria-Gasteiz (Basque Country, Spain). This wetland area displays a favourable conservation status (Aguado, Legarreta, & Miguel, 2013). However, it is worth noting that the sampling site is located in an area that has been classed as an environmentally vulnerable area (Antigüedad et al., 2010).

Regarding the chromatogram, it shows both a radial structure and ring-like concentric areas. The colours, however, are a blend of some areas with brown and yellow tones and others with grey and blue colours.

The next soil sample was collected in an ecological vegetable garden located in the town of Ozaeta (Basque Country, Spain). Fig. 8 shows the chromatogram obtained. Concerning the characteristics of this land, the most notable features are that no chemical pesticides or fertilisers are used and the farm plot undergoes regular crop rotation.

Moreover, brown, yellow and white to off-white are the major colours on the chromatogram and radial structures and the ring-like concentric areas are clearly evident.

The fifth sample was collected from an urban garden in the municipality of Gorliz (Basque Country, Spain) and Fig. 9 presents the result of the chromatography. Concerning the features of the soil, it should be noted that artificial fertilizers and plant protection products are usually used for garden maintenance. Furthermore, the ornamental grass is the predominant ground-cover in this resource and the grass is frequently mowed. However, the cuttings are usually collected which leads to soil impoverishment and to the necessity of using more fertilisers.

The chromatogram shows that the greyish shades are very relevant; besides, only three of the four ring-like areas appear and the radial structure is blurred and diffused.

Table 1 shows the summary of the qualitative assessment of each of the soil samples examined above. Concerning this table, a plus mark means that the characteristic considered matches a pattern of positive assessment and, on the contrary, a negative mark points out that a certain aspect of the soil sample matches a pattern of negative valuation.

Table 1 A summary of the qualitative assessment of each of the soil samples studied.

Sample	Colours	Radial structure	Ring-like areas	Global assessment
Cereal crop field	Greyish shades (−)	Well-defined (+)	Yes (+)	(+)
Holm-oak wood	Brown, yellow and white to off-white (+)	Vaguely defined (−)	Yes (+)	(+)
Wetland	Greyish shades (−)	Well-defined (+)	Yes (+)	(+)
Ecological vegetable garden	Brown, yellow and white to off-white (+)	Well-defined (+)	Yes (+)	(+ + +)
Urban garden	Greyish shades (−)	Vaguely defined (−)	Only 3 zones (−)	(− − −)

Discussion of results

The qualitative assessment of the chromatograms previously presented indicates that the sample from the urban garden has the poorest quality in terms of the availability of organic matter and of productive potential. This conclusion is coherent with the treatment that this resource has; that is to say, frequent mowing that removes plant debris and utilization of artificial fertilisers and plant protection products.

By contrast, the sample of the organic garden shows the highest quality and the greatest availability of organic matter. This finding is consistent with the non-use of chemical treatment in this resource and, also, with the planning of crop rotation and fallow periods. In this way, the transformation of organic matter in humus by living things in soil is favoured and this resource improves in terms of the availability of organic matter.

The chromatogram of the soil from a holm-oak wood points out that this sample is set at an intermediate level regarding the quality of organic matter. This is a significant fact, since the sample comes from a well-preserved natural environment. Even though this study cannot shed light on the reasons that may explain this finding, from an educational perspective it may be interesting to speculate about the role that the geological structure of soil plays in the formation of humus. In that regard, the subterranean drainage that characterizes the calcareous bedrock of the sampling site (Aguirre et al., 2010) constrains the surface water availability which might affect the process of humus formation. This is consistent with the fact that the holm-oak wood, from where the sample was collected, shows a strikingly poor shrub and herbaceous layer.

Conclusions and educational implications

The teaching sequence described in this paper proposes an educational tool to foster the secondary school students' knowledge concerning soil organic matter. The sequence places a particular emphasis on detailing a practical procedure to ensure that students can be actively involved in their learning process. In this regard it should be stressed that teachers' skills for designing practical activities and laboratory experiences are considered one of the most significant factors related to the improvement of science education (Wenglinsky & Silverstein, 2007).

The teaching sequence allows students to emulate the actual laboratory activity carried out in the field of soil science. More specifically, a method for comparing the availability of organic matter that different soil samples have is detailed but by avoiding very technical, expensive or inaccessible methodologies.

This is a key point of the teaching sequence, since that, finding a feasible and practical procedure to address the topic of the role that organic matter has in the productive capacity of soils is not an easy issue in the confines of a secondary school classroom.

Moreover, comparing samples from soils subject to different uses (urban utilization, intensive farming, well-preserved natural environment, etcetera) allows students to consider how the availability of organic matter in soil is closely tied, not only to the environmental characteristics of the sampling site but also to how this resource is used by human beings.

In this manner, it is believed that students might achieve the final objective that this teaching sequence pursues; that is to say, being aware of the importance that soil preservation has for ecosystems, biodiversity, and for ensuring sustainable development.

Conflict of interest

The authors declare no conflict of interest.

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