Assessing Soil Quality in School Yards: A Hands-On Activity for Middle School Students

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Abstract

Soil provides innumerable valuable ecosystem services, such as the production of food and the direct support of wildlife, by ensuring the availability of adequate habitat. However, unsustainable human activities are resulting in degradation of soils worldwide. Hence, it is of utmost importance to raise awareness about this often-overlooked environmental issue. This article presents an inquiry-based activity that challenges students to assess the ecological quality of soil in the surroundings of their classroom. Plus, students and teachers are invited to become citizen scientists by sharing their data with researchers, thus contributing to a future endeavor to map soil quality through broad geographic ranges.

Key Words: citizen science; biology education; environmental education; soil monitoring.

Introduction

Soil is composed of minerals, organic matter, air, water, and living organisms. It is essential for the support of life on Earth, delivering crucial ecosystem services such as food and habitat for thousands of species. Yet soils are increasingly becoming degraded, mostly because of unsustainable use by humans. Application of pesticides and mining are only two examples of the many activities that can severely damage soil structure and function. As a nonrenewable resource, soil takes hundreds of years to form, which makes the need to preserve this asset even more urgent (Orgiazzi et al., 2016).

Approaches to soil preservation include the propagation of recommendations, guidelines, and frameworks focused on monitoring, protecting, and recovering soil quality (e.g., Canadian Council of Ministers of the Environment, 1999; CEC, 2006; Toronto and Region Conservation Authority, 2012; FAO, 2017), but the involvement and engagement of the society at large is critical to the success of these interventions. In this context, citizen science can play a relevant role. Citizen science can be broadly defined as the active participation of nonexperts in scientific research (McKinley et al., 2017; Newman et al., 2017). This approach produces relevant data for research purposes while contributing to the education of participants in various scientific topics. Citizen science projects can be designed to integrate hands-on and inquiry-based activities (e.g., OPAL, n.d.), which are widely regarded as more effective in increasing the interest of students in scientific topics (Rocard et al., 2007; Holstermann et al., 2010; Trnova & Trna, 2011; McConney et al., 2014). Hence, this is a valuable approach to raise awareness about the importance of soil and its sustainable use among the school community.

The activity presented here – “Is the Quality of This Soil Any Good?” – challenges students to evaluate several physical, chemical, and biological parameters that reflect the quality of the soil (Table 1). Ultimately, they are invited to assess whether the soil of their schoolyard has a bad, a reasonable, or a good quality, and discuss which parameters contributed the most to the obtained result. For a complete protocol and resources, see the Supplemental Material with the online version of this article.

Methods

For Whom?

The activity is aimed at middle school students (grades 6–8) in the United States, and it is useful for exploring “Earth and Human Activity” (MS-ESS3-3 in Next Generation Science Standards; NGSS Lead States, 2013) and is aligned with other middle school curricula as well (e.g., National Research Council, 2012; NY Education Department, 2016; NJ Department of Education, n.d.). Still, given its general character, this activity can be used in formal and nonformal educational contexts worldwide.

“This approach produces relevant data for research purposes while contributing to the education of participants in various scientific topics.”
Soil compaction reduces the oxygen and water available within the soil. Besides, it also leads to a decrease in the availability of nutrients to plants. Organic matter is decomposed into nutrients by soil microorganisms, making them available for plants. Soil color can be used as an indicator of the mineral composition of soils as well as their organic matter content. Vegetation influences the amount of organic matter that reaches the ground because they are one of its major sources, and also protect the soil against erosion from rain and wind. Microorganisms decompose organic matter into nutrients, making them available for plants. Decomposition of organic matter is mostly carried out by microorganisms. Usually, soils with higher abundance, activity, and diversity of microorganisms have faster decomposition rates of organic matter (as well as of different carbon substrates), thus improving the availability of nutrients to sustain primary production (i.e., plant growth).

Pollution refers to the presence of contaminants on soils at levels able to cause effects on soil organisms and soil processes. Different types of pollution will affect the soil in different ways. For instance, the soil microbial community can degrade some organic contaminants, preventing their accumulation in this environmental compartment and the possible contamination of water tables. However, if contaminants are present at levels able to affect microorganisms, the latter’s function is compromised, and soil becomes a poor-quality habitat. Plastic waste and other nondegradable products, having been deposited in the ground, degrade over time into smaller pieces that eventually cannot be distinguished from food particles, but these residues bear no nutritional value and can affect the growth of earthworms and other soil organisms and even lead to their death.

Table 1. Physical, chemical, and biological parameters that the students are expected to evaluate and their respective relationships with soil quality. Adapted and compiled from Bardgett & van der Putten (2014), Lwanga et al. (2016), Orgiazzi et al. (2016), Rodriguez-Seijo et al. (2017), Machado et al. (2018), and USDA (n.d.).

| Parameter | Relationship with Soil Ecological Quality |
|-----------|------------------------------------------|
| Organic matter | Soil microorganisms decompose organic matter into nutrients, making them available for plants. More organic matter means more nutrients and, thus, better soil fertility in general. Organic matter in soils also represents a “storage of carbon,” removing it from the atmosphere, where carbon gases (e.g., CO$_2$) account for climate changes. |
| Soil color | Soil color can be used as an indicator of the mineral composition of soils as well as their organic matter content. For instance, a light gray color suggests the presence of quartz, while a dark black color that decreases in intensity with depth is a sign of high organic matter content. |
| Vegetation | Plants influence the amount of organic matter that reaches the ground because they are one of its major sources, and also protect the soil against erosion from rain and wind. Plus, the roots of plants (i.e., the so-called rhizosphere) are hot spots of biodiversity in soils. |
| Microorganisms | Decomposition of organic matter is mostly carried out by microorganisms. Usually, soils with higher abundance, activity, and diversity of microorganisms have faster decomposition rates of organic matter (as well as of different carbon substrates), thus improving the availability of nutrients to sustain primary production (i.e., plant growth). |
| Water infiltration and retention capacity | Water is essential for the survival of all organisms, including those living in soils. Actually, soil is considered a semiaquatic habitat. Thus, soil biodiversity depends largely on the soil’s ability to take up water and retain it. Water percolation in soils is also extremely important for its purification and, subsequently, for the recharge of water tables with water of good quality. |
| Soil compaction | Soil compaction reduces the oxygen and water available within the soil. Besides, it also leads to the collapse of the pores used as habitat by several organisms. As a result, compacted soils tend to have lower biodiversity and the worst characteristics for the development of plant roots. |
| Earthworms and other “soil engineers” | Roots and soil animals – especially earthworms – have great influence on the structure of the soil, by opening biopores and tunnels, which (1) work as adequate habitat for smaller animals, (2) make soil less compact, and (3) facilitate water infiltration and retention. These “soil engineers” also promote circulation of organic matter and accelerate its decomposition. In addition, some earthworms produce “chemical cues” that stimulate the growth of plants. |
| pH | The pH is an abiotic factor that determines which organisms can and cannot live within a given soil. Different species have different tolerance ranges to this parameter. However, soils that are too acidic (pH < 5.0) or too basic (pH > 7.5) tend to host less biodiversity. The soil pH also determines the availability of nutrients to plants. |
| Pollution | Pollution refers to the presence of contaminants on soils at levels able to cause effects on soil organisms and soil processes. Different types of pollution will affect the soil in different ways. For instance, the soil microbial community can degrade some organic contaminants, preventing their accumulation in this environmental compartment and the possible contamination of water tables. However, if contaminants are present at levels able to affect microorganisms, the latter’s function is compromised, and soil becomes a poor-quality habitat. Plastic waste and other nondegradable products, having been deposited in the ground, degrade over time into smaller pieces that eventually cannot be distinguished from food particles, but these residues bear no nutritional value and can affect the growth of earthworms and other soil organisms and even lead to their death. |

For example, it can be used by teachers in Ontario, Canada, to explore “Understanding Life Systems: Interactions in the Environment” (Ontario Ministry of Education, 2007), or by teachers in Portugal to address “Sustainability on Earth” (Bonito et al., 2013). The activity was carefully designed to require only readily available equipment and materials, many of them reusable:

- Equipment
- A mobile device with GPS (e.g., mobile phone) or computer

When & Where?
The activity can be performed during every season, although teachers should avoid implementing it two to three days after intense rainfall. Any place that has soil, such as a farm, a garden, or a lawn, would be adequate for implementation (Figure 1). Depending on the requirements and/or constraints of each class, different sites can be assessed to analyze the differences in the quality of soil patches subjected to different types and degrees of human pressure (e.g., no trampling vs. intense trampling; no visible litter vs. some litter; with or without vegetation cover). For a suggested application, see Box 1.
Box 1: Does human trampling affect soil quality?

Trampling (e.g., by pedestrians, cattle, and/or vehicles) is one of many human activities that negatively impact the soil (Korkanç, 2014; Orgiazzi et al., 2016), leading to the degradation of natural habitats. Although moderate trampling may be beneficial to certain plant species that are better adapted to deal with this disturbance (Kobayashi et al., 1997), most of its effects on the biosphere are negative (Orgiazzi et al., 2016). For instance, trampling damages vegetation and – depending on its intensity – can significantly reduce vegetative cover (Korkanç, 2014; Orgiazzi et al., 2016). As a direct consequence, the soil will become more vulnerable to erosion. Plus, trampling may directly increase the degree of soil compaction, which will result in a decrease in the quantities of oxygen and water available, as well as in reduced habitability of biopores for mesofauna. It is worth noting that these factors often lead to a decline in the biodiversity inhabiting the soil, along with reduced fertility (Orgiazzi et al., 2016). Given this rationale, teachers can challenge their students to conduct an experiment to answer the research question “Does human trampling affect soil quality?” They can apply the methods described for the present activity to monitor nearby soil patches that are subjected to different degrees of human trampling. To wrap up the lesson, teachers can engage students in a discussion about ideas for minimizing the impact of trampling on the studied soil patches and on how to improve their overall quality.

How to Proceed?

Students should be divided into groups, and each group should be assigned a different soil patch to perform the activity as illustrated in Figure 2; the estimated time frame for the activity is 60–90 minutes. Each group is expected to follow along with and fill in a single field notebook (see Supplemental Material) with the assistance of the teacher. Besides blank spaces to record observations, this field notebook contains detailed instructions on the necessary procedures in five sections:

A. Site description – characterization of the study area and description of the weather conditions during the fieldwork
B. Earthworm collection – employment of two different methods to retrieve earthworms from a soil pit, followed by recording of the observations (see Box 2)
C. Soil properties – qualitative and quantitative analysis of some soil properties, such as humidity, pH, and color
D. Interpretation of results – a scoring scheme allows students to sum points given to each assessed parameter in order to classify the quality of the studied soil as “good,” “reasonable,” or “bad”
E. Sharing the results – teachers and students are encouraged to share their data with our team via an online form (at https://forms.gle/bxM4KIqJmX1oRCyP9; see Supplemental Material)
This means that students can contribute to the production of new scientific discoveries, and this may be an additional motivation for them, as reported in regard to other citizen science campaigns (Silva et al., 2016; Vitone et al., 2016). If relevant in size and geographic coverage, the data collected via the online form for post-activity fulfillment (address provided above and in the field notebook, section E; see Supplemental Material) will be treated and used for a meta-analysis of soil quality across broad geographic areas, depending on the number and distribution of the contributions.

A practical advantage of this activity is that the supplies needed to implement it are readily available and inexpensive. However, given the lack of sophistication of the methods, the accuracy of some parameters will likely be lower than that obtained by following standard scientific protocols. Still, the results obtained with this activity are valuable from a scientific point of view as a preliminary assessment of soil quality, especially considering the broad geographic coverage that can be reached (e.g., Bone et al., 2014). Besides, the local relevance of this activity can be capitalized upon: its results can be used directly to guide future interventions in the schoolyard, with the aim of improving the quality of the soil and its ability to function as an appropriate habitat for local biodiversity. This is a suitable route for extending the learning experience of students engaged with the environment and biodiversity, contributing to the improvement of their skills for appropriate soil quality management.

This activity has been used in Portugal under the guidance of the same field notebook included in the Supplemental Material (but translated into Portuguese). So far, the activity has been repeated a total of 63 times, engaging more than 150 people in soil analysis. Meanwhile, only two relevant difficulties were found during the application of the activity. The first is related to the unpredictability of the weather, as the activity should not be performed at least three days after intense rainfall; the second concerns the allergies that students may occasionally experience (e.g., grass allergy), which may prevent them from participating in the fieldwork if these issues are not appropriately accounted for beforehand. The use of gloves must be considered if teachers expect some type of contamination based on soil use in the study area.

Advantages and disadvantages of the proposed activity are summarized in the brief SWOT analysis shown in Table 2.

**Box 2: Dealing with earthworms – trepidation vs. disappointment**

Given that this activity involves finding and handling earthworms, teachers may face two distinct challenges when implementing it. On one hand, students may be afraid or reticent to touch these animals. Hence, before heading outside to carry out the fieldwork, teachers should ask the class if anyone has concerns regarding handling earthworms. If there is a positive answer, the teacher can ease their negative feelings toward these invertebrates by stating they are harmless and by discussing their fundamental role in soil quality. Providing students with tools that allow them not to touch earthworms directly (e.g., gloves, tongues) may also be helpful. On the other hand, some participants may be disappointed if they do not find any earthworms in the soil patches. In case this happens, teachers can challenge their students to look for earthworms around their homes and bring them to school, along with a sample of the soil in which they were found. This will provide an excellent opportunity to compare the properties of both soils (with the partial application of our protocol) and debate why earthworms may be present in the soil patches near their houses but absent from those in the schoolyard.
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Table 2. Brief SWOT analysis exploring the strengths, weaknesses, opportunities, and threats inherent to the activity “Is the Quality of This Soil Any Good?”

| Strengths                                      | Weaknesses             |
|-----------------------------------------------|------------------------|
| Hands-on and inquiry-based activity           | Lower accuracy         |
| Easily acquirable and low-cost materials      |                        |
| Opportunities                                 | Threats                |
| Direct contribution to science                | Weather-dependent fieldwork |
| Improvement of the soil quality in schoolyards|                        |

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