ACTIVITIES IMPLEMENTED IN SOIL SCIENCE SUBJECTS TO LEARN SPECIFIC COMPETENCES AND SUSTAINABLE DEVELOPMENT GOALS

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Abstract

In 2015, within the United Nations, 193 Member States unanimously adopted a new Sustainable Development Agenda, called Agenda 2030. In its core, there are 17 Sustainable Development Goals (SDGs) for improving the lives of the people and the protection of the environment. The 17 SDGs are based on the so-called 5 P's: people, prosperity, peace, planet and partnerships. The SDGs are universal and everyone is needed to reach them, including universities and students. Soil plays a key role in achieving the SDG, mainly due to its functions, i.e. biomass and food production, carbon and nutrient sequestration, water filtration, landscape and heritage, source of raw materials, habitat of soil organisms, which are essential for human life and the maintenance of the ecosystems. Many of the SDGs cannot be achieved without healthy soils and sustainable soil use and management. Therefore, soil science teaching is of great importance to convey soil scientific knowledge to students and get them involved in the accomplishment of the SDGs. In this communication, we present the results of the analysis of the activities carried out by the students related with SDGs and the cation exchange capacity of soils and soil nitrogen fertilization as well as the outcomes of the activity in which students related a laboratory experiment to the SDGs.

Keywords: SDG, Soil Science, Higher Education.

1 INTRODUCTION

The 2030 Agenda for Sustainable Development was approved in 2015 at the Sustainable Development Summit, and has as its central core 17 Sustainable Development Goals (SDGs) (Figure 1), also known as the Global Goals [1]. The goal of the SDGs is to transform the world by achieving a more sustainable way of life. The 17 SDGs are specified in 169 targets and 230 global indicators.

Figure 1. Sustainable Development Goals. Source: https://www.un.org/sustainabledevelopment/

According to Keestra *et al*. [2] "Every scientific discipline faces the challenge of acting upon these SDGs, and this is particularly relevant for soil science, as a land-related discipline with important links to several of the SDGs". Many of the SDGs cannot be achieved without healthy soils and without sustainable land and soil use. Therefore, it is important to guarantee sustainable management of soils in an effort to make SDGs a reality.

Soil is a non-renewable natural resource over a human lifetime. Soils are crucial to life on Earth due to their multifunctionality (e.g. basis for healthy food production, agricultural production suitability, habitat

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for plant populations and microorganisms, carbon storage, filter of water) [3], [4]. Therefore, soil functions are fundamental for the supply of clean water, the mitigation of climate change, the provision of a habitat for biodiversity, agricultural or primary productivity, nutrient recycling, etc. [5].

Soil is subject to increasing environmental pressures that can lead to different threats such as loss of organic matter, pollution, loss of soil biodiversity, sealing, etc. [6], [7]. The report "Status of the World's Soil Resources" prepared by the Intergovernmental Technical Panel on Soils (ITPS) affirms that 33% of land is moderately to highly degraded due to the erosion, salinization, compaction, acidification and chemical pollution of soils [8]. The Sustainable Development Goals Report 2020 [9] states that two billion hectares of land on Earth are degraded, affecting some 3.2 billion people, driving species to extinction and intensifying climate change.

Dazzi and Lo Papa [10] have indicated that "Sustainable soil management is achieved through mitigation or resolution of such threats". Principle 5 of the Revised World Soil Charter states that "Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity" [11]. Schröder *et al*. [12] summarized the links between threats of soil quality characteristics, management practices, and their estimated effect on soil functions. Keesstra *et al*. [13] provided links between degradation processes, soil ecosystem services, and SDGs.

Soil is directly mentioned in only 4 of the 169 SDG targets (Table 1). Thus, according to Head *et al*. [14], soils are poorly represented in United Nations SDGs targets and indicators.

Table 1. Soil-related SDGs targets. Source: United Nations [1].

Target 2.4. "By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and **soil quality**".
Target 3.9. "By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and **soil pollution and contamination**".
Target 12.4. "By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and **soil** in order to minimize their adverse impacts on human health and the environment".
Target 15.3. "By 2030, combat desertification, **restore degraded** land and **soil**, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world".

Different authors have linked soils to the SDGs 1, 2, 3, 6, 7, 11, 12, 13 and 15 [2], [10], [15]–[18]. Lal [19] classified the soil-related SDGs into those that produce a primary impact (SDG 2, SDG13 and SDG 15) and those that produce a secondary impact (SDG 1, SDG 3, SDG 6 and SDG 7). Tóth *et a*l. [20] included SDG 11 and SDG 14 and also mentioned that SDG 7 and 12 are indirectly affected by the health of soils.

The necessity to realize and achieve the SDGs inspires a greater sense of responsibility and care for soils [18] but in order to accomplish this responsibility, learning about soils and SDGs is essential and should be encouraged.

The British Society of Soil Science (BSSS) initiative "Working with Soil – Professional Competency in Soil Science" sets out the minimum qualifications, skills, and knowledge, which the BSSS considers necessary for scientists and engineers working on various aspects of soil science [21]. Among the minimum competences related with knowledge are: i) the ways that nutrients are held and exchanged in the soil, ii) the knowledge of legal and environmental issues related to the application of fertilisers and organic materials on agricultural land, including local designations of relevance, such as Nitrate Vulnerable Zones, and iii) an understanding of the Code of Good Agricultural Practice for Farmers, Growers and Land Managers.

The Soil Science Society of America's Council of Soil Science Examiners in the document "Soil Science Fundamentals Exam" includes among the competencies: i) the definition of Cation Exchange Capacity (CEC), ii) the definition of anion exchange capacity, iii) the description and estimation of CEC based on soil organic matter content, clay content and clay mineralogy, iv) the identification of the oxidized and reduced forms of nitrogen, v) the identificatioof the useable ionic forms of nitrogen, vi) the description of the water quality implications of improper application of nitrogen, vii) the description of how leaching potential differs between nitrate-nitrogen and ammonium-nitrogen in soils of different textures [22].

CEC is one of the most important concepts in soil fertility [23]. CEC is the capacity of the soil to hold and exchange cations. CEC is one of the most important chemical characteristics of soils since it provides an insight into soil fertility and nutrient retention capacity [24] and therefore nutrient availability for plant growth. It influences the stability of the soil structure, soil pH, the reaction of the soil to the fertilizers and provides buffer against soil acidification [25]. According to Hazelton and Murphy [25] "A low CEC means the soil has lower resistance to changes in soil chemistry that are caused by land use". A deep understanding of CEC is essential to fully understand the nature of soils [26] and the phenomena that occur in them. Therefore, in-depth knowledge of soil CEC by Soil Science students is important due to its role in soil fertility, structure, and retention of contaminants.

Nitrogen (N) is one of the three main nutrients of the plants. N is a fundamental element in the formation of amino acids, plant's chlorophyll, nucleic acids [27]. N is essential for crops to achieve optimum yields. Nitrogenous fertilizers are used in agriculture in order to sustain and improve crop yields. However, not all N that is supplied is used by crops and is lost to the ecosystem through volatilization, run-off, or leaching, causing water pollution, biodiversity loss, soil acidification, impacts on human health, etc. [28], [29]. In soil N exists in various different forms and transforms from one state to another [27]. Between these forms are nitrate (NO_3^-) and ammonium (NH_4^+).

Soils have varied retentive properties depending on their texture, organic matter content, and CEC [30]. Clay contents coupled with high organic carbon provide very favourable CEC for retention of nutrients for plant uptake [31]. Nutrient cations in soils (e.g., Na^+, Ca^{2+}, NH_4^+) will be either adsorbed to the soil clay and organic matter constituents. However, due to the nitrate form of nitrogen is negatively charged, and soils have an overall negative charge, nitrate is not attracted to the negatively charged soil particles and can move freely within the root solution [27] and it tends to move wherever water moves in the soil. According to Shafreen *et al*. [27] "About 30% of soil inorganic N is lost per growing season through leaching which accounts for the high losses of soil inorganic N". It should be noted that there are soils in which anionic adsorption processes are of great importance. Geilfus has collected the cation and anion exchange capacity in various soil particles and textures [32].

The main objective of this work is to present different activities that can be carried out by students in order to acquire a greater specific competence in the knowledge of the Cation Exchange Capacity of soils or the problem of nitrates in nitrogen fertilization, and also evaluate how these same activities can help the student to reflect on the meaning of the SDGs and the need of doing a good soil use to achieve them.

2 METHODOLOGY

The activities were carried out with students enrolled on the subjects Abiotic Environment (AE), and Soil Pollution and Waste Treatment (SPWT) in the second year of their Bachelor's Degree in Environmental Sciences at the UPV for academic year 2020-2021. The total number of students enrolled in the AE was 38 and 40 in SPWT. Soil Science, Meteorology and Hydrology are taught in the AE subject. The activities described in this communication were carried out in Soil Science and Soil Pollution classes and in a laboratory practical of SPWT.

In AE class, students had to create a mind map about CEC related concepts. Then, they had to watch a video (Figure 2) about the CEC to reinforce the knowledge of the CEC (definition, units of measurement, properties and practical implications). The video is available on the educational website https://scienceofagriculture.org/.

Figure 2. Audio-visual used in the classroom to reinforce the importance of CEC in soil fertility.

At home, the students had to read two texts on mineral fertilizers (Table 2 and 3) and did the corresponding text commentaries. In both dissertations the students had to reflect the relationship of the texts with the CEC and the SDGs.

In the subject SPWT, students were asked at the beginning of the course about the importance of considering the achievement of the SDGs in academic activities. Having in mind that the students mentioned, among other academic activities, that SDGs could be included in the laboratory practicals, the students were asked to link the knowledge and the results of a laboratory practical on transport of a solute (salt) in soil with the SDGs.

Table 2.

Text 1. The CEC allows to retain the elements necessary to nourish the plants, which would otherwise be in the soil solution easily available for deep washing. Thus, the greater this "capacity", the greater the natural fertility of the soil. "Infertile soils and the undersupply of nutrients to crops in some regions is a major contributor to the yield gap ... The soil-nutrient balance can be assessed through a mass-balance of nutrient inputs, outputs and changes in stores in the soil … Many studies emphasize the inability of mineral fertilizers alone to significantly increase food production in regions where the yield gap is the greatest unless significant inputs of organic material through crop residues or manures also occur … Recent analyses suggest that globally higher annual additions of N in agricultural systems cannot occur without causing significant environmental harm, and that additions of P exceed safe boundaries in several major agricultural regions". Source: Report "Status of the World's Soil Resources" [8].

Table 3.

Text 2. Soils act as filters for pollutants, preventing them from entering the food chain and reaching bodies of water such as rivers, lakes, seas and oceans, but this potential is limited when pollution exceeds the ability of soils to deal with it. Code of Good Agricultural Practices of the Valencian Community: "In the choice of mineral nitrogen fertilizers, the behaviour of the different chemical forms in which nitrogen occurs in the soil will be considered: nitric form (NO_3^-), ammoniacal form (NH_4^+) or urea form. The nitrate ion (NO_3^-) is very mobile in the soil and is exposed to being dragged and washed from the root zone, as a consequence of leaching and runoff phenomena caused by excess water. On the other hand, the nitrate ion is absorbed by the roots of the plant immediately and, therefore, nitric fertilizers should be used at times when crops show a greater capacity to assimilate this ion. The ammonium ion (NH_4^+) is retained by the cation exchange complex in the soil and is therefore less leachable than nitrate. Said retention is a function of the type of soil, being higher in soils with a clay texture than in soils with a sandy texture. Most of the ammonium nitrogen is absorbed by the roots of the plants after the conversion of the ammonium ion into nitrate, through the action of certain microorganisms in the soil that carry out nitrification. Therefore, the absorption of ammonia fertilizers is usually slower than that of nitric, and its action is more delayed, with which they can be applied in periods of moderate nitrogen assimilation capacity by the plant". Source: ORDER 10/2018, of February 27, from the Department of Agriculture, Environment, Climate Change and, Rural Development on the use of fertilizers nitrogenous in the agricultural exploitations of the Valencian Community.

After carrying out the proposed activities, the tasks were evaluated following both, academic and correlation with SDG's criteria.

3 RESULTS

The text commentary of both texts was done by 65% of the students. Of those 24.2% did not mention the SDGs or did not reason the connection between the text, the CEC and the SDGs in the commentary of text 1. The percentage was a 37.5% in the commentary of text 2.

In text 1 there are different elements that could be commented by the students: 1) relationship between infertile soil and CEC, 2) relationship between fertilization and CEC, 3) ways to increase CEC in soils, 4) differences in relation to the CEC between fertilizing the soil with inorganic fertilizers and / or organic matter, 5) origin of the environmental damage produced by an increase in nitrogen fertilization, 6) relationship between the aforementioned and the SDGs.

In text 2 there are various elements among others that could be commented by the students: 1) cation and anion adsorption and selectivity, 2) anions and cations mobility in soils (texture), 3) leaching of nitrates in soils, 4) effects of nitrogen fertilizers in soils (e.g. pH), 5) soil CEC's impact on nitrogen management, 6) relationship between the aforementioned and the SDGs.

In the text commentary of text 1, the SDG that students most related to the CEC was SDG 2, followed by SDG 3, SDG 15 and SDG 6 (Figure 3). Regarding to text 2, the SDG that students most related to the CEC was SDG 6, followed by SDG 3 and SDG 15. Others SDGs mentioned by students were SDG 2, SDG 11, SDG 12, SDG 13 and SDG 14 (Figure 4).

Among the arguments given by the students to justify the relationship between the texts and the SDGs, some of the reasons were:

It is estimated that 95% of the food is directly or indirectly produced on soils. In order to nourish the more than 690 million hungry people and the additional 2 billion people the world will have by 2050, there is a need of a change of the global food and agriculture system. Increasing agricultural productivity is crucial to help alleviate the perils of hunger. Students obtained this information from the United Nations website on SDG 2 Zero Hunger.

Fighting hunger requires agricultural land on which productive and sustainable agriculture is practiced.

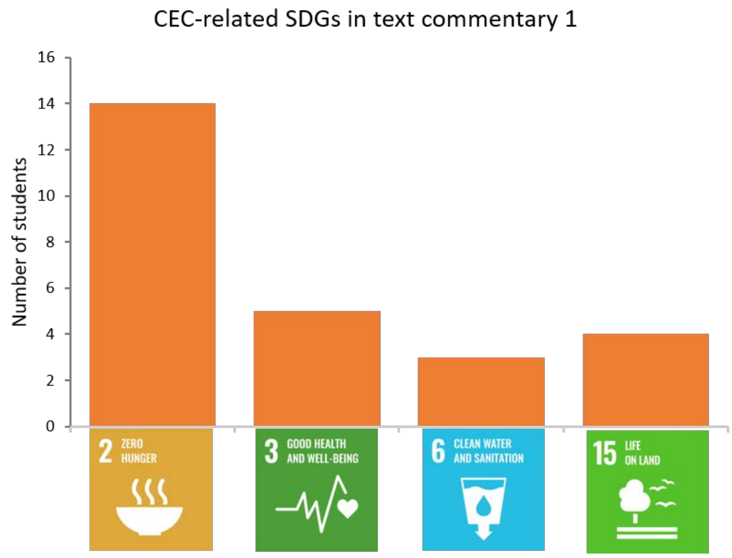

Figure 3. Number of students who related CEC with different SDGs in text commentary 1.

Soils with a greater cation exchange capacity are able to hold onto more nutrients to nourish plants and crops which are a large part of the population's food. If soils do not have a high CEC, their fertility is lower, which causes a decrease in food productivity. An increase in CEC in a certain soil is linked to an increase in its productivity.

Higher-CEC soils have a much lower percentage of cations in the soil water, so experience little cation leaching, therefore, are far less susceptible to nutrient loss.

Also, the students indicate that CEC can be improved by adding organic matter and that humus, the end product of decomposed organic matter, has the highest CEC value. Humus is an important source of nutrients. Humus is one of the cations reservoir of the soil.

Soils with low CEC have limited availability of mineral nutrients to the plant and also, they have low ability to hold applied nutrients from inorganic fertilizers.

One of the students mentions that in the yield gap between countries should be considered the difference between what is produced and what would be produced in a soil under optimal conditions. Several studies suggest that mineral fertilizers are not enough to reduce this yield gap and increase food production if they are not complemented with the contribution of organic matter.

The use of chemical fertilizers helps in overcoming hunger [33]. However, overuse of chemical fertilizers can be harmful and affect both the environment (soil organisms, water, etc.) and humans [34].

Soils with high CEC can retain a larger proportion of dissolved metals and other positively charged contaminants. Nitrates, as they have negative charge, cannot be adsorbed to soil particles and therefore reach groundwater, causing contamination of groundwater. Infants and children can be affected with the risk of the blue baby syndrome (NO_3^- can transform hemoglobin into methemoglobin) when they are feed with drinking water containing high amounts of nitrates [35]. For this reason, it is important to provide inorganic fertilizers properly. Soils with low CEC will require more frequent applications of fertilizer.

Inorganic fertilizers in the short term are very efficient, but in the long term they can compromise the natural balance of ecosystems.

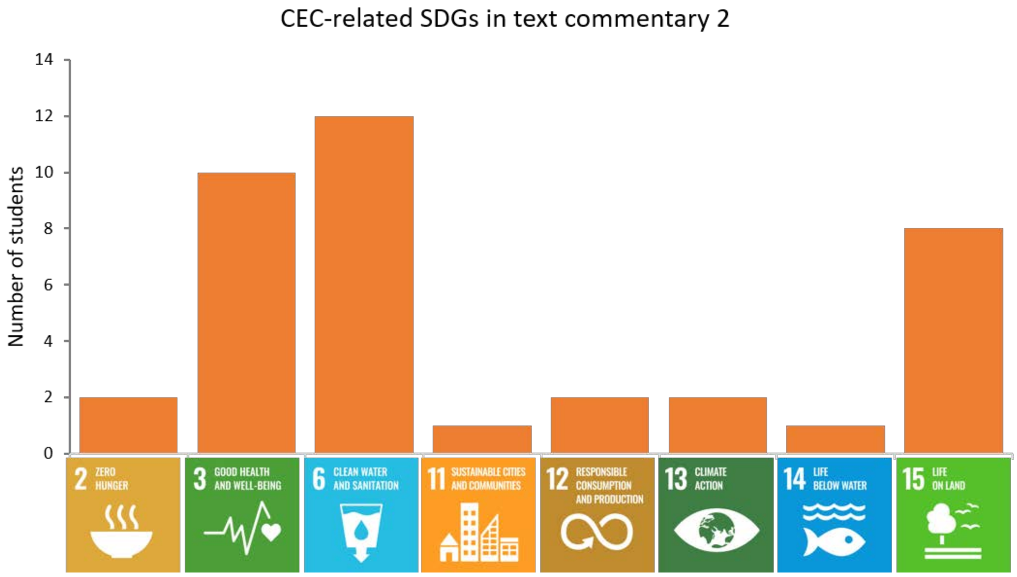

Figure 4. Number of students who related CEC with different SDGs in text commentary 2.

Several students commented on the possibility of incorporating the SDGs into the laboratory practical reports, explaining the relationship between experimental work and the SDGs and how this work can help to achieve the SDGs.

Soil Sciences laboratories at Universities can play an important role in raising awareness among students of the relationship between soil and its degradation with some of the SDGs.

Soils have the ability to store, filter and transform nutrients, substances and water [36]. According to Selim [37] "Knowledge of the transport patterns of chemicals applied to soils is essential for environmental assessment of potential leaching to groundwater supplies". The movement of solutes through the soil has important consequences in the applications of fertilizers, nutrient washing, recovery of saline soils and movement of herbicides through the soil.

Students of the subject SPWT had a laboratory practical entitled "Transport of solute (salt) in soil: miscible displacement experiment". When water containing dissolved salts passes through a volume of soil, the concentration of salts in the drainage water will gradually vary depending on the processes that take place during the passage of water through the soil. The process of replacing the soil solution with another with a different saline composition is an example of miscible displacement.

In the laboratory session, the mobility of sodium chloride applied to soils was investigated by students using batch equilibration technique. At the beginning, soil columns were maintained under soil water-saturated conditions and constant flow velocity. The extent of sodium chloride mobility was measured by quantifying the concentration in the effluent solution versus time. The solute transport parameters calculated by the students included solute dispersion coefficient, flow velocity of NaCl through the soil, partition coefficient, etc.

The students who described the relationship between the concepts learnt in the laboratory session and the SDGs were 67.5%. As can be seen in figure 5, mainly the students related the laboratory practical to SDG 6 and SDG 15. This is in accordance with target 6.3 that includes "By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materia".

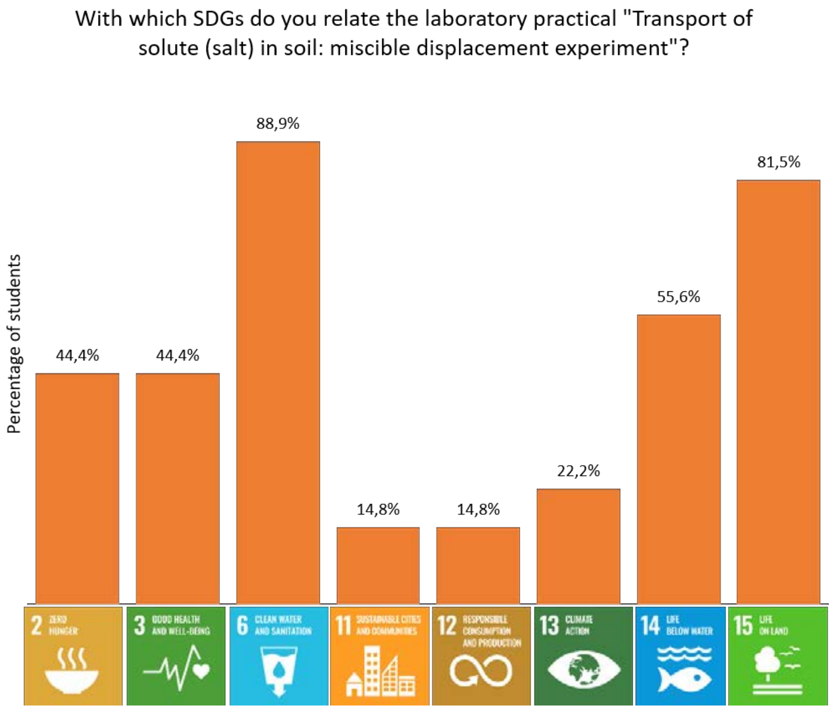

Figure 5. Percentage of students who related laboratory practical with different SDGs.

4 CONCLUSIONS

The proposed activities were motivating and stimulating for the students, given the large number of students who completed them. With these activities, students were able to work different concepts of relevance in soil sciences as CEC, mineral nitrogen in soil, nitrate pollution. However, despite the good correlation of these concepts with the achievement of certain SDGs, a low percentage of the students was able to link those concepts with the corresponding SDGs. This study confirms the low awareness of students with the achievement of sustainable development objectives and highlights the need to include this type of activities from the beginning of studies if the achievement of a complete awareness of the population is desired. Only when students have internalized what the SDGs are, will they be able to propose technical strategies to achieve them.

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