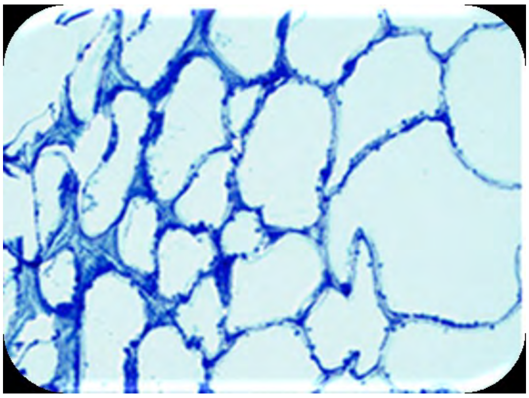
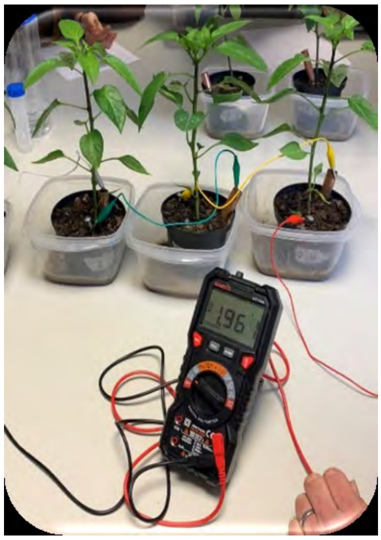
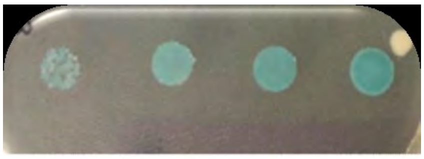
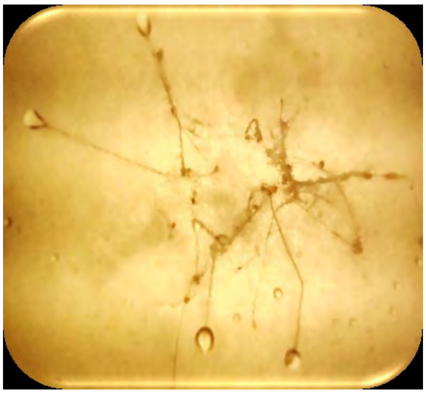
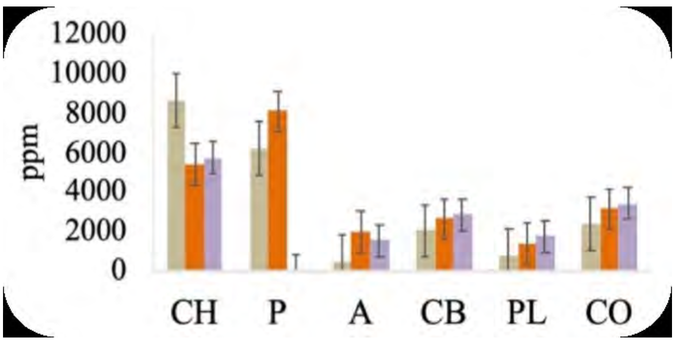
High School Students for Agricultural Science Research

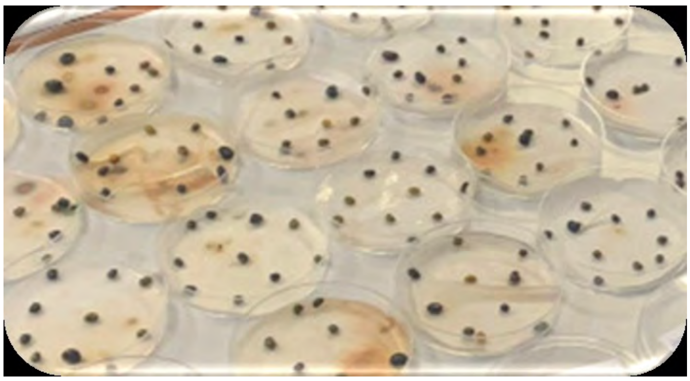
October 2023 **Volume 12**







eez Estación Experimental del Zaidín
CSIC Consejo Superior de Investigaciones Científicas

Index

Can compost improve the bio-photovoltaic energy produced by peppers? Results from the ENERGYCOMPO project

Pedro Pérez[1], Irene Grosso[1], Alejandra Castilla[1], Claudia Valdés[1], Daniel Pérez[1], David Egea[1], Manuel Estévez[1], Gabriel Martín[1], Martina González[1], Maryam Coletti[1], Marta María Torres Garzón[1], Germán Tortosa[2#]

[1]Colegio Internacional de Granada, Urbanización Cañadas de Parque, s/n, 18152, Otura-Dílar, Granada, Spain.

[2]Department of Soil and Plant Microbiology. Estación Experimental del Zaidín. CSIC. Profesor Albareda 1, 18008 Granada, Spain.

#Corresponding author: german.tortosa@eez.csic.es

Summary

Plants can produce electricity during their growth by using bio-photovoltaic energy. Similar to a battery, we can collect electricity by inserting electrodes (a cathode and an anode) into the growing substrates. In this research project, we tested two types of electrodes (Electrodes A, made of copper tube and galvanized screw; Electrodes B, made of copper foil and metallic mesh) and two growing substrates (soil and soil+compost) to optimize the electrical energy production of pepper plants. In our experiment, we measured the electrical voltage and intensity in pots during 42 days of growth, as well as several physiological parameters such as plant height, number of leaves and flowers, and shoot fresh weight. Our results demonstrated that Electrodes B generated more electrical energy than Electrodes A, perhaps due to its higher surface area. Additionally, we found that compost did not affect the electrical voltage and intensity during growth, but it had a beneficial effect on the pepper plants, with more flowers and biomass than plants grown with only soil.

Keywords: Electrical energy, electrical intensity, electrodes, multitester, organic matter, peppers, soil biological activity, voltage.

INTRODUCTION

A healthy and "alive" soil is characterized by high biological activity. This implies the simultaneous occurrence of several physical and chemical changes, such as the assimilation of compounds and materials by the living organisms that inhabit it [1]. Notable contributors to this activity are microorganisms (bacteria, fungi, or actinomycetes), insects, earthworms, or even plants through their roots. This activity can be measured using different techniques, such as soil electrical potential, which shows the electron flow produced by these chemical changes, similar to what happens in an electrochemical battery. This process has been recently described as bio-photovoltaic energy [2].

On the other hand, compost is an excellent material, rich in organic matter, nutrients, and beneficial microorganisms for plants that can enhance plant growth and, by extension, the

biological activity of soils [3]. Therefore, compost is a highly interesting fertilizer that helps plant development and sustainable and environmentally friendly agriculture [4].
In a previous CAOS project, the generation of bio-photovoltaic energy produced by onion plants grown in soils amended with and without compost was studied [5]. Soil electrical potential was measured during 90 days, and an increase in voltage was observed as the plants grew. Although compost improved onion growth, the effect of compost on soil electrical potential could not be discerned, probably due to the inadequacy of the experimental setup derived from the small pots and electrodes used during growing.
With the ENERGYCOMPO project, we aim to improve our previous experimental design in order to further explore how we can harness optimized electrical energy production during plant cultivation by adding compost as organic fertilizer.

MATERIAL AND METHODS

Growing substrates and electrode devices. In this research, two substrates were studied:

- Soil (S). Agricultural soil was collected from La Vega de Granada (Churriana de la Vega, Spain).
- Soil + compost (S+C). A mixture of 1:1 (v/v) of the former soil and compost was prepared. Bio-waste compost was prepared at Estación Experimental del Zaidín (EEZ-CSIC) by using chopped tree pruning, fresh cut grass and food waste [3].

Also, two types of electrodes were installed in the plant pots (Figure 1):

- Electrodes A: Cathodes and anodes consisted of copper tubes (120 mm long and 15 mm of diameter) and galvanized screws (60 mm long), both inserted 40 mm deep into the soil surface.
- Electrodes B: Cathodes consisted of copper foils (20 mm wide and 80 mm length) inserted 40 mm deep into soil surface, and anodes were a metallic mesh of 5 mm sieve placed at the bottom of each pot, just before adding growing substrates.

Plant experiment and treatments. Fifteen days old pepper plants (*Capsicum annuum* L.) were initially transplanted into 0.5 L pots filled with either S or S+C, according to each treatment (Figure 1). Afterward, the plants were grown at the Greenhouse and Growth Chamber Service facilities of the Estación Experimental del Zaidín (EEZ-CSIC) (https://www.eez.csic.es/en/green-houses) for 42 days (from March 7 to April 18, 2023). The plants were watered twice a week (every Tuesday and Friday) with 50 mL of tap water during the first month, and three times a week until the end of the experiment.

A total of 16 pots were assayed in this experiment, according to the following treatments (Figure 2):

- Electrodes A (8 pots): S (4 pots) and S+C (4 pots).
- Electrodes B (8 pots): S (4 pots) and S+C (4 pots).

Figure 1. An overview of the experimental setup: Electrodes A, made of a metal mesh and copper foils (A); Electrodes B, made of galvanized screws and copper tubes (B); pepper plants before transplanting (C) and electrical voltage and intensity measurement with a professional digital multitester by connecting pots as a series circuit (D).

Analysis. Before plant transplanting, bacterial isolation and growth from S, C, and S+C substrates were performed as previously described [3]. Briefly, a substrate water extraction (1:10 w/v, 5 minutes of manual shaking and gravity sedimentation) was used to inoculate Petri dishes filled with bacteria growing media (TSA medium), which were incubated in darkness at 30ºC for 24-48 hours. The number of colonies in each plate was then counted.

During plants growing, specifically at 0, 21, and 42 days after transplanting (DAT), plant height and the number of leaves were recorded. Also, the electric potential difference (or voltage) and electrical intensity (measured as μA) were measured in pot electrodes, both individual and collectively by connecting them as a series circuit. A professional digital multitester provided by EEZ-CSIC Maintenance Service was used, according to D. Pedro Palomares's instructions. The measurement of the potential and intensity was made immediately after watering.

At the end of the experiment, plant height, number of flowers, fruits, and shoots fresh weight (SFW) were measured using an analytical balance.

Figure 2. An overview of the plants, just before harvesting. The treatments were: Peppers grown with soil and electrodes A [S (EA)], peppers grown with soil and compost with electrodes A [S+C (EA)], peppers grown with soil and electrodes B [S (EB)] and peppers grown with soil and compost with electrodes B [S+C (EB)]. Four replicates (or pots) per treatment were assayed.

Results and discussion

The bio-photovoltaic energy of plants can depend, in part, on the biological activity of the rhizosphere [2]. Therefore, we can presume that soil organic matter promotes this biological activity, especially during its mineralization. To verify this, we analyzed the number of cultivable bacteria in the growing substrates. To do this, we performed an aqueous extraction of the substrates (Figure 3a) to inoculate several Petri dishes filled with a specific bacterial culture medium. According to our results, the number of colonies on the Petri plates inoculated with compost extract (C) was significantly higher than those inoculated with soil, with S+C in between (Figure 3b). These data confirmed that compost is a source of microorganisms that can help plants grow, as well as of organic matter and plant nutrients [4].

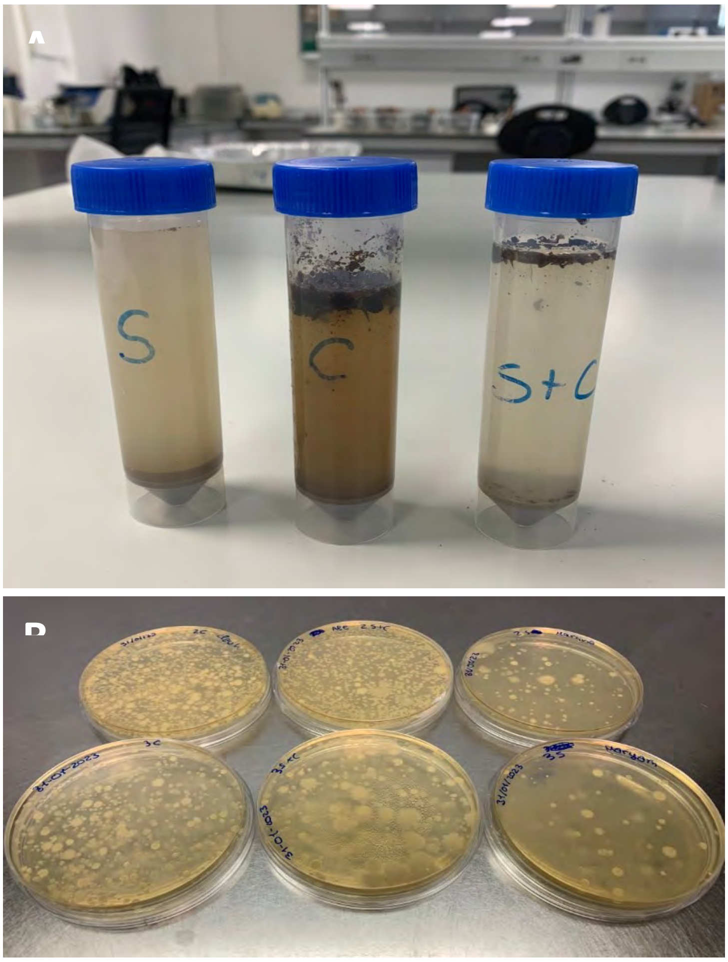


Figure 3. Cultivable bacteria presented in soil (S), compost (C) and soil + compost (S+C) growing substrates. The above picture (A) shows the water extraction used to inoculate the Petri dishes (B) filled with general growing solid media for bacteria (TSA medium). From the left to the right: C, S+C and S water extract.

Another way to estimate the bio-photovoltaic energy of plants is to implant electrodes and measure the electrical potential (or voltage) and current intensity during their growth [2]. Figure 4 shows the evolution of voltage over time in pepper pots. The results showed no differences in voltage between treatments and electrodes at the beginning of the experiment (0 DAT). As the plants grew (after 21 days of DAT), the electrical voltage of electrodes B (close to 3 V) was higher than those obtained with electrodes A, which ranged around 2.5 V. This behavior was also recorded at the end of the experiment, after 42 DAT. However, no effect of compost was observed in plants with electrodes A and B. Regarding electrical intensity (Figure 5), the behavior was difficult to interpret, with an increase in its value as the plants became larger (42 DAT). Despite that, it can be seen that electrical intensity was slightly higher in plants with electrodes B compared to A, but lower in the S+C treatments than S pots.

Although no positive effect of compost on electricity production was observed during this experimentation, its addition to pots promoted plant growth, as can be seen in Figure 6. Plants grown with the S+C treatment, regardless of electrode type, showed a higher number of flowers (6 compared to 3 of the S treatment) than those grown with only soil. The beneficial effect of compost was also noticeable in plant biomass, yielding values of 23.6 and 17.3 g, and 12.6 and 14.2 g in the S+C compared to S treatments for electrodes A and B, respectively.

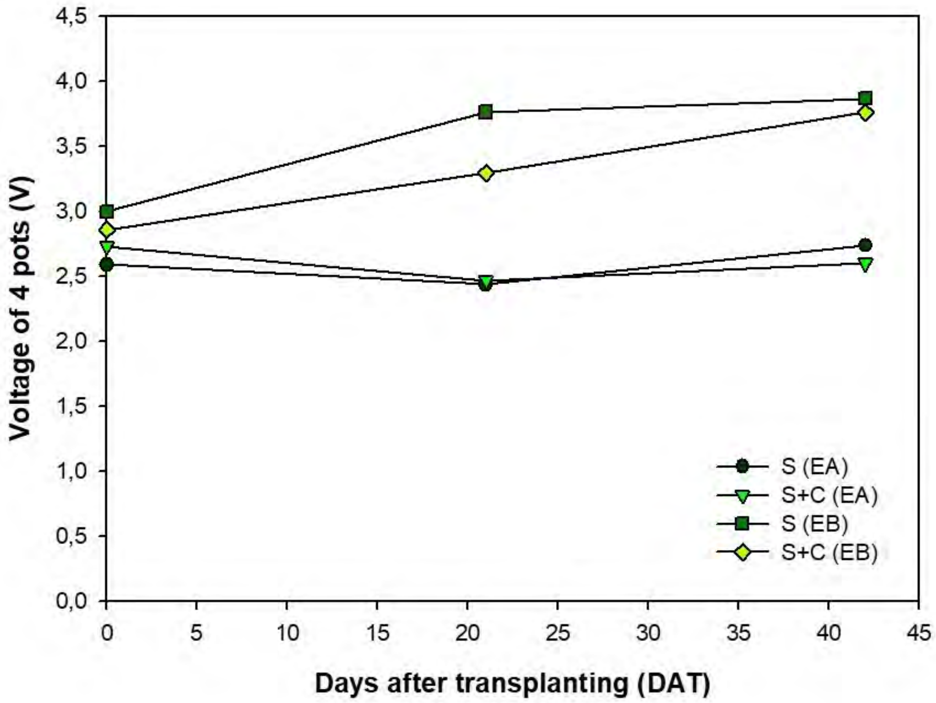


Figure 4. Evolution of electric potential difference (voltage) during the experimentation. Treatments: Peppers grown with soil and electrodes A [S (EA)], peppers grown with soil and compost with electrodes A [S+C (EA)], peppers grown with soil and electrodes B [S (EB)] and peppers grown with soil and compost with electrodes B [S+C (EB)]. Four replicates per treatment were assayed.

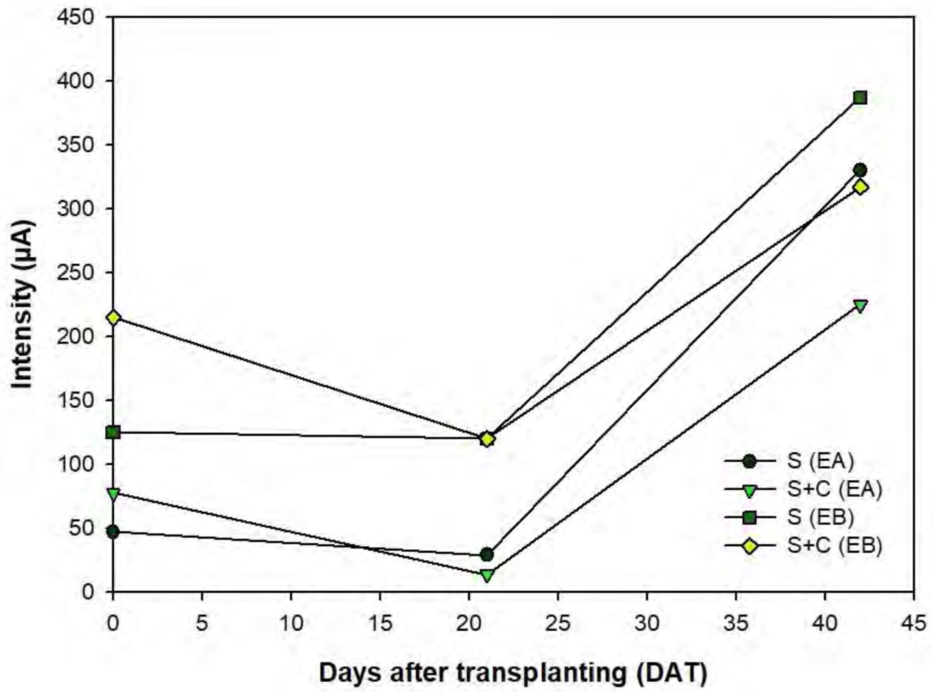


Figure 5. Evolution of electrical intensity during the experimentation. Treatments: Peppers grown with soil and electrodes A [S (EA)], peppers grown with soil and compost with electrodes A [S+C (EA)], peppers grown with soil and electrodes B [S (EB)] and peppers grown with soil and compost with electrodes B [S+C (EB)]. Four replicates per treatment were assayed.

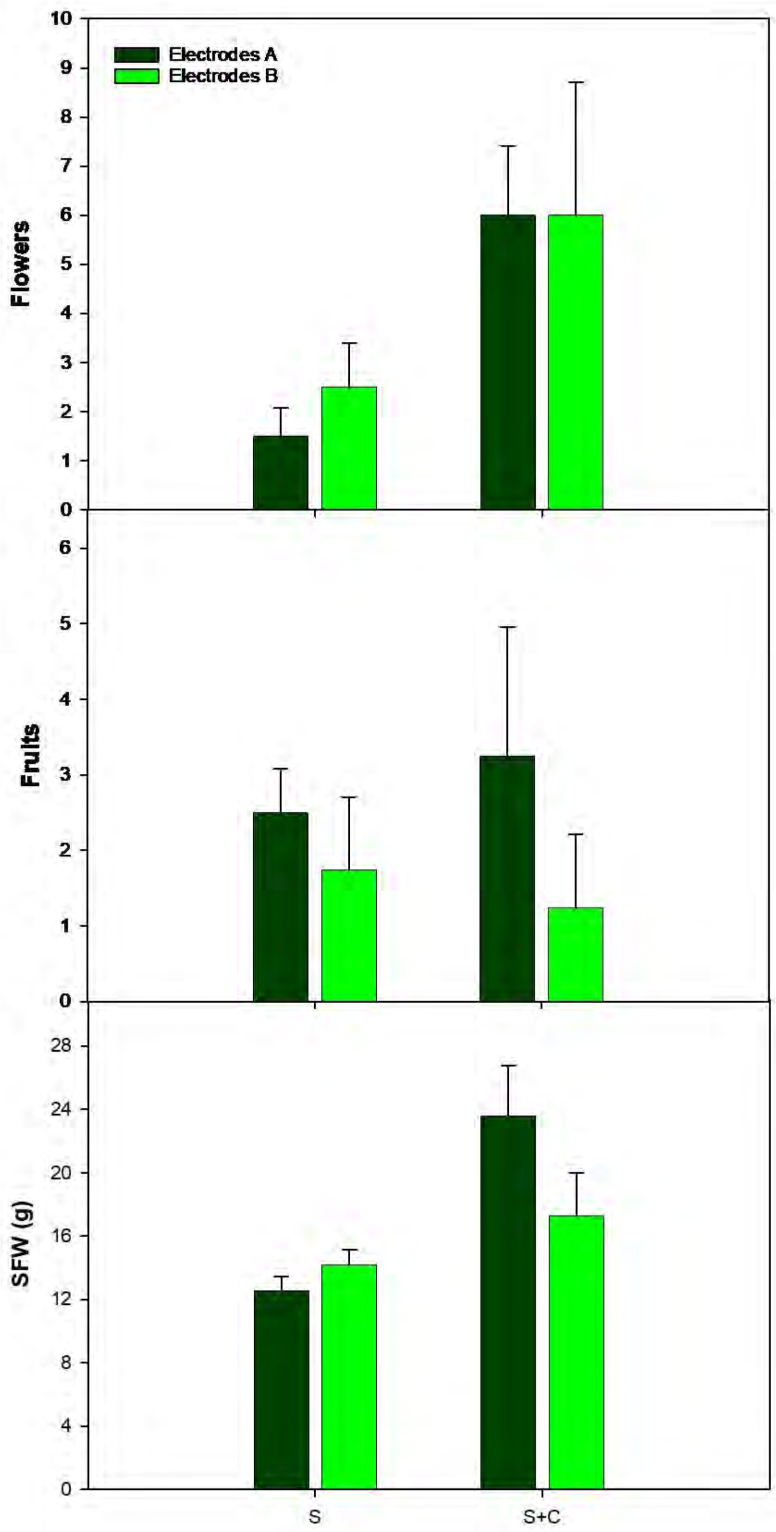


Figure 6. Number of flowers, fruits and shoot fresh weight (SFW) of plants after harvesting. Treatments: Peppers grown with soil and electrodes A [S (EA)], peppers grown with soil and compost with electrodes A [S+C (EA)], peppers grown with soil and electrodes B [S (EB)] and peppers grown with soil and compost with electrodes B [S+C (EB)].

As a conclusion, we have demonstrated that the electrode type had a strong influence on the production of bio-photovoltaic energy produced by plants. In general, electrodes B (copper foil and a metallic mesh) generated higher electrical voltage and intensity than electrodes A (copper tubes and galvanized screws), probably due to their higher surface area. On the other hand, we have concluded that compost can promote peppers growth but did not have any positive effect on energetic electricity generation by pepper plants.

According to our results, we propose the following experimental modifications to test in future research:

- Try different plants to see which one generates more electricity.
- Evaluate the differences between natural and chemical fertilizers.
- Use plants with a larger leaf surface.
- Grow more plants per pot (two or more).
- Add worms to the growing substrate to see if the plant generates more electricity.

Acknowledgements

The authors want to thank D. Pedro Palomares for his expertise with the electrical measurements with the multitester, and also to Dr José Manuel Palma Martínez, for sharing his knowledge with us about peppers plants and growth.

References

[5] Bot A, Benites J. 2005. The importance of soil organic matter. Key to drought-resistant soil and sustained food production. FAO Soils Bulletin, Nº 80, ISBN 92-5-105366-9. Available in: http://www.fao.org/3/a0100e/a0100e.pdf

[6] Salgado Gutiérrez MC, Zepeda Hernández JA, Cid del Prado Martínez M, Luna Villalobos J, Cruz Rodríguez RI. 2019. Celda biofotovoltaica para la generación de energía eléctrica a través de plantas vivas. Academia Journals, 2019. Ebook Online. ISBN: 978 939982 52 0.

[7] Díaz JM, Moro C, Coletti Y, de la Torre A, de la Torre J, Rolland A, Ledesma D, Bedmar EJ, Tortosa G. 2020. Biological insights of Estación Experimental del Zaidín (EEZ) bio-waste composting. High School Students for Agricultural Science Research. Vol. 9, Estación Experimental del Zaidín (EEZ-CSIC), ISSN: 2340-9746. Available in: https://www.ucc.eez.csic.es.

[8] Díaz Arco A, Molina Muñoz M, Navarro García E, Ortega Fernández C, Palma Pérez L, Sarmiento Vega MC, Castellano Hinojosa A, Tortosa Muñoz G, Bedmar EJ. 2016. Biofertilisers with olive-oil taste: isolation of plant growth-promoting rhizobacteria (PGPR) from "alperujo" compost. High School Students for Agricultural Science Research. Vol. 5, Estación Experimental del Zaidín (EEZCSIC), ISSN: 2340-9746. Available in: https://www.ucc.eez.csic.es.

[9] Fernández Cirre LJ, Plaza de Bruijn J, Rodríguez Moreno L, Illescas Vílchez D, Ortega Martín J, Marlon Loza Alcocer F, López Perea M, Morcillo Pérez L, Padilla Méndez E, Tortosa Muñoz G. 2022. Plants can be used as electrical batteries. High School Students for Agricultural Science Research. Vol. 11, Estación Experimental del Zaidín (EEZ-CSIC), ISSN: 2340-9746. Available in: https://www.ucc.eez.csic.es.

MY OWN IDEAS

Irene Grosso.

Sometimes, there are unexpected situations that turn into unforgettable experiences. I believe this is one of the best examples of such cases. Participating in a semi-professional experiment, working side by side with high-level researchers, has undoubtedly been a valuable opportunity to first-hand experience the life of a high-standing scientist. What can begin as a dull classroom task can turn into an exciting adventure filled with memorable moments and fun situations. I will be eternally grateful to my Physics teacher for offering me the chance to be part of such a human and innovative project. It is fascinating to observe how a group of people from different backgrounds and ideologies can come together in the name of Science with the goal of creating a better world. From adults to children in early childhood, this CAOS congress has managed to attract students and researchers from all over Andalusia, full of creativity and enthusiasm. The project itself has consisted of constant and entertaining work that has extended over several months. Thanks to the regular visits to the Zaidín research center (EEZ-CSIC), to which we are deeply grateful for their collaboration, we have managed to create research full of life and passion, dedicated to all scientists in search of a more innovative, equal, and sustainable society. Despite the failed attempts and the accompanying despair, we have managed to focus our efforts and energies on solving the various problems and achieving a satisfactory result. Of course, we could not have completed this project without the constant help and reassuring presence of our mentors, Marta María Torres and Germán Tortosa, who have worked as hard and sacrificially as the students themselves. They have been the soul and the engine of the project, encouraging us to move forward when research seemed to have no way out. In conclusion, I can only say with affection how beautiful the experience has been to see a group of young science enthusiasts fighting for their ideas and presenting their projects. Thanks to these new generations of scientists and researchers, we have a hopeful and innovative future in sight

Gabriel Martín.

I've been watching for years how other classes have participated in projects related to EnergyCompo with Germán Tortosa, and the truth is that finally being able to personally participate in a compost project has given me a clear insight into how these types of projects and scientific work are carried out. We started by getting to know Germán, who began explaining the project to us and how we were going to work on it. There were quite a few days when we went to the EEZ-CSIC and measured the plants, noting their growth and development. Finally, we attended a congress in which several schools from all over Granada and even Andalusia told us about their own projects and research. The congress was very long but entertaining. This experience has been as enriching as fun, and I believe it has sparked a lot of curiosity and interest in science within the group. It has also taught us how to conduct experiments and then share our results and feelings about them. Honestly, I recommend this experience to everyone because they will have a great time and learn many things.

Claudia Valdés.

When our Physics teacher introduced the CAOS project to us, we began with a lot of excitement and met Germán Tortosa, who helped us carry it out. I found it very interesting to make hypotheses when we all shared what we expected from it. Additionally, we made many trips to the EEZ-CSIC where we learned about laboratory work. We used materials we had not seen before, and Germán patiently taught us how to use them. This project offers many benefits for students, such as the opportunity to work in a laboratory with more equipment than what is available in schools. For example, we got to meet people working in the scientific field and ask them about their daily routines. Teamwork was excellent as we assigned tasks and explained them to each other. It was a great experience for our future because we worked and disseminated knowledge, applying both the scientific knowledge we had and the new knowledge we acquired. We also prepared a presentation to explain the results we had obtained, created graphs, and did everything involved in preparing for the congress where, after 6 months, we presented in front of a large audience. It made me realize that science requires a lot of effort to discover anything, no matter how small, and that everything needs to be verified multiple times. Furthermore, it takes a lot of work to publish a scientific article. I consider the project has been a great learning experience for me and has sparked even more curiosity about science in me. It was very rewarding to participate and step onto a stage to explain everything we did, and I would undoubtedly participate again if given the opportunity.

Daniel Pérez.

The EnergyCompo project, developed in collaboration with Germán Tortosa, has been a truly rewarding experience. Throughout the entire process, we dedicated tireless effort to create a unique solution that effectively addresses challenges in the field of energy. From the beginning, I was impressed by Germán´s passion and dedication to this project. His deep knowledge in the field of energy and his ability to think so creatively were crucial to the success we achieved. Germán demonstrated an exceptional level of commitment, always willing to explore new ideas and approaches to find effective solutions. One of the most notable aspects of the project was that it is entirely sustainable and environmentally friendly. That is, it not only focuses on energy efficiency but also seeks to harness renewable sources to minimize environmental impact. I really liked this aspect. Throughout the project's development, I could appreciate Germán´s attention to detail in every aspect of the design. He helped us solve any problems that arose, although in my opinion, these issues should have been anticipated earlier. I believe our ability to work as a team, listen to and value each other´s ideas, was key to the project´s success. Germán was always open to debate and analyze different perspectives, which allowed for a more comprehensive and robust approach to project development. In conclusion, I liked this project very much. It made us work as a team and trust each other. It has been a very rewarding experience. I liked the idea from the beginning, and I am convinced that it will leave a mark on the world in the future.

Claudia Acosta.

During the last months we have been carrying out a project where we could transform the energy of active soil into electricity. I liked the fact that from the beginning the necessary resources were always available, making it easy for us to start working at the same time that we were learning how to use each instrument. Furthermore, the days when we went to the Estación Experimental del Zaidín to carry out our experiment we were all involved in the work, and we were the ones that we experimented and investigated with the help of Germán Tortosa. This is a strong point of the project, since it gives us an experience that we cannot acquire at school. Thanks to this experimental project our ability to organize a project has improved, as well as our teamwork skills. Thanks to this project we have been able get a little closer to what could await us in the future, which is very important. On the other hand, to improve the project, I think it would be very useful to have a deeper explanation about what the project was going to be about, and stablish the steps before going to the laboratory.