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Sensing technologies to measure metabolic activities in soil and assess its health conditions

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Soil is a complex ecosystem comprised of several and mutually interacting components, both abiotic (organo-mineral associations) and biotic (microbial and pedofaunal populations and plants), where a single parameter depends on other factors and affects the same and other factors, so that a network of influences among organisms coexists with the reciprocal actions between organisms and their environment. Therefore, it is difficult to undoubtedly determine what is the cause and what the effect within relationships between factors and processes. Soil is commonly studied through the evaluation and measurement of single parameters (e.g. the content of soil organic matter (SOM), microbial biomass, enzyme activities, pH, etc.), events (e.g. soil erosion, compaction, etc.) and processes (e.g. soil respiration, carbon fluxes, nitrification/denitrification, etc.), often carried out in laboratory conditions in order to limit the number of factors acting within the ecosystem under study, but missing the information about the global soil environment that way. In the last decade, several scientists have proposed and suggested the need for a holistic approach to soil ecosystems in different contexts. Recently, we have applied a sensing system developed in the last decades and capable of analysing complex mixtures of gases and volatiles (odours or aromas) in atmospheres, namely called electronic nose (EN). Typically, ENs are devices consisting of an array of differentially and partially specific, despite selective, sensors upon diverse coatings of sensitive films, i.e. interacting with single analytes of the same chemical class, despite not highly specific for a single substance, only, but showing also lower extent of cross-selectivity towards compounds of other chemical classes. ENs can be used in the classifications of odours by processing the collected responses of all sensors in the array through pattern recognition analyses, in order to obtain a chemical fingerprint (olfactory fingerprint) typical of the analysed air sample. Due to these features, we decided to apply such a sensing technology to the analyses of soil atmospheres, because several processes in soil, both abiotic and biotic, result in gas and/or volatile production and the dynamics of such releases may also be affected by several additional environmental factors, such as soil moisture, temperature, gas exchange rates with outer atmosphere, adsorption/desorption processes, etc. Then, the analysis of soil atmosphere may provide information about global soil conditions (e.g. soil quality and health), according to a holistic approach, where several factors are contemporarily taken into account. At the same time, the use of such a technology, if adequately trained on purpose, can supply information about a single or a pool of processes sharing similar features, which occur in soil over a certain period of time and mostly affecting soil atmosphere. According to these premises and hypotheses, we demonstrated that EN is an useful technology to measure soil microbial activity, through its correlation to specific metabolic activities occurring in soil (i.e. global and specific respiration and some enzyme activities), but also soil microbial biomass. On the basis of such evidences, we also were able to use this technology to assess the quality and health conditions of soil ecosystems in terms of metabolic indices previously identified, according to some metabolic parameters and biomass quantification of microbial populations. In other studies, we also applied EN technology, despite using a different set of sensors in the array, to analyse the atmosphere of soil ecosystems in order to assess their environmental conditions after contamination with polycyclic aromatic hydrocarbons (PAHs) (i.e. semivolatile - SVOCs - organic pollutants). In this case, EN technology resulted capable of distinguishing between contaminated and uncontaminated soils, according to the differences in a list of substances, occurring in the atmospheres of differently treated soils, which were identified through SPME-GC/MS analyses and then suggested to be responsible for the different classification. Analysing the EN responses, it was also possible to follow the degradation process of pollutants by resident microbial populations over time, on the basis of the contemporary decrease of contaminant and the increased release of CO_2. Then, we suggest that EN technology may be usefully employed in the analyses of soil ecosystems in order to both supply information about global soil environment, according to the holistic approach, and about specific processes occurring therein. Furthermore, since EN technology resulted to be effective and successful in detecting processes in soil, in both natural and perturbed conditions, involving microbial populations, which are commonly considered as the most sensitive and responsive to soil en-

vironmental modifications, we suggest it might be reasonably employed in analyses concerning the assessment of soil quality and health. Consequently, such a technology may also be used to study several processes involving soil ecosystems, such as soil management practices, soil restoration, soil contamination and remediation, soil fertility, etc.