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# Harnessing Soil Cyanobacteria for Resilient Agriculture: Evidence from a 20-Year Mediterranean Orchard Trial

**Adriano Sofo[1*], Rosangela Addesso[1], Francesco Maria Calabrese[2], Carmine Crecchio[2], Luigi Lucini[3], Mohammad Yaghoubi Kanghahi[1,2]**

*[1] Department of Agricultural, Forestry, Food and Environmental Sciences (DAFE), University of Basilicata, Potenza, Italy*

*[2] Department of Soil, Plant and Food Sciences, University of Bari "Aldo Moro", Bari, Italy*

*[3]Department for Sustainable Food Process, Catholic "Sacro Cuore" University, Piacenza, Italy*

*adriano.sofo@unibas.it

**ABSTRACT**

Soil cyanobacteria are increasingly recognized as key drivers of sustainable agriculture thanks to their wide range of ecological functions. These ancient, photosynthetic microorganisms participate actively in biogeochemical cycling, enrich the topsoils with organic matter, and supply essential nutrients that support plant development. By producing extracellular polymers and diverse bioactive metabolites, they help create stable microhabitats, improve soil structure, and foster synergistic interactions with both the rhizosphere and other beneficial soil microbes. Their presence is therefore tightly linked to soil resilience, fertility, and long-term ecosystem functioning.

This study investigated the taxonomic composition and functional potential of soil cyanobacterial communities in a Mediterranean olive (*Olea europaea* L.) orchard in a semiarid, hilly area of Ferrandina (Basilicata Region, southern Italy). The orchard has been managed for over twenty years under two contrasting systems: sustainable ($S_{mng}$) and conventional ($C_{mng}$), which differed markedly in soil tillage and cover, crop residues management, fertilization and irrigation. Cyanobacteria were sampled across several representative topsoil locations (0-5 cm depth) within the orchard, and then cultured and isolated on selective nitrogen-enriched media and, to promote the growth of diazotrophic strains, on nitrogen-free media.

Sustainably managed soils hosted significantly higher cyanobacterial populations ($0.408 \times 10^2$ g$^{-1}$ soil in $S_{mng}$ vs. $0.240 \times 10^2$ g$^{-1}$ in $C_{mng}$), as counted by the densitometric and MPN methods. Light microscopy and 16S rRNA metagenomic analyses revealed clear compositional differences between systems. In the $S_{mng}$ plots, genera such as *Anabaena* and *Nostoc*, known for their nitrogen-fixing ability and ecological versatility, were more abundant and contributed substantially to community structure. Management also affected cyanobacterial metabolic profiles: cyanobacteria from the $S_{mng}$ soils showed an upregulation of the biosynthetic pathways associated with secondary metabolites, including alkaloids, phenylpropanoids, phytohormones, phytoalexins, polyketides, and terpenes, which are widely recognized for their roles in plant growth promotion and defense activation.

Overall, the findings demonstrate that sustainable soil management enhances both the diversity and functional capacity of soil cyanobacteria. These microorganisms emerge not only as crucial contributors to ecological processes and biodiversity maintenance but also as promising natural allies for improving soil health and crop productivity, two fundamental ecosystem services that were markedly higher in the $S_{mng}$ system compared with the $C_{mng}$ one.

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