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Ecological impacts of farming practices on soil quality in a Mediterranean agroecosystem

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ABSTRACT

Sustainable agriculture hinges on plant–soil–microbe cross-talk that drives nutrient cycling, stress resilience, and biodiversity. Microbe-rich root zones, the rhizosphere and rhizosheath, are dynamic hotspots that sustain nutrient turnover and plant growth.

In a two-year field study in Caselle in Pittari (Salerno, Italy), we tested how management shapes soil biological (enzymatic activities, 16S rRNA profiles) and physico-chemical properties. We ran two trials: (1) wheat under organic amendment (SUST) versus mineral fertilization (CONV); and (2) pollinator-friendly mixes (Eco-plus, Rustico) aligned with EU CAP eco-schemes. In both trials, an unmanaged control (CTRL) with spontaneous vegetation was included. Samples were collected from bulk soil, rhizosphere (rp), and rhizosheath (rs) at pre-sowing and flowering.

An initial overall survey showed that time was the dominant driver: all enzymes peaked at flowering, indicating stronger microbial stimulation during active growth. Space also mattered: rp and rs diverged from bulk soil, reflecting strong root filtering. In trial 1, PERMANOVA detected no significant differences among CONV, SUST, and CTRL, yet NMDS revealed clear early spatio-temporal structuring. Dehydrogenase activity (DHA) was higher in rp than in bulk soil ($p < 0.05$), marking intensified plant–microbe metabolism. SUST increased labile C in bulk soil, and shifts in micronutrients paralleled changes in microbial communities. Diversity, enzyme rates, and organic matter covaried positively, but plant stage explained most separation, with biodiversity highest at flowering. In trial 2, PERMANOVA detected significant effects of plant mixes ($p < 0.05$). Rustico showed markedly higher DHA and urease than Eco-plus (both $p < 0.001$), demonstrating that plant traits strongly shape microbial responses. Sites with high enzymatic activity often exhibited lower microbial diversity, suggesting that functionality was concentrated in dominant taxa—efficiency over richness.

Overall, time is the primary driver of soil microbial activity, with functional peaks tracking crop stages and shaping soil performance. The Rustico mix stands out by boosting above-ground biodiversity while amplifying below-ground microbial processes. Thus, soil-health assessment should look beyond management labels and explicitly integrate temporal variability and distinct root-associated microenvironments. Practically, deploying diverse plant mixes, reducing mineral inputs, and continuously monitoring spatio-temporal patterns are key to safeguarding soil ecosystem services.

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