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Cold Atmospheric Plasma Enriches Beneficial Soil Microbes and Enhances Microbial Resilience

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Cold atmospheric plasma (CAP) is recognized as a promising agricultural tool for modulating soil microbial communities, but most studies have focused on short-term or indirect exposures. The long-term effects of direct plasma irradiation under different treatment durations remain unclear. We investigated the impact of CAP on soil microbial communities and physicochemical properties. Soil samples were exposed to dielectric barrier discharge plasma for 30 or 60 minutes weekly for six weeks. Bacterial and fungal communities were profiled using 16S rRNA (V3–V4) and ITS2 sequencing with QIIME2, and soil parameters including nitrate and related nutrients were measured. CAP induced marked shifts in microbial structure. UniFrac PCoA showed clear separation between control and treated soils, while PCA indicated that total organic carbon, nitrogen, phosphorus, ammonium, and nitrate influenced community variation. Taxonomic profiling revealed enrichment of Firmicutes and *Actinomycetota* among bacteria and *Mucoromycota*, *Pygmaeomyces*, *Pseudogymnoascus*, and *Umbelopsis* among fungi. These groups are associated with stress tolerance, organic matter decomposition, and plant–microbe interactions, suggesting functional resilience after CAP exposure. Differential abundance analysis further showed consistent enrichment of plant growth–promoting taxa including *Dyella humi*, *Burkholderia pseudomultivorans*, *Trichoderma gamsii*, and *Pygmaeomyces thomasi*. Long-term CAP significantly restructured soil microbial communities, enriching taxa linked to stress tolerance, nutrient cycling, and plant growth. The selective increase of PGPB and beneficial fungi highlights the potential of CAP to enhance soil resilience and support sustainable agriculture.