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SEM-image comparison of microaggregates with different stabilities in ski piste soils

M. Sánchez-Marañón (1), J.M. Martín-García (2), V. Aranda-Sanjuán (2), J.L.Rosúa-Campos (3) and R. Delgado (1)

(1) Departamento de Edafología y Química Agrícola, Universidad de Granada, (2) Departamento de Geología, Universidad de Jaén, (3) Departamento de Botánica, Universidad de Granada, Spain.

The preparation of ski pistes is an anthropic activity which causes significant ecological damage requiring restoration. The pistes are normally replanted in order to reestablish plant cover and soil. The presence of stable aggregates at the soil surface is important since it affects infiltration, hydraulic conductivity, water-retention capacity, tilth, gas exchange, organic matter decomposition and erodibility. We have quantified the structural stability of aggregates of less than 2 mm in natural soils and in ski piste soils replanted by grass seeding 12 years ago, and have used scanning electron microscopy (SEM) to study the soil microstructure in order to further our understanding of the differences in stability.

The soil samples studied were collected from the top 30 cm of two native soils and three replanted ski piste soils in the Sierra Nevada ski station (Southern Spain). The soils are derived from periglacial colluviae of micaschists and quartzites on steep slopes at an altitude ranging from 2200 to 2662 m. The climate is cold temperate Mediterranean. The soils below native vegetation of *Genista*, *Juniperus* and *Festuca* are Humic Regosol and Dystric Regosol. The remaining three soils (Anthropic Regosols) have been replanted with native seeds of *Festuca indigesta*, *Agrostis nevadensis and Festuca clementei*.

The air-dried soil samples were gently passed through a 2mm sieve without breaking them up. The percentage of water-stable aggregates (WSA) between 0.25 and 2 mm was determined by a standard wet sieving method. Some of each dry sample was fixed to a sample holder, metallized with gold and observed with a Hitachi S-510 scanning electron microscope (SEM) with an acceleration voltage of 25 kV. We also determined particle-size distribution, total organic carbon, humic acids, free iron forms, Munsell

and CIELAB colour, XRD-mineralogy and soil respiration.

The SEM images of all the samples revealed a granular structure, mainly composed of individual particles of sand and coarse silt and some aggregates with a mean size of 500 um and a skeletal interior fabric. The total aggregates content measured from wet sieving ranged from 25 to 50 % by weight. The percentage of WSA in the soil fraction $<$2 mm was greater than 15 % in the natural soils and around 10 % in the replanted ski piste soils.

An aggregation mechanism recognisable with SEM in all the soils was the packing of the coarser particles (fine sand and coarse silt). Their granulometry and mineralogy influenced the packing type and shape of the microaggregates. We have described three packing types: (i) equidimensional grains of tectosilicates which act as a base for finer grains; (ii) laminar grains of phyllosilicates forming a sandwich which holds the finest particles of the interior; and, (iii) laminar grains of phyllosilicates stacked face-face and covering all the aggregate. Aggregate shape resulted pseudo-polyhedral in the first two types and pseudo-spherical in the third type. Aggregate stability was more closely related to cementing, which is revealed by SEM as a second important aggregation mechanism, specially, in natural soils. Soil cements act as bridges between the coarser particles, either directly or through clusters of clay or fine silt. These cements probably result from microbial activity, which transforms the organic material or produces carbon forms for a rapid stabilization of microaggregates. Natural soils had a higher humic acid concentration (48 g C / 100 g C) and a higher level of respiration (0.22 mg g^{-1} d^{-1} CO_2 released) than the replanted soils (20 g C / 100 g C, 0.11 mg g^{-1} d^{-1}). The soils with the greatest quantity of stable aggregates were also darker (lower CIELAB L* and Munsell value), emphasizing the role of the organic cements. Finally, the role of the fine roots and fungal hyphae in holding the mineral particles together was only important in the Humic Regosol.

We conclude that SEM observations reveal that the shape of the microaggregates depends on the granulometry and mineralogy of the coarser grains, while their stability is determined by the degree of cementing. Replanting the ski pistes has contributed organic material to the soil but has not achieved the cementing of the microaggregates, probably due to a sparse microbial population.

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