Environmental Control of Soil Structure in Mediterranean Soils

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INTRODUCTION

The Mediterranean environment offers a unique area for studying the relationship between soil structure and environmental factors. For example the consistently weak structure of many agricultural soils in the arid and semi-arid Mediterranean regions is caused by their low organic matter OM contents, which result from intensive mechanized cultivation, which is common in this region.

In this paper we will evaluate the role of the constituents of soil environment on the structural status of Mediterranean soils. With the exception of one study where the water-drop technique was used the wet-sieving aggregate stability index was used to assess aggregate stability.

Assessment of Soil Structural Stability

In the Mediterranean area of Italy were almost all these studies were done. The water stability index is used to assess aggregate stability. It is defined as WSI = 100(1-A/B) where A is the percentage of aggregates which passed through a 0.2mm sieve in 5 min. after shaking at the rate of 60 rotations per minute at room temperature and B the percentage of aggregates that passed after 60 min. We correlated WSI with other more common indices of stability and discovered that MWD, ASC%, S%, WSA > 2.0 mm and WSA < 0.25 mm gave highly significant (P = 0.001) correlations with WSI. Hence any of these indices could be used to assess soil structural stability.

ENVIRONMENTAL CONTROLS OF SOIL STRUCTURE

Freezing and Thawing Cycles

Effects of eleven cycles of freezing and thawing on stability of three soils from Modera, Vicarello and Cremona in central and northern Italy varied in the order Modena (2.05) > Vicarello (0.82) > Cremona (0.58). When these soils were subjected to five matric potentials before exposure to three cycles of freezing and thawing was found that saturation aggregate stability was reduced by 61.1% in Modena, 47.5% in Vicarello and 15.6% in Cremona and that the MWD and detected differences D (Jg⁻¹) in stability due to antecedent matric potential were more than the CDI index.

On another three soils, sandy loam Lamporecchio, sandy clay loam Cremona and clay loam Vicarello subjected to three cycles of freezing and thawing after treatment with organic manure, aggregate stability at the 54 t/ha rate decreased by 10%, 17.4% and 34.6%, respectively. The role of OM in influencing aggregate stability was soil-specific with OM accounting for 97% variation in aggregate stability in Lamporecchio soil, 84% in Cremona and 64% in Vicarello.
Wetting and Drying Cycles

After fifteen cycles of wetting and drying percent disaggregation was 93.3% in Lamporecchio, 78.2% in Cremona and 62.3% in Vicarello. In another three soils located along a climosequence that runs from south to north in Italy, aggregate stability of the Acireale (Sicily) soil varied from 1.271 (control) to 0.962 at 9 WD cycles. On Bovolone (Venetia) soil the variation was 0.301 (control) to 0.158 at 9 WD cycles whereas on Principina (Tuscany) soil the variation was 0.459 (control) to 0.245 at the 9th WD cycle. Application of 100-200 kg/ha humic substances on each of these soils increased aggregate stability and reduced the disaggregating effect of WD cycles on soil structure. On the most stable Acireale soil the effect of exposure to WD cycles on structural stability was most severe at the 3rd cycle beyond which reggregation and regaining of stability occurred as successive WD cycles increased. On the Principina and Bovolone soils successive WD cycles consistently reduced aggregate stability. This response appears to be related to the initial size of aggregates and the dominant type and amount of clay present since the dominant clay minerals are kaolinite in Acireale, illite in Principina and smectite in Bovolone.

Role of Organic Materials

Organic substances appear the most useful in assessing the structural stability of Mediterranean soils because they influence stability more than the other stabilizing agents. Generally the best stable soils benefit most from application of organic wastes whereas the most stable soils benefit least. In the Lamporecchio soil, aggregate stability increase linearly up to 10% manure rate, at Cremona maximum aggregate stability occurred at the 6% rate whereas in Vicarello aggregate stability decrease with increasing manure rates. This may be related to the texture of the soils, which were sandy loam, sandy clay loam and clay, respectively.

Exogeneous humic substances were used to improve soil physical properties especially those related to increased structural stability. Substantial improvements in these properties were obtained at relatively low rates of HA (100 to 200 kg/ha) where they reduced soil erosion by up to 40%. The HA improved aggregate stability by 55.2% in Acireale soil, 26.6% in Principina soil and 41.2% in Bovolone soil at 200 kg/ha rate.

The acting mechanisms by which the exogenous HA (or organic materials) improved soil structural properties can be attributed to both the high content of hydrophilic and hydrophobic components of HA. While the hydrophility of the humic material helps to store soil moisture, complexation of the polyvalent cations in the clay surfaces with the HA-oxygen-containing groups orients the hydrophobic components around the soil aggregate. Such hydrophobic coating reduces soil slaking in water, thereby maintaining aggregate stability and preventing soil loss by run-off erosion.

In micro aggregates of soils amended with organic wastes, it was found that humic substances are the main binding agents. The lower the soil aggregate size, the
larger the contribution of the high molecular weight fraction of humic substances, showing that a close relationship exists between aggregate stability and high molecular weight humic substances especially in the Modena, Lamporecchio and Coremona soils studied.

The interaction of humic substances and surface active agents (surfactants) on aggregate stability of sandy loam Lamprocchio and clay Modena soils revealed that on both soils, the percent water stable aggregates increased with increasing rates of HA and NS, whereas aggregate stability was reduced progressively with increasing rates of AS.

When natural aggregates of soils from Lamprocchio, Cremona and Vicarello were amended with glucose and peptone and incubated under non-sterile conditions it was observed that high rates of peptone (P) and glucose (G) enhanced structural stability on the Lamporecchio and Vicarello soils under anaerobic conditions whereas this was obtained in the Cremona soil under aerobic conditions.

On a soil where organic matter was removed (A) or retained (B) the addition of a hydrophilic polysaccharide gum (G) and a hydrophobic stearic acid (S) with or without pretreatment with hydrophobic humic acid (HA) on aggregate stability was studied. G increased aggregate stability by 750% in soil A and 335% in soil B relative to the control. S increased aggregate stability on soil A by 100% and on soil B by 131% whereas HA increased aggregate stability by 73% on soil B and 27% on soil A. The addition of HA before G reduced aggregate stability on both soils whereas the reverse occurred when HA was added before S thereby showing that aggregate stability of soil was maintained with time more by hydrophobic than hydrophilic components of organic matter.

Other Aggregate Stabilizing Substances

It was been observed that some Terra Rosa soils from southern Italy silica may contribute to aggregation by forming bridges between Fe oxides and other soil properties. The ratio of total sand to clay is the physical property that explained most of the variation in MWD of water-stable aggregates. The oxides of Fe and CaCO$_3$ and SiO$_2$ are the chemical properties most related to aggregate stability whereas feldspar, chlorite and muscovite are the minerals with the most controlling influence on aggregate stability of fifteen soils from Italy. The models are:

(a) $\text{MWD} = 0.99 - 0.64 \ (\text{TS/CL})$ which explained 41% of variation in MWD

(b) $\text{MWD} = 1.33 \ (\text{FeO}) - 3.01(\text{TiO}_2) - 1.97$ which explained 76% of variation in MWD, and

(c) $\text{MWD} = 0.026 \ (\text{Chlorite}) - 0.085 \ (\text{Muscovite}) - 0.076 \ (\text{Feldspar}) + 7.93$ which explained 64% of variation in MWD.

However, other studies revealed that it is mainly the mineralogical properties of these soils that control the micro stability of aggregates of these soils. Also, the sand/clay ratio best explained the specific dispersion energy of aggregates of these soils with the relationship
\[ D = 4.07 \exp(-0.079S/C) \]
which explained 86% of variation in D. Since D is difficult to obtain, the percent water-stable aggregate > 2.0mm can be used in place of D (Jg⁻¹).
The best-fit model, which related D to chemical properties, is
\[ D = 161(\text{FeO}) + 0.13(\text{MgO}) - 2.07 \]
and explained 75% of variation in D.
The best-fit model relating D to mineralogical properties is
\[ D = 0.025(\text{Chlorite}) - 0.016(\text{Muscovite}) - 5.84 \]
and explained 53% of variation in D.
The best-fit model relating D to physical properties is
\[ \ln D = 1.303 - 0.797(SC) - 0.0012(SC)^2 \]
where SC is sand/clay ratio. It explained 90% of variation in D.
The best-fit model relating D to structural properties is
\[ D = 0.0085 + 0.12(\text{WSA} > 2.0\text{mm}) \]
and it explained also 90% of variation in D. But because this model has a SE smaller than that with SC ratio it predicted D in ten independent soils better than the SC-based model.

A study to evaluate the relationship of six structural indices at three micro and three macro levels with aggregate stability of 15 natural aggregates showed that the percent water-stable aggregates < 0.25mm index reflected differences in OC levels more than ASC or AC indices. Similarly, the S5 index reflected OC levels more than WSI and MWD indices. Differences in PI and (sand + silt)/clay ratios of these soils were most clearly reflected by the AC index suggesting that these soil physical parameters are closely related to structural stability at the micro level.

**Effects of Land Use on the Properties of Structural Aggregates**

Measuring aggregate stability by five different methods each on three agricultural soils in Vicarello, Fagna and Gambassi (in north central Italy) which have been subjected to no tillage, conventional tillage and minimum tillage practices, it was shown that the potential of the dry aggregates to disintegrate upon contact with water was greatest in the conventionally tilled and least in the untilled treatments. The soil of the tilled plots contained less carbon and nitrogen than that of the untilled plots in all aggregate size fractions. The silt + clay contents of the aggregates accounted for between 65 and 93% of variability in the water they retained at small potentials while OC contents accounted for between 71 and 90% of variability in the stability of the aggregates irrespective of the tillage treatments.

This type of study was also performed on five soils amended with pig slurry (Modena), sewage sludge (Lamporecchio), and cattle slurry (Cremona). The Modena soils were three, M1 (clay Vertic Xerochrept), M2 (sandy loam Fluventic Xerochrept) and M3 (sandy clay loam Typic Xerochrept). In relation to the controls these treatments decreased the apparent density and dispersibility of the aggregates, increased their water retention capacity at −0.03 MPa tension but had no significant effect on their intra-porosity and particle size distributions. The OC contents of the aggregates accounted for 73-98% of variability in their tendency to disperse, whereas
their silt + clay contents accounted for 38-96% of variability in the moisture they retained at –0.03 MPa tension. Also irrespective of treatments the macroaggregates (> 0.25 mm) constituted more than 70% of the total aggregate fractions. There was a close relationship between the concentrations of C, N and P in the aggregates and their silt + clay contents.

**Conclusion**

Even though the studies reviewed in this paper concentrated on Italian soils, to the extent that they are within the Mediterranean region they can serve to give an overview of the environmental control of soil structure in soils of this region. This study has highlighted (i) the disaggregating effects of cyclic freezing/thawing and wetting/drying on soil structure and the moderating effects of organic (humic) substances, (ii) the differential effects of organic substances on structural stability of the soils, (iii) the role of intrinsic soil properties on structural stability, (iv) the damaging effects of soil tillage on aggregate stability of the soils and (v) the positive influence of pig slurry, sewage sludge and cattle slurry on the stability of these soils as well as on the physical and chemical properties of their aggregates.

**SUGGESTIONS FOR FURTHER READING**