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"Effects of Soil Management Practices on Soil Structure"

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EFFECTS OF SOIL MANAGEMENT PRACTICES ON SOIL STRUCTURE

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Seedbed-Rootbed Preparation

The first aim of soil management practices and particularly of tillage is seedbed preparation. The seedbed is usually considered to be the ploughed layer of soil which has been prepared in such a way that planted seeds will readily germinate and the young plants have a satisfactory condition for root development and growth. The agronomic practices for preparing the seedbed should be designed to take advantage of the structure-forming qualities of well-developed root systems and organic matter.

Conventional tillage. Ploughing is generally the first operation in the preparation of a seedbed-rootbed. It can contribute materially in obtaining good tilth. If the ploughing operation produces a fairly satisfactory seedbed that will require only a small amount of surface tillage, then good ploughing will aid materially the preservation of good tilth. If the ploughing operation produces a poor type of seedbed that requires a considerable amount of surface preparation, then poor ploughing will result in the gradual deterioration of soil structure.

The success of the ploughing operations in obtaining granulation of the furrow slice depends primarily upon the granular nature of the soil and the moisture content at which the soil is ploughed. There is an optimum range of soil moisture for each soil that permits the most effective results in ploughing. This is the moisture range of the friable consistency. If ploughed when it is not friable, a soil will usually be left in a cloddy condition. The breaking down of such clods requires many surface tillage operations, such as disking, rolling, and harrowing, for a quick preparation of the seedbed.

Minimum tillage. The minimum tillage consists in the preparation of seedbed without ploughing the soil. This type of tillage involves only the surface soil layer (0-5 cm) and can be carried out by conventional rotary cultivator, harrow, disc-harrow, etc.

Zero tillage. The increasing use of herbicides rather than cultivation to control weeds and the necessity to reduce energy inputs in agriculture, due to the recent energy crisis, have induced farmers to consider reduced tillage practices as an alternative to conventional tillage. This forced choice may have positive effects on soil structure, especially in Italy, where intensive cultivation and deep-ploughing have caused a decreased of soil organic matter content, evidently resulting in deterioration of soil structure. The zero tillage consists in the direct planting of the seeds in the untilled soil.

Effect of tillage on soil organic matter

The long-term intensive cultivations cause a decrease of organic matter content, moreover, in modern agriculture, there is a strong reduction in the application of of organic materials to the soil, due to the severe shortage of farmyard manure. Fig. 1 shows the possible trend of soil organic matter variations in the surface layers following continuous cultivations. The main effects of a conventional tillage consist, first of all, in the removal of residual crops from the soil surface, and, moreover, in the uniform distribution of the soil organic matter content in the ploughlayer. On the contrary, in untilled soils the organic matter decreases with depth. The same trend can also be observed for the nutrient elements present in the ploughlayer (Sequi, 1979). Associated with the decrease of soil organic matter content following the continuous cultivation there is a strong decrease of the living organism population. Sequi (1979) and Pagliai et al. (1983) reported that deep ploughing strongly reduced the earthworms in soil, in agreement with Barnes and Ellis (1979) who showed that the population of earthworms was consistently bigger on direct-drilled than in ploughed land. After many years of continuous cultivation these decreases become more and more dangerous also because the turnover of organic matter is quicker and its content become very low. This leads, as a consequence, to a soil structure deterioration.

Effect of tillage on soil water content

Soil tillage strongly influences the behaviour of water in soil and its availability for plants. This aspect is strictly connected with the previous because the capacity of soil to hold water depends on its organic matter content, especially in sandy soils. Van Ouwerkerk and Boone (1970), showed that the soil water content at the pF 2 could be influenced more by the soil organic matter content than by the total porosity of the soil.

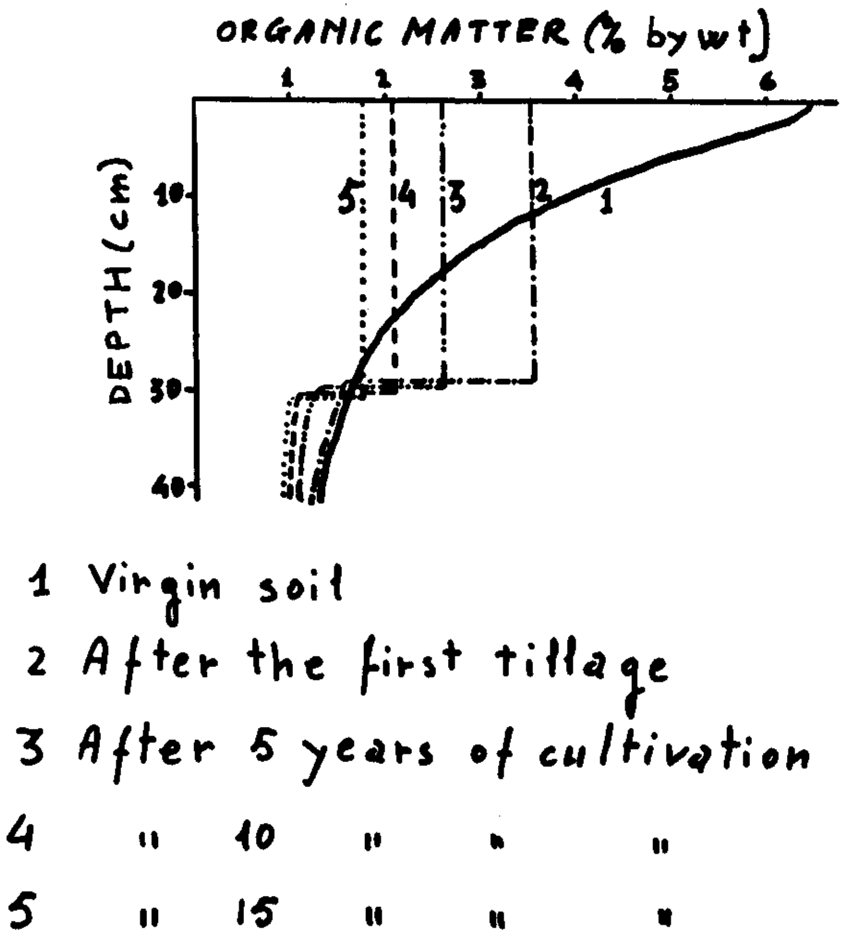


Fig. 1 - Variation of soil organic matter content when a pasture soil is transformed in corn cultivation. Modified from Sequi (1979).

Therefore, if continuous tillages cause a decrease of soil organic matter, they can also have negative effects on the water content in soil.

Fig. 2 reports some results obtained from Ellis et al. (1982). They found a water content always lower in conventionally tilled soils than in untilled or minimum tilled soils. This is because the zero tillage and minimum tillage cause a reduction of total porosity, but the proportion of storage pores (0.5-50 μm) increases (Pagliai et al., 1983).

Effect of tillage on soil aggregation and on soil aggregate stability

The aggregation of cultivated soils is much lower than soils from adjacent virgin areas. Not only are there fewer aggregates present in the cultivated soils, particularly the larger granules, but there is also a lower percentage of the finer particles in the aggregated state. Degradation of aggregates is highly correlated with decreases in organic matter. Cultivation not only exposes the accumulated organic matter in virgin soils to greater microbial decomposition but also removes the source of annual accretions to the organic matter cycle in the soil and the structure-forming activities of earthworms that are always abundant in grasslands and under forest litter.

Fig. 3 reports some data dealing with one of the most commonly used parameters for evaluating the structural conditions of a soil, i.e., the percentage of soil aggregates

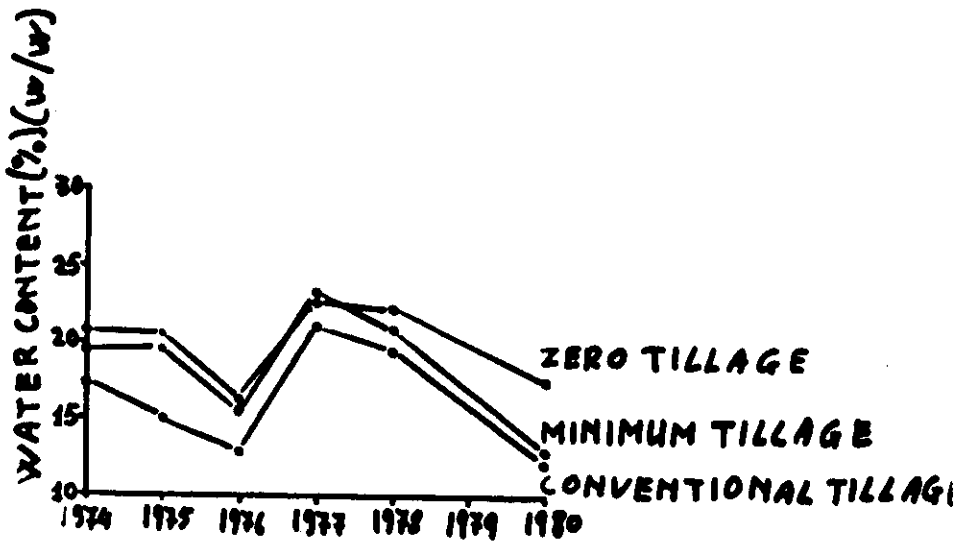


Fig. 2 - Variation of water content in the topsoil (0-5 cm) at the seedling time following different management practices in the period 1974-1980. Modified from Ellis et al. (1982).

greater than 2 mm. It can be noticed that in a virgin soil the percentage of such aggregates reaches 80-90% throughout the profile, while continuous cultivation reduces the aggregation to a value of approximately 2%. If the soil is taken under pasture, after only three years, we have the restoration of a good aggregation especially in the surface layer, where there is the major root development. After ten years of pasture the aggregation improves at every depth and in the surface is similar to that of a virgin soil.

Another aspect to be considered is the influence of soil tillage on soil aggregate stability. This parameter plays an important role in determining the soil physical fertility and it is considered the best index to evaluate soil structural conditions (Sequi, 1978), i.e., those structural conditions that can become the limiting factor of crop yield (Low, 1973). The decrease in the proportion of storage (0.5-50 µm) and transmission (50-500 µm) pores following continuous cultivation can be ascribed to the decrease of soil aggregate stability. Fig. 4 shows some results obtained from Tomlison (1974) on the stability of soil aggregates determined by the disgregating action of water in untilled and conventionally tilled soils. It can be noticed that in the surface soil layer the aggregate stability increases up to four times following the no-tillage with respect to the conventional tillage. It is necessary to stress that the surface layer is that more important from the agronomic point of view, since it is the layer in which the major part of the roots grow.

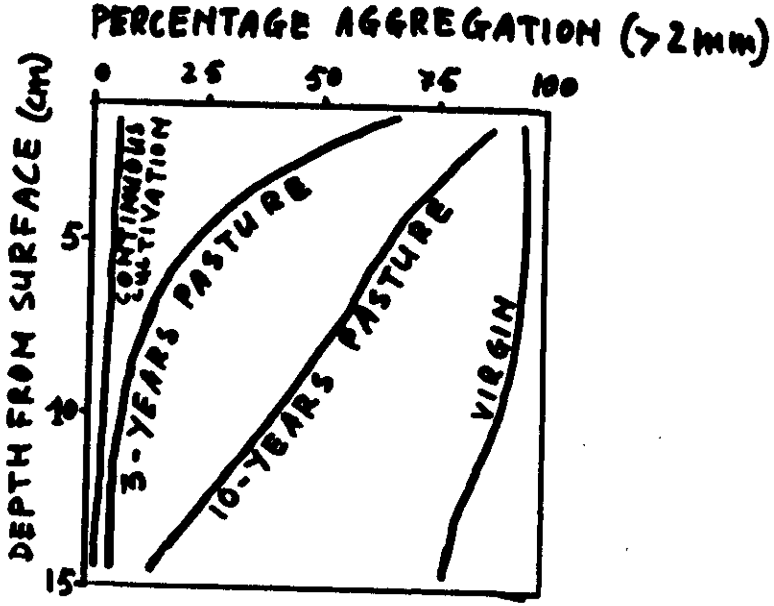


Fig. 3 - Soil structure profiles. Modified from Greacen (1958).

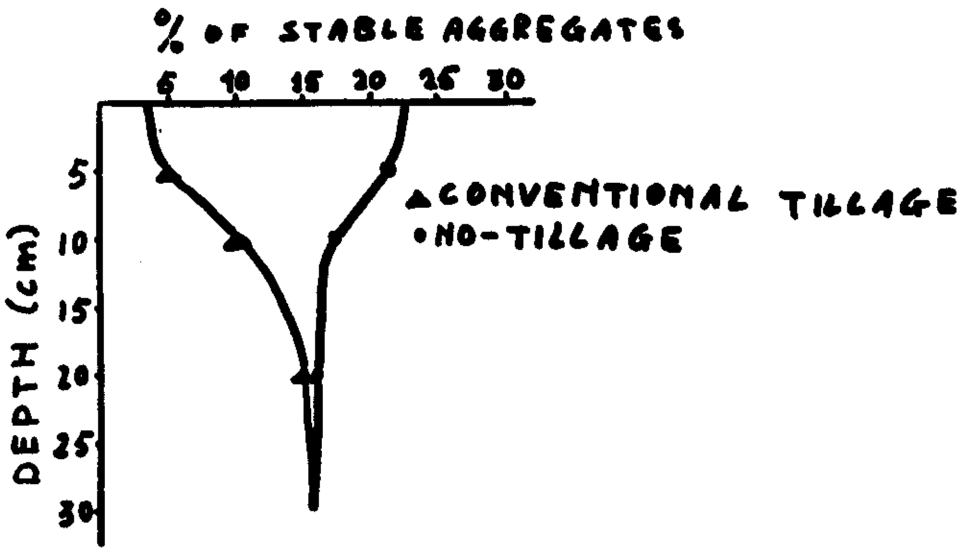


Fig. 4 - Effects of different types of tillage on soil aggregate stability. Modified from Tomlison (1974).

Effect of tillage on soil porosity

Tillage can produce good tilth by loosening and granulating the soil, and therefore increases the total porosity and particularly it produces the large planar pores surrounding or separating aggregates or clods (cf. "structural porosity", Monnier et al., 1973).

In a long-term field experiment established on a clay loam soil (Vertic Xerofluvent) under viticulture in the Po Valley, in which no-tillage and conventional tillage were tested, the total porosity, measured on thin sections, was always and significantly higher in conventionally tilled soil than in no-tilled one as reported in Fig. 5 (Pagliai et al., 1983,1984; Pagliai, 1987a). On the contrary the number of pores was significantly higher in samples of no-tilled soil. This means a different pore size distribution between the two management practices. The high variations of soil porosity in the conventionally tilled soil could be explained as the result of physical stresses, caused, for example, either by heavy rainfall that increased soil compactness, or by strong dry winds that induced a rapid soil-drying process thus influencing soil shrinkage phenomena. The intensity of these natural events can have some year-to-year variations which can influence porosity in tilled soil. The no-tilled soil, on the contrary, seemed to be more resistant to these physical stresses. The increase of porosity year by year in no-tilled soil is a clear symptom of restoration of good soil structure, and this confirms results reported in Fig. 3.

EFFECT OF TWO TYPES OF SOIL TILLAGE ON SOIL POROSITY

Year	NO-TILLAGE		CONVENTIONAL TILLAGE	
	Area (%)	No.	Area %	No.
1980	14.7 (± 0.9)	1779 (± 70)	26.1 (± 1.6)	1314 (± 64)
1981	14.8 (± 1.1)	1621 (± 65)	19.4 (± 1.2)	1355 (± 44)
1982	17.8 (± 1.2)	1625 (± 86)	34.4 (± 3.7)	1061 (± 50)
1983	19.3 (± 2.2)	1740 (± 11)	27.4 (± 3.1)	1180 (± 53)
1984	21.0 (± 1.4)	1629 (± 81)	40.4 (± 3.6)	981 (± 62)

.Fig. 5 - Effects of two types of soil managements on soil porosity expressed both as a percentaage of total area and as number of pores per thin section. The analysed area of each thin section was 5.5X6.5 cm^2; means of six replicates.

Fig. 6 reports the pore size distribution. The no-tilled soil showed strong differences with respect to the conventionally tilled soil. In the latter the higher proportion of total porosity was given by elongated pores larger than 500 µm. The proportion of pores ranging from 30 to 500 µm, which are the most important both in soil-water-plant relationships and in maintaining a good soil structure (Greenland, 1977, 1981), was higher in the no-tilled soil. Moreover Sequi et al. (1985) have found a positive correlation between soil enzyme activity and the number of pores ranging from 30 to 200 µm (Fig. 7). Therefore, in the untilled soil, where the number of these pores was higher, the enzyme activity should be higher.

In Fig. 8 are reports the length of elongated pores, which may reflect their continuity. Conventional tillage caused an increase in the length of a few large elongated pores, in fact, Fig. 8 shows that in the tilled soil more than 90% of the elongated-pore area consisted of pores >32 mm. However this high percentage was due to only few elongated pores. On the contrary, in the no-tilled soil the area-proportion of elongated pores >32 mm was about 50%, but this percentage was due to a higher number of elongated pores. This means that in the conventionally tilled soil the few longer elongated pores were also wider. Some of them were represented by cracks caused by shrinkage. These cracks were interconnected and usually showed a vertical orientation. The shrinkage was much more evident in the tilled soil than in the no-tilled one (Pagliai et al., 1983).

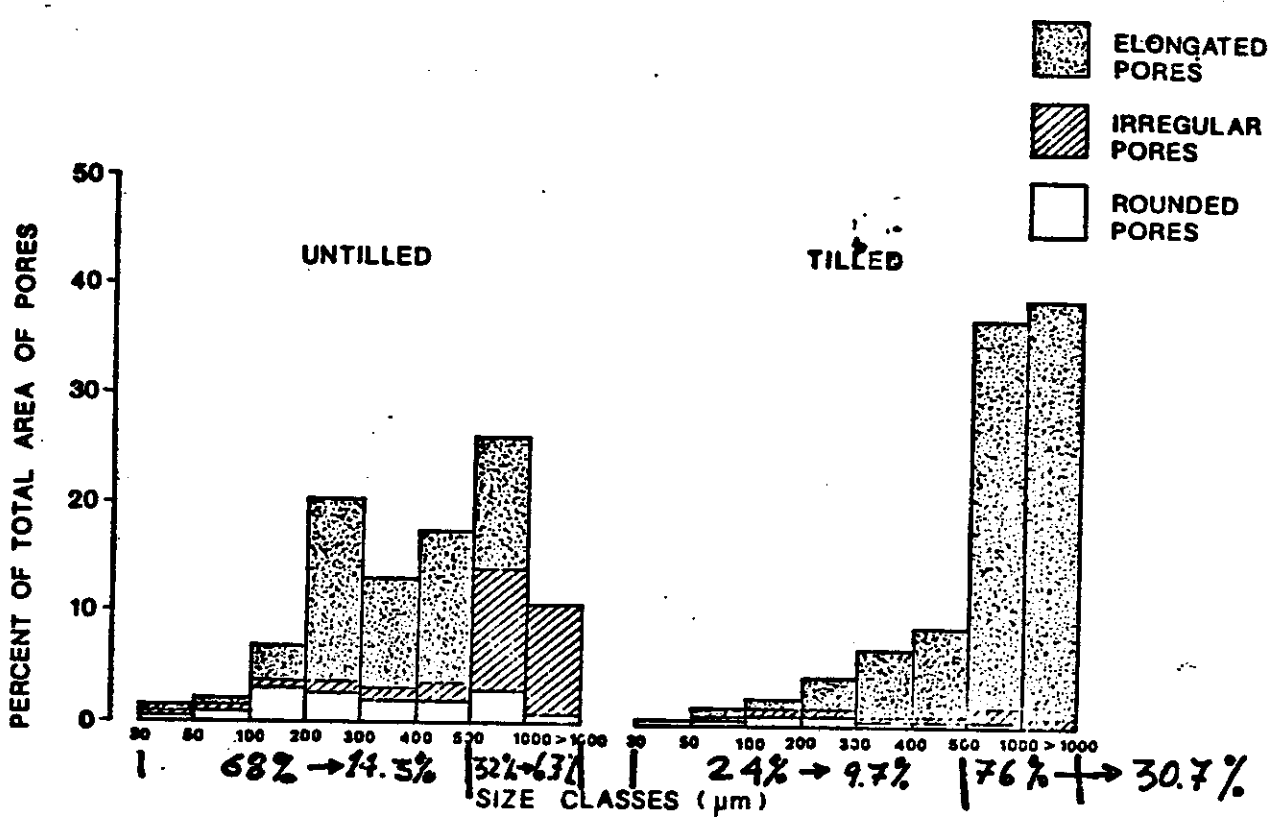


Fig. 6 – Pore shape and size distribution. Sampling of 1984.

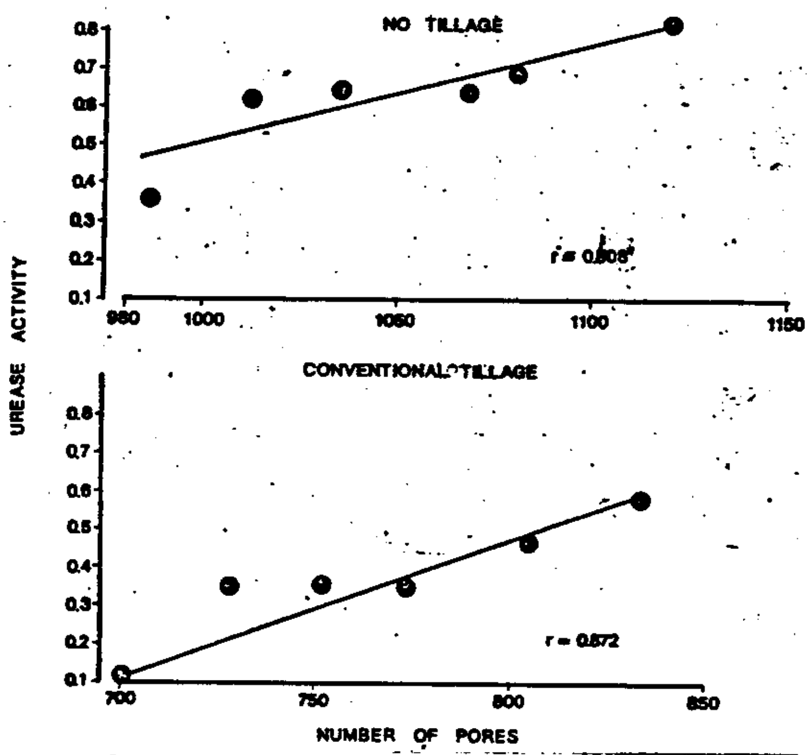


Fig. 7 – Positive correlation between urease activity (μmol h^{-1} g^{-1} soil) and number of pores in the 30-200 μm range, for 6 no-tilled and 6 conventionally tilled plots.

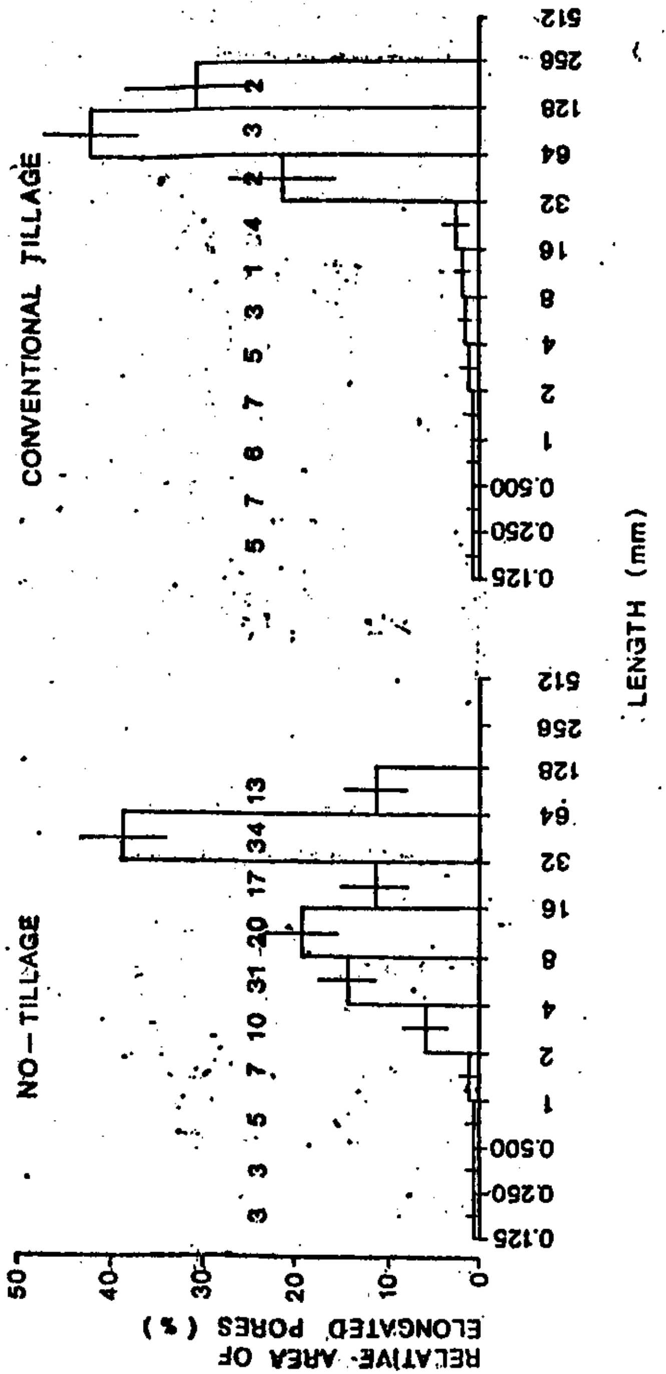


Fig. 8 - Length distribution of elongatrd pores. Numbers refer to the number of elongated pores for each class and are the mean of six replications. Bars represent confidence interval at P<0.05.

There were also great differences in the irregularity of elongated pores between the no-tilled and conventionally tilled soil, as reported in Fig. 9. In the conventionally tilled soil the highest area proportion of very irregular elongated pores (classes 0-0.3) was caused by relatively few longer and wider pores. In the no-tilled soil the highest frequency of elongated pores was in the moderately regular classes (0.5-0.7), and also the very regular classes (0.7-1) showed a high number of elongated pores. In other words, many of these pores also belonged to the smaller size classes shown in Fig. 6. The microscopic examination revealed that many of these moderately regular or regularly elongated pores were >30 mm; some of them entirely traverse the full thin section. The high area percentage and number of elongated pores in the classes of moderately regular pores may be regarded as a significant finding because they have walls which do not accomodate each other. Therefore, these pores permit passage of water even when the soil is wet and fully swollen. In contrast, flat and smooth pores as found in the regular shape classes, which have accomodating faces, tend to seal when the soil is wet and, thus prevent water movement. Furthermore, moderately regular elongated pores are not tortuous. From their length it was deduced that many of these pores were continuous and, therefore, allow the roots to grow into them. Microscopic observation confirmed that root remains were more abundant in thin sections of the no-tilled soil than in those of the conventionally tilled soil.

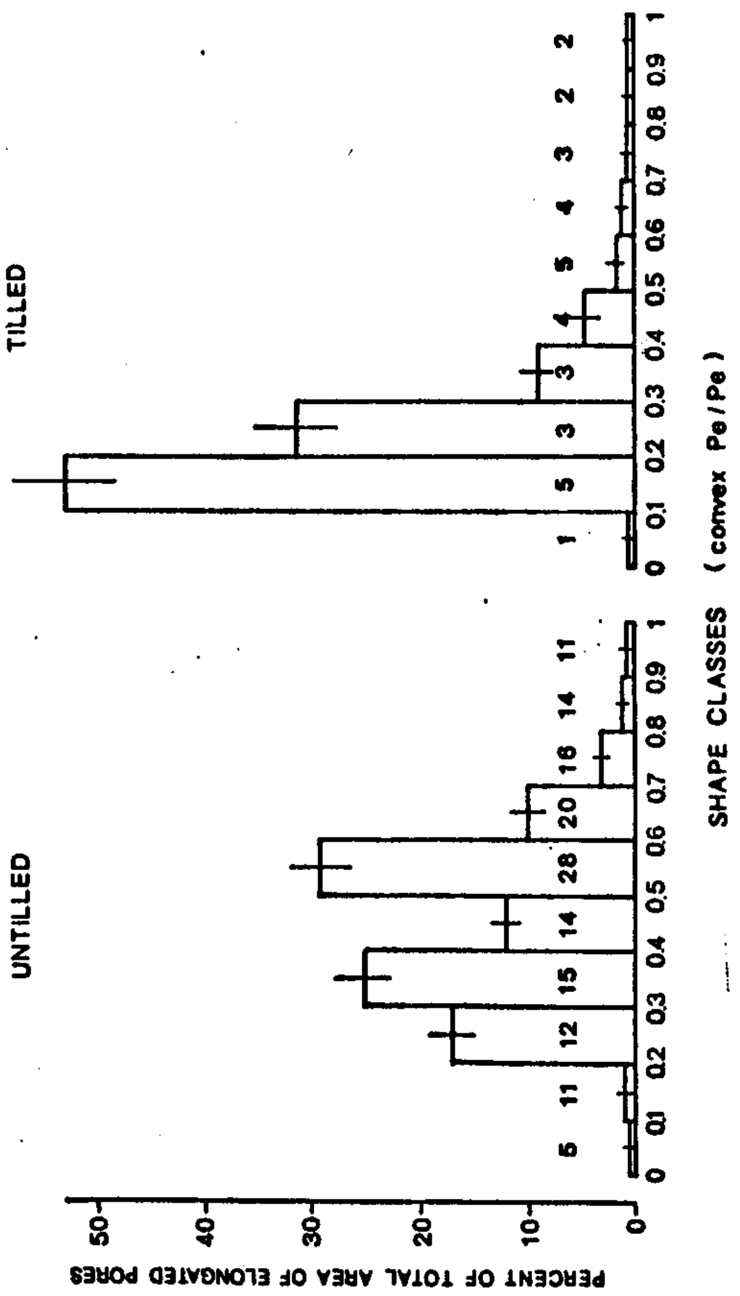


Fig. 9 - Shape distribution of elongated pores. Numbers refer to the number of elongated pores for each class and are the mean of six replications. Bars represent confidence interval at $P<0.05$.

Similar results have been obtained in another zero versus conventional tillage field experiment established on a clay soil (Typic Chromoxerert) in Sicily (South Italy) (Pagliai, 1987a).

Effect of management practices on soil compaction

Soil compaction is caused by a combination of natural forces, which generally act internally, and by man-made forces related to the consequences of soil management practices. The latter forces are mainly those related to vehicle wheel traffic and tillage implements and have much greater compactive effect than such natural forces as raindrop impact, soil swelling and shrinking, and root enlargement.

Fig. 10 shows the results of an experiment dealing with the modifications of soil porosity and structure induced by tractor wheels in a clay loam soil and for how long such modifications were visually appraisable (Pagliai, 1987b). In the compacted topsoil the porosity strongly decreased, particularly the irregular pores while the elongated ones strongly reduced their size and modified their orientation pattern. The microscopic observation revealed that these elongated pores were thin fissures parallel to the soil surface, thus originating a platy structure, and very often they lost their continuity in a vertical sense. This situation leads, as a consequence, to an increase of soil erosion. After one year the modifications induced by compaction were not visually appraisable with respect to the uncompacted topsoil. Bullock et al. (1985) found that the

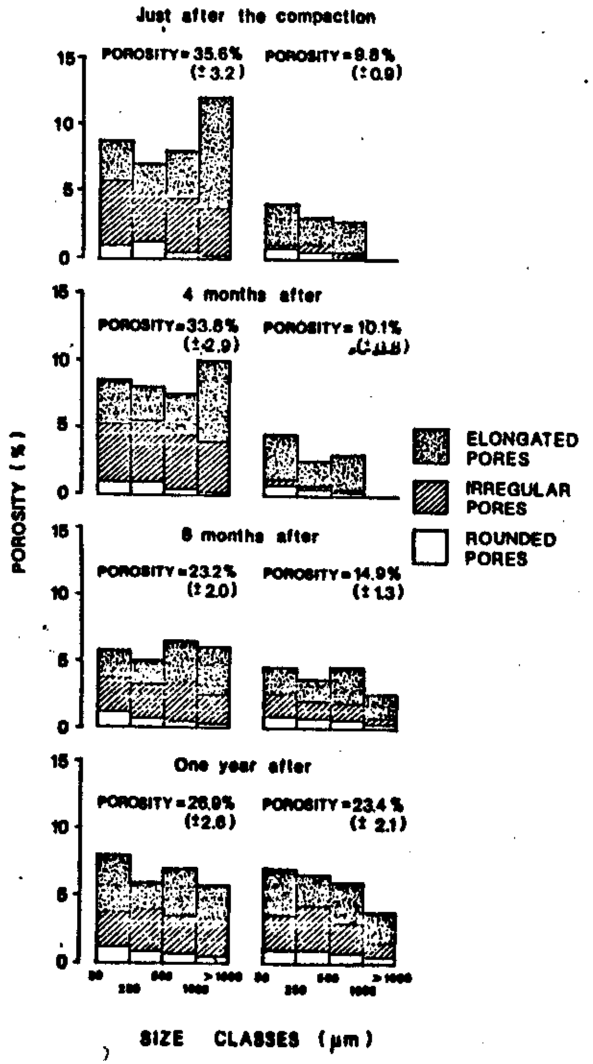


Fig. 10- Porosity and pore size distribution according to either the equivalent pore diameter for regular and irregular pores or the width for elongated pores in uncompacted (lefth) and compacted (rigth) soil; means of six thin sections.

regeneration of soil structure after compaction in clay soils could even take some years.

Continuous ploughing the soil may cause the formation of a ploughpan (ploughsole) at the lower limit of the cultivation. Fig. 11 reports the micromorphometric analysis which showed that the porosity just above the ploughsole was still high but in the ploughsole it strongly decreased to a very low value in the first cm then slightly increased but the micromorphometric analysis revealed that the ploughsole can reach a thickness even of 10 cm. The microscopic observations revealed that in the first cm the few pores present were very thin elongated pores parallel to the surface of the ploughsole. Some irregular pores were present in the lower part of the ploughsole. The presence of such a compact layer at the lower limit of the cultivation in the profile may strongly reduce the water drainage and hamper root development at depth.

Fig. 11 also shows that the effect of the wheel compaction can reach a depth of about 10 cm.

Effect of tillage on soil crusting

These specific physical modifications in the top soil can be caused by natural events such as raindrop impact which produce the mechanical destruction of soil aggregates and in the following drying process the dispersed soil particles form a thin layer on the top of the soil (structural crusts). In some cases the fine particles can be traslocated and deposited at a certain distance from their origin (depositional crusts) (Chen

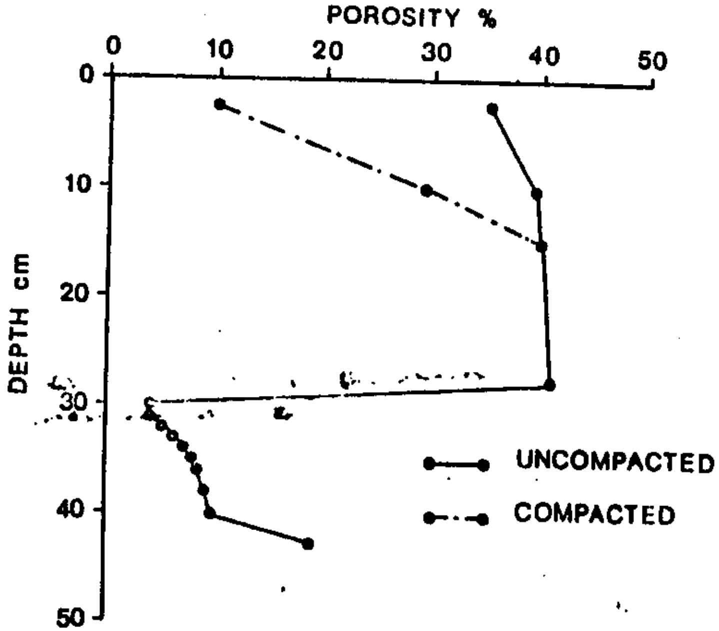
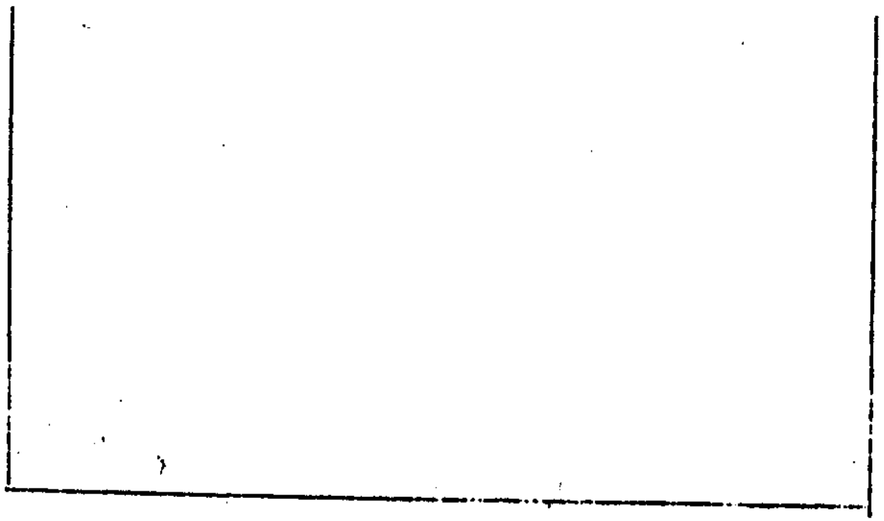


Fig. 11- Porosity as percentage of total area of thin section at selected depths.



et al., 1980). In this case the deposition of the dispersed soil particles can take place on a previously formed crust, giving a surface layer with pronounced gradation of texture (Pagliai and la Marca, 1979). When dry, these features are more compact, hard and brittle than the underlying soil material and decrease the size and number of pores and their continuity in a vertical sense, thus reducing water and air permeability. From the agronomic point of view, the most disadvantages of soil crusts are the influences they have on seedling emergence and water penetration. This latter leads, as a consequence, to an increase of surface run-off.

These surface crusts are very common in tilled plots. The microscopic observations of thin sections prepared from the surface soil samples show a thin layer of horizontally oriented plate-like particles at the top of the soil. This compact thin layer contains few, if any, large pores. In many samples of tilled plots, the surface crust is formed by several layers of this kind (depositional crusts), intercalated by some coarse materials, elongated pores and, sometimes, rounded pores ("vesicles", Brewer, 1964) formed by entrapped air during the drying process.

Soil crusts are much less developed in samples taken from the surface of no-tilled plots where layers of oriented particles are absent and pores are present even in the surface soil layers. This can be ascribed both to the better rain-stability of surface soil aggregates of no-tilled plots with respect to those of tilled ones and to the reduction of the

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effect of the rain-drop impact due to the remains of the grass plants killed by the herbicide, on the soil surface. In tilled plots, surface soil aggregates are subject to the direct action of rain-drop impact.

REFERENCES

Barnes, B.T. and Ellis, F.B. 1979. Effect of different methods of cultivation and direct drilling, and disposal of straw residues, on populations of earthworms. Journal of Soil Science, 30: 669-679.

Brewer, R. 1964. Fabric and Mineral Analysis of Soils. John Wiley, New York, 470 pp.

Bullock, P., Newman, A.C.D. and Thomasson, A.J. 1985. Porosity aspects of the regeneration of soil structure after compaction. Soil and Tillage Research, 5: 325-341.

Chen, Y., Tarchitzky, J., Brouer, J., Morin, J. and Banin, A. 1980. Scanning electron microscope observation on soil crusts and their formation. Soil Science, 130: 49-55.

Ellis, F.B., Christian, O.G. and Cannel, R.Q. 1982. Direct drilling, shallow tine-cultivation and ploughing on a silty-loam soil, 1974-1980. Soil and Tillage Research, 2: 115-130

Greacen, E.L. 1958. The soil structure profile under pastures. Australian Journal of Agricultural Research, 9: 129-137.

Greenland, D.J. 1977. Soil damage by intensive arable cultivation: temporary or permanent? Philosophical Transactions of the Royal Society of London, 281: 193-208.

Greenland, D.J. 1981. Soil management and soil degradation. Journal of Soil Science, 32: 301-322.

Low, A.J. 1973. Soil structure and crop yield. Journal of Soil Science, 24: 249-259.

Monnier, G., Stengel, P. and Fiès, J.C. 1973. Une méthode de mesure de la densité apparente de petits agglomérats terreux. Application à l'analyse des systèmes de porosité du sol. Annales Agronomies, 24: 533-544.

Pagliai, M. 1987a. Effects of different management practices on soil structure and surface crusting. In: N. Fedoroff, L.M. Bresson and M.A. Courty (Editors), Soil Micromorphology. Proceedings of the VIIth International Working-Meeting on Soil Micromorphology. Paris - July 1985. AFES, Paris, pp. 415-421.

Pagliai, M. 1987b. Micromorphometric and micromorphological investigations on the effect of compaction by pressures and deformations resulting from tillage and wheel traffic. In: G. Monnier, M.J. Goss (Editors), Soil compaction and regeneration. Proceedings of the Workshop on Soil Compaction: Consequences and Structural Regeneration Processes. Avignon, 17-18 September 1985. Published for the Commission of the European Communities by A.A Balkema, Rotterdam, pp. 31-38.

Pagliai, M. and La Marca, M. 1979. Micromorphological study of soil crusts. Agrochimica, 23: 16-25.

Pagliai, M., La Marca, M. and Lucamante, G. 1983. Micromorphometric and micromorphological investigations of a clay loam soil in viticulture under zero and conventional tillage. Journal of Soil Science, 34: 391-403.

Pagliai, M., La Marca, M., Lucamante, G. and Genovese, L. 1984. Effects of zero and conventional tillage on the length and irregularity of elongated pores in a clay loam soil under viticulture. Soil and Tillage Research, 4: 433-444.

Sequi, P. 1978. Soil structure- An outlook. Agrochimica, 22: 403-425.

Sequi, P. 1979. Lavorazioni e la struttura del terreno. L'Italia Agricola, 116: 135-159.

Sequi, P., Cercignani, G., De Nobili, M. and Pagliai, M. 1984. A positive trend among two soil enzyme activities and a range of soil porosity under zero and conventional tillage. Soil Biology Biochemistry, 17: 255-256.

Tomlinson, T.E. 1974. Soil structural aspects of direct drilling. Transactions of 10th International Congress of Soil Science. Moscow, 1: 203-213.

van Ouwerkerk, C. and Bonne, F.R. 1970. Soil physical apscts of zero-tillage experiments. Netherlands Journal of Agriculture Science, 18: 247-261.