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Tillage Impact on Soil Quality. II. Biological Properties in Surface Soil

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ABSTRACT

BACKGROUND. The purpose of our experiments was to determine the response of microbial populations to four different tillage systems (minimum tillage MT, shallow tillage SP, ripper subsoiling RS and conventional deep tillage DP), applied to continuous maize on loamy soil classified as Typic Udifluvent soil.

METHODS. The respiratory activity was determined by incubating the soil at 25 °C with soda lime pellets. Soil microbial biomass C (SMBC) was estimated using the FI method. Organic C (OC) was determined with a Mettler automatic titrator. The mineralization index (respiratory activity C/organic C ratio) and the metabolic quotient qCO_2 (respiratory activity C / biomass C ratio) were calculated from the obtained data. Phosphatase activity was determined by incubating the soil with p-nitrophenylphosphate.

RESULTS. The results of this study refer to the analyses of soil samples taken at depths of 0-15 cm, two years after the start of the experiments. In the minimum tillage system, the respiratory activity, metabolic quotient, mineralization index and phosphatase activity were higher than those of the other tillage systems, while a higher biomass value was found in the ripper subsoiling system. The higher concentration of crop residues in the surface layer and less alteration to the soil structure, inherent in minimum tillage, caused an increase in microbial metabolic activities.

CONCLUSIONS. After two years of using alternative tillage systems, minimum tillage was revealed as particularly favourable towards the development of microbial metabolic activities at depths of 0-15 cm, although it did not influence the conservation of organic matter and microbial biomass C more than the other tillage systems.

Key-words: soil tillage systems; respirometry; biomass; qCO_2; C-organic; phosphatase activity.

INTRODUCTION

Intensive agricultural production and continued use of land resources cause the decline of the agro-ecosystems through erosion and the loss of soil microbial biodiversity, and this leads to a loss of productivity.

Whalley et al. (1995) found that microorganism populations change under different management systems and that these changes are affected by differences in rooting patterns, with such effects on agriculture and the environment as different yields, erosion, NO_x emission.

Angers et al., (1993) indicated that different tillage systems modify the distribution of crop residues with depth. There is general agreement that, in the absence of tillage, organic matter tends to concentrate in the upper few centimeters of the soil. Since conventional tillage mixes the soil, the distribution is more uniform throughout the ploughed layers than in a no-till soil (Kern and Johnson, 1993; Campbell et al., 1996).

Although the microbial biomass comprises only a small portion (from 1.0 to over 4.0%) of the total soil organic C (Jenkinson and Ladd, 1981; Anderson and Domsch, 1989), it is very important as a repository of nutrients for plants (Schnürer et al., 1985).

Carter (1986) and Powlson et al. (1987), suggested that microbial biomass-C could be used as an indicator of the early changes in soil organic matter (SOM) brought about through management practices such as tillage and straw incorporation.

Changes in soil management cause the microbial biomass to increase or decrease much faster than the total amount of SOM and therefore it can be affirmed that the biomass is a much more

sensitive indicator of changing soil conditions than total SOM content, and so the biomass can serve as an early warning of such changes long before they are detected in other ways (Brookes, 1995).

Respiratory activity is usually the most widely used parameter to determine the microbiological activity of the soil. Since the breakdown of organic material is common to all heterotrophs, this parameter is often used for the complete evaluation of the microbial activity of the soil (Franzluebbers et al. 1995).

The mineralization index of C can be obtained from the ratio between emitted CO_2 and the total quantity of organic C in the soil. This will indicate how quickly the SOM in the soil is destroyed by microorganisms. An evaluation of increases and decreases in organic substances in a particular soil sample and over a given period is also required (Dommergues, 1960; Florenzano,1983).

The microbial metabolic quotient, qCO_2, represents the CO_2-C produced per unit biomass-C and time (Anderson and Domsch,1985 and 1990). Since the microbial respiration in the field is subject to extreme environmental and seasonal variations, this index is only considered an indicator of a very precise environmental stress (Brookes, 1995). When the microbial biomass is stressed, the metabolic quotient rises, i.e. an increase in the quantity of C is oxygenated per unit of biomass in order to repair and maintain the biochemical machine of the cell active (Wardle and Ghani, 1995).

The value of the qCO_2 may be used to quantify the effects caused by environmental differences. Nevertheless, the qCO_2, by its holistic nature, cannot show specific changes within the microbial population under different management regimes (Ceccherini et al., 1996).

Microorganisms are the major source of soil enzymes. Phosphatase is a general name used to describe a broad group of enzymes that catalyze the hydrolysis of both esters and anhydrides of phosphoric acid (Deng and Tabatabai, 1997). Soil phosphatase can occur exocellularly as well as within the living cell.

Part of this activity is independent of the causes that regulate the intracellular metabolic activity of microrganisms. Nevertheless the effect can be very important in understanding the life of the ecosystem because it has an essential role in the mineralization of P, causing the release of phosphates from organic esters (Nannipieri et al., 1995).

We used conventional methods to assess the effects of the different tillage systems (minimum tillage, shallow tillage, ripper subsoiling and deep tillage) on soil microflora under continous maize cultivation. The experimental plots had been deep ploughed and planted with maize for the previous twenty-seven years. The responses of surface microbial populations to different tillage systems were studied at the process level in terms of microbial biomass, soil respiration, soil organic carbon and phosphatase activity at the end of the second year after introduction of the alternative tillage systems. The mineralization index and qCO_2 were inferred from the other paramenters.

MATERIALS AND METHODS

Soil and treatments

The study was conducted at the Fagna Agricultural Experimental Centre (Scarperia-Firenze) of the Research Institute for Soil Study and Conservation (Firenze, Italy) on a loam soil (Table 1), classified as Typic Udifluvent (USDA, 1985). The climate is temperate with dry summers and autumns. The experiment, which began in 1994, consisted of three replications of each of four tillage treatments. Each plot was 10 m × 50 m. The following tillage systems were used: minimum tillage, harrowing with a disk harrow to a depth of 10 cm (MT); shallow tillage, mouldboard ploughing to a depth of 20 cm (SP); ripper subsoiling 50 cm deep (RS); conventional deep tillage, mouldboard ploughing to a depth of 40 cm (DP).

It is important to mention the background of

Table 1. Physical and chemical characteristics of the soil.

Gravel	5	%
Sand (mm 2 ÷ 0.05)	45	%
Silt (mm 0.05 ÷ 0.002)	38	%
Clay (< 0.002 mm)	17	%
pH	7.8	
Total $CaCO_3$	6	%
Organic Matter	1.8	%
Total K_2O	1.5	%
Exchangeable K_2O	100	ppm
Total P_2O_5	1.3	%
Ass. P_2O_5	65	ppm
Total N	0.12	%

this particular soil. Since 1970, the land has been cultivated with maize crops adopting the same traditional management practices. Since 1980, there has been only mineral fertilization with no addition of farmyard manure or other organic materials.

Three soil samples were collected from each plot at depths of 0-15 cm. The soil was sieved at 2 mm and kept at 5 °C; the experiments were carried out over a period of one week. This article reports the results of the second year after the introduction of the alternative tillage systems.

Soil respiration, biomass-C and metabolic quotient qCO_2

The respiratory activity was determined after harvest before the soil was prepared for the next crop, by Edwards' method (Edwards, 1982) which was modified as follows: the soil samples were divided into 3 subsamples of 100 g, adjusted to 50% of water holding capacity (WHC), incubated at 25 °C in 1 l flasks, in the presence of soda lime pellets. The soda lime was substituted twice in 10 days. The evolved CO2, as CO2-C, was measured by the gravimetric method and expressed as mg CO2 kg-1 dry soil 24 h-1.

Microbial Biomass C (MBC) was estimated with the fumigation-incubation (FI) method using the following equation (Jenkinson and Powlson, 1976):

$$BC = \frac{Fc}{kc}$$

where *Fc* is CO_2-C (evolved from fumigated soil during the 0-10 days incubation period) minus CO_2-C (evolved from non-fumigated soil during the same incubation period) and *kc* is 0.45 (Anderson and Domsch, 1978; Jenkinson, 1988; Wu et al., 1996; Martens, 1995). The biomass was expressed in mg C kg^{-1} of dry soil.

The qCO_2 was inferred from the ratio between CO_2-C and biomass-C as reported by Anderson and Domsch (1985 and 1986).

Organic carbon and mineralization index

The Organic C content (OC) was evaluated by oxidation with the method described by Yeomans and Bremner (1988), using a Mettler automatic titrator.

The mineralization index was calculated from the ratio between respiratory CO_2-C and total organic carbon content (Dommergues,1960).

Phosphatase activity

Phosphatase activities in the soil were assayed by spectrophotometer using the Tabatabai and Bremner method (Tabatabai and Bremner, 1969) which involves the determination of p-nitrophenolphosphate released by incubation at 37 °C for 1 h of 1 g of soil with universal buffer. The method makes it possible to study the activity of phosphomonoesterases (acid and alkaline phosphatases), phosphodiesterase, and phosphotriesterase in soils.

Statistical analysis

The results were statistically tested by one way completely randomised analysis of variance (ANOVA) and the means were compared employing Duncan's multiple range test. The results of the statistical analysis are summarized in tables 2 and 3.

RESULTS AND DISCUSSION

Soil respiration, microbial biomass and qCO_2

Respirometry values at depths of 0-15 cm were significantly ($P < 0.001$) higher in plots under MT compared with the other tillage treatments (Table 3). This might be due to the reduced disturbance of the soil in this tillage system, in comparison with others used in the experiment, in particular, the deep ploughing method.

Table 2. One way ANOVA randomised complete blocks among the different tillage systems.

Variable	Mean square	F	Significance level
Respirometry	291.15	42.34	0.0002 ***
Biomass-C	7273.06	6.24	0.0282 *
qCO_2	0.70	19.90	0.0016 **
C-organic	0.0031	2.48	0.1581 ns
Mineralization index	0.0013	15.3	0.0032 **
Phosphatase	13128.22	129.16	0.0000 ***

Significantly greater amounts of CO_2-C were released from zero tillage and reduced tillage soils than from conventionally tilled soil (Costantini et al., 1996).

For the microbial biomass-C content at depths of 0-15 cm, there were significant differences between tillage systems, with a higher content of biomass C under RS compared with the other tillage treatments (Table 3).

This might be due to the reduced disturbance of the surface soil in this tillage system, in comparison with others that were used in the experiment, in particular, the DP.

More abundant microbial biomass was observed in the superficial layers of MT corrisponding to greater accumulation of SOM in the upper part of the Ap horizon (Blevis et al., 1977; Doran, 1980; Sakamoto and Oba, 1991; Alvarez et al., 1995b).

In our experiments, even though the biomass C was lower in the MT plots than in RS plots, the respiratory activity was the highest. This indicates that the soil biomass, in the surface layer, has a more active metabolism under minimum tillage as also shown by the metabolic quotient (Table 3).

Organic C and carbon mineralization

The values of organic content at depths of 0-15 cm were not significantly different among the four tillage treatments (Tables 2 and 3). The experimental plots have been cultivated with continuous maize with conventional ploughing for 27 years. In the last 15 years no organic matter has been added (except maize residues). Consequently it is reasonable to expect no tillage effects on SOM contents after two years of treatment.

Angers et al. (1995), under maize production for 11 years, found that maize-derived C was evenly distributed with depth in the mouldboard plough treatment and accumulated at the surface in the shallow, reduced-tillage treatments, but had no detectable effect on SOM turnover and on the fate of maize residues when the whole Ap horizon (0-24 cm) was considered.

The mineralization index was also significantly higher in the MT plots (Table 3) and this should be related to the abundance of crop roots, rhizosphere products and more optimal air-filled porosity.

So it is possible to presume, in agreement with Ehlers (1975) and Pagliai et al. (1996), that the reduced alteration of the soil structure, due to the reduced energy input inherent to the MT, has preserved a larger number of stable biopores and assured a better circulation of the aqueous and gaseous phases, a higher availability of nutrients and an increase in microbial metabolic activity.

According to Salinas-Garcia et al. (1997) C mineralization was highest in no-tillage and minimum tillage; at the same time, the soil where mouldboard ploughing was used, the mineralization of C is much lower. Similar results were found by Alvarez et al. (1995a) after 12 years of experiments at the soil surface and decreased rapidly with depth under no-tillage and chisel tillage.

Phosphatase activity

The activities of phosphatases were significantly different for all the tillage systems. The Duncan's test showed that the highest activity resulted as being in the MT plots with the lowest determined under DP; moreover, the activity in SP plots was higher than in RS plots (Table 3).

Differences in microbial dynamics due to management practices may also be reflected by differences in the enzyme activities of soils. A study by Dick (1984) indicated that the activities of acid and alkaline phosphatase, in the 0-7.5 cm profile, were significantly greater in soils from no-tillage plots than those from conven-

Table 3. Microbial activity and phosphatase activity under different tillage systems and relative mean Duncan's test, $P \leq 0.05$. MT: Minimum Tillage; RS: Ripper Subsoiling; SP: Shallow Ploughing; DP: Deep Ploughing.

Tillage System	Respirometry (mg CO_2·kg soil^{-1}·24h^{-1})	Microbial Biomass (MBC) (mg C·kg soil^{-1})	qCO_2 (mg C-CO_2· mg MBC^{-1}·100^{-1})	Organic C (OC) (%)	Mineralization index (mg C-CO_2· OC^{-1}·100^{-1})	Phosphatase activity (µg PNF·g soil^{-1}·h^{-1})
MT	73.70 a	579.31 b	3.47 a	1.160 a	0.17 a	495.16 a
RS	59.06 b	659.50 a	2.45 b	1.170 a	0.14 b	395.50 c
SP	51.47 c	541.56 b	2.60 b	1.107 a	0.13 b	446.33 b
DP	54.50 bc	598.40 ab	2.50 b	1.113 a	0.13 b	348.83 d

tional tillage plots. According to Deng and Tabatabai (1997) the activities of acid phosphatase, alkaline phosphatase and phosphodiesterase were significantly greater in no-tillage and chisel ploughing than those in mouldboard ploughing.

CONCLUSIONS

A comparison between different cultivation systems of maize in a single-crop system requires an analysis of the results based on periods of equal length. Superficially, the results of our studies may seem limited. However, if we take into consideration that these results refer only to the end of the second year of experiments and remember that these soils had been worked for many years using conventional tillage methods, we realize that they are quite interesting because they show that even after a short period, the microflora of the soil is significantly altered.

After two years of adopting alternative tillage systems, MT was revealed as being particularly suitable for the development of microbial metabolic activities in the soil at depths of 0-15 cm, even though it did not influence the conservation of organic matter and microbial biomass C any more than the other tillage systems.

Tillage systems do significantly modify the respiration and the mineralization index. The higher respiratory activity in the MT plots may be a consequence of a greater metabolic activity of the biomass; in other words, of a differential C use efficiency. This fact was also supported by the other metabolic parameters considered, indicating that the degradation of organic substrates in the surface layer is higher under the MT system than under the other treatments. The greater microbial activity observed at the surface layer may be due to the higher concentration of crop residues, more confined to depths of 0-10 cm and not distributed in the soil profile as occurs in DP plots.

The metabolic quotient was also higher in the MT plots; this leads us to think that tillage management should also be considered among the factors of disturbance that determine an elevation of qCO_2, like rewetting of dry soil, herbicide application, acidification and substrate addition (Wardle and Ghani, 1995).

The increase in the phosphatase activity in the plots with reduced tillage, attributed to improved conditions that are created by the microflora, clearly indicates the likelihood of reducing the chemical and energy inputs without altering the fertility of the soil.

In conclusion, the MT regime in this particular soil, seems to be a good alternative to conventional ploughing, in accordance with the sustainable agricultural policy, as it supports a higher microbial soil metabolic activity.

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IMPATTO DELLE LAVORAZIONI SULLA QUALITA' DEL SUOLO. II. PROPRIETA' BIOLOGICHE NELLO STRATO SUPERFICIALE DEL SUOLO.

SOMMARIO

SCOPO. Scopo del nostro lavoro è studiare la risposta delle popolazioni microbiche a quattro differenti lavorazioni del terreno (lavorazione minima MT, aratura superficiale SP, rippatura profonda RS e aratura convenzionale DP), in una monocoltura di mais attuata su un suolo di medio impasto classificato come Typic Udifluvent.

METODI. L'attività respiratoria è stata determinata incubando i terreni a 25 °C in presenza di calce sodata in granuli. La biomassa del suolo (SMBC) è stata stimata usando il metodo della fumigazione con cloroformio e successiva incubazione. Per la determinazione del C organico (OC) ci si è avvalsi di un titolatore automatico Mettler. Da questi dati è stato calcolato l'indice di mineralizzazione (rapporto percentuale fra C della respirazione e C organico) e il quoziente metabolico qCO_2 (rapporto percentuale fra C della respirazione e C della biomassa). L'attività fosfatasica è stata determinata per incubazione del terreno in presenza di p-nitrofenilfosfato.

RISULTATI. I risultati del presente lavoro si riferiscono ad analisi effettuate due anni dopo l'inizio della prova su campioni di terreno prelevati alla profondità di 0-15 cm. Nella lavorazione minima l'attività respiratoria, il quoziente metabolico, l'indice di mineralizzazione e l'attività fosfatasica sono più alti che nelle parcelle con gli altri tipi di lavorazione, mentre il più alto valore della biomassa si rileva nelle parcelle lavorate con rippatura profonda. Evidentemente la maggior concentrazione di residui vegetali nello strato superficiale e la ridotta alterazione della struttura del suolo, nel caso della lavorazione minima, determinano migliori condizioni per l'espletarsi delle attività metaboliche dei microrganismi.

CONCLUSIONI. Dopo due anni dall'introduzione di sistemi di lavorazione del terreno alternativi all'aratura convenzionale, la lavorazione minima si rivela particolarmente favorevole per l'incremento delle attività metaboliche dei microrganismi nello strato 0-15 cm di profondità del terreno, anche se non influenza più delle altre lavorazioni il contenuto di sostanza organica e la biomassa.

Parole chiave: lavorazioni del terreno; respirazione; biomassa; qCO_2; C-organico; attività fosfatasica.