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Effect of land use change on soil properties and carbon accumulation in the Ticino Park (North Italy)

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SUMMARY - *Effect of land use change on soil properties and carbon accumulation in the Ticino Park (North Italy)* - Changes in land use and management practices can easily affect the processes which govern soil organic matter (OM) accumulation and stabilisation and turn the soil from a sink into a source of CO_2, while loosing most of its functions. This work is aimed at evaluating the modifications on OM dynamics and soil properties caused by conversion of a natural mesohygrophilous forest to poplar plantation in the Ticino Park (North Italy). Soil horizons down to 60 cm were considered and analysed for their main chemical and physical characteristics. Organic matter was separated by density in free particulate OM (FPOM), occluded particulate OM (OPOM), and mineral-associated OM (MOM). The different land use and forest management in the two sites affected the amount and distribution of OM, with a significant decrease of carbon in the topsoil of the poplar stand compared to the natural forest. Consequently, the C stock in the topsoil of the poplar stand was considerably lower than in the forest, but, surprisingly, comparable amounts were found considering the whole profiles. In the deciduous forest OM was distributed among the three fractions, guarantying the pursuance of different biological and physical functions, whereas in the poplar stand the most part of OM was bound to mineral components, with a consequent loss of soil functionality.

RIASSUNTO - *Effetto del cambio d'uso sulle proprietà del suolo e sull'accumulo di carbonio nel Parco del Ticino (Nord Italia)* - I cambiamenti d'uso e delle pratiche di gestione del suolo possono facilmente influenzare i processi che governano l'accumulo e la stabilizzazione della sostanza organica (SO) nel suolo trasformandolo in *sink* o *source* di CO_2 e causando contemporaneamente la perdita di molte sue funzioni. Lo scopo di questo lavoro è la valutazione dei cambiamenti delle dinamiche della SO e delle proprietà del suolo causati dalla conversione di una foresta mesoigrofila naturale in un pioppeto situati all'interno del Parco del Ticino (Nord Italia). Gli orizzonti pedologici fino a 60 cm di profondità sono stati campionati e analizzati per le loro principali caratteristiche chimiche e fisiche. La SO è stata separata utilizzando un metodo densimetrico in SO particolata libera (FPOM), occlusa negli aggregati (OPOM) e associata alla frazione minerale (MOM). Il diverso uso del suolo e il diverso tipo di gestione nei due siti hanno influenzato il quantitativo e la distribuzione di SO nel suolo, con una significativa diminuzione di C negli orizzonti più superficiali del pioppeto rispetto alla foresta naturale. Di conseguenza, lo stock di C in tali orizzonti si presentava nel pioppeto molto inferiore rispetto alla foresta naturale, ma sorprendentemente i valori erano invece molto simili quando venivano presi in considerazione gli interi profili fino a 60 cm di profondità. Nella foresta decidua la SO era ben distribuita tra le diverse frazioni, assicurando così tutte le funzioni biologiche e fisiche del suolo, mentre nel pioppeto la maggior parte della SO era associata alla frazione minerale, con la conseguente perdita di molte funzioni del suolo.

Key words: carbon, density fractionation, stabilisation, primary plain forest, poplar plantation
Parole chiave: carbonio, frazionamento densimetrico, stabilizzazione, foresta planiziale primaria, pioppeto

1. INTRODUCTION

Soil organic matter (OM) plays a key role in ensuring agroecosystem productivity and the long-term conservation of soil resources. Adequate levels of OM are essential to maintain or improve chemical fertility, soil porosity, infiltration capacity, moisture retention, and resistance to water and wind erosion. On a global scale, OM represents the largest terrestrial repository of C (~1500 Pg C) and, thus, it is a key component of the C cycle. In this perspective, the capability of soil to accumulate and preserve organic matter has drawn much attention, in order to develop strategies to manage soils so as to increase their C storage and reduce the atmospheric CO_2. The United Nations Framework Convention on Climate Change (UNFCCC) has introduced the Land Use, Land Use Change and Forestry (LULUCF) approach, which aims at C sequestration through afforestation, reforestation, re-vegetation and forest-, crop-, and grassland management as a form of GHG-offset activities (Izaurralde *et al.* 2001; McCarl & Schneider 2001). On the other hand, changes in land use and management can have profound effects on quantity and dynamics of SOM and, in turn, on the soil ecosystem functions. On global scale, inaccurate managements have a large impact on the atmospheric CO_2 concentration (IPCC 2001; Allmaras *et al.* 2000). In particular, it is well established that converting natural forests or grasslands into agricultural fields generally leads to a decline in OM (Ellert & Gregorich 1996). Similarly, cultivation generally decreases the total OM, but there are contrasting results in the literature on the impact of fast-growing plantation forests and their management.

There is a growing interest in planting fast-growing hardwood species (such as hybrid poplars) to sustainably supply the fibre needed by the pulp and paper industries and meanwhile to meet a significant portion of the Kyoto commitments, especially in regions such as Europe and North America, with vast and fast-growing plantation forests (FAO 2004). Short-rotation plantations of Populus can rapidly fix atmospheric CO_2 in the tree components such as stems, branches and coarse roots but also increase the cycling of C and nutrients in soil through more labile litter pools consisting of leaves twigs and fine roots (Grigal & Berguson 1998; Berthelot *et al.* 2000; Sartori *et al.* 2006; Meiresonne *et al.* 2007). Furthermore, because of the high intensity of cultivation during initial years of plantation establishment, the dynamics and storage of OM and the connected soil properties need to be better understood. Various patterns of change in soil C in fact have been associated with short-rotation tree plantations, including transient losses (Hansen 1993), subsequent gains (Hansen 1993; Makeschin 1994) and no change (Ulzen-Appiah *et al.* 2000), even if often detection of short or even medium term land-use and/or management induced changes in total OM is difficult, due to high natural soil variability (Smith 2004).

Man-induced alterations affect not only the total C content of soils, but also its distribution among the various pools (Cambardella & Elliott 1994; Golchin *et al.* 1994), causing changes in the size distribution and stability of aggregates, as well as in OM properties (Six *et al.* 2000a, 2000b; John *et al.* 2005). However, the overall response of those pools to management practices remains poorly understood (Six *et al.* 2000a), especially in the context of hybrid poplar plantations.

Density fractionation is one method utilized to separate OM fractions with different biogeochemical functions and characteristics (Cambardella & Elliott 1993, 1994; Golchin *et al.* 1994; Swanston *et al.* 2002; Dubeux *et al.* 2006). It is a method which alters less the original composition of OM and the obtained fractions seem to be more sensitive indicators of environmental changes than total C (Cambardella & Elliott 1994; Six *et al.* 2000b) and to relate closely to OM mineralization and aggregate formation (Janzen *et al.* 1992; Christensen 2001).

In this work we aim at better understanding of the effect of short-rotation forestry on OM storage and dynamics and the relative ecosystem functionality by comparing a poplar plantation with the previous land use, i.e. a natural pristine forest.

2. STUDY AREA

The studied area is located within the Ticino's Regional Park, a UNESCO Man and Biosphere area since 2002, being one of the most important remains of the original ecosystem of the Po Valley. The area encompasses a mosaic of typical fluvial ecosystems, with large river habitats, wetlands, riparian woods and patches of the primary plain forest that covered the entire valley during Roman colonization. In particular such forests are nowadays extremely rare because of the heavy human impact on the whole plain, especially after the Second World War.

The sampling sites were a relict of pristine forest (Bosco Siro Negri) and a poplar plantation located within a former hunting forest reserve. Both sites are about 10 km NW of the city of Pavia, on the west bank of the Ticino River, and are characterised by the same temperate climate, with mean annual temperature of 12.3 °C and average precipitation of 802 mm per year (long term meteorological station of Pavia). The geological substrate is a relatively young alluvial deposit of sand and loamy materials covering gravels of various dimensions.

The Bosco Siro Negri, a 11 ha fully protected nature reserve since 1970, represents the natural forest. Being unmanaged for the last 70 years and documented as unmanaged hunting reserve for 200 years (Tomaselli & Gentile 1971), it is an extremely well preserved remains of the original alluvial forest along the Ticino River. The structure of the vegetation is that of a typical closed forest (mean height about 20 m) dominated by *Quercus robur* ssp. *robur*, *Acer campestris*, *Robinia pseudoacacia*, *Ulmus minor* and *Populus nigra* var. *europaea*, with different lower tree layers made up by younger individuals of the same species and *Corylus avellana*, *Prunus padus* and rich shrub and herbaceous layers.

The poplar plantation is located less than 1 km south of Bosco Siro Negri and it comprises 46 ha of a singular even-aged poplar clone with uniform management since the 1970s when the original forest was removed.

The cultivation cycle is 14 years, with trees 25-30 m high and a diameter at breast height of 25-30 cm. It is a low intensity management, with no irrigation and with clearing of ground vegetation by harrowing 1-2 times per year.

The major tillage is done during the first year of the cultivation cycle: after logging in October, the soil is prepared by drilling of the old stumps, deep (50-60 cm) ploughing and levelling; in spring, the new plantation is establish by inserting 4-5 m long shoots into soil down to 150-200 cm, followed by clearing of weeds for at least three times in the year. The actual plantation was established in spring 2005, with *Populus x euroamericana* I-214 clone, in a 6 x 6 scheme.

Being located on a river bank, the vegetation and soil morphology are governed by the river dynamics and particularly by water table fluctuations (varying by 2-3 m within normal years) and occasional flooding. The tree rooting system is shallow and concentrated in topsoils and the soil surface, if not levelled, is rather irregular, with more elevated areas and depression where water can remain longer, even if the general drainage is good.

The last flooding in November 2002 caused the transects and all the sampling points in the poplar plantation to be submerged for up to 80 cm, while only the most northern point in the natural forest was flooded. According to records of the Parco Ticino in the last 20 years, similar flooding events occurred in 1993, 1994, and 2000 (Furlanetto 2003).

3. METHODS

3.1. Soil sampling

Soils were sampled in summer 2006, when popular trees were 2 years old. To account for the heterogeneity, soils were sampled along transects at both sites (Ferré *et al.* 2005). In the natural forest, one single N-S transect was sampled at four points (NF19, NF16, NF22 and NF24), with decreasing elevation northward. In the poplar plantation two transects, with 2 sampling points each, were located approximately N-S (PP5 and PP1 from north to south) and E-W (PP6 and PP10 from east to west), to account for the growing gradient of the poplars, which were bigger when growing S and E. Furthermore, the sampling points PP5 and PP6 were located along the poplar rows, while the other 2 points (PP5 and PP10) were located between rows.

Soil pits were dug down to 60 cm and bulk and volumetric samples were taken by horizon. In the pristine forest, the forest floor was sampled, using a wooden frame (25x25 cm), while in the poplar plantation no litter layer was present.

3.2. Soil characterisation

Soil samples were oven dried at 40 °C to constant weight. The material from the organic layers was ground and sieved to <0.75 mm, while the mineral soil was sieved to <2 mm and then, partly, to <0.5 mm. Bulk density was determined gravimetrically by drying a known volume of sample at 105°C and corrected for stone content (determined by sieving). The pH was determined potentiometrically on soil:water suspensions (soil:water ratio 1:2 for mineral and 1:20 for organic samples). The cation exchange capacity (CEC) was determined with 0.1 M $BaCl_2$ at pH 8.1 and the exchangeable Na, Ca, Mg and K in extracts were determined by atomic absorption spectrometry (AAS). Soil texture was analyzed by a combined sieving and sedimentation method after dispersion in Na hexametaphosphate. Total C and N were determined on an elemental analyzer (LECO CNS-1000). Carbonate C was not present in the samples. All the analyses were performed in two replicates.

3.3. Density fractionation

Density fractionation of mineral soils was carried out on the <2 mm. Samples of C horizons were not included because of their extreme low C content. The procedure was adapted from Golchin *et al.* (1994) and Sohi *et al.* (2001) and was carried out using Na polytungstate (NaPT; Sometu, Berlin, Germany) solution of a density of 1.6 g cm^{-3}, based on the assumption that the density of organic matter is typically <1.5 g cm^{-3}. The procedure included ultrasonic dispersion to break down the aggregates and to release occluded POM (OPOM). The aim of the fractionation scheme was to separate OPOM with little or no interaction with mineral phases and so the intensity of the sonication was adapted to the type of soil (Cerli *et al.* 2007). Three of the samples were therefore fractionated (see below) using different amount of ultrasound (100, 200, 300 J ml^{-1}; output of ultrasonic energy calibrated calorimetrically according to Schmidt *et al.* 1999) and the C and N content of the obtained fractions was used to assess the energy input (here 200 J ml^{-1}) necessary to achieve complete release of OPOM without mineral "contamination".

Thereafter, all samples were fractionated using the following procedure: 125 ml of the NaPT solution were added to 25 g soil, gently shaken and allowed to stand for one hour. Then, after centrifugation at 6800 g for 20 min, the free particulate organic matter (FPOM) was separated by careful removal of the floating material and filtration on a glass fibre filter (GF/F, Whatman GmbH, Dassel, Germany). The settled soil was ultrasonically dispersed in NaPT solution (density 1.6 g cm^{-3}, soil-to-solution ratio 1:5) by applying 200 J ml^{-1}, then allowed to stand for one hour, centrifuged at 6800 g for 20 min and, similar as for the FPOM, the occluded particulate organic matter (OPOM) was finally separated by removal and filtration (GF/F filter) of the floating material. FPOM and OPOM fractions were washed with deionized water until the electrical conductivity was <20 µS cm^{-1}, then oven dried at 40 ºC to constant weight. The remaining soil material with a density >1.6 g cm^{-3} (heavy fraction), containing the mineral-associated organic matter (MOM), was also washed with deionized water until the electrical conductivity was <20 µS cm^{-1}, then freeze dried. Density fractionation was done twice per sample, and all fractions were analysed for their C and N content.

The mean of two replicates and the standard error were calculated (Webster 2001). The propagation error technique (Skoog & West 1987) was used to calculate the standard errors of values obtained by subtraction.

4. RESULTS AND DISCUSSION

4.1. General soil characteristics

The four soil profiles along the transect in the natural forest were similar and all classified as *Fluvisols* (IUSS Working Group 2006). They comprised A1 and A2 mineral horizons over an AC (only in NF19 and NF24) and the C horizon, typically of a coarser substrate, indicating a different material. The 2-5 cm organic layers were classified as Mésomull (AFES 2005), except for NF19, where the more depressed morphology resulted in an *Eumull* (AFES 2005).

The content of fine material in almost all the soil horizons decreased along the transect from north to south, resulting in a change in texture from sandy loam to loamy sand (Tab. 1). The pH was similar for the profiles, except for NF19, which was more acidic, probably due to the site morphology (Tab. 1). The cation exchange capacity reflected well the small differences among the profiles but showed no trend along the transect (Tab. 1). Fine material and cation exchange capacity decreased with soil depth while bulk density and pH increased (Tab. 1).

The profiles under the poplar plantation were all classified as well as *Fluvisols* (IUSS Working Group 2006). They had no organic layers but a sequence of two or three Ap horizons followed by the C horizon. Analyses confirmed the general homogeneity of soils, most likely resulting from 30 years of cultivation (Tab. 2). The only exception was PP5, which had a coarser texture and lower cation exchange capacity, most likely as a result of a slight differently textured alluvial deposit (Tab. 2).

Tab. 1 - Soil horizons depth, bulk density, pH, particle size distribution, exchangeable cations, and CEC values of the four profiles in the natural forest.
Tab. 1 - Profondità degli orizzonti, densità apparente, pH, granulometria, cationi scambiabili e capacità di scambio dei quattro profili di suolo nella foresta naturale.

code	horizons	horizon depth cm	bulk density g cm^{-3}	pH	sand %	silt %	clay %	Na $cmol_{(+)}$ kg^{-1}	K $cmol_{(+)}$ kg^{-1}	Ca $cmol_{(+)}$ kg^{-1}	Mg $cmol_{(+)}$ kg^{-1}	CEC $cmol_{(+)}$ kg^{-1}
NF24	A1	6	0.5	4.6	74	24	2	0.27	0.30	5.82	0.53	20.2
	A2	2.5	1.0	4.6	75	22	3	0.25	0.20	2.00	0.19	10.9
	CA	13.5	1.2	4.7	86	12	2	0.20	0.17	0.51	0.06	4.23
	C	38	n.d.	5.1	96	3	1	0.21	0.13	0.37	0.06	2.95
NF22	A1	5	1.0	5.4	74	24	2.	0.30	0.31	10.8	1.1	17.5
	A2	20	1.1	5.0	74	24	2	0.23	0.12	2.18	0.25	6.09
	C	35	1.2	6.0	94	5	1	0.22	0.10	1.10	0.16	0.79
NF16	A1	10	0.9	5.1	65	32	3	0.29	0.27	10.3	1.1	21.0
	A2	20	1.0	5.1	62	35	3	0.30	0.17	3.81	0.43	10.0
	C	30	1.2	5.7	86	13	1	0.20	0.15	1.87	0.21	2.73
NF19	A1	8	0.8	5.6	62	36	3	0.28	0.37	8.97	1.1	16.3
	A2	12	1.0	5.2	63	34	3	0.24	0.16	5.02	0.50	9.47
	CA	15	1.1	5.3	68	29	3	0.26	0.13	3.18	0.30	5.72
	C	25	1.2	6.1	83	16	1	0.19	0.11	1.91	0.21	3.30

Tab. 2 - Soil horizons depth, bulk density, pH, particle size distribution, exchangeable cations, and CEC values of the four profiles in the poplar plantation.
Tab. 2 - Profondità degli orizzonti, densità apparente, pH, granulometria, cationi scambiabili e capacità di scambio dei quattro profili di suolo nel pioppeto.

code	horizons	horizon depth cm	bulk density g cm^{-3}	pH	sand %	silt %	clay %	Na $cmol_{(+)}$ kg^{-1}	K $cmol_{(+)}$ kg^{-1}	Ca $cmol_{(+)}$ kg^{-1}	Mg $cmol_{(+)}$ kg^{-1}	CEC $cmol_{(+)}$ kg^{-1}
PP1	Ap1	12	1.0	6.0	48	46	6	0.29	0.21	5.55	0.85	8.39
	Ap2	18	1.3	5.9	46	49	5	0.26	0.15	5.24	0.71	8.32
	C	30	n.d.	5.9	47	47	6	0.49	0.13	5.31	0.72	8.06
PP6	arrowed	10	n.d.	5.8	64	32	4	0.35	0.17	4.84	0.53	7.47
	Ap1	12	0.9	5.6	52	43	5	0.36	0.20	4.96	0.71	9.67
	Ap2	28	1.3	5.9	55	41	4	0.41	0.21	5.25	0.81	7.53
	Ap3	15	n.d.	5.6	48	46	6	0.36	0.22	5.49	0.57	7.57
	C	10	n.d.	5.6	38	55	7	0.50	0.17	5.25	1.0	12.5
PP5	Ap1	20	1.0	6.0	89	9	2	0.22	0.21	1.58	0.23	1.30
	Ap2	12	1.3	6.1	86	11	3	0.24	0.15	1.39	0.21	1.58
	C	28	n.d.	6.0	84	12	4	0.20	0.11	1.66	0.27	1.36
PP10	Ap1	12	1.4	5.6	57	37	6	0.25	0.22	3.77	0.50	9.38
	Ap2	33	1.4	5.7	51	45	4	0.32	0.20	4.72	0.55	9.20
	C	15	n.d.	5.9	82	15	3	0.53	0.10	1.56	0.27	2.00

4.2. *Carbon and nitrogen*

The litter layer in the natural forest was thin and weakly developed, having on average 143 g C kg^{-1} and 8.3 g N kg^{-1}. The C content in the mineral soil strongly decreased with soil depth from 27.5-39.2 g C kg^{-1} in topsoils down 2.0 g C kg^{-1} and less in the C horizons (Tab. 3). The N content paralleled that of C, with largest values in the top mineral horizons and dropping with depth. The resulting C/N ratios are representative of a broadleaf forest soil in NF22 and NF24 while in NF19 and NF16 they were slightly lower suggesting a higher mineralization rate in top horizons and in the litter layer (17.2). The C stocks of the first 30 cm ranged between 2.6 and 5.8 kg C m^{-2} and from 0.30 to 1.0 kg C m^{-2} between 30 and 60 cm. The soil profile NF24 had a lower C and N content in all horizons. Except for NF24, the other profiles had average C stocks of 6.0±0.47 kg m^{-2} down to 60 cm, which increases to 6.8±0.47 kg m^{-2} when including the litter layer.

In the poplar plantation the lacking organic layer and the cultivation practices resulted in a generally low C and N concentration (Tab. 4). In contrast to the NF, the different horizons had rather similar contents of C and N, with slightly higher values in the Ap2 horizons.

4.3. *Density fractionation*

Density fractionation of soil under natural forest and poplar plantation revealed the MOM to be the dominant fraction, representing up to 92% weight, while FPOM and OPOM constituted minor proportion, being slightly more prominent under the natural forest than under poplar plantation (Tabs 5-6).

Under natural forest, the free light material was more prominent in the surface horizons of NF22 and NF24 (up to 4% weight) and decreased down the soil profile (Fig. 1). There was more occluded than free light material in the top 10 cm of the NF19 (3% weight) and NF16 soils (5%

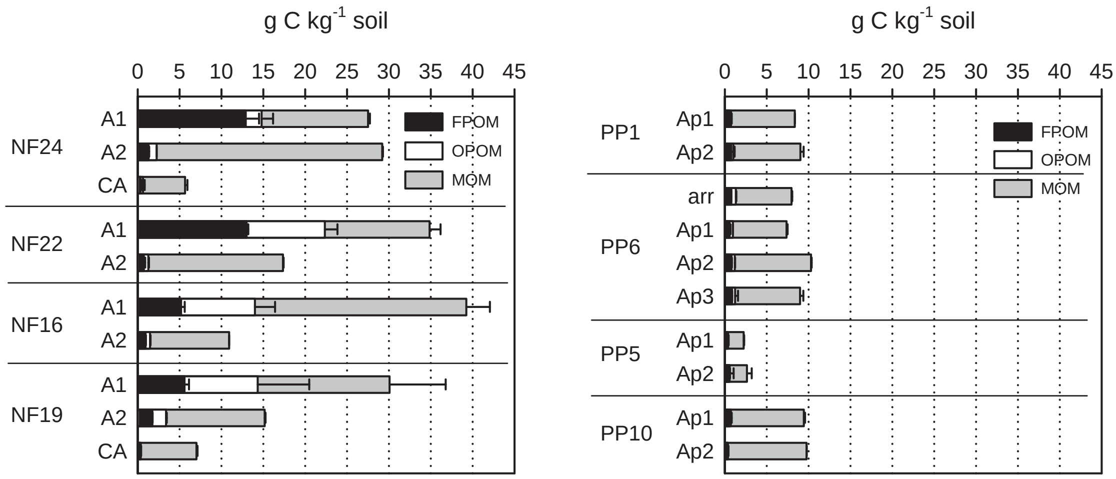

Fig. 1 - Distribution of C in the three density fractions separated from the four profiles in the natural forest and the poplar plantation.
Fig. 1 - Distribuzione del C nelle tre frazioni ottenute dai quattro profili di suolo nella foresta naturale e nel pioppeto.

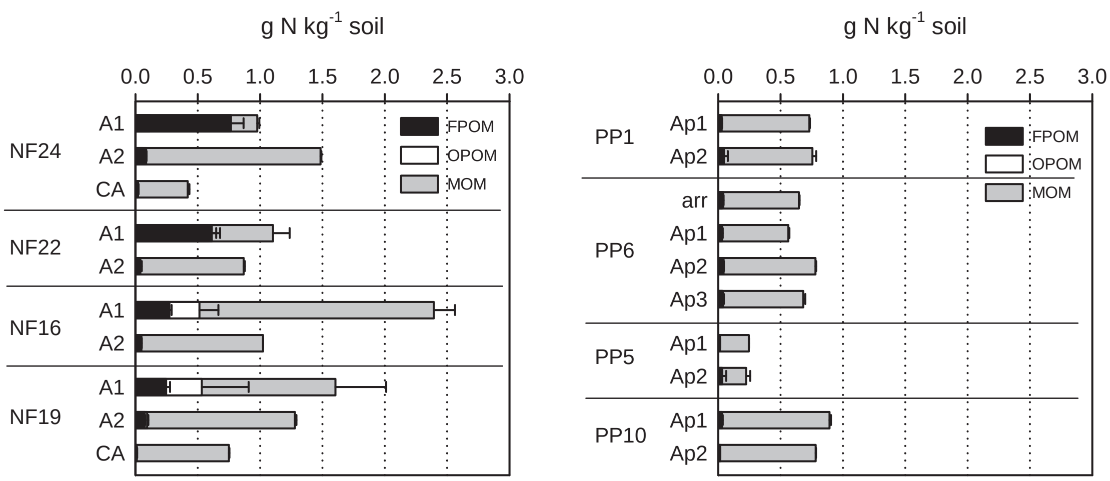

Fig. 2 - Distribution of N in the three density fractions separated from the four profiles in the natural forest and the poplar plantation.
Fig. 2 - Distribuzione dell'N nelle tre frazioni ottenute dai quattro profili di suolo nella foresta naturale e nel pioppeto.

weight). The FPOM contained 9 to 30% (NF22 and NF24) of the soil N. The OPOM was richer in N, holding up to 23% of the soil N; the MOM contained the largest portion of the soil N.

Under poplar plantation the FPOM and OPOM content was never more than 10% of total C in all horizons, except the Ap2 horizon of PP5. The most part of C was concentrated in the MOM fraction. Parallel to total C all

Tab. 3 - Soil C content, C/N ratio and C stocks along the four profiles in the natural forest.
Tab. 3 - Contenuto in C, rapporto C/N e stock di C lungo i quattro profili di suolo nella foresta naturale.

code	horizons	horizon depth cm	C g kg^{-1} soil	N g kg^{-1} soil	C/N	C kg m^{-2}	N kg m^{-2}
NF24	A1	6	27.5	1.86	14.8	0.83	0.06
	A2	2.5	29.2	1.63	17.9	0.73	0.04
	CA	13.5	5.66	0.46	12.4	0.92	0.07
	C	38	1.06	0.10	10.8	0.25	0.02
NF22	A1	5	34.9	2.30	15.2	1.69	0.11
	A2	20	17.4	0.95	18.4	3.82	0.21
	C	35	0.83	0.08	10.6	0.36	0.03
NF16	A1	10	39.2	3.18	12.3	3.49	0.28
	A2	20	10.9	1.10	9.9	2.27	0.23
	C	30	2.25	0.23	9.7	0.80	0.08
NF19	A1	8	30.1	2.38	12.6	2.02	0.16
	A2	12	15.2	1.45	10.5	1.82	0.17
	CA	15	7.04	0.77	9.2	1.19	0.13
	C	25	2.05	0.19	10.6	0.63	0.06

Tab. 4 - Soil C content, C/N ratio and C stocks along the four profiles in the poplar plantation.
Tab. 4 - Contenuto in C, rapporto C/N e stock di C lungo i quattro profili di suolo nel pioppeto.

code	horizons	horizon depth cm	C g kg^{-1} soil	N g kg^{-1} soil	C/N	C kg m^{-2}	N kg m^{-2}
PP1	Ap1	12	8.36	0.78	10.7	1.00	0.09
	Ap2	18	9.02	0.82	11.0	2.11	0.19
	C	30	8.91	0.79	11.3	3.47	0.31
PP6	harrowed	10	7.98	0.72	11.1	0.00	0.00
	Ap1	12	7.38	0.62	12.0	0.80	0.07
	Ap2	28	10.3	0.85	12.2	3.74	0.31
	Ap3	15	8.99	0.75	11.9	1.75	0.15
	C	10	5.54	0.50	11.1	0.72	0.06
PP5	Ap1	20	2.26	0.27	8.4	0.45	0.05
	Ap2	12	2.64	0.26	10.2	0.41	0.04
	C	28	2.22	0.31	7.3	0.23	0.03
PP10	Ap1	12	9.44	0.93	10.1	1.59	0.16
	Ap2	33	9.76	0.80	12.2	4.51	0.37
	C	15	2.00	0.19	10.6	0.28	0.03

Tab. 5 - Soil recovery after density fractionation of the mineral horizons and C and N content of density fractions of the four profiles in the natural forest.
Tab. 5 - Distribuzione in peso del suolo tra le frazioni e loro contenuto in C e N lungo i quattro profili di suolo nella foresta naturale.

code	horizons	horizon depth cm	F POM g kg^{-1} soil	O POM g kg^{-1} soil	MOM g kg^{-1} soil	C F POM % tot C	C O POM % tot C	C MOM % tot C	N F POM % tot N	N O POM % tot N	N MOM % tot N
NF24	A1	6	41.4	4.61	954	46.9	6.85	46.2	41.2	6.26	52.6
	A2	2.5	4.76	2.33	993	4.47	3.29	92.2	5.27	3.54	91.2
	CA	13.5	1.44	1.11	997	6.40	4.99	88.6	4.55	3.61	91.8
	C	38									
NF22	A1	5	41.6	37.2	921	37.3	26.8	35.9	26.7	25.3	48.0
	A2	20	2.63	1.63	996	4.27	3.02	92.7	4.32	3.85	91.8
	C	35									
NF16	A1	10	18.3	50.2	932	13.2	22.5	64.3	8.56	16.2	75.3
	A2	20	3.27	1.41	995	8.67	4.97	86.4	4.42	2.95	92.6
	C	30									
NF19	A1	8	17.7	29.2	953	18.6	29.0	52.4	10.4	22.3	67.3
	A2	12	6.79	3.94	989	11.6	10.8	77.6	5.23	6.51	88.3
	CA	15	1.16	0.48	998	3.43	1.80	94.8	1.58	0.87	97.6

Tab. 6 - Soil weight distribution after density fractionation and C and N content of density fractions of the four profiles in the poplar plantation.
Tab. 6 - Distribuzione in peso del suolo tra le frazioni e loro contenuto in C e N lungo i quattro profili di suolo nel pioppeto.

code	horizons	horizon depth cm	F POM g kg^{-1} soil	O POM g kg^{-1} soil	MOM g kg^{-1} soil	C F POM % tot C	C O POM % tot C	C MOM % tot C	N F POM % tot N	N O POM % tot N	N MOM % tot N
PP1	Ap1	12	2.63	0.58	997	6.15	2.77	91.1	3.59	2.56	93.8
	Ap2	18	3.24	0.79	996	8.27	2.96	88.8	5.62	2.05	92.3
	C	30									
PP6	arrowed	10	3.22	1.26	996	9.88	6.50	83.6	5.67	4.19	90.1
	Ap1	12	2.15	0.89	997	7.99	5.02	87.0	4.95	3.62	91.4
	Ap2	28	3.07	0.93	996	7.76	3.78	88.5	5.05	2.68	92.3
	Ap3	15	3.20	1.04	996	9.58	4.12	86.3	5.23	4.23	90.5
	C	10									
PP5	Ap1	20	1.00	0.61	998	10.2	7.43	82.4	5.08	3.94	91.0
	Ap2	12	4.13	0.78	995	19.7	2.04	78.2	12.2	1.60	86.2
	C	28									
PP10	Ap1	12	2.14	0.51	997	6.07	1.58	92.4	3.22	0.98	95.8
	Ap2	33	1.34	0.27	998	3.16	0.78	96.1	1.92	0.66	97.4

these fractions were homogeneous along the profile. The FPOM contained 1 to 12% of the soil N, while the OPOM was poorer (0.7 to 5.7 % of soil N) and the MOM fraction richer than the corresponding fraction in the natural forest.

5. DISCUSSION

The natural forest and poplar plantation are located on the same type of soil, which has been influenced by periodical flooding events and erosion by the Ticino River and anthropogenic disturbances (land use change and cultivation), resulting in modification of vegetation, fauna activity and site conditions. In particular the replacement of the natural forest by the poplar plantation strongly affected the soil system, even if the management practices used are not intensive. The short harvesting cycle and soil tillage resulted in a strong redistribution of C along the profile and a general reduction of OM in the uppermost soils.

In the natural forest, the continuous input of fresh organic material resulted in surface organic layers and organic-rich A horizons (Batjes 1996). Martens *et al.* (2003) reported for similar forests much higher values of about 76 g C kg^{-1} in the first 4 cm of soil. The role of old-growth forests as C sinks is normally considered to be negligible (Jarvis 1989; Melillo *et al.* 1996), because of the equilibrium between photosynthesis and respiration. However, some authors have demonstrated the importance of including mature forests in the models for terrestrial C dynamics to correctly evaluate the global C balance (Carey *et al.* 2001; Zhou *et al.* 2006).

The distribution of C among the different density fractions reveals that a relevant part of the organic matter was unprotected, representing fresh debris material easily biodegradable. A relevant part of organic matter was occluded into aggregates, favouring soil structure, especially where the texture was less sandy. It could be therefore inferred that, in spite of the long-term equilibrium, the presence of free OM favours the biological activity and the recycling of nutrients, as deduced by the N content, but the increased soil respiration results in a consistent loss of C as CO_2 (Alvarez & Alvarez 2000). Ferré *et al.* (2005) reported for the study site slightly higher CO_2 emissions compared with poplar plantations, however the differences were not statistically significant.

It has to be considered that although being an unmanaged forest, this site has suffered different natural disturbances over time such erosions and sedimentation by the Ticino river, periodical flooding, presence of cormorants, insect attack, summer drought and pollution, resulting in a gradual decline (Rossini *et al.* 2006). The result is an average accumulation of 4.64 kg C m^{-2} in the first 30 cm and of 5.27 kg C m^{-2} if considering the whole profile down to 60 cm, which are lower values compared with broadleaf forests of temperate regions (Sanesi 2000).

However, the most part of organic matter in the soils was intimately associated with the mineral phase. This may be the result of high biotic activity, leading to an oxidative transformation of organic compounds and, thus, to an enrichment of the carboxyl groups capable to form strong bonds to the mineral phase. The resulting organic-mineral associations may stabilize OM against microbial degradation and prolong carbon residence time in soil (von Lützov *et al.* 2006).

The differences among the sampling points reflect the complex and variable site morphology, creating a patchwork of microclimates and vegetation types. The transect approach tries to include these differences, thus accounting for the different dynamics.

In the poplar plantation, the lower C content in the upper mineral layers can be attributed to the reduced input of organic material and to the increased decomposition induced by the cultivation practices (Guo & Gifford 2002; Vesterdal *et al*. 2002). The lower C/N ratio and the little free organic material supports the hypothesis of a rapid degradation resulting in fast disappearance of the more labile material. Organic matter input derived from concurrent herbaceous species, which were periodically removed by harrowing or by ploughing at the beginning of the new cultivation cycle. In 2005, the change from an open but mature stand to almost uncovered soil changed the input of organic material (Jug *et al.* 1999) as well as the microclimatic conditions. The higher nutrient demands of the new plantation could have also induced accelerated decomposition (Vesterdal *et al.* 2002; Cerli *et al*. 2006). The high decomposition rate and the lignin-rich debris, in particular from the stumps, could be responsible for the low fertility of the soil, as indicated by the low CEC and N content.

The quantity of occluded organic material was low in all profiles at all depth. The ploughing, causing breakdown of aggregates and the speeding up of their turnover, could further increase the degradation processes by exposing organic material to biodegradation and oxidative agents (Six *et al.* 1998, 1999, 2000a).

The land use change determined also a different distribution of C along the profile, with values in the C horizons of PP1 and PP6 (along the plantation rows) being even higher then in the respective horizons of the natural forest. This has been reported for many agricultural soils and attributed to the intensity of cultivation and depth of ploughing (Del Galdo *et al.* 2003). The C increase in Ap2 horizons could be due to the incorporation of stump residues from the precedent cycle and to a minor extent also to the developing root system of the new poplars.

In term of C storage at profile scale, the poplar plantation showed only slightly lower values than the natural forest, in spite of 40 years of different soil use and management. This surprising and unexpected result seems in sharp contrast with the latest considerations regarding the effect of soil cultivation on soil C (Lal 2004). It has to be considered that the periodic flooding of the Ticino river, which affected more intensively the poplar plantation than the natural forest, may have caused a texture richer in silt and clay (Tab. 2). This could favour organic matter protection from microbial utilisation due to adsorption of organic compounds at clay surfaces (Tisdall & Oades 1982; Gleixner *et al.* 2002) and to occlusion of organic material into micropores inaccessible for microorganisms (Elliott & Coleman 1988; Gleixner *at al*. 2002; Guggemberger & Kaiser 2003). The major portion of C was in fact recovered in the heavy mineral fraction, pointing at strong interactions with the mineral phase, and consequently to possibly higher stabilization of C. This is further supported by the lower C content in the PP5 profile where the texture was more sandy than in the other profiles.

Another cause of smaller C loss in the poplar plantation could be the timing of the sampling, right after the drilling of stumps. The C stocks estimated in 2003 (Ferré *et al.* 2005) were smaller (-2 kg C m^{-2}) than those we found, indicating that the C balance is strongly depending on the phase of the cultivation cycle, and thus should be considered with care.

6. CONCLUSIONS

The land use change from a primary floodplain forest to poplar plantation has modified many chemical and physical soil properties. The quantity and quality of organic input at the two sites influenced the C content and distribution along the soil profile. In the natural forest, the presence of a litter layer and the natural incorporation of plant remains into the top mineral soil resulted in a C profile sharply decreasing with depth, thus contrasting the homogeneous depth distribution under the poplar plantation, which seems to be caused by cultivation practices. In the poplar plantation, the transfer of C into the deeper horizons by ploughing and the input of fine soil particles during flooding events, resulted in unexpected similar C stocks at the two sites.

In the natural forest, organic matter was partly free, thus bioavailable, while another fraction was stabilized within aggregates and by formation of strong organo-mineral complexes, particularly in the deeper horizons. On the opposite, in the poplar stand the most OM was bound to mineral components, while little amounts were in the free and occluded light fractions. The lack of litter input and the periodical disturbances seem to accelerate the turnover and disruption of aggregates therefore OM mineralization rate, leaving behind only organic material strongly protected against decomposition.

From these results, it appears that the main effects of a 40-years change from pristine forest to poplar plantation are related to the C (re-)distribution both along the soil profile and among density fractions. Although C storage was apparently little affected, the soil biological activity, fertility, and structure declined under the poplar plantation. This means that in a longer perspective, soil quality and functionality may be impacted at a larger extent than indicated by the simple C balance.

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