FARMYARD MANURE VERSUS SLURRY: IS IT WORTHWHILE TO REMOVE CROP RESIDUES FROM THE FIELD TO INCREASE SOIL CARBON STOCK ELSEWHERE?

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1 INTRODUCTION

Agronomists have long recognized the effect of farmyard manure application on maintaining and increasing soil organic carbon, and consequently soil fertility and water retention. More recently, it was suggested that increasing soil carbon stock might contribute in curbing the rise of atmospheric CO_2 concentration (Lal, 2002). Nevertheless, Schlesinger (1999) contend that no net sink of carbon (C) is likely to accompany the use of manure. In particular, this author argued that manuring is not a valid method for soil C sequestration because of the extra land required to produce the manure used on a given area. The scope of this study is to add light to the current debate on the effectiveness of farmyard manure in promoting soil C storage. Our discussion is based on experimental data collected on a medium-term field experiment in which farmyard manure and semi-liquid manure were repeatedly applied over the years.

2 MATERIALS AND METHODS

2.1 Site characterization and agronomic details

A long-term field experiment was started in 1995, and still on-going, at the experimental station of CRA-FLC, Centro di Ricerca per le Produzioni Foraggere e Lattiero Casearie, located in Lodi, High Po Valley, Northern Italy (Lat. 45°19' N, Long. 9°28' E, 80 m a.s.l.). The soil at the site is classified as a coarse-loamy, mixed, mesic, Typic Haplustalf. The climate is temperate subcontinental, the average annual rainfall is about 800 mm, well distributed along the year, and the average annual daily temperature is 12.5 °C with a minimum of 1.1°C in January and a maximum of 22.9 °C in July (Onofrii et al., 1993, Borrelli and Tomasoni, 2005). The experiment compares two rotations: the annual double crop R1, Italian ryegrass, *Lolium multiflorum* Lam.+ silage maize, *Zea mays* L.; and the 6-year rotation R6, in which 3 years of double crop Italian ryegrass + silage maize are followed by three years of alfalfa, *Medicago sativa* L.), harvested for hay. Italian ryegrass was sown in middle October to late November and harvested in the first decade of May, silage maize was sown from the end of May to beginning of June and harvested in the middle of September. Alfalfa was sown from the end of March to beginning of April, and the crop stand lasts three years. Each rotation has received two types of dairy manure: 1) farmyard manure (FYM) with added maize stover; 2) semi liquid manure (SLM) without addition of stover. The amounts applied matched the criterion of returning to each unit land area the excreta produced by the number of adult dairy cows sustained, in terms of net energy, by the forage produced in each rotation, corresponding to 6 adult cows ha^{-1} for R1 and 4 adult cows ha^{-1} for R6, respectively. Consequently, 66 t ha^{-1} of FYM and 100 m^3 ha^{-1} of SLM were applied annually to R1; 44 t ha^{-1} of FYM and 66 m^3 ha^{-1} of SLM were applied annually to R6. The average manure composition was 0.66 N %, 0.48 % P_2O_5 and 0.70 % K_2O for FYM; 0.255 % N, 0.18 % P_2O_5 and 0.30 % K_2O for SLM. Both FYM and SLM were incorporated into the soil by plowing at 0.3 m depth immediately after their distribution. Moreover, each manure treatment was applied in combination with two rates of industrial N, applied in form of urea: N0 (i.e. 0 kg N ha^{-1} for all crops) and N1 (i.e. 75 kg N ha^{-1} for Italian ryegrass; 150 kg ha^{-1} N for maize; 0 kg N ha^{-1} for alfalfa). The experimental design was a strip-split-split–plot, with three replications. Each phase of the rotations was present every year, in order to control the years interaction effect. This includes one plot for the annual rotation R1 and six plots for the 6-year rotation R6. The size of the elementary plot was 84 m^2.

In the area under study, maize is normally irrigated by flooding irrigation, with about 1000 m^3 per hectare for each water supply (Ciotti, 1978, Cereti et al. 1985), and irrigation turns regulated by water consortium. This implies that in year with lack of water availability water limited production conditions cannot be avoided. Alfalfa normally is not irrigated, unless in very critical years, in order to avoid drowning of the rooting system. In the present trial sprinkler irrigation was applied to maize, at each water supply from the water consortium, in order to avoid that contiguous plots of alfalfa would receive water supply. Weeds were controlled chemically. Data reported in this paper refers to soil sampling, and analysis, of the year 2006.

2.2 Soil sampling and analysis

Soil samples were collected from all plots on September 2006, after the harvest of silage maize, about 12 years from the outset of the experiment. Three independent soil cores were collected for each plot, for the soil layers 0.-0.3 m which corresponds to the depth of annual ploughing. Soil cores were collected using a soil sampler drill, model Eijkelkamp, 4 cm diameter. Samples from each plot were combined and sieved. The sieved soil was used to determine the soil organic matter through chromic acid digestion, according to the Walkley-Black method and total N using the Kjeldahl method, according to Page et al. (1982). The Statistical analysis were performed using the GLM procedure of the SAS systems (Sas, 1990).

3 RESULTS AND DISCUSSION

The effect of manure application, in combination with the rotation, on soil organic carbon (SOC), and total N concentration are reported in table 1 (ANOVA) and table 2 (mean values). In figure 1 are shown the values of C to N ratio of each treatment in comparison with the one measured at the outset of the experiment. The application of FYM, compared to SLM, increased SOC +27 % for the rotation R1, and +14 % for the rotation R6. Interestingly, the highest value of SOC, i.e. 2.47 %, measured on the intensive treatment R1 combined with FYM, is still lower than to the value of 2.94% reported by Lanza and Spallacci (1970) after 18 years of continuous application of 40 Mg of FYM ha^{-1} integrated by mineral N, on a loam soil in Modena, Po Valley, Northern Italy. Thus, it is likely that the level of SOM in the present experiment is still increasing. Compared to initial conditions, the maximum increase of the soil C to N ratio was observed for rotation R1 combined with FYM, that received the highest amount of FYM. In good agreement, little if any increase of the soil C to N ratio was observed for the combination of rotation R6 and SLM, that received the lowest amount of SLM and little crop residues.

TABLE 1 **ANOVA Analysis results P value**

Source	df	C org (Mg ha^{-1})	total N (g kg^{-1})
Block	**2**	-	-
Manure (M)	**1**	0.0202	0.0424
Error1	**2**	-	-
Rotation (R)	**1**	0.0235	ns
M x R	**1**	0.0623	ns
Error2	**4**	-	-
Nitrogen (N)	**1**	ns	ns
M x N	**1**	ns	ns
R x N	**1**	ns	ns
M x R x N	**1**	ns	ns
Pool error	**8**		

TABLE 2 **Soil Organic C and total N after 12 years from the outset of the experiment**

Manure	Rotation	C org (Mg ha^{-1})	Total N (g kg^{-1})
FYM	R1	61.06 a	1.62 a
	R6	53.49 b	1.46 a
SLM	R1	48.10 c	1.27 b
	R6	46.87c	1.29 b

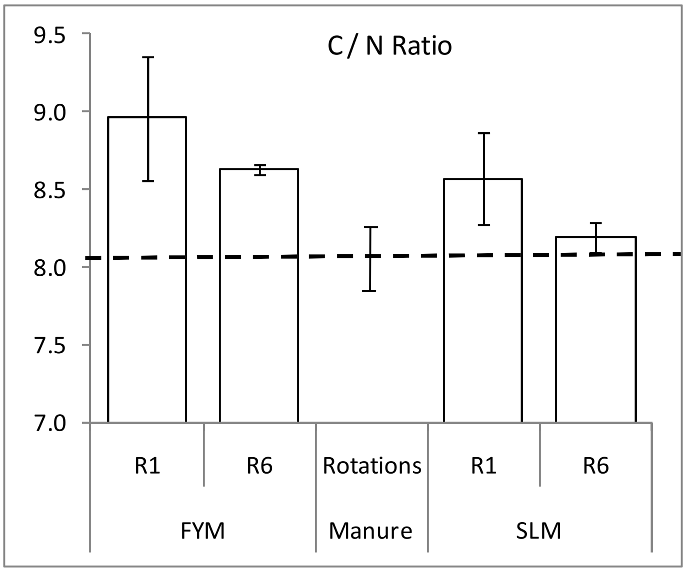

FIGURE 1 **Soil C/N ratio after 12 years from the outset of the experiment. The dashed line indicate the level of C/N ratio at the outset of the experiment. Bars indicate standard errors.**

While it is quite evident that FYM remarkably increased soil C stock, a cautionary remark is appropriate here. From the standpoint of C cycle it is important to notice that, in the present experiment, forage production combined with SLM application represent an almost closed system, in which the excreta produced are returned to the same unit land area feeding the animals. On the contrary, in case of FYM it is crucial to consider that the maize stover necessary for composting the manure was produced outside the experimental plots. Therefore, most of the carbon embedded in FYM was imported from land area external to the forage rotations under study. This external cropland need to be cultivated with grain maize, either in monocrop or in rotation, to provide the maize stover necessary for composting the animal excreta of these forage-based systems under study. Consequently, the observed increase of the soil C stock occurred at the expenses of external land area that was deprived of maize crop residues. According to Draghetti (1991) about 3-5 kg of litter per day is necessary for one adult cow. Assuming an average of 4 kg litter cow^{-1} day^{-1} x 365 days = 1460 kg of maize stover cow^{-1} year^{-1}. Hence, the 4 and 6 cows sustained by the rotations R1 and R6 require respectively about 5840 and 8760 kg of maize stover year^{-1}. Assuming an average maize stover production of 9000 kg ha^{-1}, about 0.65 and 0.98 ha of grain maize must be deprived annually of their maize crop residues for composting the FYM necessary for 1 ha of the rotation R6 and R1 receiving FYM. Yet, assuming that the grain maize is rotated in a three-year rotation, about 3 x 0.65 = 1.95 ha and 3 x 0.98 = 2.94 ha would be necessary to provide annually the maize stover necessary to enrich the soil C stock of one hectare cultivated with the forage rotations devised in the present experiment.

Our findings are in good agreement with Schlesinger (1999; 2000) who pointed out that no net sink for C is likely to accompany the use of manure on agricultural land when the boundaries of the system are properly considered. Schlesinger (1999) using data of Missouri, estimated that the entire above-ground plant production on 3.0 ha of land was required to supply the manure to each hectare of manured land. Consequenlty, the author concluded that greater concentrations of SOM in manured fields can be expected to be associated with declining SOM on a proportionally larger area of off-site lands. Our experimental data, however, refers to a different situation in which intensive forage rotation systems produce heavy load of manure. Under our experimental conditions are maize crop residues, rather than manure, that need to be produced on extra land to produce the farmyard manure necessary to increase soil carbon storage. In contrast, Bertora et al. (2009) pointed out that farmyard manure application is a superior technique with respect to slurry application because the composting allows more carbon to be transformed into stable organic matter. Moreover, Yamulki (2006) indicated that increasing the carbon content of the manure heap with high-C additives, such as straw or maize stover, may provide the opportunity for N_2O and CH_4 emission reduction. Nevertheless, our data suggest that a pitfall is just around the corner: unless farmyard manure is evenly distributed on the whole surface providing the crop residues needed to its preparation, it may result in “robbing Peter to pay Paul”.

4 CONCLUSIONS

Our findings suggest that the claim FYM is particularly effective in increasing soil C stock has to be tempered against the fact that FYM preparation implies removal of crop residues from original cropland and concentration of C elsewhere. Thus, we suggest that the strategy of applying SLM and leaving grain crops residues where they are produced, is likely to be more sustainable at territorial level.

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