Effectiveness of the GAEC cross-compliance standard *management of stubble and crop residues* in the maintenance of adequate contents of soil organic carbon

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Abstract

Several studies carried out on the effects of stubble and crop residue incorporation have shown positive effects on chemical-physical soil characteristics. However, not all studies agree on the extent of soil organic matter increase which derives from this process, as this effect is strongly affected by other factors: the pedo-climatic features of the area in which the study is carried out, the type of crop residue incorporation and the agronomical management adopted to improve the decomposition of the incorporated fresh organic material. The burning of stubble and straw is common in the areas where cereals are traditionally grown. The adoption of this method is based on different technical and work-related factors, which become less important when taking into account the impact on the local environment and soil.

A research is currently carried out at the CRA-SCA experimental farm in Foggia (Southern Italy) on the effects of either residues incorporation or burning on the chemical-physical characteristics of the soil and on the wheat yield performance since 1977. This experiment allows for a comparison among the effects of burning, the simple incorporation of stubble and crop residues and incorporation carried out with some agronomical techniques (such as the distribution of increasing amounts of nitrogen on crop residue before incorporation) and the simulation of rain (50 mm) on the decomposition of organic material.

The objective of the study was to understand the effect of the different residues management practices on soil chemical properties after 32 years of experimentation. The simple incorporation of straw and stubble showed a slight increase in organic soil matter of 0.7% with respect to burning. The best results for soil organic carbon and soil quality were obtained when residual incorporation included a treatment with additional mineral nitrogen.

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Introduction

Several studies have been carried out throughout the world on the incorporation of crop residues into the soil (Lemke *et al*., 2010; Convertini *et al*., 1998; Maiorana *et al*., 1992, 1993, 1996, 1997, 2001, 2003; Ferri *et al*., 1993; Fischer *et al*., 2002; Franzluebbers, 2002; Lal, 1997, 2009; Bonciarelli *et al*., 1972, 1974; Morel *et al*., 1981; Nicholson *et al*., 1997). All of these have highlighted the positive effect of this technique on the chemical-physical characteristics of the soil but they do not all agree on the extent of increase in soil organic matter which derives from this process, as this effect is strongly affected by other characteristics such as the pedo-climactic features of the area in which the study is carried out, the type of crop residue incorporation and the agronomical practices adopted to improve the decomposition of the incorporated fresh organic material.

The burning of stubble and straw is common in areas where cereals are traditionally cultivated. The adoption of this method is based on a series of factors: it is not always possible to harvest rows of straw due to the irregularity or steepness of the land; there is less need for straw following a reduction in livestock farming and heads of cattle; it is a cheap way to clear soil of residues, avoiding machinery utilization and reducing the tillage depth; it is necessary to eradicate the inoculums of any diseases present in the residue of the previous crop; it is necessary to reduce the number of germinable weed seeds.

Up to several decades ago, the widespread presence of cereal crops, linked to the large number of local livestock farms, allowed farmers to dispose of straw produced in the field following grain harvests. However, the last twenty years have seen a slow and still progressive decrease in the number of heads of cattle and consequently of livestock farming. Furthermore, there has been an increase in areas dedicated to cereals, which were previously used for fodder crops.

In response to this situation, cereal farmers continued (and increased) burning straw and stubble at the end of cereal crop cycles.

The use of this technique showed a number of advantages: it was cheap, it was a fast method to clear the soil and it partially destroyed weed seeds. The only negative factor taken into consideration was that of the risk of fires (Convertini *et al*., 1998). The choice of burning as opposed to incorporation undervalued the advantages and potential long-term benefits of the latter such as the positive effects on soil fertility and on a number of physical-mechanical characteristics. However, these factors also contrasted with the certainty of greater labour costs needed to incorporate crop residues into the soil and a decrease in grain production, at least to begin with (Convertini *et al*., 1998). A number of studies have demonstrated that burning residue over a period of twenty years did not result in any significant reduction in grain yield or soil organic matter; subsequently, a reduction in microbic activity was noted with an increase in the loss of soil organic carbon (Rasmussen *et al*., 1991). Straw and stubble burning does not, therefore, determine a rapid loss of soil carbon but significantly affects important physical properties, since soil colour, aggregate stability and the rate of water infiltration differ depending on whether straw is burnt or incorporated (Rasmussen *et al*., 1980).

However, a large supply of straw, with or without nitrogen, does not guarantee the maintenance of soil nitrogen and carbon levels; on the other hand, even where organic supply which is not considerable, some soils cultivated in the same way and under the same environmental conditions maintain or even increase their levels of nitrogen and carbon. Morel *et al*. (1981) underlined the importance of considering the role of roots in influencing the level of soil organic matter. Lemke *et al*. (2010) carried out different research studies in 22 locations to evaluate the effect of incorporation over varying periods of time, which, however, were at minimum 11 years. Results showed that even an appropriate use of residue did not always result in an increase in soil organic matter; indeed, in some cases, small losses were noted, independently of the cultivation techniques used. This demonstrates that it is not possible to derive conclusions valid for all soil types, climates and different uses of residue.

The choice of residue management can influence soil quality, whose measurable parameters are influenced by a number of factors. The general indicators are quantitative measurements of properties or expression of natural phenomena that take place at soil level and also provide the results of a number of variables. Many of the properties used as indicators of changes in soil quality are considered static indicators (soil organic matter, ratio of organic carbon to total nitrogen value) as they tend only to show variations over a long period of time. However, other indicators are effective in demonstrating changes over a short period of time and are thus known as dynamic, such as the kinetics of organic carbon mineralization, microbial biomass carbon content and the ratio of biomass carbon to total organic carbon (Pinzari et al., 2000).

This research is part of EFFICOND (Environmental eFFectiveness of CrOss-compliaNce stanDards), a national project of the CRA (Agricultural Research Council) started in 2009 to meet the specific needs of the National Rural Network (RRN) to monitor and assess the environmental-protection measures imposed by the Common Agricultural Policy (CAP) on the national agricultural policy and implemented via the Regional Rural Development Plans (PSR). The project's main goals are the assessment of the Standards' environmental efficacy and the development of agri-environmental indicators for the assessment of the Standards' efficacy at a national level.

The Standards of Good Agricultural and Environmental Condition (GAEC) form part of the requirements under cross compliance and apply to any farm receiving payments under the Single Payment Scheme. The standard *management of stubble and crop residues* concerns the agronomic objective to *maintain soil adequate contents of soil organic carbon* indicated in Annex IV of EC Regulation no. 1782/03. This standard was introduced by different Decrees of the Ministry of Agricultural, Food and Forestry Policies (Mipaaf) on cross compliance from mid-2004 (Decree 1787/2004 et seq.) until the end of 2009. The Mipaaf Decree of December 2009, issued following the CAP Health Check, kept this standard (Standard 2.1) as part of Norm 2 *Maintain soil organic matter levels through appropriate practices*. The standard was made compulsory but there are still exceptions related to regional laws to regulate the burning of stubble.

The objective of this study is to evaluate the fertility of a soil in the province of Foggia over a 32-year period in which nine agronomical treatments of burning and incorporation of stubble, both with and without nitrogenous fertilizer and irrigation of straw, were scheduled. Field research focussed on a continuous cultivation of durum wheat.

Materials and Methods

The field research, carried out in the framework of EFFICOND Project, began in the autumn of 1977 at the CRA-SCA Experimental Farm in Foggia, Italy (41° 26' N, 15° 30' E, 90 m above sea level). This is included in an agricultural area dedicated to cereal, leguminous vegetables and industrial horticulture. The soil has a clay-loam texture with an alluvial origin, classified by Soil Taxonomy-USDA as fine, mesic, Typic Chromoxerert (Soil Survey Staff, 1992). The principal characteristics are shown in Table 1.

The climate is classified by FAO-UNESCO Bioclimatic Maps *as accentuated thermo-Mediterranean*, characterized by hot summers with low precipitation, which over recent years has fallen predominantly in the winter months which are cold and wet; indeed, most rainfall is concentrated in the autumn and winter.

The experimental layout, a randomized block with five replicates, compared nine different residues management systems on unit plots measuring 80 m^2, as follow: T1 burning of wheat crop residues; T2 incorporation of stubble and straw into the soil; T3 incorporation + 50 kg ha^{-1} of N on residues; T4 incorporation + 100 kg ha^{-1} of N on residues; T5 incorporation + 150 kg ha^{-1} of N on residues; T6 as T3 treatment + 500 m^3 ha^{-1} of water on residues; T7 as T4 treatment + 500 m^3 ha^{-1} of water on residues; T8 as T5 treatment + 500 m^3 ha^{-1} of water on residues; T9: incorporation of crop residues without addition of N on residues and as top dressing. The minimum doses of nitrogen added to

Table 1. Initial characteristics of the soil.

Parameter	Value
Total N	0.12%
Total P (P_2O_5)	0.12%
Available P (P_2O_5)	41 ppm
Total K (K_2O)	1.25%
Exchangeable K (K_2O)	1561 ppm
$CaCO_3$	7.30%
Organic matter°	2.10%
C/N	10
pH (in water)	8.33
Gravel	0.00%
Coarse sand	4.6%
Fine sand	14.9%
Clay	49.4%
Silt	31.1%
Permeability	4.20 cm h^{-1}
Soil water content at matric potential of:	
0.03 MPa	39.21%
1.50 MPa	21.42%

°Total organic carbon with Walkley and Black method multiplied by 1.724.

the residue (as urea) were determined taking into account that the soil micro-organisms (fundamental in the decomposition of crop residue) require a quantity of N between 0.8 and 1.4 kg per 100 kg of dry matter incorporated; the amount of water used simulated a rainfall of 50 mm. In all treatments, 100 kg of P_2O_5 were applied (mineral perphosphate) during the principal ploughing phase (40-45 cm deep) as well as 100 kg of N as top dressing (ammonium nitrate), with the exception of treatment T9.

In order to verify the effects of 32 years of consecutive treatments, soil samples at two depths (0-20 and 21-40 cm) were taken on March 19th 2009 and the following parameters were measured: total nitrogen (N Tot) (Kjeldahl method), available phosphorus (P_2O_5) (Olsen method), exchangeable potassium (K_2O), sodium (Na), calcium (Ca), magnesium (Mg), Total Organic Carbon (TOC) (Springer and Klee method), Total Extracted Carbon (TEC) and humic and fulvic acids (HA+FA). The TOC, TEC and HA+FA parameters were used to calculate the following indicators (Ciavatta *et al*. 1990): the degree of humification (DH), the ratio of humic carbon content (HA+FA) to TEC, and the humification rate (HR), the ratio of humic carbon quantity (HA+FA) to that of total organic carbon (TOC). DH is a qualitative-quantitative indicator directly correlated to the quantity of humic substances extracted. HR is a qualitative indicator of the soil organic matter present in the soil. The soil organic matter (SO) was calculated from TOC. Statistical analysis was carried out using SAS procedures (SAS, 1998) considering the sample soil depth as strip factor. The differences between average values were analyzed with a probability level of $P \leq 0.05$, using the SNK method. Moreover, the orthogonal contrast methodology shown in Table 2 (SAS, 1998) was used to evaluate the significance of average values.

Results and Discussion

Table 3 shows the average values of the soil chemical parameters from samples taken during the spring of 2009, before the application of nitrogen fertilization. The effects of the treatments were statistically significant for K, TOC, SO, HA+FA, DH and HR, with a probability level of 0.05. Moreover, the treatments T4, T5 and T6, i.e. straw incorporation with N addition to residue, showed total N values of +4%, +5.8% and +2.5% respectively, higher than average values. Treatment T6 showed the highest P_2O_5 content, being +31.8% higher than the average value. Treatment T1, i.e. burning of stubble and straw, is notable for the highest K content (1615 mg kg^{-1}), +3.2% compared to the field average. The addition of N to wheat residues, even in treatments without irrigation, proved to be the most favourable solution not only in terms of nutritive element content but also for SO content; indeed, T4 showed the highest content of SO (2.5%).

Even though the TEC contents of the treatments were not significantly different, treatments T7 and T8 showed the higher values (9.49 and 9.47 g kg^{-1}, respectively). The degree (DH) and rate (HR) of humification, as qualitative-quantitative parameters of the SO, showed their highest values in treatment T9, with no fertilization or irrigation. This indicates that the simple incorporation of residue did not allow for any increase in SO (as shown by the values below the average) but improved some indicator of soil quality rather than global soil quality.

Table 4 and Figure 1 show the ANOVA results based on the orthogonal contrasts of the most important chemical parameters. After 32 years, burning (in comparison with incorporation, contrast C1) showed a statistically significant increase of 3.6% in K content, while incorpo-

Table 2. Coefficients of orthogonal contrasts applied for ANOVA.

Name	Description	T1	T2	T3	T4	T5	T6	T7	T8	T9
C1	Burning *vs* all	8	-1	-1	-1	-1	-1	-1	-1	-1
C2	Incorp: N *vs* N0	0	-1	-1	-1	-1	-1	-1	-1	8
C3	Incorp: Nstraw0 *vs* Nstraw	0	7	-1	-1	-1	-1	-1	-1	0
C4	Incorp: Wat0 *vs* Wat	0	0	1	1	1	-1	-1	-1	0
C5	Incorp and Wat0: linear component	0	0	-1	0	1	0	0	0	0
C6	Incorp and Wat0: deviation of linearity component	0	0	-1	2	-1	0	0	0	0
C7	Incorp and Wat: linear component	0	0	0	0	0	-1	0	1	0
C8	Incorp and Wat: deviation of linearity component	0	0	0	0	0	-1	2	-1	0

Incorp., Straw incorporation; N0, no Nitrogen; Nstraw, nitrogen on straw; Nstraw0, no nitrogen on straw; Wat, water on straw; Wat0, no water on straw.

Table 3. Chemical parameters of soil analysis of 19/03/2009.

Treat.	N. Tot g kg^{-1}	P_2O_5 mg kg^{-1}	K mg kg^{-1}	Na mg kg^{-1}	Ca mg kg^{-1}	TOC g kg^{-1}	SO %	TEC g kg^{-1}	HA+FA g kg^{-1}	DH %	HR %
T1	1.18	42.60	1615	16.83	5685	14.10	2.42	9.02	7.04	78.18	50.02
T2	1.19	37.17	1533	16.55	5647	13.56	2.33	8.98	7.64	85.17	56.46
T3	1.17	53.28	1563	12.45	5795	14.37	2.47	9.33	7.66	82.23	53.23
T4	1.25	43.98	1544	17.20	5684	14.54	2.50	9.16	7.61	83.34	52.54
T5	1.27	36.73	1528	13.82	5594	13.90	2.39	9.26	7.29	78.80	52.43
T6	1.23	57.80	1565	20.83	5758	14.48	2.49	9.01	7.31	81.27	50.44
T7	1.16	40.52	1607	22.18	5743	14.21	2.44	9.49	8.04	84.90	56.51
T8	1.20	34.63	1554	18.62	5736	14.50	2.49	9.47	7.81	82.56	54.24
T9	1.17	47.92	1581	17.78	5865	14.05	2.42	9.31	8.29	89.07	59.03
Means	1.20	43.85	1565	17.36	5723	14.19	2.44	9.22	7.63	82.83	53.88
	ns	ns	*	ns	ns	*	*	ns	*	*	*

TOC, total organic carbon; SO, soil organic matter; TEC, total extracted carbon; HA, humic acids; FA, fulvic acids; DH, degree of humification; HR, humification rate; ns, no significant difference; *significant difference for P<0.05.

Table 4. Results of ANOVA related to the orthogonal contrasts for the most important parameters. The significant P-values are reported in italics.

Contrast	K	TOC	SO	TEC	HA+FA	DH	HR
C1	*0.0293*	0.7113	0.7204	0.3037	*0.0204*	0.0631	0.0472
C2	0.3347	0.5369	0.5514	0.7837	*0.0210*	*0.0248*	*0.0170*
C3	0.2845	*0.0109*	*0.0115*	0.19	0.9387	0.2897	0.1418
C4	0.112	0.5691	0.5603	0.6717	0.3434	0.4931	0.5429
C5	0.284	0.2114	0.2208	0.8268	0.3221	0.3523	0.7786
C6	0.9546	0.2249	0.2201	0.5938	0.6675	0.3753	0.9043
C7	0.7543	0.9685	0.9798	0.1258	0.1831	0.7235	0.1846
C8	0.0975	0.3981	0.4078	0.3475	0.1420	0.3495	0.0962

TOC, total organic carbon; SO, soil organic matter; TEC, total extracted carbon; HA, humic acids; FA, fulvic acids; DH, degree of humification; HR, humification rate.

ration showed a slight but not significant increase of 0.7%, in TOC and SO with respect to burning. The C1 was also significant for HA+FA (7.04 and 7.71 g kg^{-1} for burning and incorporation treatments, respectively) and HR (7.04 and 7.71% for burning and incorporation treatments, respectively). The contrast C2 gave unexpected results indicating significant and higher HA+FA, DH and HR for T9 compared to other treatments from T2 to T8. Such result could be attributed to the particular location of the treatment T9. In fact originally it was not randomized in the experimental design, but it was added later. For this reason we excluded this result from the following conclusions.

If only incorporation treatments are taken into account, it can be seen that the addition of N to crop residues at the time of incorporation (contrast C3) resulted in a significant increase in TOC content of 5.7% compared to treatments where incorporation was carried out without N addition to residue, while the corresponding (but no significant) increase in TEC was 3.3%. The addition of 50 mm of water on the straw had no significant effects on any of the parameters discussed in this study (contrast C4). Finally, the four contrasts (from C5 to C8) based on linear components and deviations to linearity to the nitrogen application on stubble, proved not to be significant in any way.

In the framework of EFFICOND Project, Raglione and Lorenzoni (*personal communication*) carried out a field research based on comparison of stubble burning and soil incorporation of stubble or straw of soft wheat cultivated in Central Italy (alluvial plain of Rieti) on two soils with silt loam and silty clay texture (classified as *Typic Eutrudept* and *Vertic Eutrudept*, respectively). According to our results, in the second year of the research the Authors did not find significant differences among the treatments for TOC of the shallowest soil layer (0 - 10 cm of depth). Table 5 shows their results about TOC.

Table 5. Total organic carbon in the field research of Rieti for a shallow soil layer (0-10 cm of depth).

Soil	Agronomic practice	Total organic carbon g kg^{-1} 2009	2010
Typic eutrudept	Straw incorporation	10.3	9.9
	Stubble incorporation	10.1	9.7
	Stubble burning	9.9	9.7
Vertic eutrudept	Straw incorporation	17.6	17.1
	Stubble incorporation	18.2	16.6
	Stubble burning	17.0	17.5

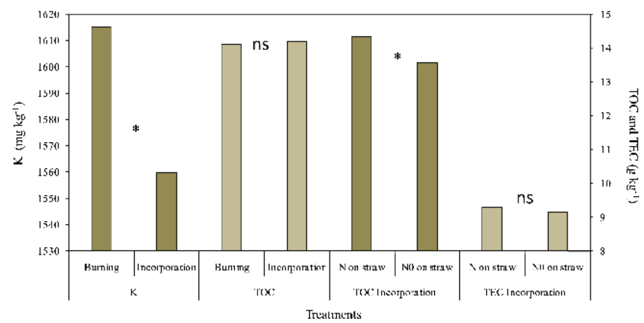

Figure 1. Soil content of potassium (K), total organic carbon (TOC) and total extracted carbon (TEC); *significant difference for P<0.05; ns, no significant difference.

Conclusions

The principal objective of this paper was to report the results of soil fertility monitoring carried out after 32 years of continuous residue management, based either on burning or soil incorporation in a one-year rotation of durum wheat in Southern Italy.

The results obtained confirmed that the incorporation of crop residue improved both the quantity and the quality of soil organic matter. However organic matter-related processes are typically slow. Comparing the effects of this practice versus the burning of residues, after 32 years of continuous treatment, we found differences in favor of straw incorporation. This was evident on humic and fulvic acid contents, degree of humification and humification rate (+9.5, +6.7 and +8.7% for incorporation compared to burning practice, respectively). The incorporation of straw stubble resulted in higher levels of total and extracted soil organic carbon (TOC and TEC) than burning, but those increases were only of 7% and 2.5%, respectively, and were not statically different.

An examination of the data shows that, as reported in literature, better results are obtained by adding N to straw at the time of incorporation, even at the lowest rate of 50 kg ha^{-1}. This is due to an improved decomposition of fresh organic matter. On the opposite, the irrigation of 50 mm on the stubble did not significantly affect the content and quality of soil organic matter.

In conclusion, incorporation of stubble and straw appears to be in line with the objective of maintaining soil organic matter levels. However, this aim is achieved only partially because the residue incorporation is more oriented towards maintaining existing carbon organic contents than actually increasing them. The latter would require that supplemental and synergic measures should be undertaken within the implemented regulations and directives of Statutory Management Requirements (SMR). Furthermore, in agreement with literature, optimum performances on soil fertility level are obtained by adding nitrogen to straw at the time of incorporation, even at low doses of 50 kg

ha^{-1} of N, since the addition of nitrogen allows for an improved decomposition of stubble and straw on wheat based systems.

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