EEET ECOLOGICAL ENGINEERING
& ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2022, 23(5), 256–271
https://doi.org/10.12912/27197050/152182
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Received: 2022.07.02
Accepted: 2022.07.20
Published: 2022.08.01

Effect of Crop Residues Management on Soil Fertility and Sugar Beet Productivity in Western Morocco

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ABSTRACT

The competitiveness of sugar beet in the Doukkala irrigated perimeter makes this crop the main one compared to wheat, vegetables and forage. However, the dominance of small plots drives farmers to practice 2 to 3 years rotation of sugar beet. This work, carried out on contrasting and representative soils between 2012 and 2019, aims to study the effects of sugar beet residues incorporation on the soil organic matter, soil properties, and sugar beet root yield and sugar content under reel field conditions and actual rotation system. The results showed that the rate of soil organic matter (SOM) increased by +28.8% during eight agricultural seasons. Plots that never received crops residues experienced an average decrease in SOM rate of -19%. The maximum average increase in the SOM rate of +194% was observed at the level of the plots, where sugar beet residues were incorporated six times. This variation in SOM is more marked in coarse-textured soils. The variations of Mg, K, P, Ca, Zn, B, $CaCO_{3,}$ soil pH, CEC are positively correlated with statistical significance with SOM variation. The multiple linear regression model for predicting the variation in SOM content, depending on soil texture, initial SOM content and number of residue incorporations, with ($R^2 = 0.81$, RMSE = 26.15) shows that this variation is significantly favored by coarse soil elements and the number of residues incorporation and that it is unfavorable in soils with a dominant fine texture and initially rich in organic matter. Yield and sugar content were improved by 31% (67,45 Mg·ha^{-1} in 2012 and 86,38 Mg·ha^{-1} in 2019) for root yield and by 4% (16.68% in 2012 and 17,37% in 2019) for sugar content in plots with six residues incorporations. Data from this study suggest that the use of sugar beet residues is benefical for improving soil properties and thus increasing soil organic status and crop performances.

Keywords: soil fertility, soil organic matter, residues incorporation, sugar beet, Doukkala, Morocco.

INTRODUCTION

In a quest to increase income, farmers practice an agriculture characterized by a high degree of intensification that degrades the soil and affects the environment (Harraq et al., 2022). To this end, the restitution of crop residues has recently become a recommended practice to ensure sustainable agriculture since the removal of these residues has a negative effect on the soil and crop yield in the long term (Archer et al., 2020).

Several studies have shown that the return of residues from certain crops has a positive effect on soil organic carbon (Chalise et al., 2019), nitrogen fertilization (Li, 2021), water retention in the soil (Lu, 2020), the stimulation of soil microbial activity (Ma et al., 2022) and structural stability of the soil (Xiao et al., 2022). But few studies have been devoted to investigate the effect of sugar beet residues on soil fertility and crop yield under intensive agricultural systems in semi-arid climate.

The case of sugar beet in the Doukkala irrigated perimeter (DIP) in Morocco is a good example where this crop represents the main crop in the agricultural system with an acreage of about 20,000 ha. It produces about 1.73 million tons of roots, and up to 230,000 tons of sugar, representing 40% of national sugar production (COSUMAR, 2019). This crop has a very important place thanks to its competitiveness with fodder and cereal crops (Redani et al., 2015) on the one hand, and thanks to the pre-financing of crop inputs from which the beet growers benefit within the framework of the aggregation around the sugar factory located in Sidi Bennour in Morocco, on the other hand.

In this context of strong competitiveness of the crop to which is added the land structure characterized by the small size of farms, sugar beet is the first choice of farmers in the irrigated perimeter of Doukkala (Cances, 2005) followed by cereals, fodder and market gardening. Thus, farmers have tended to practice rotations with 2 to 3 years of sugar beet followed by either wheat (SSW) or even (SSSW) in cereal areas, or a forage crop (SSF) in fodder areas, or vegetable (SSV) in market crop areas. Furthermore, combining crop and livestock is a strategy used to maintain productivity and diversifies income sources of family farms. However, livestock requires large amounts of feed to ensure production, and farmers use plant residues to supplement animal feed. Therefore, soils are subjugated to an agricultural intensification coupled to a non-restitution of crop residues; which contributes to a depletion of soil organic matter. In most sugar beet plots, there is little or no application of organic manure and little crop residue is incorporated to the soil. This results in a significant decrease of the soil organic matter (SOM) (Badraoui et al., 2000). These losses are amplified by the mineralization process accentuated by the hydric and thermal conditions favorable for the mineralizing microflora in this region. The soil organic matter content in the irrigated perimeter of Doukkala is very low with an average of 1.3% (Naman et al., 2015).

The mechanical harvesting of sugar beet was introduced in the DIP in 2012, as the labor supply for harvesting became more challenging to secure and harvest the sugar that has grown in the field and extract it profitably, as completely as possible. The sugar beet tops are removed, they remain for fertilization in the field. Despite sugar beet growers' reluctance, a growth in mechanical harvesting encouraged sugar beet growers to incorporate beet residues to the soil. Crop residues, which represent sugar beet 7,5 Mg. Dry Matter. ha^{-1} (Collaud, 2014), constitutes a source of soil organic matter (SOM) that improves the physical and chemical properties of the soil (Malhi et al., 2006). This maintenance is possible by recycling the nutrients plants need (Naman et al., 2018).

This work conducted on contrasting soils between 2012 and 2019 has as objectives (1) monitor the evolution of organic matter rate in the sugar beet plots since the introduction of sugar beet residues incorporation promoted by mechanical harvesting; (2) assess the relationship between the variation in SOM and the other soil chemical and physical properties (3) model the variation of SOM as a function of soil properties and the number of residues incorporation (4) determine the effect of residues incorporation on sugar beet yield and sugar content under these beet-dominant cropping systems.

MATERIALS AND METHODS

Study area

The Doukkala irrigated perimeter (DIP) (Figure 1) is one of the largest irrigated perimeters in Morocco. It corresponds to a vast plain located south of the city of El-Jadida on the Atlantic coast. It is of strategic importance for national production, especially sugar beet which represents 20% of the area sown annually. The climate is semi-arid Mediterranean with a mild temperate winter and a generally hot and dry summer. The average annual rainfall, temperature, humidity and evaporation reaches 317 mm (125–592 mm), 18 °C (4–40 °C), 80% and 1700 mm respectively.

Data and laboratory analysis

To globally characterize the study area, 419 soil samples were collected twice randomly from the same plots across the study area in 2012 and 2019 at a depth of 0–30 cm. Sugar beet root yields and sugar content of the plots were also measured in 2012 and 2019.

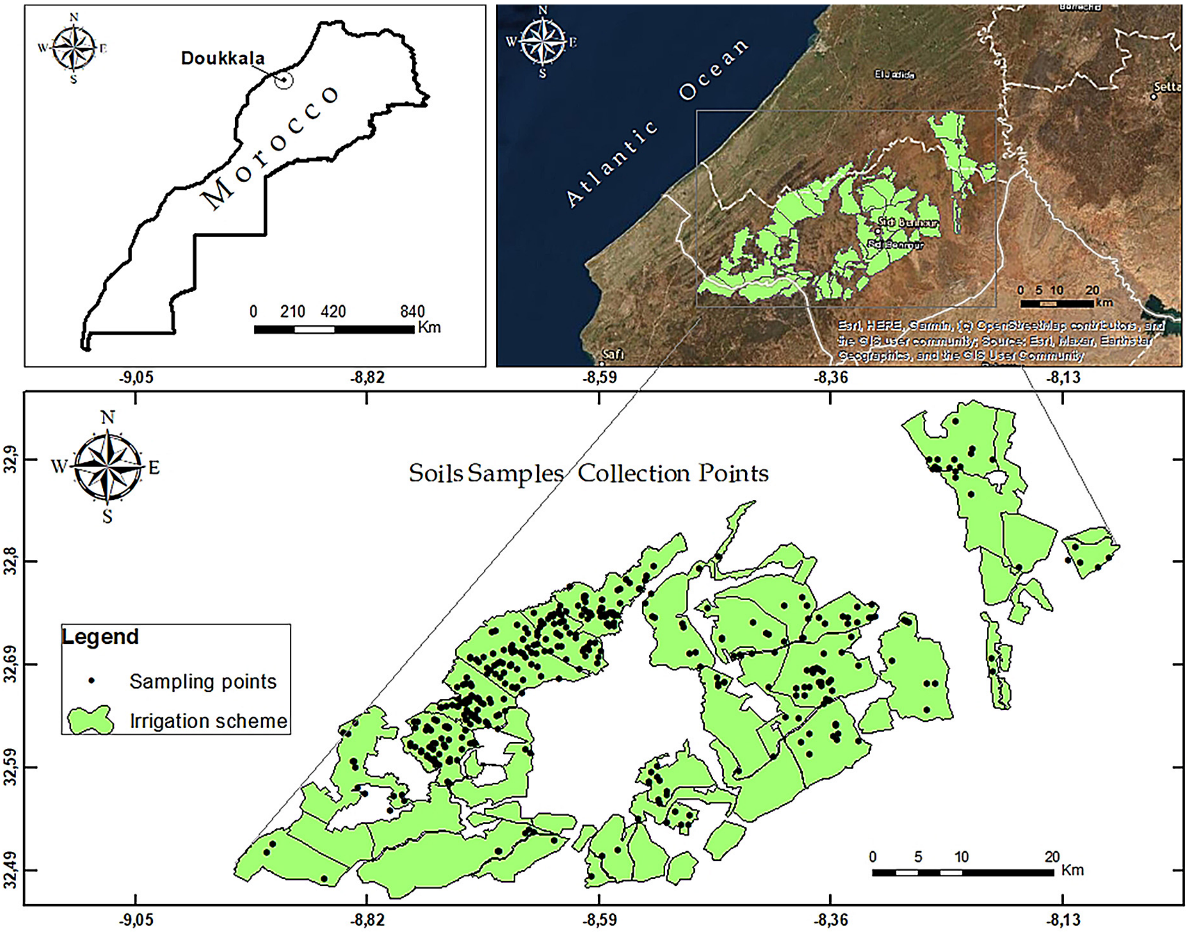

Figure 1. Location of the Doukkala irrigated perimeter

The plots were the subject of a monitoring based on the number of sugar beet residues incorporations (NRI) during the eight seasons between 2012 and 2019. The tagging and monitoring of mechanically harvested areas among the area sown in sugar beet was done using GPS fixed on the harvesting machines.

The coordinates of each sampling point were collected by portable GPS (Garmin), composite soil samples were collected from each plot. They were air-dried then crushed and sieved to 2 mm before planting Soil tests were carried out using the following methods: particle size distribution by the Robinson pipette by Bouyoucos method (Beretta et al., 2014), soil pH according to (Bates et al., 1973). The CEC is determined according to the Metson method (Metson, 1957). The carbonate content ($CaCO_3$, in d.m.% at 105 °C) is determined by the volumetric method (ISO 10693 standard); carbonates are destroyed by attack with hydrochloric acid yielding CO_2 measured with a Shreiber apparatus. The volume of CO_2 produced is compared to that produced by pure calcium carbonate (ISO 10693, 1995); nitrates (NO_3-N) by the chromotropic acid method, ammonium (NH_4-N) by colorimetry (blue indophenol); organic matter is tested by the Walkey-Black method (Walkley & Black, 1934), available phosphorus by the Olsen method (Olsen, 1954), exchangeable potassium, calcium and sodium by ammonium acetate extraction by atomic absorption and flame photometer according to (Simard, 1993). Available iron, manganese, copper, and zinc by the DTPA method (Lindsay & Norvell, 1978).

Multiple linear regression and validation

To model the variation of SOM as a function of soil properties, initial SOM and NRI, multiple linear regression (MLR) using the following equation (1):

$$y = b0 + b1X1 + b2X2 + \cdots + bnXn. \tag{1}$$

where: y is the predicted variable with regression coefficients $b1$ to n and y-intercept $b0$ when the values for the predictor variables are $X1$ to n.

The model has been validated by coefficient of determination (R^2), Root Mean Square Error (RMSE) (Equation 2), and p-value.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(y(i) - \hat{y}(i))^2}{N}} \quad (2)$$

where: *y(i)* and *ŷ(i)* are respectively the observed and predicted values of the SOM Variation, and *N* is the total number of observations ($N = 419$).

Statistical analysis

The data were processed statistically using the software JMP-SAS- version Pro 14, namely Pearson correlation, the means comparison (ANOVA) and the multiple linear regression model (MLR).

RESULTS AND DISCUSSIONS

Distribution of sugar beet farms

The distribution of sugar beet farms during the study period from 2012 to 2019 shows that farms with an area of less than 2.5 ha represent 65% of the total sugar beet area in the perimeter and (Figure 2).

The plots soil characteristics

The studied plots represent a large selection of cropping systems and soil types, ranging from frankly sandy to very clayey soils (Table 1, 2 and 3). For the granulometric composition the analyses were made only in 2012 knowing that the texture of the soil remains unchanged in long term.

Distribution of sugar beet plots according to the NRI

Ninety-four plots, which represent 22% of the plots, were always harvested manually and their sugar beet residues were never incorporated to the soil because after harvest, leaves and crowns were collected and used for animal feeding (Figure 3) plots that received sugar beet residues once represent 34%, while the plots with 2, 3, 4, 5 and 6 residues incorporations (RI) during the 8 seasons of the study represent 9%, 11%, 11%, 6%, and 7%, respectively.

SOM evolution of the plots between 2012 and 2019

The average SOM content of the plots has increased from 1.56% in 2012 to 1.95% in 2019,

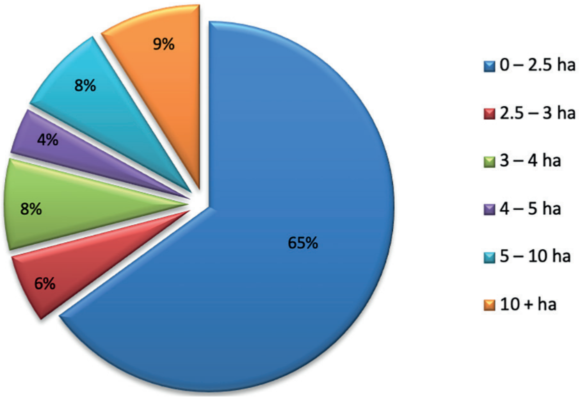

Figure 2. Distribution of sugar beet area classes from 2012 to 2019

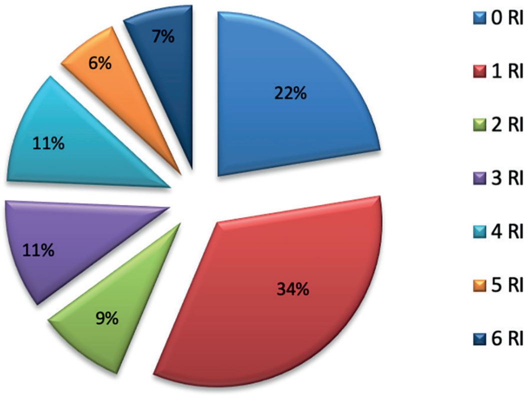

Figure 3. Distribution of the plots according to the number of residues incorporations

Table 1. Granulometric composition of soils ($n = 419$) for 2012

Indicator	Units	Min	Max	Mean	SD	CV	Skewness	Kurtosis
Textural elements								
Clay	%	2.5	50	29.07	9.61	33.05	-0.27	-0.517
C. Sand	%	5.8	35.6	16.73	4.94	29.51	0.549	0.45
F. Sand	%	18.3	78.3	40.54	9.78	24.12	0.489	-0.101
C. Silt	%	0.5	27.2	4.94	2.20	44.52	3.024	24.762
F. Silt	%	0.3	31.2	8.66	4.32	49.89	1.292	3.61

Note: Min – Minimum; Max – Maximum; SD – Standard deviation; CV – Coefficient of variation; C – Coarse; F – Fine.

Table 2. Characterization of the physical and chemical indicators of soils and concentration of trace elements ($n = 419$) for 2012

Indicator	Units	Min	Max	Mean	SD	CV	Skewness	Kurtosis
Physical and chemical indicators								
pH	-	1.8	8.7	7.73	0.49	6.4	-4.98	51.73
SOM	%	0.43	5.72	1.50	0.55	36.7	1.83	9.18
K_2O	mg/kg	46	1913	241.48	179.90	74.5	6.07	46.95
P_2O_5	mg/kg	2	702	53.50	58.99	110.2	5.89	55.17
MgO	mg/kg	86	2634	1241.07	528.09	42.6	0.01	-0.66
CaO	mg/kg	560	9268	4152.83	1761.39	42.4	0.19	-0.49
CEC	cmol/kg	5.75	64.52	34.02	12.97	38.1	0.00	-0.60
$CaCO_3$	%	0	27.4	1.55	3.17	204.6	4.35	25.28
Na_2O	mg/kg	103	3008	528.13	323.13	61.2	3.60	19.86
EC	ms/cm	0.08	3.21	0.28	0.23	79.4	7.87	86.29
NO_3-N	mg/100 g	0.24	27.9	1.99	2.06	103.3	6.21	63.25
NH_4-N	mg/100 g	0.11	1.64	0.43	0.15	34.5	1.97	11.99
Mineral-N	mg/100 g	0.67	28.35	2.42	2.09	86.6	6.01	59.55
Trace elements								
Fe	mg/kg	3.55	62.49	12.64	5.63	44.6	2.50	15.18
Mn	mg/kg	2.59	56.06	16.52	9.21	55.7	1.46	2.76
Zn	mg/kg	0.08	3.06	0.48	0.37	76.2	3.01	12.92
Cu	mg/kg	0.12	41.81	0.73	2.02	277.9	20.15	410.27
B	mg/kg	0.19	1.28	0.46	0.17	36.2	1.47	3.49

Note: SOM – Soil organic matter; CEC – Cationic exchange capacity; K_2O – Potassium; P_2O_5 – Phosphorus; MgO – Magnesium; CaO – Calcium; NO_3-N – Nitrates; NH_4-N – Ammonium; $CaCO_3$ – Total carbonates; Na_2O – Sodium; EC – Electrical conductivity; B – Boron; Fe – Iron; Mn – Manganese; Zn – Zinc; and Cu – Copper; Min – Minimum; Max – Maximum; SD – Standard deviation; CV – Coefficient of variation.

Table 3. Characterization of the physical and chemical indicators of soils and concentration of trace elements ($n = 419$) for 2019

Indicator	Units	Min	Max	Mean	SD	CV	Skewness	Kurtosis
Physical and chemical indicators								
pH	–	6.6	9	8.08	0.39	4.86	-0.80	0.53
SOM	%	0.43	4.99	1.92	0.77	40.26	0.96	1.18
K_2O	mg/kg	68	1276	272.58	139.83	51.30	2.37	11.02
P_2O_5	mg/kg	0	387	87.38	61.76	70.67	1.60	2.92
MgO	mg/kg	178	3465	1503.10	597.93	39.78	-0.03	-0.23
CaO	mg/kg	582	19088	6846.91	4055.71	59.23	0.51	-0.77
CEC	cmol/kg	5.47	112.27	50.40	23.81	47.25	0.27	-0.74
$CaCO_3$	%	0	40.8	2.40	4.23	176.29	3.28	18.04
Na_2O	mg/kg	50	8299	676.56	571.18	84.42	7.06	81.03
EC	ms/cm	0.07	3.94	0.45	0.39	85.58	4.03	23.64
NO_3-N	mg/100 g	0.12	58.73	3.95	7.39	187.12	4.93	28.25
NH_4-N	mg/100 g	0.1	13	0.66	1.01	151.90	7.66	75.56
Mineral-N	mg/100 g	0.41	62.22	4.61	7.98	172.97	4.97	28.55
Trace elements								
Fe	mg/kg	2.63	55.44	11.73	6.11	52.13	2.31	9.87
Mn	mg/kg	3.33	89.49	21.74	13.29	61.13	1.68	3.43
Zn	mg/kg	0.16	9.57	1.01	0.89	87.52	3.63	23.70
Cu	mg/kg	0.16	1.77	0.64	0.22	34.43	1.41	3.54
B	mg/kg	0	3.86	0.47	0.43	91.48	3.41	16.56

Note: SOM – Soil organic matter; CEC – Cationic exchange capacity; K_2O – Potassium; P_2O_5 – Phosphorus; MgO – Magnesium; CaO – Calcium; NO_3-N – Nitrates; NH_4-N – Ammonium; $CaCO_3$ – Total carbonates; Na_2O – Sodium; EC – Electrical conductivity; B – Boron; Fe – Iron; Mn – Manganese; Zn – Zinc; and Cu – Copper; Min – Minimum; Max – Maximum; SD – Standard deviation; CV – Coefficient of variation.

corresponding to an increase of 28.8% in eight years (Table 4). There is a highly significant difference at ($P < 0.001$) in the SOM content of the survey plots between 2012 and 2019.

a) SOM variation according to NRI:

SOM content decreased by 19% in the plots that did not benefit from any RI while there was an increase of SOM content with the increase of the NRI.

The statistical analysis shows no significant difference between SOM in the case of plots with 1, 2 and 3 RI and this group is significantly different from 0 RI at ($P < 0.0001$). There was a significant difference between 4 and 5 RI at ($P < 0.05$) and between 5 and 6 RI at ($P < 0.0001$).

The SOM content increase was less noticeable during the three first seasons studied and it became greater during the following harvests (Figure 4). SOM variation between 2012 and 2019 is positively correlated with the number of residues restitutions.

Soudi et al., (2000) reported that in 10 years without RI, the average loss of SOM ranges from 18.1 to 32.6%. Losses were found to be higher in sandy soils and in less developed soils. This can be explained by the small fraction of clay which is capable to protect the SOM by the associations between the clay mineral colloids and the humic colloids. Low wastage rates are observed for clay soils.

b) SOM variation according to soil texture:

SOM variation was positively correlated with soil gross sand content and negatively correlated with soil clay content (Table 5). Minasny & McBratney, (2018) showed that SOM associated with sand content is essentially in the form of plant

Table 4. SOM variation according to the number of residue incorporation

NRI	SMO content in 2012, %	SMO content in 2019, %	SOM content variation (%)*
0	1.81	1.41	-19%a
1	1.38	1.65	29%b
2	1.73	2.12	22%b
3	1.49	2.06	40%b
4	1.38	2.48	80%c
5	1.23	2.61	115%d
6	1.15	2.97	194%e
Mean	1.56	1.95	28.8%

* Values followed by the same letter are not significantly different.

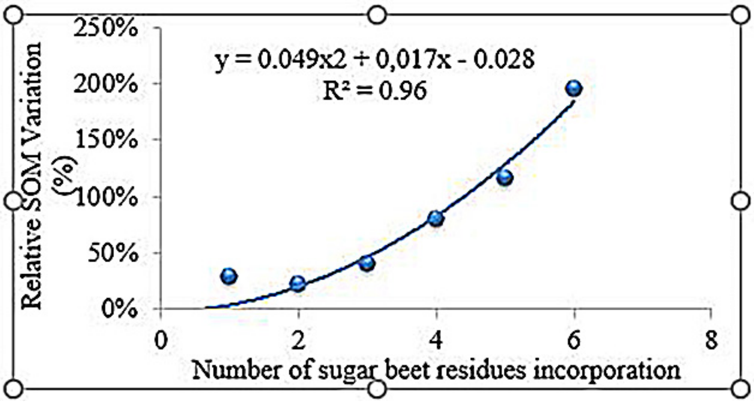

Figure 4. Relationship between the number of sugar beet residues incorporation and SOM content variation between 2012 and 2019

Table 5. Correlation for 419 plots between relative SOM variation (%), NRI, soil texture and SOM (%) in 2012

Parameter	NRI	SOM (%) in 2012	SG (%)	SF (%)	LG (%)	LF (%)	A (%)
SOM variation (%)	,676**	-,450**	,226**	,171**	0,054	-,109*	-,183**

Note: **the correlation is significant at the 0.01 level; *the correlation is significant at the 0.05 level.

debris, while those associated with clay have a much more pronounced amorphous character.

Linear regression of SOM variation with clay and sand gave an $R^2 = 0.53$ and $R^2 = 0.41$ respectively (Figure 5). Studies carried out in Mediterranean area by (Turmel et al., 2015) on sandy, silty or clayey soils have shown that SOM associated with sands (plant debris) have a much higher renewal rate than SOM associated with clay and silt. In sandy soils where both SOM content and renewal rates are higher for fractions greater than 50 or 20 µm than for finer fractions, plant debris necessarily plays a major role in the mineralization of SOM. In clay soils, the renewal rate of SOM associated with clays is lower than that of plant debris, but the quantities involved being much greater, it is these fractions that will play a major role in the mineralization of SOM in the soil. Soil temperature and humidity (Joshi et al., 2003; Natelhoffer & Fry, 1988), the organic nitrogen concentration in the humus (Vervaet et al., 2002), and the pH (Aciego Pietri and Brookes, 2008) are also parameters that positively influence the net mineralization of nitrogen. On the other hand, the lignin:N ratio (Joshi et al., 2003) as well as the C:N ratio of the soil (Côté et al., 2000) negatively influence the net mineralization of nitrogen. Plant species can also influence nitrogen mineralization through the secretion of specific compounds from the leaves (Hättenschwiler and Vitousek, 2000) or by the roots (Subbarao et al., 2007).

Prediction model of SOM variation

A statistically significant prediction model of SOM variation was derived from linear multiple regression of SOM variation as a function of the percentage of sand, silt, clay, the number of residues incorporations and the initial content of SOM in 2012 (Figure 6).

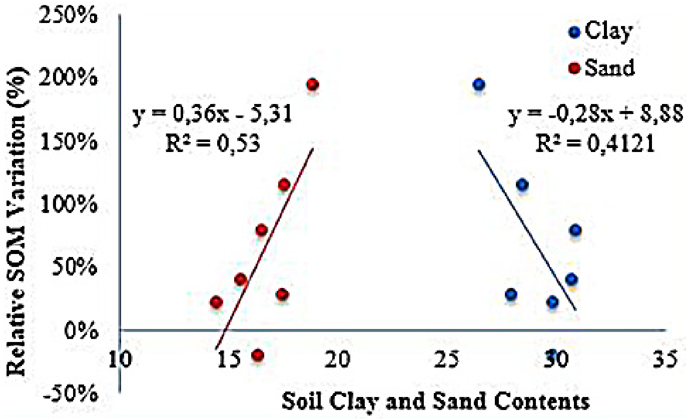

Figure 5. Relationship between relative SOM variation and soil sand and clay contents

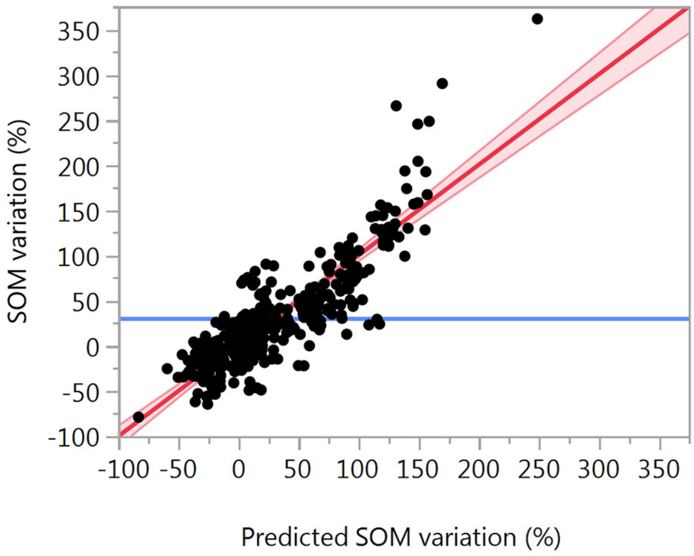

Figure 6. Observed vs. predicted regression scatter plots of SOM for the 419 plots

SOM variation (SOMV) prediction model can be expressed by the equation (3), with a highly significant coefficient of determination (R^2 = 0.81, $p < 0.0001$, RMSE = 26.15).

$$\text{SOMV}\ (\%) = 27.59\ \text{NRI} - 15.67\ \text{SOM} + \\ +1.2\ \text{Sand} + 1.96\ \text{Silt} + 0.7\ \text{Clay} - 112.23 \tag{3}$$

where: NRI – number of residues incorporations and SOM measured in 2012.

Variation of soil properties and nutrients for 419 plots

Besides the increases in SOM, sugar beet residues incorporation in soil resulted in several changes in soil properties between 2012 and 2019 (Table 6). Some properties and elements experienced increases between 2012 and 2019 namely +5% for pH, +61% for EC, +48% for CEC, +99% for NO_3^-, +57% for NH_4^+, +64% for P_2O_5, +13% for K2O, +21% for MgO, +64% for CaO, +28% for NaO, +31% for Mn, +110% for Zn, +4% for B and +30% for $CaCO_3$, others have experienced decrease namely -7% for Fr and -13% for Cu (Table 6).

The humification coefficient of sugar beet residues are as low as 0.2 and therefore for a quantity of dry fresh organic matter of 1.2 Mg·ha^{-1}, the annual humus production is 240 kg·ha^{-1}·year^{1} (Naman et al., 2015). This low humification of sugar beet crop residues may be due to its low lignin content which is at the origin of the humus skeletons (Mustin Michel, 1987) and which does not exceed 3.31% of its biochemical composition relative to its content of soluble substances (53.85%) easily mineralized, hemicellulose (23.48%) and cellulose (19.35%) (Naman et al., 2018).

In addition, the C:N ratio of the dry sugar beet residues is 8.6 (Rahn et al., 2003) for the leaves which means that their soil incorporation gives rise to an immediately mineral nitrogen release for plants according to (Davet, 1996). Which is in agreement with the results found in this study, a large increase of nitrate and ammonium nitrogen soil contents (Table 6). The sugar beet residues contain in g·kg^{-1} of dry matter, 17.90 N, 0.86 P, 6.01 K, 5.57 Mg, 8.87 Ca and 29.2 Na. In view of the contributions in kg·ha^{-1} of major elements, sugar beet residues provide 22.91 N, 2.54 P_2O_5, 9.24 K_2O, 11.8 MgO, 15.87 CaO and 37.07 NaO (Naman et al., 2015).

Since between 2012 and 2019, the all sugar beet plots received the same dose of fertilizer, application rate was 60.5 kg N·ha^{-1}, 60.5 kg P·ha^{-1}., 160.5 kg K·ha^{-1}, and 7 kg B·ha^{-1} and nitrogen topdress was 92 kg N·ha$^{-1,}$ in this context it can be suggested that observed increases in most of the soil nutrients are in relation with the number of residues incorporations.

It should be noted that farmers provide additional amounts of cover fertilizer, but this remains a general practice among all sugar beet growers in the DPI.

Table 6. Soil properties mean values in 2012 and 2019 and their variation (n = 419)

Soil test	**U**nits	Average in 2012	Average in 2019	Variation (%)	Statistical significance
pH	-	7.72	8.08	5%	P <0.0001
EC	dS·m^{-1}	0.28	0.45	61%	P <0.0001
Cations Exchange Capacity (CEC)	cmol (+)·kg^{-1}	34.02	50.40	48%	P <0.0001
N-NO_3^-	mg·kg^{-1}	1.98	3.94	99%	P <0.0001
N-NH_4^+	mg·kg^{-1}	0.42	0.66	57%	P <0.0001
P2O5	mg·kg^{-1}	23.33	38.23	64%	P <0.0001
Exchangeable K	cmol (+)·kg^{-1}	0.51	0.58	14%	P <0.01
Exchangeable Mg	cmol (+)·kg^{-1}	6.24	7.55	21%	P <0.0001
Exchangeable Ca	cmol (+)·kg^{-1}	14.84	24.46	65%	P <0.0001
Exchangeable Na	cmol (+)·kg^{-1}	1.70	2.18	28%	P <0.0001
Available Fe	mg·kg^{-1}	12.65	11.74	-7%	P = 0.025
Available Mn	mg·kg^{-1}	16.52	21.71	31%	P <0.0001
Available Zn	mg·kg^{-1}	0.48	1.01	110%	P <0.0001
Available Cu	mg·kg^{-1}	0.72	0.63	-13%	P = 0.35
Available B	mg·kg^{-1}	0.45	0.47	4%	P = 0.53
$CaCO_3$	%	1.88	2.46	30%	P = 0.515

The decrease in Fe and Cu contents may be due to binding of these ions with humic substances resulting from the humification of sugar beet residues, this small decrease can be explained by the weak humification of sugar beet residues mentioned above. this result confirms laboratory work conducted by (Vizier, 1978) which showed that the humic and fulvic acids extracted from several types of soil can form complexes with iron in the proportion of 15 to 35 mg of Fe per 100 mg of C, i.e. an Fe : C ratio of 0.15 to 0.35. In the same direction, other work carried out by (Zanin et al., 2019) gave a good relation between the total losses of carbon and to a lesser degree of iron and the rate of extraction of the humified matter.

Variation of soil properties and nutrients according to SOM variation

knowing that the correlations found (Table 7), and that 77% of the plots studied benefited from at least one incorporation of sugar beet residues, which is moreover the most recent, it can be possible to attribute these increases, especially for poorly mobile elements in the soil, to the sugar beet residues incorporation.

a) Total soil ($CaCO_3$)

A decrease in soil $CaCO_3$ was expected following successive RI found by (Ge et al., 2020) but the results show that there are positive and statistically significant correlations between $CaCO_3$ and the increase in SOM ($r = 0.29$; $P < 0.0001$) and between $CaCO_3$ and soil Calcium ($r = 0.39$; $P < 0.0001$), in addition to the strong relationship with the number of RI (Figure 7a). This confirms the low humification of sugar beet residues under the climatic conditions of the DIP and which don't give enough humic acids which inhibit the nucleation of $CaCO_3$. This low humification combined with the release of Calcium in the soil positively correlated with the number of residues incorporations, it promotes the increase of $CaCO_3$ in the soil. On the other hand, the relatively high phosphorus content of the soils in the study area may create competition with humic acids on the $CaCO_3$ fixation sites, especially when present before the humic acids are newly formed (Perassi and Borgnino, 2014), which supports the results found in this study.

In the absence of precise analyzes of the nature of the newly formed humic acids and the nature of their functional groups and their molecular weights which promotes their attachment to the $CaCO_3$ in soil, thus inhibiting calcite growth. it can be assumed that the humic acids present in the soil following RI of sugar beet are of low molecular weight, with saturation of their Phenolic and carboxylic acid functional groups by excess Ca^{2+} ions in the soil (Hoch et al., 2000).

Table 7. Correlation of variation of pH, electrical conductivity (EC), cationic exchange capacity (CEC) and elements on soil with SOM variation in 419 plots

Indicator	SOM	Na$_2$O	Fe	Mn	Zn	Cu	B	MgO	K2O	P$_2$O$_5$	CaO	CaCO$_3$	pH	CEC	EC	NH$_4$-N	NO$_3$-N	N
SOM	1																	
Na2O	0,074	1																
Fe	-0,004	0,014	1															
Mn	0,034	0,036	,320**	1														
Zn	,262**	0,010	-0,028	,149**	1													
Cu	0,057	0,065	,325**	,333**	,170**	1												
B	,102*	,222**	,166**	,358**	,182**	,229**	1											
MgO	,499**	,164**	,183**	-0,074	0,030	,119*	,145**	1										
K2O	,383**	,251**	0,063	,249**	,268**	,225**	,387**	,390**	1									
P$_2$O$_5$	,178**	0,006	,168**	,402**	,416**	,191**	,284**	-0,054	,284**	1								
CaO	,589**	,180**	-,119*	-,229**	-0,042	-,106*	-0,021	,525**	,286**	-,121*	1							
CaCO$_3$	,295**	0,003	-,120*	-,112*	0,054	-0,076	-0,058	0,084	0,093	-0,026	,393**	1						
pH	,154**	-0,025	-,149**	-,211**	-0,033	-,149**	-,126*	0,063	0,059	-,130**	,295**	,248**	1					
CEC	,628**	,290**	-0,046	-,205**	-0,026	-0,054	0,048	,673**	,383**	-,115*	,965**	,339**	,249**	1				
EC	0,029	,585**	0,008	,152**	,107*	0,078	,408**	,136**	,287**	,136**	-0,002	0,065	-,112*	0,079	1			
NH$_4$-N	0,040	0,045	0,067	,129**	,205**	0,022	,267**	0,060	,156**	,170**	-,114*	-0,019	-0,095	-0,082	,369**	1		
NO$_3$-N	0,045	,144**	0,021	,157**	0,072	0,059	,444**	0,015	,175**	,118*	-0,054	-0,013	-,111*	-0,032	,486**	,475**	1	
N	0,051	,190**	0,045	,190**	,124*	0,060	,484**	0,042	,203**	,188**	-0,072	-0,014	-,132**	-0,037	,578**	,573**	,960**	1

Note: **the correlation is significant at the 0.01 level; *the correlation is significant at the 0.05 level.

b) CEC

The results relating to the increase of +49% positively correlated with high statistical significance to the variation of the SOM (*r* = 0.63; *P* <0.0001) are in agreement with (Turmel et al., 2015) who also confirms an increase in CEC when residues were retained compared to soils without residues confirming the relationship found (Figure 7b). McGrath et al., (1988) have demonstrated that CEC of a sandy soil increase from 75 to 158 cmol $^{(+)}$/kg as soil OC increased from 0.46 to 1.39%.

c) Soil pH

The results obtained concerning the slight pH increase of +5% between 2012 and 2019 significantly correlated with the variation of the SOM (*r* = 0.15; *P* = 0.0016) is consistent with the results obtained also by studding the relationship of pH with the number of residues incorporations (Figure 7c), which confirm that the decomposition of plant residues releases in the soil organic anions. Their mineralization consumes protons (H^+) and therefore contributes to alkalize the soil. Thus, restoring crop residues and intercropping cover to the ground makes it possible to limit its acidification or even alkalize it, while their export amplifies the tendency towards acidification.

Turmel et al., (2015) indicated that decomposition of organic anions contributes to the change in soil pH by decarboxylation of organic anions that consume H+ anions; if the initial soil pH is less than the pKa of the weak acid group. Although increasing the pH is clearly useful in terms of improving the availability of microelements, lowering the pH should be limited to avoid increasing the solubility of toxic elements (Xu et al., 2013).

d) Electrical conductivity

The found increase of +23% was not correlated to the SOM variation (*r* = 0.03; *P* = 0.3512). Chintala et al., (2014) observed an increase in electrical conductivity following the addition of corn stover biochar. Electrical conductivity, which is directly related to the salt concentration in the soil solution, has been shown to increase with increasing application rates.

It should be noted that the irrigation water endowments in the DIP have experienced restrictions in recent years, dropping from 600 Mm^3 in 2012 to 0 Mm^3 in 2020, the combined effect of which is the continuous decrease in rainfall of 326 mm in 2012 to 186 mm in 2019 can also contribute to soil salinization.

e) Comparison of increase properties and elements averages by NRI

The one-factor ANOVA analysis showed that in 2012 the parameters studied did not show any statistic difference at the start of the experiment. But the same analysis for 2019 showed that the maximum values of increase for the major elements Mg, K, P, Ca, Zn and soil properties pH, CEC and $CaCO_3$ are found at the level of the plots which were the subject of the residues incorporation six times compared with the other plots (Table 8). For EC, Mineral Nitrogen, Na, B, Mn, Cu and Fe, no difference was found in the 2012 and 2019.

Mineralization of sugar beet residues releases the main components of these residues into the soil. The C:N of the sugar beet residues is 13.8, 40 and 18.55 respectively for the leaves, the collars and the mixture incorporated to the soil, promotes mineralization and the supply of soil nutrients (Youssef, 2018).

In addition, the absence of difference between relative variation of nitrogen average in relation to the NRI can be explained by the predisposition to leaching of mineral nitrogen found strongly correlated with the nitric form (*r* = 0.95; *P* < 0.0001) in the soil and which can reach according to (Naman et al., 2018) 75 kg·ha^{-1} and 41 kg·ha^{-1} for vertisol and fersiallitic soil, respectively.

Table 8. ANOVA of soil parameters variation between 2012 and 2019 by the NRI

NRI	Mean of relative variation %*									
	pH	CEC	N	Mg	K	P	Ca	Na	Zn	$CaCO_3$%
0	4 b	21 d	109 a	9 b	9 c	153 a	35 c	40 a	0.34 b	142 c
1	4 b	56 cd	202 a	62 b	39 b	264 a	68 c	75 a	0.49 b	239 bc
2	2 b	40 cd	127 a	8 b	28 bc	252 a	60 c	27 a	0.53 b	591 abc
3	5 b	86 bc	240 a	45 b	29 bc	246 a	118 bc	71 a	0.43 b	981 abc
4	4 b	69 bcd	303 a	58 b	33 bc	298 a	88 c	53 a	0.61 b	334 bc
5	21 a	146 b	98 a	77 b	31 bc	167 a	212 b	28 a	0.63 b	1590 ab
6	10 ab	266 a	60 a	247 a	110 a	324 a	373 a	44 a	1.25 a	2112 a

Note: *Values followed by the same letter in the column are not significantly different.

The absence of difference in the average relative variation of Na in the soil compared to the NRI confirms the sanitizing role of sugar beet for Na by the high level absorption of this element from the soil solution (Götze et al., 2017) and their concentration at the harvested root level (Wu et al., 2015).

The presence of difference between the different NRI concerning the average relative variation of Zn with strong relationship (Figure 8h) confirms the results of (Sagardoy et al., 2009) and who showed that the concentrations of Zn in the leaves of plants grown with an excess of Zn were high but fairly constant, whereas that total Zn uptake per plant decreased markedly with high Zn input. These data indicate that sugar beet could be a good model to study Zn homeostasis mechanisms in plants, but is not an efficient species for Zn phytoremediation.

Tahiri et al. (2014) indicate that the so-called secondary mineralization of humus, which is slow, releases in addition to major nutrients essential for plant growth other minor nutrients. This progressive decomposition is doubly interesting, on one hand, it is spread over almost the entire vegetation period, which corresponds well to the concern of a regular and continuous diet avoiding the loss of nutrients by leaching or by insolubilisation. On the other hand, it appears complete in the sense that the microbial decomposition of buried plant debris releases both major and minor elements.

Evolution of sugar beet performances

Based on the results, the root yield increased by 10.5% from 67.3 Mg·ha^{-1} to 74.4 Mg·ha^{-1} in 2012 and 2019 respectively for the 419 plots, literature reviewed highlighted that the use of organic amendments in combination with mineral fertilizers improved crop yields in many cropping systems over 10 years, compared to compost and amendments alone (Bi et al., 2009; Ros et al., 2006) This confirms that good mineral nutrition results more from long-term maintenance of the richness of the soil and microbiological activity, intermediate between the root and the mineral elements, than from the supply, in each crop, of the amount of fertilizer it would be supposed to absorb (Hartl et al., 2003).

For the root yield, the agronomic potential of the plots must be taken into account. This is why variation in yield as a variable was studied, especially since the comparison of the average yields in 2012 showed that there is no difference between the plots monitored. The one-way

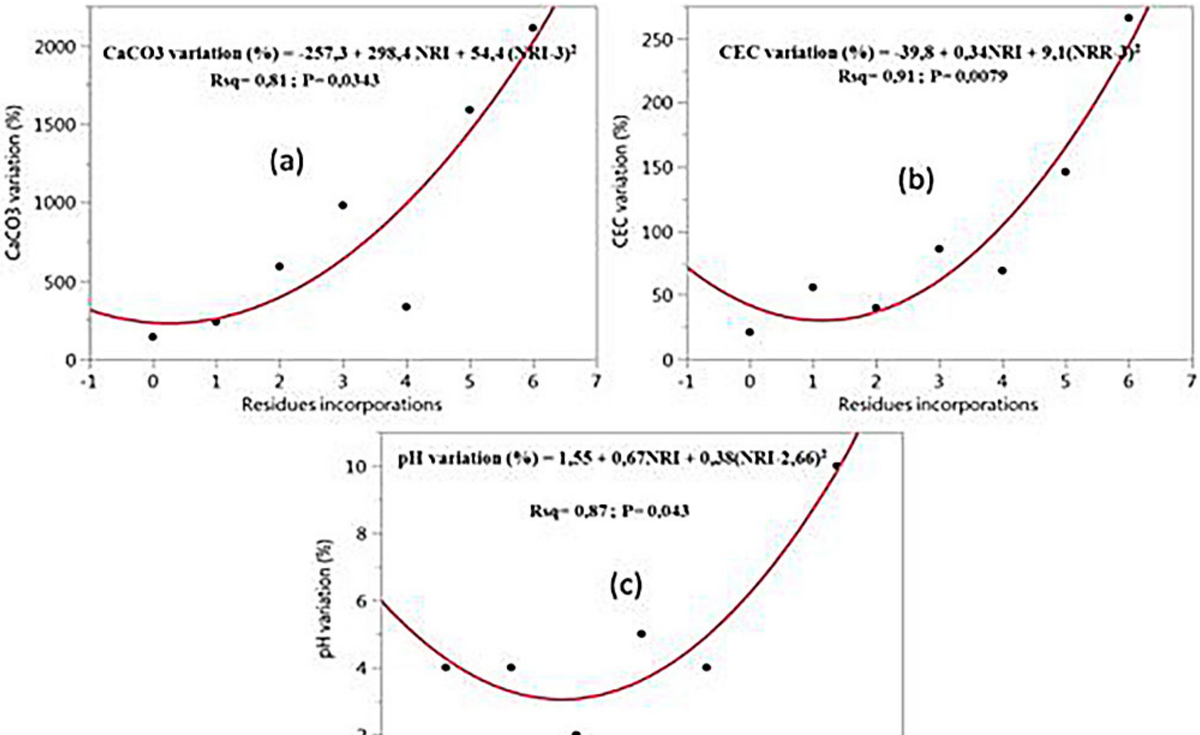

Figure 7. Relationship between the NRI and soil properties pH (a); CEC (b) and $CaCO_3$ (c)

ANOVA showed that the maximum increases in yield are found in the plots that were subject to 6 RI compared with the other plots (Table 9). The regression showed that there is a strong, almost linear relationship between yield in 2019 and the NRI with ($R^2 = 0.86$; $P = 0.0026$) and between the relative increase in yield and the NRI with ($R^2 = 0.85$; $P < 0.0027$) (Figure 9a and b).

The maximum sugar content is found at the level of plots which have been subject to 6 RI compared with the plot without RI ($P = 0{,}0270$) (Table 11) the sugar content in 2019 follows a linear relationship

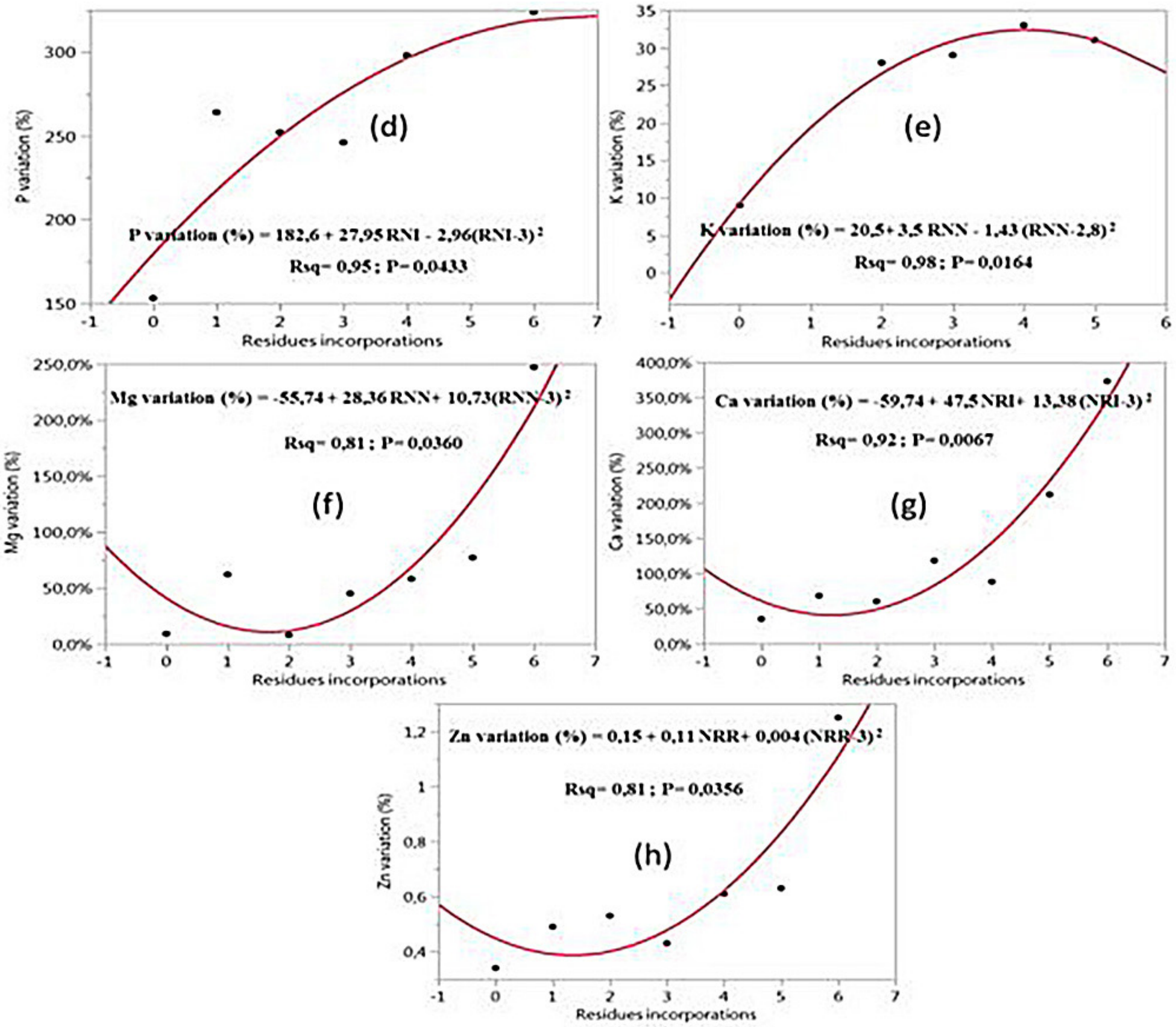

Figure 8. Relationship between the NRI and nutrients phosphorus (d); potassium (e); magnesium (f); calcium (g) and zinc (h)

Table 9. ANOVA analysis of yield and sugar content variation by the NRI

Number of residues incorporations *	Root yield (Mg. ha^{-1})		Root yield variation	Sugar content (%)		Sugar content variation
	2012	2019		2012	2019	
0	66.31 a	68.04 c	5% b	15.77 a	15.42 b	-2% a
1	67.78 a	70.57 bc	6% b	16.85 a	16.14 ab	-4% a
2	68.19 a	70.39 bc	5% b	16.86 a	15.49 ab	-8% a
3	65.27 a	74.84 b	17% ab	16.85 a	16.47 ab	-2% a
4	66.77 a	85.74 a	30% a	16.82 a	16.08 ab	-4% a
5	71.31 a	89.72 a	28% a	16.54 a	17.17 ab	4% a
6	67.45 a	86.38 a	31% a	16.68 a	17.37 a	4% a

Note: *Values followed by the same letter are not significantly different.

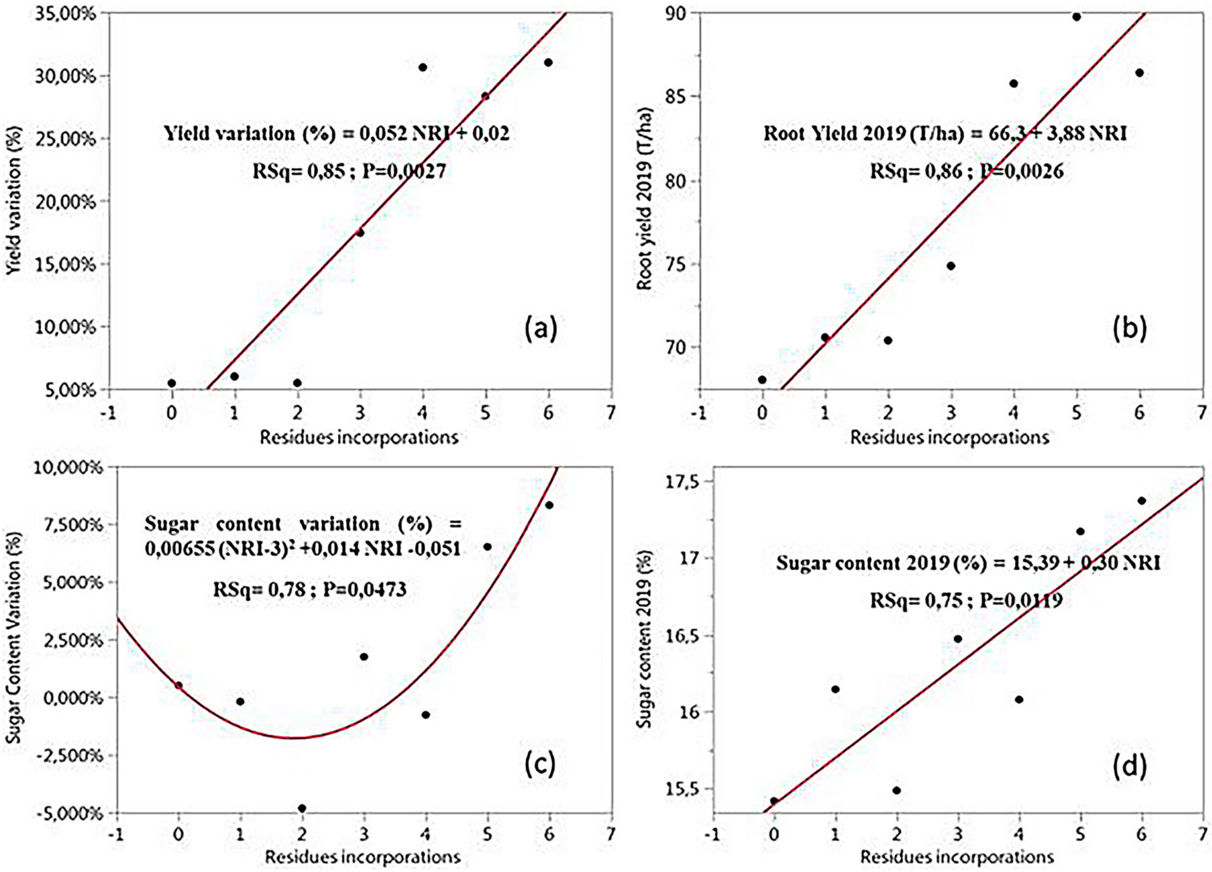

Figure 9. Relationship between the number of residues incorporations and yield average

with the number of residues incorporations with (R^2 = 0.74; P = 0.0119) (Figure 9d). The one-factor ANOVA showed that sugar content variation evolves inversely for 1 and 2 RI and that from 3 to 6 RI this evolution was increasing. The regression showed that there is a strong non-linear relationship between the relative increase in sugar content and the NRI. the regression curve shows that the increase in the rate of MOS following RI (Figure 9c) has a negative effect on the sugar content up to 2.12% of SOM which corresponds to 2 RI, but from 2.12% up to 2.97% of SOM which correspond respectively to 2 and 6 RI, the effect is positive in an almost linear relationship. This non-linear relationship with (R^2 = 0.78; P = 0.0473) can be explained for the drop in sugar content by the combination of nitrogen inputs by cover fertilizers combined with nitrogen from the intense mineralization of crop residues for 1 and 2 residues incorporations which decreases the content in beet sugar following an excess of nitrogen fertilization (Islamgulov et al., 2019), but from 2 to 6 RI it can be suggested that the increase is due to the achievement of balance between the mineralization and the humification of SOM thus confirming the results found in this direction (Rossi & Beni, 2018), while indicating that from the third restitution of sugar beet residues we observe an immobilization of nitrogen despite the constant amendment by mineral fertilizers. this is due to the high C:N ratio of sugar beet crowns, especially since the mechanically harvested part is relatively superior in comparison with the manual method.

The number of plots receiving the sugar beet residues was promoted by increasing mechanical harvesting in the area. The introduction of sugar beet mechanical harvesting was progressive since there were fewer harvesters at the beginning and the farmers were reluctant. The sugar beet area mechanically harvested compared to the total sugar beet area has increased from 3% in 2012 to 99% in 2019 of the total area.

CONCLUSIONS

The aim of this work was to monitor the fertility of sugar beet plots practiced in an intensive system and to evaluate the effect of this crop residues incorporation to mitigate the degradation of the organic status of the soil.

The plots which did not undergo any residues incorporation experienced a decrease of -19% in the SOM, while the restitution of sugar beet residues made it possible over a period of eight sugar beet growing seasons to improve the SOM of sugar beet plots in an almost linear relationship with the number of incorporations, the increase was +194% for 6 incorporations. However, this variation is a function of the texture and the initial SOM, it is more pronounced in soils poor in SOM and / or with a dominant coarse texture and less important in soils rich in SOM and / or with dominant fine texture. In general, the dominant fine-textured plots presented higher SOM rates than the coarse-textured plots.

During the period studied, the incorporations led to a slight alkalization of the soils which is favorable to the availability of elements in the soil, and an increase in CEC and the content of nutrients in the soil, namely N, P, K, Mg, Ca, B, Mn, Zn and $CaCO_3$ and a slight drop in Fe and Cu. A significant correlation with the variation of the SOM was observed for P, K, Mg, Ca, B, Zn and $CaCO_3$ thus confirming the strong mineralization of the sugar beet residues which release their main constituents on the one hand and that the increase in nitrogen observed is mainly due to the excessive supply of nitrogenous mineral fertilizers given the lack of correlation between this element and the variation of the SOM. The increase in EC of +23% for the 419 plots is probably due to the application of mineral fertilizers and restriction of irrigation water, since it does not show a significant correlation with the increase in SOM.

The multivariate correlation of the variation of SOM with the different particle size fractions, the initial SOM content and the number of residues incorporations made it possible to establish a statistically significant prediction model with a positive coefficient with respect to coarse and fine sand, coarse and fine silt and the number of residues incorporations, and negative with the initial stock of SOM. This correlation is not significant for clay. This is confirmed by the negative correlation found between the content of SOM with the coarse elements, which accentuate the variation of SOM favoring its mineralization, while the correlation is positive with the elements. purposes which bring into play SOM associated with it as a regulator of the variation of the SOM.

In general, the root yield of sugar beet has resumed its increase since the 2012 season, the maximum variation in yield and sugar content as well as the 2019 yields and sugar content were observed at the level of the plots which received 6 incorporations in eight seasons. Positive and strong relationships were found between the number of incorporations and these parameters, which confirms the interest, proven by the literature, of maintaining the organic status of soils through restitution, which increases the efficiency of elements in the soil.

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