Alternative sugar beet production using shallow tillage and municipal solid waste fertiliser

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Original article

Alternative sugar beet production using shallow tillage and municipal solid waste fertiliser

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Abstract – The application of conventional agricultural practices, e.g. deep soil tillage and repeated, plentiful mineral fertilisation, can lead to a progressive deterioration of soil fertility, especially in Mediterranean environments characterised by scanty rains and high summer temperatures. As a consequence, to maintain high levels of both crop productivity and soil organic matter and to improve some soil properties, a reduction of agricultural inputs and a greater supply of organic material are needed. In the light of these considerations, we carried out a two-year field experiment in Southern Italy to determine the effects of reduced soil tillage and municipal solid waste compost application on growth parameters, production and quality of sugar beet crops, and on both soil chemical characteristics and mineral nitrogen deficit. Two soil tillage depths were compared: conventional tillage, till 40–45 cm and shallow tillage, at 15–20 cm. Within each soil tillage, the following N-fertilising strategies were tested: (1) mineral fertilisation, with 100 kg N ha^{-1}; (2) organic fertilisation with municipal solid waste compost at 100 kg N ha^{-1}; (3) mixed fertilisation, with 50% of organic N as municipal solid waste compost, and 50% of mineral N; and (4) slow-release organic-mineral N fertiliser, at 100 kg N ha^{-1}. All these treatments were compared with a lower level of mineral fertiliser at 50 kg N ha^{-1}, and with an unfertilised control. Our findings show first the absence of a significant difference in root and sucrose yields between reduced tillage and deep tillage; as shown by roots (36.02 t ha^{-1}) and sucrose (3.41 t ha^{-1}) yields for reduced tillage and 35.76 and 3.51 t ha^{-1}, respectively, for the deepest tillage. Secondly, among the N treatments, the mixed organic-mineral N fertilisation gave productions statistically not different from mineral N fertilisation; as shown by root yields (36.38 versus 36.40 t ha^{-1}) and sucrose yields (3.56 versus 3.65 t ha^{-1}). Third, the mixed organic-mineral N induced a reduction of 13.2% in α-amino N content by comparison with the mineral treatment of 100 kg N ha^{-1}. Fourth, our results showed that the applications of the municipal solid waste compost increased the extracted and the humified organic carbon by +27.7 and +25.4%, compared with the mineral fertiliser, and did not raise the content of heavy metals. These findings highlighted that in Southern Italy it is sustainable to adopt alternative sugar beet production, safeguarding crops' quantitative and qualitative performance, decreasing the production costs and using the natural resources better.

sugar beet / soil tillage depths / municipal solid waste / yield / quality / soil characteristics / mineral N deficit

1. INTRODUCTION

The application of conservative agricultural practices, such as reducing both soil tillage depths and mineral fertiliser levels, has become indispensable for conserving soil resources, preserving its productive potential and maintaining and/or improving environmental quality. Several authors indicate that no or shallow tillage can reduce soil erosion and improve soil water retention, and soil organic C and N contents (Lal, 1989; Franzluebbers et al., 1995; Rasmussen et al., 1998). The addition of organic materials, e.g. crop and animal residues, and manure and compost from organic waste, can increase the soil organic matter content and improve some properties of soil (Celik et al., 2004). In this context, municipal solid waste is increasingly applied in many countries as compost which, while it has low nutrient contents and poor fertilising value, can have beneficial effects on physical, chemical and biological soil properties (Giusquiani et al., 1988; Serra-Wittiling et al., 1996; Crecchio et al., 2004), apart from the additional benefit of reduced waste disposal costs. Nevertheless, this kind of compost can contain dangerous levels of heavy metals, substances harmful to human and animal welfare. Therefore, its evaluation should not only concern the nutrients and organic matter levels, water content and degree of maturity, but also the environmental risks. Several authors have shown interesting results obtained with the application of municipal solid waste compost on different species (Maynard, 1995; Eriksen et al., 1999; Maiorana et al., 2005; Montemurro et al., 2005a), but there still is a lack of information concerning its application on sugar beet (*Beta vulgaris* L.) grown in Southern environments.

Proper N management for sugar beet fertilisation can be useful, since a plentiful mineral N application increases the potential of nitrate leaching into groundwater and it also results in a high top growth of plants, a lower sucrose concentration and a higher level of impurities in the roots (Winter, 1990; Shock et al., 2000), thus decreasing the crop profitability. Carter and Traveller (1981) reported that sugar beet root quality has steadily decreased since the early 1950s with the increased use of N fertiliser.

Therefore, we studied the effects of different soil tillage systems and fertiliser strategies on sugar beet crops, to provide

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and develop agronomical recommendations for sugar beet production, considering both economic and environmental concerns. To accomplish this objective, a two-year field experiment on sugar beet was conducted to establish quantitative and qualitative parameters, yield components, mineral soil-N deficit and chemical soil properties.

2. MATERIALS AND METHODS

2.1. Experimental site

The experiment was carried out in Foggia, Southern Italy, on the experimental farm of the Institute in the years 2001 and 2003 on a spring-sowing sugar beet crop (*Beta vulgaris* L., cv. Azzurra), grown with durum wheat (*Triticum durum* Desf.) in two-year rotation. The climate is "accentuated thermomediterranean", as classified by UNESCO-FAO. The weather during the trial period was characterised by great variability, since the total annual rainfall was 455 and 571 mm, respectively, for 2001 and 2003, vs. 551 mm of the long-term averages 1952–2000. The average annual temperatures were 16.4 °C in 2001 and 15.5 °C in 2003, both higher than the 15.4 °C of the 1952–2000 period.

The soil of the experimental field was a silty-clay Vertisol of alluvial origin, classified as Typic Chromoxerert, Fine, Mesic, mixed by USDA (Soil Survey Staff, 1992). The main starting characteristics of the soil were: total N = 1.22 g kg^{-1}, determined by the Kjeldahl digestion and distillation method; available P = 56 mg kg^{-1}, by the Olsen and Sommers method; exchangeable K = 1018 mg kg^{-1}, by the Thomas method; organic matter = 20.7 g kg^{-1}; pH = 8.13, by 1:2 soil water suspension.

2.2. Treatments and experimental design

The study was conducted on elementary plots of 40 m^2 each laid out in a randomised complete block with a split-plot arrangement and three replications. Within each block, the level of split was assigned to the following two soil tillage depths: conventional tillage, obtained by mouldboard ploughing at 40–45 cm, and shallow tillage, by disk harrowing at 15–20 cm. Within each soil tillage depth, five N fertilisation treatments and an unfertilised control were compared. Considering that the optimal N level for sugar beet crops in the trial area is 100 kg N ha^{-1}, this amount was distributed as: (1) mineral fertilisation; (2) organic fertilisation, with municipal solid waste compost; (3) mixed fertilisation, with 50% of organic N, as municipal solid waste compost, and 50% of mineral N; (4) slow-release organic-mineral N fertiliser, Azoslow, made by ILSA. These treatments were compared with a reduced level of mineral N fertiliser, 50 kg N ha^{-1}, and an unfertilised control. The fertilisers were applied as following: ammonium nitrate, half at sowing, half as a top dressing, for the mineral fertiliser treatment; ammonium nitrate, only at sowing, for the reduced level of mineral N fertiliser; municipal solid waste compost, one month before sowing, for the organic treatment; 50% of the total amount of N as municipal solid waste compost, one month before sowing, and 50% of mineral N, as a top dressing, for the organic treatment; slow-release organic-mineral N fertiliser, at sowing, for the slow-release treatment. Phosphorus fertiliser (50 kg P_2O_5 ha^{-1}) was broadcast in the autumn, at the main soil ploughing. At the most representative phenological phases of sugar beet, the plots were irrigated with a total water volume of 1500 m^3 ha^{-1} in 2001 and 1390 m^3 ha^{-1} in 2003. In each trial year, the same amount of municipal solid waste compost was applied. The amendment was obtained by Cupello engineering through an aerobic transformation of municipal solid waste by selective collection. The mean chemical composition of the compost is reported in Table I. The composition of Azoslow is: total N 29%; organic N 5%; mineral N, as urea 24%; total organic carbon 18%.

Table I. Chemical composition of municipal solid waste compost.

Parameters	Values
Total N (g kg^{-1})	1.47
Total organic carbon (g kg^{-1})	13.75
Total extracted carbon (g kg^{-1})	7.67
Humified organic carbon (g kg^{-1})	2.51
Cu (mg kg^{-1})	330
Zn (mg kg^{-1})	751
Pb (mg kg^{-1})	670
Ni (mg kg^{-1})	217
Cd (mg kg^{-1})	1.3
C/N	9.55

2.3. Sampling and measurements

Three plants of sugar beet were sampled from each plot during plant vegetative development at 63 and 51 days after sowing in 2001 and 2003, respectively, at the root swelling, which occurred at 74 and 87 days after sowing, and at the ripening stage, at 102 and 101 days after sowing. From those samples, the Leaf Area Index and the total dry matter of leaves and roots, by drying samples at 70 °C until constant weight, were determined. At harvesting time, which took place at 147 and 134 days after sowing, the length and the maximum girth of roots, the productive and qualitative parameters, e.g. sucrose concentration, α-amino N, potassium, sodium, alkalinity coefficient, molasses sucrose and juice purity, and total plant N content were recorded on a sample of a 6-m^2 portion of each plot.

At the beginning (t0) and at the end of the two trial years (tf), three soil samples were collected from the plots of the control, the highest mineral N and the organic treatments in the 0–40 cm layer, pooled into one sample and analysed to determine both the organic carbon fractions and the heavy metal contents, using atomic absorption spectrometry.

Table II. Effect of years and experimental treatments on the main productive and agronomic parameters of sugar beet.

	Root yield ($t\ ha^{-1}$)	Sucrose yield ($t\ ha^{-1}$)	Root dry matter ($t\ ha^{-1}$)	Mean root weight (g)	Harvest Index (%)	Root girth (cm)	Root length (cm)
Years							
2001	31.71 b	2.95 b	1.58 b	314.1 b	70.03	22.74 b	23.40 b
2003	40.07 a	3.97 a	1.85 a	465.3 a	69.49	26.26 a	35.33 a
Soil tillage							
Conventional	35.76	3.51	1.73	373.4	69.69	24.49	29.04
Shallow	36.02	3.41	1.70	405.9	69.83	24.51	29.68
N treatments							
Mineral(1)	36.40	3.65 a	1.77 a	437.6 a	70.79	25.16	28.84
Organic	36.15	3.26 ab	1.70 a	376.3 ab	68.82	24.44	29.95
Mixed	36.38	3.56 ab	1.78 a	428.6 a	71.19	24.97	29.70
Slow-release	37.49	3.43 ab	1.65 ab	356.0 b	68.56	23.62	28.94
Reduced	32.50	3.71 a	1.82 a	391.3 ab	70.72	24.51	29.42
Control	36.43	3.16 b	1.56 b	348.3 b	68.47	24.30	29.34

Within years, soil tillage and N treatments, the values in each column followed by different letters are significantly different according to the Least Significant Difference and Duncan's Multiple Range Test at $P \leq 0.05$, for two or more values, respectively. Within each column and experimental treatment the values without letters indicate no significant difference among means.
(1) Mineral = mineral fertiliser at 100 kg N ha^{-1}; Organic = municipal solid waste at 100 kg N ha^{-1}; Mixed = 50 kg N ha^{-1} of municipal solid waste and 50 kg N ha^{-1} of mineral fertiliser; Slow-release = 100 kg N ha^{-1} of slow-release organic-mineral N fertiliser; Reduced = mineral fertiliser at 50 kg N ha^{-1}; Control = unfertilised treatment.

2.4. Statistical analysis

SAS statistical procedures (SAS Institute, 1990) were applied for the statistical analysis of variance, in which the years were considered as a random effect, while the soil tillage and N treatments were considered as a fixed one. Differences between means were analysed with the Least Significant Difference and Duncan's Multiple Range Test, at the $P \leq 0.05$ probability level, for two or more than two values, respectively. Pearson correlation coefficients were used to compare sugar beet yields and quality with yield components and qualitative parameters. For clearness of exposition, only the main effects of the experimental treatments are presented in this paper, as a great proportion of the interactions were not significant. In particular, no interaction was found between soil tillage and N fertilisation treatments; therefore, the results shown in the tables and figures do not include this interaction, and they are presented as an average of the main effects.

3. RESULTS AND DISCUSSION

This research aimed to study alternative sugar beet production and, in particular, to evaluate the effect of two soil tillage depths and different organic and mineral N fertilisation strategies on sugar beet performance. Therefore, yield, quality, N uptake, mineral soil N deficit, and plant and soil characteristics were determined in a two-year field experiment.

3.1. Effect of years, soil tillage and N treatments on sugar beet yield and growth

Table II shows that the root yields of 31.71 and 40.07 t ha^{-1} for 2001 and 2003, respectively, and sucrose yields (2.95 and 3.97 t ha^{-1}) were significantly higher in the second trial year, thus showing the influence of seasonal weather trends. Therefore, in these conditions, the agronomic management should be modified during the cropping cycles with corrective action to raise the plant growth to its optimum levels. This variability in the climatic pattern is particularly accentuated in Mediterranean environments, where rains are almost always scanty and unevenly distributed in each year, being concentrated mainly in the winter months. The differences in yield capability between the two trial years were probably due to the highest mean temperature recorded in August 2001, which was +1.3 °C in respect to 2003, during the last part of the sugar beet cropping cycle. Similar differences were also found in dry matter, weight, girth and length of roots. On the contrary, soil tillage depths did not affect root and sucrose yields or agronomic components, as found in other crops by Steinbach et al. (2004) and Maiorana et al. (2005).

The effects of N treatments caused significant differences in sucrose yield, ranging from 3.16 t ha^{-1} of control to 3.71 of reduced mineral N treatment, although the total mineral elements available in the soil at the beginning of the experiment and the fertiliser N applied in the four treatments with 100 kg N ha^{-1} application were nearly the same. The differences in sucrose yield were probably due to the root dry

Table III. Leaf Area Index of sugar beet plants as affected by N treatments.

Tillage	Days after sowing	Fertiliser treatments						LSD*
		Mineral[(1)]	Organic	Mixed	Slow-release	Reduced	Control	
				2001				
Conventional tillage	63	0.80	0.73	0.74	0.92	0.86	0.86	0.21
	74	3.71	4.22	2.57	4.52	3.88	3.70	1.48
	102	5.91	6.53	5.29	6.09	8.31	5.36	1.90
	119	3.57	3.05	3.28	3.48	4.50	3.67	1.39
Shallow tillage	63	0.70	0.85	0.70	0.80	0.89	0.70	0.25
	74	3.09	4.61	4.27	5.91	6.09	3.79	1.77
	102	5.02	7.01	5.25	6.45	6.25	5.89	2.27
	119	2.34	3.87	2.87	3.77	2.87	3.12	1.42
				2003				
Conventional tillage	51	0.51	0.66	0.78	1.03	1.04	0.57	0.48
	87	2.83	3.18	2.91	3.39	2.84	3.06	1.29
	101	3.82	3.64	3.32	3.32	3.45	2.52	1.89
Shallow tillage	51	0.57	0.63	0.54	0.87	0.78	0.62	0.35
	87	2.71	2.39	2.96	2.35	2.54	2.18	1.04
	101	2.82	2.56	3.14	2.97	3.57	2.36	1.25

* The values of the Least Significant Difference (LSD) were calculated within each year, soil tillage and days after sowing.
(1) Mineral = mineral fertiliser at 100 kg N ha^{-1}; Organic = municipal solid waste at 100 kg N ha^{-1}; Mixed = 50 kg N ha^{-1} of municipal solid waste and 50 kg N ha^{-1} of mineral fertiliser; Slow-release = 100 kg N ha^{-1} of slow-release organic-mineral N fertiliser; Reduced = mineral fertiliser at 50 kg N ha^{-1}; Control = unfertilised treatment.

matter, which showed a trend similar to that of sucrose yields. No significant difference among N treatments was found in the harvest index and in the girth and length of roots.

During the sugar beet cropping cycles, the effect of soil tillage depths and N fertilisation treatments on its growing ability was evaluated by means of the Leaf Area Index. In the 2001 trial year (Tab. III), the plants reached the highest Leaf Area Index values, as a mean of N treatments, at the ripening stage, which occurred at 102 days after sowing for both conventional and shallow soil tillage (6.25 and 5.98, respectively). Similar behaviour was recorded in 2003 at 101 days after sowing, with values ranging from 3.34 of conventional tillage to 2.90 of shallow tillage (Tab. III).

The N treatments did not cause any significant difference for this parameter in the 2001 and 2003 trial years at either soil tillage depth. Furthermore, the organic application with the compost allowed the crops to reach good values of Leaf Area Index compared with mineral fertilisers. Substantial differences were found in Leaf Area Index values, as a mean of the whole cropping cycle, between the trial years (3.62 and 2.21 as a mean of 2001 and 2003, respectively). The highest plant development recorded in 2001, confirmed by the maximum and mean Leaf Area Index values, significantly and inversely reflected the root yield of the sugar beet (Tab. II), showing that the partitioning of the photosynthates was more evident in the plant tops than in the roots, and that the sucrose stored in the roots was used to support the increase in top growth (Carter and Traveller, 1981).

3.2. Effect of years, soil tillage and N treatments on sugar beet quality

The effect of experimental treatments on sugar beet qualitative parameters is reported in Table IV. Hao et al. (2001a) found that sugar beet yields, quality and impurity, e.g. α-amino N, Na and K contents, were not affected by tillage systems. The results of our research confirmed these findings, since there was no significant difference between conventional and shallow tillage in all qualitative parameters, as already observed in the productive ones (Tab. II). Conversely, the results indicate that N treatments not only affected crop development, but also sucrose concentration and, consequently, sucrose yield (Tab. II). Thus, N recommendations for sugar beet crop may involve a detailed profit evaluation related to the quality factors, as suggested by Bilbao et al. (2004). In particular, a significantly lower value of α-amino N (13.2%) was recorded for mixed N fertiliser in respect to the highest mineral N treatment (1.74 and 1.97 meq 100 g^{-1} pulp, respectively), indicating that compost application can reduce the level of this

Table IV. Effect of years and experimental treatments on the qualitative parameters of sugar beet.

	Sucrose concentration (%)	α−amino N (meq 100 g^{-1} pulp)	Sodium (meq 100 g^{-1} pulp)	Potassium (meq 100 g^{-1} pulp)	Molasses sucrose (meq 100 g^{-1} pulp)	Alkalinity index	Degree of purity (%)
Years							
2001	9.31 b	1.96 a	1.14	3.03	1.25 a	2.17	98.48
2003	9.93 a	1.75 b	1.15	3.07	1.10 b	2.41	98.51
Soil tillage							
Conventional	9.81	1.87	1.17	3.05	1.19	2.27	98.49
Shallow	9.47	1.84	1.11	3.05	1.15	2.31	98.51
N treatments							
Mineral(1)	10.03 a	1.97 a	1.29 a	3.49 a	1.24 a	2.49 ab	98.40 b
Organic	9.02 ab	1.80 ab	1.23 a	2.79 b	1.13 ab	2.28 ac	98.53 a
Mixed	9.78 a	1.74 b	1.18 a	3.48 a	1.09 b	2.68 a	98.45 ab
Slow-release	9.15 ab	1.84 ab	1.09 ab	3.07 ab	1.16 ab	2.28 ac	98.50 a
Reduced	11.41 a	1.89 ab	1.12 ab	2.71 b	1.19 ab	2.08 bc	98.54 a
Control	8.67 b	1.87 ab	0.94 b	2.74 b	1.23 a	1.92 c	98.55 a

Within years, soil tillage and N treatments, the values in each column followed by different letters are significantly different according to the Least Significant Difference and Duncan's Multiple Range Test at $P \leq 0.05$, for two or more values, respectively. Within each column and experimental treatment the values without letters indicate no significant difference among means.

(1) Mineral = mineral fertiliser at 100 kg N ha^{-1}; Organic = municipal solid waste at 100 kg N ha^{-1}; Mixed = 50 kg N ha^{-1} of municipal solid waste and 50 kg N ha^{-1} of mineral fertiliser; Slow-release = 100 kg N ha^{-1} of slow-release organic-mineral N fertiliser; Reduced = mineral fertiliser at 50 kg N ha^{-1}; Control = unfertilised treatment.

qualitative parameter. Therefore, the application of municipal solid waste compost is compatible with good levels of sugar beet yield and quality, and thus this organic material could partially substitute mineral N fertilisation, as found in other crops in similar (Maiorana et al., 2005; Montemurro et al., 2005a) or different environments (Maynard, 1995; Eriksen et al., 1999). The 100 kg N ha^{-1} treatment also presented the highest value of sodium (1.29 meq 100 g^{-1} pulp) and the lowest degree of purity (98.40%). These results indicate that an excessive and/or late N application, as occurred with the highest N treatment, increased the impurities in roots, decreasing the extractive ability of stored sucrose, which further decreased refined sucrose production, as found by Carter and Traveller (1981) and Pocock et al. (1988).

In Table V the correlation coefficients among yields, quality and total N uptake with yield components and qualitative parameters are presented. Even if with different absolute values, a significant and positive correlation was found among root and sucrose yields and length, girth, weight and dry matter of roots. Conversely, there was a significant and negative correlation among Leaf Area Index values recorded at root swelling, at ripening and as a mean value, with yields and N uptake, indicating that plant growth and leaf expansion in this crop are not positive characters for sucrose production. As found in other species in the same environment (Montemurro et al., 2002), significant correlations were recorded between total plant N uptake and yields, confirming the role also played by this parameter in sugar beet production. On the contrary, although with less absolute value, the N uptake was significantly and negatively correlated with the α-amino N, which is one of the most considered parameters of sugar beet quality.

3.3. Effect of soil tillage and N treatments on mineral soil N deficit and soil characteristics

As the amount of N application and N uptake were the total of the two-year experiment, all fertilising treatments in both soil tillages showed a mineral N (N-NO_3 + N-NH_4 exchangeable) deficit in the soil (Figs. 1 and 2). Among the N treatments, the highest soil N deficit was obviously found in control, whether in conventional tillage, or in the shallow one. Therefore, although the unfertilised treatment showed an interesting level of root yield (Tab. II), its application is not in line with common agricultural practices, as there can be a progressive impoverishment of the soil N content. The good yield performance of control was probably due to the large contribution of the N present in the soil at the beginning of the experiment, with values equal to 20.7 and 1.22 g kg^{-1} of organic matter and total N, respectively. Furthermore, Steinbach et al. (2004) suggest that the residues of previous crops and the high mineralisation rate could play a central role in N supplies in growing plants. It should be noted that, even if without significant differences, the organic, mixed and the highest N mineral treatments showed a lower N deficit in both conventional and shallow tillage, indicating a positive effect on sustainable crop production. Finally, the soil tillage did not determine any substantial difference in the soil N deficit trend.

Table V. Correlation coefficients among productive, qualitative and agronomic parameters of sugar beet.

	Root yield	Sucrose yield	α-amino N	Total N uptake
Root length	0.5941 ***	0.6801 ***	–0.4743 ***	0.4389 ***
Root girth	0.4798 ***	0.6768 ***	–0.2616 *	0.4976 ***
Mean root weight	0.4897 ***	0.7496 ***	–0.3868 ***	0.5489 ***
Root dry matter	0.2408 *	0.7896 ***	–0.2791 *	0.4548 ***
Sodium	0.0510 n.s.	0.1352 n.s.	–0.1268 n.s.	0.3051 **
Potassium	–0.1143 n.s.	0.0792 n.s.	–0.1025 n.s.	0.2420 *
Sucrose content	0.1644 n.s.	0.3093 **	–0.1494 n.s.	0.2755 *
Molasses sucrose	–0.4605 ***	–0.3531 **	1.000 ***	–0.2664 *
Alkalinity index	0.1433 n.s.	0.2285 *	–0.5267 ***	0.3563 **
Degree of purity	0.2052 n.s.	–0.0094 n.s.	–0.1507 n.s.	–0.2171 n.s.
Leaf Area Index at root swelling	–0.4088 ***	–0.3895 ***	0.3106 **	–0.2997 **
Leaf Area Index at ripening	–0.4410 ***	–0.4240 ***	0.3265 **	–0.3656 **
Leaf Area Index (mean value)	–0.4956 ***	–0.4236 ***	0.3400 **	–0.3664 ***
Harvest index	–0.2721 *	–0.1063 n.s.	0.1117 n.s.	–0.1310 n.s.
Root yield	–	0.4304 ***	–0.4602 ***	0.4282 ***
Sucrose yield		–	–0.3529 **	0.4795 ***
α-amino N			–	–0.2664 *

*, **, *** Significant at the $P < 0.05$, 0.01 and 0.001 levels, respectively; n.s. = not significant.

Figure 3, in which the effect of N treatments on both organic carbon fractions and heavy metal levels is reported, shows a general increase in organic matter. The means of both extracted and humified organic carbon increased from the beginning (t0) to the end (tf, as averages of only control, the highest mineral N and municipal solid waste treatments) of the two-year experiment, with increases that ranged from 5.97 to 7.11 g kg^{-1} in the first fraction, and from 3.35 to 4.68 g kg^{-1} in the second one. Particularly, the organic amendment application increased the extracted and the humified organic carbon by 27.7 and 25.4%, respectively, in comparison with the 100 kg N ha^{-1} treatment. These findings were probably due to both tillage management, carried out on the three tested treatments, and municipal solid waste use. Our results agree with the conclusions of Hao et al. (2001b), who reported that tillage systems which limit or reduce soil disturbance, and the incorporation of crop residues generally caused an increase in soil organic matter. In particular, the application of municipal solid waste compost significantly increased the extracted organic carbon content at the end of the trial, with values equal to 6.44, 6.54 and 8.36 g kg^{-1} for control, the highest mineral N and organic treatments, respectively. Even if without significant differences, the same behaviour was found for humified organic carbon (4.41, 4.27 and 5.35 g kg^{-1} for the three

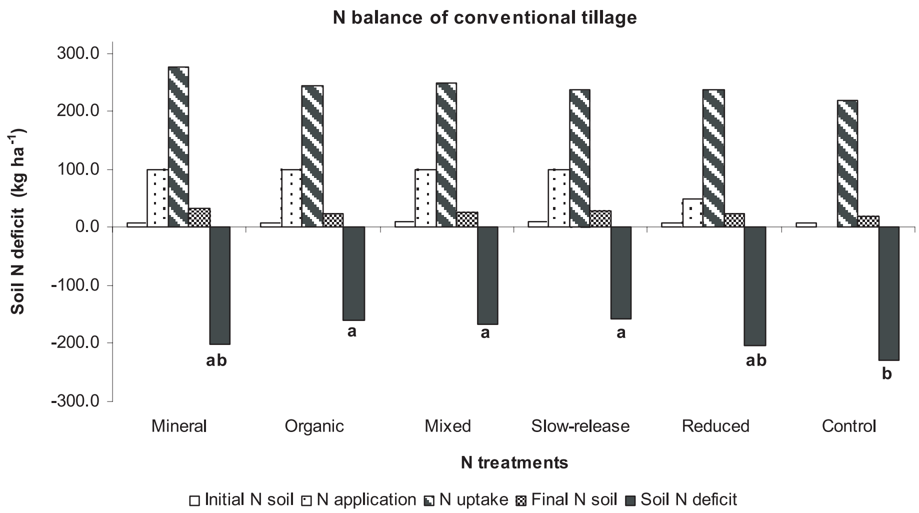

Figure 1. Soil N mineral deficit as a mean of the two-year experiment for conventional soil tillage as affected by N treatments. Within each determination, the histograms with the same letters are not significantly different at $P \leq 0.05$, according to Duncan's Multiple Range Test. Histograms without letters indicate no significant difference among means. [(1)] Mineral = mineral fertiliser at 100 kg N ha^{-1}; Organic = municipal solid waste at 100 kg N ha^{-1}; Mixed = 50 kg N ha^{-1} of municipal solid waste and 50 kg N ha^{-1} of mineral fertiliser; Slow-release = 100 kg N ha^{-1} of slow-release organic-mineral N fertiliser; Reduced = mineral fertiliser at 50 kg N ha^{-1}; Control = unfertilised treatment.

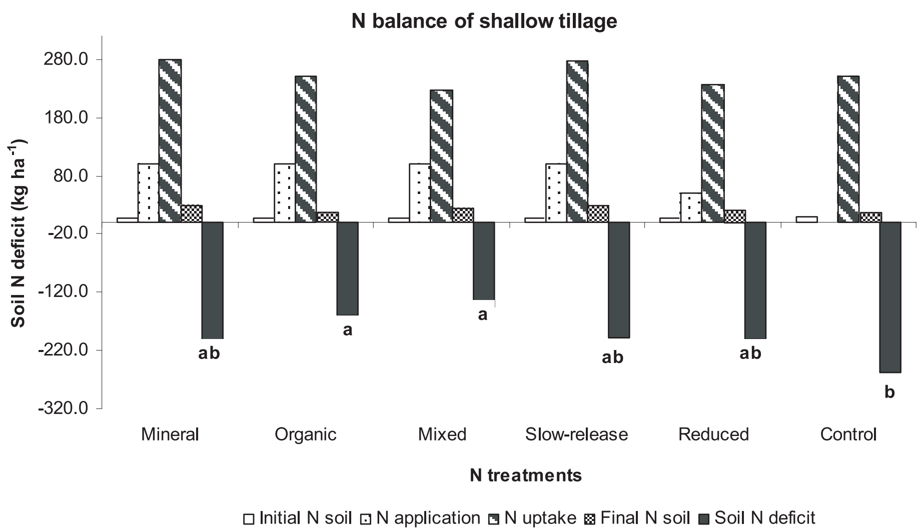

Figure 2. Soil N mineral deficit as a mean of the two-year experiment for shallow soil tillage as affected by N treatments. Within each determination, the histograms with the same letters are not significantly different at $P \leq 0.05$, according to Duncan's Multiple Range Test. Histograms without letters indicate no significant difference among means. [(1)] Mineral = mineral fertiliser at 100 kg N ha^{-1}; Organic = municipal solid waste at 100 kg N ha^{-1}; Mixed = 50 kg N ha^{-1} of municipal solid waste and 50 kg N ha^{-1} of mineral fertiliser; Slow-release = 100 kg N ha^{-1} of slow-release organic-mineral N fertiliser; Reduced = mineral fertiliser at 50 kg N ha^{-1}; Control = unfertilised treatment.

treatments), thus indicating that the application of organic material in the soil can have positive effects on sustainable cropping systems. Similar results were found in other species in the same environment (Montemurro et al., 2005a, b).

Regarding the Pb, Cu, Zn and Ni content, Figure 3 also shows that these heavy metals did not significantly increase, either during the whole trial period, or among the organic and the other two treatments. As suggested by Montemurro et al. (2005a), the lack of trace elements accumulated in the soil could be due to the dilution effects.

4. CONCLUSION

We found that: (i) the shallow soil tillage depth did not negatively affect root and sucrose yields or the qualitative parameters of sugar beet. (ii) The municipal solid waste compost can be considered a suitable agronomic practice, as a partial substitute for the mineral N fertiliser, considering that the mixed treatment, characterised by 50% of organic compost and 50% of mineral fertiliser, did not determine responses statistically different to those of the highest mineral N treatment.

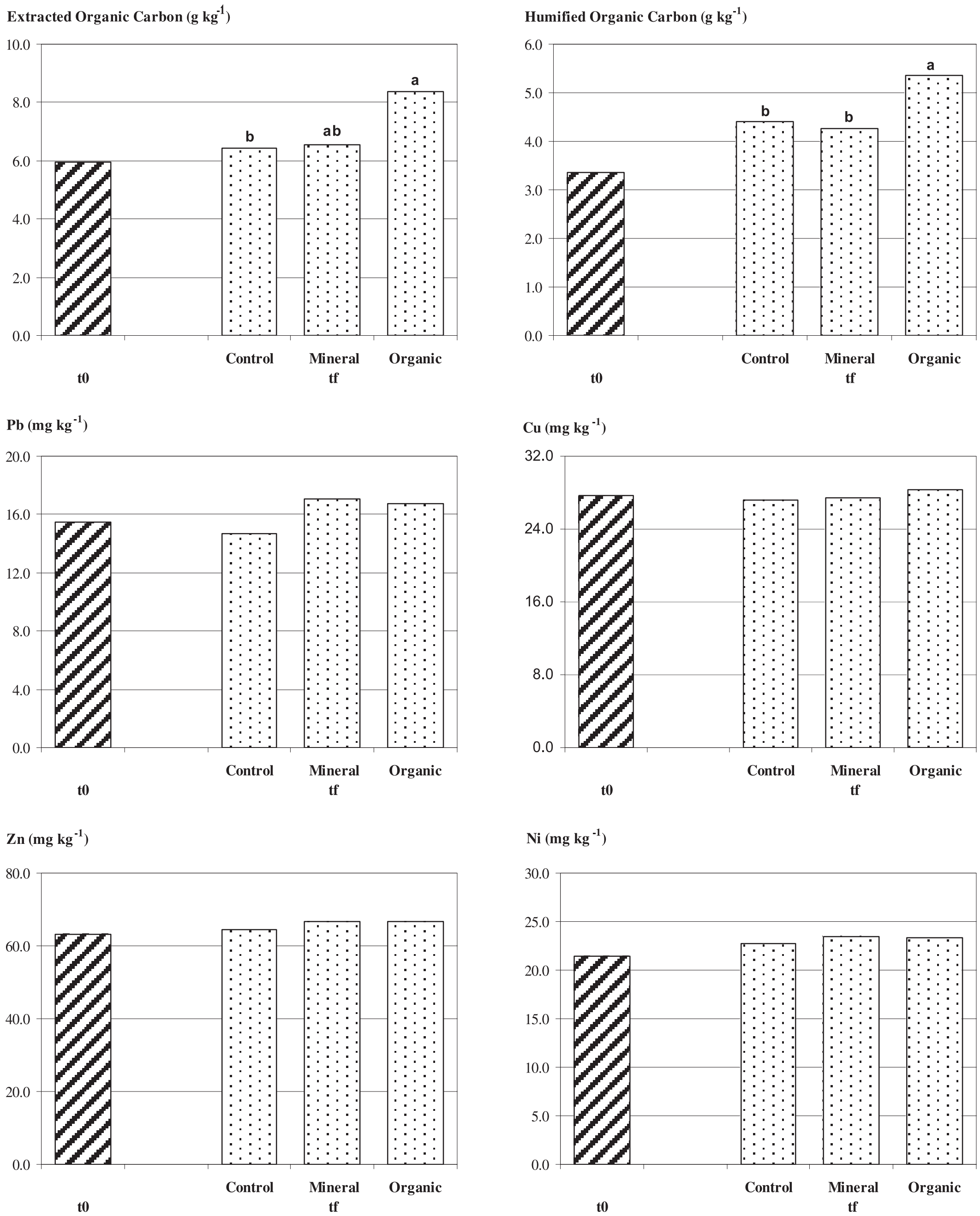

Figure 3. Chemical characteristics of the soil and heavy metal levels at the beginning (t0) and at the end of the two-year experiment (tf) as affected by N treatments. Within tf values, the bars with the same letters are not significantly different at $P \leq 0.05$, according to Duncan's Multiple Range Test. Histograms without letters indicate no significant difference among means. Control = unfertilised treatment; Mineral = mineral fertiliser at 100 kg N ha^{-1}; Organic = municipal solid waste at 100 kg N ha^{-1}.

In addition, the least N soil deficit in both conventional and shallow tillage and an increase in the extracted and the humified organic carbon, without significant variations in the soil heavy metal content, were found by using organic amendment. (iii) N fertiliser should be applied before sowing or during the early stages, at such amounts to optimise plant growth and sucrose production, otherwise the N surplus determines an excessive top growth of plants, as confirmed by the high Leaf Area Index values found in our experiment. These findings point out that in Southern conditions the reduction of agronomic inputs is not only a feasible practice from both an economic and productive point of view, but it also enables beneficial environmental effects.

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REFERENCES

Bilbao M., Martinez J.J., Delgado A. (2004) Evaluation of soil nitrate as a predictor of nitrogen requirement for sugar beet grown in a Mediterranean climate, Agron. J. 96, 18–25.

Carter J.N., Traveller D.J. (1981) Effect of time and amount of nitrogen uptake on sugarbeet growth and yield, Agron. J. 73, 665–671.

Celik I., Ortas I., Kilic S. (2004) Effects of compost, mycorrhiza, manure and fertiliser on some physical properties of a Chromoxerert soil, Soil Till. Res. 78, 59–67.

Crecchio C., Curci M., Pizzigallo M.D.R., Ricciuti P., Ruggiero P. (2004) Effects of municipal solid waste compost amendments on soil enzyme activities and bacterial genetic diversity, Soil Biol. Biochem. 36, 1595–1605.

Eriksen G.N., Coale F.J., Bollero G.A. (1999) Soil nitrogen dynamics and maize production in Municipal Solid Waste Amended soil, Agron. J. 91, 1009–1016.

Franzluebbers A.J., Hons F.M., Zuberer D.A. (1995) Tillage and crop effects on seasonal soil carbon and nitrogen dynamics, Soil Sci. Soc. Am. J. 59, 1618–1624.

Giusquiani P.L., Marocchini C., Businelli M. (1988) Chemical properties of soils amended with compost of urban waste, Plant Soil 109, 73–78.

Hao X., Chang C., Conner R.L., Bergen P. (2001a) Effect of shallow tillage and crop sequence on crop yield and quality under irrigation in a southern Alberta clay loam soil, Soil Till. Res. 59, 45–55.

Hao X., Chang C., Lindwall C.W. (2001b) Tillage and crop sequence effects on organic carbon and total nitrogen content in an irrigated Alberta soil, Soil Till. Res. 62, 167–169.

Lal R. (1989) Conservation tillage for sustainable agriculture: Tropics versus temperate environments, Adv. Agron. 42, 85–97.

Maynard A.A. (1995) Cumulative effects of annual addition of MSW compost on the yield of field-grown tomatoes, Compost Sci. Util. 3, 47–54.

Maiorana M., Charfeddine M., Montemurro F., Vonella A.V. (2005) Reduction of agronomical inputs of Sunflower (Helianthus annuus L.), Helia 28, 133–146.

Montemurro F., Convertini G., Maiorana M., Ferri D. (2002) N-use efficiency, yield and quality in maize-winter barley rotation, Agrochimica 46, 146–154.

Montemurro F., Convertini G., Ferri D., Maiorana M. (2005a) MSW compost application on tomato crops in Mediterranean conditions: effects on agronomic performance and nitrogen utilization, Compost Sci. Util. 13, 234–242.

Montemurro F., Maiorana M., Convertini G., Fornaro F. (2005b) Improvement of soil properties and nitrogen utilisation of sunflower by amending municipal solid waste compost, Agron. Sustain. Dev. 25, 369–375.

Pocock T., Milford G.F.J., Armstrong M. (1988) Progress in research towards side-specific fertiliser requirement, Br. Sugar Beet Rev. 56, 41–44.

Rasmussen P.E., Albrecht S.L., Smiley R.W. (1998) Soil C and N changes under tillage and cropping systems in semi-arid Pacific Northwest agriculture, Soil Till. Res. 47, 197–205.

SAS Institute, SAS/STAT Software (1990) SAS Institute Inc. Cary, NC, USA.

Serra-Wittiling C., Houot S., Barriuso E. (1996) Modification of soil water retention and biological properties by municipal solid waste compost, Compost Sci. Util. 4, 44–52.

Shock C.C., Seddigh M., Saunders L.D., Stieber T.D., Miller J.G. (2000) Sugarbeet nitrogen uptake and performance following heavily fertilised onion, Agron. J. 91, 10–15.

Soil Survey Staff, Keys of Soil Taxonomy (1992) In Technical monograph 19, 5th ed., SMSS, Blacksburg, Virginia, USA.

Steinbach H.S., Alvarez R., Valente C.R. (2004) Balance between mineralization and immobilization of nitrogen as affected by soil mineral nitrogen level, Agrochimica 48, 204–212.

Winter S.R. (1990) Sugarbeet response to nitrogen as affected by seasonal irrigation, Agron. J. 82, 984–988.