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Full Length Research Paper

Impact of applying composted biosolids on wheat growth and yield parameters on a calcimagnesic soil in a semi-arid region

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A field trial in a semi-arid climate was carried out on wheat (*Triticum aestivum* var. Marchouch) growing on a calcimagnesic soil using compost applied at 42 T/ha during the three years of study, but in different ways: C1, C2 and C3. Over this period, the level of total Kjeldhal nitrogen (TKN) increased in the soil amended by high doses (C2 and C3, by about 33 and 50%) compared with steady low amendment (C1) and to both controls NF (soil without fertilisation) and MF (soil receiving mineral fertilization). Adding compost also led to a positive influence on cation exchange capacity (CEC) by increasing humic substance levels (HS) which doubled in plots C2 and C3 compared with both controls. In NF soil, the TKN, total organic carbon (TOC) and the pH of soil showed a clear negative correlation with the agronomic parameters. In the MF soil, most physico-chemical parameters correlated well with the agronomic parameters: input of mineral elements balancing export through harvest. In amended soil, especially in C3 plots, HS and CEC showed significant correlations with most agronomic parameters (P1: 69.1%) due to enhanced CEC and sequestration of available carbon in the form of stable humic structures.

Key words: Compost, wheat growth, calcimagnesic soil, semi-arid region.

INTRODUCTION

Processing effluent in wastewater treatment plants generates a by-product-sludge, in quantities sufficiently large for its elimination to pose problems. The problems are usually underestimated or poorly taken into account in the design of the plants (Amir, 2005). However, chemical analysis of the sludge (also known as biosolids) shows it to be rich in fertilizing elements, especially nitrogen and phosphorus; hence, the proposal to use it as an amendment for soils leached by erosion and/or exhausted by intensive cropping (Bousselhaj et al., 2004). Spreading the sludge directly on the land can lead to contamination of food crops through the presence of chemical and organic micropollutants (Krogstad et al., 2005; Mantovi et al., 2005; Dai et al., 2006; Oleszczuk et al., 2006), hence the necessity to treat the biosolid before it is recycled (Amir et al., 2005a,b,c).

The treatment of sewage sludge by composting in a mixture with cellulose-based waste gives a product that is stable, presents a satisfactory level of hygiene is rich in humic substances and that has an agreeable smell (Jouraiphy et al., 2005; Lu et al., 2008). In many studies,

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the agronomic value of the soil has been shown to be improved by applying compost (Bazzoffi et al., 1998; Casado-Vela et al., 2007; Wie and Liu, 2005; Mantovi et al., 2005; Senesi et al., 2007). It has been demonstrated how the application of compost has a positive effect on the physical and chemical properties, the structure of the soils and on the soil-plant system (Inbar et al., 1992; Ayuso et al., 1996; Ostos et al., 2008). The authors suggest that the richness of compost in humic substances influences the fertility of the soil, improving its structure by increasing the biological activity and the availability of nutrients and by complexing toxic metals (Ayuso et al., 1996; O'Dell et al., 2007).

In addition, it would appear that spreading compost also improves the resistance of wheat to various types of stress, inhibits the activity of certain parasites and/or fungi and phytopathogenic bacteria (Beffa, 1998; Selivanovskaya et al., 2006).

Walker and Bernal (2008) reported that the increase in the CEC is directly proportional to the quantity of compost added, the larger nutrient pool being potentially available for plant growth (cations).

The greater density of plant roots following the application of compost improves the stability of the soil, reduces the risks of erosion and provides a higher soil water retention capacity (Ros et al., 2006; Chu et al., 2007).

In this study, we aimed to determine the relationship between physicochemical parameters (especially TKN, HA contents and CEC) and agronomic parameters (growth parameters and the yield) in soil amended with compost applied in different ways (C1, C2, C3) compared with un-amended soil and soil subjected to mineral fertilization. The agronomic essay was conducted using common wheat (*Triticum aestivum* var. Marchouch) on a calcimagnesic soil in a semi-arid region.

MATERIALS AND METHODS

Compost preparation

The samples of activated sludge were from the aerobic waste-water treatment plant in the town of Khouribga (Morocco). The composting trial was run on quite a large scale: 10 m^3 of sludge was mixed with 5 m^3 of green waste piled into a prism-shaped heap 8 m long and 1.5 m high, on a platform. When ready for composting, the mixture contained about 60% water and had a C/N ratio of 29.8. The compost was processed over a period of 135 days and was mixed every fortnight to keep the mixture well aerated. The agronomic essay was conducted with the final compost aged 135 days.

Experimental set-up in the field

The experiment was run in the field in the Sidi El Aydi experimental site (INRA Settat, Morocco) on fallow calcimagnesic soil. The soil had a clayey texture, was slightly basic and had a low proportion of organic matter (Table 1).

The area of field cultivated was 120 m^2. The experiment was performed in twenty blocks: 3 treatments and 2 controls randomly repeated 4 times (3 compost application protocols: C1, C2, C3; no fertilization NF and mineral fertilization MF) (Figure 1). The area of each of the 20 basic plots was 3 × 2 m. Compost application was: C1 = 1.4 kg/m^2 (14 t/ha), C2 = 2.8 kg/m^2 (28 t/ha) and C3 = 4.2 kg/m^2 (42 t/ha). All "C" plots received 4.2 kg/m^2 of compost over three years, but in different ways so as to compare the impact of receiving the whole quantity at once versus fractionation of the input over two or three years.

Plots C3 received the whole amount (4.2 kg/m^2) in the first year. Plots C1 and C2 amended during the first year were again amended at the start of the second year with an additional input of compost of about 1.4 kg/m^2. In the third year, only plots C1 received the same amount (1.4 kg/m^2) again. All plots received the same amount over the three years (4.2 kg/m^2).

Two controls were also used: in one, soil was not fertilised (NF) and in the second, reasonable mineral fertilisation (MF) was applied, using 150 kg/ha ammonium sulphate. This level of mineral fertilization is that generally used in the Chaouilla area where potassium and phosphorus are not considered growth-limiting factors. The wheat was sown (at about 120 kg/ha) in rows 25 cm apart.

Physicochemical analysis of the soil

Samples of soil were taken from different sides of the plots, in such a way as to obtain homogeneous representative samples of about 500 g. The samples were used for the various physicochemical analyses. The pH was measured in a 1:2 v:v soil-water suspension. Total organic carbon (TOC) was determined by potassium dichromate oxidation (Nelson and Sommers, 1982). Total nitrogen was assayed using the Kjeldahl method. Ammonium ion was assayed following distillation in alkaline medium and nitrates after reduction by Dewarda alloying (Ezelin, 1998). Humic substances were extracted with 0.1 M NaOH and assayed after oxidation in alkaline potassium permanganate (Jouraiphy et al., 2005). The soil cation exchange capacity (CEC) was determined by saturation with ammonium acetate at pH 7. Exchangeable alkaline cations (Na^+, K^+, Ca^{++}, Mg^{++}) were extracted with ammonium acetate and assayed by atomic absorption spectroscopy or flame emission spectroscopy (Na, K) (Houba et al., 1995).

Following the recommendations of the French standards association (AFNOR NF X 31-151) (1993), to obtain the total Zn, Cu, Pb and Ni content; 1 g of each sample was mineralised for 4 h at 550°C and then dissolved in 5 ml of hydrofluoric acid. The solution obtained was evaporated to dryness and the residue then taken up in concentrated HNO_3/HCl (1:1) solution. The acid solution was filtered (45 µm) and diluted for analysis by atomic absorption spectrometry "Unicam 929".

Analysis of the yield parameters

The leaf area index (LAI 2000) was measured at the heading stage at noon under a clear sky. A sample was taken in the form of 500 mm of a line of wheat, also at the heading stage to measure fresh weight. Dry weight was determined from the fresh-weight sample dried in an oven at 70°C for 48 h.

At the time of harvest, heads of wheat were taken over 1 m^2 of each plot to determine the biomass and the various yield parameters studied.

Statistical analysis

Comparison of the averages was carried out by ANOVA test post hoc Tukey, for a confidence interval of 95%. Principal component analysis (PCA) was carried out between different physico-chemical

Table 1. Physicochemical characteristics of the soil and of the compost as used.

Characteristic	Soil	Compost
Clay (%)	66	/
Silt (%)	25	/
Sand (%)	9	/
pH	8.40	6.23
Total Kjeldahl nitrogen *	0.24	1.69
Total organic carbon *	1.22	20.55
NH_4^+ mg/kg	4.24	40.16
NO_3^- mg/kg	12.91	9.65
CEC $Cmol^+$/kg	35.93	84.55
Humic substances (mg/g)	7.5	57.33
C/N	5	12.20
Decomposition with respect to the biosolids/green waste starting mixture (%)	/	60.80

***%**Dry weight.

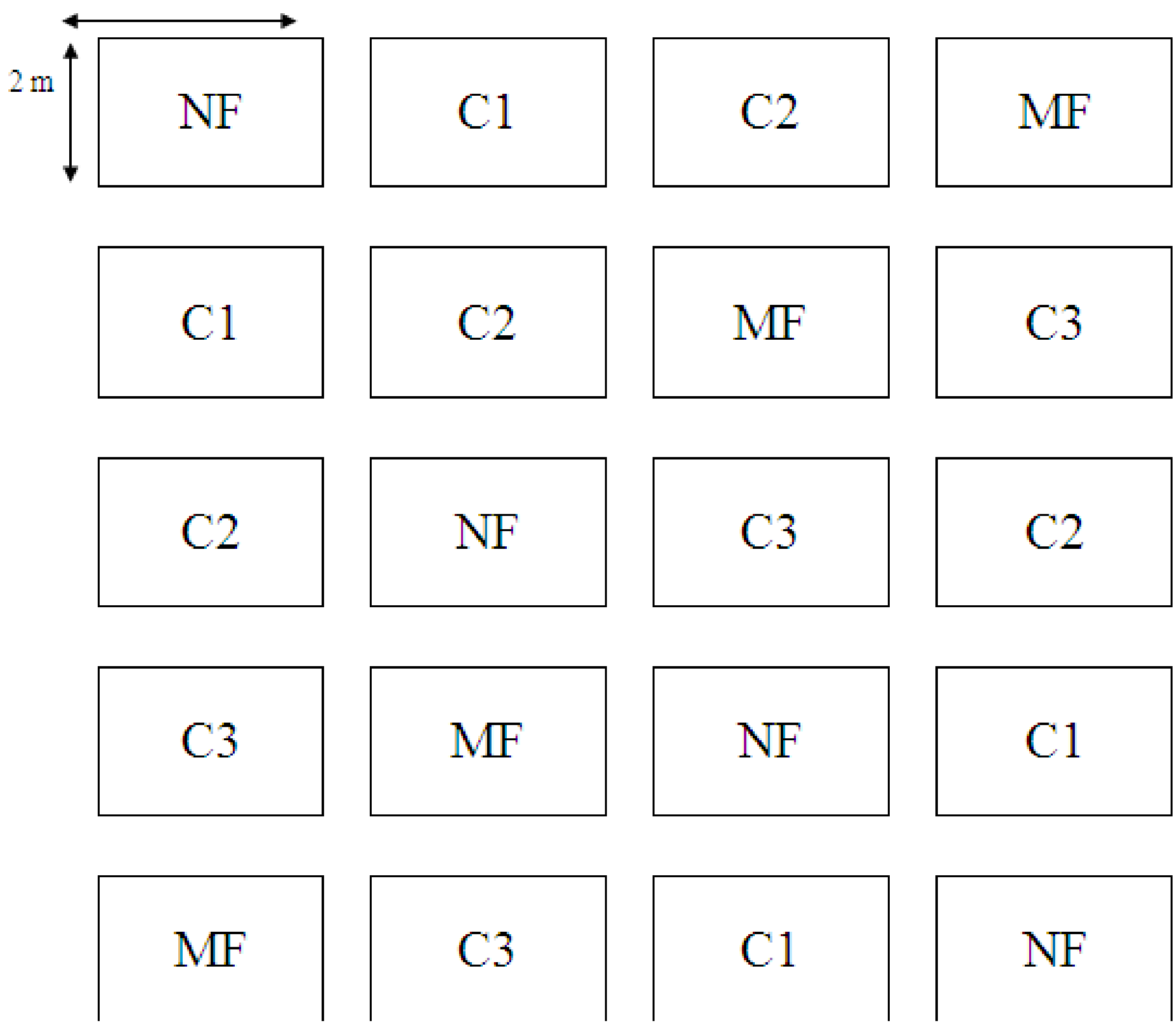

Figure 1. The random layout of differently treated blocks in the experiment field: NF soil without fertilization, MF soil was subjected to mineral fertilization; C1, C2 and C3 soil amended in year 1 of the experiment by 1.4, 2.8 and 4.2 kg/m^2, respectively.

Table 2. Effect of the biosolids-green waste compost on the key physical and chemical properties of the soil.

Parameter	Year	NF	C1	C2	C3	MF
pH	1st	8.33[a]	8.17[b]	7.83[c]	7.42[d]	8.27[ab]
	2nd	8.37[a]	7.89[c]	7.39[d]	7.35[d]	8.29[b]
	3rd	8.46[a]	7.73[b]	7.61[b]	7.42[b]	8.39[a]
Total organic carbon (%)	1st	1.15[d]	1.59[a]	1.50[b]	1.48[ab]	1.47[a]
	2nd	1.11[c]	1.63[a]	1.58[a]	1.55[a]	1.57[a]
	3rd	1.44[a]	1.21[c]	1.11[d]	1.07[c]	1.34[a]
Humic substances (g/kg)	1st	0.69[d]	0.94[c]	1.08[b]	1.29[a]	0.74[d]
	2nd	0.75[d]	0.94[c]	1.11[b]	1.30[a]	0.75[d]
	3rd	0.71[b]	0.92[b]	1.38[a]	1.56[a]	0.80[b]
CEC (meq/100g)	1st	35.38[d]	42.28[c]	47.89[b]	52.13[a]	36.77[a]
	2nd	36.13[d]	43.17[c]	48.05[b]	55.21[a]	35.92[d]
	3rd	35.65[b]	46.83[a]	46.92[a]	47.20[a]	32.87[d]

Values in the same row followed by the same letter are not significantly different. NF: No fertilization control; MF: mineral fertilization control; C1: 14 t/ha compost; C2: 28 t/ha compost; C3: 42t/ ha compost.

parameters of soils and agronomic parameters (growth and yield parameters) of wheat. The analysis of correlation was also performed between these parameters by the bilateral test of Pearson's correlation and the level for statistical significance was set at 0.01.

RESULTS AND DISCUSSION

Impact on the soil of compost spreading

The physicochemical characteristics of the soil and of the compost used are reported in Table 1. The data representative of the effect of compost amendment on the physicochemical properties of the soil with respect to the controls with or without fertilizers during the three years of the experiment are reported in Tables 2 and 3. The results show some significant effects of the compost on the chemical properties of the soil according to the mode of compost application and with respect to both controls. The pH of the soil decreased, tending towards neutral values. This effect was strongest in plots originally receiving the largest quantities of compost added, the soil pH in plots C3 and C2 decreased more than in plots C1 during the first and second years. In addition to the fact that compost contains abundant buffering substances, the decrease in pH was probably also due to the decomposition of the labile organic matter of compost or soil to yield organic acids. In fact, some authors have demonstrated that the addition of organic amendments such as compost to the soils increased their mineralization capacities (Pedra et al., 2007) or contributed to the incorporation of low molecular weight structural components with little aromatic polycondensation into soil HAs (Pedra et al., 2008). Mineral fertilisation (treatment MF) did not change the pH.

Compost amendment significantly raised the level of nitrogen in the soil. During the first year of the experiment, the level of nitrogen rose, with respect to the NF control, by 13, 20 and 22% following C1, C2 and C3 compost application, respectively. Mineral fertilization raised the level of nitrogen by only about 6%. This is in line with the results of other compost-amendment studies (Pinamonti, 1998; Prone et al., 1999, Courtney and Mullen, 2008). Some N release (24%) was recorded in plots C3, after in the second year even though no compost was added. Plots C3 and C2 showed a significant increase after the three years of about 19 and 21%, respectively. Application of compost in separate amounts C1 showed no large difference in the third year compared with the control and MF. Casado-Vela et al. (2007) reported that the levels of TKN and nitrate showed an increasing trend in soil proportionally to the compost dose. Gragnon and Simard (1999) report that at the end of each growing season, the level of nitrogen remained high indicating that the mineralization of the compost occurred progressively. This can be accounted for by the steady release of nitrogen in an available form, as the compost is increasingly degraded. Olsen (1986) reported that the main advantage of organic amendments (composted manure) was their aptitude to continually release mineral nitrogen to the plants to achieve high yields.

In our study, the level of organic carbon decreased, while the amounts of humic substance (HS) were significantly improved in the compost-amended soil. Thus, depending on the way in which the compost was

Table 3. Effect of the biosolids-green waste compost on key soil mineral levels.

Parameter	Year	NF	C1	C2	C3	MF
Total Kjeldahl nitrogen (%)	1st	0.232d	0.263b	0.276ab	0.283a	0.246c
	2nd	0.236d	0.276c	0.311b	0.353a	0.245d
	3rd	0.252b	0.256b	0.334a	0.336a	0.253b
Mg^{++} (ppm)	1st	49.50c	52.52b	52.61b	57.64a	49.46c
	2nd	48.63d	54.44b	58.22a	58.28a	50.87c
	3rd	48.38c	54.97b	58.65a	57.38a	53.06b
Ca^{++} (ppm)	1st	1199.01e	1677.98c	1990.33b	2106a	1412.35d
	2nd	1414.67e	1820.99b	2102.94a	2099.67a	1334.65c
	3rd	1399.72c	1814.49b	2109.99a	2095.19a	1333.17c
Na^{+} (ppm)	1st	20.19e	29.13c	33.62b	38.65a	22.09d
	2nd	20.11e	32.59c	40.04a	39.05a	21.34d
	3rd	21.17 d	33.57c	40.89 a	38.90a	36.47b
K^{+} (ppm)	1st	630.73e	693.57c	728.88b	679.97d	679.97d
	2nd	624.66d	727.40b	779.20a	774.52a	664.15c
	3rd	627.96d	732.00b	778.50a	780.08a	664.25c

Values in the same row followed by the same letter are not significantly different. NF: No fertilization control; MF: mineral fertilization control; C1: 14 t/ha compost; C2: 28 t/ha compost; C3: 42t/ ha compost.

spread, improvements occurred especially in plots C2 and C3 compared with plots C1 and both controls NF and MF. The phenomenon was attributed to increased sequestration of biolabile compounds by hydrophobic protection from HS as suggest by many authors (Lichtfouse et al., 1998; Spaccini et al., 2002). Evanylo et al. (2008) also found in their work that significant increases in the amounts of C and N sequestered in soil were achieved with applications of compost giving agronomic N levels, but most of the C applied at 20% of the agronomic N level was rapidly mineralized. They suggest that soil C sequestration occurs at higher, but not lower, levels of compost application. Fernández et al. (2007) explained that this phenomenon is due to a decrease of acidic functional group content and an increase of proton binding affinities of carboxylic- and phenolic-type groups of soil humic acids and fulvic acids after amendment with composted sewage sludge.

The cationic exchange capacity (CEC) is one of the key parameters characterising the absorption capacity of a soil. Our results indicate that the CEC was proportional to the level of compost added. However, after three years, whatever the mode of compost addition, the CEC reached similar levels in plots C1, C2 and C3 and remained greater than both control NF and even MF (Tables 2 and 3). Hartl and Erhart (2003) and Giusquiani et al. (1995) have shown a significant correlation between compost input and the CEC values in the soil. We also observed an increase in the levels of saturation of alkaline elements (Ca, K, Na) with the increase in the CEC, these amounts were higher in plots C2 and C3 than in plots C1 and NF control and even exceeded the values for the MF trial (Tables 2 and 3). Similar results were reported by Kahle et al. (2002), who suggest that the increased CEC in the compost-amended soil can be explained by the physicochemical properties of the constituents of the compost. Several studies have shown that humic substances in compost enhance the availability of minerals and the uptake of macro-elements (N, P, K, Mg, and Ca) by plants (Ayuso et al., 1996; Eyheraguibel et al., 2008). Spreading compost seems to have a positive effect on the physicochemical properties of the soil which can have positive effects on plant growth and yield (Celik et al., 2004). The added compost could represent a source of energy and nutrient to the micro-organisms of the soil and thus, influence the biological processes taking place therein (Swift and Woomer, 1993).

Furthermore, levels of metal trace elements in the compost were lower than those reported in different international norms for compost intended for agronomic application (Table 4). This implies that this compost was safe to use in terms of the absence of micropollutants (Jouraiphy et al., 2005; Hafidi et al., 2008; Amir et al.,

Table 4. Total content of element trace metallic in compost and normalized values for agricole usage (Amlinger, 2004).

Metal	Concentration in biosolid-green waste compost (mg/kg)*	Norm in France (mg/kg)	Norm in Switzerland (mg/kg)	Norm in USA (mg/kg)
Zn	208	600	400	400
Cu	52	300	100	300
Pb	81	180	150	150
Ni	12.6	60	60	50
Cr	7.2	120	100	100

* Results expressed in basis of dry matter.

2005 a, b, c).

Impact of compost spreading on the growth and yield parameters of wheat

Table 5 reports the impact of the compost on the growth parameters (foliar index, fresh weight and dry weight) and on the yield and their corresponding parameters (number of heads/m^2, number of grains/m^2 and biomass). The foliar index provides an estimation of the volume of plant cover by measuring the interception of light. The more voluminous the plant cover, the more light is intercepted and the higher the foliar index recorded. Analysis of the results indicates that the application of compost significantly enhanced the foliar index. During the first year, the foliar index increased with the input of compost by 69, 76 and 150% for compost applications C1, C2 and C3, respectively with respect to the NF control. The increase reached only 17.5% with mineral fertilisation compared with the NF control. By the third year, the foliar index reached similar values (no significant difference) for all three levels of compost application (C1, C2 and C3). However, compost input in the form of a single application in plots C3 and C2 seemed more beneficial than applications repeated over time. The data indicate that applying 42 tonnes of compost per hectare (C3) led to maximum foliar index from the first year which remained high until the third year. Dick and McCoy (1993) reported that the benefits of applying compost lasted for several years. They suggest an improvement of plant nutrition due to nutrient availability with time.

The improvement of plant cover led to an increase in fresh matter and total biomass. The fresh, dry weights and biomass increased with the amount of compost added to plots C1, in contrast to both NF and MF controls which decreased. These three parameters were highest in plots C2 and mainly C3 even after three years of compost application.

The yield of grain also increased with compost spreading: for the first year the increases were 24, 56.6 and 111% for applications C1, C2 and C3 with respect to the NF control. The amount of grain increased with the amount of compost added in repeated applications C1; but the best values were recorded in plots C3 even three years after application.

The yield was higher in compost-amended soil than in the NF control even applying the amount C1. According to Pedneault (1994), good compost increases the yields compared with non-fertilised land, even when it is applied in small quantities. The yields after applying C2 and C3 became higher than after mineral fertilization MF. Using compost in a single application in plots C3 showed a greater yield than C1 applications repeated over time and it remained high even after the 3rd year of the experiment. This indicates that the total dose all in one is more advantageous than the fractionated dosage of compost, which is probably due to this soil needing a large amount of organic amendment equivalent to more than 42 t/ha. This could also be explained by the fact that the high amounts of humic substances provided by large quantities of compost applied at the first year may have greater benefits for plant growth later.

In a study by Fagbenro and Agboola (1993) investigating the impact of humic acids on the growth of teak (*Tectona grandis* L.f.) a positive correlation was established between the concentration of humic substances and the height of the plants, the diameter of the trunks and the total dry matter content. The concentration of the humic substances plays an important role on the response of the plants. There is an optimal concentration to be applied, which varies from one plant to another (Atiyeh et al., 2002).

Mineral fertilization also improved the yield but its impact remained limited compared with that of compost (Courtney and Mullen, 2008). These results are in agreement with those of Arancon et al. (2004) who reported that the increase of the yield following application of compost is often greater than that of fertilized controls.

The yield parameters (heads/m^2, grain yield in t/ha, number of grains/m^2) also significantly increased with compost compared with both control NF and MF (Table 5). This is the result of a general improvement of the physical, chemical and biological condition of the soil following the amendment with compost. Ribeiro et al. (2000) reported that the addition of compost to *Pelargonium hortorum* grown on solid substrates led to a

Table 5. Effects of the amendments on the various yield parameters.

Parameter		NF	C1	C2	C3	MF
	1st year	1.43e	2.42c	2.53b	3.58a	1.68d
Foliar index	2nd year	1.24c	2.28b	3.25a	3.21a	1.35c
	3rd year	1.08c	4.03a	4.07a	4.28a	2.10b
Mean		1.25	2.91	3.28	3.69	1.71
	1st year	130.3e	204.7c	242. 3b	288.9a	173.2d
Fresh weight (g)	2nd year	119.4d	220.8b	273.6a	273.8a	163.8c
	3rd year	70.0d	221.9b	225.8ab	237.1a	107.6c
Mean		106.6	215.8	247.3	266.6	148.2
	1st year	52.9c	96.3b	91.6b	145.6a	76.7bc
Dry weight (g)	2nd year	46.9d	82.8b	138.7a	137.4a	65.5c
	3rd year	28.0d	128.7b	143.3ab	148.4a	55.9c
Mean		42.6	102.6	124.5	143.8	66.0
	1st year	649.5e	993.6c	1210.8b	1370.6a	931.4d
Biomass (g)	2nd year	520.3d	793.8b	1010.0a	1026.8a	607.5c
	3rd year	369.8d	998.1b	1027.2b	1145.4a	555.1c
Mean		513.2	928.5	1082.7	1180.9	698.0
	1st year	194.5e	257.8b	296. 8b	380.0a	235.3d
N° of heads per m²	2nd year	175.5d	274.0b	363.5a	365.3a	223.8c
	3rd year	113.8e	272.8c	304.8b	318.3a	172.5d
Mean		161.25	268.16	321.66	354.5	210.5
	1st year	4401.5d	5466.5c	6892.5b	9294.3a	5561.5c
N° of grains per m²	2nd year	4154.5d	6272.3b	8767.5a	8748.0a	5184.0c
	3rd year	3294.8d	7115.8b	7355.5b	7993.4a	4579.0c
Mean		3950.3	6284.9	7671.8	8678.6	5108.2
	1st year	17.1d	25.1c	28.9b	33.1a	23.0c
Yield qx/ha	2nd year	15.6d	27.1b	32.4a	33.2a	21.7c
	3rd year	11.5b	26.1b	26.3b	26.9	14.4d
Mean		14.2d	26.1b	29.2b	31.1a	19.7

Values in the same row followed by the same letter are not significantly different. NF: Control (no fertilization); MF: control (mineral fertilization); C1: 14 t/ha compost, C2: 28 t/ha compost, C3: 42t/ ha compost.

significant increase in the number of umbels per plant and of flowers per umbel for proportions of compost reaching 20% v/v. This effect of compost on the increase in plant biomass and yield and their corresponding parameters also results from the efficiency of the mineral nutrition of the wheat. Some authors also demonstrated that the uptake of macro-elements (N, P, K, Mg and Ca) and micro-elements (Cu, Fe, Zn) is increased by the application of compost (Baca et al., 1992; Cordovil et al., 2007; Walker and Bernal, 2008).

Analyzing the overall yield parameters shows positive and significant results. In general, soil physical and chemical properties were improved with the application of compost, but the positive effects occurred more quickly with the higher levels of application. High annual levels of compost application greatly increased the soil C, N and mineral element concentrations compared with un-fertilized controls.

From statistical analysis (PCA and correlations), it appeard that in non-amended soil, the levels of TKN and TOC and the pH of soil correlated negatively well with the agronomic parameters according to correlation matrices (Table 6) and the first principal component (P1 : 81%) (Figure 2).

In compost amended soil C1, C2 and mainly in C3 plots, it is the amount of HA and the CEC that show significant positive or negative correlations with most agronomic parameters (Table 6). Fabrizio et al. (2009)

Table 6. Coefficient Pearson's correlation between different physico-chemical parameters of each soil and agronomic parameters (growth and yield parameters) of wheat.

Parameter	pH	TOC	HA	CEC	TKN	FI	Fw	dw	biomass	Nhe	Ngr	Y
Correlation NF soil												
pH	1	0.915	0.115	0.125	0.993	-0.964	-0.991	-0.998	-0.985	-0.997	-0.996	-0.999
TOC	0.915	1	-0.297	-0.287	0.955	-0.775	-0.96	-0.94	-0.83	-0.943	-0.947	-0.929
HA	0.115	-0.297	1	1	0	-0.37	0.019	-0.046	-0.286	-0.037	-0.024	-0.077
CEC	0.125	-0.287	1	1	0.01	-0.383	0.009	-0.057	-0.295	-0.047	-0.034	-0.087
TKN	0.993	0.955	0	0.01	1	-0.928	-1	-0.999	-0.958	-0.999	-1	-0.997
Correlations MF soil												
pH	1	-0.823	1	-0.998	0.963	0.819	-1	-0.915	-0.723	-1	-0.973	-1
TOC	-0.823	1	-0.823	0.788	-0.945	-1	0.836	0.524	0.203	0.813	0.668	0.828
HA	1	-0.823	1	-0.998	0.963	0.819	-1	-0.915	-0.723	-1	-0.973	-1
CEC	-0.998	0.788	-0.998	1	-0.946	-0.787	0.997	0.938	0.763	999	0.985	0.998
TKN	0.963	-0.945	0.963	-0.946	1	0.943	-0.969	-0.774	-0.512	-0.959	-0.875	-0.966
Correlations C1 soil												
pH	1	0.721	0.778	-0.879	0.195	-0.73	-0.953	-0.565	0.137	-0.906	-0.986	-0.613
TOC	0.721	1	0.996	-0.964	0.82	-1	-0.478	-0.979	-0.588	-0.36	-0.827	-0.106
HA	0.778	0.996	1	-0.983	0.768	-0.997	-0.522	-0.958	-0.516	-0.439	-0.873	0.02
CEC	-0.879	-0.964	-0.983	1	-0.639	0.968	0.694	0.89	0.353	0.594	0.947	0.16
TKN	0.195	0.82	0.768	-0.639	1	-0.81	0.11	-0.92	-0.95	0.24	-0.36	0.66
Correlations C2 soil												
pH	1	-0.159	-0.091	-0.122	-0.559	-0.467	-0.645	-0.824	0.902	-0.916	-0.96	-0.565
TOC	-0.159	1	-0.969	0.999	-0.695	-0.799	0.857	-0.429	0.283	0.542	0.43	0.905
HA	-0.091	-0.969	1	-0.977	0.852	0.923	-0.703	0.639	-0.512	0.317	-0.192	-0.771
CEC	-0.122	0.999	-0.977	1	-0.721	-0.82	0.838	-0.462	0.318	0.511	0.396	0.888
TKN	-0.599	-0.695	0.852	-0.721	1	0.988	-0.226	0.948	-0.886	0.227	0.351	-0.322
Correlations C3 soil												
pH	1	-0.612	0.47	-0.795	-0.688	0.765	-0.234	0.97	0.764	-0.289	-0.092	-0.51
TOC	-0.61	1	-0.986	0.966	-0.153	-0.978	0.912	-0.786	0.042	0.934	0.844	0.992
HA	0.47	-0.99	1	-0.91	0.32	0.93	-0.97	0.67	-0.21	-0.98	-0.92	-0.999
CEC	-0.79	0.97	-0.91	1	0.11	-0.999	0.776	-0.919	-0.216	0.81	0.677	0.927
TKN	-0.69	-0.15	0.316	0.11	1	-0.059	-0.545	-0.491	-0.994	-0.496	-0.659	-0.274

TOC, Total organic carbon; HA, humic acid; CEC, cation exchange capacity; TKN, total Kjeldahl nitrogen; FI, foliar index; Fw, fresh weight; dw, dry weight; Nhe, number of heads; Ngr, number of grains; Y, yield

report a linear response between the dose of compost application and both C degradation and retention. The amount of C sequestered was similar to the total recalcitrant C content of compost and the labile C pool of compost was completely degraded. Increasing the levels of humic substances can therefore contribute to making a significant increase in the CEC, especially in light soils with a low absorption capacity.

In fact, through PCA analysis in C3, the CEC parameter become further near of numerous agronomic parameters and the HA show high negative correlation with them according to P1 (69.1%). Sodhi et al. (2009) have reported that application of rice straw compost either alone or in combination with inorganic fertilizers in a rice-wheat system significantly improved the aggregate stability and C sequestration in soil compared with a control or with inorganically fertilized plots.

In the MF soil, most physico-chemical parameters correlated well with the agronomic parameters and moreover, were situated near them (HA was on the opposite of the sheet) in the PCA diagrams. This could be explained by the fact that in the case of mineral fertilization, the plant benefits from all nutritional elements, which leads to a better equilibrium between the input of mineral elements and plant harvest. However, the yields and growth parameters after applying compost

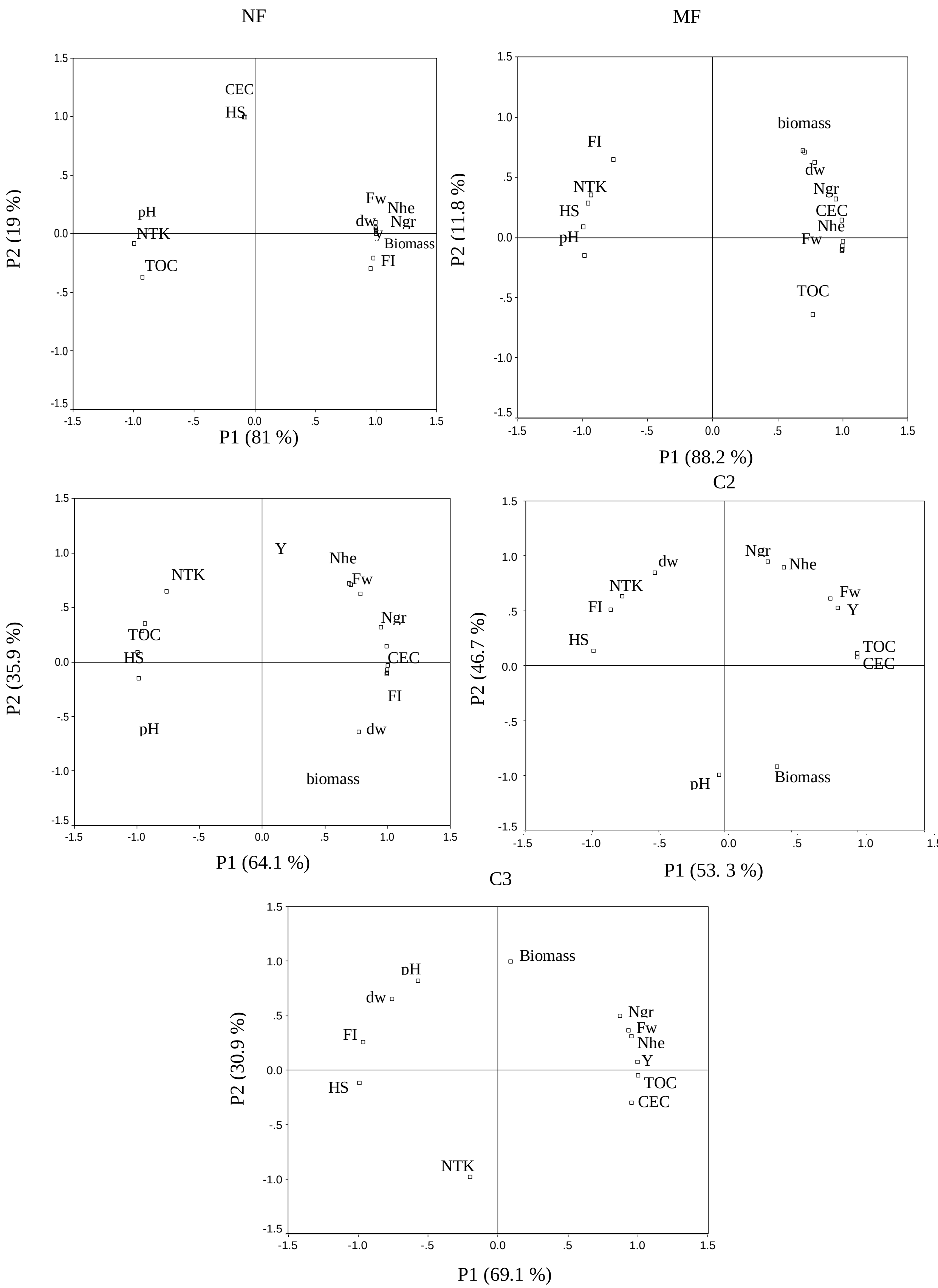

Figure 2. Principal component analysis between different physico-chemical parameters of each soil and agronomic parameters (growth and yield parameters) of wheat.

mainly in C3 became higher than after mineral fertilization MF. A change of kinetics apparently occurred between export in crops and nutrient availability. The addition of compost simultaneously led to better mineral nutrition of the plants and also to changes in some of the physico-chemical parameters of the soil such as TKN availability, pH of soil and also sequestration of available carbon in the form of stable humic matter improving soil structure, its water-retention and its ion-exchange capacity (Ouédraogo et al., 2001; Walker and Bernal, 2008). Chen and Aviad (1990) demonstrated that the humic substances contained in compost improve plant growth. They suggest that the humic substances enhance the uptake of mineral elements by plants. Evanylo et al. (2008) reported that compost can provide crop N requirements and those high levels of application supply a portion of mineralizable N from such a stable N fertility source.

In fact, the higher correlations of TKN with most other physico-chemical and agronomic parameters in MF and NF soil than in amended soil which show low correlations could be explained by the strong increase of nitrogen in C3 and C2. While in MF and also NF, the level of TKN remained apparently in equilibrium with plant consumption.

Suzuki et al. (1990) reported that after 20 years of annual compost application or mineral fertilization of a plot used to grow rice, the levels of nitrogen in the compost-amended soil were higher than those receiving mineral fertilizer.

Accordingly, the benefits from long-term additions of compost in small amounts may accrue with time. It is therefore, necessary to calculate the rate of organic amendment required to increase or maintain organic matter concentration for the enhancement of soil fertility.

Conclusion

The agronomic value of biosolids composted with green waste was assessed in a field study on wheat (*T. aestivum* var. Marchouch) in the calcimagnesic soil of semi-arid areas using three levels of compost application (14, 28 and 42 t/ha) over three successive years. Application of the compost improved the various physicochemical characteristics of the soil. The difference was greatest in soil amended by the whole amount of compost (42 t/ha) in a single application (rather than progressively over the years) and remained greater even three years after compost application. This indicates that, the soil studied needed a large amount of compost. The beneficial effects on the physicochemical properties of the soil, led to an improvement of the various growth parameters (foliar index, dry matter and total biomass) and yield parameters (number of heads of wheat/m^2, number of grains per head and grain yield) of the wheat.

In compost amended soil and especially in C3, statistical analysis revealed that it is the amount of humic substances and CEC that showed high correlations with the agronomic parameters compared with un-amended soil, where TKN and TOC demonstrate a high importance. The reduced of TKN availability and the fact that the carbon added in soil with compost is essentially sequestered in the form of humic substances could explain the low correlations between either TKN or TOC and the agronomic parameters, in contrast to the situation noted in soil subjected mineral fertilization. So, this confirms that the addition of compost may not only enhance plant growth, but also contribute to the maintenance of soil fertility over the following years when appropriate amounts of compost have been applied.

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