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Nitrogen fertilizer value of sewage sludge co-composts

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Abstract – We evaluated the nitrogen fertilizer value of a sewage sludge and of four composts obtained from this same sludge. The sewage sludge was extracted from the wastewater treatment plant of Beni-Mellal city (Morocco). The extracted sewage sludge was composted alone, mixed with domestic solid waste, with olive cakes and with sawdust. The experiment was carried out in pots of vegetation under natural conditions. The humidity was maintained close to 80% of the field capacity. Ray-grass from Italy was used as a plant test. The research lasted 140 days, during which 4 cuts of the plant were investigated. The results obtained showed that all the amendments tested allowed an increase in the output in dry biomass and nitrogen plant uptake. This increase was more significant with non-composted and composted sewage sludge alone than with the other co-composts. The apparent coefficient of nitrogen utilization (CAU) recorded oscillated between 50 and 38%, testifying a great aptitude of the amendments tested to provide nitrogen to plants. The values of the apparent rates of nitrogen mineralization obtained were 38, 29, 28, 27 and 25%, respectively, for non-composted sludge; sewage sludge compost; sewage sludge-olive cakes compost; sewage sludge-domestic solid waste compost and sewage sludge-wood sawdust compost.

co-compost / sewage sludge / domestic solid waste / agro-industrial waste / nitrogen fertilizer value

1. INTRODUCTION

For the last fifty years, the escalation of economic activity's production and consumption has led to a considerable increase in the production of agro-manufactures and urban wastes whose management reveals difficult problems [18]. If the majority of agricultural residues are returned to the land, by-products of the transformation of agricultural products (wastes of agro-food industries) and residues of consumption (domestic solid waste and wastewater sewage sludge) are also, for the most part, disposed of in the natural media without controls, and therefore constitute a source of pollution for the environment [33].

Indeed, these products often contain raised contents of organic matter and fertilizing elements which often tend to be valued in agriculture, especially currently, where one observes a growing deficit in organic matter contents of cultivated soils, especially in Mediterranean countries, and the always growing cost of mineral fertilizers. It has become increasingly evident that it is necessary to search for the best elimination means of organic waste and to privilege, as much as possible, their re-orientation to agricultural lands, in the crude state or after certain processing [7].

Among waste-processing methods, composting has often been used to improve properties of wastes before their spreading on agricultural lands. Indeed, it has been shown that composts have a positive influence on plant growth [12, 14, 19, 21, 30]. Composting allows the improvement of physical soil properties such as porosity, the stability of aggregates and their water retention capacity [11, 23, 25]. Composts allow equally an increase in organic matter contents and the capacity of cationic exchange of soils [9]. Nevertheless, it is necessary to specify that composts can sometimes have negative effects on outputs of cultures, especially linked to the spreading of intensive composts presenting raised contents in heavy metals [5] or in soluble salts [31]. However, most ominous effects have been observed during the application of non-mature composts [13].

Sewage sludge represents a fermentable substrate, often rich in mineral elements but always difficult to use alone because of its high humidity rate and its fine structure.

At the beginning of the century, sewage sludge was often used only as an adjuvant to composts of other organic wastes (contribution of water and nitrogenous fermentable matter). However, with the development of wastewater treatment systems, sewage sludge has become a quantitatively important waste and great effort has been put into its composting techniques [21].

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According to the same authors, the rustic composting of sewage sludge is possible by taking care of the deficient content in carbon, so as to have a C/N ratio of between 20 and 30, and choosing a carbonaceous adjuvant which also has a structuring role that allows the maintenance of aerobic conditions during the composting process.

The objective of this work is to study the possibility of composting urban sewage sludge and its agricultural value as an organic amendment in its raw state or after the composting process. In our work, we tested the composting of sludge alone or in mixture with other solid wastes (domestic solid waste and wood sawdust), often used during the composting of residuary sewage sludge for its structuring role, and another by-product of the olive industry (olive-oil cakes). All these products are considered as a source of pollution for the environment and have to be managed. Special attention has been paid to the nitrogen agronomical value of these co-composted urban sewage sludges.

2. MATERIALS AND METHODS

To fulfill the above objective, a mixture corresponding to 50% of dry matter of sewage sludge and 50% of dry matter of the other products [domestic solid waste, wood sawdust or olive cakes] were composted in silos in bricks for a period of 240 days. The C/N ratios in the beginning were 8.8 for sewage sludge, 20.3 for sewage sludge-domestic solid waste, 21.1 for sewage sludge-olive cakes and 25.7 for sewage sludge-wood sawdust. The composting conditions were optimal, with maximal temperatures during the phase of stabilization reaching 67 °C, 58 °C, 57 °C and 50 °C, respectively, for sewage sludge-domestic solid waste compost, sewage sludge-olive cakes compost, sewage sludge compost and sewage sludge-wood sawdust compost. The problem of humidity did not exist since the sewage sludge presented a rate of 93% of dry matter.

2.1. Experimental device

The experiment was carried out in pots of vegetation under natural conditions. The pots were placed in random blocks comprising two kinds of processing: the type of amendment product and the dose used. Three repetitions of each amendment dose were used: 0, 5, 20 and 50 tons of dry matter per hectare.

2.1.1. Organic amendments tested

The residuary sewage sludge used in this study comes from an activated sludge plant with prolonged aeration purifying the wastewater of Beni Mellal city (South of Morocco). It concerns a thickened secondary sewage sludge, dried on beds of sand for a period of 3 months. The amendments used were: non-composted sewage sludge (SS), sewage sludge compost (SC), sewage sludge-domestic solid waste compost (50% dry matter each) (SDSWC), sewage sludge-olive cake compost (50% dry matter each) (SOCC) and sewage sludge-wood sawdust compost (50% dry matter each) (SWSC). The main characteristics of the amendment products obtained are illustrated in Table I.

Table I. Physico chemical characteristics of sludge and composts studied.

	SS	SSC	SDSWC	SOCC	SWSC
Dry matter (%)	96.7	48	44.5	51.9	47.6
pH	7.01	6.50	7.50	6.70	6.90
Electric conductivity (dS m ⁻¹)	1.58	2.25	1.64	1.32	0.66
Organic carbon (C %)	24.2	16.5	16.0	20.9	20.5
TKN (N %)	2.74	2.15	1.5	1.9	1.23
C/N	8.8	7.6	10.6	11	16.7
N-NH ₄ ⁺ (mg kg ⁻¹)	1470	90	205	100	85
N-NO ₃ ⁻ (mg kg ⁻¹)	420	390	80	290	110

Non-composted sewage sludge (SS), sewage sludge compost (SC), sewage sludge-domestic solid waste compost (SDSWC), sewage sludge-olive cake compost (SOCC), sewage sludge-wood sawdust compost (SWSC).

2.1.2. The culture procedures

The soil used has a pH of 7.68; about 3.63% of organic matter, 1.42 g kg⁻¹ of total nitrogen, and around 265 and 168 mg kg⁻¹, respectively, of ammonium and nitrate. Its texture presents 31% of clay, 38.2% of silts and 26.5% of sands. The soil was air-dried and sieved with a 4-mm sieve. After homogenization, plugs of 2.5 kg of soil were placed in plastic pots of 21 cm diameter and 18 cm in height. Quantities of sewage sludge or composts corresponding to the doses retained were well mixed with the soil to insure a uniform distribution.

The plant test used was ray-grass from Italy (*Lolium perenne*), that responds particularly well to nitrogenous manure and allows by its long growth cycle the realization of several pots able to receive the dosage of absorbed nitrogen contents during the experiment. Thus, the kinetic of nitrogen liberation from organic amendments is approached better. All the pots were pierced in the base and had a carpeted gravel bottom to insure good drainage of irrigation water. In each pot, 3 g of seeds were sown in concentric circles. The pots were irrigated to maintain the soil humidity close to 80% of the field capacity during the experiment. The quantity of lost water was estimated by weighing the pots, and was done once a day.

2.2. Sampling and analytic determination

The soil and organic amendments were analyzed at the beginning of the test for a complete characterization. Monthly spaced cuts (4 in total) of the aerial part of the plants were undertaken in order to follow the kinetic of nitrogen liberation by the amendments. After each cutting, the harvested biomass served for the determination of the output in aerial dry biomass and nitrogen appropriated by the plant, determined according to Kjeldahl's method. For the purpose of evaluating the effect of the different kinds of processing on residual nitrogen of the soil after the last cutting, reserving soil samples from all pots served for the determination of the total nitrogen by Kjeldahl's method, ammonia nitrogen and nitrate by extraction with a solution of steady KCl and double distillation in the presence of magnesia then Dewarda alloy.

2.2.1. Estimation of the coefficient of nitrogen utilization by plants

So as to estimate the availability of nitrogen of the sewage sludge and the different composts, we calculated apparent coefficients of nitrogen utilization according to the following formula:

$$CAU = (NT - N0) / Napp * 100$$

where CAU is the Apparent Coefficient of nitrogen utilization; NT is N appropriated in the presence of organic amendment (mg kg^{-1} of soil); N0 is N appropriated in the absence of organic amendment (mg kg^{-1} of soil); and Napp is N applied (mg kg^{-1} of soil).

2.2.2. Estimation of nitrogen mineralization in the soil

For the purpose of estimating the mineralization rate of the nitrogen in the sewage sludge and composts, under natural temperature conditions but controlled humidity, we established a global statement that allows the calculation of the quantity of nitrogen mineralized between the seeding and the end of the experiment (140 days). This statement can be written as follows:

$$Nmin = NT0 + Napp - NTF.$$

Nmin: mineralized N (mg kg^{-1}). NT0: total N of the soil in the initial state (mg kg^{-1} of soil); NTF: total N after the last cutting (mg kg^{-1} soil); Napp: N supplied by the product of amendment (mg kg^{-1} of soil).

This equation has been used by several authors to deduce net nitrogen mineralized from farm dung, commercial composts, poultry refuse and residuary sewage sludge [2, 4, 15, 30].

This statement supposes that the quantity of nitrogen susceptible to being lost from the system is very small. As relative humidity was maintained close to the capacity of the field, nitrogen losses by leaching and by de-nitrification were negligible.

2.2.3. Apparent rate of nitrogen mineralization in the soil (TAM)

The estimation of the apparent rate of nitrogen mineralization of the different amendments is made according to the following formula:

$$TAM = (Nminapp - NminT) / Napp * 100$$

TAM: apparent rate of mineralization; Nminapp: N mineralized in the presence of the amendment; NminT: N mineralized in the absence of the amendment; Napp: N supplied by the amendment.

3. RESULTS AND DISCUSSION

3.1. Output in biomass

Globally and for all tested amendment types, there was an improvement of the obtained biomass in comparison with the

Table II. Obtained biomass and cumulative yields under each type of amendment (g of dry matter per pot).

Amendment dose	SS	SC	SDSWC	SOCC	SWSC
0 t ha ⁻¹	9.8f*	9.8f	9.8f	9.8f	9.8f
5 t ha ⁻¹	11.1e	11.1e	10.2e	10.9e	10.2e
20 t ha ⁻¹	15.2b	15.3b	12.1d	12.0d	11.5de
50 t ha ⁻¹	20.8a	20.9a	15.9b	13.1c	14.1c

* Data with the same alphabetic letter are not significantly different according to Newman and Keul's test (at 5%). Non-composted sewage sludge (SS), sewage sludge compost (SC), sewage sludge-domestic solid waste compost (SDSWC), sewage sludge-olive cake compost (SOCC), sewage sludge-wood sawdust compost (SWSC).

Table III. Effect of the amendments on the production rate (mg of dry matter per day and per pot for 140 days).

Amendment	SS	SC	SDSWC	SOCC	SWSC
0 t ha ⁻¹	70	70	70	70	70
5 t ha ⁻¹	81	97	77	81	77
20 t ha ⁻¹	109	121	102	86	90
50 t ha ⁻¹	149	149	113	94	101

Non-composted sewage sludge (SS), sewage sludge compost (SC), sewage sludge-domestic solid waste compost (SDSWC), sewage sludge-olive cake compost (SOCC), sewage sludge-wood sawdust compost (SWSC).

control without amendment. The biomass harvested in the absence of organic amendment was 9.75 g per pot. This value is inferior to those recorded even with the weakest application for all tested amendments, 5 tons of dry matter per hectare (Tab. II). The most significant values were obtained in pots receiving the highest dose (50 t ha⁻¹) of composted sewage sludge or non-composted sewage sludge. The increase in outputs of the biomass recorded in this case was 213% in comparison with the control. In the presence of other co-composts, even with the most significant application (50 t ha⁻¹), the increase in the output did not exceed 160% as compared with the control.

The calculation of the production rate of biomass (mg per day and per pot) reflects almost the same trends. The average production rates of the dry matter are shown in Table III. These results show that there is a significant effect of the type and the dose of the amendment on the quantity of dry matter produced. These rates are different from one amendment to another, and increase with the dose supplied of the same amendment. The maximal speed was recorded for non-composted sewage sludge and composted sewage sludge, and was around 150 mg per day and per pot. These speeds are close to those obtained by other authors [30] using commercial composts or ovine refuse, but used at doses equal to 80 t ha⁻¹.

3.2. Quantities of nitrogen exported by the plant

The quantities of nitrogen appropriated by the ray-grass are illustrated in Table IV. It seems that this quantity increases with the applied dose of sewage sludge and that it differs with the

Table IV. Cumulative Nitrogen uptake by the plants (mg N per pot) for each type of amendment.

Amendment	SS	SC	SDSWC	SOCC	SWSC
5 t ha ⁻¹	287d*	272d	258d	264d	243e
20 t ha ⁻¹	462b	444b	339c	375c	309cd
50 t ha ⁻¹	692a	704a	430b	446b	455b

* Data with the same alphabetic letter are not significantly different according to Newman and Keul's test (at 5%). Non-composted sewage sludge (SS), sewage sludge compost (SC), sewage sludge-domestic solid waste compost (SDSWC), sewage sludge-olive cake compost (SOCC), sewage sludge-wood sawdust compost (SWSC).

type of amendment. The classification in function of the amendment type is as follows: sewage sludge compost > non-composted sewage sludge > sewage sludge-olive cake compost > sewage sludge-domestic solid waste compost > sewage sludge-wood sawdust. The maximum assimilation was 704 mg per pot, obtained with the BC at the dose 50 t ha⁻¹. These values are comparable with those obtained with commercial composts [30] and exceed those obtained for a sludge originating from a stabilization pond [15].

3.3. Apparent Utilization Coefficient of nitrogen by the plant (CAU)

The values obtained by calculating the average CAU of the three amendments (5, 20 and 50 tons ha⁻¹) for each type of amendment are 51, 45, 42, 39 and 39%, respectively, for sewage sludge compost, non-composted sewage sludge, sewage sludge-domestic solid waste compost, sewage sludge-olive cake compost and sewage sludge-wood sawdust compost. The highest CAU is obtained with sewage sludge compost. The other composts are similar and are inferior to those of the non-composted sewage sludge. These results do not necessarily mean that the nitrogen in the sewage sludge compost is more available than that in the non-composted sewage sludge, because one cannot neglect the effect of the amendment of sludge on the evolution of organic nitrogen in the soil. Indeed, the quantity of nitrogen supplied by the composted sludge is more significant than that of the other amendments. In addition, nitrogen in non-composted sludge would be in a more easily available form than that in composts which would be in more stable forms in the course of the composting process. Note also that a significant proportion of the nitrogen in the non-composted sewage sludge is in ammonia form, probably immobilized by the soil before even serving for the cultures [20, 34].

Several authors [1, 22, 26] mention that there is immobilization of a significant proportion of ammonia nitrogen just after waste application to the soil.

Another author [10] has shown that the real utilization coefficient in marked nitrogen of mineral fertilizer is situated between 50 and 70%. This shows that appreciably half of the mineral N is reorganized in cultivated soils. Another work carried out on a culture of corn [6] states a reorganization of 30% of the nitrogen supplied to the cultures. This same author points out that 15% is reorganized by roots and 15% in the soil, and that 10% of the remaining nitrogen is found in the aerial part of the next culture against only 1% of nitrogen reorganized in microbial processes. In a previous study carried out on sludge from stabilization ponds or activated sludge, we recorded a CAU that reached 60% for stabilization pond sewage sludge and did not exceed 30% for the activated sludge [2].

3.4. Mineralized nitrogen and apparent rate of mineralization

The quantity of nitrogen mineralized in the soil without external contribution is 154 mg kg⁻¹, which is very significant. The quantity of mineralized nitrogen depends on the type of amendments and the quantity of nitrogen supplied (Tab. V). The quantity of nitrogen mineralized in the presence of amendments equal to 5 t ha⁻¹, and sometimes even 20 t ha⁻¹, clearly exceeds the total quantity of supplied nitrogen, which suggests the significant contribution of the organic nitrogen already existing in the soil tested.

The comparison of the mean value of the three amendment doses (5, 20 and 50 t ha⁻¹) shows that the highest apparent rate of nitrogen mineralization (TAM) is obtained for the non-composted sludge (Tab. VI) and we can classify the amendment efficiency as follows: non-composted sewage sludge > sewage sludge compost > sewage sludge-olive cake compost = sewage sludge-domestic solid waste compost > sewage sludge-wood sawdust.

The nitrogen in non-composted sewage sludge seems to be in a more easily degradable form, but after composting, the nitrogen is transformed into a more stabilized residual form, more difficult to decompose [17]. Other authors have also observed that availability of nitrogen is higher in fresh sludge than in composted ones [24, 27, 28]. The apparent coefficient of nitrogen utilization of fresh sludge, recently composted sludge or very old compost, respectively, are 30, 21 and 6% [4]. In an experiment in the field, other authors recorded a CAU of

Table V. Applied (Napp) and mineralized (Nmin) quantities of nitrogen per type and dose of the amendment (mg/kg of soil).

Amendment	SS		SC		SDSWC		SOCC		SWSC	
	Napp	Nmin	Napp	Nmin	Napp	Nmin	Napp	Nmin	Napp	Nmin
5 t ha ⁻¹	52	174	41	163	28	159	36	167	24	169
20 t ha ⁻¹	211	230	165	212	115	190	146	184	95	189
50 t ha ⁻¹	527	369	413	280	288	251	365	263	236	274

Non-composted sewage sludge (SS), sewage sludge compost (SC), sewage sludge-domestic solid waste compost (SDSWC), sewage sludge-olive cake compost (SOCC), sewage sludge-wood sawdust compost (SWSC).

Table VI. Apparent rate of nitrogen mineralization (TAM) of each type of amendment.

amendment	SS	SC	SDSWC	SOCC	SWSC
5 t ha ⁻¹	38.5	22.0	17.9	36.0	20.8
20 t ha ⁻¹	36.6	35.2	31.3	20.6	26.3
50 t ha ⁻¹	40.8	30.5	33.7	29.9	29.7
Mean	38.6a*	29.2b	27.6c	28.8c	25.6d

* Data with the same alphabetic letter are not significantly different according to Newman and Keul's test (at 5%). Non-composted sewage sludge (SS), sewage sludge compost (SC), sewage sludge-domestic solid waste compost (SDSWC), sewage sludge-olive cake compost (SOCC), sewage sludge-wood sawdust compost (SWSC).

animal waste composts of about only 9.2% against 28.5% for the same wastes in the fresh state [3]. In our case, the lowest mineralization rate was obtained for sewage sludge- wood sawdust compost. Indeed, wood sawdust is well known for high contents of complex molecules which are very difficult to degrade, such as lignin and others [21]. We also noted that it contained the lowest contents of nitrogen.

We can consider that the sludge studied in this work has a high aptitude for providing nitrogen for the cultures and contributes significantly to improving their yield, and could be used as an amendment for poor soils. Composting this sludge leads to a decrease in its aptitude for providing nitrogen to plants. Nevertheless, this decrease in the nitrogen mineralization rate could be considered as a positive phenomenon that could delay the nitrogen reaching the soil, and in this way minimize the nitrogen lost by leaching in the field. Thus, nitrogen supplied by organic amendments constitutes a delayed stock of nitrogen for several years after application [8, 16, 29, 32]. In addition to the effect on nitrogen, the sewage sludge composting process could help to minimize considerably the sanitary risk of sludge; composting also improves the sludge's texture, which could have a beneficial effect later on the physical properties of the soil [9, 11, 25]. The mixture of sludge at 50% with other adjuvants could contribute to diluting the toxic ion contents in the sludge used alone.

4. CONCLUSION

The present study shows clearly that biomass production and nitrogen uptake by plants were improved after the amendment of the soil by sludge, with or without composting. However, this improvement seems to be greater in the case of non-composted sludge, or when it is composted alone. The apparent rates of nitrogen mineralization obtained were 38, 29, 28, 27 and 25%, respectively, for non-composted sewage sludge, sewage sludge compost, sewage sludge-olive cake compost, sewage sludge-domestic solid waste compost and sewage sludge-wood sawdust compost.

The decrease in both CAU and TAM, after composting, is principally linked to the transformation of nitrogen to more stabilized forms. The co-compost, using a mixture of domestic solid wastes, and their growing value in agriculture, could con-

stitute an attractive process, aiding the simultaneous management of these two very problematic wastes in all the world's cities.

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