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ENVIRONMENTAL SUSTAINABILITY AND POLLUTION PREVENTION

The impact of sewage sludge and compost on winter triticale

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Abstract There is an increasing interest in the agricultural application of organic waste such as soil amendment, due to the possibility of recycling valuable components, organic matter, and nutrient elements necessary for plant growth. The present study was carried out to evaluate the effects of sewage sludge, and green waste compost application, on a forage crop, triticale "*X Triticosecale Wittmack*" compared to unfertilized control. The experimental design was installed in the glasshouse conditions at the Regional Field Crop Research Center in Beja, Tunisia. Sewage sludge and green waste compost were added by four rates (0, 5, 10, and 20 t/ha) in soil, 15 days before triticale sowing. The main results showed that plant response differs depending on the type of adding fertilizer. Indeed, compost inputs decreased shoot length and production of triticale, among all sewage sludge rates, by average values of 26 and 60% respectively at final harvest, as compared to unamended soil. However, amendment with different rates of sewage sludge significantly ($p < 0.05$) increased different plant growth and yield attributes.

Keywords Sewage sludge · Compost · Growth · Production · Triticale

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Introduction

In Tunisia, agriculture soils and soil-forming materials commonly lack organic matter. They are consequently infertile and possess poor physical structure and water holding capacity. The application of inorganic fertilizers on depleted soils often fails to provide the expected benefits. This is basically because of low organic matter and low biological activity in the soil (Bot and Benites 2005). For this purpose, a wide range of organic waste might be proposed as solutions to meet short- and long-term soil and plant needs. These include waste products such as sewage sludge, compost (Alvarengaa et al. 2015). It is used in agricultural fields to help improve soil quality of infertility soils as well as to increase the yield of various crops (Kchaou et al. 2010; Ozyazici 2013; Bedada et al. 2014).

However, to be considered beneficial, it must be of high quality and safe for humans, plants, and the environment. In other words, it should be free from pathogenic organisms, contain acceptable levels of trace elements and organic contaminants, and be sufficiently mature and stable (Sullivan and Miller 2001; Baffi et al. 2007).

In the present study, we proposed to investigate the effect of sewage sludge and green waste compost when used as soil amendment on germination, development, and biomass yield of a forage crop triticale "*X Triticosecale Wittmack*;" one of the most important crops in the development of forage systems, because its high yield, high energy forage produced and its better tolerance to foliar diseases.

Material and methods

A preliminary laboratory test was conducted to assess the effect of sewage sludge (SS) and compost (C) on seed germination of triticale. Compost was supplied from the experimental compostiong station of Grombalia (Tunisia) and was prepared essentially, from ground green waste. Table 1 summarizes its main composition.

Sewage sludge was obtained after aerobic biological treatment of sludge from wastewater treatment plant located in Beja, North-west of Tunisia. Air-dried sewage sludge was collected from sludge drying beds. The main chemical characteristics of the sludge used confirmed that none of heavy metals excessed the maximum limits allowed by Tunisian standards regulations (NT 106.2, 2002) (Table 2), indicating the possibility of its use with no immediate threat of soil or plant contamination.

The two tested amend were mixed with soil using different proportions (control 0%; SS1 or C1, 1%; SS2 or C2, 2%; and SS3 or C3, 4%). Extracts of sewage sludge and compost were obtained by shaking the mixture with 100 ml of distilled water for 1 h at laboratory temperature. The control consisted of 100% soil only and distilled water. Ten triticale seeds (*X Triticosecale Wittmack*) were placed in Petri dishes, filled with filter paper soaked in 5 ml of different amend extracts and incubated in the dark at a temperature of 25 °C for 5 days. Each treatment was replicated four times.

The rate of seed germination (G %) was calculated according to the following formula:

$$G\,(\%) = \frac{Number\ of\ seeds\ germinated\ in\ each\ treatment}{Total\ number\ of\ tested\ seeds}$$

After that, we decided to go on with a pot trial to investigate the effect of sewage sludge and compost on triticale growth and production.

For that, an unfertilized vertisol was collected at a depth of 20 cm from the experimental field of the Regional Field Crop Research Center in Beja, Tunisia. Plastic pots were filled with a mixture of sieved soil with various rates of sewage sludge or green waste compost, the equivalent of 0 (control), 5 (SS1 or C1), 10 (SS2 or C2), and 20 t/ha (SS3 or C3) for each amend. The final mass of the soil mixture plus amend was 4 kg. Each treatment was replicated four times.

Table 1 Average composition of applied compost (approved by Ecocert)

Dry matter (DM)	75%
Organic matter	70%
Total organic N	1.5%
Total organic P	0.4%
Total K	0.4%
Humic substances	6% DM
Cellulose	21% DM
Lignin	20% DM
Water retention	85%

Table 2 Average main chemical composition of applied sewage sludge compared to Tunisian standards (NT 106.20) (2002)

Parameters	Sewage sludge	NT 106.20 (2002)
pH	6.80 à 27.2 °C	
Humidity (%)	7.55	
Dry matter (%)	92.45	
Organic matter (g/kg DM)	685	
TOC (g/kg DM)	368	
Total nitrogen (g/kg DM)	24.4	
Total phosphore (g/kg DM)	12.0	
Cd (mg/kg DM)	0.659	20
Cu (mg/kg DM)	120	1000
Pb (mg/kg DM)	38.6	800
Ni (mg/kg DM)	4.70	200
Zn (mg/kg DM)	470	2000
Cr (mg/kg DM)	70.5	500
Hg (Ug/kg DM)	218	–

Each pot was seeded (four seeds per pot) with triticale, 15 days after application for amend. The water content of the soil was adjusted to 70% of field capacity (Söderberg 2013).

Plants were cultured in an adapted culture room inside a glasshouse fitted with an air conditioning unit to keep a temperature of 28 °C with natural light intensities and relative humidity (RH) of 62%. Various parameters were followed through experiment (once a week) such as plant length, number of leafs and tillers per plant, and chlorophyll index. The later parameter was measured, non-destructively, on the penultimate leaf of each plant, using the Minolta SPAD-502 meters.

Five months after sowing (at grain maturity), the whole plants were removed from the pots and separated into roots, and above ground parts to determine the weight of each part of the plant in each pot, and also to measure yield parameters such as ear number per plant, kernel number per ear. All samples were finally dried at 80 °C, weighed and then ground for further analyses.

Collected data in this study were analyzed and examined statistically using an analysis of variance (ANOVA) from the Statistical Analysis System (SPSS 20.0 for Windows). Means were compared by the Duncan Test at a 5% level of significance. The mean values of each treatment are designed by letters (a, b, c...) which represent the significance degree of the difference between the means. The letter "a" means the highest average. Means represented by two letters in common indicated that the difference is not significant or weakly significant.

Results and discussion

Germination test

The effect of the mixtures on the seed germination of triticale are shown in Table 3.

Both compost and sludge treatments decreased the germination rate of triticale seed by approximately 15 and 25%, respectively, compared to control. Apparently, certain constituents present in the tested amendments could be responsible for reducing seed germination potential. According to Wollan et al. (1978) and Fuentes et al. (2006), similar effects may be induced by heavy metals released in aqueous solution, by concentrations much higher than those in dried form of sludge or compost, where the most of the total metal load is in insoluble or unavailable forms. In addition, the corresponding effects on seed germination may be attributed to the imbalanced nutrients of the mixtures due to high initial rates of decomposition and more rapid evolution of volatiles compounds such as ammonia and ethylene (Wollan et al. 1978).

Growth test

The previous results relative to the preliminary laboratory test draw attention to the fact that it is unwise to sow seed immediately after mixing the soil with organic amend to allow for equilibration and to avoid inhibition of seed germination. For this purpose, sewage sludge and green waste compost were added in soil, before 15 days from triticale sowing. Various growth plant tests are followed through the trial pot to evaluate crop response to these applications. Figure 1 shows the effect of the different treatments on plant length (a), leaf number (b) and chlorophyll index (c) during the experimental period.

The main finding showed that compost application did not led to an increase in plant length, leaf number, and chlorophyll index. The values of these variables were near or below that is shown by the control. The results obtained from the present experiment are confirmed by an earlier study by Szejniuk et al. (2009), who showed that lupine clearly negatively responded to an addition of compost to soil, decreasing the shoot height by as much as 1/3. A slightly different opinion is presented by Czyzyk et al. (2002), who reported that varied rates of compost applied did not have a significant effect on plant emergence, which was uniform in all the combinations of the experiment. However, in some other studies, positive effects of compost application on plant growth had been reported (Ouédraogo et al. 2001; Bonanomi et al. 2014). Winiarska and Lekan (1991) reported that the diversification of plant responses to an addition of compost to soil might be related to individual abilities of particular plants to utilize nutrients taken up from organic fertilizers. Fılıpek-Mazur and Gondek (2003) showed that an unfavorable effect of compost observed in the first year after its application decreased in successive years of the study. According to Buchanan (2002), reductions in crop develop may be associated with the incorporation of immature or very mature composts into the soil. In fact, very immature or very mature composts may temporarily reduce or immobilize available soil N and have a negative impact on crop development and yield. Similar behavior was reported by Mamo et al. (1998) and Tiquia (2010) who demonstrated that the dual, contrasting effect of compost on plant growth can be associated both to the release of essential mineral nutrients for plant nutrition and to the presence of inhibitory compounds. Two mutually non-exclusive hypotheses have been proposed to explain the inhibitory effect of compost: N immobilization by microbial competition and the release of phytotoxic compounds, including short-chain organic acids, tannins, and phenols.

In contrast, it is clear that the amendment of sludge increased triticale develop by inducing plant length and leaf number and enhancing chlorophyll index during the develop cycle, at any application rate (Fig. 1). Numerous publications describe advantages of sewage sludge application to agricultural soil, mainly for its influence on crops develop and yield (Singh and Agrawal 2008; Cerny et al. 2010; Belhaj et al. 2016). This may be explained by the fact that this biosolid has great potential in improving the nutritional quality of soil (Singh and Agrawal 2007). The sewage sludge is rich in nutrients that plants need for their development, particularly the anions and cations (Sing and Sinha 2002). Our findings corroborate those of Motta et Maggiore (2013) and Ozyazici (2013), which reported the positive contribution of sewage sludge on mais and wheat development. The SS2 and SS3 levels (10 and 20 t/ha) seemed to be more efficient and provided high and significant improvement in terms of development; this is due to the high availability of nutrients which is based on sludge doses (Lobo et al. 2013).

Table 3 Seed germination (G %) of triticale grown on sewage sludge (SS1, SS2, and SS3) and compost (C1, C2, and C3) extracts

	Treatment						
	Control	Sewage sludge			Compost		
		SS1	SS2	SS3	C1	C2	C3
G (%)	80	50	60	50	60	70	63

Control: unamendmend soil, SS1 or C1: 1% sewage sludge or compost amendment, SS2 or C2: 2% sewage sludge or compost amendment, SS3 or C3: 4% sewage sludge or compost amendment

Shoots and roots productions

Regarding the influence of the two tested amendments on the yield parameters, measured at final harvest (grain maturity),

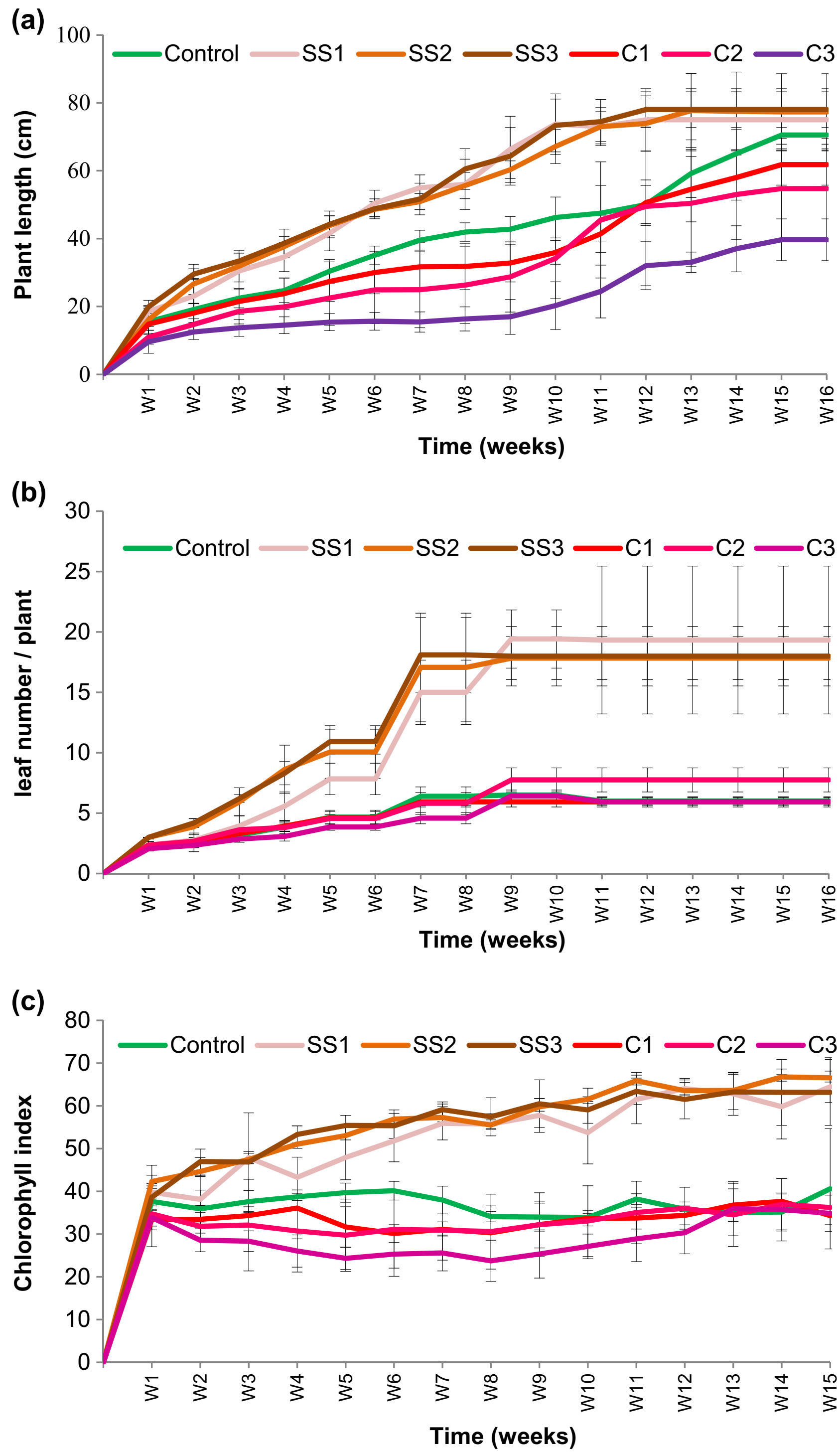

Fig. 1 Effect of sewage sludge and compost amendments on plant length (**a**), leaf number (**b**), and chlorophyll index (**c**). Control: unamendmend soil, SS1 or C1: 1% sewage sludge or compost amendment, SS2 or C2: 2% sewage sludge or compost amendment, SS3 or C3: 4% sewage sludge or compost amendment, vertical lines in each point show + or – standards deviations (n = 4)

similar trends were showed as those observed with growth parameters (Table 4).

All compost treatments led to lower yields of triticale (grain and straw productions) than those obtained on the control and sewage sludge treatments. Similar tendencies were observed in a study of the effect of compost addition on the yield of lupine green matter in pot experiments (Szejniuk et al. 2009). A decrease in green forage yield depending on the year of the study and the substrate was 37.1–63.9% for yellow lupine and 32.3–94.3% for blue lupine. In agreement with the finding of Brinton and Evans (2001) and Chefetz et al. (1996), reductions in the above-ground yields of triticale (straw and grain) may be related to the decrease in roots develop, which was also closely depending on the level of compost stability. In addition, the corresponding effects may be attributed to the release of metal elements from the mixture components to

Table 4 Yield parameters of triticale plants grown in sewage sludge (SS1, SS2, SS3) and compost (C1, C2, C3) treatments

Treatment	DM yield of above ground parts (g/plant)	DM yield of root parts (g/plant)	Ear number/plant	Kernel number/ear	Kernel weight/ear (g)
Control	1.42^{b}	0.19^{c}	1.00^{b}	27.67^{b}	1.21^{c}
SS1	6.7^{a}	1.06^{ab}	3.00^{a}	50.11^{a}	2.15^{b}
SS2	5.95^{a}	1.55^{a}	3.11^{a}	59.00^{a}	2.74^{b}
SS3	5.49^{a}	0.62^{bc}	3.67^{a}	63.33^{a}	3.48^{a}
C1	0.76^{bc}	0.19^{c}	1.00^{b}	19.77^{bc}	0.75^{cd}
C2	0.65^{bc}	0.11^{c}	1.11^{b}	16.55^{bc}	0.87^{cd}
C3	0.34^{c}	0.06^{c}	1.00^{b}	9.29^{c}	0.45^{d}

Control: unamendmend soil, SS1 or C1: 1% sewage sludge or compost amendment, SS2 or C2: 2% sewage sludge or compost amendment, SS3 or C3: 4% sewage sludge or compost amendment, average values followed by the same letter are not significantly different at $p < 0.05$

the soil environment and their consequent uptake by the plants (Fuentes et al. 2006). It has been found that especially copper may have a strong toxic effect to the plants, mainly on the growth of the roots (Fargasova 1998).

Once again, the highest values were reached for all parameters in the sewage sludge treated soil, at any application rate. İn addition, the SS3 level (20 t/ha) provided high improvement in terms of grain yields production (Table 4). Increased grain yield was primarily due to increased ear number per plant (Table 4). Our findings corroborate those of Monreal et al. (2007), which reported the positive contribution of sewage sludge on the production of dry matter and leaf area of sugar beet plants. The beneficial effects of sewage sludge in yield production are usually attributed to an improvement in the soil conditions by the supply of additional C from the sludge due the sewage sludge application (Christie et al. 2001; Bipfusa et al. 2008). In addition, sludge provides a short-term input of other plant available nutrients, particularly N (Kchaou et al. 2010), and stimulation of microbial activity and it contributes to long-term maintenance of nutrients and organic matter pools. Thus, the fertilizer N value of sewage sludge can be significant, but varies considerably depending on origin and processing to application (Peterson 2003).

Conclusion

The main finding showed how different the result of the pot trial are from these of the preliminary test. İn fact, the germination test seemed to confirm the existence of some toxic properties of compost and sewage sludge leading to a reduction of seed germination rates. Nevertheless, we will see after, that sewage sludge (this is not the case with the compost) increased triticale growth and production at any application rate.

Thus, sewage sludge could be used as an alternative to synthetic fertilizers. However, further analyses of mineral composition of each plant parts (roots, straws, and grains) are needed to confirm fertilizing capacity of used sewage sludge, but also to explain the negative effects induced by the compost treatments. İn addition, long-term field studies are recommended to follow its environmental impacts, because even if the use of sludge with low metal content may have no immediate threat, long-term sewage sludge application may result in the accumulation of some heavy metals in the soil and their entry into plants in quantities above the maximum permitted concentrations.

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