Anaerobic digestates from cow dung and food waste as fertilizers: effect on tomato growth and yield

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Abstract. Organic farming systems aim to reduce chemical inputs including fertilizers and ensure sustainable and eco-friendly production while recycling local renewable resources such as organic wastes. The aim of this study is to investigate the effect of two anaerobic digestates on tomato yield and growth in open field conditions. Digestates consisting of cattle dung and food waste from a 15 m^3 demountable digester and fixed-dome digester, respectively, were applied to tomato cultivation using tree fertilization treatments: 1) raw (PD100) and 2) diluted up to 50% (PD50) cattle dung digestate, 3) food waste digestate (DD), and an unfertilized treatment (control) for 21 weeks. The results showed that tomato plants fertilized with PD50 and DD were significantly higher (+34% and +33%, respectively) compared to the control and PD100 ($p<0.05$), and all digestate treatments significantly ($p<0.05$) enhanced plant elongation compared to the control. This study suggests that anaerobic digestates can be a helpful alternative in the perspective of partial substitution of chemical fertilizers for sustainable tomato production.

1 Introduction

Ensuring sustainable food, clean energy and enough water has become increasingly challenging for the world population. While the latter is expected to increase from 6.8 to 9 billion by 2050, the food and water needs, as well as energy demand, are expected to rise to 60% and 100%, respectively [1]. On the other hand, most inputs used in modern agriculture are pesticides, precision irrigation, selected seeds, herbicides, and chemical fertilizers. Chemical fertilizers are substances with a high concentration of nutrients required for plant growth and development. Radionuclides and potentially toxic elements (PTEs) are produced by the fertilizer industry, where most of the metals are present, including cadmium (Cd), arsenic (As), mercury (Hg), nickel (Ni), lead (Pb), and copper (Cu); and natural radionuclides including Po210, Th232, and U238 [2]. The application of chemical fertilizers may result in the accumulation of these PTEs in agroecosystems. In addition, agricultural soil quality has decreased due to the extended use of chemical fertilizers, which has resulted in a decrease in soil organic matter (SOM) content as well as an increase in environmental pollution and soil acidity [3]. Chemical fertilizers are considered harmful to agriculture because salt is one of the main products used in the process, which has a negative impact on soils and plants [4]. In the long term, and due to the rapid release of nutrients from chemical fertilizers, they don't serve to maintain the nutrients and fertility of the soil [5, 6]. For these reasons, using biofertilizers instead of chemicals is currently a popular new trend toward sustainable agriculture. This is due to their security, progressive release of nutrients, and positive effects on soil, plants, and the environment [7, 8].

Simultaneously, organic waste is expected to be generated in large quantities, which will have a negative impact on the environment if poorly managed. Indeed, organic waste mismanagement has severe consequences for water, air, and soil resulting in significant disruption to food production [9, 10]. It is therefore imperative to look for sustainable waste treatment and recovery solutions [11].

Anaerobic digestion (AD) is known to be an effective option for the recovery of organic waste, as it has a positive impact on the energy-fertilizer-pollution nexus, enabling waste to be treated efficiently and thus avoiding pollution, producing renewable energy in the form of biogas, and recycling nutrients by recovering the digestate for fertilizing agricultural soils [12, 13]. Anaerobic digestate was widely studied and recognized to have a good potential for replacing partially and or completely mineral fertilizers thanks to its agronomical and crop nutritional properties [14, 15].

Besides, tomato *(Solanum lycopersicum* L.) is a vegetable crop of great nutritional and economic importance. It is one of the most widely cultivated

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horticultural crops, with a global surface area of 5 million hectares and a world production of 182 million tonnes [16]. Besides, the agronomic potential of digestates produced during the AD process was evaluated by numerous authors and has shown a positive effect on the yield and fruit quality of tomatoes [17–22]. For instance, Cristina et al. [17] employed four anaerobic digestates: two liquids (primary and secondary digestate) and two solids (centrifuged and dewatered digestate) from treated sewage sludge. These digestates were sprayed on tomato plants for three months to assess their fertilizing properties. Results demonstrated improved growth metrics and no evidence of a phytotoxic effect. Additionally, the soil's characteristics and the components found in tomato leaves indicated an enrichment. In another study, Tallou et al. [20] applied digestates obtained from the AD of olive mill wastewater mixed in different proportions with phosphate waste on tomatoes. The results showed good performance and improvement of fruit quality, such as titratable acidity, total soluble sugars, color, and weight of tomatoes compared to the control plants.

As far as we know, the present study is the first to investigate the effect of anaerobic digestates from different raw materials (cattle dung and food waste) and different digesters (15 m^3 demountable digester and fixed-dome digester) on tomato crops. In this study, we used two previously characterized liquid digestates with different chemical compositions and quality [13, 23]. This work aims to verify whether these two digestates from different wastes and digesters affect tomato yield and growth parameters differently.

2 Material and Methods

2.1. Origin of digestates and their characterization

The two liquid digestates presented below were obtained respectively from a 15 m^3 household Puxin digester (PD) and a 20 m^3 fixed dome digester (DD) as described by Erraji et al. [13, 23]. Cattle dung was used as feedstock for the Puxin digester, while the fixed dome digester was fed with food waste in codogestion with cattle dung. The two biogas plants are installed at the Campus of Technology, Mohamed Premier University Oujda, and the Training Institute for Renewable Energies and Energy Efficiency of Oujda (IFMEREEO), Morocco, respectively. The physico-chemical characterization of these two digestates as well as their phytotoxicity test results are presented in Table 1.

Table 1. Physical-chemical characterization of digestates used in the experiment [13, 23]

Parameter	PD	DD
Dry matter (%)	1.00	1.00
Volatile solids (% DM)	50.00	8.00
pH	7.50	8
EC (mS/cm)	5.54	1.10
TKN (mg/L)	200.00	61 .00
C/N ratio	12.00	5.06
Potassium (mg/L)	19.00	2.50
Phosphorus (mg/)	87.00	1.40
Cd (mg/L)	<<0.20	< 0.20
Pb (mg/L)	<<1.00	< 0.10
Ni (mg/L)	11.00	0.54
Cr (mg/L)	2.50	0.10
Germination Index (%)	37	168

PD: Cattle dung digestate from Puxin digester [13], DD: Food waste-cattle dung digestate from fixed dome digester [23]

2.2. Experimental site and soil characterization

Soil samples were taken before and after tomato cultivation at a depth of 0-20 cm and analyzed for physico-chemical parameters (Table 2).

Table 2. Soil characterization before and after tomato cultivation and corresponding standard methods

Parameter	BC	AC	Unit	Analysis method/PNT
Organic Matter	0.83	0.83	%	$K_2Cr_2O_7$–H_2SO_4 oxidation method
Total Nitrogen (TN)	0.80	0.70	‰	Thermal conductivity
Phosphorus (P)	0.39	0.39	g/kg	Spectrometry ICP-OES
Carbon Elemental (C)	4.24	4.50	%	Elemental analysis
Magnesium (Mg)	0.50	0.83	g/kg	Spectrometry ICP-OES
Potassium (K)	0.33	0.41	g/kg	Spectrometry ICP-OES
Copper (Cu)	18.20	16.90	mg/kg	Spectrometry ICP OES/C5110228
Chromium (Cr)	39.00	37.00	mg/kg	Spectrometry ICP-OES/C5110228
Nickel (Ni)	23.20	22.00	mg/kg	Spectrometry ICP-OES/C5110228
Calcium (Ca)	7.61	7.34	g/kg	Spectrometry ICP-OES
Zinc (Zn)	0.21	0.06	g/kg	Spectrometry ICP-OES/C5110228
Iron (Fe)	22.80	21.74	g/kg	Spectrometry ICP-OES

BC: Before cultivation, AC: After cultivation

2.3.Experimental plan and modalities

Open field experiment on tomato crop (*Solanum lycopersicum* L. variety Campbell 33) was carried out in a 60 m^2 plot on loamy soil and no previous crop from April 16, 2020, to September 11, 2020, in the Campus of Technology of Oujda, Morocco (34.7687337127204, -1.9451314891664029). Prior to cultivation, the plot was plowed at a depth of 15 cm and then harrowed. Tomato seedlings were transplanted into the open field using an average plant density of 15000 plants/ha (spacing 1m × 0.65 m) after being raised in the nursery for 25 days. The drip system was installed to ensure regular irrigation. Weeds were controlled by manual weeding and tomato plants were staked with canes.

The modalities consisted of the application of tree fertilization treatments: 1) raw (PD100) and 2) diluted up to 50% (PD50) cattle dung digestate from Puxin digester, 3) food waste-cattle dung digestate from fixed dome digester (DD), and a non-fertilizing modality (control) for 21 weeks. The amount of digestate applied to the tomato crop was based on an average total amount of digestate application of 70 m^3/ha for PD100 and DD, and 35 m^3/ha for PD50, respectively. The corresponding nitrogen inputs are shown in Table 3. Digestate application began at the five-leaf stage with a low dose, then gradually increased to the maximum dose during flowering and fruit swelling. As tomato fruits reached ripening progressively, red fruits were harvested and weighed until the end of the experiment. Tomato fruit yield was calculated as the total weight of fruits per plant. Plant lengths were also measured at the end of the experiment.

Table 3. Experiment design and quantities of digestates and nitrogen applied to tomato cultivation

Modalities	Raw PD (PD100)	Diluted PD (PD50)	DD	Control
Supplied product (kg/m^2)	7	3.5	7	0
Provided N (g/m^2)	2.7	1.3	1.1	0

2.4.Statistical analysis

In order to detect the effect of digestates on the agronomic characteristics of the tomato fruit yield and plants height, the data were subjected to an analysis of variance (one-factor ANOVA) followed by a comparison of the means by the Tukey test at the 5% probability using the SPSS version 22 software.

3 Results and discussion

3.1.Effect of digestates on tomato fruits yield

The use of organic fertilizers such as anaerobic digestates to substitute chemical fertilizers partially or completely is widely recommended to promote sustainable agricultural production [16, 24]. However, the heterogeneity of the NPK nutrient content of digestates makes it difficult to supply crops with the quantities required for their development and growth [25]. Nevertheless, for this study, the average amounts of nitrogen provided during the experiments are 27kg/ha, 13kg/ha, and 11kg/ha respectively in the case of the application of raw digestate from cattle dung (PD100), diluted digestate from cattle dung (PD50) and food waste digestate from the dome digester (DD).

The effect of digestate on tomato yield is shown in Fig. 1 and fruits samples are shown in Fig. 2. Within a cropping cycle of 150 days, tomato plants produced average fruit yields of 355, 352, 263, and 208 g/plant when fertilized with 50% diluted cattle dung digestate (PD50), food waste digestate (DD), control treatment, and crude cattle raw digestate (PD100), respectively (Fig. 1). The yields obtained for both PD50 and DD treatments were significantly higher (+34% and +33%, respectively) compared to the control and PD100 (p<0.05). The PD50 and DD digestates therefore have a positive effect on tomato development, by making available the necessary nutrients for plants. Previous studies investigating organic fertilization regimes based on digestate without chemical fertilization on tomatoes are in line with this study [18, 19]. Edosa et al. [19] showed that the combination of digestate, poultry manure, and *Glomus mosseae* gave the best tomato yield and improved other soil parameters. Ronga et al. [18] found that both liquid digestate alone and combined with biochar recorded better tomato yield than that obtained with unfertilized treatment. In some studies, digestate application on tomatoes showed a better effect on fruit yield than the chemical fertilizer [16, 17]. Therefore, substantial benefits can be achieved by replacing partially or totally the inorganic fertilizer with anaerobic digestate. It should be noted that the yields recorded in this study were relatively low compared to those of conventional tomato farming based on chemical fertilizers, as conversion to organic farming is always associated with a decrease in crop yields [26, 27].

The fruit yield in the raw digestate PD100 was significantly lower (p<0.05) than that of all the other fertilized treatments by approximately 41% (Fig. 1). This inhibiting effect on tomato productivity was previously confirmed by the phytotoxicity test on the cress plant, whose germination index (GI= 37%) was below the limit of GI>50% considered as phytotoxic [28]. This inhibiting effect of raw digestate may be due to the relatively high salt concentration (EC= 5.54mS/cm), the presence of high concentrations of NH_4^+, or the organic acids of the digestate [29]. It is, therefore, necessary to assess the phytotoxicity of digestate before its application to crops and to use the appropriate dose depending on the degree of phytotoxicity.

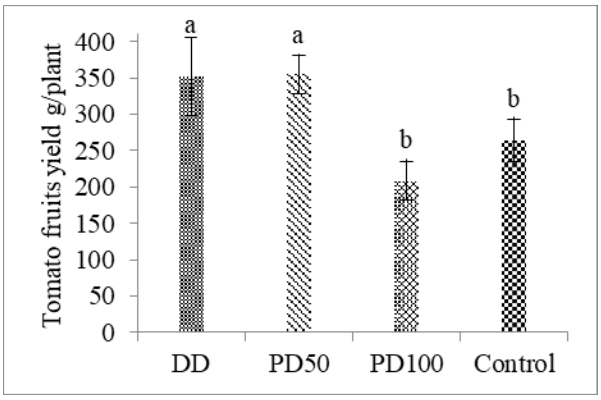

Fig. 1. Effect of digestates on tomato fruit yield in the field conditions. Means (±SE, *n*=10) with the same letter are not significantly different ($p < 0.05$). PD100 and PD50: cattle dung raw and diluted up to 50% digestate from Puxin digester, respectively; DD: food waste-cattle dung digestate from fixed dome digester; Control: treatment without fertilizer

Fig. 2. Tomato fruits sample. PD100 and PD50: cattle dung raw and diluted up to 50% digestate from Puxin digester, respectively; DD: food waste-cattle dung digestate from fixed dome digester; Control: treatment without fertilizer

3.2. Effect of digestates on tomato plants' height

As for the vegetative growth of tomato plants, the results showed that all digestate treatments enhanced significantly ($p<0.05$) the plant elongation compared to the control. The tallest plants (64cm) were observed in the PD50 fertilization, with an increase of +36% compared to the non-fertilized plants (Fig. 3). This positive effect on the plant's growth is due to the nitrogen supplied by the digestate. The same positive effect of digestate on plant height was reported by Li et al. [16].

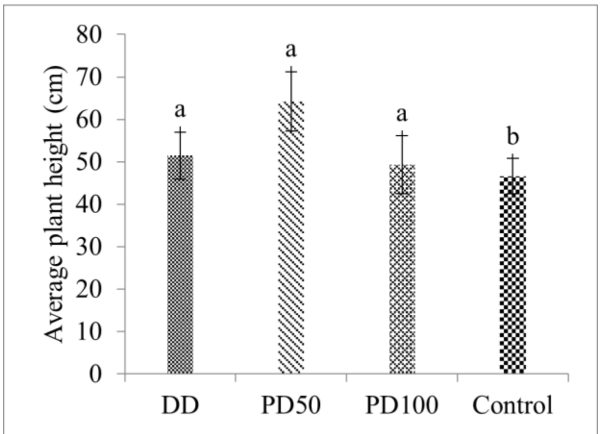

Fig. 3. Effect of digestates on tomato plants height in the field conditions. Means (±SE, n=10) with the same letter are not significantly different ($p < 0.05$). PD100 and PD50: cattle dung raw and diluted up to 50% digestate from Puxin digester, respectively; DD: food waste-cattle dung digestate from fixed dome digester; Control: treatment without fertilizer

Conclusion

In this study, two digestates obtained from different raw materials and anaerobic digestion processes were tested for their performance on the yield and growth of tomato crops in field conditions as part of an organic farming system for substituting chemical fertilizers. Our results showed a positive effect on tomato yield, particularly in the case of diluted cow dung digestate (PD50) and food waste digestate application. A positive effect on tomato plant height was also observed after applying the digestates. The results of this study suggest that anaerobic digestate has great potential for vegetable crops by improving yields and reducing the costs associated with the use of chemical fertilizers and the environmental impacts of the mismanagement of organic waste. However, the optimal application of digestate to tomato crops still needs to be determined to obtain better yields. A comparison should be conducted with chemical fertilizers to elucidate the real performance of digestate in a perspective of complete substitution of chemical fertilizers. In conclusion, our study can contribute to help farmers engaged in organic farming to enhance their understanding of the use of suitable organic fertilizers for their crops while profitably recycling available bioresources in a sustainable manner.

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