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Agricultural use of digestate for horticultural crop production and improvement of soil properties

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ABSTRACT

The usefulness of a digestate from an anaerobic codigestion process as a fertiliser product was evaluated in a field experiment using two horticultural crops (watermelon and cauliflower), during two successive growing seasons. The effects of the digestate were compared with those of a traditional organic amendment (cattle manure) and a conventional mineral fertiliser. Digestate addition to soil provided a source of available nutrients (nitrogen and phosphorus) in the short-term and had positive effects on soil biological properties such as microbial biomass and enzyme activities, compared to the non-amended soil. The digestate application to soil led to yields comparable to the mineral fertilisation for the summer watermelon crop. However, for the winter cauliflower crop, only plots treated with the mineral fertiliser had good production. Nitrogen from the digestate is rapidly and highly available for plant growth in the short-term but also can be easily lost, together with a slow rate of microbial processes due to low temperatures, could reduce the fertilising capacity of the digestate. This seemed to be the main limiting factor for the winter cauliflower crop, where digestate or cattle manure, used as basal dressing, were not enough to satisfy the crop demand for nitrogen during its whole growth cycle.

1. Introduction

The large quantities of biodegradable wastes produced by the intensive livestock production systems can have a negative impact on the environment, if they are not managed adequately. The anaerobic digestion of wastes for biogas production is of great interest for livestock waste management and energy recovery, according to the European policies concerning renewable energy production (Holm-Nielsen et al., 2009). This is clearly evidenced in Spain by the Slurry Biodigestion Plan (BOE, 2009), which promotes the treatment of animal manures and slurries through anaerobic digestion. The main benefits of anaerobic digestion are: energy savings through production of a renewable energy source (biogas); reduction in greenhouse gas emissions and air and water pollution; sanitisation of wastes and preservation of natural resources by using the end-products as soil amendments and fertilisers (Möller and Stinner, 2009; Stinner et al., 2008).

Together with biogas, anaerobic digestion produces a residual material (digestate), whose adequate management or disposal must be addressed in order to avoid any constraint to the development of anaerobic digestion systems. The legislative trends in the field of wastes management are based on integrated management, adding value to these by-products; thus, digestate addition to soil – resulting in benefits for agriculture and/or ecological improvement – is considered an appropriate option (Directive, 2008/98/EC). For the sustainable recycling of digestates in agriculture, they must satisfy certain quality characteristics such as stability and hygiene (Alburquerque et al., 2012; BSI, 2010; Siebert et al., 2008).

Also, intensive agriculture has promoted soil degradation and loss of organic matter and fertility, increased production costs (to maintain productivity) and contributed to CO_2 emissions (European Environment Agency, 2010). In this context, the recycling of digestates in agricultural systems has an important role, by reducing the use of mineral fertilisers, which leads to positive effects with respect to resource conservation (less fossil fuel and mineral resource consumption), climate change mitigation and soil quality maintenance. Northern European countries such as Denmark, Sweden, Scotland or Germany have used digestate in agriculture, mainly for cereal production (Möller and Stinner, 2009; Ortenblad, 2002; Rodhe et al., 2006; Smith et al., 2007). But these results cannot be extrapolated directly to Spanish intensive

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Table 1
Main characteristics of the digestate and the cattle manure used in the experiment on a fresh and dry weight basis for digestate and cattle manure, respectively.

Parameter	Digestate	Cattle manure
Dry matter (%)	1.9	47.1
pH	8.3	8.4
Electrical Conductivity ($dS\,m^{-1}$)	30.5	11.9
Total organic carbon (%)	0.47	35.8
Total nitrogen (%)	0.38	2.61
C/N ratio	1.2	13.7
P_2O_5 (%)	0.05	0.73
K_2O (%)	0.24	2.21
CaO (%)	0.07	6.4
MgO (%)	0.03	1.0
Na ($mg\,kg^{-1}$)	524	5190
Fe ($mg\,kg^{-1}$)	20	3222
Cu ($mg\,kg^{-1}$)	4	166
Mn ($mg\,kg^{-1}$)	3	164
Zn ($mg\,kg^{-1}$)	30	249

Digestate: Cd 0.01, Ni 0.2, Pb 0.04, Cr 0.1 and Hg <0.5 $mg\,kg^{-1}$ fresh weight. Cattle manure: Cd 1.1, Ni 8, Pb 82, Cr 10 and Hg <0.5 $mg\,kg^{-1}$ dry weight.

crop production systems, characterised by high fertiliser demand and short intercrop period under Mediterranean climate conditions. Therefore, there is a need for research in order to assess the adequate agronomic use of digested materials in Mediterranean intensive agriculture.

In the present study, the suitability of a digestate for use as fertiliser under field conditions has been evaluated for two horticultural crops over a two-year period, by analysing the effects of digestate addition on soil fertility and crop production and by comparing the fertilising capacity of the digestate with those of a mineral fertiliser and a traditional organic fertiliser (cattle manure).

2. Materials and methods

2.1. Materials

The study was carried out in an experimental field, belonging to "Fundación Ruralcaja Grupo CRM" situated in Paiporta (Valencia, eastern Spain). The main characteristics of the soil classified as a Typic Xerofluvent (Soil Survey Staff, 2010) were: sandy loam texture, pH 8.0, electrical conductivity (EC) (1:5) 0.12 $dS\,m^{-1}$, total organic carbon 0.89%, C/N 8.3, $CaCO_3$ 23.2%, available-P 34 $mg\,kg^{-1}$ and available-K 442 $mg\,kg^{-1}$.

The digestate was collected from an industrial anaerobic co-digestion plant, which treated a mixture of pig slurry with 1.0% sludge from a slaughterhouse wastewater treatment plant and 6.5% biodiesel wastewaters, at a temperature of 37 °C and with a hydraulic residence time of 21 days. The cattle manure was collected from a farm close to the experimental site. Both the digestate and cattle manure were stored (<4 °C) and characterised rapidly, in order to determine the application rate based on crop nitrogen demand before each application to the field.

The collected digestate was a liquid material and the cattle manure was solid; both had alkaline pH and high EC. The cattle manure showed higher C/N ratio and contents of organic carbon and nutrients than the digestate (Table 1). The mineral treatment consisted of a NPK 15–15–15 complex for basal fertilisation, while NH_4NO_3 and K_2SO_4 were added by fertigation.

The tested crops in the present study were watermelon (*Citrullus lanatus* var. lanatus) cultivar (cv.) 'Precious Petite' (Syngenta), as a summer crop, and cauliflower (*Brassica oleracea* var. botrytis) cv. 'Meridien' (Clause-Tezier), as a winter crop. Watermelon and cauliflower seeds were sown in a seedbed and seedlings of uniform size were transplanted to the field after one month (2.5×0.8 m spacing for watermelon and 0.64×0.5 m for cauliflower), leading to a plant density of 5000 and 31,250 plants per ha for watermelon and cauliflower, respectively.

2.2. Experimental design and layout

The experiment was a field assay, having a fully randomised design with three replication plots of 32 m^2 each per treatment. Four treatments were established: control soil without fertilisation, mineral fertilisation, digestate and cattle manure (the traditional organic fertiliser in this area). Successive crops of watermelon and cauliflower (watermelon–cauliflower–watermelon–cauliflower) were grown for two consecutive growing seasons during 2009 and 2010.

The organic amendments (digestate and cattle manure) were added manually to the plots and immediately incorporated into the soil using a rotavator (depth of 30–40 cm), to ensure their uniform distribution and avoid ammonia volatilisation. Digestate (64 and 66 $m^3\,ha^{-1}$, on average, for the first and the second crop seasons for watermelon and cauliflower, respectively) and cattle manure (20 and 22 $Mg\,ha^{-1}$, on average, for the first and the second crop seasons for watermelon and cauliflower, respectively) were added as the basal fertilisation between four and eight weeks before planting. This stabilisation period in soil was used to reduce or avoid potential detrimental effects associated to immature organic materials. For the mineral fertiliser treatment the N–P–K complex was applied two weeks before planting as a basal dose (647 and 646 $kg\,ha^{-1}$, on average, for the first and the second crop seasons for watermelon and cauliflower, respectively). In addition, a standard fertilisation programme was applied through a drip system, considering different sectors for each treatment, as is normally done in fertigation trials with watermelon and cauliflower (Table 2). Crop management followed the standard agronomic practices used in the area (soil preparation, crop cycles, fertilisation and phytosanitary treatments, etc.). The amount of both digestate and cattle manure applied was calculated according to their total-N concentration, adjusting the other macronutrients (P and K) with mineral fertiliser during the crop development, by drip irrigation. Thus, for the digestate, cattle manure and mineral fertiliser treatments, the same amount of N, P and K was applied to the experimental plots for each crop (240 N, 90 P_2O_5 and 250 $K_2O\,kg\,ha^{-1}$ for watermelon and 280 N, 100 P_2O_5 and 300 $K_2O\,kg\,ha^{-1}$ for cauliflower). Control treatment did not receive any fertiliser but was drip irrigated using the same amount of water as the rest of the treatments.

2.3. Plant and soil samplings

The watermelons and cauliflowers were harvested when the commercial size was obtained; shape criteria and the field evaluation (vigour, homogeneity and % coverage) were then determined. Marketable and non-marketable yield was determined based on fruit/curd quality parameters such as size, shape, colour, external appearance, damage, etc. A comparison of the production data was made among treatments and the macro- and micronutrients in plant leaves and marketable products were analysed. Representative plant material samples were taken randomly per plot, washed with distilled water, oven dried at 60 °C for 24 h, ground and stored for analysis.

In addition, the effect of the different fertilising treatments on soil enzyme activities, microbial biomass and physico-chemical properties was evaluated. For each plot, soil samples (0–20 cm depth) were taken in ten different, random sites and combined to obtain a representative sample. Special care was taken in order to sample the soil where plants were growing.

Each soil sample was divided into two fractions, one of which was immediately sieved to <2 mm and stored without drying at