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Closing the cycle for the cut rose industry by the reuse of its organic wastes: A case study in Ecuador

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ABSTRACT

The soil conditions and the yield and quality of *Rosa* sp. var. Freedom were determined following the incorporation into the soil of rose waste composts, with or without fertigation; the effects of these treatments were compared with those of non-stabilised chopped rose wastes + fertigation (FWF). The growing conditions were those of a commercial greenhouse. The use of the composts, alone or combined with fertigation, increased the available P and K contents of the soil with respect to FWF. However, only the compost + fertigation treatments improved, in general, the soil fertility regarding the organic matter (OM), nitrogen and available micronutrient concentrations, in comparison to FWF. When the composts were added alone, irrigation with alkaline water increased the soil pH and, in consequence, reduced the availability of micronutrients. Overall, the combined use of compost and fertigation increased the cut rose yield and quality relative to the application of compost alone and FWF. Principal component analysis indicated that the OM, available Cu, Mn and Zn and total N contents and the pH of the soil were the principal soil parameters determining the yield and quality of the roses. This analysis classified the treatments in three groups: the compost + fertigation treatments; the treatments with compost alone; and the FWF treatment. The compost + fertigation treatments gave the highest net income (average for these treatments = 80388.92 US dollars ha^{-1}). Therefore, the compost + fertigation treatments were highly beneficial with regard to increasing soil fertility and cut rose yield, quality and profitability.

1. Introduction

Ecuador is one of the most biodiverse countries in the world and it has a large number of species of flowering plants; around 2433 new species have been discovered in the last 13 years (Ministerio del Ambiente, 2014). In 2017, it exported around 150,000 tonnes of flowers, generating an income of 850 million US dollars (USD), equivalent to 0.86% of the gross domestic product (Banco Central del Ecuador, 2017). The rose is the flower with the highest production and commercialisation in this country, with more than 300 varieties being grown, of which 60 varieties are exported. In 2016, the cultivated area of roses was 5486 ha, producing 3805 million cut-rose stems (Instituto Nacional de Estadísticas y Censos, 2016). Annually, 140,000 tonnes of roses are exported to the markets of the United States, Europe, Russia and, in recent years, China (Expoflores, 2017).

The rose crop requires a high soil organic matter (OM) content, as well as good soil aeration and drainage, as the roots are very demanding with regard to the availability of oxygen; therefore, soil puddling should be avoided. The optimum value of soil pH for the rose crop is around 6.5 and the soil salinity should be below 1 dS m^{-1} (Ferrer Marti and Salvador Palomo, 1986). Fertilisation is achieved through irrigation, applying nitrogen as ammonium nitrate or ammonium sulphate, potassium as potassium nitrate, phosphorus as phosphoric acid or monopotassium phosphate and magnesium as magnesium sulphate. The lack of any essential element can decrease plant growth and reduce the flower quantity and quality (INFOAGRO, 2017). However, intensive production of cut flowers leads to high nutrient application and the excess of nutrients not taken up by the plants leaches from the soil, which can cause environmental damage, such as water eutrophication

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and soil salinisation (Chang et al., 2010; Sahle and Potting, 2013).

The sustainability of agricultural systems is a global goal. The use of organic fertilisers can contribute to the sustainability by reducing the chemical fertiliser application. Bearing this in mind, in the cultivation of roses, the addition to the soil of the waste created during the production cycle implies the return of nutrients removed by the plants and can contribute to diminishing environmental contamination and to the operation of this industrial sector as part of a circular economy. In this economic model, the lower input of basic materials and diminished output of residues are emphasised - in order to complete the productive cycle while boosting profitability and minimising environmental damage (Ghisellini et al., 2016). The implementation of this economic model in developing countries can help their economic growth and the reduction of their poverty (Díaz, 2017).

Monthly, rose crops produce around 40 kg of waste ha^{-1}, a result of the labours of disbudding, defoliation, pruning, harvesting, postharvesting and renewal of crops (Barriga, 2006). The management of these wastes is not adequate, since they generally accumulate in the open spaces belonging to the companies or are burnt, generating serious environmental problems such as emission of unpleasant odours, leaching of potentially toxic compounds, emissions of greenhouse gases, phytotoxicity and pathogen dissemination (Onursal, and Ekinci, 2015). However, in the last few years, some companies have begun to apply the rose wastes to the soil, after an uncontrolled biodegradation process. Organic amendment application is necessary to maintain the high OM content of the rose-growing soils, but these amendments must be stable. The organic nitrogen degradation of a stable material is low, which generates low ammonia contents in the soil; thus, the soil pH does not increase, reducing the rose leaf chlorosis that arises due to the lower micronutrient availability at high soil pH (Ehret et al., 2005).

Therefore, the treatment of rose wastes by composting is, in principle, very appropriate to produce stable organic amendments. The compost pile constitutes an ecosystem in which diverse microbial populations, composed of bacteria, fungi and actinomycetes, sequentially degrade the OM in the presence of oxygen, generating a stable, humified product of great nutritional value due to the recycling of the nutrients present in the waste (Bernal et al., 2017). In recent years, the use of compost as an organic fertiliser or in growing media for ornamental plants has become very important, providing very-good plant yields and quality and economic benefits. In this context, Ostos et al. (2008) showed that the use of green and urban waste-based compost for peat substitution augmented plant growth and nutrition of the native shrub *Pistacia lentiscus* L. Also, the use of cattle manure compost plus synthetic aggregate-based substrates increased the plant height and flower number of ornamental French marigold, with respect to a control with peat (Jayasinghe et al., 2010). In addition, Papafotion and Vagena (2012) observed that the media prepared by mixing peat with cotton gin compost (up to 50%) did not produce negative effects on the chrysanthemum plant quality, and the need for chemical regulators of plant growth was reduced. Rinnaldi et al. (2014) found that the addition of different types of compost as co-ingredients in the growing media for ornamental rosemary cultivation stimulated the growth of plants, especially in the case of the green composts. The use of a selected green-compost-based substrate for geranium cultivation also increased the plant growth and its quality (Massa et al., 2018), while the flowering and growth of calendula plants in media with green-waste compost were similar to those of the control with peat (Gong et al., 2018).

Several research groups have shown that the use of compost improves the fertilising capacity of soil (Paredes et al., 2005; Bedada et al., 2014; Agegnehu et al., 2016; Dai et al., 2017) and of growth substrates (Altieri et al., 2014; Mendoza-Hernández et al., 2014; Gavilanes-Terán et al., 2017). Therefore, the use of compost as an organic fertiliser or as a substrate for soilless cultivation can reduce the dependence on mineral fertilisers and the nutrient requirements in fertigation. However, there is insufficient information available on nutrient availability and the plant response in relation to the use of organic fertilisers as nutrient sources in flower production (Ruppenthal and Conte e Castro, 2005; Verlinden and McDonald, 2007; Chang et al., 2010).

So, bearing in mind the aforementioned general situation and the paucity of specific information regarding flower crops, the idea of the work reported here was to appraise the use of flower waste composts as organic amendments, with or without fertigation, for the cut flower production of *Rosa* sp. cv. Freedom cultivated under commercial greenhouse conditions.

2. Material and methods

2.1. Study site and materials

The experiment was carried out in a commercial greenhouse of the White River Roses farm (Penipe-Chimborazo, central Ecuador; 1°36′09″ S, 78°32′34″ W and elevation 2501 m a.s.l.), with an average temperature of 26.1 °C and average relative humidity of 51.9%. On this farm, 34 varieties of flowers are grown in a cultivable area of 6 ha, of which 2 ha are dedicated to *Rosa* sp. var. Freedom. In 2017, this farm produced 132.6 tonnes of flowers, with a gross income exceeding 700,000 USD.

The soil used in this work is an Inceptisol (Soil Survey Staff, 2014) with a sandy-loam texture, slightly-alkaline pH, low salinity and a high OM content. Its relevant characteristics are presented in Table 1.

Three composts were employed as organic amendments (proportions of the wastes on a fresh weight basis): compost 1 (50% rose waste + 15% broiler chicken manure + 35% sawdust), compost 2 (50% rose waste + 15% hen manure + 35% sawdust) and compost 3 (50% rose waste + 15% quail manure + 35% sawdust). The composting process for these composts is detailed in Idrovo-Novillo et al. (2018). Non-stabilised chopped rose wastes (FW) were used as the control. Table 2 displays the composition of these materials.

The rose seedlings used were obtained by grafting *Rosa* sp. cv. Freedom on *Rosa hybrida* cv. Natal Briar rootstock, with buds in a T form. Propagation of the grafted plants was carried out for three months, in pots (9 cm diameter x 7 cm height) containing a mixture of soil rich in OM and gravel as the growing medium. Then, the young plants, around 20 cm in height and having two short stems with leaves, were planted in the greenhouse soil, in rows.

Table 1
Initial characteristics of the greenhouse soil (values on a dry matter basis).

	Value
Sand (%)	71.0
Clay (%)	7.0
Silt (%)	22.0
Texture	Sandy-loam
pH	7.59
Electrical conductivity (dS m^{-1})	0.68
Organic matter (%)	3.89
Total N (g kg^{-1})	1.53
Available P (mg kg^{-1})	81
Available K (g kg^{-1})	0.82
Available Fe (mg kg^{-1})	162
Available Cu (mg kg^{-1})	8.42
Available Mn (mg kg^{-1})	83
Available Zn (mg kg^{-1})	21

Table 2
Main characteristics of the organic amendments used (dry weight basis).

	FW	Compost 1	Compost 2	Compost 3
pH	6.5	8.4	8.2	8.2
Electrical conductivity (dS m^{-1})	3.16	2.99	2.99	2.12
Organic matter (%)	80.8	57.5	54.6	42.3
Organic C/Total N	21.0	11.5	11.4	11.8
Total N (g kg^{-1})	21.6	26.7	28.0	19.9
P (g kg^{-1})	2.47	6.81	10.24	7.00
Na (g kg^{-1})	0.83	3.58	4.21	2.85
K (g kg^{-1})	19.8	22.2	20.5	14.7
Fe (mg kg^{-1})	2266	4391	4503	6368
Mn (mg kg^{-1})	84	204	255	207
Cu (mg kg^{-1})	16	30	32	28
Zn (mg kg^{-1})	43	98	148	129
Cr (mg kg^{-1})	7	12	14	19
Cd (mg kg^{-1})	0.04	0.21	0.24	0.20
Pb (mg kg^{-1})	0.06	0.08	0.07	0.08
Ni (mg kg^{-1})	8	15	15	21
Hg (mg kg^{-1})	<0.05	<0.05	<0.05	<0.05

FW: non-stabilised chopped rose wastes; Compost 1: compost of rose waste + broiler chicken manure + sawdust; Compost 2: compost of rose waste + hen manure + sawdust; Compost 3: compost of rose waste + quail manure + sawdust.

Table 3
Average characteristics of the fertigation solution and the irrigation water.

	Fertigation solution	Irrigation water
pH	7.61	8.41
Electrical conductivity (dS m^{-1})	1.01	0.27
CO_3^{2-} (mg L^{-1})	<10	59
HCO_3^- (mg L^{-1})	69	111
N (mg L^{-1})	21	<1
P (mg L^{-1})	12.2	<1.7
K (mg L^{-1})	134.3	1.7
Ca (mg L^{-1})	717	307
Mg (mg L^{-1})	8.3	8.3
S (mg L^{-1})	13.37	<0.05
Fe (mg L^{-1})	0.63	1.97
Mn (mg L^{-1})	0.81	0.02
Cu (mg L^{-1})	0.11	<0.01
Zn (mg L^{-1})	<0.25	<0.25
B (mg L^{-1})	0.37	<0.05
Mo (mg L^{-1})	<0.01	<0.01
Cl$^-$ (mg L^{-1})	<0.1	<0.1
Na (mg L^{-1})	6.98	5.64

2.2. Experimental design

The design was a complete randomisation, involving seven treatments with three replicates per treatment, each occupying a plot of 2 m^2 (2 m × 1 m). The treatments were: non-stabilised chopped flower wastes + fertigation (FWF), compost 1 + fertigation (C1F), compost 2 + fertigation (C2F), compost 3 + fertigation (C3F), compost 1 + water irrigation (C1), compost 2 + water irrigation (C2) and compost 3 + water irrigation (C3). The soil of the plots was disinfected with different commercial fungicides and homogenised by tillage before cultivation. The amendments were applied uniformly to the soil, to a depth of 30 cm, using a rototiller. The application rate was adjusted to give a final OM content in the soil of 5%, corresponding to 21, 22, 23 and 30 kg (on a fresh weight basis) plot^{-1} for FWF, C1, C2 and C3, respectively. The organic materials were added to the soil 12 days before planting; subsequently, all the plots were irrigated with water. Small rose (*Rosa* sp. var. Freedom) plants, uniform in size, were chosen and 24 were transplanted in each plot, in two rows (12 plants row^{-1}), 16 cm apart in the same row (120000 plants ha^{-1}). The plots were 1 m apart and in this separation area six rose seedlings were planted in each row. In this separation area, organic amendment was not applied to the soil. This separation was established to avoid intrusions of soluble compounds between treatments, which could affect the results.

The usual pest-control regime of the company was carried out. Fertigation and irrigation with water alone were applied during the growing season at a weekly rate of 78 L plot^{-1}. The main physico-chemical characteristics of the fertigation solution and the irrigation water are shown in Table 3.

Topsoil samples were collected before the addition of amendments (for the initial characterisation of the greenhouse soil), before planting (S1) and after the last harvest (S2). Six subsamples taken from distinct points in each plot, in the top 0–30 cm of soil, were combined to produce a single sample. The samples were passed through a 2-mm-mesh sieve and air-dried for analysis.

When the flowers reached the commercial quality, they were harvested and the flower diameter and yield, the stem length and weight and the vase life of the flowers were recorded for each plot. The roses were harvested twice and once a week during the first and second harvest months, respectively. The experimental design is shown schematically in Fig. 1.

2.3. Economic analysis of rose production

The methodology of the economic analysis of rose production was that used by Cappa et al. (2015) to determine the impact of three distinct rates of inorganic fertiliser application on the profitability of coffee plantations in the Loja region of Ecuador. The economic viability criterion used was net income, which was determined as the difference between the gross income and cost of flower production. The yield of roses obtained and their average sale price in 2017 (Banco Central del Ecuador, 2017; Expoflores, 2017) were used to estimate gross income. The total costs were derived from the setting-up and running of the plantation: principally fertilisation, pruning, harvesting and weed, disease and pest control.

2.4. Analytical methods

The relevant parameters of the composts were analysed in samples, according to Idrovo-Novillo et al. (2018). Also, the physico-chemical parameters of the fertigation solution and the irrigation water were measured according to the Standard Methods for the Examination of Water and Wastewater (2017). In soil:water (w/v) extracts of 1:2.5 and 1:5 were determined the pH and electrical conductivity (EC), respectively (Allison and Moodie, 1965). The modified Walkley and Black method was used to analyse the oxidisable organic carbon (Yeomans and Bremner, 1989). The soil OM content was estimated by multiplying the percentage of organic carbon by the Van Bemmelen coefficient (1.724). To calculate the percentage of organic carbon, the percentage of oxidisable organic carbon was multiplied by 1.29, a recovery factor that includes the percentage of non-oxidisable organic carbon in the conditions of the technique used (MAPA, 1994). The available P in the compost and soil samples was measured colorimetrically, as decribed by Olsen et al. (1954). Extracts obtained with 1 N ammonium acetate and DTPA were used to determine the soil available K and micronutrient concentrations, respectively (Knudsen et al., 1982), by inductively-coupled plasma mass spectrophotometry. Total N was measured by the Kjeldahl method. To determine soil texture a Bouyoucos densimeter was used. All analyses of the compost, fertigation solution, irrigation water and soil samples were made in triplicate.

The flower yield was determined on a fresh weight basis, by

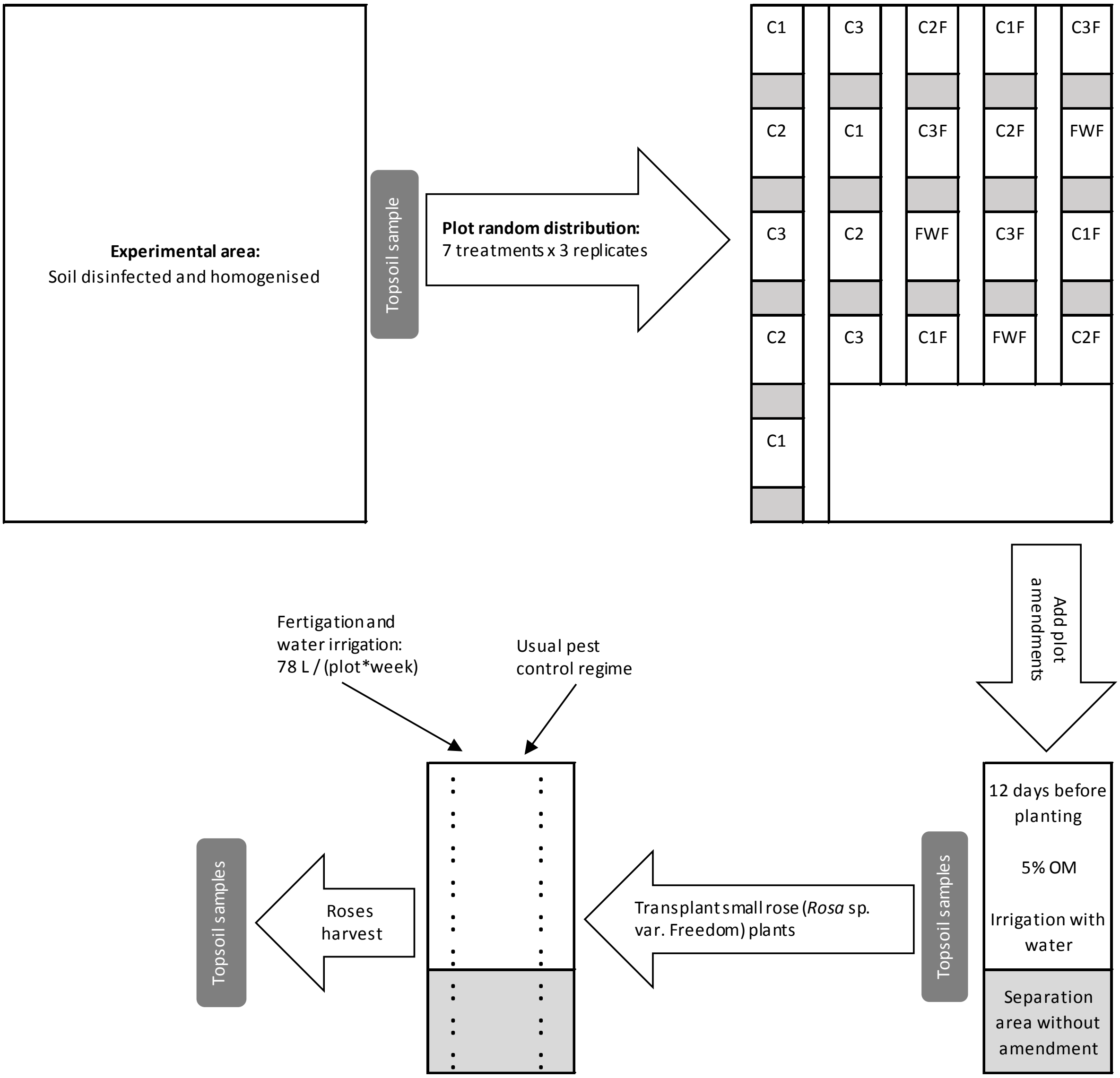

Fig. 1. Scheme of the experimental design. (C1: compost of rose waste + broiler chicken manure + sawdust; C2: compost of rose waste + hen manure + sawdust; C3: compost of rose waste + quail manure + sawdust; FWF: non-stabilised chopped rose wastes + fertigation; C1F: C1 + fertigation; C2F: C2 + fertigation; C3F: C3 + fertigation).

weighing all the harvested cut flowers (flower + stem) of each of the treatment plots. Then, half of the harvested flowers were taken at random and separated from the stem, to weigh the stems. For all the harvested flowers, the stem length was measured from the pedicel, using a flexometer, and the rose diameter was determined by measuring the largest diameter of the flower, with a Vernier caliper. The vase life of cut roses not separated from the stem was determined as the time from the placement of the cut flower in the vase until the detection of at least one of the senescence symptoms: bending of the pedicel, wilting, bluing, petal abscission and leaf abscission and yellowing (In and Lim, 2018).

2.5. Statistical methods

For the soil parameters, the variables used were treatment and sampling. One-way analysis of variance (ANOVA) was used to determine the significant effects of these variables and the Tukey-b test was established for separation of the treatment means. The same statistical procedures were employed for the flower quality and yield parameters. The mean values calculated from data of S1 (before planting) and S2 (after the last harvest) of all the parameters measured in the soil and regarding flower yield and quality were analysed by principal component analysis (PCA). This describes these correlated variables as a new set of uncorrelated, mutually orthogonal variables, each of which is a linear combination of the original variables. The new, calculated variables are called ‘principal components’ (PCs). The PCA was performed using the mean values of the three replicates of each treatment. The factor loadings of the data were scrutinised after the application of Varimax normalised rotation to the PCs coordinate system. Loadings $> |0.6|$ represent significant correlations between the original variables and the derived components (Rinaldi et al., 2014). The statistical procedures were carried out with the SPSS (v. 22.0) programme.

3. Results and discussion

3.1. Effect of the treatments on soil agronomic parameters

The application of the composts to the soil produced an initial

Table 4
Evolution of soil pH, salinity and organic matter and macronutrient content during the growth and flowering of the rose plants (dry weight basis).

Treatment	pH		EC (dS m^{-1})		OM (%)		N_{total} (g kg^{-1})		P_{av} (mg kg^{-1})		K_{av} (g kg^{-1})	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
C1	7.5 b	8.0 c	0.75 a	0.24 ab	5.0 a	3.9 a	2.53 b	1.63 a	118 ab	41 bc	1.21 bc	0.84 cd
C2	7.6 b	7.8 b	1.07 ab	0.28 b	4.9 a	4.3 a	2.20 ab	1.60 a	149 bc	43 c	1.07 abc	0.88 d
C3	7.6 b	7.8 b	1.00 ab	0.18 a	5.1 a	3.9 a	2.50 b	1.57 a	172 c	37 ab	1.29 c	0.79 bc
FWF	7.2 a	7.5 a	1.53 c	0.24 ab	5.0 a	4.3 a	1.87 a	1.70 a	100 a	35 a	0.95 a	0.68 a
C1F	7.5 b	7.5 a	0.79 ab	0.24 ab	4.9 a	5.5 b	2.57 b	2.33 b	115 a	43 c	1.26 bc	0.76 b
C2F	7.5 b	7.5 a	0.95 ab	0.24 ab	5.1 a	5.4 b	2.23 ab	2.40 b	148 bc	40 bc	1.04 ab	0.78 bc
C3F	7.6 b	7.5 a	1.17 b	0.23 ab	5.3 a	5.5 b	2.47 b	2.33 b	173 c	41 bc	1.28 c	0.75 b
F-ANOVA												
Treatment	7**	37**	11***	2*	0.5^{NS}	28***	5**	11***	15***	6**	7**	14***
Sampling	8**		175***		5*		13***		242***		111***	

C1: compost of rose waste + broiler chicken manure + sawdust; C2: compost of rose waste + hen manure + sawdust; C3: compost of rose waste + quail manure + sawdust; FWF: non-stabilised chopped rose wastes + fertigation; C1F: C1 + fertigation; C2F: C2 + fertigation; C3F: C3 + fertigation.
S1: before planting; S2: after the last harvest; EC: electrical conductivity; OM: organic matter; N_{total}: total nitrogen; $_{av}$: available.
***, ** and *: significant at $P < 0.001$, 0.01 and 0.05, respectively. ^{NS}: not significant.
Mean values in columns followed by the same letter are not statistically different according to Tukey's b test at $P < 0.05$.

increase in soil pH, in comparison to the control (FWF) (Table 4). After the last harvest, the soils that had received fertigation had the lowest pH values. The fertigation adjusted the soil pH to a value of 7.5, whereas the treatments with irrigation water gave final pH values in the range 7.8–8.0, probably due to the alkalinity of the water used (Table 3). Kaps and Odneal (1998) also observed that irrigation with alkaline water increased the soil pH during an experiment with different blueberry cultivars grown in a high-pH soil of Missouri, amended with sulphur to reduce its pH. The pH increased in the soils of all the treatments throughout the experiment, except in the soils receiving compost and fertigation. A rise in soil pH diminishes the availability of essential micronutrients through a decline in their solubility (Bernstein et al., 2006), which negatively affects plants that are sensitive to chlorosis induced at high pH, such as roses (Ehret et al., 2005).

The FWF soils had higher initial EC values than those treated with compost (Table 4). This was mainly due to the lower salt content of the composts (Table 2), a consequence of the leaching of salts caused by the watering of the piles during the composting process (Idrovo-Novillo et al., 2018). Only the soils amended with compost had initial EC values within or close to the optimal range for rose crops (EC < 1 dS m^{-1}) (Ferrer Marti and Salvador Palomo, 1986). Roses have a low tolerance of salinity, which negatively affects their growth and flower number in soils with an excessive concentration of ions, as observed by Cai et al. (2014) in a study on the response of six garden roses to three salinity levels. After the last harvest, the soil salt content did not differ significantly among the treatments, the EC value stabilising at around 0.24 dS m^{-1} in all soils. This parameter suffered a considerable reduction over time, possibly as a result of the nutrient uptake by the crop and the leaching of salts to deeper soil layers.

Before planting, no significant differences in the OM percentage were observed (Table 4). The value of this parameter decreased in most of the treatments throughout the development of the crop, except in the case of the soils receiving compost and fertigation, which had the highest final contents of OM. This decrease was probably due to OM mineralisation, whereas the increase might be attributable to the exudation of soluble OM from the roots. This latter result is in agreement with the greater rose yield found in the C1F, C2F and C3F plots, as will be discussed later. Paredes et al. (2016) also observed an increase in the soil organic carbon content during a field experiment with lettuce grown in a clayey-loam soil amended with spent mushroom compost. These authors indicated that the organic compounds in the root exudates contributed to the increase over time in the organic carbon in the soil.

Before planting, the N_{total} and K_{av} concentrations were higher in the soils amended with compost 1 or 3 (with and without fertigation) than in the control soil (FWF) (Table 4). However, the initial P_{av} contents were higher in the C2, C3, C2F and C3F soils in comparison to FWF. At the end of the experiment, the N_{total} concentrations were significantly higher in the plots receiving compost and fertigation. Dai et al. (2017), in a meta-analysis of the effects of long-term fertilisation on the gross transformation rates of soil N, also showed that the joint application of organic amendments and mineral fertiliser can augment the availability of N to plants and diminish the rate of N loss, relative to the use of mineral fertiliser alone. These authors indicated that the use of chemical fertiliser alone does not maintain the N availability over time by balancing the N mineralisation-immobilisation processes in soil, and that this type of fertilisation also accelerates the nitrification processes, inducing greater potential N losses through nitrate leaching. Water eutrophication and soil salinisation due to nutrient leaching from fertigation are the most-important environmental problems in the intensive production of cut flowers (Chang et al., 2010; Sahle and Potting, 2013); with a combination of compost and chemical fertilisation, these problems could be reduced. In general, the final P_{av} and K_{av} concentrations were significantly higher in the soils with compost than in the soil receiving FWF. This effect of compost use could help reduce the application of chemical fertilisers in the next season of cut rose production. The addition of compost to soil has also been shown to increase the available P and K contents in a field study with Swiss chard (Paredes et al., 2005) and in a long-term farm trial with various crops (Bedada et al., 2014). The soil contents of all the macronutrients studied (N, P and K) decreased in all treatments along the experiment, possibly due to the intake of nutrients by the plants or the leaching of these nutrients into deeper layers.

In most of the treatments where compost was used the initial content of available micronutrients was higher than in the control (Table 5). After the last harvest, the concentrations of available Fe were very similar in all soils. However, the final contents of available Cu, Mn and Zn were lower for the treatments C1, C2 and C3. The pH increase in these soils during the experiment, the result of irrigation with alkaline water (Table 4), probably reduced the availability of these micronutrients. The contents of the available micronutrients declined throughout the experiment for most of the treatments, possibly due to uptake by the crop. Also, it is worth noting that all soils had final heavy metal contents below the levels considered toxic in the soil, according to the US guidelines on the maximum allowable concentrations of trace elements in

Table 5
Evolution of soil micronutrients during growth and flowering of the rose plants (dry weight basis).

Treatment	Fe_{av} (g kg^{-1})		Cu_{av} (mg kg^{-1})		Mn_{av} (mg kg^{-1})		Zn_{av} (mg kg^{-1})	
	S1	S2	S1	S2	S1	S2	S1	S2
C1	1.52 ab	0.55 b	16 ab	10 a	188 bc	127 b	37 ab	6 a
C2	1.60 bc	0.45 a	17 b	10 a	213 cd	122 b	38 b	3 a
C3	1.83 d	0.44 a	21 c	10 a	222 d	114 a	44 c	3 a
FWF	1.39 a	0.49 ab	14 a	15 c	126 a	155 c	33 a	13 b
C1F	1.57 bc	0.50 ab	16 ab	14 bc	185 b	179 e	37 ab	15 bc
C2F	1.67 c	0.48 ab	18 b	14 bc	213 cd	181 e	39 b	17 c
C3F	1.85 d	0.48 ab	21 c	13 b	225 d	167 d	44 c	17 c
F-ANOVA								
Treatment	30***	4*	29***	37***	33***	291***	141***	60***
Sampling	969***		46***		25***		309***	

For the abbreviations see Table 4.
*** and *: significant at $P < 0.001$ and 0.05, respectively.
Mean values in columns followed by the same letter are not statistically different according to Tukey's b test at $P < 0.05$.

agricultural soils (Cu < 100 mg/kg and Zn < 220 mg/kg) (Kabata-Pendias and Pendias, 1992).

3.2. Effect of the treatments on the rose yield and quality parameters

The start of the rose production occurred later in the plants without fertigation (Table 6). This could be related to the lower Zn contents, throughout the cultivation period, in the soils receiving compost and irrigated with water alone. Ahmad et al. (2010) reported a link between early rose production and fertilisation with Zn + B, in an analysis of the impacts of the foliar application of B, Zn and Fe on vegetative growth and flower quality of three rose cultivars.

The flower stem length is considered the most-important parameter in the quality evaluation of cut roses (Nazari et al., 2009). The compost + fertigation treatments gave the highest average values for stem length, whereas, in general, its values did not vary significantly among the compost treatments without fertigation and the control (Table 6). The lower micronutrient availability at the beginning of the experiment in the case of FWF and throughout the experiment for the C1, C2 and C3 treatments could have contributed to the lower values of this rose quality parameter for these treatments. Different authors have observed a positive relationship between rose stem length and the additional supply of micronutrients (Khoshgoftarmanesh et al., 2008; Ahmad et al., 2010). The stem weights of the C1F, C2F and C3F roses were similar to those obtained with FWF. However, the values of this parameter were higher for the roses supplied with compost + fertigation than for the plants from plots with compost + water irrigation.

The values of flower diameter and vase life were in the ranges 34.5–36.9 mm and 13.5–14.4 days, respectively (Table 6). The values of these parameters were very similar for most of the treatments studied, except in the cases of C1 and C3F, which exhibited the lowest and the highest values of both parameters, respectively. Chang et al. (2010) also reported that the vase life of cut flowers (*Anthurium andreanum* Lind.) was not significantly influenced by the use of organic or chemical fertilisers.

Regarding rose production, there were no significant differences in the value of this parameter in most of the treatments with compost only (without fertigation), in comparison to the control (Table 6). However, the compost + fertigation treatments gave the highest flower yields, not showing differences as a result of the type of compost used. This finding could be related to the higher nitrogen contents in the C1F, C2F and C3F soils throughout the experiment (Table 4), these treatments providing enough nitrogen for the optimal development of the cut roses. Alvarado-Camarillo et al. (2018) observed that the nitrogen demand for the development of the flowering shoots is greater than that of other parts of the rose plant.

3.3. Multivariate analysis

Principal component analysis was performed for all the parameters measured in the soil and cut roses (n = 16). For this statistical analysis, the value of the Kaiser–Meyer–Olkin measure of sampling adequacy (KMO) was > 0.5 and the Bartlett's test of sphericity had a P value < 0.001. Furthermore, all variables had an extraction value > 0.5. These values show the adequacy of the model utilised. In this model more than 70% of the variability was explained by two PCs: PC1 explained 59.4% and PC2 26.6% (Table 7). PC1 grouped the parameters related to the yield and quality of the flowers and some agronomic properties of the soil, such as OM, Cu_{av}, Mn_{av}, Zn_{av}, N_{total} and pH. So, this factor was associated with the soil parameters on which the yield and quality of the roses depended. The time that elapsed until the first harvest and soil pH were correlated negatively with the other variables, suggesting that a rise in soil pH lowered the availability of the micronutrients and a lower content of these elements in the soil extends the period until first harvest, as mentioned above. PC2 was related to soil nutrients that were less limiting to the rose cultivation (P_{av}, K_{av} and Fe_{av}) and EC. All the variables involved in PC2 were positively correlated, except EC, showing that the soluble ions of P, K and Fe did not contribute to soil salinity.

PC1 separated the compost + fertigation treatments from the rest of the organic amendments used, treatments C1F, C2F and C3F being distributed on the positive side of this axis (Fig. 2). These

Table 6
Comparative effects of the different treatments on the quality of cut roses.

Treatment	Time to first harvest (days)	Stem length (cm)	Stem weight (g)	Flower diameter (mm)	Vase life of flower (days)	Flower yield (kg ha^{-1})
C1	183.3 b	45.0 ab	35.7 ab	34.5 a	13.5 a	17030 ab
C2	186.2 b	43.0 a	33.4 a	34.6 ab	13.8 ab	11393 a
C3	184.1 b	45.7 ab	36.5 abc	34.7 ab	13.7 ab	15088 ab
FWF	175.1 a	47.2 b	38.7 bcd	36.0 ab	13.9 abc	20134 b
C1F	173.0 a	53.5 c	42.1 d	36.3 ab	14.1 bc	32541 c
C2F	174.3 a	50.9 c	39.9 cd	36.5 ab	14.1 bc	27644 c
C3F	176.0 a	51.6 c	41.6 d	36.9 bb	14.4 c	28824 c
F-ANOVA	17***	23***	13***	3**	6***	17***

For the abbreviations see Table 4.
*** and **: significant at $P < 0.001$ and 0.01, respectively.
Mean values in columns followed by the same letter are not statistically different according to Tukey's b test at $P < 0.05$.

Table 7
Loadings of the variables to the principal components (PC) extracted by principal component analysis, for the soil and rose yield and quality parameters studied (only significant loadings > |0.6| are reported).

	PC1	PC2
Explained variance (%)	59.4	26.6
Cumulative variance (%)	59.4	86.0
Flower diameter	0.971	
OM	0.960	
Stem length	0.957	
Stem weight	0.953	
Flower yield	0.945	
Zn_{av}	0.942	
Vase life of flower	0.922	
Time to first harvest	−0.885	
Cu_{av}	0.826	
N_{total}	0.782	
Mn_{av}	0.707	
pH	−0.641	
K_{av}		0.901
Fe_{av}		0.874
P_{av}		0.821
EC		−0.703

For the abbreviations see Tables 4 and 5

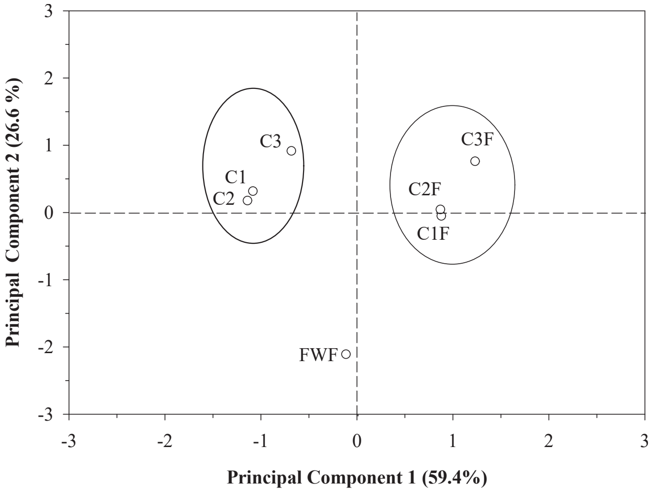

Fig. 2. Treatment scores in PC1 and PC2. The drawn ellipses demonstrate the separation of the treatments along the principal components, but they are not based on statistical tests. (C1: compost of rose waste + broiler chicken manure + sawdust; C2: compost of rose waste + hen manure + sawdust; C3: compost of rose waste + quail manure + sawdust; FWF: non-stabilised chopped rose wastes + fertigation; C1F: C1 + fertigation; C2F: C2 + fertigation; C3F: C3 + fertigation).

treatments gave, in general, the highest rose yield and quality since they supplied the micronutrients and nitrogen demanded by this crop. PC2 discriminated the treatments, on the positive side of this axis being distributed most of the treatments with composts, separated from the control (on the negative side of PC2). Therefore, the P_{av}, K_{av} and Fe_{av} contents and the EC values of the soil caused this separation.

3.4. Rose profitability

Table 8
Costs associated with annual flower production.

Costs associated	Value (USD ha^{-1} $year^{-1}$)
Labour cost	70714.60
Energy	1920.00
Irrigation water	96.00
Chemical fertilisers	7200.00
Phytosanitary products	7200.00
Compost 1 cost	3293.40
Compost 2 cost	3633.48
Compost 3 cost	4580.95
Flower waste cost	145.72

USD: dollars, USA.

Table 8 shows the costs associated with annual flower production in this case study, using the fertilisation scenarios “flower waste with fertigation” and “compost with and without fertigation”. In the former, the costs of the energy used to crush this waste and the labour employed for this operation were taken into account. The compost production costs included the costs of the raw materials (poultry manures and sawdust) and their transport, the cost of crushing the flower residues and the cost of the labour required for the preparation of the mixtures, for the turnings and for the control of the process, as well as the cost of the water applied during the composting process. The differences in the compost costs were mainly due to the different doses of these composts (22, 23 and 30 kg (on a fresh weight basis) $plot^{-1}$ for Composts 1, 2 and 3, respectively) required to adjust the final OM content in the soil to 5%, since the raw material, transport and labour costs were very similar for the three composts. The average cost of compost production was 31 USD/tonne. This is within the range established for the production of compost in European countries (20–60 € $tonne^{-1}$ ≈ 23–70 USD $tonne^{-1}$) (European Commission, 2014). Also, this compost cost was close to the average cost for the production of the most-cost-effective mixture, according to the optimal physical-chemical characteristics (21.58 € $tonne^{-1}$ ≈ 24.60 USD $tonne^{-1}$) (Proietti et al., 2016). However, this cost is lower than the cost of compost in Ecuador: 150 € $tonne^{-1}$ ≈ 175 USD $tonne^{-1}$. This high cost in Ecuador is a consequence of the paucity of commercial composting plants in this country, which has to import most of the compost it uses (Jara-Samaniego et al., 2017). Among the costs associated with the cut rose production, labour costs were the main component. In an environmental and economic study for two protected crops (tomato and rose), Torrellas et al. (2012) also observed that labour was one of the principal costs for rose production. During the cut flower production many labour-intensive tasks are performed - such as the application of organic amendments and pesticides, disbudding, defoliation, pruning, harvesting, post-harvesting and renewal of crops (Barriga, 2006). Also, the costs associated with chemical fertilisers and pesticides use were noteworthy. The cut rose industry is one of the sectors where pesticides and mineral fertilisers are used intensively (Sahle and Potting, 2013). This industry has notable economic losses due to pesticide overdoses, estimated at 64.73 € ha^{-1} (75.73 USD ha^{-1}) (Yilmaz, 2015).

An economic comparison of the non-stabilised chopped flower wastes + fertigation and the composts with and without fertigation was made for the roses, taking into account only the net income (Cappa et al., 2015) (Table 9). The reference price for exported flowers, as of June 2017, was 5.80 USD per kilogram (Expoflores, 2017). The net income differences between the treatments were statistically significant. The treatment with the lowest net incomes was C2 (−18215.88 USD ha^{-1}); with this treatment the costs were higher than the gross income. No significant differences were found among the net incomes of the C1, C3 and FWF treatments. This could be due to the fact that the flower productions in these treatments were similar (Table 6) and the costs in C1 and C3 were lower than in FWF, since in the former treatments chemical fertilisers were not used in the irrigation. On the other hand, the treatments that combined compost application with fertigation (C1F, C2F and C3F) showed the highest net income values of this

Table 9
Gross income, costs and net income of annual rose production in the different treatments.

Treatment	Gross income (USD ha^{-1} year^{-1})	Costs (USD ha^{-1} year^{-1})	Net income (USD ha^{-1} year^{-1})	
C1	98776.05	83954.80	14821.25	ab
C2	66079.00	84294.88	−18215.88	a
C3	87511.78	85242.35	2269.43	ab
FWF	116778.07	87876.32	28901.75	b
C1F	188742.12	91154.80	97587.32	c
C2F	160335.52	91494.88	68840.64	c
C3F	167181.15	92442.35	74738.79	c
F-ANOVA			15***	

For the abbreviations see Tables 4 and 8.
***: significant at $P < 0.001$.
Mean values in columns followed by the same letter are not statistically different according to Tukey's b test at $P < 0.05$.

study, which indicates greater profitability for cut rose production with these treatments. Similar results were found by Iqbal et al. (2017) in an economic comparison of conventional nitrogen fertilisation with urea and the use of poultry manure compost (PCM) in combination with different ratios of urea, for a maize crop; the net income was greatest in the treatment PMC + urea at 25:75. These authors showed that the use of compost significantly improved the quality of the soils and plants and could diminish the environmental impact of such crops. Hence, these results indicate that fertilisation combining compost and chemical fertiliser will have a positive effect on the commercial aspects of the cultivation and contribute to improving its economic profitability.

4. Conclusions

The results obtained in this study indicate that the combined application of rose waste composts and fertigation improved the soil fertility, especially the OM, nitrogen and available micronutrient contents, in comparison to the use of non-stabilised chopped rose wastes + fertigation. The greater stem length and yield of *Rosa* sp. var. Freedom plants grown in soil treated with the combination of rose waste composts and fertigation confirmed these beneficial effects. This study also shows that the increase in the cut rose yield due to these treatments could compensate the costs of production of the composts, giving the highest net income. The significantly-lower responses of the yield and quality of *Rosa* sp. var. Freedom to the treatments with rose waste composts without fertigation could have arisen from an insufficient micronutrient supply from these composts, due to the high soil pH produced by the irrigation with alkaline water.

A more-detailed study is required to show whether the rose waste composts alone, using irrigation water with pH adjustment, could supply the necessary nutrients for the rose crop; in this case, these composts could replace the chemical fertigation in cut rose production under greenhouse conditions.

In conclusion, this work indicates that rose wastes from the cut-flower-based industry in Ecuador, in the form of compost, can be utilised for organic fertilisation and soil improvement in rose cultivation, thereby closing the production cycle and, at the same time, providing greater profitability and diminishing any negative environmental effects.

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