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Evaluation of composted green waste fertigation through surface and subsurface drip irrigation systems on pot marigold plants (*Calendula officinalis* L.) grown on sandy soil

Khalid M. Elhindi [1, 2*]

[1]**Plant Production Department, College of Food and Agriculture Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia**
[2]**Vegetable and Floriculture Department, Faculty of Agriculture, Mansoura University, Egypt**

[*]**Corresponding author: Elhindikhalid2010@yahoo.com**

Abstract

The aim of this study was to evaluate the effects of composting in sandy soil using surface and subsurface drip irrigation systems on the growth, quality and chemical composition of *Calendula officinalis* plants and soil fertility after harvesting. For this purpose, field experiments were conducted at the Dirab experimental farm in the College of Food Sciences and Agriculture, Saudi Arabia during the winter growing seasons of 2010 and 2011. A split plot experimental design was used with three replicates, and the main plots were presented with irrigation systems, i.e., surface and subsurface drip irrigation, while the subplots were presented with composted green waste additives at 0, 30, 60, 120 kg ha^{-1}. The results showed that increasing compost application rates of up to 120 kg ha^{-1} enhanced the vegetative growth, flowering parameter and chemical composition in plants. The increased composting rates were associated with reduced nutrient leaching, which was reflected by increasing macronutrient concentrations in the plants and in the soil after harvesting. The subsurface drip irrigation system was more efficient than surface drip irrigation in improving the growth, quality and chemical composition of plants, and the fertility of the soil after harvesting.

Keywords: Compost; pot marigold; sandy soil; subsurface drip irrigation; surface drip irrigation.
Abbreviations: BD– bulk density; CGW– composted green waste; DIM– drip irrigation methods; SDI– surface drip irrigation; SP– saturation percent; SSDI– subsurface drip irrigation; TP– total porosity.

Introduction

Composting requires the use of agricultural residues, natural microbial flora, and inorganic nutrients, such as nitrogen and phosphorus, and the application of proper moistening to generate a final product with increased ability to improve soils and enhance plant growth (Lampkin, 1990). The natural recycling of farm-waste organic matter through composting is aimed at minimising nutrient loss, reducing waste accumulation and limiting greenhouse gas emission. Developing inexpensive and nutrient-rich organic media alternatives will not only eliminate environmental impacts but also reduce nursery costs and fertilisation and irrigation rates (Wilson et al., 2001). Recent studies have demonstrated that organic residues, after proper composting, can be used with excellent results (Chen et al., 1988; Piamonti et al., 1997; Garcı´a-Go´mez et al., 2002). The compost from green residues has been used successfully. Marculescu et al. (2002) revealed that soil enriched with macro and microelements through the use of organic Fertilizers plays an essential role in the growth and development of *Chrysanthemum balsamita* L. plants and the biosynthesis of organic substances at all levels. In addition, dill plants (*Anethum graveolens* L.) treated with different combinations of organic Fertilizers showed significant increases in growth and yield (Khalid and Shafei, 2005). Although marketable, plants grown with higher percentages of compost (75% or 100%) were reduced in size and appeared to have an abnormal root distribution (Wilson et al., 2001). Composting positively affects the structure, porosity, water holding capacity, and nutrient and organic matter content of the soil (Smith, 1996; El-Ghamry and El-Naggar, 2001) and improves plant growth and quality (Pinamonti and Zorzi, 1996). Sandy, infertile soils are common in Saudi Arabia. It has been proposed that organic waste amendments could increase the water and nutrient-holding capacity of these soils, thereby enhancing soil fertility. The beneficial effects of organic soil amendments include decreased soil bulk density and increased water holding capacity, aggregate stability, saturated hydraulic conductivity, water infiltration rate, and biochemical activity (e.g., Martens and Frankenberger, 1992; Turner et al., 1994). Therefore, this study is focused on the recycling of green residues from fields prior to planting and will provide important information for reducing waste management problems, conserving plant nutrients and understanding the effects of organic soil amendments on the physical and chemical properties of infertile sandy soil in Saudi Arabia. The measurements were acquired on soil obtained from plots that were previously used to document the effects of these amendments on plant growth and soil nutrient concentrations (Neilsen and Nelson, 1998). Drip irrigation involves the application of small frequent irrigation systems to saturate the soil and fulfil plant water requirements. There are specific problems in the management of sandy soils, including their excessive permeability and low water and nutrient holding capacities (Suganya and Sivasamy, 2006). The use of modern irrigation systems (surface and subsurface drip) in cultivating ornamental plants has improved the growth and quality of flowers (Gengoglan et al., 2006; El-Shawadfy, 2008). Therefore, managing the use of irrigation and plant nutrients is a major challenge for sandy soil amelioration efforts. The term ‘micro-irrigation’ refers to drip, trickle, spray, microjet or mini-sprinkler systems designed for the efficient use of available water through a slow and frequent delivery directly to the plant root zone. Moreover, drip irrigation provides an efficient method of Fertilizer delivery that is virtually free of the cultural constraints that characterise other production systems. Subsurface drip irrigation is considered to be the most modern irrigation system, which contributes immensely to improving crop water use efficiency and water conservation (Hanson and May, 2004). Most agricultural irrigation scientists agree that fertilisation through subsurface drip irrigation could serve as ideal fertigation systems. Rajkumari et al. (2006) hypothesised that injecting N Fertilizer into subsurface irrigation systems could theoretically be as efficient as the irrigation delivery system itself. Achieving maximum fertigation efficiency requires knowledge of crop nutrient requirements, soil nutrient supply, Fertilizer injection technology, irrigation scheduling, and crop and soil monitoring techniques. If properly managed, fertigation through drip irrigation lines could reduce overall Fertilizer application rates and minimise the adverse environmental impact of crop production (Hochmuth, 1992). Pot marigold plants (*Calendula officinalis*) were used in this study because of its increasing popularity among consumers and proven performance in Saudi Arabia. The pot marigold can be used to make dyes because it contains two classes of pigments: flavonoids and carotenoids, which can be used as yellow and orange natural colours (Boucaurd-Maiture et al., 1988). In addition, dyes made from these flowers are safer than synthetic dyes, which showed risks for use in medicinal or culinary purposes (Cromack and Smith, 1988). The aim of this study is to examine the effectiveness of composted green waste (CGW) additives on improving the growth, quality and nutrient concentrations in pot marigold plants and in the soil after harvesting using both surface and subsurface drip irrigation systems in sandy soil.

Results and discussion

Effects of drip irrigation systems and compost application levels on growth and quality indicators.

The data presented in Table 4 showed that composted green waste (CGW) additives increase vegetative growth and flowering, and this effect was highly significant ($p< 0.05$). Meanwhile, composting rates of 120 kg ha^{-1} produced higher growth than rates of 30 or 60 kg ha^{-1}. These results could be attributed to the improvement of moisture retention and nutrient supply in sandy soils after composting (Suganya and Sivasamy, 2006). However, composted green waste application rates significantly affected the quality of pot marigold flowers. This effect could be attributed to the increasing nutrient retention in the rhizosphere, which provides a continuous supply of plant nutrients that improve the quality of flowers. Moreover, improved flowering could be associated with increasing soil aggregates as a consequence of the increased organic matter content through composting (Fortun et al., 2006). The formation of these aggregates could protect pot marigold plants at all growth stages, and improve flower quality. Drip irrigation methods significantly affect pot marigold growth ($p< 0.05$), and subsurface drip irrigation is more associated with higher yield quantity than surface drip irrigation. There were significant differences in the growth parameters of pot marigolds under SDI and SSDI. The salt distribution in the soil profile under SSDI was better than that in the sandy soil under SDI, as the harmful effects of salt in the root zone and evaporation from the soil surface were reduced. These results are consistent with those of El-Tantawy (2000), Gengoglan et al. (2006) and El-Shawadfy (2008). These authors concluded that the use of modern irrigation systems (surface and subsurface drip) in growing horticulture crops has increased growth parameters. In addition, the ability of subsurface drip irrigation to improve plant growth could be attributed to a reduction in water loss from the soil surface through evaporation. Moreover, subsurface drip irrigation allows the maintenance of optimal soil moisture in the root zone, which improves the efficiency of water and Fertilizers (Thompson and Doerge, 1996). Compared with surface drip irrigation, subsurface drip irrigation slightly improved the quality of flowers in marigold plants, i.e., carotenoid content and reducing and non-reducing sugar percentages. The interaction between irrigation treatments and compost application rates significantly ($p< 0.05$) affected pot marigold growth and quality as shown in Table 4. Meanwhile, fertigation with composted green waste in a subsurface drip irrigation system at 120 kg ha^{-1} produced superior results.

Effect of irrigation system and compost application levels on chemical composition.

The data presented in Table 5 show that the use of composted green waste (CGW) additives in fertigation systems significantly ($p< 0.05$) increased the chemical composition of pot marigold plants, i.e., photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoids) in leaves and flowers, macro- and micronutrients in shoots and reducing and non-reducing sugars in flowers. The increased vegetative and flowering parameters must have led to an increase in the photosynthetic pigments of the plant, thus increasing the amount of intercepted light during photosynthesis. The photosynthetic pigments in pot marigold plants were significantly increased after the application of the three rates of CGW; however, higher values were observed at 120 kg ha^{-1} than at 30 or 60 kg ha^{-1}. The role of compost application is primarily associated with the increased water-holding capacity of the composted green waste, which has a high compost addition rate (Perner et al., 2007). These results could also reflect the effect of adding organic manure to increase the availability and absorption of the essential nutrient elements, particularly Fe^{++}, Mg^{++} and NH_4^+ cations, which are necessary for enzyme activation and chloroplast and chlorophyll formation as previously reported (Stoffela and Kahn, 2001). In addition, the effect of composting on photosynthetic pigments often improves soil structure and reduces nutrient leaching (Elhindi et al., 2006). However, the increased concentrations of reducing and non-reducing sugars could be attributed to the application of CGW, which stimulates metabolite synthesis in the plant, accelerates different plant growth parameters and increases the dry weight of shoots. This increment might reflect the ability of microorganisms to produce growth regulator substances. These phytohormones play an important role in plant growth through promoting photosynthesis, translocation and dry matter accumulation in plants (Kannaiyan, 2002). Moreover, the enhanced chemical composition, as a result of composting at 120 kg ha^{-1}, could be attributed to high N contents and a low C/N ratio (Table 3). Saadawy et al. (2005) and Zarad and Mohamed (2005) observed similar trends with indoor plants and *Stevia rebaudiana*, respectively. The data in Table 5 shows that the use of irrigation systems affects the chemical composition of pot marigold plants. Subsurface drip irrigation (SSDI) slightly increased the chemical composition in the pot marigold plant compared with surface drip irrigation (SDI). It is known that the drip irrigation is important in increasing the availability and absorption of nitrogen and other minerals in the plant, thereby increasing the total chlorophyll content in the leaves. The photosynthetic pigment content is reduced in water-stressed plants compared with well-watered plants, and water stress induces the destruction and developmental retardation of chlorophyll (El-Fawakhry, 2004). A further reduction of the shoot dry weight could result from the reduction of photosynthesis and chlorophyll production in the leaves. Similarly, the reduction of root development could reflect increased energy consumption within the plant to take in water, increase protoplasm density, change respiratory paths, and activate the pentose phosphate pathway (Elhindi et al., 2006). These effects might correspond with the partial or complete blockage of the stomata in response to water stress, which leads to a decrease in CO_2 absorption. However, plants consume large amounts of energy to absorb water, which reduces photosynthetic production. These observations indicated with drip irrigation might increase water availability in the root zone, resulting in improved plant water status and stomatal conductance, which eventually affects photoassimilate production (Nunez-Barrious, 1991, Nielsen and Nelson, 1998). As shown in Table 5, the effect of the interaction between drip irrigation systems and composted green waste (CGW) application levels was not significant ($p< 0.05$). Nevertheless, it was obvious that application of (CGW) at 120 kg ha^{-1} in a subsurface drip irrigation system was the superior treatment.

Effect of irrigation system and compost application levels on nutrients concentration in shoots.

The data revealed that the rate of the application of composted green waste (CGW) significantly ($p< 0.05$) increased the amount of macro- and micronutrients remaining in the shoots of pot marigold plants (Table 6). The application of 120 kg ha^{-1} manifested the highest concentration of nutrients in plants compared with rates of 30, 60 kg ha^{-1} and the control treatment. The role of (CGW) application is primarily associated with the enrichment of nutrient uptake. The addition of compost increases cation exchange (ability to capture and release cations, such as K^+, Ca^{2+}, or NH^{4+}) in the soil, and could also form aqueous complexes with micronutrients (Aiken et al., 1985). These effects are associated with increasing nutrient concentration in pot marigold plants. Moreover, these effects are primarily attributed to improved nutrient supply in sandy soils (Suganya and Sivasamy, 2006). It is evident from the data presented in Table 6 that the macro- and micronutrients in pot marigold shoots gradually increased significantly with the gradual increase in the rate of compost applications. This positive effect on macro- and micronutrient concentrations under composting might result from the improved physical properties of the soil and the availability of nutrients, which influence root and vegetative growth and consequently macro- and micronutrient concentrations in plants. In addition, composting enhances these effects through improving the water holding capacity of the soil and providing nutrients to the plants. These effects are consistent with the observations of El-Dissoky (2005). Moreover, the increased composting rates were associated with decreased nutrient leaching, which was reflected through the increased concentration of macronutrients, such as nitrogen, in plants and in the soil after harvesting. However, although the use of irrigation systems increased soil fertility after pot marigold harvesting, this effect was not significant ($p< 0.05$). The increased soil fertility could be attributed to the controlled and uniformed application of water and nutrients. The results presented in Table 6 show that the use of irrigation systems slightly increased the nutrient concentration in the pot marigold, potentially as a result of strengthening the rooting system, which was reflected through increased nutrient uptake in the plants (Cooper and Chunhua, 1998). The effect of the interaction between drip irrigation systems and composted green waste (CGW) application levels (Table 6) was not significant ($p < 0.05$). The application of composted green waste (CGW) at 120 kg ha^{-1} in subsurface drip irrigation generated the highest macro-and micronutrient values observed in pot marigold shoots. The effects of composted green waste (CGW) application rates on the physical characteristics, i.e., bulk density (BD), soil total porosity (TP) and saturation percent (SP), in the soil were highly significant ($p < 0.05$) (Table 7). These characteristics are important for soil–water–plant relationships and the maintenance of soil structure. The results show that increasing compost application rates up to 120 kg ha^{-1} improved the soil total porosity (TP) and saturation percentage, but the soil bulk density (BD) was reduced. This decrease might be attributed to the high content of organic matter in compost, which influences the formation of the soil aggregates that reduce BD and improve soil structure. Organic matter has high water holding capacity. Therefore, its addition to the soil should increase the amount of available water to plants. In contrast, the TP and SP increased with increasing CGW rate. The lowest values for the bulk density were observed with CGW application, which was also associated with highest values for total porosity. A similar enhancement of the soil properties was previously reported as a result of organic amendments to the soil (Martens and Frankenberger, 1992). Subsurface drip irrigation increased the physical properties of the soil compared with surface drip irrigation; however, this effect was not significant ($p< 0.05$) for BD and SP. This effect could be attributed to the use of subsurface drip irrigation to replenish depleted soil water and avoid physiological water stress in pot marigold plants. Therefore, moisture management is extremely important at all stages of plant development because it influences stand establishment and flower quality (Smesrud et al., 1997). These findings were consistent with the observations of Aliabadi et al. (2009) and Fatima et al. (2006).

Effect of irrigation system and compost application levels on nutrients concentration in soil after harvesting stage.

The data presented in Table 8 revealed that application of composted green waste (CGW) in a fertigation programme significantly increased the concentration of macro- and micronutrients remaining in soil after harvesting ($p< 0.05$). This effect could be attributed to the improved nutrient supply in sandy soils (Suganya and Sivasamy, 2006). However, subsurface drip irrigation increased soil fertility after harvesting pot marigold plants compared with surface drip irrigation, but this effect was not significant ($p< 0.05$) because of the controlled uniformity of the application of water and nutrients. The effect of the interaction between drip irrigation systems and composted green waste application levels, as shown in Table 8, was not significant ($p< 0.05$). The application of PWC at 120 kg ha^{-1} in a subsurface drip irrigation system generated the highest macro- and micronutrients values in the soil after harvesting.

Table 1. Averages of air temperature, relative humidity, pan evaporation and total precipitation during the growing season.

Month	Average Temperature(^{0}C)	Average relative humidity (%)	Average pan evaporation (mm)	Total precipitation (mm)	Average wind speed (km day^{-1})	Monthly evapotranspiration (m^3 month^{-1})
November	16.13	57.0	3.7	2.0	128.73	432.5
December	14.34	56.0	2.0	11.56	119.54	367.0
January	13.11	59.3	2.7	9.3	123.27	526.8
February	15.16	59.0	2.4	37.15	128.26	425.0

Table 2. Some chemical analyses of the irrigation water.

			Soluble cations and anions (mequiv. L^{-1})							
			Cations				Anions			
EC (dS m^{-1})	pH	SAR	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
0.43	7.83	2.8	1.0	0. 5	2.4	0.2	-	0.1	2.7	1.3

Each value within the table is the mean of six replicates sampled from irrigation.

Table 3. Physical properties and nutrient and metal concentrations of the CGW material used in this study.

Physical/Chemical Property	Value
Percent moisture (%)	29.45
Water-holding capacity @ 10 kPa — (g g^{-1})	1.02
pH	7.35
Total carbon (%)	30.76
Total nitrogen (%)	0.85
C:N ratio	37.70
Total P (µg g^{-1})	1390.65
Total Ca (µg g^{-1})	23700.00
Total Mg (µg g^{-1})	1250.00
Total K (µg g^{-1})	1270.00
Total Na (µg g^{-1})	1780.00
Total Zn (µg g^{-1})	429.00
Total Cu (µg g^{-1})	115.00
Total Mn (µg g^{-1})	173.00
Total Fe (µg g^{-1})	4113.00
Total Cd (µg g^{-1})	3.00
Total Pb (µg g^{-1})	275.00
Total Ni (µg g^{-1})	27.00

Materials and methods

Field location and experimental design

Field trials were conducted at the Experiments and Research Station (Dirab) in the College of Food Sciences and Agriculture, King Saud University, located at 50 km south of Riyadh City (240 6` N, latitude; 460 5` E, longitude, 650 m above sea level) in sandy soil. A split plot experimental design was employed with three replicates. The main plots were assigned to the two irrigation systems, i.e., surface and subsurface drip irrigation, while the sub-plots were presented composted green waste (CGW). The experimental area (plot) was 2 m² (2 m x 1 m) containing 4 rows. The plant rows were spaced at 0.75 m apart, and the distance between each plant was 0.25 m.

Climatic conditions

The meteorological data were obtained from the Meteorology unit of the Research and Experiments Station (Dirab) in the College of Food Sciences and Agriculture, Saudi Arabia. The actual plant water requirement was estimated using the reference evapotranspiration (ET_o), which was calculated daily using the Penman–Monteith's formula (Allen et al., 1998): $ET_P = K_P E_{pan}$

where K_p is the pan coefficient, which depends on the type of pan conditions, i.e., humidity, wind speed and environmental conditions (0.75), and E_{pan} is the the pan evaporation in mm/day, which represents the mean daily value of the period considered. The meteorological and evapotranspiration data obtained during the growing season are presented in Table 1.

Cultivation

In the first week of November, during the two successive seasons of 2010/2011, the seeds were sown in the nursery in foam trays filled with a mixture of peat moss and vermiculite (1:1 volume). The trays were maintained under unheated plastic house conditions. After 4 weeks, the seedlings were transferred to the open air under field conditions. Irrigation was performed as needed until the plants generated the first two true leaf stage in the area where the irrigation treatments were applied. Fertilizer was added to all pot marigold plants according to the recommendations of Navid et al. (2009): 90 kg ha^{-1}nitrogen (urea), 100 kg ha^{-1} ammonium phosphate and 200 kg ha^{-1} K_2O. These Fertilizers were added using a drip irrigation system from the 2nd until the 7th week of the plant growth stage. The composted green waste (CGW) used in this study was state-of-the-art, recycled green waste obtained from crop residues of horticultural plants grown in greenhouses. The physical response of the soil was tested

Table 4. Effect of drip irrigation methods (DIM), composted green waste (CGW) application levels and their interaction on vegetative growth and flowering quality.

Treatments		Vegetative growth				Flowering growth		
		Plant height (cm)	Plant dry wt. (g/plant)	Leaf area (cm^{2})	Branches no/plant	Flowers no/plant	Flower diameter (cm)	Flower dry wt.(g/plant)
Significance level								
DIM		* ^{z}	*	*	*	*	*	*
CGW		*	*	*	*	*	*	*
DIM × CGW		NS	NS	NS	NS	NS	NS	NS
Mean values as affected by drip irrigation systems								
	Surface	51.72±2.46^{b}	253.47±9.70^{b}	39.10±02.35^{b}	6.19±1.05^{b}	08.95±1.18^{b}	3.71±0.57^{b}	86.17±5.09^{b}
	Subsurface	54.00±2.88^{a}	257.09±9.74^{a}	54.43±10.92^{a}	7.18±1.22^{a}	11.46±1.71^{a}	4.75±1.12^{a}	88.55±4.75^{a}
Mean values as affected by composted green waste application levels								
	Without	49.85±1.16^{c}	242.40±2.47^{d}	36.62±00.75^{d}	5.46±0.63^{c}	08.40±1.04^{d}	3.34±0.60^{d}	79.96±1.89^{d}
	30 kg ha^{-1}	52.50±1.53^{b}	254.03±1.87^{c}	47.6710.45±^{c}	6.39±0.54^{b}	09.43±1.09^{c}	3.89±0.59^{c}	87.40±1.42^{c}
	60 kg ha^{-1}	53.45±1.52^{b}	256.08±1.98^{b}	49.18±09.93^{b}	7.00±0.89^{b}	10.97±1.69^{b}	4.53±0.61^{b}	89.51±1.49^{b}
	120 kg ha^{-1}	55.65±1.51^{a}	268.56±2.40^{a}	53.58±12.67^{a}	7.90±1.06^{a}	12.01±1.64^{a}	5.15±0.87^{a}	92.53±1.53^{a}
Surface drip irrigation	Without	48.53±1.05	240.40±1.01	36.11±0.55	5.00±0.59	07.46±0.01	3.10±0.06	78.43±1.01
	30 kg ha^{-1}	51.43±1.15	252.53±0.97	38.14±0.58	5.99±0.32	08.43±0.05	3.53±0.52	86.43±0.97
	60 kg ha^{-1}	52.33±1.10	254.46±1.01	40.13±0.57	6.50±0.82	09.39±0.06	3.5±00.56	88.43±1.01
	120 kg ha^{-1}	54.60±1.10	266.50±0.85	42.02±0.48	7.27±1.17	10.51±0.15	4.24±0.28	91.40±1.05
Subsurface drip irrigation	Without	51.16±1.25	244.50±1.25	37.14±0.56	5.91±0.64	09.35±0.02	3.58±0.94	81.50±0.95
	30 kg ha^{-1}	53.57±1.06	255.53±1.01	57.20±0.53	6.78±0.68	10.43±0.05	4.26±0.07	88.46±1.01
	60 kg ha^{-1}	54.56±0.91	257.70±0.95	58.23±0.68	7.50±0.99	12.55±0.11	5.08±0.42	90.60±1.00
	120 kg ha^{-1}	56.70±1.08	270.63±0.91	65.14±0.63	8.54±0.88	13.50±0.04	6.06±0.43	93.66±0.96

Mean values followed by the same letter within the treatments are not significantly different ($p< 0.05$) according to the Duncan's multiple range test. ^{z} NS and * are non-significant and significant ($p<0.05$), respectively.

after the application of this organic amendment. The CGW was prepared using water at a rate of 100 L/20 kg of CGW, stored for 48 hrs, and subsequently injected into the drip irrigation network and applied using a fertigation programme at rates of 30, 60 and 120 kg ha^{-1}. The physical, chemical, and biological characteristics of the composted green waste material were analysed during the course of using the method of Graetz (1995), which is summarised in Table 3.

Plant sampling and analysis

After 110 days of cultivation, a random sample of three plants from each plot was harvested and prepared for chemical analysis. The plant materials were dried in an oven at 70 °C until a constant weight was achieved. The dried plants were weighed and subsequently ground into a powder to assess the reducing and non-reducing sugar contents, which was assessed according to AOAC (1990). The concentrations of the photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoids) in the leaves and flowers, and the macro- and micronutrients in the shoots were assessed. The total carotenoid contents were determined in each dried flower head per plant (mg/g) according to Britton et al. (1995). However, the chlorophyll a and b content in the leaves (mg/g fresh weight) was determined using the method of Moran (1982). To analyse the macronutrient content in the pot marigold leaves, the samples were obtained from each plot, dried at 70 °C, and ground to a powder using stainless steel equipment. From each sample, 0.2 g was digested with 5 cm^3 of a sulphuric (H_2SO_4): perchloric ($HClO_4$) acid (1:1) mixture according to Peterburgski (1968) to determine the NPK concentrations. The total nitrogen was determined using the micro-Kjeldahl method (Hesse, 1971). The total phosphorus was determined colorimetrically at 680 nm using a spectrophotometer (Spekol) as previously described (Cottenie et al., 1982).

The total potassium was determined using a Gallen Kamp flame photometer according to Cottenie et al. (1982).

The total micronutrient (Fe–Mn–Zn) concentration was measured in a digestive solution of $HClO_4$, H_2SO_4 and HNO_3 in accordance with the method of Chapman and Pratt (1982) using the atomic absorption spectrophotometer PerkinElmer model 5000. At the end of each growing season, the following parameters were measured from each replicate: height, number branches, herb dry weight, total leaf area, flowers diameters, total flower number and flower dry weight per plant.

Soil sampling and analysis

After harvesting at the end of each growing season, surface soil samples were collected from each plot using a soil auger at 25 cm relative to the drip lines and a depth of 30 cm. The collected samples were air-dried, crushed, passed through a 2-mm sieve and preserved for analysis. The soil was sandy in texture (90.67 sand, 6.28 silt and 3.05 % clay) with a pH of 8.4, EC 0.31 dS/m, $CaCO_3$ 5.36 % and F.C 10.7 %. The available soil N, P and K were 28.12, 5.40, and 160 mg/kg, respectively, and the iron, zinc and manganese concentrations were 3.16, 1.9 and 0.87 mg/kg, respectively, before pot marigold planting. However, the soluble anions were measured at K^+ 0.21, Na^+ 1.0, Ca^{++} 0.6, Mg^{++} 0.3, HCO_3^- 0.3, Cl^- 1.0, SO_4^{2-} 0.21 meq/L. To assess the soil characteristics, the following ideal methods were used: Particle size distribution was conducted using the pipette method of Dewis and Fertias (1970). The field capacity of the soil was determined using the method of Richards (1954). The hydraulic conductivity was determined using the Darcy equation according to Singh (1980). The total carbonate content was estimated gasometrically using a Collins Calcimeter and quantified according to Dewis and Fertias (1970). The soil reaction (pH) was measured in the saturated soil paste using a combined electrode pH meter according to the previously published methods of Richards (1954). The total soluble salts were determined by measuring the electrical conductivity from the extraction of saturated soil paste at dS m^{-1} (Jackson, 1967). The concentration of water-soluble cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and anions (CO_3^{2-}, HCO_3^- and Cl^-) were determined from the extraction of saturated soil paste according to the methods of Hesse (1971), whereas (SO_4^{2-}) ions were calculated as the difference between the total cations and anions. Soluble Ca^{2+} and Mg^{2+} were determined using titration with a standardised versenate solution. Soluble Na^+ and K^+ ions were determined using a flame photometer. Soluble CO_3^{2-} and HCO_3^- ions were determined using titration with a standardised H_2SO_4 solution. Soluble Cl^- ions were determined using titration with standardised silver nitrate solution. Soil available nitrogen was extracted using KCl (2.0 M) and determined using the same method as described for the determination of the total N in the plant. The available phosphorus was extracted from the soil with $NaHCO_3$ (0.5 M) at pH 8.5 and determined colorimetrically after treating with ammonium molybdate and stannous chloride at a wavelength of 660 nm according to Jackson (1967). The available potassium was extracted from the soil with ammonium acetate (1.0 M) at pH 7.0 and measured using a flame photometer as previously described (Hesse,1971). The available iron, zinc and manganese were extracted using the DTPA method (Lindsay and Norvell, 1978) and measured using an atomic absorption spectrophotometer PerkinElmer model 5000. The volume displacement method was used for the determination of the total porosity (TP) and saturation percent (SP) in the soil as previously described (Niedziela and Nelson, 1992). The soil bulk density (BD) was determined using the core method according to Blake and Hartge (1986).

Irrigation setup

Two irrigation systems were selected to irrigate the pot marigold plants in the main plots: surface drip irrigation "SDI" and subsurface drip irrigation "SSDI". The drip irrigation lines were twin-wall drip tapes (GR is the common commercial name), with outlets spaced at 0.5 m and drippers with a standard 4 L/h discharge at a 1.5 bar working pressure. Drip irrigation lines were laid above and under the ridges of plant rows, and the installation depth of the subsurface drip lines was 0.25 m. The spacing between the lateral lines was 0.5 m, and the irrigation water was obtained from a groundwater source. The water samples were collected at every irrigation application, and analysed for electrical conductivity (EC), and primary cations (Ca^{2+}, $Mg^{2+,}$ Na^+ and K^+) and anions (CO_3^{2-}, HCO_3^- and Cl^-) content according to Chapman and Pratt (1982); the SO_4^{2-} ions were calculated as the difference in the amounts of the total cations and anions. The mean values from the irrigation water analysis are presented in Table 2.

Statistical analysis

The data in the present study were statistically analysed according to Snedecor and Cochran (1980), and the differences between the means of the treatments were

Table 5. Effect of drip irrigation methods (DIM), composted green waste (CGW) application levels and their interaction on chemical composition.

Treatments		Chemical composition				
		Chlorophyll a (mg/g fresh wt)	Chlorophyll b (mg/g fresh wt)	Crotenoides in flowers(mg/plant)	Reducing sugars (%)	Non-reducing sugars(%)
Significance level						
DIM		*^{z}	*	*	*	*
CGW		*	*	*	*	*
DIM × CGW		NS	NS	NS	NS	NS
Mean values as affected by drip irrigation systems						
	Surface	0.33±0.03^{b}	0.11±0.05^{b}	254.96±3.20^{b}	1.18±0.02^{b}	10.70±1.12^{b}
	Subsurface	0.45±0.05^{a}	0.19±0.05^{a}	263.60±6.60^{a}	1.20±0.04^{a}	11.43±1.19^{a}
Mean values as affected by composted green waste application levels						
	Without	0.33±0.02^{d}	0.10±0.02^{d}	252.58±2.51^{d}	1.16±0.01^{c}	09.70±0.67^{c}
	30 kg ha^{-1}	0.39±0.02^{c}	0.14±0.02^{c}	257.96±3.95^{c}	1.18±0.01^{b}	10.92±0.59^{b}
	60 kg ha^{-1}	0.42±0.02^{b}	0.17±0.01^{b}	261.51±5.58^{b}	1.19±0.01^{b}	11.31±0.89^{b}
	120 kg ha^{-1}	0.44±0.02^{a}	0.21±0.03^{a}	265.08±7.22^{a}	1.23±0.03^{a}	12.33±0.46^{a}
Surface drip irrigation	Without	0.28±0.01	0.06±0.03	250.43±1.1	1.16±0.01	09.44±0.71
	30 kg ha^{-1}	0.33±0.02	0.11±0.01	254.43±0.9	1.18±0.01	10.45±0.69
	60 kg ha^{-1}	0.35±0.01	0.13±0.01	256.46±0.9	1.19±0.01	11.26±0.71
	120 kg ha^{-1}	0.38±0.02	0.16±0.01	258.53±0.9	1.21±0.01	11.27±0.64
Subsurface drip irrigation	Without	0.39±0.03	0.14±0.02	254.73±0.9	1.17±0.01	09.61±0.76
	30 kg ha^{-1}	0.45±0.01	0.18±0.01	261.50±0.8	1.19±0.01	10.45±0.35
	60 kg ha^{-1}	0.48±0.01	0.20±0.01	266.56±08	1.20±0.01	11.34±1.17
	120 kg ha^{-1}	0.50±0.02	0.26±0.02	271.63±0.9	1.26±0.01	11.37±0.11

Mean values followed by the same letter within the treatments are not significantly different ($p < 0.05$) according to the Duncan’s multiple range test.

[z] NS and * are non-significant and significant ($p < 0.05$), respectively.

Table 6. Effect of irrigation system (DIM) and compost (CGW) application rates on nutrients concentration in pot marigold shoots.

Treatments		Macronutrients concentration			Micronutrients concentration		
		N (%)	P (%)	K (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
Significance level							
DIM		*^{z}	*	*	*	*	*
CGW		*	*	*	*	*	*
DIM × CGW		NS	NS	NS	NS	NS	NS
Mean values as affected by drip irrigation systems							
	Surface	1.23±0.04^{b}	0.21±0.02^{b}	2.15±0.07^{b}	25.08±1.88^{b}	14.08±2.23^{b}	18.08±2.04^{b}
	Subsurface	1.24±0.03^{a}	0.22±0.03^{a}	2.21±0.12^{a}	27.50±3.45^{a}	15.66±3.03^{a}	22.33±4.56^{a}
Mean values as affected by pruning wastes compost application levels							
	Without	1.21±0.01^{b}	0.18±0.01^{c}	2.08±0.04^{d}	23.66±1.37^{c}	11.50±1.05^{c}	17.66±1.60^{c}
	30 kg ha^{-1}	1.22±0.02^{b}	0.21±0.01^{b}	2.15±0.03^{c}	25.16±1.17^{b}	14.50±1.05^{b}	18.83±1.34^{bc}
	60 kg ha^{-1}	1.24±0.01^{ab}	0.22±0.01^{b}	2.20±0.02^{b}	26.16±1.17^{b}	15.50±1.05^{b}	20.66±1.60^{bc}
	120 kg ha^{-1}	1.26±0.01^{a}	0.25±0.02^{a}	2.30±0.01^{a}	30.16±2.93^{a}	18.00±2.19^{a}	23.66±4.30^{a}
Surface drip irrigation	Without	1.19±0.01	0.18±0.01	2.06±0.04	23.00±1.00	11.00±1.00	16.67±1.52
	30 kg ha^{-1}	1.21±0.01	0.21±0.01	2.15±0.03	24.33±0.57	14.00±1.00	18.00±1.00
	60 kg ha^{-1}	1.23±0.01	0.22±0.01	2.19±0.01	25.33±0.57	15.00±1.00	19.67±1.52
	120 kg ha^{-1}	1.25±0.01	0.24±0.01	2.23±0.02	27.67±0.57	16.33±1.15	18.00±1.00
Subsurface drip irrigation	Without	1.22±0.01	0.18±0.01	2.10±0.03	24.33±1.52	12.00±1.00	18.67±1.52
	30 kg ha^{-1}	1.23±0.03	0.21±0.01	2.16±0.03	26.00±1.00	15.00±1.00	19.67±1.52
	60 kg ha^{-1}	1.25±0.02	0.23±0.01	2.21±0.02	27.00±1.00	16.00±1.00	21.67±1.52
	120 kg ha^{-1}	1.27±0.02	0.26±0.01	2.38±0.07	32.67±1.52	19.67±1.52	29.33±1.52

Mean values followed by the same letter within the treatments are not significantly different ($p < 0.05$) according to the Duncan's multiple range test. ^{z} NS and * are non-significant and significant ($p<0.05$), respectively.

Table 7. Effect of irrigation system (DIM) and compost (CGW) application rates on soil physical properties.

Treatments		Soil physical properties		
		Bulk Density (g cm^{-3})	Porosity (%)	Saturation (%)
Significance level				
DIM		NS^{z}	NS	*
CGW		*	*	*
DIM × CGW		NS	NS	NS
Mean values as affected by drip irrigation systems				
	Surface	1.22±0.06	56.46±2.67	67.89±3.27^{b}
	Subsurface	1.18±0.07	56.94±3.51	68.74±4.54^{a}
Mean values as affected by pruning wastes compost application levels				
	Without	1.30±0.02^{c}	55.01±0.97^{d}	66.53±0.88^{d}
	30 kg ha^{-1}	1.24±0.01^{b}	56.34±0.69^{c}	68.05±0.98^{c}
	60 kg ha^{-1}	1.18±0.01^{b}	57.38±0.66^{b}	68.80±1.08^{ab}
	120 kg ha^{-1}	1.16±0.02^{a}	58.06±2.24^{a}	69.84±2.45^{a}
Surface drip irrigation	Without	1.31±0.02	54.72±0.69	66.52±1.14
	30 kg ha^{-1}	1.22±0.01	56.31±0.81	67.56±0.91
	60 kg ha^{-1}	1.18±0.01	57.17±0.52	68.26±1.17
	120 kg ha^{-1}	1.16±0.01	57.64±0.78	69.22±0.9
Subsurface drip irrigation	Without	1.30±0.02	55.30±1.11	66.54±0.8
	30 kg ha^{-1}	1.20±0.01	55.38±0.72	68.55±0.92
	60 kg ha^{-1}	1.16±0.01	57.59±0.82	69.43±0.71
	120 kg ha^{-1}	1.14±0.01	58.48±0.92	70.46±0.88

Mean values followed by the same letter within the treatments are not significantly different ($p < 0.05$) according to the Duncan's multiple range test. ^{z} NS and * are non-significant and significant ($p<0.05$), respectively.

Table 8. Effect of irrigation system (DIM) and compost (CGW) application rates on nutrients concentration in soil after harvesting.

Treatments		Macronutrients concentration			Micronutrients concentration		
		N (%)	P(%)	K(%)	Fe(mg kg^{-1})	Mn(mg kg^{-1})	Zn(mg kg^{-1})
Significance level							
DIM		*^{z}	*	*	*	*	*
CGW		*	*	*	*	*	*
DIM × CGW		NS	NS	NS	NS	NS	NS
Mean values as affected by drip irrigation systems							
	Surface	48.03±2.18^{b}	5.86±1.07^{b}	209.58±11.23^{b}	3.33±0.28^{b}	1.16±0.04^{b}	1.07±0.15^{b}
	Subsurface	48.75±1.47^{a}	9.11±0.92^{a}	223.41±12.35^{a}	3.36±0.29^{a}	1.22±0.08^{a}	1.11±0.15^{a}
Mean values as affected by pruning wastes compost application levels							
	Without	46.61±1.17^{c}	5.29±0.56^{c}	200.50±04.42^{d}	3.07±0.03^{c}	1.14±0.02^{c}	0.85±0.03^{d}
	30 kg ha^{-1}	47.30±0.94^{c}	6.01±0.61^{b}	213.83±12.35^{c}	3.17±0.06^{c}	1.16±0.02^{b}	1.12±0.02^{c}
	60 kg ha^{-1}	48.43±0.50^{b}	6.46±0.19^{b}	221.33±07.50^{b}	3.43±0.15^{b}	1.17±0.03^{b}	1.18±0.04^{b}
	120 kg ha^{-1}	51.20±0.77^{a}	7.77±0.30^{a}	230.33±06.71^{a}	3.72±0.14^{a}	1.29±0.07^{a}	1.21±0.02^{a}
Surface drip irrigation	Without	46.00±1.00	4.63±0.27	196.67±1.52	3.05±0.02	1.12±0.01	0.83±0.01
	30 kg ha^{-1}	46.67±0.57	5.30±0.22	202.67±2.51	3.16±0.06	1.15±0.01	1.11±0.01
	60 kg ha^{-1}	48.33±0.57	6.18±0.27	214.67±2.51	3.41±0.16	1.16±0.01	1.15±0.02
	120 kg ha^{-1}	51.10±1.15	7.30±0.23	224.33±1.52	3.70±0.13	1.23±0.02	1.21±0.02
Subsurface drip irrigation	Without	47.23±1.12	5.94±0.46	204.33±1.52	3.09±0.01	1.16±0.01	0.88±0.02
	30 kg ha^{-1}	47.93±0.81	6.72±0.49	225.00±1. 0	3.18±0.06	1.18±0.01	1.14±0.01
	60 kg ha^{-1}	48.53±0.05	6.74±0.01	228.00±1.0	3.45±0.17	1.19±0.03	1.21±0.02
	120 kg ha^{-1}	51.30±0.36	8.24±0.16	236.33±1.52	3.76±0.17	1.36±0.01	1.23±0.01

Mean values followed by the same letter within the treatments are not significantly different ($p< 0.05$) according to the Duncan's multiple range test.

[z] NS and * are non-significant and significant ($p<0.05$), respectively.

considered significant at a 5% confidence level using CoStat (Version 6.303, CoHort, USA, 1998–2004).

Conclusion

Based on the results of our experiment, it is reasonable to conclude that the application of composted green waste additives significantly improves the vegetative growth and flowering quality, chemical constituents of plant, physical properties of the soil and the macro- and micronutrient content in the remaining soil after pot marigold harvesting compared with the control treatment. The application rate of 120 kg ha^{-1} was better for increasing these values than rates of 30 or 60 kg ha^{-1}. The results also showed that subsurface drip irrigation was more efficient than surface drip irrigation for enhancing quantitative and qualitative growth parameters and nutrient concentrations in plants and fertility in the soil after harvesting.

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