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Corresponding Author: Dr. Daniele Massa, Ph.D

Corresponding Author's Institution: Council for Agricultural Research and Economics

First Author: Daniele Massa, Ph.D

Order of Authors: Daniele Massa, Ph.D; Fernando Malorgio, Prof.; Sara Lazzereschi, Ph.D; Giulia Carmassi, Ph.D; Domenico Prisa, Ph.D; Gianluca Burchi

Abstract: Peat is the most representative component for the preparation of growing media used in horticulture. However, environmental issues and increased cost production, related to peat extraction and commercialization, are stimulating the rise of new materials and technologies for suitable alternatives to peat based substrates. Among other locally produced materials, green compost is one of the main alternatives for peat substitution although its variability in chemo physical characteristics represents the main constraint. Therefore, many works focus their attention on compost characteristics while there is a need of studies carried out at whole substrate plant system. In the present work, two composts (selected and mixed green compost), which differed for the initial composting raw materials, were evaluated for peat substitution and their influence on plant growth and quality, nutrient and water uptake, and gaseous exchange activity, was assessed. A bedding plant (geranium), cultivated in intensive growing system, was chosen as test plant and 100 % (pot volume) peat as control substrate. During the greenhouse experiment, plants were grown in five different substrates, i.e. only peat, 30 % and 50 % peat volume replaced by the two composts. Substrate characteristics, plant growth and biometric parameters, water and nutrient uptake, and gaseous exchange activity were evaluated as crop performance indicators. The mixed green compost influenced negatively plant nutrition and photosynthesis thus reducing significantly plant biomass accumulation and quality when replaced at the highest compost/peat ratio. The selected green compost was a more valuable substrate for peat substitution than mixed green compost supporting the diffused and shared opinion that high quality compost can be produced through a careful raw material selection.

Suggested Reviewers: Neil Scott Mattson PhD

Professor, Cornell University College of Agriculture and Life Sciences
nsm47@cornell.edu
Expert in ornamental plants, substrate cultivation, plant nutrition, greenhouse cultivation

Antonio Ferrante PhD
Professor, Universita degli Studi di Milano
antonio.ferrante@unimi.it
Expert in ornamental crops, plant physiology, plant post-harvest,molecular biology, substrate cultivation

Edgar Acosta PhD
Professor, University of Toronto
edgar.acosta@utoronto.ca
Expert in products from biowastes for diversified uses

Galo Antonio Carillo PhD
Professor, Escola Politécnica da Universidade de São Paulo
galoroux@usp.br
Expert in products derived from biowaste for use as emulsifiers and others

Francesco Orsini PhD
Università di Bologna
f.orsini@unibo.it
Expert in plant physiology, substrate cultivation, horticulture

crea
Consiglio per la ricerca in agricoltura
e l'analisi dell'economia agraria
LANDSCAPING PLANTS AND NURSERY RESEARCH UNIT

DR. DANIELE MASSA
DANIELE.MASSA@CREA.GOV.IT
CREA-VIV
VIA DEI FIORI, 8
51012 PESCIA (PT), ITALY
T +39 0572 451033
F +39 0572 453309

Dear Editor-in-chief,

please find enclosed the manuscript entitled “***Evaluation of two green composts for peat substitution in Geranium cultivation: effect on plant growth, quality, nutrition, and photosynthesis.***” submitted for evaluation.

The paper reports a detailed study regarding the influence that physicochemical characteristics of composts have on plant nutrient and water uptake, and photosynthesis, which in turn mostly determine plant growth and quality of bedding plants. Peat substitution is currently one of the main concerns for nursery and potting plant production due to the cost of substrate and the environmental issues related to peat extraction. The main object of this work was to evaluate two different locally-produced green composts as candidates for the replacement of peat in potted geranium cultivation. The two composts differed for the initial composting raw materials. Peat was used as control treatment while the effects of physicochemical characteristics of four substrate mixtures were evaluated on plant growth and quality, nutrient and water uptake, and gaseous exchange activity.

Kind regards.

Pescia, 27th June 2016

Daniele Massa

Daniele Massa

- Two locally-produced composts (selected- and mixed-green compost) were used for peat substitution
- *Pelargonium zonale* L. was chosen as test plant for the greenhouse experiment
- Plant biomass accumulation and biometric parameters, leaf chlorophyll (SPAD index) content and gaseous exchange activity, tissue nutrient concentration, and plant water uptake were evaluated
- Selected-green compost performed at the same level of the peat control substrate and better than mixed-green compost

Title

Evaluation of two green composts for peat substitution in *Geranium* cultivation: effect on plant growth, quality, nutrition, and photosynthesis.

Daniele Massa[1*], Fernando Malorgio[2], Sara Lazzereschi[1], Giulia Carmassi[2], Domenico Prisa[1], Gianluca Burchi[1].

[1]Council for Agricultural Research and Economics, Landscaping plants and nursery research unit. Via dei Fiori 8 - 51012 Pescia (PT), Italy

[2]Department of Agriculture, Food and Environment, University of Pisa. Viale delle Piagge 23 - 56124 Pisa, Italy

*Corrisponding author:
Daniele Massa
Council for Agricultural Research and Economics, Landscaping plants and nursery research unit. Via dei Fiori 8 - 51012 Pescia (PT), Italy
Tel +39 0572 451033
Fax +39 0572 453309
daniele.massa@crea.gov.it

Abstract

Peat is the most representative component for the preparation of growing media used in horticulture. However, environmental issues and increased cost production, related to peat extraction and commercialization, are stimulating the rise of new materials and technologies for suitable alternatives to peat-based substrates. Among other locally-produced materials, green compost is one of the main alternatives for peat substitution although its variability in chemo-physical characteristics represents the main constraint. Therefore, many works focus their attention on compost characteristics while there is a need of studies carried out at whole substrate-plant system. In the present work, two composts (selected- and mixed-green compost), which differed for the initial composting raw materials, were evaluated for peat substitution and their influence on plant growth and quality, nutrient and water uptake, and gaseous exchange activity, was assessed. A bedding plant (geranium), cultivated in intensive growing system, was chosen as test plant and 100 % (pot volume) peat as control substrate. During the greenhouse experiment, plants were grown in five different substrates, i.e. only peat, 30 % and 50 % peat volume replaced by the two composts. Substrate characteristics, plant growth and biometric parameters, water and nutrient uptake, and gaseous exchange activity were evaluated as crop performance indicators. The mixed-green compost influenced negatively plant nutrition and photosynthesis thus reducing significantly plant biomass accumulation and quality when replaced at the highest compost/peat ratio. The selected-green compost was a more valuable substrate for peat substitution than mixed-green compost supporting the diffused and shared opinion that high-quality compost can be produced through a careful raw material selection.

Keywords

Organic waste reuse, *Pelargonium zonale* L., photosynthesis, plant nutrition, bedding plants, substrate cultivation

1 Introduction

Notwithstanding the controversial debate on the environmental and economic sustainability of peat harvested from bog wetlands (Altmann, 2008; Bullock et al., 2012; Holmes, 2009), this material remains one of the most diffused organic substrates employed in the horticultural industry (Raviv, 2013; Schmilewski, 2009; Sonneveld and Voogt, 2009). Some studies point out how the volume of peat harvested per year is negligible compared with the total natural peat accumulation (Daigle and Gautreau-Daigle, 2001) as well as the area exploited for peat removal is negligible compared with total peatland area (Altmann, 2008). Nevertheless, peat moss is a non-renewable resource in the short-medium period and its extraction process and use are highly impacting wetland ecosystems other than producing greenhouse gas emissions (Bullock et al., 2012; Cleary et al., 2005). As matter of fact, in the last ten years, the diffused negative opinion on the criticisms related to peat extraction has been contributing to stimulate government regulations more and more restrictive for peat extraction and use in agriculture (Bullock et al., 2012; Holmes, 2009). For example the European Union denies the “Ecolabel” to substrate containing peat. Therefore, it must be taken into account by growers that peat availability in the next years could be limited by regulations looking at the safeguard of ecosystems producing peat.

A part from environmental issues, it should be also considered that the price of substrates strongly impacts production costs for potted ornamental plants although such crops are highly remunerative among other cultivated species (Brito et al., 2015; De Lucia et al., 2013; Daughtrey and Benson, 2005). This is mainly due to the price of substrate transport and extraction; the latter is also one of the main parameter negatively affecting the environmental sustainability of peat when compared with other substrates produced at local level (De Lucia et al., 2013). Moreover, it is reasonable to think that the increasing restrictions for peat extraction will force peat-producing companies to adopt more and more ecofriendly strategies thereby increasing cost production. As matter of fact, the cost peat has been increasing constantly in the last years (Raviv, 2013).

Indeed, peat represents an ideal substrate in horticulture for its physicochemical characteristics that are optimal for many plant species and management of different cultivation systems; among all, the low electrical conductivity, nutrient and non-nutrient content, and the high porosity and water retention capacity (Raviv, 2013; Sonneveld and Voogt, 2009). However, many other organic materials have been successfully tested for peat replacement (Chong, 2005; Larcher and Scariot, 2009). Among these, compost is a valuable candidate (Raviv, 2013). Composting is one of the most effective strategies to convert organic waste - otherwise to be disposed of - in valuable material to be reused for sustainable carbon use (Martínez-Blanco et al., 2013). Therefore, in the last decade, many works have been carried out on different composted materials as candidates for peat substitution, which includes municipal solid waste (Moldes et al., 2007; Ostos et al., 2008), sewage sludge (De Lucia et al., 2013; Ostos et al., 2008), animal manure (Shober et al., 2010; Tittarelli et al., 2009), agro-industrial waste (Bustamante et al., 2008; Kritsotakis et al., 2011), and green waste as well (Brito et al., 2015; López-Cuadrado et al., 2008; Mugnai et al., 2007; Olszewski et al., 2009; Tittarelli et al., 2009).

The standardization of compost characteristics is seen as one of the major concerns for its operative use (Raviv, 2013; Sonneveld Voogt, 2009). However, protected horticulture is one of the most specialized agricultural sectors, which offers technical solutions to control and modify root zone characteristics very promptly (Chong, 2005). The possibility of selecting local-produced raw materials for composting is an option to achieve high-quality and standardized composts at low cost (Raviv, 2013). This intent cannot be realized for many composted material such as, for example, organic urban refuse. These aspects make the production and use of green compost, for peat substitution, a strategy worthwhile to pursue.

Indeed, chemo-physical characteristics of the substrate may influence plant performance at different extents; therefore, most works on compost use in agriculture focus their attention on material characterization. Nevertheless, the effects of peat substitution with compost, on cultivated plants, have been often evaluated by observations limited only to plant growth (e.g.

Estévez-Schwarz et al., 2009; Olszewski et al., 2009). Many works report also effects on nutrient and/or non-nutrient element concentrations in plant tissues, and/or on other tissue characteristics (Brito et al., 2015; De Lucia et al., 2013; Larcher and Scariot, 2009; López-Cuadrado et al., 2008; Tittarelli et al., 2009). Very rarely, gaseous exchange activity and/or plant water relations have been assessed for plants cultivate in compost-based substrates (e.g. Mugnai et al., 2007; Bakry et al., 2013). Indeed, there is a lack of works assessing the effects of peat substitution with green compost on plant nutrition and photosynthesis that in turn mostly determine plant growth and quality.

The main object of this work was to evaluate two different locally-produced green composts as candidates for the replacement of peat in potted geranium cultivation. The two composts differed for the initial composting raw materials. Peat was used as control treatment and compared with four further substrate mixtures by the evaluation of plant growth and quality, nutrient and water uptake, and gaseous exchange activity.

2 Materials and Methods

2.1 Potting substrate mixtures and treatments

Two different composts were tested in the experiment. Both composts, provided by private companies, were obtained at local level (Tuscany, Italy) from green refuses. The main difference was in the pristine materials used for the composting process. In one case, only greenhouse and nursery green waste (mostly plant trimmings, prunings and crop residues) was used to obtain the “selected-green compost” (SC). The second compost (mixed-green compost, MC) was instead produced by using green refuse from different cultivation systems, public and private green areas, and heterogeneous environments including urban, peri-urban and costal areas. Composting process was carried out following high quality procedures. In both cases, trapezoidal piles of green organic material were composted for a period of roughly six months until compost maturation. During the composting period, temperature was monitored and the piles were managed to keep a target humidity of 55-65 % with the aim of ensuring optimal conditions for microbial metabolism. The obtained composts were analysed before starting the experiment according to UNI 10780 (1998). The main chemical characteristics of both composts are reported in Table 1; none of the analysed parameters exceeded Italian regulations (D.Lgs. n° 75, 29 April 2010).

The above composts were then combined with peat to obtain the tested substrates. Five different treatments, which corresponded to five different container media mixtures, were tested in the experiment: i.e. i) 100 % peat (PC) chosen as standard (control) substrate following growers' common practices for bedding plants cultivated at local level; ii) 30 % peat volume replaced by selected-green compost (SC30); iii) 50 % peat volume replaced by selected-green compost (SC50); iv) 30 % peat volume replaced by mixed-green compost (MC30); v) 50 % peat volume replaced by mixed-green compost (MC30).

2.2 Plant material and growing conditions

The experiment was carried out at the Landscaping Plants and Nursery Research Unit of the Italian Council for Agricultural Research and Economics, Pescia, Tuscany, Italy (lat. 43°54' N, long. 10°42' E), in an unheated plastic greenhouse, under typical Mediterranean climate conditions. The greenhouse was covered with polyethylene film. A 40 % shading net was placed above the canopy to avoid harmful temperatures during sunny days.

Geranium (*Pelargonium zonale* L.) cuttings with four unfolded leaves were transplanted into 1.5-L pots (Ø 14 cm) on 14 March 2014. All plants were fed with the same amount of nutrients supplied through controlled release fertilizer (5 kg m^{-3} of Osmocote Pro® 3-4 months) blended with the substrate before transplant. Fertilizer was added taking into account plant nutrient requirement, possible nutrient leaching due to water drainage, and chemical composition of the irrigation water. The latter was assessed, on the average of historical laboratory analysis, before experiment initiation. Adjustments of water pH were performed by using sulphuric acids to keep pH value close to 6.0.

Plants were moved to the greenhouse and placed in benches for pot cultivation. Eight plants per replicate were spaced to obtain a crop density of 16 pt m^{-2} and arranged in a randomized block design with six replicates (48 plants per treatment) for a total of 240 pots. Plants were irrigated drop by drop by means of a pressure-compensated dripper per pot ensuring a flow rate of 2 L h^{-1}. The irrigation was trigged using a standard timer that was adjusted weekly on the basis of climate conditions and water leaching fraction (i.e. the ratio between the quantity of water drained out from substrate and the quantity of water supplied during irrigation).

Radiation, relative humidity, and air temperature were monitored over the whole experimental period by a portable data logger (Decagon Em50; Decagon Devices Inc., Pullman, WA 99163 - USA). Minimum, mean and maximum daily averaged photosynthetic active radiation were 32.5, 142.3, and 323.3 µmol m^{-2} s^{-1}, respectively. Mean daily cumulated global radiation was 6.1 MJ m^{-2} d^{-1}. Average of minimum, mean and maximum daily air temperature was 11.8, 17.7 and 26.6 °C, respectively. Air mean daily relative humidity averaged 66.5 %.

2.3 Substrate and plant analyses

The physicochemical characteristics of the peat control substrate and each mixture obtained by peat and composts were determined before the addition of chemical fertilizer. Total N and C content were assessed on a dry matter basis (EN 13654-1, 2001 and UNI 10780, 1998, respectively) while other chemical parameters were analysed in the 1:5 (V:V) substrate:water extract: i.e. pH (EN 13037, 1999), EC (EN 13038, 1999), N-NO_3, P-PO_4, K, Ca, Mg, Fe, Na, and Cl (EN 13652, 2001). In addition, physical parameters were determined according to De Boodt et al. (1974).

During the experiment, crop water balance was calculated on three over six replicate per treatment. Leaching fraction, for the operative irrigation management, was calculated as the ratio between the water drained out from the substrate and the total water supplied during irrigation. The first quantity was determined weekly by measuring the water volume drained out from eight pots (per replicate) in a drainage tank; the tank was covered with plastic film thereby making negligible water evaporation. The latter quantity was measured by a flow meter placed on the irrigation pipe. Finally, the difference between irrigation and water drainage represented crop evapotranspiration.

Plants were monitored continuously for general status while standard agricultural practices were adopted for pest and disease management. A non-destructive analysis was performed at 55 days after transplant (DAT). Plant height (H, cm pt^{-1}), mean diameter (of the canopy projected to the soil), number of flowers (n pt^{-1}), and leaf chlorophyll (SPAD index) were measured for all plants. Plant volume (V, cm^3) of an ellipsoid was calculated by combining the two former parameters. Chlorophyll content was assessed by averaging SPAD index of six leaves pinched from the bottom to the canopy of each plant (for a total of 288 measurements per treatment).

Between the first non-destructive analysis and the end of the experimentation, leaf gaseous exchange analysis was performed at 65 DAT. A portable gas analyzer (Portable Photosynthesis System Ciras-2, PPSystems, Amesbury, MA 01913 USA) was used to measure the photosynthetic light response curve of two plants per replicate in three replicates, over six, per treatment (i.e. six plant per treatment). Measurements were performed between 9.00 and 12.00 am on the first mature and healthy leaf of the main stem. During measurements, to maintain comparable analytical conditions, the chamber was set at a constant value of CO_2 (400 g m^{-3}), temperature (27.7 ±5.2 %) and vapour pressure deficit (VPD = 1.1 ±0.3 kPa); the last two quantities were calculated as the average of climate data recorded with a datalogger, in the same daily period of measurements, during three days before measurement initiation. Photosynthetic active radiation (PAR) was varying, during the analysis, from saturating light to zero, using the following steps: 0, 50, 150, 300, 800, 1400, 2000 µmol m^{-2} s^{-1}. During the analysis, leaf transpiration rate (E, mmol m^{-2} s^{-1}) and stomatal conductance (Gs, mmol m^{-2} s^{-1}) were also monitored. Finally, data obtained from the same replicate was averaged, and then three photosynthetic light response curves per treatment were fitted with a modified non-rectangular hyperbola as reported by Thornley and Johnson (1990). Non-linear statistic model procedure was used to fit Eq. 1 where Pn (µmol CO_2 m^{-2} s^{-1}) is the leaf net photosynthetic rate, α (µmol CO_2 µmol PAR m^{-2} s^{-1}) is the quantum yield, I_{leaf} (µmol PAR m^{-2} s^{-1}) is the incident leaf radiation, Pn_{max} (µmol CO_2 m^{-2} s^{-1}) is the maximum photosynthetic rate for $I_{leaf} \rightarrow \infty$, θ (dimensionless) is the equation curvature (sharpness), R_d (µmol CO_2 m^{-2} s^{-1}) is the leaf dark respiration. Finally, the light compensation point (I_{Pn0}, µmol PAR m^{-2} s^{-1}) was calculated by rearranging Eq. 1.

$$Pn=\frac{\alpha\cdot I_{leaf}+Pn_{max}-\sqrt{(\alpha\cdot I_{leaf}+Pn_{max})^2-4\cdot\theta\cdot\alpha\cdot I_{leaf}}}{2\cdot\theta}-Rd \qquad \text{Eq. 1}$$

The experiment lasted 85 DAT and ended with the final plant destructive analysis. In this case, all measurements already determined with the first non-destructive analysis (55 DAT) were repeated. Furthermore, all plants were separated into flowers, stems and leaves, and the respective biomass of eight plants per replicate was weighted to assess fresh and dry weight (dried in a forced-air oven at 80 °C for 72 h), and organ partitioning. Leaf area was measured through a leaf area meter (WinDIAS Image Analysis System, Delta-T Devices, UK). Afterward, a quantity of dry matter from all organs was stored and analysed for mineral content. Reduced N was determined by Kjeldahl distillation after dry matter digestion with sulphuric acid. A portion of dry matter was subjected to nitric-perchloric acid digestion to be analysed for: i) P content through colorimetric method using a spectrophotometer (Evolution™ 300 UV-Vis Spectrophotometer, Thermo Fisher Scientific Inc., MA USA); ii) K, Ca, Mg, Fe and Na content through atomic absorption spectrophotometry (AAS240 FS Varian, Australia). Finally, Cl was determined through titration with mercury nitrate after dry matter water extraction.

2.4 Statistics

Collected data were analysed by one-way ANOVA, to assess significant ($P \leq 0.05$, 0.01 and 0.001) differences among treatments. Mean values were then separated by Tukey's (HSD) multiple-range test (P = 0.05). Data analysis included also non-linear models for fitting Eq. 1 to photosynthetic light response curves. Statistics and graphics were supported by the programs

Statgraphics Centurion XV (Stat Point, Inc., Herndon, VA, USA) and Prism 5 (GraphPad Software, Inc., La Jolla, California USA).

3 Results

3.1 Substrate mixture characteristics

Table 2 shows the main physicochemical characteristics of the substrate mixtures obtained by the combination of selected-green compost or mixed-green compost with peat at the different substitution ratios. Total N was significantly increased by the addition of both composts while C content showed an opposite trend with the exception of MC30 that did not cause significant reductions. The combination of both parameters shows a significant decrease in C/N ratio when both composts were applied at increasing volume.

Determinations performed on the 1:5 water extract (see section 2.3) showed a significant increase in pH for the selected-green composts only when it was used to replace peat volume by 50 %. The mixed-green compost caused the same significant increase but in both 30 and 50 % substitution. At the end of the cultivation, pH values of all treatments were levelled around pH 6.1 ranging within pH 5.6-6.7; only the treatment SC30 was significantly lower than the peat control treatment (Fig. 1). Electrical conductivity was increased by the addition of both composts thereby causing the 84 % increase, on average, compared with the peat control treatment. Among compost treatments, SC50 caused the highest EC value, however such an increase was significantly higher only with respect to MC30 (Table 2). The same initial trend was observed at the end of the cultivation in the analysed substrates for EC; in this case, the former treatment and the MC30 treatment performed at the highest level compared with the other substrates while the peat control treatment showed the lowest EC value (Fig. 1). Nitrate and Mg concentrations were both increased only by the use of selected-green compost that caused the highest values when replaced at 50 % of peat volume (Table 2). Similar results were observed for soluble P with the exception of MC50 that performed at the same level of SC30 but at lower level than SC50 treatment. Selected-green compost at 50 % peat substitution showed also a higher concentration in Ca, which was instead significantly lower in MC30 and MC50 substrates compared with the peat control treatment (Table 2). Both composts enhanced the presence in the root zone of other macro and micronutrients in comparison with peat substrate. These were K and Fe that were increased by 177 and 75 % (on the average of compost treatments), respectively. However, the presence of composts in the substrates also increased the concentration of saline ions. In spite of the different content in the pristine materials (Table 1), Na concentration in the water extract was increased at the same extent in all compost treatments compared with the peat control treatment. On the contrary, Cl concentration in water extract (Table 2) reflected data shown in Table 1. In this case, the addition of mixed-green compost caused a remarkable increase (+404 %) compared with the peat control substrate. Chloride in the selected-green compost was significantly higher than the in the control substrate only for SC50 treatment; however, Cl concentration observed in the latter was significantly lower than those observed in both treatments obtained by mixed-green compost (i.e. MC30 and MC50).

Among physical parameters, bulk density was significantly increased by the presents of both composts compared with 100 % peat treatment while opposite trends were observed for water container capacity and total porosity. On the contrary, no significant difference could be observed for both easily available water and water buffering capacity (Table 2).

3.2 Plant biomass accumulation and quality

Table 3 summarizes all destructive measurements performed on the biomass accumulated at the end of the experiment (85 DAT). The highest fresh weight values for leaves resulted by compost treatments SC30, SC50 and MC30 although no significant difference was found compared with the peat control treatment. Similar results were obtained for leaf dry weight and plant leaf area. Only the mixed-green compost MC50 treatment decreased significantly fresh and dry weight, in comparison with the other compost treatments, and plant leaf area that showed the lowest value among all treatments. Finally, the above treatment caused the highest leaf to total weight ratio. No significant variation was instead observed for leaf dry weight percentage among all treatments. Stem biomass accumulation showed significant higher values for both composts when applied at 30 % peat substitution ratio compared with the peat control treatment whereas no difference was observed between the latter and both composts replaced at 50 % of peat volume. A different scenario is shown in Table 3 for stem dry weight that was significantly lower for MC50 compared with the other treatments; differences between fresh and dry weight reflected the pattern of the dry matter percentage that was consequently lower in the latter treatment as compared with the other ones (-14 % on average). The presence of compost at 50 % peat substitution ratio affected severely flower fresh and dry weight that were both significantly reduced as compared with peat control treatment; the other compost treatments performed at the same level of the latter treatment (Table 3). On the other hand, the presence of compost reduced flower dry matter percentage compared with the peat control treatment (-24 % on average). Finally, the total (shoot) fresh weight, measured at the end of the experiment, resulted significantly higher in the compost treatments SC30 and MC30 compared with the peat control treatment, which performed at the same level of SC50. Only MC50 reduced significantly the total shoot fresh and dry weight of geranium compared with the other four treatments (Table 3).

Plant aesthetic characteristics, which varied significantly among the different treatments, are reported in Fig. 2. All plant performance indicators were measured in two different periods, i.e. at 55 DAT by non-destructive analysis and at the end of the experiment by destructive analysis. Plant height and flower number were not influenced by any treatments at 55 DAT whereas a significant reduction was observed for treatment MC50 at the end of the experiment (-21 % and -14 % on average, respectively). On the contrary, the same treatment reduced significantly plant volume as determined both at 55 and 85 DAT. Smaller variations were found for SPAD index that showed an opposite tendency considering the two measurement periods; this indicator was reduced by the presence of 50 % mixed-green compost measured at 55 DAT whereas all compost treatments performed at the same level of the peat control treatment at 85 DAT, or even better as in the case of SC50 (Fig. 2). The former data were in agreement with Fig. 3.

3.3 Leaf gaseous exchange activity

The effects of the different treatments on leaf gaseous exchange activity are summarized in Fig. 3. Equation 1 was successful in fitting photosynthetic rates, measured at different light intensity, explaining 99 % of the measurement variability. All photosynthesis parameters were estimated at high level of significance ($P < 0.001$). However, only Pn_{max} was significantly affected by the different treatments; the other parameters averaged as follow: $\alpha = 0.046$ (µmol CO_2 µmol PAR^{-1}), $\theta = 0.824$ (dimensionless), $R_d = 1.940$ (µmol CO_2 m^{-2} s^{-1}), $I_{Pn0} = 42.395$ (µmol PAR m^{-2} s^{-1}). The 30 % compost treatment of both selected- and mixed-green compost gave the highest Pn_{max} values (23.68 and 23.06 µmol CO_2 m^{-2} s^{-1}, respectively) that resulted significantly increased compared with the peat control treatment and SC50 (20.87 and 20.89 µmol CO_2 m^{-2} s^{-1}, respectively); the latter treatments performed both at the same level of significance. On the contrary, the 50 % peat substitution with mixed-green compost gave poorer results (17.19 µmol CO_2 m^{-2} s^{-1}) thereby reducing significantly the maximum leaf photosynthetic capacity compared with both the peat control treatment and the other compost treatments (-19 % on average). The observed trends were already clear starting from 800 µmol PAR m^{-2} s^{-1} as showed by the photosynthetic response curves in Fig. 3. Finally, a significant ($P < 0.0001$) relationship was found between total plant dry weight and Pn_{max}; the linear regression reported in Fig. 3 was suitable to explain 80 % of the experimental variability found between the two observed parameters.

Leaf stomatal conductance and transpiration followed the same trend showing a significant reduced activity by the application of composts compared with the peat control treatment (Fig. 3).

3.4 Plant nutrient and water uptake

Table 4 shows nutrient and non-nutrient ion concentrations in the different organ of plant shoots. Nitrogen concentration in all investigated plant tissues was significantly increased by the presence of the selected-green composts compared with the peat control treatment (+25 % on average); a similar trend was observed also for mixed-green composts but only for stem dry matter. The presence of compost enhanced significantly the accumulation of P only when it was replaced at the maximum ratio of peat volume (50 %) and only for leaves. Potassium concentration showed the major remarkable effects among all nutrient ions; in this case the presence of compost generally increased ion concentration in all investigated organs with the exception of stems in the SC30 treatment that performed at the same level of the peat control substrate. However, the highest values were recorded for mixed-green compost treatments that showed up to 184 % increase in stems (i.e. stems of MC50). The presence of composts did not affect much the concentration of Ca in plant tissues with the exception of MC50 treatment that reduced significantly Ca content in two over the three investigated organs compared with the peat control substrate. On the contrary, all compost treatments enhanced the accumulation of Mg in stems and flowers while no difference was observed for leaves. Iron concentration was enhanced by the presence of the selected-green compost; however, significant differences could be found only in comparison with MC50.

Table 4 also show the concentration of Na and Cl in plant tissues as they represent the most important saline ions in Mediterranean cultivation areas. In general, the presence of composts reduced significantly the concentration of Na in leaves and flowers with the exception of the SC30 treatment that produced results similar to the peat control substrate. A different trend was observed for stems where only the replacement of peat at the maximum investigated volume, with the mixed-green compost, allowed a significant reduction in Na compared with the peat control treatment. Conversely, the addition of mixed-green compost caused a significant increase in Cl tissue content compared with the peat control and the selected-green compost treatments; the most remarkable increase (+40 %) was detected in leaf tissue for MC50 compared with the peat control substrate.

Data collected on the cumulated water uptake (Fig. 4) showed reduced values for the plants treated with 50 % mixed-green compost compared with the other treatments. However, such a reduction was statistically significant only starting from 68 DAT. At the end of the experiment, the total amount of water taken up by plants in the above treatment was, on average, 18 % lower than in the other treatments.

4 Discussion

Peat substitution with selected- or mixed-green compost altered significantly the chemical composition of the root zone compared with the peat control substrate (Table 2). However, as expected by the compost composition reported in Table 1, N and C concentration, and C/N ratio remained within the limits imposed by Italian regulations. Substrates obtained by mixing peat and green composts exhibited pH values higher than the optimal range (i.e. roughly 5.5-6.5) expected in the root zone to ensure high nutrient availability and plant nutrient uptake (De Lucia et al., 2013), especially in presence of mixed-green composts (Table 2). The increase in pH by using compost in growing media is common (Mugnai et al., 2007; Tittarelli et al., 2009) and represents one of the main concerns for its wide application in different agricultural sectors (Brito et al., 2015; Sonneveld and Voogt, 2009). Nevertheless, it should be underlined that, in substrate-grown crops, the adjustment of pH is one of the simplest technical practices especially if drip irrigation is adopted for watering plants (Chong, 2005); as shown in Fig. 1, the expedient of adjusting pH in the irrigation water with sulphuric acid was sufficient to level pH of all treatments within optimal range (Sonneveld and Voogt, 2009).

The higher EC exhibited by compost mixtures related to an increased potential capacity in nutrient ion availability (Table 2). Cation concentration is significantly correlated with EC in the root zone and it can be used to estimate nutrient availability for substrate cultures (Sonneveld and Voogt, 2009). To this purpose, K was found to be significantly higher in all compost treatments compared with the peat control treatment. The presence of selected-green compost enhanced also Ca and Mg concentration. Together with macro-cations, the presence of both the two composts enhanced P and Fe availability in the root zone while the selected-green compost showed also remarkable concentrations in N-NO_3. This nutrient budget could be likely used by plants thereby reducing the supply of chemical fertilizers (Martínez-Blanco et al., 2013); in other works, composts mixed with peat have been found improving growth and quality of bedding plants compared with low-fertilized substrates (Estévez-Schwarz et al., 2009).

Indeed, the different substrates influenced plant nutrient content (Table 4); the presence of selected-green composts enhanced N, P, K and Mg concentration (basing on tissue average) compared with peat control treatment while only K content was higher in the mixed-green compost treatments. The presence of composts in growing media is often associated with enhanced nutrient tissue content in ornamental crops (e.g. De Lucia et al., 2013). The higher nutrient concentration in the root zone can boost plant nutrient uptake (Marshner at al., 2011; Massa et al., 2009), even determining nutrient luxury accumulation (Richard-Molard et al., 2008). Furthermore, green composts are reach in organic substances, bearing similarities with humic and fulvic acids (Table 1), which have been found improving plant nutrition processes (Calvo et al., 2014), such as N accumulation in ornamental plants (Massa et al., 2016). The presence of humic-like substances in the root zone induces higher P availability for cultivated plants since they prevent calcium phosphate precipitation (Calvo et al., 2014). Increases in K or Mg tissue content were found for bedding plants cultivated in green compost compared with peat substrates (Grigatti et al., 2007; López-Cuadrado et al., 2008). All these effects can be recognized in Table 4. However, the most remarkable increase was observed for K tissue concentration in all composts compared with the peat control treatment; the highest value in K was caused, on tissue average, by MC50 treatment (Table 4). A significant negative correlation was found between K and Na concentrations in plant tissues (R = -0.70, $P < 0.0001$, n = 45); the latter was generally reduced by the presence of compost. Calcium was the only macronutrient significantly reduced, on tissue average, by MC50 compared with the peat control substrate. The above results were in agreement with the hypotheses that: i) increased K concentration in the root zone may help ornamental plants to counteract Na passive intake (Massa et al., 2009); ii) higher K intake into the symplast is generally coupled to depletion in

Ca (Li et al., 2013). The lower Ca accumulation could be also due to the lower water uptake (Fig. 4) caused by MC50 treatment (Marshner, 2011).

However, the different macronutrient contents observed among the different treatments (Table 4) did not seem to influence plant growth (Table 3). In the present experiment all plants were fed with an optimal dose of chemical fertilizers (see section 2.2) that probably mitigated the effects of possible nutrient contributions by composts to plant biomass accumulation and quality. This is due to the fact that plant nutrient uptake rates increase hyperbolically by increasing nutrient concentration in the root zone thus approaching a constant value after an optimal threshold is reached (Massa et al., 2009), afterward no increase in yield and quality can be detected by increasing nutrient concentration in the root zone (Marshner, 2011). As matter of fact, most of the investigated growth parameters for the selected-green compost and MC30 treatments were at the same level of the peat control treatment (Table 3). The only significant increase, by comparison between compost and peat treatment, was observed for the total fresh weight in the 30 % peat replacement of both selected- and mixed-green compost; such an increase was related to the higher stem fresh weight. To this purpose, heterogeneous results were obtained in other works with bedding plants where the application of green waste, for partial peat substitution, produced enhanced macronutrient concentration in plant tissues with and without significant effects on plant growth and quality depending on species (Grigatti et al., 2007).

Conversely, mixed-green compost at the higher 50 % rate of peat substitution reduced significantly plant leaf area and dry weight in all organs (Table 3). The negative influence of this treatment was also observed on aesthetic and biometric parameters (Fig. 2), which are strongly related to product marketability in ornamental crop productions; among all SPAD index that has been proposed as quality parameter due to its correlation with leaf greenness (Loh et al., 2002). We suspect that such a poor performance was mainly due to direct and indirect consequences of the high Cl concentration caused by mixed-green compost in the substrate (Table 2) and its consequent accumulation in plant tissues (Table 4). Geranium and other ornamental plants typically show positive correlation between Cl concentration in the root zone and Cl tissue content, which in turn may cause detrimental effects on plant performance (Breś et al., 2016; Cai et al., 2014). Excess Cl in the root zone limits N uptake of ornamental plants (Massa et al., 2009) thus increasing energy consumption for active N intake. High Cl concentration in green composts has been found reducing plant growth and quality of bedding plants depending on species (Garcia-Gomez et al., 2002).

Data collected on photosynthesis (Fig. 3) were in strong agreement with biomass accumulation (Table 3). Photosynthetic response curves showed a significant reduction in Pn_{max} while no other curve parameter resulted significantly influenced. The reduction in net photosynthesis, caused by the mixed-green compost at 50 % peat substitution, was probably the main driving variable affecting plant growth. The above results were consistent with leaf chlorophyll (SPAD index) content (Fig. 2) and the highest value in leaf/shoot dry weight ratio, which is a typical plant adaptation response to lower carbon intake per leaf unit area (Table 3). Reduced chlorophyll content and photosynthesis efficiency have been correlated to higher Cl accumulation in leaf tissue of geranium (Breś et al., 2016) as also observed in this work (Table 4). Conversely, no relationship could be found between net photosynthesis and substrate physical characteristics as instead reported by other authors (Bakry et al., 2013). Since physical parameter changes were comparable among compost treatments with respect to 100 % peat treatment, we can conclude that the physical characteristics of the substrates played a minor role in influencing plant performance in the present experiment. Furthermore, no significant difference was found among compost treatments for leaf stomatal conductance and evapotranspiration rate measured at 65 DAT (Fig. 3). Therefore, the lower water uptake observed in the MC50, compared with the other treatments, was mainly related to the lower plant leaf area (Table 3).

In general, the poor performance of the mixed-green compost arose only at 50 % of peat substitution. This evidence is compatible with the hypothesis that the high Cl concentration in the mixed-green compost had a major role in the reduction of plant growth and quality compared with the other treatments. In fact, as observed from the early studies by Maas and Hoffman (1977), plant response to the presence of saline ions in the root zone can be described by a segmented linear model, in which plant growth and quality are kept constant up to a specie-specific tolerance threshold; afterward, a linear decrease can be observed. This model has been widely validated on ornamental (Villarino and Mattson, 2011) and other horticultural crops (Magán et al., 2008).

The above results suggested that the selected-green compost was a more valuable and production-safely product for peat substitution in geranium cultivation while the mixed-green compost determined major uncertainty. These evidences are in agreement with the hypothesis that high-quality compost can be produced through a careful raw material selection (Raviv, 2013).

5 Conclusions

Data reported in this paper show how compost characteristics may influence plant growth and quality in relationship with plant physiology. The selected-green compost used in the test trial, on container-grown geranium, was more valuable than the mixed-green compost for peat substitution. The former compost ensured high plant quality since all investigated plant indicators performed at the same level (not significantly different) of the standard peat substrate, or even better as in the case of nutrient tissue content (i.e. N, P, K and Mg, on tissue average). The latter compost affected negatively plant biomass accumulation, biometric parameters, SPAD index, net photosynthesis, Ca tissue content and water uptake when replaced at 50 % peat substitution rate. The collected data show how i) compost characteristics can influence plant growth, quality, nutrition and photosynthesis, and ii) the use of selected composting raw material can contribute to produce high-quality compost for the substitution of peat in substrate-grown ornamental crops.

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References

Altmann M., 2008. Socio-economic impact of the peat and growing media industry on horticulture in the EU. www.epagma.eu/ (accessed 25.06.16).

Bakry, M., Lamhamedi, M.S., Caron, J., Bernier, P.Y., Zine El Abidine, A., Stowe, D.C., Margolis, H.A., 2013. Changes in the physical properties of two Acacia compost-based growing media and their effects on carob (*Ceratonia siliqua* L.) seedling development. New Forests 44, 827-847. http://dx.doi.org/10.1007/s11056-013-9368-6.

Breś, W., Bandurska, H., Kupska, A., Niedziela, J., Frąszczak, B., 2016. Responses of pelargonium (*Pelargonium x hortorum* L.H. Bailey) to long-term salinity stress induced by treatment with different NaCl doses. Acta Physiol. Plant. 38, 1-11. http://dx.doi.org/10.1007/s11738-015-2048-8.

Brito, L.M., Reis, M., Mourão, I., Coutinho, J., 2015. Use of Acacia waste compost as an alternative component for horticultural substrates. Commun. Soil Sci. Plant Anal. 46, 1814-1826. http://dx.doi.org/10.1080/00103624.2015.1059843.

Bullock, C.H., Collier, M.J., Convery, F., 2012. Peatlands, their economic value and priorities for their future management - The example of Ireland. Land Use Policy 29, 921-928. http://dx.doi.org/10.1016/j.landusepol.2012.01.010.

Bustamante, M.A., Paredes, C., Moral, R., Agulló, E., Pérez-Murcia, M.D., Abad, M., 2008. Composts from distillery wastes as peat substitutes for transplant production. Resour. Conserv. Recycl. 52, 792-799. http://dx.doi.org/10.1016/j.resconrec.2007.11.005.

Cai, X., Niu, G., Starman, T., Hall, C., 2014. Response of six garden roses (*Rosa x hybrida* L.) to salt stress. Sci. Hortic. 168, 27-32. http://dx.doi.org/10.1016/j.scienta.2013.12.032.

Calvo, P., Nelson, L., Kloepper, J.W., 2014. Agricultural uses of plant biostimulants. Plant Soil 383, 3-41.

Chong, C., 2005. Experiences with wastes and composts in nursery substrates. Horttechnology 15, 739-747.

Cleary, J., Roulet, N.T., Moore, T.R., 2005. Greenhouse gas emissions from Canadian peat extraction, 1990-2000: A life-cycle analysis. Ambio 34, 456-461.

Daigle J.Y., Gautreau-Daigle H., 2001. *Canadian Peat Harvesting and the Environment.* North American Wetlands Conservation Council Committee. Ottawa, pp 45.

Daughtrey, M.L., Benson, D.M., 2005. Principles of plant health management for ornamental plants. Annu. Rev. Phytopathol. 43, 141-169. http://dx.doi.org/10.1146/annurev.phyto.43.040204.140007.

De Lucia, B., Cristiano, G., Vecchietti, L., Rea, E., Russo, G., 2013. Nursery growing media: Agronomic and environmental quality assessment of sewage sludge-based compost. Appl. Environ Soil Sci. 2013. http://dx.doi.org/10.1155/2013/565139.

De Boodt, M., Verdonck, O., Cappaert, I., 1974. Method for measuring waterrelease curve of organic substrates. Acta Hortic. 37, 2054-2063.

EN 13037. 1999. Soil improvers and growing media - Determination of pH. CEN, European Committee for Standardization. Central Secretariat: Rue de Stassart, 36 B-1050 Brussels.

EN 13038. 1999. Soil improvers and growing media - Determination of electrical conductivity. CEN, European Committee for Standardization. Central Secretariat: Rue de Stassart, 36 B-1050 Brussels.

EN 13652. 2001. Soil improvers and growing media - Extraction of water soluble nutrients and elements. CEN, European Committee for Standardization. Central Secretariat: Rue de Stassart, 36 B-1050 Brussels.

EN 13654-1. 2001. Soil improvers and growing media - Determination of nitrogen - Part 1: Modified Kjeldahl method. CEN, European Committee for Standardization. Central Secretariat: Rue de Stassart, 36 B-1050 Brussels.

Estévez-Schwarz, I., Seoane-Labandeira, S., Núñez-Delgado, A., López-Mosquera, M.E., 2009. Characterization and evaluation of compost utilized as ornamental plant substrate. Compost Sci. Util. 17, 210-219.

Garcia-Gomez, A., Bernal, M.P., Roig, A., 2002. Growth of ornamental plants in two composts prepared from agroindustrial wastes. Bioresource Technol. 83, 81-87. http://dx.doi.org/10.1016/s0960-8524(01)00211-5.

Grigatti, M., Giorgioni, M.E., Ciavatta, C., 2007. Compost-based growing media: Influence on growth and nutrient use of bedding plants. Bioresource Technol. 98, 3526-3534. http://dx.doi.org/10.1016/j.biortech.2006.11.016.

Holmes, S., 2009. Growing media developments in the UK. Acta Hortic. 819, 23-26.

Kritsotakis, I.K., Kabourakis, E.M., 2011. Grape vine waste and giant reed biomass composts as peat and mineral fertilizer substitutes for producing organic tomato transplants. J. Crop Im. 25, 664-679. http://dx.doi.org/10.1080/15427528.2011.600425.

Larcher, F., Scariot, V., 2009. Assessment of partial peat substitutes for the production of *Camellia japonica*. Hortscience 44, 312-316.

Li, Y., Qin, J., Mattson, N.S., Ao, Y., 2013. Effect of potassium application on celery growth and cation uptake under different calcium and magnesium levels in substrate culture. Sci. Hortic. 158, 33-38. http://dx.doi.org/http://dx.doi.org/10.1016/j.scienta.2013.04.025.

Loh, F.C.W., Grabosky, J.C., Bassuk, N.L., 2002. Using the SPAD 502 meter to assess chlorophyll and nitrogen content of benjamin fig and cottonwood leaves. Horttechnology 12, 682-686.

López-Cuadrado, M.C., Ruiz-Fernández, J., Masaguer, A., Moliner, A., 2008. Utilization of different organic wastes from madrid as growth media for pelargonium zonule. Acta Hortic. 779, 623-630.

Maas, E.V., Hoffman, G.J., 1977. Crop salt tolerance. Current assessment. J. Irrig. Drain. Div. 103, 115-134.

Magán, J.J., Gallardo, M., Thompson, R.B., Lorenzo, P., 2008. Effects of salinity on fruit yield and quality of tomato grown in soil-less culture in greenhouses in Mediterranean climatic conditions. Agr. Water Manage. 95, 1041-1055.

Marschner, H., 2011. Marschner's mineral nutrition of higher plants, 3 ed. Accademic Press, London.

Martínez-Blanco, J., Lazcano, C., Christensen, T.H., Muñoz, P., Rieradevall, J., Møller, J., Antón, A., Boldrin, A., 2013. Compost benefits for agriculture evaluated by life cycle assessment. A review. Agron. Sustain. Dev. 33, 721-732. http://dx.doi.org/10.1007/s13593-013-0148-7.

Massa, D., Mattson, N.S., Lieth, H.J., 2009. Effects of saline root environment (NaCl) on nitrate and potassium uptake kinetics for rose plants: a Michaelis-Menten modelling approach. Plant Soil 318, 101-115. http://dx.doi.org/10.1007/s11104-008-9821-z.

Massa, D., Prisa, D., Montoneri, E., Battaglini, D., Ginepro, M., Negre, M., Burchi, G., 2016. Application of municipal biowaste derived products in *Hibiscus* cultivation: Effect on leaf gaseous exchange activity, and plant biomass accumulation and quality. Sci. Hortic. 205, 59-69. http://dx.doi.org/http://dx.doi.org/10.1016/j.scienta.2016.03.033.

Moldes, A., Cendón, Y., Barral, M.T., 2007. Evaluation of municipal solid waste compost as a plant growing media component, by applying mixture design. Bioresource Technol. 98, 3069-3075. http://dx.doi.org/10.1016/j.biortech.2006.10.021.

Mugnai, S., Pasquini, T., Azzarello, E., Pandolfi, C., Mancuso, S., 2007. Evaluation of composted green waste in ornamental container-grown plants: Effects on growth and plant water relations. Compost Sci. Util. 15, 283-287.

Olszewski, M.W., Trego, T.A., Kuper, R., 2009. Effects of peat moss substitution with arboretum and greenhouse waste compost for use in container media. Compost Sci. Util. 17, 151-157.

Ostos, J.C., López-Garrido, R., Murillo, J.M., López, R., 2008. Substitution of peat for municipal solid waste- and sewage sludge-based composts in nursery growing media: Effects on growth and nutrition of the native shrub *Pistacia lentiscus* L. Bioresource Technol. 99, 1793-1800. http://dx.doi.org/10.1016/j.biortech.2007.03.033.

Raviv, M., 2013. Composts in growing media: What's new and what's next? Acta Hortic: 982, 39-52.

Richard-Molard, C., Krapp, A., Brun, F., Ney, B., Daniel-Vedele, F., Chaillou, S., 2008. Plant response to nitrate starvation is determined by N storage capacity matched by nitrate uptake capacity in two Arabidopsis genotypes. J. Exp. Bot. 59, 779-791. http://dx.doi.org/10.1093/jxb/erm363.

Schmilewski, G., 2009. Growing medium constituents used in the EU. Acta Hortic. 819, 33-46.

Shober, A.L., Wiese, C., Denny, G.C., Stanley, C.D., Harbaugh, B.K., Chen, J., 2010. Plant performance and nutrient losses during containerized bedding plant production using composted dairy manure solids as a peat substitute in substrate. Hortscience 45, 1516-1521.

Sonneveld, C., Voogt, W., 2009. Plant nutrition of greenhouse crops. Springer, New York.

Thornley, J.H.M., Johnson, I.R., 1990. Plant and crop modelling. A mathematical approach to plant and crop physiology. Clarendon Press, Oxford.

Tittarelli, F., Rea, E., Verrastro, V., Pascual, J.A., Canali, S., Ceglie, F.G., Trinchera, A., Rivera, C.M., 2009. Compost-based nursery substrates: Effect of peat substitution on organic melon seedlings. Compost Sci. Util. 17, 220-228.

UNI 10780. 1998. Compost - Classification, requirements and use criteria. UNI, Ente Nazionale Italiano di Unificazione. Via Battistotti Sassi 11B, 20133 Milano, Italy.

Villarino, G.H., Mattson, N.S., 2011. Assessing tolerance to sodium chloride salinity in fourteen floriculture species. Horttechnology 21, 539-545.

Figures captions

Fig. 1 Effect of treatments on electrical conductivity (EC) and pH as determined in the 1:5 (V:V) water extract at the end of the experiment (85 DAT). Columns represent the average of three replicates ± standard deviation. Statistical analysis was performed through one-way ANOVA; different letters for the same period/date indicate significant differences according to Tukey's (HSD) multiple-range test ($P = 0.05$).

Fig. 2 Effect of treatments on plant height (H), number of flowers, plant volume (V), and leaf chlorophyll (SPAD index) content. Measurements were performed at 55 (grey columns) and 85 (black columns) DAT through non-destructive or destructive analysis, respectively. Columns represent the average of six replicates ± standard deviation. Statistical analysis was performed through one-way ANOVA; different letters for the same date indicate significant differences according to Tukey's (HSD) multiple-range test ($P = 0.05$).

Fig. 3 Effect of treatments on leaf gaseous exchange activity. 3A reports net photosynthesis (Pn) response to PAR; points represent the average of three replicates (± mean standard error is reported on the upper left side to avoid line overlaps) while lines represent non-linear regressions performed by fitting a non-rectangular hyperbola (Eq. 1) to measured data; the presence of an asterisk indicates significant differences at the corresponding PAR intensity assessed through one-way ANOVA ($P \leq 0.05$). 3B reports total (shoot dry weight) versus maximum Pn rate (Pn_{max}) as determined by the non-linear regression analysis performed through Eq. 1 (± mean standard error is reported on the upper right side to avoid line overlaps). 3C and 2D report the mean leaf stomatal conductance (Gs) and transpiration (E), respectively, measured during light-response curves; columns represents the average of three replicates ± standard deviation. Statistical analysis was performed through one-way

ANOVA; the presence of different letters indicates significant differences according to Tukey's (HSD) multiple-range test ($P = 0.05$).

Fig. 4 Effect of treatments on water uptake (WU) cumulated over the whole period of observation. Points represent the average of three replicates ± standard error. Statistical analysis was performed through one-way ANOVA; the presence of an asterisk indicates significant differences at the corresponding date for $P \leq 0.05$.

Tables

Table 1 Chemical and microbial characterization of the composts (compost SC and MC) used for the preparation substrate mixtures.

Parameter	Units	SC	MC	Reference values[a]
Humidity	$g\ 100g^{-1}$	25.6	17.3	<50
Total N	$g\ 100g^{-1}$	1.8	2.6	
Total C	$g\ 100g^{-1}$	22.2	28.3	>20
C/N ratio		12.6	10.9	<50
Humic and fulvic acids	$g\ 100g^{-1}$	14.2	7.6	>2.5
pH (1:10)		7.6	7.5	6.0-8.5
EC (1:10)	$\mu S\ cm^{-1}$	264	322	
Na	$g\ kg^{-1}$	1.05	2.49	
Cl	$g\ kg^{-1}$	1,21	3.47	
Cd	$mg\ kg^{-1}$	<0.25	<0.25	<1.5
Cr	$mg\ kg^{-1}$	<0.25	<0.25	<0.5
Hg	$mg\ kg^{-1}$	<0.10	0.11	<1.5
Ni	$mg\ kg^{-1}$	36.9	44.6	<100
Pb	$mg\ kg^{-1}$	48.1	15.9	<140
Cu	$mg\ kg^{-1}$	128.3	62.0	<230
Zn	$mg\ kg^{-1}$	177.2	144.9	<500
Salmonella	$MPN\ 25g^{-1}$	absent	absent	absent
Escherichia coli	$CFU\ g^{-1}$	<10	<10	<m=1000 or M=5000

[a] Limit values imposed by the Italian law D.Lgs. n° 75, 29 April 2010.

Table 2. Physicochemical characterization of the control substrate (PC) and compost mixtures (SC30, SC50, MC30, MC50). Total nitrogen (N) and carbon (C) are expressed as concentration in the dry weight (g 100g^{-1}) whereas pH, electrical conductivity (EC, µS cm^{-1}), and nutrient ($N\text{-}NO_3$, $P\text{-}PO_4$, K, Ca, Mg and Fe) and saline ions (Na and Cl) concentrations (mg L^{-1}) were measured in the 1:5 (V:V) water extract. Bulk density (BD, g cm^{-3}), water container capacity (CC, % V/V), total porosity (TP, % V/V), easily available water (EAW, % V/V), and water buffering capacity (WBC, % V/V) are reported for substrate physical characteristics. All parameters were determined before the addition of controlled release chemical fertilizers.

Parameter	PC	SC30	SC50	MC30	MC50	ANOVA[a]
Chemical characteristics						
N	0.98 b	1.35 a	1.52 a	1.39 a	1.52 a	**
C	37.85 a	28.12 bc	25.37 c	35.00 a	30.57 b	***
C/N	38.55 a	21.15 c	16.82 d	25.28 b	20.09 cd	***
pH	5.99 b	6.68 ab	6.96 a	7.43 a	7.47 a	**
EC	177.07 c	273.47 ab	453.67 a	241.33 b	332.67 ab	***
N-NO3	1.43 c	17.24 b	34.32 a	2.26 c	2.48 c	***
P-PO4	1.82 c	2.72 b	4.43 a	2.45 bc	2.69 b	***
K	21.27 c	50.81 b	69.09 a	47.24 b	68.40 a	***
Ca	16.01 bc	19.49 b	26.96 a	12.47 c	11.63 c	***
Mg	1.63 c	5.13 b	8.32 a	1.96 c	2.25 c	***
Fe	0.88 b	0.96 a	0.98 a	1.96 a	2.25 a	**
Na	16.91 b	22.30 a	25.60 a	22.35 a	25.51 a	***
Cl	9.17 d	15.50 cd	20.83 c	38.50 b	54.00 a	***
Physical characteristics						
BD	0.08 c	0.19 b	0.28 a	0.18 b	0.20 b	***
CC	85.60 a	70.40 bc	65.31 c	73.71 b	72.26 b	***
TP	94.77 a	87.16 b	80.97 c	87.47 b	86.25 b	***
EAW	27.81	23.70	31.20	30.80	29.71	n.s.
WBC	7.55	6.11	7.49	8.85	6.92	n.s.

[a]Statistical analysis performed through one-way ANOVA; n.s. = non significant or *,**,*** = significant at $P \leq 0.05$, 0.01 and 0.001, respectively. Different letters for the same parameter indicate significant differences according to Tukey's (HSD) multiple-range test ($P = 0.05$).

Table 3. Biomass accumulated in the different organs is reported as fresh weight (FW, g pt^{-1}), dry weight (DW, g pt^{-1}), percentage of DW (%DW, g $100g^{-1}$), leaf area (LA, cm^2 pt^{-1}); biomass partitioning is reported as leaves, stems, and flower DW percentage of total – shoots – (Tot) DW (%Lv/Tot DW, %St/Tot DW, %Fl/Tot DW, respectively). Measurements were performed during the final destructive analysis (85 DAT). Values represent the average of six replicates.

Organ	Parameter	PC	SC30	SC50	MC30	MC50	ANOVA[a]
Leaves	FW	69.06 ab	78.39 a	77.13 a	80.08 a	65.04 b	**
	DW	6.16 ab	6.79 ab	6.54 ab	7.01 a	5.92 b	*
	%DW	8.94	8.73	8.49	8.83	9.08	n.s.
	%Lv/Tot DW	37.57 b	39.70 ab	38.86 ab	39.92 ab	41.89 a	*
	LA	1208.89 ab	1390.24 a	1265.67 ab	1329.99 a	1121.15 c	**
Stems	FW	24.20 c	30.97 a	28.18 abc	30.45 ab	24.59 bc	**
	DW	2.80 a	2.88 a	2.78 a	2.93 a	2.12 b	**
	%DW	11.61 a	9.33 ab	9.88 ab	9.84 ab	8.59 b	**
	%St/Tot DW	17.22	16.77	16.51	16.74	14.95	n.s.
Flowers	FW	54.01 a	52.00 a	50.32 ab	53.84 a	41.89 b	**
	DW	7.44 a	7.44 a	7.53 a	7.56 a	6.07 b	*
	%DW	13.75 a	10.38 b	10.62 b	10.36 b	10.57 b	***
	%Fl/Tot DW	45.21	43.53	44.63	43.34	43.15	n.s.
Total	FW	147.27 b	161.36 a	155.64 ab	164.38 a	131.52 c	**
	DW	16.41 a	17.11 a	16.85 a	17.49 a	14.11 b	**
	%DW	11.14	10.66	10.83	10.78	10.72	n.s.

[a] Statistical analysis performed through one-way ANOVA; n.s. = non significant or *,**,*** = significant at $P \leq 0.05$, 0.01 and 0.001, respectively. Different letters for the same parameter indicate significant differences according to Tukey’s (HSD) multiple-range test ($P = 0.05$).

Table 4. Mineral concentration (g kg^{-1} of DW) in the different organs and their average as determined at the final destructive analysis (85 DAT). Values represent the average of three replicates.

Organ	Element	PC	SC30	SC50	MC30	MC50	ANOVA
Leaves	N	23.01 b	28.42 a	28.56 a	24.92 b	24.69 b	**
	P	2.35 b	4.02 ab	6.05 a	4.95 ab	5.78 a	**
	K	35.35 c	40.28 c	59.74 a	49.85 b	62.89 a	***
	Ca	24.77 a	22.63 ab	20.27 ab	21.55 ab	18.85 b	*
	Mg	4.11	5.28	4.73	4.97	4.85	n.s.
	Fe	0.31	0.43	0.17	0.47	0.43	n.s.
	Na	9.19 a	9.28 ab	3.47 c	5.39 bc	3.32 c	***
	Cl	23.90 b	21.54 b	20.20 b	24.73 b	33.33 a	**
Stems	N	11.29 c	18.06 a	16.19 b	14.93 b	16.19 b	***
	P	3.31	6.22	7.14	4.87	7.14	n.s.
	K	23.00 c	34.63 bc	43.73 b	43.92 b	65.43 a	***
	Ca	34.36 b	39.38 a	35.43 ab	31.92 bc	27.97 c	***
	Mg	3.45 c	6.34 a	6.53 a	4.85 b	5.34 b	***
	Fe	0.10 ab	0.14 a	0.15 a	0.07 ab	0.06 b	*
	Na	6.05 b	9.18 a	7.03 ab	4.23 bc	1.64 c	***
	Cl	19.26 b	21.90 b	19.69 b	27.91 a	29.58 a	***
Flowers	N	20.67 b	23.15 a	22.73 a	21.70 ab	20.49 b	**
	P	5.75	6.54	6.72	6.86	7.01	n.s.
	K	28.53 d	33.94 c	42.58 b	40.44 b	46.94 a	***
	Ca	9.76	9.71	9.67	9.58	9.36	n.s.
	Mg	2.29 b	2.77 a	2.72 a	2.78 a	2.74 a	*
	Fe	0.21	0.29	0.29	0.25	0.36	n.s.
	Na	7.30 a	6.03 ab	4.37 c	4.70 bc	3.55 c	***
	Cl	13.81 b	13.33 b	15.74 ab	16.32 a	16.45 a	*
Tissue average	N	18.32 c	23.21 a	22.49 a	20.52 b	20.02 bc	***
	P	3.80 b	5.59 a	6.64 a	5.56 ab	6.36 a	***
	K	28.96 d	36.29 c	48.68 b	44.74 b	58.42 a	***
	Ca	22.96 a	23.91 a	21.79 a	21.02 ab	18.73 b	**
	Mg	3.28 b	4.80 a	4.66 a	4.20 ab	4.31 a	**
	Fe	0.21	0.29	0.20	0.26	0.28	n.s.
	Na	7.51 a	8.16 a	4.96 b	4.77 bc	2.84 c	***
	Cl	18.99 c	18.92 c	18.54 c	22.99 b	26.45 a	***

[a] Statistical analysis performed through one-way ANOVA; n.s. = non significant or *,**,*** = significant at $P \leq 0.05$, 0.01 and 0.001, respectively. Different letters for the same parameter indicate significant differences according to Tukey's (HSD) multiple-range test ($P = 0.05$).

Figures

Fig. 1

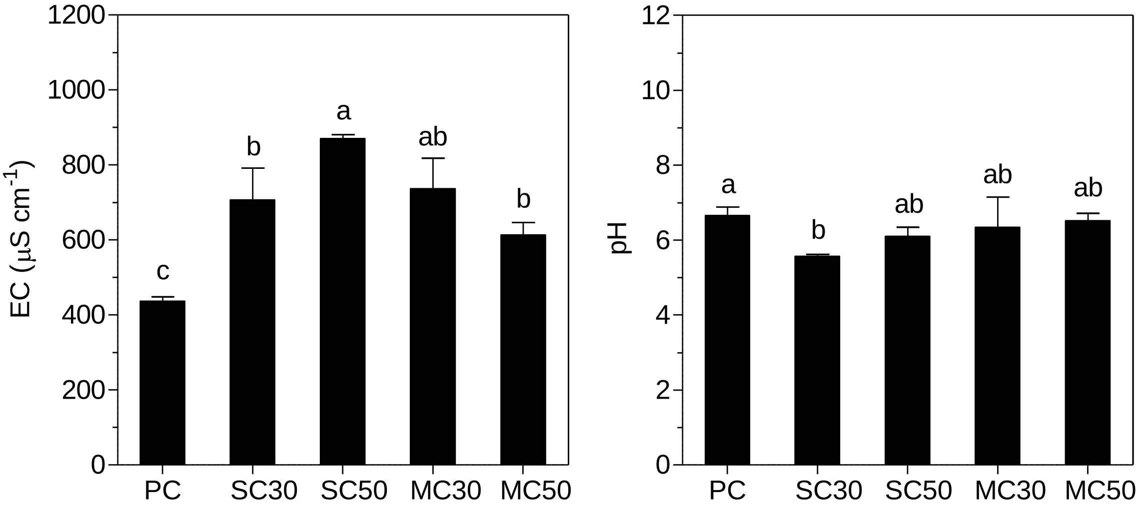


Fig. 2

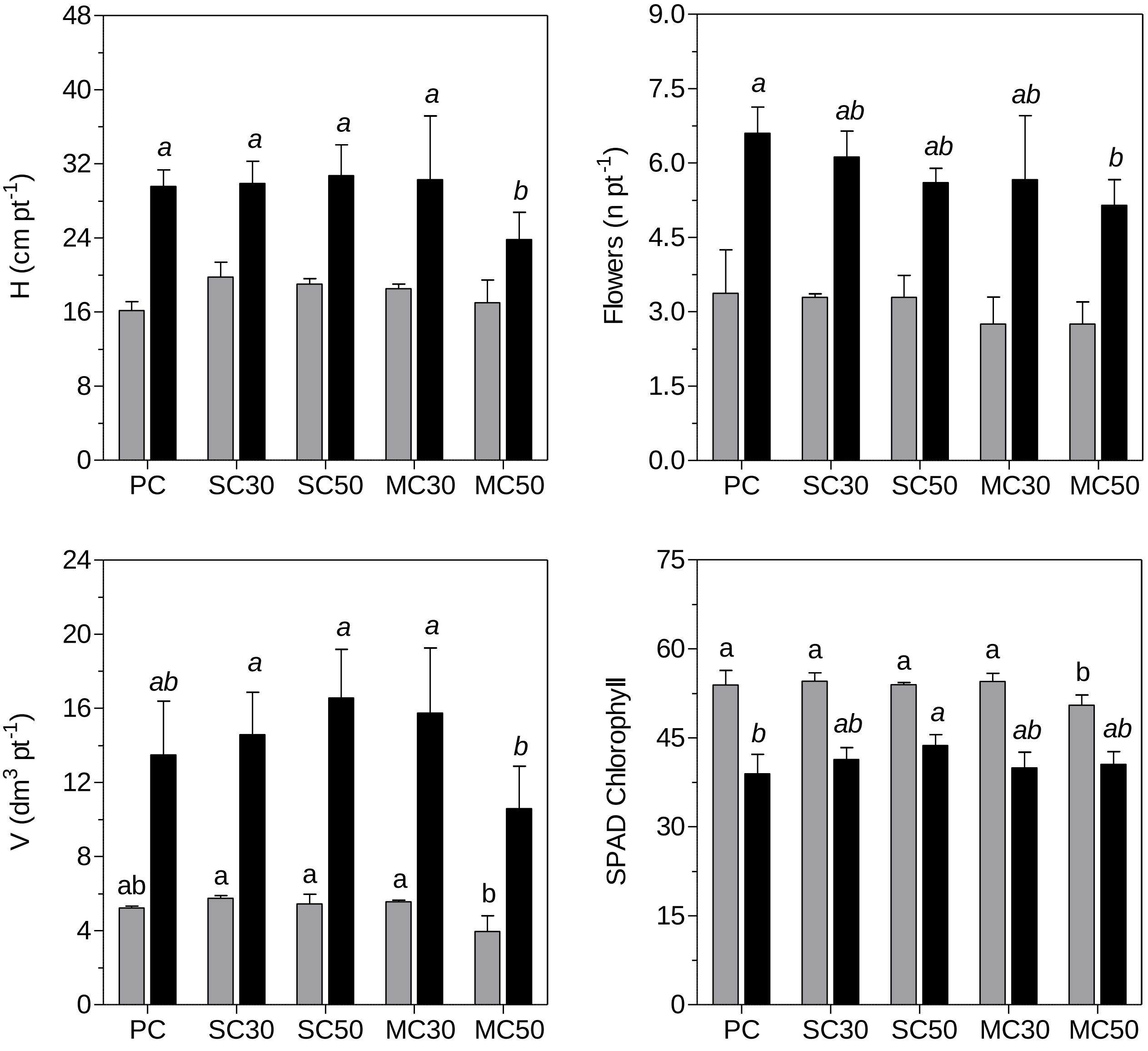

H (cm pt-1)
0
8
16
24
32
40
48
a
a
a
a
b
PC
SC30
SC50
MC30
MC50
Flowers (n pt-1)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
a
ab
ab
ab
b
V (dm3 pt-1)
0
4
8
12
16
20
24
ab
ab
a
a
a
a
a
a
b
b
SPAD Chlorophyll
0
15
30
45
60
75
a
b
a
ab
a
a
a
ab
b
ab

Fig. 3

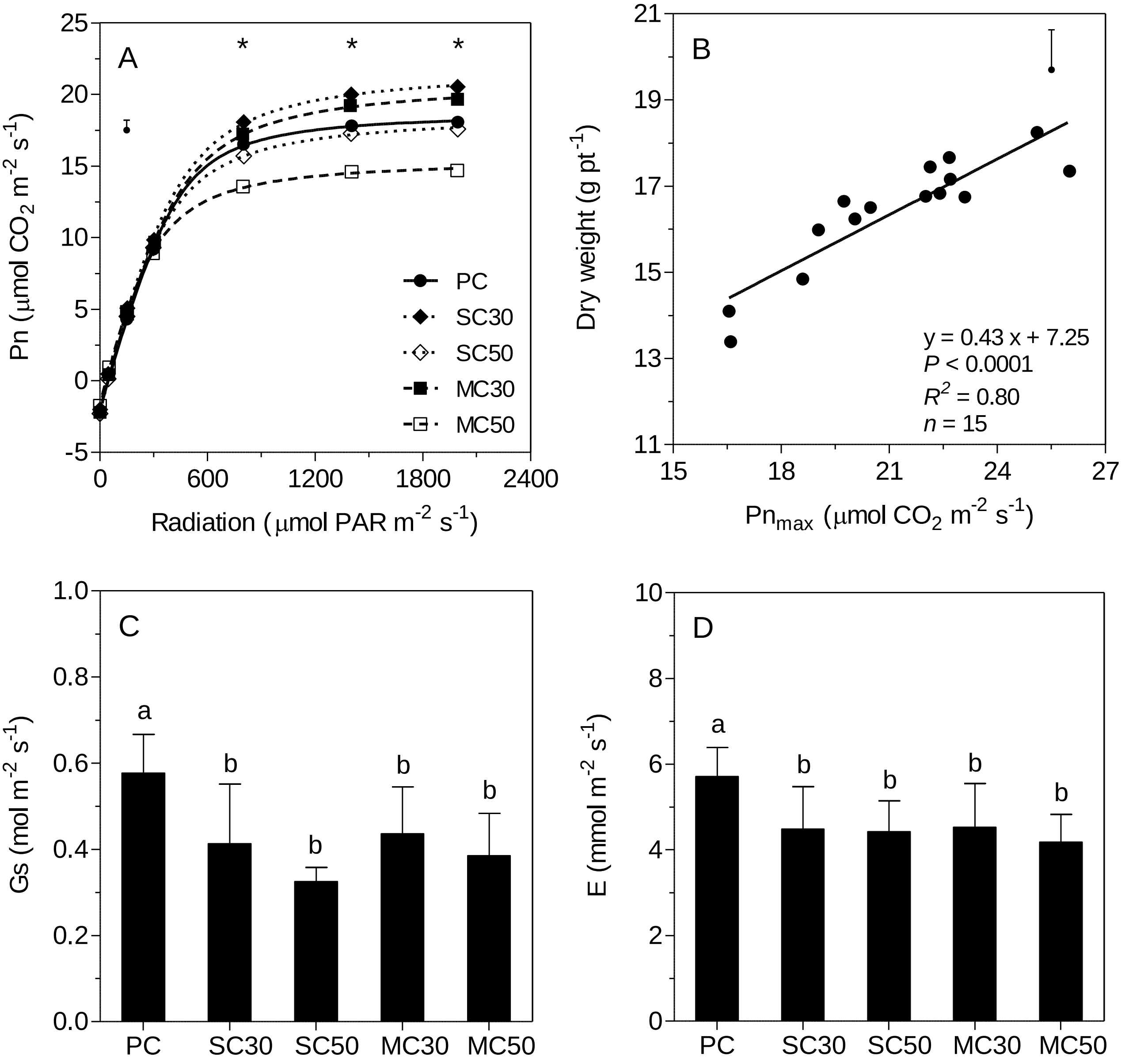
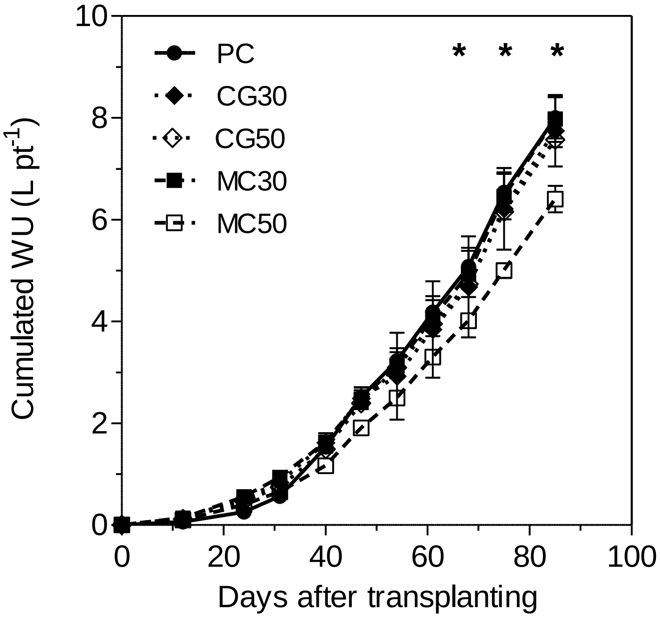

A
*
*
*
Pn (μmol CO$_2$ m^{-2} s^{-1})
Radiation (μmol PAR m^{-2} s^{-1})
25
20
15
10
5
0
-5
0
600
1200
1800
2400
PC
SC30
SC50
MC30
MC50
B
Dry weight (g pt^{-1})
Pn$_{max}$ (μmol CO$_2$ m^{-2} s^{-1})
21
19
17
15
13
11
15
18
21
24
27
y = 0.43 x + 7.25
P < 0.0001
R^2 = 0.80
n = 15
C
Gs (mol m^{-2} s^{-1})
1.0
0.8
0.6
0.4
0.2
0.0
a
b
b
b
b
PC
SC30
SC50
MC30
MC50
D
E (mmol m^{-2} s^{-1})
10
8
6
4
2
0
a
b
b
b
b
PC
SC30
SC50
MC30
MC50

Fig. 4


10
8
6
4
2
0
Cumulated WU (L pt^{-1})
0
20
40
60
80
100
Days after transplanting
PC
CG30
CG50
MC30
MC50
* * *