Sustainable Urban Agriculture using Compost and an Open-pollinated Maize Variety

Florian Ulm[1], David Avelar[1,2], Peter Hobson[2], Gil Penha-Lopes[1],
Teresa Dias[1], Cristina Máguas[1], Cristina Cruz[1]

[1]Faculdade de Ciências da Universidade de Lisboa, Centre for Ecology, Evolution and Environmental Changes, Campo Grande, C2, 1749-016 Lisbon, Portugal

[2]Centre for Econics and Ecosystem Management, Writtle University College, Chelmsford, CM1 3RR, Essex, Great Britain

Abstract

Global urbanization leads to the loss of periurban farming land and increases dependency on distant agriculture systems. This provokes greenhouse gas emissions associated with transportation and storage while disconnecting nutrient cycles, as urban organic waste is not recycled into the agricultural system. Urban food production based on composted local biomass could reduce these problems, but currently used hybrid crops rely strongly on inorganic fertilizers. On the contrary, open-pollinated varieties were bred for productivity under organic fertilization, such as compost. Hypothesising that open-pollinated varieties retain high nutritional value under low nutrient conditions, a commercial hybrid and a local open-pollinated variety of maize were cultivated in non-fertilized soil and under two compost applications: Municipal compost as high nutrient input or locally produced green waste compost and municipal compost mix, as medium nutrient input. Unfertilized plots exhibited low grain production (1.9 t/ha), but yields under green waste compost/municipal compost (6.1 t/ha) and municipal compost (7.8 t/ha) treatments were comparable to observations from maize under inorganic fertilization. Contrary to the commercial variety, the open-pollinated variety exhibited higher grain micronutrient concentrations, e.g. 220 % higher zinc concentrations and lower accumulation of heavy metals, e.g. 74 % lower nickel concentrations. This variety-related effect was found in all treatments and was independent of soil micronutrient concentrations. In conclusion, both compost mixes were effective in increasing grain yield in both maize varieties. However, the open-pollinated variety produced grain with higher nutritional values in soil and all treatments, indicating it is potentially better suited for compost-based sustainable urban agriculture.

1. Introduction

Global society reached a turning point in 2007 when urban populations exceeded the population living on the countryside (United Nations, 2010), a trend which is expected to continue as cities become polycentric and new peri-urban centres emerge close to existing urban conurbations (Satterthwaite *et al.*, 2010). This development has far reaching consequences for the lives of people in the urban environment. In general, urbanization leads to improved living standards and life expectancy, however, it also becomes increasingly challenging to create resilient urban food supply systems, with subjects such as malnourishment as well as food and nutrition insecurity being pending issues in urban environments (Knorr et al., 2018).

Peri-urban farming might be a viable option to produce food close to urban agglomerations and relieve some of the problems of urban nutrition, however, the rate of expansion of most cities worldwide exceeds urban population growth, which has intensified the competition for nearby agricultural land (Seto and Ramankutty, 2016). The increasing distance between food production and urban consumption sites gives rise to a vast infrastructure needed to distribute and store food while increasing greenhouse gas emissions (GHG) and food waste (Bloem and de Pee, 2017). Another large part of urban waste is organic waste originating from urban green spaces such as gardens, parks and wastelands, which together constitute the largest source of municipal solid waste (Reyes-Torres *et al.*, 2018). This green waste is not only composed of pruning from planted species, but is also increasingly derived from invasive plant species, which rapidly dominate invaded ecosystems and threaten native species found in urban landscapes (Alvey, 2006). Removing this biomass can decrease invasive species pressure, while providing an important source of biomass. However, as urban green waste has a low bulk volume and little economic value, it is commercially unappealing and expensive to collect and process, thus most often this waste ends up almost entirely in landfills on former agricultural land (Adhikari *et al.*, 2010), with further consequences for water quality and GHG emissions.

A possible contribution to solve the issues of waste management and urban food security at the same time is to compost organic urban waste. This process also has great potential in diminishing GHG emissions, as compost can be used as soil amendment, increasing soil organic matter (SOM) concentrations while sequestering carbon (Bong et al., 2017). Increased SOM concentrations additionally help to maintain soil structure and reduce nutrient leaching, and can turn degraded urban sites into productive farmland (Beniston *et al.*, 2016). Thus, municipal waste compost (MC) could help to create a clean, zero-waste system where resources are reused for urban and peri-urban farming (Lim et al., 2016). While MCs often exhibit a high nutrient content (Cerda et al., 2017), other frequently used composts, such as green waste compost (GWC) are poor in macronutrients essential for plant growth (Reyes-Torres et al., 2018). Nevertheless, GWC has many beneficial aspects as an organic soil amendment, such as high recalcitrance, high CN ratios as well as low heavy metal pollution. Due to these characteristics, mixing GWC into contaminated urban soils can decrease heavy metal loads (Fitzstevens *et al.*, 2017). This could be of interest in urban agriculture, as high-nutrient urban composts, such as MC, often also exhibit high levels of contaminants and heavy metals, which accumulate along the food chain (Wei et al., 2017).

While there is substantial work available on mixing feedstock for GWC production with nutrient-rich material, such as manure, food waste or inorganic fertilizers in order to decrease composting time or improve compost quality itself (Reyes-Torres et al., 2018), only recently GWC with subsequent fertilizer combinations were assayed for peri-urban food production, with promising results (Eldridge et al., 2018). However, there are still many issues to address, for example, usage of compost with low nutrient content, such as GWC/MC mixes, can lead to yield reduction if used without chemical fertilizer on very nutrient demanding crops, such as tomato (Ribas-Agustí et al., 2017). In some pedo-climatic conditions, the addition of MC might lead to lower yields compared to conventional farming, at least when considering short term compost application (Forte et al., 2017). On the other hand, after an initial decrease in maize yield in the first year of application, pure GWC/MC treatments can perform better along time than conventional farming or even mixtures of GWC/MC with additional inorganic fertilizer (Bedada et al., 2014). Also, while lower yields in organic agriculture working with compost might be inherent, there is also ample evidence that food produced using only organic amendments is more nutritious (Rahmann et al., 2017). This is of increasing importance for urban populations, as there remain serious deficiency problems for nutritionally essential micronutrients, even in heavily industrialized countries (FAO, 2013).

Even though micronutrient deficiency in urban centres remains a problem, genetic crop selection is still mainly aimed at increasing growth and yield in food crops, with an associated decrease in micronutrient and vitamin concentrations in the edible portion of the plant, the so-called “dilution effect” (Marles, 2017). This effect is long known and most noticeable in high yielding staple crops of global importance, such as maize, which accounts for 20 % of the global food calories (Pixley and Bjarnason, 2002). Also, modern commercial food crops were bred to exploit an abundance of nutrients to produce high yielding growth (van Bueren *et al.*, 2011), while in contrast, many of the more traditional, open-pollinated varieties (OPV) were bred to maintain yields and nutrient concentrations also in low-input agricultural systems (Patto *et al.*, 2008). Thus, the biofortification (increase in nutritional value) of staple crops, such as maize, has become a pending issue and recently, OPVs were recognized for being valuable genetic sources for this undertaking (Puglisi et al., 2018). Taking these observations about plant nutrition into account, research into increased recycling of nutrients from society (Röös et al., 2018) and the selection of crop varieties accustomed to low-input farming

(Tsvetkov et al., 2018) are research goals of utmost importance to improve sustainability in (urban) agriculture.

With these major topics in mind, the work presented here joins nutrient recycling through composting with the prospect of OPVs of maize (*Zea Mays*) as potentially biofortified varieties. In the urban context of constrained space, high growth rates and yields are essential to turn food production relevant, however, to also be sustainable, plant nutrition needs to rely on locally available sources. In a novel approach both of these aspects were assessed simultaneously by growing a commercial hybrid variety and an OPV solely on MC and GWC as nutrient sources and subsequently measuring yield and mineral nutrition. The treatments consisted of either non-fertilized local soil or two types of nutrient applications: either MC alone as a high nutrient input, or mixed with GWC as a lower nutrient input treatment. Apart from exhibiting lower nutrient concentrations, it was also assumed that GWC might have lower heavy metal concentrations. As the GWC employed was derived from a local invasive species (*Acacia longifolia*), it represents, to our knowledge, the first test of compost from this feedstock as an organic soil amendment for maize. Plant vegetative and grain yield as well as soil and grain micro and macronutrients were measured using inductively coupled plasma–optical emission spectroscopy as a state of the art methodology for ionomic profiling (Jaradat and Goldstein, 2018) and the data sets analysed using modern multivariate and univariate techniques. Putting forward the hypothesis that while the compost treatments would in general increase maize yield, it was also postulated that the OPV exhibits higher grain nutrient concentrations than the commercial variety, thereby putatively rendering it a more suitable option for this type of agriculture.

2. Materials and Methods

2.1. Sample dates, setup and preparation

The study site is located within the Permaculture Living Laboratory (“PermaLab”) on the campus for Faculty of Science at the University of Lisbon (38°45'29.30"N, 9°9'30.40"W), and measures approximately 30 m by 10 m. It was divided into 16 smaller plots, each measuring 4 m^2. An automatic drip feed system (GREENTEC, AZUD, Spain) regulated equal water supply to each of the sub-plots throughout the growing period. Aside from the control plots, different mixtures of composts were applied superficially to the other plots and the top 20 cm of soil horizon mixed with the respective composts using a gasoline tiller (GM 105FQSTYLE, Chongqing Jiamu Machinery Co. Ltd, China). The MC used in this study was bought from the company ValorSul in Lisbon and is derived from food waste which is anaerobically digested for biogas production and then composted using wood chips as a bulking agent (ValorSul, 2018) (Class IIA from Decreto-Lei nº 103/2015). GWC for the GWC/MC treatments was prepared on site from *Acacia longifolia* plant material (Ramos, 2016). In brief, plant material was harvested and ground mechanically into pieces < 10 cm and then composted in custom made bioreactors. The bioreactors were build from ROOFMATE^{TM} (DOW, 2018) extruded polystyrene foam insulation sheets of 5 cm thickness, which were joined using polyurethane foam adhesive spray and sealed with acrylic to maintain temperature and humidity constant. Compost was cured for 40 days in controlled mesophilic conditions (40 - 53°C), keeping volumetric water content above 40 %. Final mature composted material had: 1.5 N %, 48.0 C % and a CN ratio of 34.3.

The extrapolated amount of compost applied in all cases was 2,812.5 m^3/ha, based on experiments from Brito et al., 2015, who used *Acacia longifolia* compost mixed with other substrates and soil as horticultural growth substrates (50 % v/v). The MC treatments were prepared by adding 2,812.5 m^3/ha MC to the plots and the GWC/MC treatments were prepared by mixing in 937.5 m^3/ha of mature GWC with 1,875 m^3/ha of MC before application. After compost application, the experimental plots were left to settle for one week and maize grain then sown in rows by hand to a depth of 1 cm, at a density of 5.5 plants/m^2 towards the end of June 2016. No biocides or mechanical clearing were applied during the course of the experiment and all plots received equal amounts of tap water by drip irrigation. At the end of the growing season (first week of October), plant height and amount of ears were determined and aboveground biomass of all plants was harvested and separated out in to stems, leaves, ear husks, cobs and grain. The material from each plant was air-dried at room temperature and weighed. To account for interference from air humidity, subsamples were taken and dried in an oven at 60 °C until constant weight to extrapolate total dry weight per plant. Plant height, number of ears and dry weight of plant and grain mass were treated as pseudo replica, pooled per plot and subsequently their mean was used for statistical analysis. If any plant was damaged by adverse conditions, like wind or animal interference, etc. it was removed from analysis, however, there were never less than 6 plants pooled per plot. This way, the true replicates per plot and variety were: $n_{Control} = 5$; $n_{MC} = 5$; $n_{GWC/MC} = 3$. Nutrient analysis were done on pooled grains per variety per plot and to assess single kernel weight, kernels were grouped by variety and the weight of a single kernel calculated by extrapolating from weighing 36 batches of 10 kernels each.

2.2. Plant variety and phenology

The maize varieties used in this experiment were a commercial hybrid variety (SY Sincero, Syngenta, Portugal), termed “commercial variety” later in the text, and a traditional, regional OPV called “pata-de-porco multicolorido”, which describes its multi-coloured kernels and ear fasciation.

2.3. Soil collection, preparation and organic matter analysis

At the end of September 2016, 3 topsoil subsamples were taken from each plot to a depth of 10 cm from the surface and mixed thoroughly to obtain a pooled sample. The collected soil was sifted through a 2 mm sieve and then dried at 60 °C until constant weight before being transferred to a muffle furnace (L3 Nabertherm, Lilienthal, Germany) for 6 hours at 600 °C to determine the soil organic matter. This process was followed by further exposure for 2 h at 950 °C to determine the carbonate content on loss of ignition in accordance with the method described in Heiri *et al.* (2001). Finally, each sample was ground to produce a powder using a ball mill (Mixer Mill MM 400, Retsch, Germany) in preparation for isotopic and ionomic analysis.

2.4. Ionomics, total carbon, nitrogen and stable isotope analysis

Ionomics values for each of the plants were determined using inductively coupled plasma optical emission spectrometry (ICP-OES; Thermo Elemental Iris Intrepid II XDL; Franklin, MA, USA) after a microwave assisted digestion with HNO3:H2O2 (4:1, v:v) in the Ionomics Service of the Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC, Spain) following ISO/IEC guidelines (UNE-EN ISO/IEC 17025, 2018).

Stable isotope ratio analyses were also measured at the Stable Isotopes and Instrumental Analysis Facility (SIIAF), Centre for Ecology, Evolution and Environmental Changes (cE3c), located in the Faculty of Sciences, University of Lisbon - Portugal. Values for δ^{13}C and δ^{15}N were determined for each sample using continuous flow isotope mass spectrometry (CF-IRMS), on a Sercon Hydra 20-22 (Sercon, UK) stable isotope ratio mass spectrometer, coupled to a EuroEA (EuroVector, Italy) elemental analyser for online sample preparation by Dumas-combustion (Preston and Owens, 1983). A delta Calculation was performed according to d = [($R_{sample} – R_{standard}$)/$R_{standard}$] * 1000, where R is the ratio between the heavier and lighter isotopes. In the analysis, $\delta^{15}N_{Air}$ values refer to concentrations found in air, and $\delta^{13}C_{VPDB}$ values are referred to as PDB (Pee Dee Belemnite). The reference materials used were Sorghum Flour Standard OAS and Wheat Flour Standard OAS (Elemental Microanalysis, UK), for nitrogen and carbon isotope ratio (where $\delta^{15}N_{Air}$ (Sorghum Flour OAS) = 1.58 +/- 0.15 ‰, $\delta^{15}N_{Air}$ (Wheat Flour OAS)= 2.85 +/- 0.17 ‰, and $\delta^{13}C_{VPDB}$ (Sorghum Flour OAS) = -13.68 +/- 0.19 ‰, $\delta^{13}C_{VPDB}$ (Wheat Flour OAS) = -27.21 +/- 0.13 ‰) (Coleman and Meier-Augenstein, 2014). The level of predicted uncertainty in the observed value for the isotope ratio analysis was $\leq$ 0.1 ‰ and calculated using the results from 6 to 9 replicates of secondary isotopic reference material (wheat flour, $\delta^{15}N_{Air}$ = 2.88 +/- 0.19 ‰, $\delta^{13}C_{PDB}$ = -27.27 +/- 0.19 ‰), which were interspersed among samples in every batch analysis. The major mass signals for N and C were used to calculate total N and C abundances, using Sorghum Flour Standard OAS and Wheat Flour Standard OAS, with 1.47 % N, 46.26 % C and 1.47 % N, 39.53 % C respectively, as elemental composition reference materials (Elemental Microanalysis, UK).

2.5. Statistical analysis

Plant traits (Height, Plant Weight, Grain Weight, Ears) were measured for each plant to provide a mean value calculated for all plants per plot. Stable isotope ratio and Ionomic analyses were performed on aggregated sample data for each plot. Statistical analyses were performed with the package “stats” using version R 3.3.2 (R Core Team, 2016) and executed on RStudio (IDE version 1.0.136). Additional packages used were: “Hmisc”, “lawstat”, “lmtest” and “FactoMineR” (Lê *et al.*, 2008). Pairwise comparisons between groups were calculated using Pairwise Welch´s t-test with Bonferroni - Holm correction. If only two groups were compared, Welch´s t-test was used. Normality assumptions for group wise comparisons were verified using the Shapiro-Wilk Normality Test. If the normality assumption was violated, data was transformed to log or square root values. Linear regressions were performed after verifying assumptions using the Breusch-Pagan Test for homoscedasticity and the Shapiro-Wilk Normality Test on the regression model residuals. Figure 3 is a network plot created from a spearman correlation matrix. Figure 4 is based on an RV coefficient matrix, generated by using the package FactoMineR to highlight relationships between groups of variables. For multivariate explorative data analysis of grain and plant traits, a multiple factor analysis (MFA) was employed, using plant traits, grain nutrients and the two factors treatment type and plant variety as input (Figure 5).

3. Results and Discussion

3.1. Soil changes

The topsoil conditions in all the study plots were significantly altered by the compost addition (**Table 1**). Apart from SOM, the quantities of total C and N were both ca. 10-fold higher in the treatment plots than in the control. For most macro- and micronutrients, soil amended with MC exhibited higher nutrient levels than with GWC/MC, whilst the control soil plots recorded the lowest values for all nutrients except for K and Mn, where no significant difference was found. The original soil in the study plot had lower than average levels of N and S for the city (0.31 % and 0.05 %, respectively) (Costa *et al.*, 2012), while after the compost treatment macro- and micronutrient concentrations far exceeded the mean concentrations reported for most Lisbon soils (Costa *et al.*, 2012). Urban environments are often viewed as hostile to food crop production because of unnaturally high levels of heavy metals; particularly bulk lead (Fitzstevens *et al.*, 2017). However, readings for heavy metals were unaltered by the treatments with the exception of Cd, which in the MC treatment showed levels twice as high as in the control plots, while for the plots treated with GWC/MC, there was a moderate increase in Cd. In any case, heavy metal concentrations well below the lower guideline values considered to be of risk to the ecology of soils and even for Cd, where soil with MC additions showed increased values, ca. half of the threshold value of 1 µg Cd per g soil (Tóth *et al.*, 2016).

Table 1: Topsoil parameters (< 20 cm) of untreated soil (control), soil with municipal compost (MC) and soil with a mix of green waste compost and municipal compost (GWC/MC). Numbers depict means ($n_{Control}$ = 5; n_{MC} = 5; $n_{GWC/MC}$ = 3) with standard errors in parentheses. Letters depict significant differences (pairwise Welchs´ t-test with holm correction; $p < 0.05$, values were square root transformed to conform with normality assumption).

		GWC/MC	MC	Control
General	SOM (%)	16.99 (3.44)^a	23.05 (2.07)^a	5.69 (0.21)^b

characteristics	Carb (%)	3.55 (0.43)^{a}	4.41 (0.34)^{a}	2.06 (0.16)^{b}
	δ^{13}C (‰)	-24.13 (0.09)^{a}	-23.64 (0.2)^{a}	-20.14 (1.01)^{b}
	δ^{15}N (‰)	10.7 (0.31)^{a}	9.98 (0.35)^{a}	5.52 (0.11)^{b}
	C (%)	9.27 (1.7)^{a}	11.6 (0.72)^{a}	1.64 (0.18)^{b}
	N (%)	0.9 (0.15)^{a}	1 (0.08)^{a}	0.12 (0.02)^{b}
Macronutrient concentrations (mg/g)	P	5.86 (1.48)^{b}	9.72 (1.17)^{a}	0.31 (0.02)^{c}
	K	3.79 (0.73)	4.22 (0.48)	4.07 (0.28)
	Ca	34.77 (6.75)^{b}	49.57 (4.94)^{a}	12.22 (0.76)^{c}
	S	1.64 (0.37)^{b}	2.43 (0.25)^{a}	0.3 (0.01)^{c}
	Mg	3.57 (0.8)^{ab}	4.57 (0.29)^{a}	2.67 (0.26)^{b}
	Na	0.71 (0.17)^{ab}	1.16 (0.22)^{a}	0.26 (0.03)^{b}
Micronutrient and heavy metal concentrations (µg/g)	B	11.15 (2.41)^{ab}	14.35 (1.05)^{a}	7.33 (0.48)^{b}
	Mn	145.96 (25.79)	174.48 (5.6)	180.61 (12.55)
	Zn	119.09 (27.06)^{b}	172.91 (14.9)^{a}	42.33 (1.41)^{c}
	Fe	10,895.99 (1381.13)^{a}	9,965.15 (725.88)	15,749.67 (685.98)^{b}
	Cu	29.66 (5.91)^{b}	41.62 (2.76)^{a}	16.33 (1.39)^{c}
	Mo	0.44 (0.09)^{a}	0.53 (0.15)^{a}	0.08 (0.05)^{b}
	Ni	10.19 (1.33)	11.08 (0.42)	12.76 (0.81)
	Cd	0.37 (0.1)^{ab}	0.55 (0.05)^{a}	0.28 (0.02)^{b}
	Pb	19.32 (2.4)	19.59 (0.69)	22.21 (0.91)
	Cr	44.31 (2.68)	44.12 (3.02)	43.47 (3.48)
	As	0.33 (0.11)	0.95 (0.34)	0.16 (0.14)

In the case of macronutrients, the largest differences between treated and control plots were observed for P levels, which were 32 times higher under MC treatment, and 20 times higher under GWC/MC treatment. Most of the readings for macro- and micronutrient levels registered between 1.5 and 3 times higher in the MC treatment, with the exception of Mo, which was 7 times higher in the MC plots, and 6-fold higher in the plots subjected to GWC/MC treatment. However, even though GWC/MC and MC treatments were effective in increasing Mo concentrations, the values recorded here were nevertheless lower than Lisbon average values of 1.67 µg/g (Costa et al., 2012) and at the plant growth limiting end of soil Mo concentrations (Marschner, 2012).

3.2. Effects on plant biomass and nitrogen

In all experimental plots treated with compost the growth of maize plants and the accumulation of biomass were significantly higher than they were in the control sites, irrespective of the variety used (**Figure 1, left**). Similarly, grain yield was significantly higher in treated plots (**Figure 1, right**), although, the commercial variety grown in MC plots yielded higher grain counts than the OPV grown in GWC/MC plots. Based on the values displayed in Figure 1 (grain yield per plant), the average grain yield for the OPV of maize was extrapolated to be 1.8 t/ha in the control plots; 5.3 t/ha in the GWC/MC plots; and 7.2 t/ha for soil treated with MC. For the commercial variety, the average grain yield was calculated at 2 t/ha in the control plots; 6.9 t/ha in the GWC/MC plots; and 8.3 t/ha in the MC plots. Thus, both maize varieties grown with compost compete favourably in grain yield with industrially produced transgenic or non-transgenic commercial hybrid varieties in Portugal (Skevas *et al.*, 2010). By extrapolating from the yield data, ca. 22 m^2 of compost-fed urban ground would be sufficient to produce enough maize in the period of 3 months to support one individual for the year, leaving the rest of the year to grow other crops.

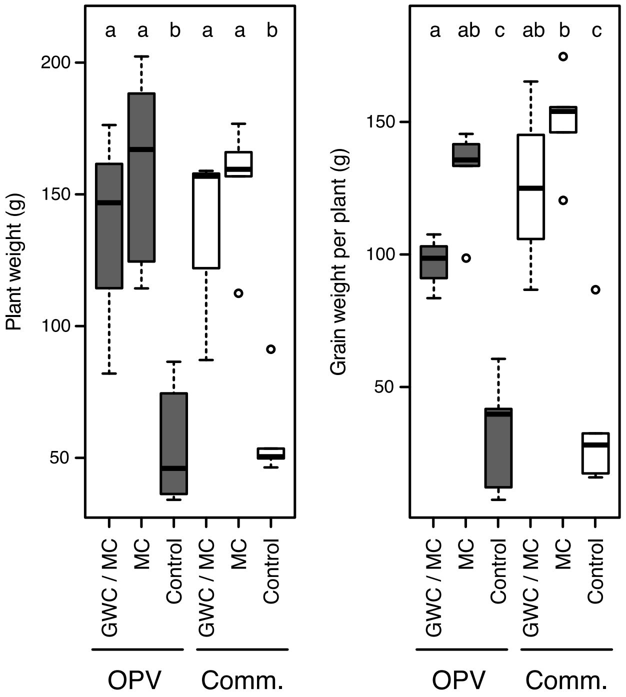


Figure 1: Boxplots describing the differences in vegetative plant weight (left) and grain weight (right) of both corn varieties (open-pollinated and commercial) in all treatments (per variety: $n_{Control} = 5$; $n_{MC} = 5$; $n_{GWC/MC} = 3$). Letters depict significant differences (pairwise Welch's´ t-test with holm correction; p <

0.05). GWC = Green Waste Compost; MC = Municipal Compost. OPV = open-pollinated variety, Comm. = commercial variety.

Interestingly, while there were marked differences in plant weight and grain yield between treatments (F = 26.71, p < 0.001 for GWC/MC plots; and F = 50.58, p < 0.001 for the MC plots), there was no clear evidence of significant differences in N concentrations in the grain between treated plots (F = 2.86, p = 0.081), but there was a significant difference in levels of N between the two varieties (F = 29.58, p < 0.001). Grain from the OPV yielded higher N concentrations in both control as well as all treated plots (**Table 2**), indicating higher protein content in this variety. The mean difference observed here (1.4 times more N in the OPV vs. the commercial variety) is in accordance with results found for other Portuguese OPVs, which reported up to 1.3 times higher protein content in OPVs, compared to hybrid varieties (Brites *et al.*, 2010). This effect might be due to higher N use efficiency inherent to this variety, as OPVs of maize might be more resource efficient under low nutrient conditions (Omondi et al., 2014) and accumulate more protein (Flint-Garcia, 2017). Similar to the pattern observed for N concentrations, K and P concentrations did not change in response to the treatments (F = 0.0258, p = 0.974 and F = 0.5191, p = 0.603, respectively), but were significantly higher in the OPV kernels in all treatments (F = 100.64, p < 0.001 and F = 116.1389, p < 0.001, respectively). While mean K concentrations found in the commercial variety (3645 µg/g) are below values found in OPVs in another study (3745 µg/g; Jaradat and Goldstein, 2018), the OPV observed here exhibits substantially higher K concentrations (5332 µg/g). On the contrary, the P values observed in the commercial variety are lower (2685 µg/g) than what was observed in OPVs in the study mentioned above (3362 µg/g; Jaradat and Goldstein, 2018), while they are higher than in the OPV observed in this study (4298 µg/g). In contrast to K, where an increased concentration in OPVs kernels is a beneficial trait, higher P values can be potentially problematic if P is stored mainly as phytic acid. The ratio of free P in comparison to phytic acid was not measured, however, it is known from other OPVs that they can potentially exhibit high free P and low phytic acid levels (Puglisi et al., 2018), rendering them more suitable as P source for human consumption.

Table 2: Nutrient concentrations in maize grain of plants growing in soil without treatment (Control), soil with municipal compost (MC) and soil with a compost-mix (GWC/MC) of green waste compost (GWC) and MC. All values are given in µg/g, values in bold show significant differences between open-pollinated and commercial variety. Numbers depict means (per variety: $n_{Control} = 5$; $n_{MC} = 5$; $n_{GWC/MC} = 3$) with standard errors in parentheses. Asterisks depict p-values (* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$; Welch's t-test, values were square root transformed to conform with normality assumption). OPV = open-pollinated variety, Comm = commercial variety

	GWC/MC		MC		Control	
	OPV	Comm.	OPV	Comm.	OPV	Comm.
N	15,333.33 (1,666.67)	9,666.67 (333.33)	16,200 (969.54)	12,200 (1,019.80)*	14,200 (1,240.97)	9,800 (374.17)*
P	4,411.80 (78.59)	2,740.47 (202.43)*	4,455.05 (99.36)	2,567.32 (72.15)***	4,028.44 (305.09)	2,747.81 (147.45)**
K	5,396.02 (192.22)	3,566.51 (189.06)**	5,345.69 (111.04)	3,679.58 (208.68)**	5,253.05 (248.11)	3,688.55 (199.39)**
S	1,105.02 (89.76)	713.64 (39.16)*	1,174.91 (20.41)	758.48 (30.82)***	1,002.36 (71.97)	804.44 (46.53)
Mg	1,846.34 (97.23)	1,015.90 (101.56)**	1,907.84 (60.22)	939.79 (39.24)***	1,582.74 (160.11)	1,046.24 (54.63)*
Ca	75.81 (6.41)	45.76 (8.68)	79.71 (6.07)	59.78 (7.05)	97.79 (9.29)	90.07 (9.80)
B	2.47 (0.14)	1.76 (0.04)*	2.49 (0.22)	1.67 (0.19)*	2.39 (0.18)	1.89 (0.08)*
Mn	19.93 (1.31)	10.89 (0.80)**	22.26 (1.02)	10.84 (0.41)***	19.16 (1.58)	12.34 (0.45)**
Zn	53.36 (3.77)	23.28 (2.15)**	54.64 (1.75)	23.22 (1.14)***	50.81 (5.16)	26.47 (1.27)**
Fe	30.90 (4.89)	23.74 (2.51)	39.68 (2.79)	29.67 (7.00)	31.88 (2.15)	21.94 (3.20)*
Cu	3.00 (0.04)	1.57 (0.07)**	3.45 (0.08)	1.66 (0.11)***	3.20 (0.32)	1.76 (0.16)**
Mo	0.24 (0.11)	0.01 (0.01)	0.25 (0.08)	0.01 (0.01)*	0.23 (0.08)	0.00 (0.00)**
Ni	0.07 (0.05)	0.24 (0.14)	0.02 (0.01)	0.20 (0.07)*	0.20 (0.05)	0.51 (0.06)*

While the OPV was apparently more efficient in nutrient acquisition, resource efficiency was not reflected in grain weights, with significantly lower weights (Welchs´ t-test, $p < 0.001$), for the OPV with 0.312 g (± 0.004 SE), compared to the commercial variety, which yielded 0.347 g (± 0.005 SE) per grain. This is contrary to earlier reports indicating higher kernel weights for OPVs compared to hybrid varieties, however kernel weights were in general high in comparison to values observed by other authors, ranging around 0.26 – 0.28 g (Flint-Garcia, 2017). On the other hand, the increased grain weight in the commercial variety could be related to the dilution effect, which is known to occur in maize (Marles, 2017). While in both varieties grain yield was clearly connected with the compost treatments (**Figure 1**), only the grain of the commercial maize variety exhibited a linear, positive correlation between grain N concentrations with SOM levels (**Figure 2**). Thus, both varieties respond to fertilization with increased grain yield, however, the commercial variety also increases nutritional value with increased fertilization, while the OPV accumulates N largely independent of fertilization. From a nutritional standpoint, the OPV is therefore indicated as a better food source also in nutrient-poor agricultural regimes.

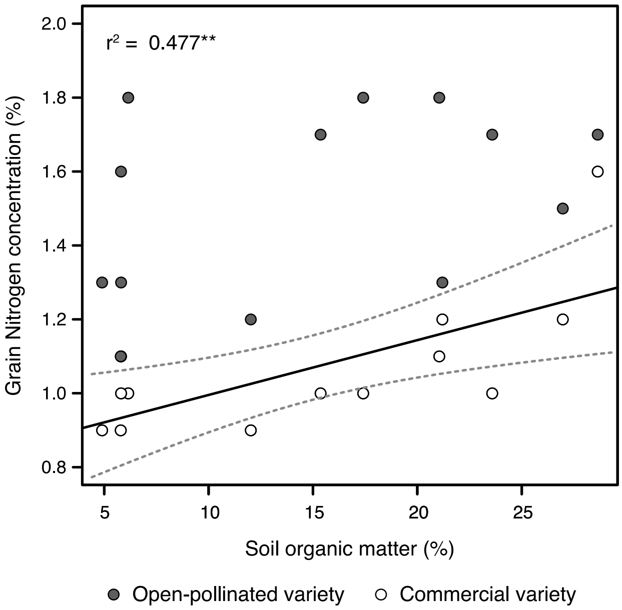


Figure 2: Pearson correlation between grain nitrogen (N) content and soil organic matter (OM). Dark grey dots depict the open-pollinated variety, white dots the commercial variety. Only the commercial variety shows a significant correlation between soil OM and grain N concentrations (black line, 95 % confidence interval and r^2 shown).

3.3. Grain micronutrient concentrations in commercial and open-pollinated varieties

The status of other nutrients recorded in grain samples was variable between treatments and maize varieties (**Table 2**). Apart from Ca, Ni and S, all other recorded nutrients were observed to be higher in the OPV growing under control conditions and also in the MC plots, with the exception of Ca and Fe. The results for the GWC/MC plots indicated the main nutrients with the exception of Ca, Fe, Mo and Ni were higher in the OPV of maize. As maize is also a source of essential minerals and the average consumption of maize per capita in Portugal is 48 g/day (FAOSTAT, 2013), this portion would provide 52 % of females and 36 % of males with their daily requirements of Zn if open-pollinated varieties were selected for (FAO and WHO, 2005). Current biofortification goals in breeding programs set the target goals for Zn and Fe concentrations in kernels at 33 and 52 µg/g, respectively (Hindu et al., 2018), thus, kernels of the OPV even under unfertilized conditions achieve about 155 % and 62 %, respectively, of these targets. In terms of trace elements, the average consumption of OPV maize would furthermore provide 35 % of daily needs of Mo (34 µg) (Food and Nutrition Board, Institute of Medicine, 2000). In contrast, the commercial variety would yield less than 2 % of daily requirements. What is more, heavy metals did not accumulate in the grain of the OPV, and levels for Ni recorded in samples were around 0.51 µg/g, which would equate to 13.5 % of the recommended daily threshold limit for Ni of 2.8 µg Ni/kg body weight (ESFA, 2015) in an average diet of maize. An analysis using a network plot and Spearman's correlation matrix revealed a relationship between various macro- and micronutrients (**Figure 3**). For instance, in the kernels of the OPV, macronutrients such as N, P, S and Mg were positively correlated with the micronutrients Mn and Zn, while Ni was negatively correlated with Fe, Mg and S. On the contrary, in the commercial variety, Ni was positively correlated with other nutrients, such as S, Mg, Na, Mn and Zn. Interestingly, in both varieties, no correlation was found between Zn and Fe, which is in accordance with Indian varieties, but in contrast to observations from African cultivars (Akinwale et al., 2016). The positive correlation between P and various micronutrients in the OPV was also found in several maize varieties selected for biofortified crops, potentially indicating a co-selection of traits relevant for higher kernel nutrient accumulation (Gu et al., 2015). Contrary to these positive correlations, the correlations between S and Mg with Ni are negative in the OPV, while being highly positive in the commercial variety. This is potentially problematic, as any accumulation of micronutrients in this variety would be accompanied by an increase in Ni.

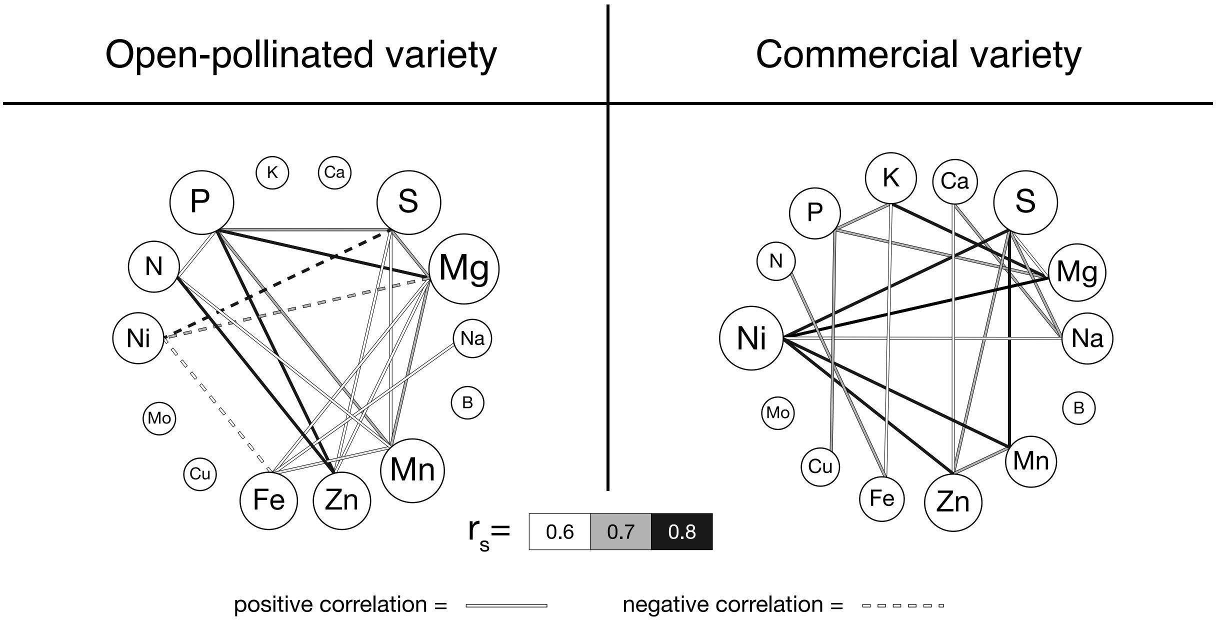


Figure 3: Nutrient Network, based on a matrix of spearman correlations (r_s) between all macro- and micronutrients found in the maize kernels (dotted lines indicate negative correlation, full lines indicate positive correlations). White, grey or black lines indicate the strength of the relationship (0.6, 0.7 and 0.8, respectively), while the sphere sizes indicate the amount of existing relationships (min = 0; max = 6), basis for the nutrient network was n = 13 for each variety.

While RV coefficients (**Figure 4**) suggest a strong relationship between soil micro- and macronutrient concentrations and grain production in both varieties, they also suggest that in the OPV, the micronutrient concentrations appear to be linked to plant traits, whereas, in the commercial variety these concentrations were more closely associated with soil micronutrient concentrations. These results could suggest the selective breeding strategies for commercial maize favour nutrient up-take and grain yield at the expense of other traits (van Bueren *et al.*, 2011). Thus, when growing these varieties under conditions of slow nutrient release, the genetic traits of the plant that dictate its eco-physiology are important considerations in strategies for sustainable urban agriculture. For example, the differences observed in our trials could be due to higher arbuscular mycorrhizal fungi (AMF) colonization rates in the OPV, which has been shown in other OPVs grown alongside commercial hybrids (Hess *et al.*, 2005). If this were the case, it would also explain the observed differences between the two varieties in the take-up of Ni. The commercial variety accumulated larger concentrations of this metal unlike its open-pollinated counter-part (**Table 2, Figure 3**). While AMF colonization was not measured, this would be an interesting field for further research, as changes in Ni accumulation has been reported after AMF colonization (Ramírez-Flores et al., 2017).

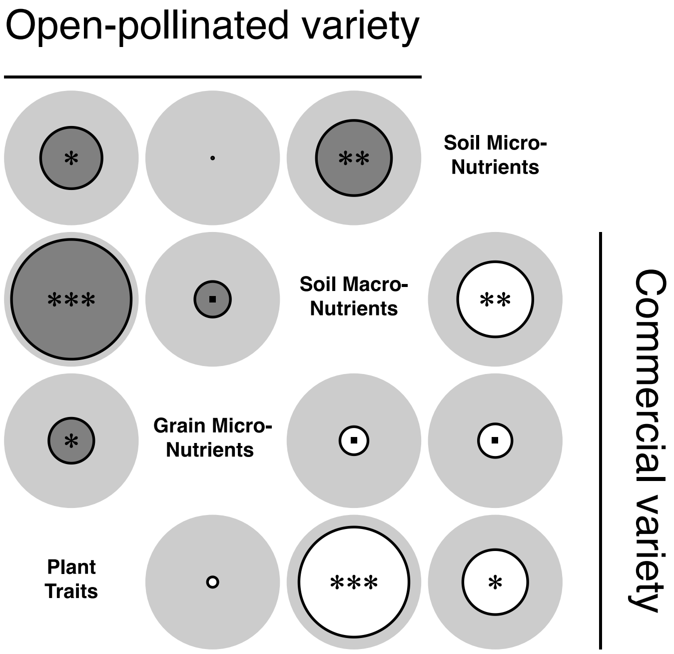


Figure 4: Schematic describing the relationships between two data matrices each, sphere size shows similarity (RV-coefficients), with the light grey spheres indicating a similarity of 100%. Dark grey spheres indicate open-pollinated variety, white spheres commercial variety. Three asterisks: $p < 0.001$, two asterisks: $p < 0.01$, one asterisk: $p < 0.05$, square: $p < 0.1$, n = 13 per variety.
Plant Traits = Plant Height; Number of Ears; Grain weight; Vegetative Plant Weight; total grain C, N and P. **Soil Macronutrients =** Soil organic matter (SOM), soil carbonates, total C, N, P, K, Ca, S, Mg. **Soil Micronutrients =** Na, B, Mn, Zn, Fe, Cu, Mo, Ni, Cd, Pb, Cr. **Grain Micronutrients =** Concentration of B, Mn, Zn, Fe, Cu, Mo, Ni, Mg, Ca, S, Na, K, Al in grain.

A multiple factor analysis (MFA) using data on grain nutrient concentrations and plant traits (**Figure 5, left**) revealed again a strong distinction between the OPV and commercial variety. The first dimension (X axis), explaining 41 % of the total variance separated OPV and commercial variety, while the second dimension (Y axis), explaining 28 % of the total variance, separated the different experimental treatments, in which the control plots were distinct from the two treatments. This orthogonal statistical response further underlines that variety effect and treatment effect were independent, with varieties being clearly separated by grain nutrient content (52 %) as well as C, N and P concentration and the number of ears per plant (46 %) (**Figure 5, right**). Accordingly, the nutrient status of the grain is linked primarily to plant variety, while indicators of plant productivity, such as plant height and weight as well as grain weight per plant, are mainly related to the treatments applied. As development of multi-nutrient rich strains of maize is of utmost importance for the sustainable nutrition of the global population (Jaradat et al., 2018), this pattern underlines the recently proposed selection of OPVs as a good way forward to achieve this feat (Puglisi et al., 2018). Also, the clear, positive effect of both compost types on the yield of both maize varieties measured here, contributes to evidence from recently published work on the feasibility of using GWC in periurban farming (Eldrige et al., 2018). Lastly, as the GWC used in this project was derived from a locally invasive plant (*A. longifolia*) and had no adverse effects on maize growth, e.g. similar responses than MC, these results add to recent work about its possible usage in agriculture or horticulture (Brito et al., 2015).

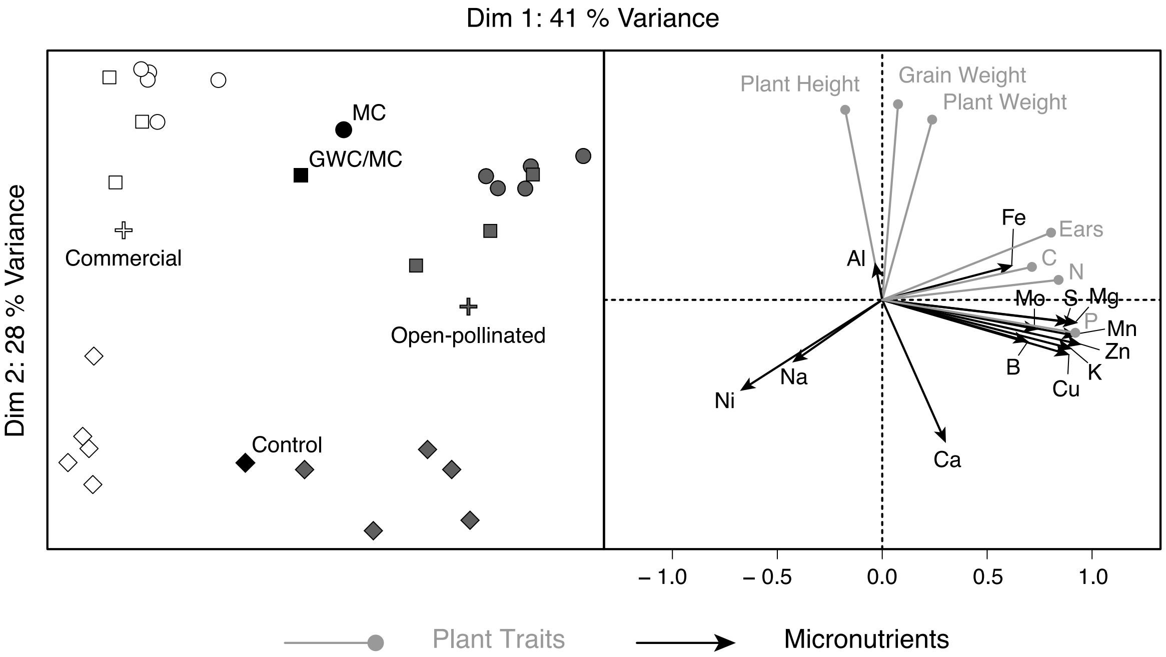


Figure 5: Multiple factor analysis (MFA) of variables related with the maize plants (n = 13 per plant variety). The three groups used in this MFA were:
Grain micronutrient content = B, Mn, Zn, Fe, Cu, Mo, Ni, Mg, Ca, S, Na, K, Al
Plant traits = plant height, plant weight, grain weight, number of ears, total C, N, P
Factors = treatments, varieties
Left: Individual factor map, including the centroids of the varieties (crosses), the individual data points of open-pollinated (grey) and commercial (white) maize varieties and the treatment centroids in black (sphere = municipal compost, square = municipal compost and green waste mix, diamond = untreated soil)
Right: Correlation cycle of all variables used.

4.4. Conclusions

This study demonstrated that it is possible to cultivate a staple food crop (*Zea Mays*) with adequate yields (up to 8.3 t/ha) in an urban setting, using only MC and GWC from nearby sources. As fertilization was based solely on soil amendments from composted food and green waste, this helps to achieve sustainable urban consumption patterns by recycling organic waste while increasing soil organic matter (up to 4 fold), thus mitigating GHG emissions. Furthermore, comparing an OPV and a commercial maize variety, it was found that the former exhibits higher nutrient use efficiency and increased macro- and micronutrient concentrations without accumulating heavy metals. It was found that this effect was variety and not treatment dependent, which points to OPVs as potentially interesting candidates for biofortified staple crops. In conclusion, this work contributes to a growing body of scientific evidence supporting alternative methods of intensive sustainable farming that can be adapted to urban landscapes.

Acknowledgements

We would like to thank the Faculdade de Ciências da Universidade de Lisboa for the permission to set up the plots on the faculties' campus. Also, we would like to thank the association "Colher para Semear" (https://colherparasemear.wordpress.com/) for providing the open-pollinated seeds, as well the start-up 2AdaPt (http://2adapt.pt) for logistic support and all volunteers and guardians of the HortaFCUL permaculture project (http://hortafcul.wixsite.com/home) for their help in setting up and maintaining the plots. We also would like to thanks Fundação para a Ciência e Tecnologia for supporting the PhD grant PD/BD/106061/2015 of FU, PhD grant PD/BD/52595/2014 of DA, as well as FCT Investigator contract (IF/00940/2015) of GPL.

References

Adhikari, B.K., Trémier, A., Martinez, J., Barrington, S., 2010. Home and community composting for on-site treatment of urban organic waste: perspective for Europe and Canada. Waste Management & Research. 28, 1039-1053.

Akinwale, R.O., Adewopo, O.A., 2016. Grain iron and zinc concentrations and their relationship with selected agronomic traits in early and extra-early maize. Journal of Crop Improvement. 30, 641-656.

Alvey, A.A., 2006. Promoting and preserving biodiversity in the urban forest. Urban Forestry & Urban Greening. 5, 195-201.

Barker, A.V., Pilbeam, D.J., 2015. Handbook of plant nutrition. CRC press, Boca Raton.

Bedada, W., Karltun, E., Lemenih, M., Tolera, M., 2014. Long-term addition of compost and NP fertilizer increases crop yield and improves soil quality in experiments on smallholder farms. Agriculture, Ecosystems & Environment. 195, 193-201.

Beniston, J.W., Lal, R., Mercer, K.L., 2016. Assessing and managing soil quality for urban agriculture in a degraded vacant lot soil. Land Degradation & Development. 27, 996-1006.

Bloem, S., de Pee, S., 2017. Developing approaches to achieve adequate nutrition among urban populations requires an understanding of urban development. Global Food Security. 12, 80-88.

Bong, C.P.C., Lim, L.Y., Ho, W.S., Lim, J.S., Klemeš, J.J., Towprayoon, S., Ho, C.S., Lee, C.T., 2017. A review on the global warming potential of cleaner composting and mitigation strategies. Journal of Cleaner Production. 146, 149-157.

Brites, C., Trigo, M.J., Santos, C., Collar, C., Rosell, C.M., 2010. Maize-based gluten-free bread: influence of processing parameters on sensory and instrumental quality. Food and Bioprocess Technology. 3, 707-715.

Brito, L.M., Mourão, I., Coutinho, J., Smith, S.R., 2015. Co-composting of invasive Acacia longifolia with pine bark for horticultural use. Environmental Technology. 36, 1632-1642.

van Bueren, E.L., Jones, S.S., Tamm, L., Murphy, K.M., Myers, J.R., Leifert, C., Messmer, M.M., 2011. The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: a review. NJAS-Wageningen Journal of Life Sciences. 58, 193-205.

Coleman M, Meier-Augenstein W. 2014. Ignoring IUPAC guidelines for measurement and reporting of stable isotope abundance values affects us all, Letter to the Editor, Rapid Communications in Mass Spectrometry. 28, 1953-1955

Costa, C., Reis, A.P., Da Silva, E.F., Rocha, F., Patinha, C., Dias, A.C., Sequeira, C., Terroso, D., 2012. Assessing the control exerted by soil mineralogy in the fixation of potentially harmful elements in the urban soils of Lisbon, Portugal. Environmental Earth Sciences. 65, 1133-1145.

EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain)., 2015. Scientific Opinion on the risks to public health related to the presence of nickel in food and drinking water. EFSA Journal 2015. 13, 202.

Eldridge, S.M., Chan, K.Y., Donovan, N.J., Saleh, F., Orr, L. Barchia, I., 2018. Agronomic and economic benefits of green-waste compost for peri-urban vegetable production: implications for food security. Nutrient Cycling in Agroecosystems. 111, 155-173.

Dow Chemical, 2018. http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_098b/0901b8038098b998.pdf?filepath=styrofoam/pdfs/noreg/291-42625.pdf&fromPage=GetDoc. (accessed 25 October 2018)

Fitzstevens, M.G., Sharp, R.M., Brabander, D.J., 2017. Biogeochemical characterization of municipal compost to support urban agriculture and limit childhood lead exposure from resuspended urban soils. Elementa Science of the Anthropocene, 5. http://doi.org/10.1525/elementa.238 (accessed 25 October 2018)

Flint-Garcia, S.A., 2017. Kernel Evolution: From Teosinte to Maize. In: Larkins, B.A. (Ed.), Maize Kernel Development. CABI, Oxfordshire, pp. 1-15.

Food and Agriculture Organization of the United Nations and World Health Organization., 2005. Vitamin and mineral requirements in human nutrition. http://apps.who.int/iris/bitstream/handle/10665/42716/9241546123?sequence=1/ (accessed 10 September 2018)

Food and Agriculture Organization of the United Nations., 2013. The state of food and agriculture. Rome. http://www.fao.org/docrep/018/i3300e/i3300e.pdf (accessed 10 September 2018)

Food and Nutrition Board, Institute of Medicine., 2000. Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium and zinc. Washington (D.C.): National Academies Press. Food and Nutrition Board, Institute of Medicine. https://www.nap.edu/read/10026/chapter/1 (accessed 10 September 2018)

Forte, A., Fagnano, M., Fierro, A., 2017. Potential role of compost and green manure amendment to mitigate soil GHGs emissions in Mediterranean drip irrigated maize production systems. Journal of Environmental Management. 192, 68-78.

Gu, R., Chen, F., Liu, B., Wang, X., Liu, J., Li, P., Pan, Q., Pace, J., Soomro, A.A., Lübberstedt, T., Mi, G., 2015. Comprehensive phenotypic analysis and quantitative trait locus identification for grain mineral concentration, content, and yield in maize (Zea mays L.). Theoretical and Applied Genetics. 128, 1777-1789.

Hess, J.L., Shiffler, A.K., Jolley, V.D., 2005. Survey of mycorrhizal colonization in native, open-pollinated, and introduced hybrid maize in villages of Chiquimula, Guatemala. Journal of Plant Nutrition. 28, 1843-1852.

Heiri, O., Lotter, A.F., Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. Journal of Paleolimnology. 25, 101-110.

Hindu, V., Palacios-Rojas, N., Babu, R., Suwarno, W.B., Rashid, Z., Usha, R., Saykhedkar, G.R. and Nair, S.K., 2018. Identification and validation of genomic regions influencing kernel zinc and iron in maize. Theoretical and Applied Genetics. 1-15.

Jaradat, A.A., Goldstein, W., 2018. Diversity of maize kernels from a breeding program for protein quality III: Ionome profiling. Agronomy. 8, 9.

Knorr, D., Khoo, C.S.H., Augustin, M.A., 2018. Food for an Urban Planet: Challenges and Research Opportunities. Frontiers in Nutrition. 4, 73.

Lê, S., Josse, J., Husson, F., 2008. FactoMineR: An R Package for Multivariate Analysis. Journal of Statistical Software. 25, 1-18.

Lim, S.L., Lee, L.H., Wu, T.Y., 2016. Sustainability of using composting and vermicomposting technologies for organic solid waste biotransformation: recent overview, greenhouse gases emissions and economic analysis. Journal of Cleaner Production. 111, 262-278.

Marles, R.J., 2017. Mineral nutrient composition of vegetables, fruits and grains: The context of reports of apparent historical declines. Journal of Food Composition and Analysis. 56, 93-103.

Marschner, H., 2012. Marschner’s mineral nutrition of higher plants. Elsevier, Amsterdam.

Omondi, E.C., Norton, J.B., Ashilenje, D.S., 2014. Performance of a local open pollinated maize variety and a common hybrid variety under intensive small-scale farming practices. African Journal of Agricultural Research. 9, 950-955.

Patto, M.C.V., Moreira, P.M., Almeida, N., Satovic, Z., Pego, S., 2008. Genetic diversity evolution through participatory maize breeding in Portugal. Euphytica. 161, 283-291.

Pixley, K.V., Bjarnason, M.S., 2002. Stability of grain yield, endosperm modification, and protein quality of hybrid and open-pollinated quality protein maize (QPM) cultivars. Crop Science. 42, 1882-1890.

Preston T, Owens NJP. 1983. Interfacing an automatic elemental analyser with an isotope ratio mass spectrometer: the potential for fully automated total nitrogen and nitrogen-15 analysis. Analyst. 108, 971–977.

Puglisi, D., Landoni, M., Cassani, E., Toschi, I., Lucchini, G., Cesari, V., Borlini, G., Scapin, A., Pilu, R., 2018. Traditional farmers' varieties: a valuable source of genetic variability for biofortification programs. Maydica. 63, 10.

Rahmann, G., Ardakani, M.R., Bàrberi, P., Boehm, H., Canali, S., Chander, M., David, W., Dengel, L., Erisman, J.W., Galvis-Martinez, A.C., Hamm, U., 2017. Organic Agriculture 3.0 is innovation with research. Organic Agriculture. 7, 169-197.

R Core Team., 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Ramos, M., 2016. Contribuição para a conservação sustentável de ecossistemas dunares invadidos por Acacia longifolia (MSc dissertation). http://repositorio.ul.pt/bitstream/10451/27479/1/ulfc120778_tm_Mariana_Ramos.pdf (accessed 10 September 2018)

Ramírez-Flores, M.R., Rellán-Álvarez, R., Wozniak, B., Gebreselassie, M.N., Jakobsen, I., Olalde-Portugal, V., Baxter, I., Paszkowski, U., Sawers, R.J., 2017. Co-ordinated Changes in the Accumulation of Metal Ions in Maize (Zea mays ssp. mays L.) in Response to Inoculation with the Arbuscular Mycorrhizal Fungus Funneliformis mosseae. Plant and Cell Physiology. 58, 1689-1699.

Reyes-Torres, M., Oviedo-Ocaña, E.R., Dominguez, I., Komilis, D., Sánchez, A., 2018. A systematic review on the composting of green waste: Feedstock quality and optimization strategies. Waste Management. https://doi.org/10.1016/j.wasman.2018.04.037 (accessed 25 October 2018)

Ribas-Agustí, A., Seda, M., Sarraga, C., Montero, J.I., Castellari, M., Muñoz, P., 2017. Municipal solid waste composting: Application as a tomato fertilizer and its effect on crop yield, fruit quality and phenolic content. Renewable Agriculture and Food Systems. 32, 358-365.

Röös, E., Mie, A., Wivstad, M., Salomon, E., Johansson, B., Gunnarsson, S., Wallenbeck, A., Hoffmann, R., Nilsson, U., Sundberg, C. and Watson, C.A., 2018. Risks and opportunities of increasing yields in organic farming. A review. Agronomy for Sustainable Development. 38, 14.

Satterthwaite, D., McGranahan, G., Tacoli, C., 2010. Urbanization and its implications for food and farming. Philosophical Transactions of the Royal Society of London B: Biological Sciences. 365, 2809-2820.

Seto, K.C., Ramankutty, N., 2016. Hidden linkages between urbanization and food systems. Science. 352, 943-945.

Skevas, T., Fevereiro, P., Wesseler, J., 2010. Coexistence regulations and agriculture production: A case study of five Bt maize producers in Portugal. Ecological Economics. 69, 2402-2408.

Tóth, G., Hermann, T., Da Silva, M. R., Montanarella, L., 2016. Heavy metals in agricultural soils of the European Union with implications for food safety. Environment International. 88, 299-309.

Tsvetkov, I., Atanassov, A., Vlahova, M., Carlier, L., Christov, N., Lefort, F., Rusanov, K., Badjakov, I., Dincheva, I., Tchamitchian, M., Rakleova, G., 2018. Plant organic farming research–current status and opportunities for future development. Biotechnology & Biotechnological Equipment. 32, 241-260.

UNE-EN ISO/IEC 17025, 2018. https://www.iso.org/obp/ui/#iso:std:iso-iec:17025:ed-3:v1:en. (accessed 10 September 2018)

United Nations Human Settlements Programme, 2010. State of the World's Cities 2010/11: Cities for All: Bridging the Urban Divide. Earthscan, London.

Valorsul, 2018. http://www.valorsul.pt/pt/seccao/areas-de-negocio/produtos/ricaterra-corretivo-agricola-organico/ (accessed 25 October 2018).

Wei, Y., Li, J., Shi, D., Liu, G., Zhao, Y., Shimaoka, T., 2017. Environmental challenges impeding the composting of biodegradable municipal solid waste: A critical review. Resources, Conservation and Recycling. 122, 51-65.

Highlights

- Open-pollinated and commercial maize were grown using compost in an urban setting.
- Municipal compost and a mix of green waste compost were tested.
- Maize grain production and vegetative growth was similar on both compost treatments.
- Nitrogen and micronutrient concentrations were higher in open-pollinated maize grain.
- Grain micronutrient levels were high in open-pollinated maize, independent of treatment.

Figure 1

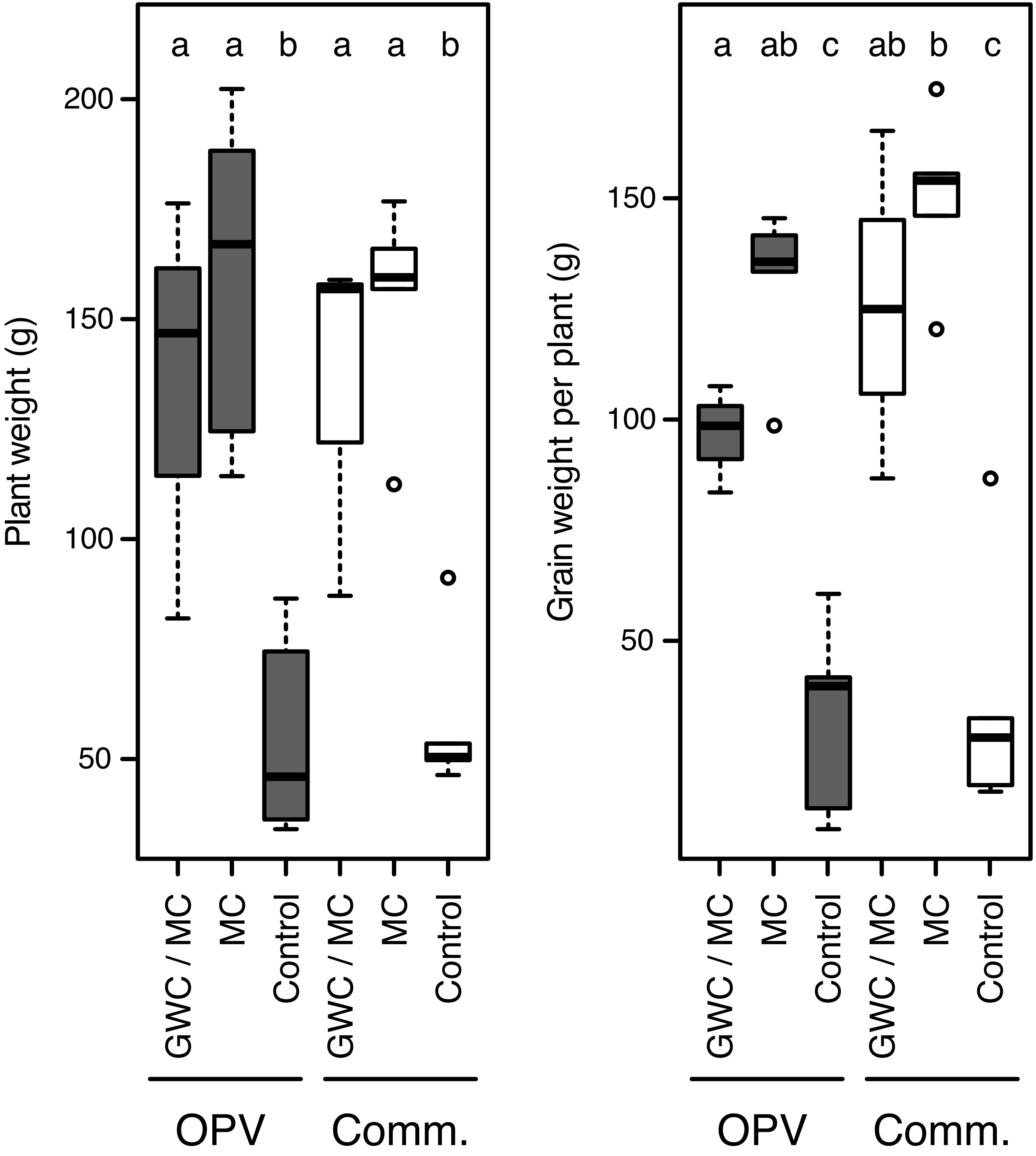

a
a
b
a
a
b
200
150
100
50
Plant weight (g)
GWC / MC
MC
Control
GWC / MC
MC
Control
OPV
Comm.
a
ab
c
ab
b
c
150
100
50
Grain weight per plant (g)
GWC / MC
MC
Control
GWC / MC
MC
Control
OPV
Comm.

Figure 2

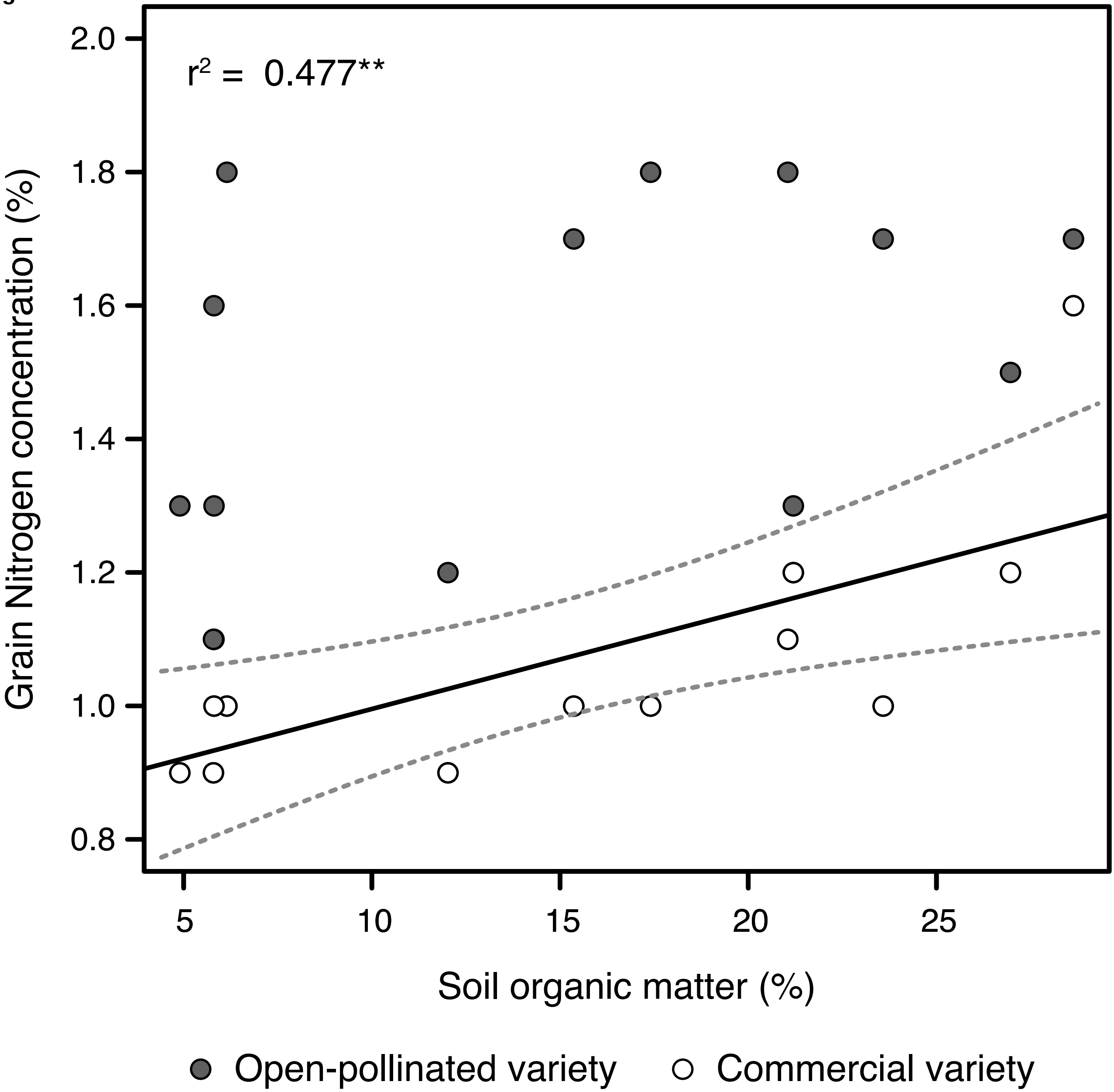

r² = 0.477**
Grain Nitrogen concentration (%)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
5
10
15
20
25
Soil organic matter (%)
● Open-pollinated variety
○ Commercial variety

Figure 3


Open-pollinated variety
Commercial variety
K
Ca
P
S
N
Mg
Ni
Na
B
Mo
Cu
Fe
Zn
Mn
K
Ca
P
S
N
Mg
Ni
Na
Mo
B
Cu
Mn
Fe
Zn
r_s=
0.6
0.7
0.8
positive correlation =
negative correlation =

Figure 4

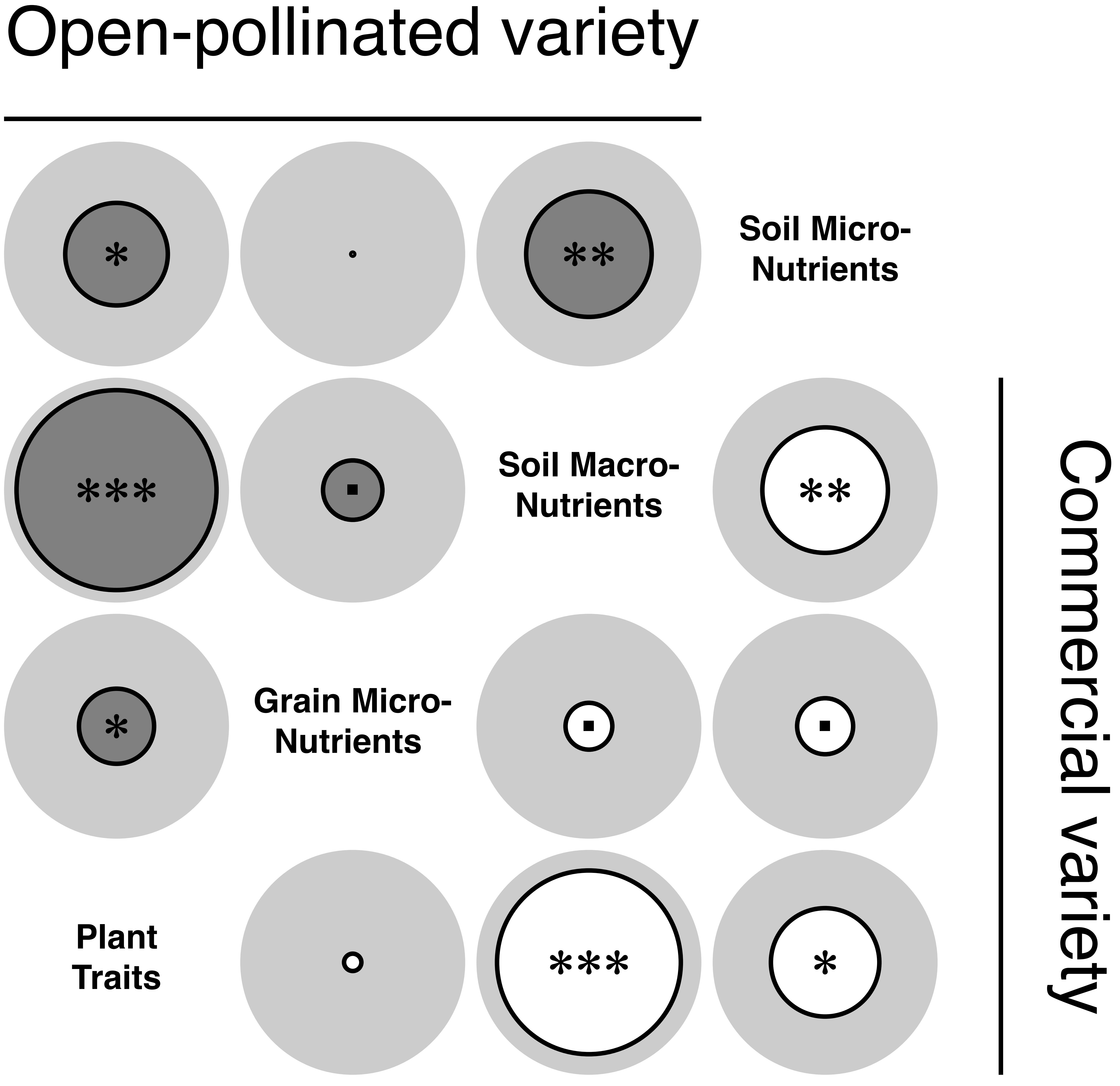
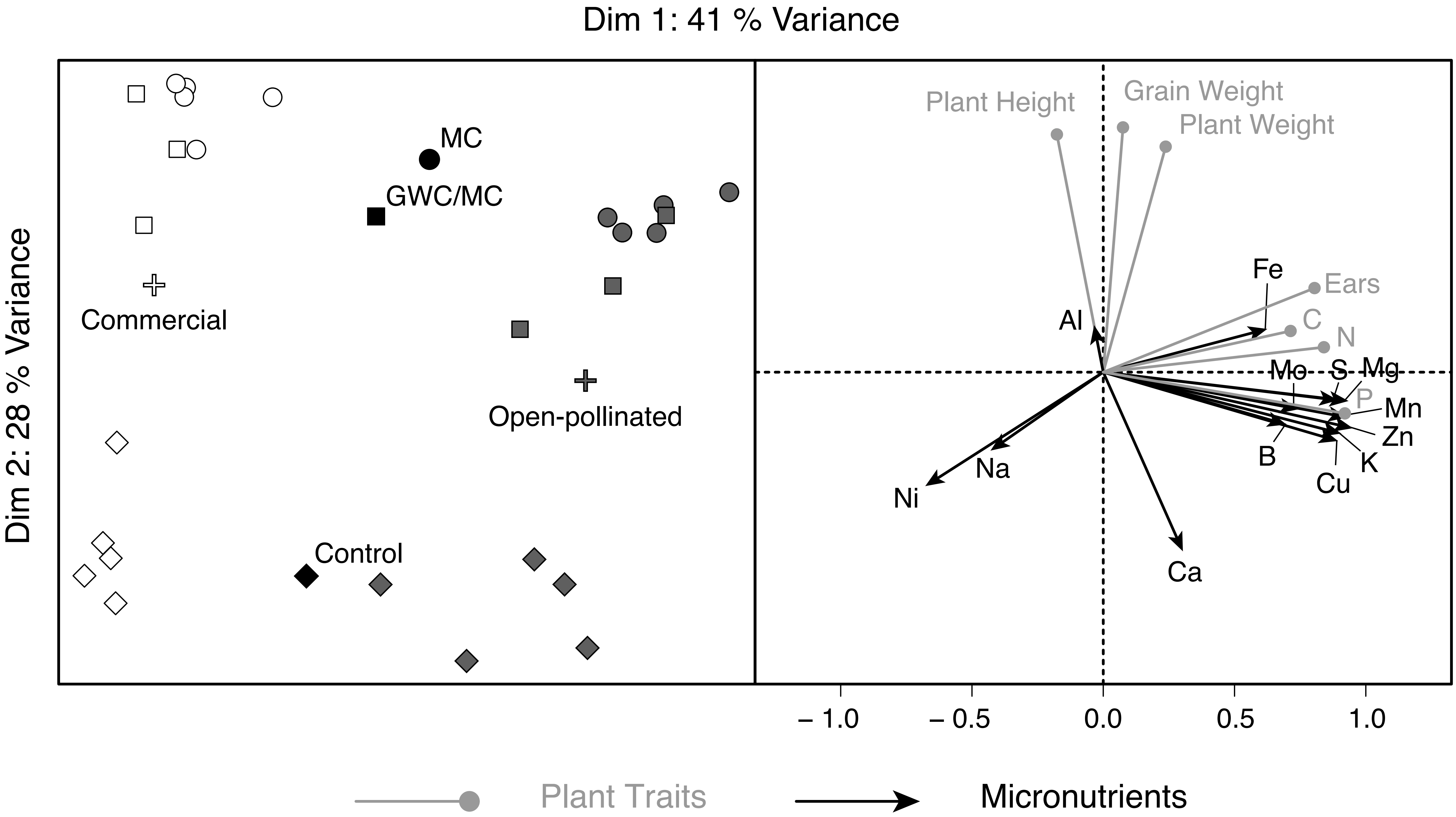

Open-pollinated variety
*
**
Soil Micro-Nutrients
***
Soil Macro-Nutrients
**
*
Grain Micro-Nutrients
Plant Traits
***
*
Commercial variety

Figure 5


Dim 1: 41 % Variance
Dim 2: 28 % Variance
MC
GWC/MC
Commercial
Open-pollinated
Control
Plant Height
Grain Weight
Plant Weight
Fe
Ears
Al
C
N
Mo
S
Mg
P
Mn
Zn
K
Cu
B
Na
Ni
Ca
– 1.0
– 0.5
0.0
0.5
1.0
Plant Traits
Micronutrients