Effects of plastic fragment size and concentration on plant performance are mediated by soil properties and water availability

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Abstract

Purpose: Increasing attention has been devoted to the effects of plastic contamination on soil water content and plant performance. However, little is known about how plastic in soil may interact with climate change factors, such as drought. We hypothesized that 1) Plastic affects soil water content negatively, and such effect is mediated by plastic size and concentrations, water availability and soil texture; 2) plants attain higher growth in soil where the negative effects of drought and plastic are small.

Methods: We tested the joint effects of water availability, soil texture, and plastic fragments (varying in concentration and size), on soil water content and growth of the model plant *Arabidopsis thaliana*.

Results: While increasing concentrations and size of plastic negatively affected soil water content, likely by favoring the formation of fractures within soil aggregates, they positively affected plant growth, likely by increasing soil porosity and facilitating root growth. In low water availability such responses were generally stronger, while soil texture mediated linear *vs.* unimodal responses in soil water content.

Conclusion: Plastic contamination in soil is bound to increase overtime, and it may interact with drought in affecting soil and plants in non-linear ways. This implies that plastic contamination may either amplify or mitigate the effects of climate change on plants, soil and their interactions.

Introduction

A major focus of ecological research is the study of plant responses to global change factors (Peñuelas et al., 2018; Pugnaire et al., 2019). While some of these factors, such as climate change, have been the focus of much research on plant communities, other novel stressors of anthropogenic origin have emerged only recently. Among those is plastic contamination in terrestrial environments (Baho et al., 2021; Rillig et al., 2021). Although the number of studies addressing the effect of plastic contamination on ecological communities is increasing, we have virtually no knowledge about the potential interactive effects of climate change factors, such as drought, and plastic contamination on soil and plants. This knowledge is urgently needed not only for understanding global change effects on natural ecosystems, and productivity of agricultural systems.

Since the 1950s, a steadily increasing amount of plastic waste has been introduced into the environment. The estimated global annual production of plastic has exceeded 300 million metric tons (Nizzetto et al., 2016; Geyer et al., 2017), and it is predicted to increase. Due to its high durability, plastic waste persists in the environment for a long time (Rillig et al., 2021), during which it breaks off in smaller particles largely variable in size (centimeters to micrometers), shape, and behavior (Barnes et al., 2009; Rillig, 2012; Souza Machado et al., 2019).

Although much knowledge on the effect of plastic contamination on the environment comes from research on aquatic systems (Baho et al., 2021), terrestrial ecosystems have been signaled as ‘major sinks’ of plastic debris (Buks et al., 2020; Evangeliou et al., 2020). A major input of plastic into terrestrial environments comes from agricultural practices, where the use of mulching foils is extensive (Steinmetz et al., 2016; Souza Machado, Kloas, et al., 2018; Qi et al., 2018). Mulching foils are large plastic sheets (chiefly composed of polyethylene) that are applied on the soil to reduce evaporation, stabilize temperature, hinder the growth of weeds, and optimize crop germination (Steinmetz et al., 2016; Qi et al., 2018; Weithmann et al., 2018). Though mulching foils are usually removed upon germination, they often break apart and leave behind many smaller fragments that are spread over space by wind and runoff (Allen et al., 2019; Evangeliou et al.,2020) or into deeper soil horizons by soil organisms (Kiyama et al., 2012; Helmberger et al., 2020). In agricultural areas, the annual consumption of mulching films varies between 5 and 35 kg ha^{-1}, amounting to plastic residuals in the range of 72–260 kg ha^{-1} (Liu et al., 2018). Thus, agricultural areas are potential hotspots of plastic contamination from which plastic debris can be dispersed into adjacent natural communities.

Experimental studies indicate that plastic fragments can affect several soil properties, such as soil porosity and soil water content (Lehman et al., 2019; Souza Machado, Lau, et al., 2018; Kim et al., 2021). Although, such effects vary in strength and direction depending on the properties of plastic fragments, e.g. shape, size, concentration and chemical composition (Lehman et al., 2021), studies have indicated that higher concentration and larger sizes of plastic fragments are associated with lower soil water content due to either increased evaporation or percolation (Souza Machado, Lau, et al., 2018, Wan et al., 2019; Lozano et al., 2021). When plastic fragments are incorporated in soil aggregates, they may favor the formation of fractures lines and thus reduce soil aggregate stability (Lehmann et al., 2019; Souza Machado et al., 2019; Wan et al., 2019; Liang et al., 2021; Lozano et al., 2021). This, in turn, leads to increased water loss when the presence of plastic results into the formation of larger soil pores, or in a decreased water loss when plastic fragments mediate the formation of smaller pores through which water moves more slowly. Therefore, soil texture might interact with the manner in which plastic affects soil water content, but little is known about this interaction.

Soil texture determines the spatial arrangement of soil aggregates and pore networks, affects soil water content, and the movement of water and nutrients in soils (Kemper, 1965; Rose & Rose, 2004). Clay-rich soils are characterized by smaller pores relative to sand-rich soils, and under optimal watering conditions, water percolates faster in sand-rich soils compared to clay-rich soils. However, under drought conditions clay-rich soils form larger aggregates, leading to wider soil pores and faster water loss (Horn et al., 1994; Beven & Germann, 1982). Thus, the effects of plastic fragments on soil properties may be mediated by soil texture (e.g. clay *vs.* sand content) and by the degree of water availability, giving rise to high context-dependence in such interactions.

Soil structure and soil water content are known to affect plant growth and performance (De Vries et al., 2012; Kaisermann et al., 2017; Martorell et al., 2021), and plastic fragments may influence such responses to an extent that is so far not fully understood (Rillig et al., 2019). On the one hand, plastic-mediated shifts in soil water content can either mitigate or amplify the effects of drought on plants. On the other hand, plastic fragments may facilitate the growth of roots by increasing the size and number of soil pores, thus attenuating the potential decline of soil water content. These processes can have long-term consequences on plant species and communities, especially in the context of climate-change-induced droughts (Lozano & Rillig, 2020). This is interesting, because negative effects of plastic on soil properties may be accompanied by effects on plants that are not necessarily negative.

We present the results of two experiments, where we tested the response of soil water content and plant performance to two water treatments (optimal *vs.* reduced) and two soil textures (clay-rich *vs.* sand-rich) contaminated with plastic fragments of varying concentration and size. We hypothesized that 1) the presence of plastic fragments leads to a decreased soil water content, and this effect is more pronounced a) when plastic fragments are present in higher concentrations or larger sizes, b) in clay-rich soils compared to sand-rich soils, c) in low compared to high water treatments; 2) plastic fragments have an indirect effect on plant performance, which is mediated by soil water content. Namely, plant performance is lower in treatments combinations where we expect soil water content to be reduced.

Material And Methods

To test if water availability and soil texture mediate the effects of plastic contamination on soil water content and plant performance, we set up two greenhouse experiments where we added plastic fragments in increasing concentration (*Experiment 1*) and increasing size (*Experiment 2*) to two soils differing in texture, and exposed them to two different watering treatments (Fig. 1).

Substrate preparation

To mimic different soil textures, we prepared two soil substrates by mixing sand and clay in different proportions. The sand-rich soil was obtained by mixing 70% sand and 30% clay in volume, and the clay-rich soil was obtained by reversing the ratios and mixing 70% clay and 30% sand in volume. The sand, which was purchased from the German company Flammer Bauunternehmung GmbH, originated from the Rhine river banks. The clay was purchased from the company Sand- und Kieselwerk Matthäus Bischoff GmbH & Co. KG. Before preparing the two soil mixtures, we autoclaved the sand for five hours at of 110°C, and we reduced the size of the clay aggregates first processing it through a soil shredder and then sieving it through a 5 mm mesh sieve. Subsequently, sand and clay were mixed in the prescribed proportions using a cement mixer. After mixing, the soil was checked again for large aggregates to guarantee an even texture.

Plastic fragments: To produce plastic fragments, we used a black low-density polyethylene (LDPE) mulching film (IsolenTM Premium Schwarz produced by Barbier Group, www.barbiergroup.com), with density between 0.915 to 0.935 g/cm^3 and thickness of 30 µm (as per product specification). Folded foils were perforated with a round hollow punch to produce fragments that were homogeneous in shape (circular) and varied in diameter: 4 mm, 6 mm and 8 mm (Supplementary Information Fig. 4). Fragments were subsequently inspected to separate multiple layers of film, when found stuck together. Plastic fragments were stored in previously sterilized glass jars for approximately three weeks. For *Experiment 1*, in which we manipulated the concentration of plastic fragments, we used plastic fragments 6 mm in size and mixed them with soil in four different concentrations of 0g/kg (control treatment), 1 g/kg (0.1% w/w), 5 g/kg (0.5% w/w) and 10 g/kg (1% w/w). These concentrations are consistent with environmentally relevant estimates under different levels of contamination (Scheurer & Bigalke 2018; Jambeck 2015; Fuller 2016). For *Experiment 2*, in which we manipulated the size of plastic fragments, we used fragments in concentration of 1 g/kg and mixed them with soil using the three different sizes produced (4 mm, 6 mm, 8 mm), and a control treatment where no plastic fragments were added. Plastic fragments were evenly incorporated into the two different soil substrates, and subsequently the different combinations of soil and plastic fragments were distributed into 0.3 l pots (diameter 9 cm, height 7 cm). Controls soils were mixed as well to account for the effect of soil mixing.

Watering treatments: We applied two watering treatments to simulate high water availability and drought. Pots assigned to the high water treatment received an amount in water corresponding to 75% of the mean pot saturation weight, whereas pots assigned to the low water treatment received an amount of water corresponding to 30% of mean pot saturation weight. Pots were watered three times a week to maintain a stable water level in soil and avoid pulses. Because water holding capacity changes depending on the clay:sand ratio, the actual watering amount changed with soil texture, but was kept constant across plastic treatments within each combination of soil texture and watering by means of weighting the pots weekly.

To disentangle the effects of plastic fragments on soil water content from those on plant performance, we prepared pots containing only soil but no plants. The combination of soil texture, plastic fragments (concentration or size) and watering resulted in 16 treatments for each experiment. All treatment combinations were applied to both planted and unplanted pots and were replicated ten times, resulting in 320 pots for each experiment. Pots were kept in a greenhouse at 20°C with a day/night cycle of 10 and 14 hours.

Target species

We used the phytometer *Arabidopsis thaliana var. columbia* for both experiments. Seeds of *A. thaliana* were sown in standard greenhouse soil and cold-stratified at 8°C for four days. Subsequently, they were moved to a climate chamber at 20–22°C for 11 days, and when they reached an appropriate size (15 days after sowing), they were transplanted individually in assigned pots. Before planting, seedlings' roots were quickly immersed in water to remove potential soil residues. During the first week after planting, any individual found dead was replaced. To minimize mortality, all pots were initially watered to saturation (i.e. 50 ml for pots with sand-rich soils and 60 ml for pots with clay-rich soils), and water treatments were imposed starting a week after transplanting. Plants received nutrients once a week (Wuxal® Super, liquid 8-8-6 NPK fertilizer) initially at a concentration of 5 ml/l, and subsequently at a concentration of 1 ml/l.

Measurements

All pots were weighed weekly, and the weight of unplanted pots was used as a proxy for soil water content. Measurements of plant diameter (cm) and height (cm) were taken weekly. Nine weeks after planting, we recorded the number of fruits produced and subsequently, we harvested plant above- and below-ground biomass (g). After washing the roots to remove soil and plastic fragments, all above- and below-ground biomass was oven dried at 70°C for 48 h, and weighed on a high precision scale (Kern 770/GS/GJ Version 2.1). Radial growth (cm) was estimated as the difference between the initial plant diameter and diameter measured on the seventh week of measurement. Root-to-total mass ratio was calculated as the proportion of root to total biomass weight.

Statistical analyses

We analyzed each experiment separately. We assessed correlations among response variables within each experiment using the R package *GGally* (Schloerke et al., 2021). Then, we tested the effects of soil texture, plastic fragments (concentration or size), watering treatment and all two-way and three-way interactions applying linear models for aboveground biomass, root-to-total mass ratio, radial growth and plant height, and generalized linear models with negative binomial distribution for number of fruits, using the R package *MASS* (Venables & Ripley, 2002). Aboveground biomass was square-root transformed to fulfill model assumptions. We built a separate model for each response variable.

Because the differences in pot weight within each treatment were consistent across time, we used final pot weight (g) as a proxy for soil water content. Soil water content was analyzed using linear models, as a function of soil texture, plastic fragments (concentration or size), water treatment and all two-way and three-way interactions. To test whether patterns of soil water content were consistent in planted and non-planted pots (i.e. accounting for potential effects of plant roots on soil aggregation and porosity) we applied the same model to the final weight of planted pots. All significant interactions were assessed with Tukey HSD posthoc tests using the R package *emmeans* (Lenth et al., 2021). Data analysis and visualization were carried out in the software R v. 4.1.2 (R Core Team, 2021) and the packages *tidyverse* (Wickham et al., 2018), *patchwork* (Pedersen, 2020), and *RColorBrewer* (Neuwirth, 2014).

Results

Effect of plastic fragments concentration and size on soil water content

Experiment 1: Effects of plastic fragments concentration

We found significant interactions between soil texture and watering treatment, and between soil texture and plastic concentration (Table 1, Fig. 2a). The mean difference in soil water content between water treatments was twice as large in clay-rich soil compared to sand-rich soil. In clay-rich soils we found a hump-shaped relationship between plastic concentration and soil water content in both water treatments. In particular, soil water content was lowest in control treatments (no plastic) and highest in the intermediate plastic concentrations (0.1 and 0.5%), with the highest plastic concentration (1%) in between. On the contrary, in sand-rich soils, the effect of plastic concentrations on soil water content decreased linearly with increasing plastic concentrations in both low- and high-water treatments. Results for pot weight of planted pots were largely consistent with those of unplanted pots (Supplementary Information, Table S1, Fig. 6a), with the exception of clay-rich soil in high water treatment, where we found a linear negative response of soil water content to plastic concentration.

Table 1
results of linear models for *Experiment 1*, testing the effects of water treatment ('watering'), soil texture ('soil') and concentration of plastic fragments ('plast_conc') on soil water content of unplanted pots and radial growth of *A. thaliana* plants. Significant effects ($p < 0.05$) are reported in bold.

Model terms	Soil water content			Radial growth		
	df	F.test	p.value	df	F.test	p.value
soil	1	295.10	**< 0.001**	1	18.26	**< 0.001**
watering	1	18.80	**< 0.001**	1	243.93	**< 0.001**
plast_conc	3	19.35	**< 0.001**	3	15.72	**< 0.001**
soil:watering	1	32.72	**< 0.001**	1	7.36	**0.008**
soil:plast_conc	3	22.86	**< 0.001**	3	3.28	**0.023**
watering:plast_conc	3	1.96	0.122	3	2.10	0.103
soil:watering:plast_conc	3	2.19	0.092	3	2.04	0.111

Experiment 2: Effects of plastic fragments size

We found a significant three-way interaction among soil texture, plastic size and watering treatment (Table 2, Fig. 2b). In both water treatments and across soil textures, the highest level of soil water content was found in pots with plastic fragments size 4 mm. In clay-rich soil, soil water content of pots treated with larger plastic fragments (6 mm and 8 mm) was not significantly different from control pots, and this was the case for both water treatments. In sand-rich soil, we found the larger differences in soil water content between control pots and plastic-treated pots compared to clay-rich soil. Such differences were comparatively larger in low water treatments compared to high water treatments. Results of pot weight for planted pots were very similar to those on unplanted pots, with the exception of clay-rich soil in low water treatments, where soil water content increased with plastic size (Supplementary Information, Table S2, Fig. 6b).

Table 2
results of linear models for *Experiment 2*, testing the effects of water treatment (‘watering’), soil texture (‘soil’) and size of plastic fragments (‘plast_size’) on soil water content of unplanted pots and radial growth of *A. thaliana* plants. Significant effects ($p < 0.05$) are reported in bold.

Model terms	Soil water content			Radial growth		
	df	**F.test**	**p.value**	**df**	**F.test**	**p.value**
soil	1	15.17	**< 0.001**	1	6.00	**0.016**
watering	1	76.64	**< 0.001**	1	481.75	**< 0.001**
plast_size	3	5.25	**0.002**	3	0.62	0.603
soil:watering	1	3.42	0.066	1	0.23	0.632
soil:plast_size	3	0.51	0.674	3	0.37	0.772
watering:plast_size	3	0.54	0.656	3	0.16	0.924
soil:watering:plast_size	3	4.50	**0.005**	3	1.07	0.366

Effect Of Plastic Fragments Concentration And Size On Plants

In both experiments, radial growth, above- and below-ground biomass, and plant height were strongly positively correlated (Supplementary Information, Fig. S7). Additionally, root-to-total ratio and number of fruits showed limited responses to the experimental factors and were not affected by plastic treatments. Thus, we present the results for radial growth only, while the other results are shown in the Supplementary Information, Appendix 1.

Experiment 1: Effect of plastic fragments concentration

We found significant two-way interactions between soil texture and water treatment, and between soil texture and plastic fragments concentration (Table 1, Fig. 3a). In both soil textures, plant growth was significantly higher in high water treatments, but the positive effects of high watering on plant growth were in average 35% higher in clay-rich compared to sand-rich soil.

In clay-rich soil, growth was consistently higher in plastic concentrations of 0.5% (5g/kg) and 1% (10g/kg) compared to the lowest concentration 0.1% and control treatments with no plastic. In sand-rich soil, plants attained the highest radial growth when exposed to the highest concentration of plastic fragments (i.e. 1%), compared to lower plastic concentrations and control treatments.

Experiment 2: Effect of plastic fragments size

When looking at the full dataset, we found that the effect water treatment was highly significant (Table 2, Fig. 3b), and its effect size was between 10 and 20 times stronger than the effects of soil texture and plastic size. To check whether the strong effect size of watering treatment masked smaller, yet potentially important, effects of soil texture and plastic size, we split the data across watering treatments, and tested the combined effects of plastic size and soil texture on plant growth. In low watering treatments (Supplementary Information, Fig. 5a), we found a significant interaction between soil texture and plastic size ($F_3 = 4.07$, $p = 0.012$), whereby in sand-rich soil plant growth was higher when plants were exposed to plastic fragments of size 6 mm and 8 mm (the two larger sizes) compared to control treatments (no plastic added) and plastic fragments of size 4 mm (the smallest fragments). Such differences among plastic treatments were not detected in clay-rich soil. In high watering treatments (Supplementary Information, Fig. 5b), we found a significant effect of soil texture, where growth was in average 10% higher in sand-rich soil compared to clay-rich soil ($F_1 = 32.02$, $p < 0.001$).

Discussion

Our overall results indicate that soil texture modulated the effects of plastic fragments both on soil and plants, and that at least some of the responses were amplified under low water availability. However, not all these effects were in the direction we initially hypothesized. In the following, we discuss our findings with respect to our initial hypotheses.

Effect of plastic fragments concentration and size on soil water content

Soil texture did not modulate the strength of soil response to plastic treatments, but it mediated different response patterns to plastic concentration, where in clay-rich soils we observed a hump-shaped response and in sand-rich soils a linear response. These results suggest the importance of accounting not only for different levels of plastic contamination, but also for different soil texture.

Increasing plastic concentration and size were associated with higher soil water loss. However, with the exception of sand-rich soils in *Experiment 1*, control treatments had consistently the lowest levels of soil water content. Increased soil water content in low concentrations of plastic fragments, was also found for different types of plastic materials in in a study by Souza Machado et al. (2019), but was not detected for polyethylene fragments (Wan et al., 2019). Previous studies have suggested that high concentration and size of plastic fragments may favor soil water loss by means of hindering the process of soil aggregation (Lehmann et al., 2019; Lozano et al., 2021) and contributing to an increased number and size of soil pores through which water percolates or evaporates. Also, non-linear responses of soil to increasing size and concentration of plastic have been previously observed (Souza Machado, Lau, et al., 2018), and have been motivated by the fact that adding plastic fragments to soil elicits changes to multiple abiotic and biotic soil properties simultaneously. To date, however, it is not yet possible to fully disentangle such interactions due to the high complexity of soil systems.

In general, the effect of plastic treatments on soil water content was stronger in low water treatments, but the role of water availability in mediating the effects of plastic contamination on soil was subtler than we anticipated. Drought, similarly to plastic contamination, affects soil aggregation and wettability (Denef et al., 2001), thus the effects of low water availability on soil properties may be amplified by the presence of plastic fragments. However, both plastic contamination and drought have been also linked with different effects on the composition of soil microbial communities (Ochoa-Hueso et al., 2018; Naylor & Coleman-Derr, 2018; Fu et al., 2022; Lin et al., 2020). Thus, the interaction among these two factors may lead to changes in soil abiotic and biotic properties that are complex and difficult to predict. This suggests that the effects of plastic contamination on soil properties may be amplified under drought, with potential implications for climate change responses in soil and plant communities.

Effect Of Plastic Fragments Concentration And Size On Plants

Surprisingly, plants grew more when exposed to the higher concentrations of plastic fragments and, to a smaller extent, to larger plastic sizes. Namely, plants grew more in combinations of soil texture and plastic fragments where soil water content was found to be the lowest. This is opposite to previous results showing negative impacts of plastic on plant growth (Boots et al., 2019; Bosker et al., 2019). Souza Machado et al. (2019) found increased root biomass in plastic treated soil, which could be indication of plant response to increased water stress, whereas Lozano et al. (2021) suggested that increased plant biomass in soil containing microplastic may be due to plants alleviating soil water loss. In our study we did not find indication of increased investment in root biomass in the presence of plastic, and soil water content was similar among planted and unplanted pots. The only instances in which soil water content of planted pots showed a different pattern compared to unplanted pots (i.e. Experiment 2 in clay-rich soil and low water treatment), did not correspond with significant effects of plastic on plant growth. These results suggest that plastic may have mediated shifts in soil properties other than soil water content, which had an effect plant growth. For example, high concentration or size of plastic fragments may have reduced resistance of soil to root penetration, thus facilitating plant growth (Zimmerman & Kardos, 1961; Ruser et al., 2008). Additionally, the presence of polyethylene films in soil was associated with increased abundance of Proteobacteria (Huang et al., 2019), a group of plant-growth promoting bacteria (Fierer et al., 2007; Hortal et al., 2013).

While the effect of soil texture mediated in some cases the pattern of soil and plant response to plastic contamination, watering treatment modulated the strength of this response. This introduces a series of methodological considerations. First, accounting for soil texture is essential to understanding if and how patterns of plant and soil responses to plastic contamination may vary across soils, and may help reconcile several contrasting results in the existing literature (e.g. Machado 2019; Lozano 2021), where experiments were conducted using one type of substrate. Second, water availability appeared to have a stronger effect than plastic contamination in our experiments, and this was particularly the case in *Experiment 2*, where we applied the lowest of the concentrations of plastic fragments used in this study

(1 g/kg). While this concentration corresponds to high levels of contamination for natural areas, and possibly also for agroecosystems (Scheurer & Bigalke, 2018; Jambeck et al., 2015; Fuller & Gautam, 2016), we cannot exclude that such levels of contamination may be reached or surpassed in a not so distant future, given the increasing accumulation of plastic in the environment (Geyer et al., 2017). Thus, it would be advisable that future studies consider how optimal levels of watering may mask the subtle, yet present, effects of plastic contamination on soil water content and plant growth.

Our results present a clear proof of concept of the potential combined effects of water availability and plastic contamination on soil properties and plant performance. Namely, increasing size and concentration of plastic fragments had a non-linear effect on soil water content, however such pattern was not reflected in plant growth response, suggesting that plastic may modify other biotic and abiotic properties of soil important for plant performance. Finally, water availability mediated the magnitude of soil response to plastic concentration, which in the light of predicted increases of climate change-induced drought and growing amounts of plastic contamination, even in pristine areas, may lead to complex and hard to predict effects on plant and soil communities.

Declarations

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Author Contributions: ST conceived the idea and designed the methodology, with support from MM and KT; AK and US set up the experiments and collected the data; ST, AK, US analysed the data; ST led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for submission.

Data Availability Statement: data will be uploaded on the Dryad Digital Repository upon manuscript acceptance.

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Figures

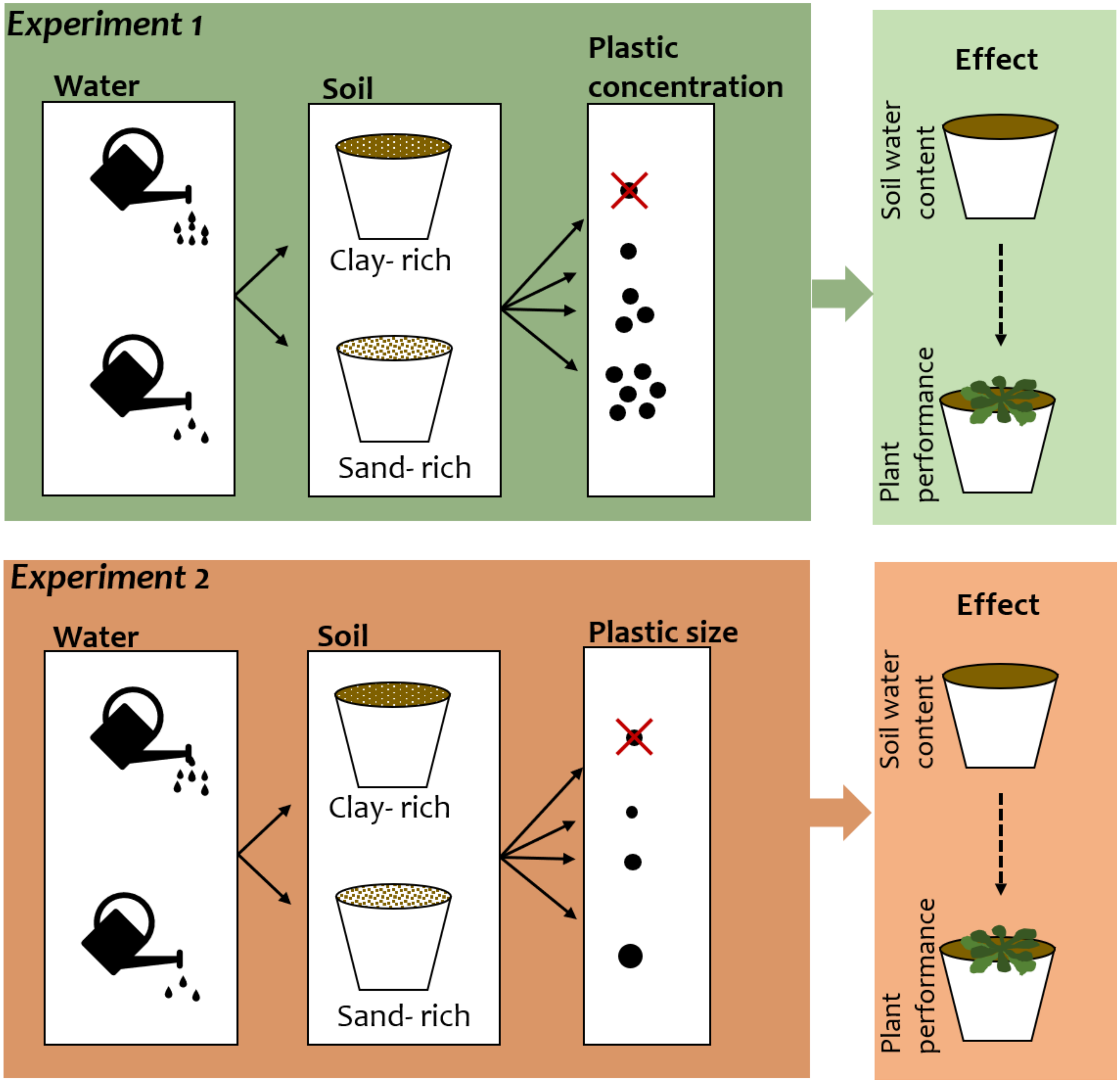

Figure 1

Scheme of the two experiments, where we tested how soil water content and plant performance respond to different levels of water availability (low *vs.* high), soil texture (clay-rich *vs.* sand-rich) and plastic concentration (*Experiment 1*) or plastic size (*Experiment 2*).

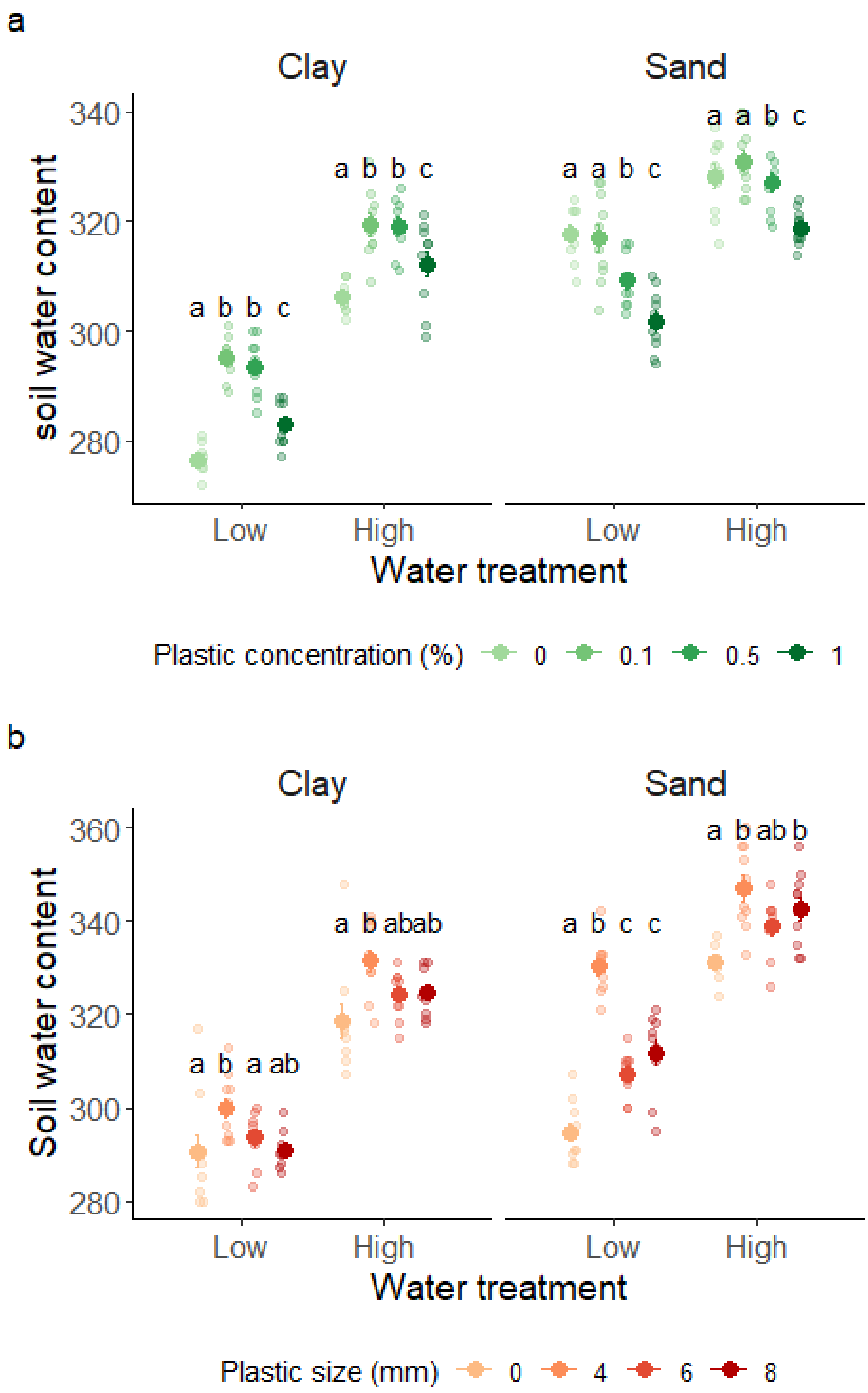

Figure 2

Plots showing mean ± 1SE soil water content (for which pot weight was used as a proxy) of unplanted pots, as a function of water treatment, soil texture and plastic fragments' concentration (a) or size (b). Results of significant differences ($p < 0.05$) for pairwise comparisons of the effects of plastic fragments within each combination of soil texture and water treatment are reported with different letters. Semi-transparent dots represent the raw data. Lower pot weight represents a proxy for lower soil water content.

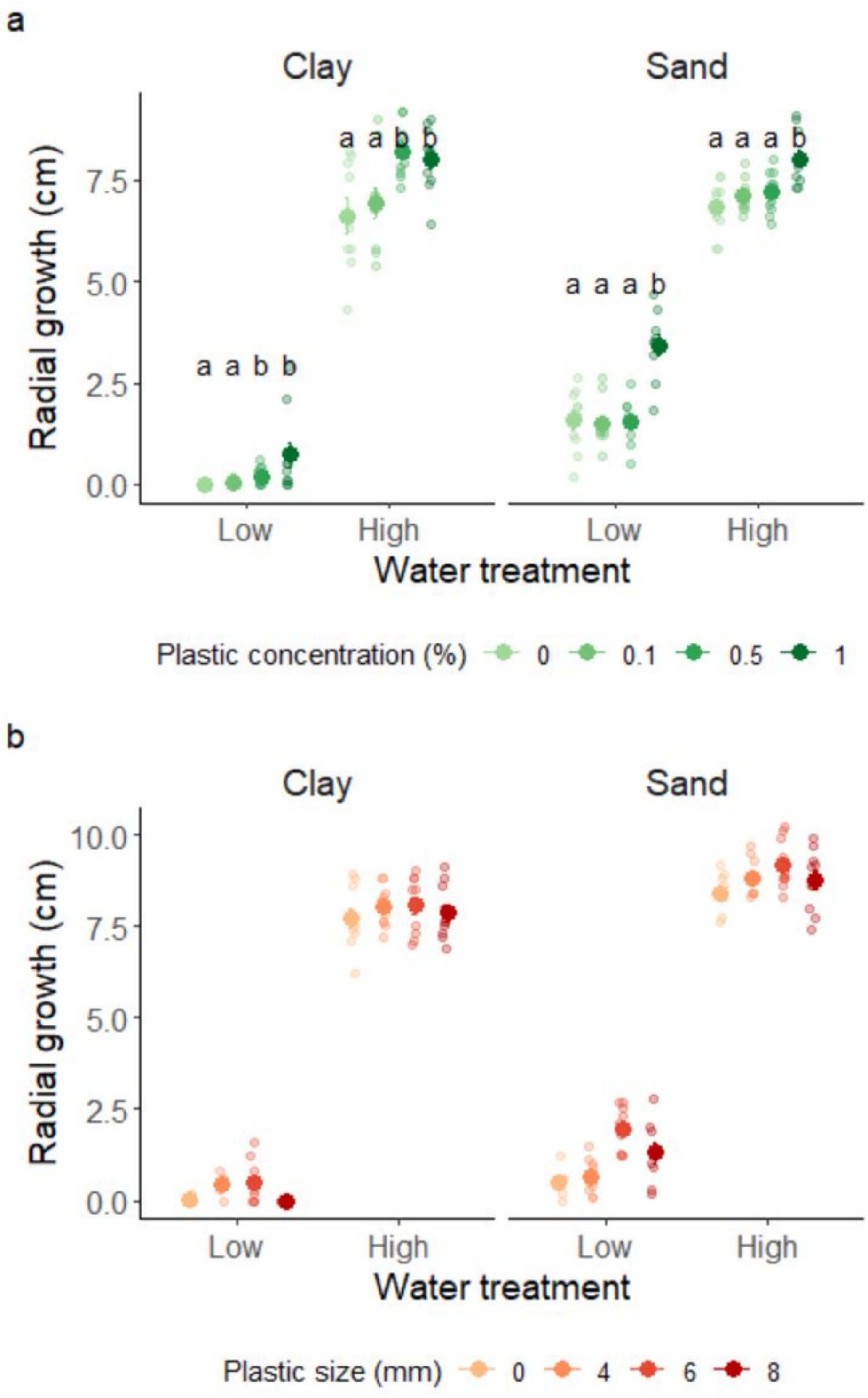

Figure 3

Plots showing mean ±1SE radial growth of *A. thaliana* as a function of water treatment, soil texture and plastic fragments' concentration (a) or size (b). Results of significant differences ($p< 0.05$) for pairwise comparisons of the effects of plastic fragments within each combination of soil texture and water treatment are reported with different letters. Semi-transparent dots represent the raw data.

Supplementary Files

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