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Half of the (big) picture is missing!

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Running head: Half of the (big) picture is missing!

Key words: Belowground organs, coarse roots, fine roots, plant drawing, rhizomes, tubers
Despite advances in visualization techniques, drawings are still an important tool for generalization and simplification of concepts in plant sciences. Therefore, a correct illustration is key for a comprehensive and realistic understanding of plant forms and functions. Conversely, graphical misrepresentation of plants can have a large, detrimental impact on communication among researchers, hindering the correctness and comparability across studies. It is interesting that although we demand accuracy in scientific communication, plants are often portrayed with mistakes or unrealistically. This concern is particularly relevant for belowground plant parts and organs.

Plants are often illustrated as if belowground parts are formed by fine roots only. This may reflect an unbalanced focus of ecologists on fine roots while overlooking coarse, non-acquisitive roots and belowground stems (Fig. 1; Laliberté, 2017; Freschet and Roumet, 2017; Klimešová et al., 2018). Thick roots, rhizomes, bulbs and tubers rarely play a role in absorbing water and nutrients, but can affect resource acquisition by determining fine root placement and longevity (Klimešová et al., 2018). Most importantly, these coarse organs do provide other key functions including anchorage in the soil, connection and transport of resources to aboveground parts, storage of carbohydrates and of buds for resprouting, space occupancy, resource sharing, and support for fine root placement in the soil (Klimešová et al., 2018; Pausas et al. 2018). For example, the acquisitive properties of a root system are affected by the growth direction of coarse roots; a horizontal growth direction will result in a shallow root system while an oblique growth direction will distribute fine roots in the lower soil horizons.

Additionally, acquisitive and non-acquisitive belowground plant parts and organs are tightly interconnected; fine roots (acquisitive function) and coarse organs (e.g. thick roots, rhizomes; non-acquisitive functions) can greatly tradeoff (e.g. de la Riva et al., 2016). This implies that, for instance, resource acquisition can be largely affected by other functions. A good example is represented by root foraging; plants capable of resource sharing through rhizomes tend to invest less in foraging for nutrients through fine roots (Weiser et al., 2016). In addition to their role in plant functioning, coarse belowground organs also contribute to define key ecosystem properties because they may constitute most of the
belowground biomass in many ecosystems (e.g. Pausas et al., 2018). Examples of key ecosystem functions affected by coarse organs include protection against soil erosion (Stokes et al., 2009), contribution to nutrient cycling and carbon sequestration (Freschet and Roumet, 2017; Klimešová et al., 2018). We urgently need to refine our understanding of coarse belowground organs starting by considering them in our studies and then representing them accurately in drawings, i.e. with all their organs correctly reported and positioned, and with adequate size proportions.

Fig. 1

The widespread poor depiction (and related lack of consideration) of belowground parts is due primarily to methodological constraints. Sampling belowground organs is generally destructive, and plant organs, taken out of their natural soil environment, lose their spatial structure and placement. Ecologists can use a variety of methods to study roots in situ. However, most of these methods do not allow the observation of belowground plant organs as a whole (e.g. fine and thick roots, rhizomes; Klimešová et al., 2018). Solutions to these challenges are becoming available based on fundamental previous work (e.g. Rauh 1937; Kutschera and Lichtenegger 1982, 1992; Bell 1991), involving different ways of looking at plants, i.e. plants as modular organisms (Klimešová et al., 2019).

Even when a study focuses on the acquisitive function, a diagram showing belowground plant parts should also contain coarse belowground organs (e.g. rhizomes, thick roots). Therefore, omitting coarse roots and belowground organs from illustrations contributes to neglecting important belowground plant functions (Klimešová et al., 2018, 2019). The main goal of this essay is to provide examples in which plants are portrayed comprehensively and realistically, i.e. including the entire set of belowground organs (Fig. 2, 3). While several works have accurately represented whole plants of temperate herbaceous species (e.g. Kutschera and Lichtenegger, 1982, 1992; Klimešová, 2018), very little information is available for other biomes and growth forms (but see work done in fire-prone regions by Pate and Dixon, 1982; Pausas et al., 2018, and for tropical trees by Jeník, 1977). We believe that a more
realistic and comprehensive drawing of plants will motivate future research to include all the
belowground plant parts, organs, traits and ultimately functions.

Fig 2 & 3

Final remarks

A picture is a powerful tool in science communication and researchers should always seek maximum
accuracy when depicting their study organisms, as required for written and oral communication. In this
contribution, we provide key examples of common types of belowground plant organs showing fine
roots as well as coarse organs, such as thick roots and rhizomes, either in a more realistic or more
schematic fashion (see Fig. 2 and 3). We also stress that much of the research attention is still focused
on aboveground plant parts and organs, mainly informing on functions of sexual reproduction and plant
economics (Fig. 1; Laliberté, 2017). We call for a broader research agenda in plant functional ecology,
especially for the belowground compartments (Klimešová et al., 2018), which would include overlooked
plant traits and functional axes, such as those associated with plant modularity (Klimešová et al., 2019).
We are convinced that the examples reported in Fig. 1 and 2 have the potential to i) raise awareness
around understudied belowground plant organs and related traits and functions, ii) promote the
implementation of more correct portrayal of plants, and iii) finally help achieve a more balanced view
of plant morphology and functioning.

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Author Contributions
JK conceived the research idea that was further developed and refined by all the co-authors, TCD drew the pictures.

References


Fig. 1 – Comparison of plant organs in trees with realistic proportions (left panel) and biased proportions according to number of trait observations in TRY database modified from Laliberté (2017) (right panel).

Fig. 2 – Line drawing examples of common growth forms of woody plants worldwide. Schematic diagrams are illustrated in boxes indicating the type of belowground organs. Stems are in grey, roots in black, leaves in green, and generative organs in red. A: *Elaeis guineensis* – Jourdan and Rey (1997); B: *Anaxagorea dolichocarpa* – Shoot system: Barthelemy (1988), root system: Atger (1992); C: *Rhus typhina* – Charles-Dominique (2011); D: *Ceratostema loranthifolium* – Charles-Dominique (original work); E: *Prunus virginiana* – Charles-Dominique (2011). For definition of morphological terms, refer to Bell (1991).

Fig. 3 – Line drawing examples of common growth forms of herbaceous plants worldwide. Schematic diagrams are illustrated in boxes indicating the type of belowground organs. Stems are in grey, roots in black, leaves in green, and generative organs in red. A: *Phragmites australis* – Comtois (2010); B: *Euphorbia esula* – Klimešová (2018); C: *Vernonia guineensis* – Monnier (1968); D: *Rumex thrysiflorus* – Shoot system: Klimešová (2018), root system: Kutschera and Lichtenegger (1992); E: *Nassella trichotoma* – Charles-Dominique (original work). For definition of morphological terms, refer to Bell (1991).
A tree with realistic organ proportions

A tree with organ proportions reflecting trait-sampling effort