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Half of the (big) picture is missing!

Jitka Klimešová, Jana Martínková, Gianluigi Ottaviani, Tristan
Charles-Dominique

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1 **Half of the (big) picture is missing!**

2

3 Jitka Klimešová^{1,2*}, Jana Martínková¹, Gianluigi Ottaviani¹, Tristan Charles-Dominique³

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5 ¹ Institute of Botany, The Czech Academy of Sciences, Dukelská 135, Třeboň, 37982, Czech Republic

6 ² Department of Botany, Faculty of Science, Charles University, Benátská 2, Praha, 12844, Czech

7 Republic

8 ³ CNRS UMR 7618; Sorbonne University; Institute of Ecology and Environmental Sciences, 4 Place

9 Jussieu, 75005, Paris, France

10

11 * Corresponding author: Jitka Klimešová, Institute of Botany, The Czech Academy of Sciences,

12 Dukelská 135, Třeboň, 37982, Czech Republic, email: jitka.klimesova@ibot.cas.cz

13

14 Manuscript received _____; revision accepted _____.

15

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

17

18 **Key words:** Belowground organs, coarse roots, fine roots, plant drawing, rhizomes, tubers

19

20 **The missing part**

21

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

29

30 Plants are often illustrated as if belowground parts are formed by fine roots only. This may reflect an
31 unbalanced focus of ecologists on fine roots while overlooking coarse, non-acquisitive roots and
32 belowground stems (Fig. 1; Laliberté, 2017; Freschet and Roumet, 2017; Klimešová et al., 2018). Thick
33 roots, rhizomes, bulbs and tubers rarely play a role in absorbing water and nutrients, but can affect
34 resource acquisition by determining fine root placement and longevity (Klimešová et al., 2018). Most
35 importantly, these coarse organs do provide other key functions including anchorage in the soil,
36 connection and transport of resources to aboveground parts, storage of carbohydrates and of buds for
37 resprouting, space occupancy, resource sharing, and support for fine root placement in the soil
38 (Klimešová et al., 2018; Pausas et al. 2018). For example, the acquisitive properties of a root system are
39 affected by the growth direction of coarse roots; a horizontal growth direction will result in a shallow
40 root system while an oblique growth direction will distribute fine roots in the lower soil horizons.
41 Additionally, acquisitive and non-acquisitive belowground plant parts and organs are tightly
42 interconnected; fine roots (acquisitive function) and coarse organs (e.g. thick roots, rhizomes; non-
43 acquisitive functions) can greatly tradeoff (e.g. de la Riva et al., 2016). This implies that, for instance,
44 resource acquisition can be largely affected by other functions. A good example is represented by root
45 foraging; plants capable of resource sharing through rhizomes tend to invest less in foraging for nutrients
46 through fine roots (Weiser et al., 2016). In addition to their role in plant functioning, coarse belowground
47 organs also contribute to define key ecosystem properties because they may constitute most of the

48 belowground biomass in many ecosystems (e.g. Pausas et al., 2018). Examples of key ecosystem
49 functions affected by coarse organs include protection against soil erosion (Stokes et al., 2009),
50 contribution to nutrient cycling and carbon sequestration (Freschet and Roumet, 2017; Klimešová et al.,
51 2018). We urgently need to refine our understanding of coarse belowground organs starting by
52 considering them in our studies and then representing them accurately in drawings, i.e. with all their
53 organs correctly reported and positioned, and with adequate size proportions.

54

55 Fig. 1

56

57 The widespread poor depiction (and related lack of consideration) of belowground parts is due primarily
58 to methodological constraints. Sampling belowground organs is generally destructive, and plant organs,
59 taken out of their natural soil environment, lose their spatial structure and placement. Ecologists can use
60 a variety of methods to study roots *in situ*. However, most of these methods do not allow the observation
61 of belowground plant organs as a whole (e.g. fine and thick roots, rhizomes; Klimešová et al., 2018).
62 Solutions to these challenges are becoming available based on fundamental previous work (e.g. Rauh
63 1937; Kutschera and Lichtenegger 1982, 1992; Bell 1991), involving different ways of looking at plants,
64 i.e. plants as modular organisms (Klimešová et al., 2019).

65

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

75 realistic and comprehensive drawing of plants will motivate future research to include all the
76 belowground plant parts, organs, traits and ultimately functions.

77

78 Fig 2 & 3

79

80 **Final remarks**

81

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

95

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97

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101

102 **Author Contributions**

103

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

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151

152

153 Figure captions

154

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

158

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

166

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





