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## Half of the (big) picture is missing!

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► **To cite this version:**

Jitka Klimešová, Jana Martínková, Gianluigi Ottaviani, Tristan Charles-Dominique. Half of the (big) picture is missing!. *American Journal of Botany*, 2020, 107 (3), pp.385-389. 10.1002/ajb2.1438 . hal-02998989

**HAL Id: hal-02998989**

**<https://hal.science/hal-02998989>**

Submitted on 17 Nov 2020

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

2

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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

## 96 **Acknowledgments**

97

98 JK, JM, and GO were supported by the Czech Science Foundation (GAČR Projects 19-13103S, 19-  
99 13231S, 19-14394Y). We thank the Editor and two anonymous reviewers for providing insightful  
100 comments in previous versions of the manuscript.

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).







