# Half of the (big) picture is missing!

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

# Half of the (big) picture is missing!

Jitka Klimešová[1,2]*, Jana Martínková[1], Gianluigi Ottaviani[1], Tristan Charles-Dominique[3]

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

[2] Department of Botany, Faculty of Science, Charles University, Benátská 2, Praha, 12844, Czech Republic

[3] CNRS UMR 7618; Sorbonne University; Institute of Ecology and Environmental Sciences, 4 Place Jussieu, 75005, Paris, France

* Corresponding author: Jitka Klimešová, Institute of Botany, The Czech Academy of Sciences, Dukelská 135, Třeboň, 37982, Czech Republic, email: jitka.klimesova@ibot.cas.cz

Manuscript received _______; revision accepted _______.

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

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

## The missing part

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.

## Acknowledgments

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

## Author Contributions

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

## References


Atger, C., 1992. Essai sur l'architecture racinaire des arbres. Ph. D. dissertation, University of Montpellier 2, France.

Barthelemy, D., 1988. Architecture et sexualité chez quelques plantes tropicales: le concept de floraison automatique. Ph. D. dissertation, University of Montpellier 2, France.

Bell, A. D. 1991. *Plant form*. Oxford University Press.

Charles-Dominique, T., 2011. Analyse des relations entre plasticité architecturale des buissons et prolifération de leurs populations. Ph. D. dissertation, University of Montpellier 2, France.

Comtois, A., 2010. Étude préliminaire de l'architecture végétale du roseau commun (*Phragmites australis*, Poaceae). Internship report, Institut de recherche en biologie végétale, Montréal, Canada.

de la Riva, E. G., A. Tosto, I. M. Pérez- Ramos, C. M. Navarro- Fernández, M. Olmo, N. P. R. Anten, T. Marañón, and R. Villar. 2016. A plant economics spectrum in Mediterranean forests along environmental gradients: is there coordination among leaf, stem and root traits? *Journal of Vegetation Science* 27: 187–199.

Freschet, G. T., and C. Roumet. 2017. Sampling roots to capture plant and soil functions. *Functional Ecology* 31: 1506–1518.

Jeník, J. 1977. Roots and root systems in tropical trees: morphologic and ecologic aspects. In: P. B. Tomlinson, P. B., and M. Zimmerman [eds.], *Tropical Trees as Living Systems*. pp. 323-350. Cambridge University Press.

Jourdan, C. and Rey, H., 1997. Architecture and development of the oil-palm (*Elaeis guineensis* Jacq.) root system. *Plant and Soil* 189: 33-48.

Klimešová, J. 2018. Temperate herbs: an architectural analysis. Academia, Praha.

Klimešová. J., J. Martínková, and G. Ottaviani. 2018. Belowground plant functional ecology: towards an integrated perspective. *Functional Ecology* 32: 2115–2126.

Klimešová, J., J. Martínková, J. Pausas, M. Moraes, T. Herben, F.-H. Yu, J. Puntieri et al. 2019. Handbook of standardized protocols for collecting plant modularity traits. *Perspectives in Plant Ecology, Evolution and Systematics*, 40, 125485, https://doi.org/10.1016/j.ppees.2019.125485.

Kutschera, L., and E. Lichtenegger. 1982, 1992. *Wurzelatlas mitteleuropäischer Grünlandpflanzen*. Gustaf Fisher, Stuttgart.

Laliberté E. 2017. Below-ground frontiers in trait-based plant ecology. *New Phytologist* 213: 1597–1603.

Monnier, Y., 1968. Les effets des feux de brousse sur une savane préforestière de Côte-d'Ivoire. Direction de la recherche scientifique Ministère de l'éducation nationale de la République de Côte-d'Ivoire.

Pate, J. S., and K. W. Dixon. 1982. *Tuberous, Cormous and Bulbous Plants: Biology of an Adaptive Strategy in Western Australia*. University of Western Australia Press, Perth.

Pausas J. G., B. B. Lamont, S. Paula, B. Appezzato-da-Glória, and A. Fidelis. 2018. Unearthing belowground bud banks in fire-prone ecosystems. *New Phytologist* 217: 1435–1448.

Rauh, W., 1937. Die Bildung von Hypocotyl-und Wurzelsprossen und ihre Bedeutung für die Wuchsformen der Pflanzen. *Nova Act. Leopoldina* 4: 395–555.

Stokes A., C. Atger, A. G. Bengough, T. Fourcaud, and R. C. Sidle. 2009. Desirable plant root traits for protecting natural and engineered slopes against landslides. *Plant and Soil* 324: 1–30.

Weiser, M., T. Koubek, and T. Herben. 2016. Root foraging performance and life-history traits. *Frontiers in Plant Science* 7: 779.

Figure captions

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 thyrsiflorus* – 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).

Figure 1

Click here to access/download;Figure;Fig. 1.tif

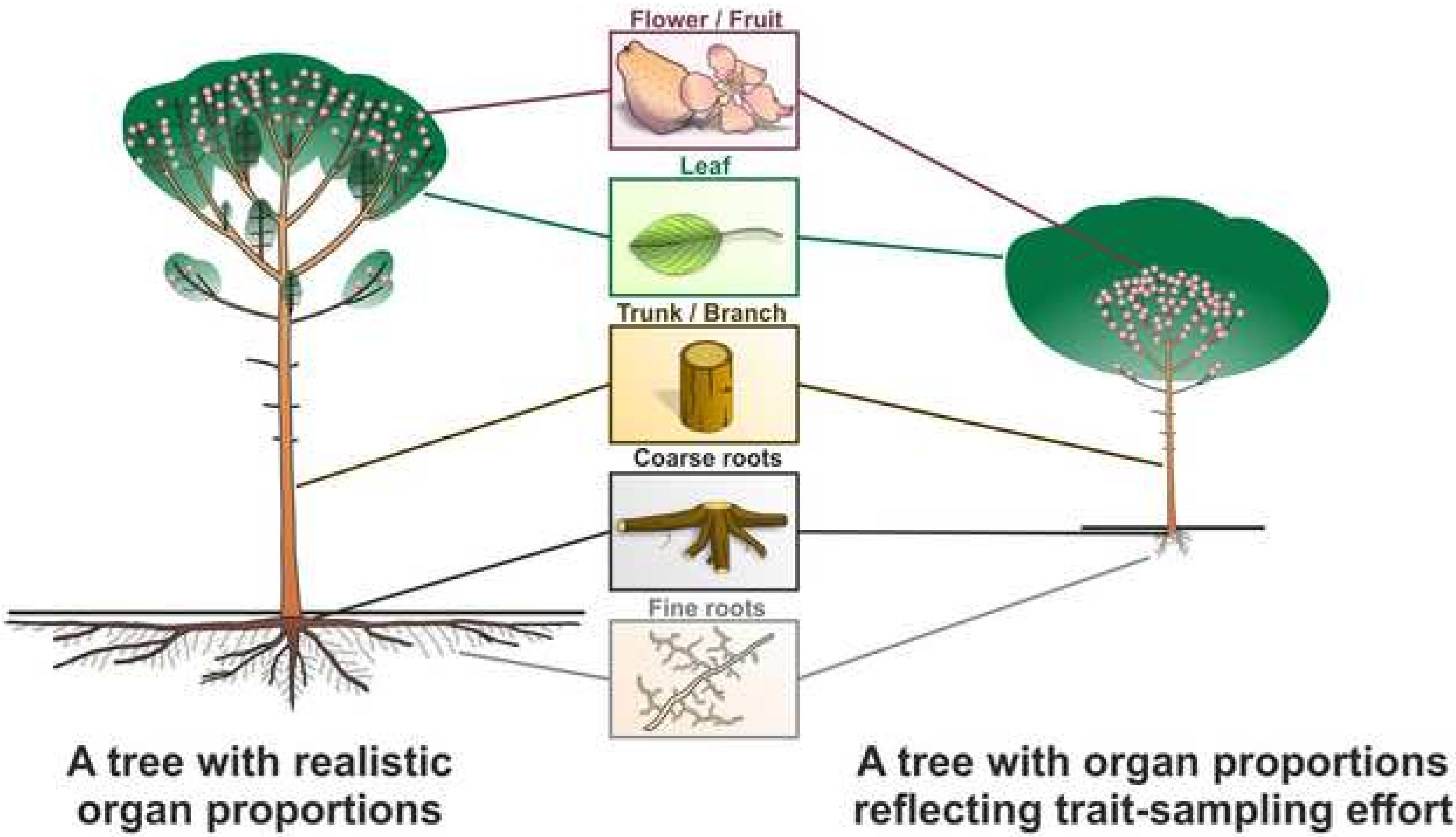
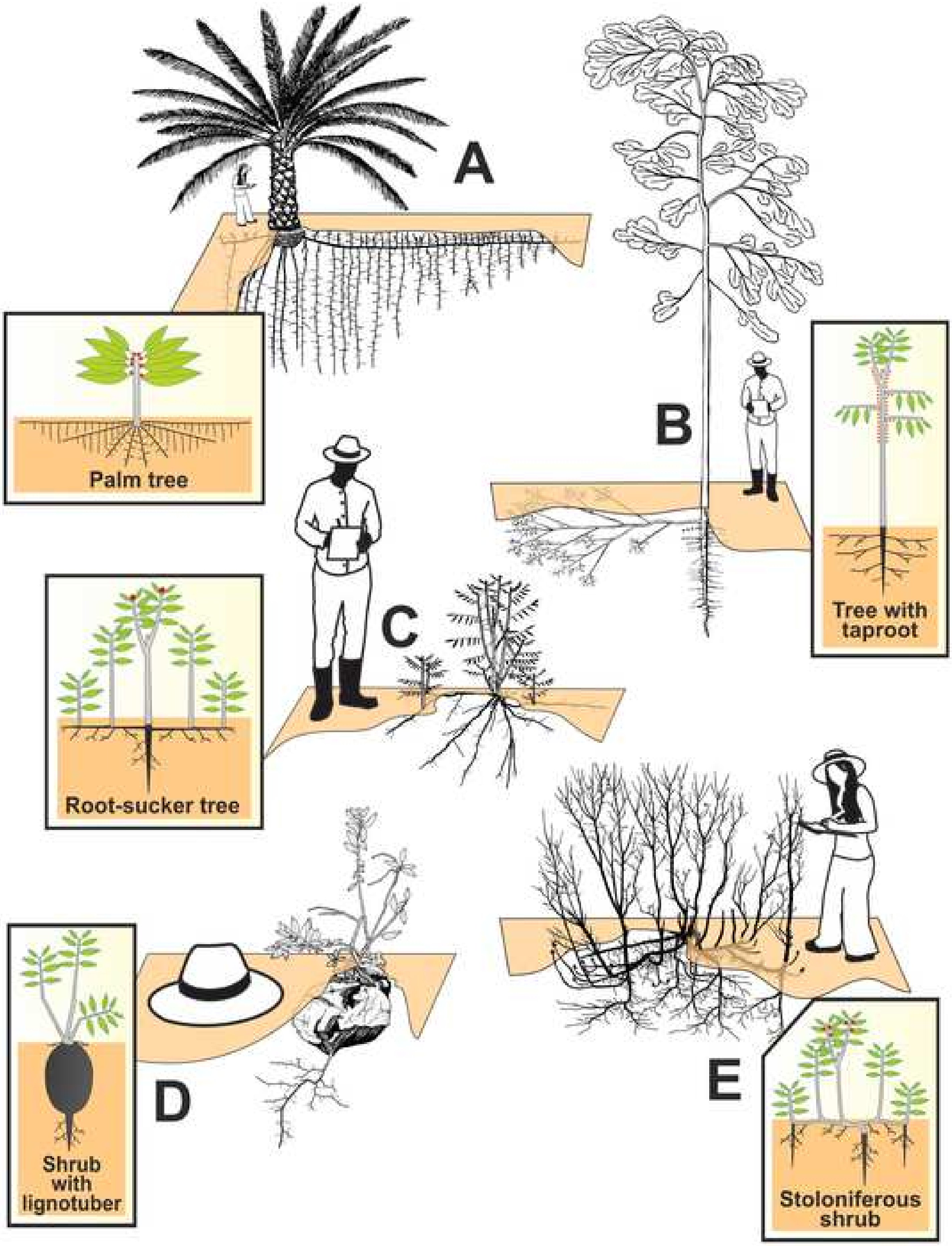
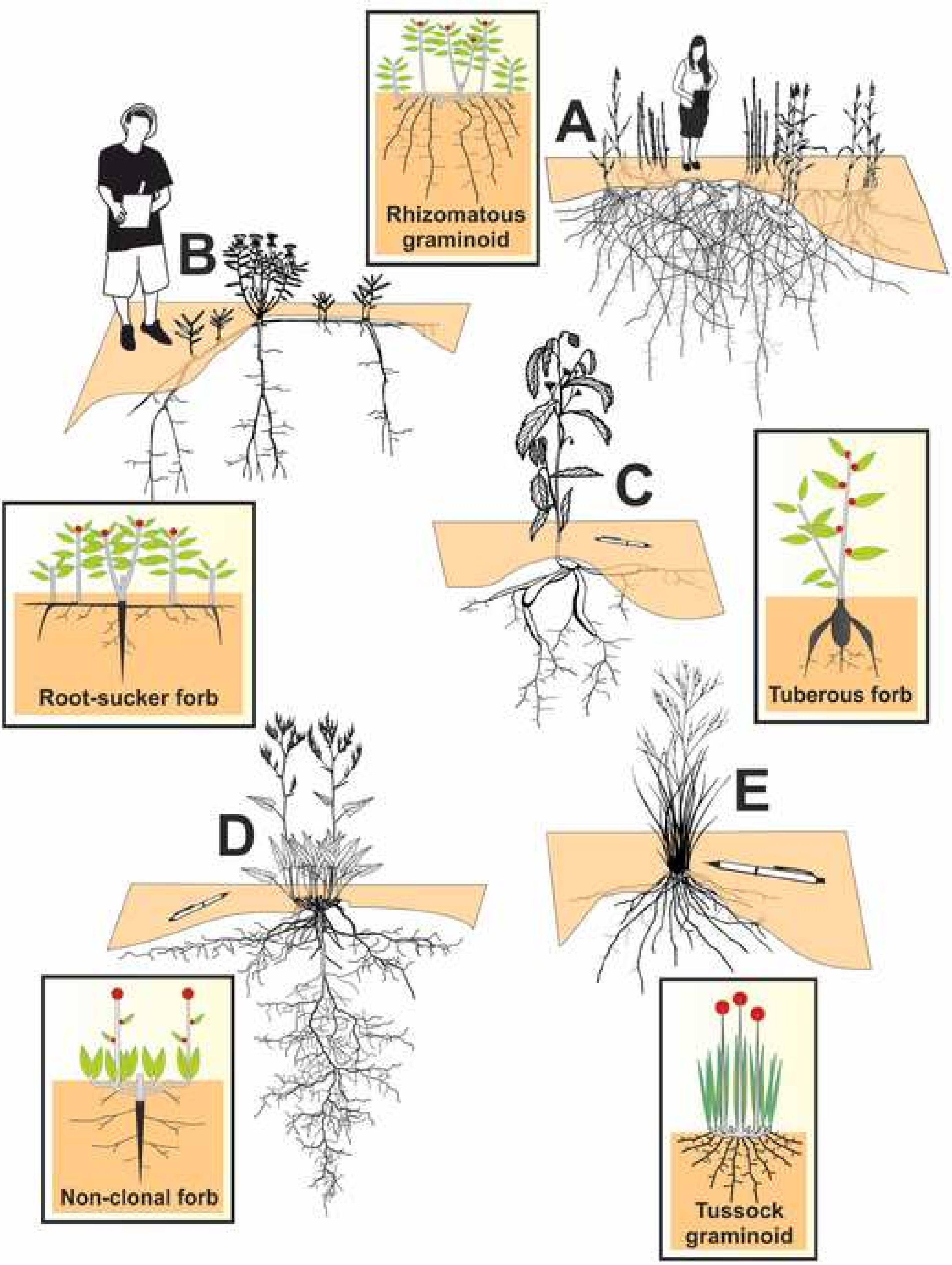


Figure 2




A
Palm tree
B
Tree with taproot
C
Root-sucker tree
D
Shrub with lignotuber
E
Stoloniferous shrub


A
Rhizomatous graminoid
B
Root-sucker forb
C
Tuberous forb
D
Non-clonal forb
E
Tussock graminoid