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The study of plant roots – insight into a hidden world

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Scientists in plant ecology for have many years emphasized only the aboveground plant structures and ignored the hidden belowground plant parts. Our honoured colleague Lore (Eleonore) Kutschera, who was born on September 14, 1917 in Villach, Kärnten and died on Oktober 16, 2008 in Klagenfurt) and her nearest co-workers (Erwin Lichtenegger †, Monika Sobotik and lately Dieter Haas) have for many years drawn attention to the importance of plant roots hidden in the soil. As a plant scientist, Lore Kutschera stressed the whole plant and tried to relate the structure and function of belowground plant parts to their structure and function aboveground.

In the course of evolution, roots have developed as organs dependent in their function on assimilated products produced in abundance by the shoots, translocated, stored and used by the root systems. Plant growth performance depends on the integrated functioning of both roots and aboveground leaves. Roots may differ in morphology, anatomical complexity, size, function and in the manner in which they develop, grow and exploit their environment.

The relatively high carbohydrate investment in plant roots versus plant shoots was overlooked in many earlier ecosystem studies. From careful excavations of root systems is possible to demonstrate that that the below-ground parts of the plant are just as important in terms of length, volume and weight. Defining interactions of roots with the surrounding soil environment has been in the focus in many recent ecosystem investigations. The work by Lore Kutschera and her group, in this context, has been of great fundamental help.

The important root functions

The efficiency of the water and mineral nutrient uptake processes in the soil is determined, to a great extent, by the rate of penetration of the soil horizons by recently formed root tips and their gradual death and decomposition. The more space occupied by the root systems and growing root tips, the more potential soil resources that can be controlled by the plant. In response to the immobility of nutrients and extreme dilution of essential nutrients, except for in resource-rich micro sites, evolution has given rise to various root systems that, by means of a progressive ramification pattern, bring the active root surface area into contact with the soil.

Roots, which are not developed under the restrictions imposed by the soil or by the aqueous environment, may be functional for a prolonged time. Thus, in aeroponic systems, in which roots are fed by nutrient mists, roots may stay alive and be functional for an almost unlimited period of time (cf. Waisel 2002). However, plants and plant roots continuously die; death is not only the consequence of environmental stress but also of physiological decline, or senescence. Although a perennial plant may theoretically live for ever, each individual organ has a limited life-span.

The work by Lore Kutschera and her group illustrates how roots are developed under different environmental conditions and differ in morphology, anatomical complexity, size, and function. The contribution of soil carbon from plant roots versus plant shoots was overlooked in many earlier ecosystem studies. Deficiency of mineral nutrients may further lead to the development of stems and roots at the expense of the leaves.

Fig. 1. The root systems of winter and summer barley (*Hordeum vulgare*) in the beginning of May 2004 and in the middle of June 2003 at two different agricultural sites in Austria (Kutscrera et al 2009).

The root systems of annual and biennial crops

Annual and biennial plants are characterized by both the form of vegetative organs such as leaves, stems and roots and storage organs most frequently in seeds (Figs. 1, 2, 3). Annual or biennial plants may stay alive for only one or two growing seasons; senescence takes place in all vegetative structures when the next generation, represented by the seeds, is shed. Distribution of the assimilated carbon in different organs takes place in a way which is specific to each plant and to each agricultural cropping system.

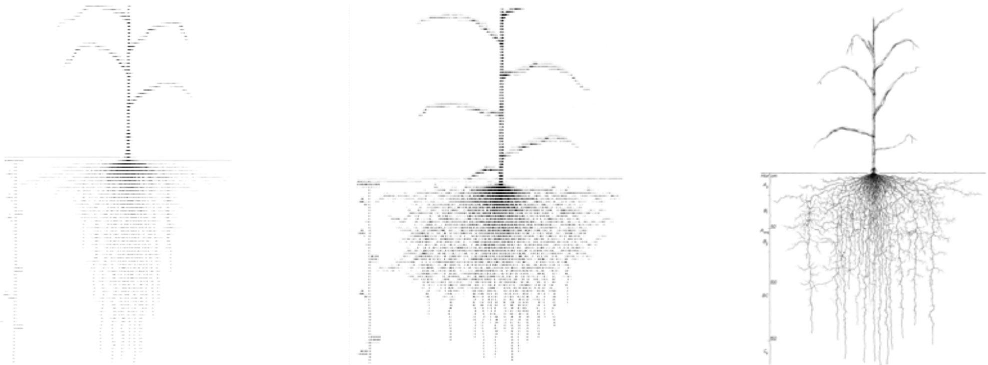

Fig. 2. The root systems of maize (*Zea mays*) in the middle of July 1993 at three different sites in Austria (Kutscrera et al 2009).

Fig. 3. The root systems of sunflower (*Helianthus annuus*) in the middle of July 2003 at two different sites in Austria (Kutscrera et al 2009).

The root systems of perennial crops

The main sources of organic matter in arable soils are from plant litter (plant roots, stubble, leaves, mulch) and animal manures. The amounts of CO_2 released from dead roots are affected by environmental factors such as temperature, soil water conditions, nutrient availability, soil pH, chemical toxicity, soil strength, soil aeration, quality of soil organic matter and plant related factors such as plant age, competition and carbon economy.

The carbon cycle in agricultural soils is complex and includes processes such as mineralization, immobilization, soil amendment with fertilizers and plant residues and animal waste, soil compaction, crop uptake and losses due to runoff. For arable crops, 10-40% of the total net carbon assimilation is located below-ground and released from roots (Amos and Walters 2006; Gregory et al. 1996; Pritchard and Rogers 2000; Rasse et al. 2005; van Veen et al. 1991).

Plants roots may functionally be recognized as both reproductive and food-storage organs. Substantial soil volumes may be occupied by roots of perennial plants (Fig. 4). Perennial plants may stay alive for several growing seasons, with senescence continuously occurring in all vegetative structures. Most available data on root production and root turnover of perennial plants in terrestrial ecosystems suggest large carbon flows to the soil from dead roots and a rapid turnover of the dead root tissues. Research into root senescence is complicated by the fact that cessation of root penetration periodically is not synonymous with root death.

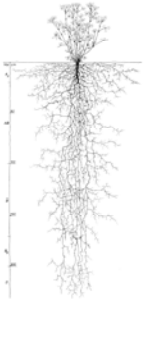

Fig. 4. The root system of alfalfa (Medicago sativa) at the end of July 2003 at an Austrian agricultural site (Kutscrera et al 2009).

The root systems of plants in natural systems

For plants in a competitive and varying environment, the survival and not necessarily high above-ground productivity, seems to be an evolutionarily stable strategy. The root system of the same species may vary considerably in different ecosystems (Fig. 5). Substantial carbon expenditure in the production of new roots appears to be a significant phenomenon in a variety of ecosystems. Our understanding of the turnover rates of roots under field conditions are however incomplete as well as the mechanisms of root litter formation. Cooler ecosystems accumulate high levels of soil organic matter because the break down of dead roots does not take place as quickly at low temperatures.

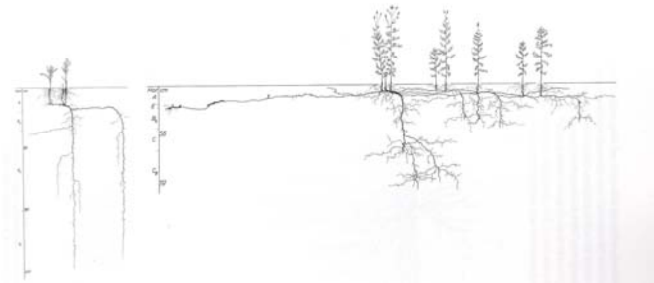

Fig. 5. Different root systems of the creeping thistle (*Circium arvense*) from Jädraås, in Sweden and from Klagenfurt, in Austria (Kutschera et al. 1997).

The root environment in this context seems to be a key factor, which determines whether a plant species will survive. The root systems of trees differ from those of other perennial plants by their woody framework of long-lived structural roots supporting a mass of short-lived, non-woody fine roots associated with mycorrhizal fungi (Fig. 6). Roots comprise a substantial portion of the total biomass of forest ecosystems. Generally, roots account for 15 to 30 percent of the total tree biomass. High annual fluctuations in fine-root growth and turnover rates are to be found in forest stands of different ages, tree density and vegetation type (Persson and Stadenberg 2009).

General conclusions

- Roots will grow into any soil volume where the correct environment of air, mineral nutrients and water exists to meet the plant's needs.
- The relatively high contribution of soil carbon from plant roots versus plant shoots has been overlooked in many ecosystem studies.
- Death and decomposition of roots in terrestrial ecosystems could be even more important, than above-ground plant parts, as a source of organic matter.
- Root litter is produced in intimate contact with soil minerals and microbial material and forms the bases for the complex biological cycles in the soil by bacteria, fungi, insects and inorganic site factors.

Fig. 6. The root system of a 13-year-old Scots pine (*Pinus sylvestris* L.) at Jädraås in Central Sweden (Kutschera et al. 1997).

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