# 7th ISRR Symposium Root Research and Applications

September 2-4, 2009, Vienna / Austria

In Memoriam of Univ.Prof. DI Dr. Eleonore Kutschera
(1917-2008)

# SHORT PAPER ABSTRACTS

Institute of Hydraulics and Rural Water Management
Department of Water, Atmosphere and Environment
University of Natural Resources and Applied Life Sciences, Vienna
Muthgasse 18, 1190 WIEN, AUSTRIA

A Compact Disc with the full short papers of the symposium is available at the Institute of Hydraulics and Rural Water Management, Department of Water, Atmosphere and Environment, University of Natural Resources and Applied Life Sciences, Vienna, Muthgasse 18, 1190 WIEN, AUSTRIA

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# CONTENT

# Foreword

Scientists in plant ecology have for many years emphasized the above-ground plant structures but ignored the hidden belowground plant parts. However, intensive root research is a prerequisite for a comprehensive view of the plant and of ecosystems. During recent decades, six symposia organized by the *International Society of Root Research (ISRR)* have stressed the importance of the plant roots hidden in the soil. The 7th Symposium of the ISRR "*Root research and applications*" is now to take place in honour of our dear colleague Prof. Dr. Lore Kutschera, who organized the 1st Symposium in Austria in 1982. The 7th symposium on root research was still initiated by Lore Kutschera and is organised by the University of Applied Life Sciences and Natural Resources, Vienna (BOKU) in collaboration with the ISRR. Since Lore Kutschera is no longer with us it became the desire of the people involved to devote the symposium to her memory, and thus to pay respect to the long-lasting scientific service she has provided to ISRR and the research community. Just in time before the conference the 7th atlas on roots (Wurzelatlas der Kulturpflanzen gemäßigter Gebiete mit Arten des Feldgemüsebaues) has been published. The two occurrences of the number "7th" is more than a simple coincidence: it shows that Lore Kutschera was present throughout the years in the IRRS and the respective symposia. This last root atlas marks perhaps the end of an era, but the spirit in which it was produced needs to be preserved and is an example and motivation for young researchers.

The 7th symposium brings together many disciplines and serves also to explore ways forward in root research. The aims of our symposium are to address the complexity of root research by bringing together multidisciplinary root research workers, and to support the transfer of new findings into practice, from the plant scale up to ecosystems level. For example, the belowground carbon inputs are comparatively poorly represented in models of soil carbon dynamics and large-scale biogeochemical models. Death and decomposition of roots in terrestrial ecosystems could be even more important than above-ground plant parts, as a source of organic matter supply. Indeed, the most scientifically challenging phases of carbon and nutrient cycles occur belowground. Root responses to environmental stresses such as water and nutrient deficiencies, climatic fluctuations and

anthropogenic effects, ranging from plant to ecosystems level, are all important issues to be addressed.

The papers to be presented at our symposium have been selected by a pre-reviewing process organized by the symposium organizers and including root scientists from different disciplines and nationalities. The treated topics include areas of root research from cellular level to eco-systems scale. Many new possibilities and new technologies are emerging to continue the work done so far. As in other science there have been many achievements, but there is still much hidden below ground. However, looking below ground only is not enough. This was very much seen by Lore Kutschera. In the 7$^{th}$ root atlas she stated "I do not want to have and to do only a half in my life. We all don't want to be seen as half only. Therefore we need as botanists to take care of the whole" (translated from German).

In this spirit it is hoped that the 7$^{th}$ symposium on root research serves science and opens many new ways for research, and will strengthen the research community.

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| President of ISRR | Head of IHLW – BOKU |

# 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.

# SESSION 1

# ROOT GROWTH, ANATOMY AND MORPHOLOGY

Oral Presentations

# Inquisitive, problem-solving roots and the new 'Neurobiology' of plants

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Plant organogenesis is evidently a two-track process. One track – the constitutive track – involves the expression of stereotypical cell division patterns of stem cell populations and the building up of histological compartments. It is governed by genetic and closely allied internal epigenetic factors. The second track – the facultative track – is perhaps no less rigorous but leads to developmental plasticity. It, too, is governed by genetic factors but, in this case, their expression is influenced by environmental thresholds. Root systems show very good evidence of these two tracks, and much was written on this by Professor Lore Kutschera. It seems that two-track development utilises both intrinsic and determinate elements as well as extrinsic and indeterminate elements. This developmental pattern runs throughout Nature, from the molecular level (ten Hove and Heidstra 2009) to the cosmic level (Barlow et al. 2009); organismal development thus represents the reconciliation of the chaotic and the ordering principles by a living system.

The thresholds that regulate the dynamics of development can be thought of as being analogous to the activation energies of chemical reactions. Plasticity of development involves the crossing of these thresholds, and some investigators (e.g. Trewavas 2005) see these crossings in anthropomorphic terms, referring to them as evidence of a prototypical 'plant intelligence' whose expression leads to 'decisions' in a general context of 'problem solving'.

Do the two mentioned tracks of development communicate with each other, and if so, how? Clearly, there must be communication between these two tracks (Barlow 2006) because often the stem cells that feature in the first track have to be initiated and activated at new sites on the plant body. From the classical viewpoint this has to do with 'correlations' which were based on particular spatio-temporal patterns of hormonal flow. But in a new way of thinking about development (Baluška et al. 2006), these correlations can be reconsidered in the light of a proposed 'plant neurobiological'

system. Featured in this scenario (Barlow 2008) are action potentials and variation potentials which serve as informational signals, phloem and xylem elements are the informational channels, and hormones (e.g., auxin) act as facilitators of information flow acting in the manner of neurotransmitter molecules at synapse-like end-walls of cells.

# Fine root morphology of *Pinus pinaster* as affected by site fertility

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Fine roots are essential for nutrient uptake and the morphology of fine roots may adapt to variations in environmental conditions such as the availability of nutrients and water. Our objective was to investigate how fine root morphology of *Pinus pinaster* in the Landes of Gascony (France) was affected by site fertility. Our hypothesis was that site fertility differs between stands having different understory vegetation and that these differences would affect fine root morphology of *Pinus pinaster* fine roots. Data on specific root lengths (SRL) from top soil layers (litter, 0–15 and 15–30 cm mineral soil) were used as an evaluator of fine root morphology. Six treatments from a fertilisation trial were compared with data from 27 natural sites with contrasting understory. The results showed an overall range of SRL in litter and mineral soil of 11.8–34.6 in the fertilisation trial and of 4.8–32.6 m $g^{-1}$ for the natural sites. The highest values occurred for increased levels of nutrients and or water (in the fertilisation experiment) as well as in a natural stand with *Ulex europeaus* (a nitrogen fixing species) as dominant understory and in a stand with mixed understory. The lowest values occurred consistently in *Calluna vulgaris* and *Erica cinerea* dominated stands. *Molinia* and *Pteridium* dominated stands show intermediate to high values. We conclude that differences in understory can be indicator of or contribute to differences in site fertility, which lead to morphological adaptations of the fine root system of overstory forest trees.

Keywords: fine root morphology, *Pinus pinaster*, site fertility specific root length, understory

# Initiation of vascular cambium derivatives produces new branch roots in a woody parental axis: Effect on root architecture

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The anatomical differences of traces formed in woody parental roots enable the formation of two categories of branch roots: "primary branch roots" (PBR) and "secondary branch roots" (SBR). PBR are those roots hypothesized to be formed by primary tissues such as perycycle, endoderm or xylary parenchyma. SBR are roots hypothesized to be formed by cambium initials and/or phloem derivatives. After their formation the SBR primordia elongate through the secondary phloem, cortex, and phellogen before protruding externally from a swelling bark. A proteomic approach is used to produce a map of woody root axis, and to puts in evidence the occurrence of quantitative variations in a number of proteins in relation to SBRs production. The identities and possible physiological roles of these differentially expressed proteins is discussed in relation to root branching in woody roots. We suggest that SBRs emission improves the adaptation of woody plants to their rooting environment thorough a modification of root architecture.

Keywords: root primordium, vascular cambium, lateral roots

# Spatial 2D distribution and depth of sugarcane root system in a deep soil

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Sugarcane root system depth is a key parameter for water and mineral uptake but it is still very little known. Rooting depth of sugarcane (variety R570) has been determined in a deep soil in Reunion Island. In depth, it is therefore difficult to use the soil core method. Over a 1.5 m wide soil profile, roots were counted down the root front using a 5cmx5cm mesh grid to spatialize results. Data were entered into the *RACINE2* software. It calculates root length density (RLD) and from RLD, distances between roots (ARD), producing, 2D root distribution maps and depth-related RLD profiles. Below 2 m, RLD was weak but not nil, and root fronts on the 4 measurement sites were 405, 390, 400, and 325 cm deep. RLD decreases with depth from .6 to .01 cm $cm^{-3}$ at a 2 m depth. There was a power relationship between depth and RLD. ARD values are lower than 10 cm at 2-m depth. Below 3 meters, they fluctuated between 10 and 50 cm. If roots in the soil can absorb water up to 5 cm, roots below 1.5 m may allow survival in case of drought. The study was carried out in good crop conditions, in deep soil. Findings bring new important information for Reunion Island, where it was thought that RF was less than 2 m in depth (data used in crop models). These results also contribute to a better understanding of the sugarcane root system.

Keywords: root front, Reunion Island, root length density, root distribution, root spatial variability, Sugarcane root system

# Variation in fine root traits by branch order within a *Chamaecyparis obtusa* stand

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Recent studies have revealed that both morphological and physiological variability exist within fine roots <2.0 mm in diameter and that an approach based on branch order should replace the arbitrary diameter approach to partition tree roots into homogenous units. Fine root traits by branch order have been clarified in several tree species, but variation in the traits of branch order roots to soil nitrogen (N) status had not yet been examined. Moreover, few studies have compared root traits by branch order to those by diameter class. The objective of this study was to clarify the relationships in root traits between branch order and diameter class and the variability in the root traits by branch order within a stand of *Chamaecyparis obtusa*, especially in relation to soil N status. In a *C. obtusa* stand (30 m × 60 m) on Mt. Hiei-zan in western Japan, 180 fine root systems were collected at a depth of 10 cm in July 2008. In total, 11,222 individual roots were dissected by branch order, with distal roots numbered as first-order roots. Roots that were <0.5 mm in diameter accounted for 72% of the total length among the first three root orders. The length of individual roots varied highly, by up to fivefold, within the stand, while variation in diameter was consistently low. The soil N concentration was positively correlated with the specific root length (SRL) of first-order roots and N concentrations of first- and second-order roots, but not with that of third-order roots or with the diameter and length of individual roots. We conclude that <0.5 mm diameter roots include mainly first- and second-order roots but also some third-order roots, and that roots <0.5 mm in diameter have different responses to soil N status in this tree species.

Keywords: branch order, *Chamaecyparis obtusa*, root nitrogen, root tissue density (RTD), soil nitrogen, specific root length (SRL)

# Rooting profiles with depth – the case of the Wurzelatlas mitteleuropäischer Ackerunkräuter und Kulturpflanzen

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The drawings in the Wurzelatlas mitteleuropäischer Ackerunkräuter und Kulturpflanzen (Atlas of Central European weeds and arable crops, but also in the Atlases by Kutschera et al.) offer a unique opportunity to analyze rooting patterns of very different crops and herbs determined using a consistent methodology. Using 203 drawings, the images of the rooting patterns with depth are analyzed. As a result, we obtain a relation between pixels and depth which can be subject to different conversions, and to different analyses, e.g. the mathematical description of the changes in rooting pattern with depth, or the distribution of interroot distances with depth. Subsequent analyses allow correlating the parameters of this description to soil and location parameters. Some results will be presented and discussed in relation to water uptake of the different species.

Keywords: image analysis, root water uptake, rooting pattern

# Plasticity of grass root functional traits and root mass in response to cutting frequency and N fertilisation

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In productive grasslands, management practices can alter root mass investment, e.g. extensive management (low cutting frequency, low N fertilisation) induced higher root accumulation than for intensive one. Change of root morphology may have consequences on root distribution of length, root resources use or root longevity. We report response of seasonal root mass variation and root functional traits to cutting frequency (three and six cuts per year, C- and C+, respectively) and N fertilisation (120 and 360 kg N $ha^{-1}$ $yr^{-1}$, N- and N+, respectively) of 13 grass species grown for three years in field situation as monocultures. Root mass of the 0-15cm depth increased in C- and N- treatments, 10% and 22%, respectively. These effects were more pronounced in spring in comparison with summer and autumn, +44% and +53% for the response to cut and N fertilisation, respectively. Primary roots of C- treatment had significantly higher diameter (+27%) and consequently lower specific root length (SRL, -16%) than C+ treatment. Finest roots ($2^{nd}$ and $3^{rd}$ order) of N+ exhibited significant lower tissue density (TD) and diameter and higher SRL values than N- treatment. These results emphasise plasticity of root functional traits of grasses in response to cutting and N fertilisation. Extensive treatments favoured higher root allocation and root traits syndrome related to conservation of nutrient, whereas intensive management induced root trait values related to exploitative strategy.

Keywords: grass, root functional traits, cut, N fertilisation, root types

# Genetics of root architecture

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Different varieties of *Arabidopsis thaliana* show variation in their density of root branching from the primary root. We have taken advantage of the polymorphism between varieties of the plant to generate a QTL map of regions of the genome that associate with a change in root branching. This data has been combined with the known positions of polymorphisms (determined by DNA sequencing) and tissue specific microarray expression data in order to prioritise genes as root branching candidates. We will present our investigations of the role played by candidate root architecture genes in the physiology of the root system in a model plant and in a crop plant.

Keywords: root architecture, quantitative trait loci, root branching

# The importance of anatomical structure of roots for physiological processes

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Besides the characteristics of the species, the inner structure of the root is influenced by the place and time of origin during the growth period. From the root tip up to the base of a particular root the zones of cell division, cell elongation, formation of root hairs and those zones of the root branching by different aging processes can be distinguished. The root tip which is covered by a root cap and mucilage is protected against evaporation and water contact. From the end of the root cap the cells are exposed. The cells can elongate by water uptake or shrink by water loss. All processes of geotropic growth take place there.

Some differences are illustrated using the example of *Zea mays* plants. Seedling roots, roots emerging from several nodes of the shoot as well as lateral roots of different orders will be compared. The distances from the tip and from the base of the root are also very important. Distinctive features as root diameter, the size of the stele and of the cortex, the relation of cortex and stele, the number and width of the xylem vessels, the size of cells, special thickenings, stage of lignification as well as symptoms of maturation are observed.

Keywords: root structure of *Zea mays*, root cap, seedling root, shoot root, geotropic growth

# Gypsum improves subsoil root growth

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In many parts of the world, crop root growth into subsoils is limited by physical (pans) and chemical barriers (toxic levels of Al and/or low levels of Ca). Plow and hard pans are usually either out of the reach of mechanical cultivation implements or require large amounts of energy for their disruption. Because lime does not readily move down the soil profile, its ameliorative effect is confined to the topsoil. On the other hand, gypsum ($CaSO_4.2H_2O$) readily moves down the profile where it supplies elevated levels of soluble Ca and precipitates Al. In addition, together with tap-rooted crops, it reduces the penetration resistance of subsoil pans allowing roots of other crops to proliferate in the subsoil. As a result, roots can access the subsoil where adequate quantities of water become available which were previously out of their reach. This additional water results in increased yields, particularly during drought periods. Many examples of the success of gypsum in overcoming subsoil physical and chemical limitations resulting in improved growth and yield of alfalfa (*Medicago sativa*), bermudagrass and fescue pastures (*Cynodon dactylon,* and *Festuca arundinacea*) and turf (*Zoysia* spp.), cotton (*Gossypium hirsutum*), maize (*Zea mays*), sorghum (*Sorghum bicolor*), and soybean (*Glycine max*) are presented.

Keywords: subsoil, Al toxicity, calcium deficiency, root proliferation, gypsum, row crops

# Root architecture of wheat and barley is affected by expression of reduced height genes

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Most modern temperate cereal cultivars contain major dwarfing genes, but there are conflicting reports in the literature about their effects on root growth. Near-isogenic lines were used to characterise the effects of semi-dwarfing and dwarfing alleles on root growth of *Triticum aestivum* cv Mercia and cv Maris Widgeon. These NILs (*Rht*-B1b, *Rht*-D1b, *Rht*-B1c, *Rht*8, *Rht*-D1c and *Rht*-12) were grown in gel chambers, soil-filled columns and in the field. Total root length of the dwarf lines (*Rht*-B1c, *Rht*-D1c, and *Rht*12) was significantly different to that of the control although the effect was dependent on the experimental methodology; in gel chambers root length of dwarfing lines was increased by about 40% while in both soil media it was decreased (by 24-33 %). Root dry mass was 22% to 30% of the total dry mass in the soil-filled column and field experiments. However, no significant differences in root length were found between semi-dwarfing lines and the control line in any experiment, nor was there a significant difference between the root lengths of the two cultivars grown in the field. Although total root length was altered by dwarf alleles at the reduced height genes, root architecture (average root diameter, lateral root: total root ratio) was not affected by height reducing alleles. A direct effect of dwarfing alleles on root growth, rather than a secondary partitioning effect, was suggested by these experiments. A barley mutant (*sln*1.d), orthologous to *Rht*-B1b and *Rht*-D1b had a comparable phenotype to *Rht*-B1c and *Rht*-D1c and was used to explore differences in genes expression between the control and the GA mutant. Microarray data and microscopy of *Hordeum vulgare* cv Himalaya were used to identify putative target genes of the gibberellic acid pathway in roots and to give new insights into the interdependence of root and shoot growth.

# Tree root systems architecture in earth dike

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Trees growing on earth dikes generates safety problems and reduces dike durability. Root systems generate internal and external erosion risks which can be important on dikes wooded for a long time. Erosion risks increase with tree age and stand density.

The aim of this study is to analyse root systems characteristics of trees rooted in canal dikes and flood protection dikes. Root systems structure and morphology depend on species and materials.

On various species studied, different types of roots can be observed. Short and long roots are characterized by differences in diameter decrease, branching frequency and inclination. A root typology is determined.

Keywords: stump structure, root system architecture, root typology, earth dikes safety

# Report of the nomenclature workgroup from ISRR V, Reprise

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The International Society for Root Research (ISRR) held a workshop on root nomenclature during the 5th Symposium at Clemson University, but the report has never been published. With the increasing emphasis on modeling root growth and development, it is appropriate to revisit that report. The report defined four types of root: Tap Root, Lateral Root, Basal Root, and Shoot Borne Root. To summarize the report: the tap root is the extended radicle or its replacement (in some species, e.g. maize (*Zea mays* (L.)), this can be a seminal root which replaces the radicle); a basal root is a root originating from the hypocotyl or mesocotyl (*i.e.* seminal roots other than the tap root; a shoot borne root is a root originating from shoot tissues (stem, petiole, leaf, etc.); and a lateral root is a root originating from another root. The rationale for these definitions as well as decisions on nomenclature for lateral roots of different orders, and definitions of "fine root" will be presented.

Keywords: Nomenclature, tap root, basal root, shoot borne root, lateral root

# Poster Presentations

# Relationship between pericycle cell length and lateral root spacing in maize root

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Exogenous auxin inhibits seminal root elongation and promotes the formation of lateral roots (LR). Searching for one possible relationship between the inhibition of elongation and the spacing of LR, we have simultaneously determined pericycle, cortex and epidermis cell lengths and LR density in NAA-treated maize roots. The inhibition of root elongation is proportional to NAA concentration and correlates with a decrease in cell length. NAA treatments reduced pericycle cell length in a range from 30 to 50%. The first step in the LR formation is a division of the founder cells that, in maize, are some pericycle cells located opposite to phloem poles. Treatment with 0.01 µM NAA results in increased number of LRs and reduced pericycle cell length. Nevertheless, 0.05 µM NAA, which strongly reduced pericycle cell length, did not stimulated LR formation. This result suggests that auxin stimulation on LR formation is modulated by pericycle cell length.

Keywords: auxin, lateral root, pericycle

# Effect of co-inoculation with rhizobia and mycorrhiza on root parameters of lucerne (*Medicago sativa* L.) under dry organic farming conditions

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Knowledge of root traits associated with tolerance to water deficit condition is important for further understanding drought tolerance mechanisms of whole plant. This experiment was designed to investigate effect of dual inoculation of rhizobium and mycorrhiza on some important root characters under water deficit condition. The trial was located on the organically managed fields of the University of Natural Resources and Applied Life Sciences, Vienna(Raasdorf) in April 2007. Three factors included Rhizobium inoculation*;* Mycorrhiza inoculation and Irrigation, each one at two levels (with and without application) have been studied in a factorial experiment in the form of complete randomized block design. Results showed that increasing water deficit affected root dry weigh, specific root mass and root length significantly at 1% level and but co-inoculation of rhizobium and mycorrhiza with irrigation could increase root parameters. Regarding to the data's of root dry weight, there were not any significant differences between treatments for main effect of rizobium,double interaction of rhizobium x mycorrhiza, rhizobium x irrigation ,mycorrhiza x irrigation and triple interaction of rhizobium x mycorrhiza x irrigation but there were significant differences for main effect of mycorrhiza and main effect of Irrigation at 5% and 1% probability level ,respectively in both harvests. Our study demonstrated that responses of root parameters to dry condition varied with symbiont microbial activity in the soil and root characteristics associated with drought resistance in lucerne included enhanced root growth, water uptake and the maintenance of root activity.

Keywords: mycorrhiza, rhizobia, lucerne, roots parameters

# Studies on the development of root systems in young forest stands of deciduous trees in naturally-afforested agricultural lands

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The article summarises study data on accumulation of the biomass of 10 – year birch and 12 – year grey alder stands in above-ground and root biomass. The research goal was to determine the volume of birch and grey alder biomass and its characteristic components: the biomass of the above-ground part – the biomass of the stem and branches, as well as the biomass of roots: the mass of coarse roots and fine roots. An analysis was carried out on the number of active root tips, root length, volume and total root mass, as well as its influence on the development of the above-ground part of the aforementioned tree species.

The biomass of fresh roots (stump part + coarse roots) and the above – ground part (stem mass + branch mass) of 10-year birch stands was determined – respectively 24.7 t ha$^{-1}$ and 55.65 t ha$^{-1}$, while in 12-year grey alder stands it was respectively 52.12 and 131.6 t ha$^{-1}$. The morphological parameters of fine roots in birch stands per 1 ha are the following: biomass – 5.431 t ha$^{-1,}$ root length – 3,169 km ha$^{-1}$, root volume – 8.11 m$^3$ ha$^{-1}$ in air – dry condition. The morphological parameters of fine roots in grey alder stands per 1 ha are the following: biomass – 12.5 t ha$^{-1}$, root length – 7.29 km ha$^{-1}$, root volume – 18.65 m$^3$ ha$^{-1}$ in air-dry condition.

The studies show that 2.28 times more biomass can be accumulated in 10-year grey alder stands in comparison with birch stands of the same age.

Keywords: birch, grey alder, root morphology, fine roots biomass, length of roots, roots volume.

# Root and nodule efficiency in soybean (*Glycine max* (L) Merr.) in differing conditions of water and nitrogen supply

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Irrigation and nitrogen fertilization are important agricultural practices to increase soybean yield and quality. Irrigation and late N supply in soybean were tested in a two-year field trial in a silty-loam soil, to evaluate their effects on root growth, nodule activity and isoflavone accumulation in seed of two soybean varieties. The unusual nitrogen fertilization in soybean aimed at covering declining nitrate-reductase and still low nitrogenase-reductase activities. Root profiles of volumetric root length density (RLD) and diameter were revealed at harvest by auger sampling. Morphological features of nodules, such as section area, axis and perimeter, were detected by image analysis, and their activity estimated as foliar ureides. Irrigation had contrasting effects on root growth in two considered varieties, but generally increased seed yield, with some positive influence on seed quality. In conditions of optimal water availability, seed protein contents increased, as well as number of nodules and their efficiency (*i.e.*, foliar ureides).

Keywords: nodule size, seed protein, root length density, root diameter

# Root anatomy and growth of three *Arabidopsis* species differing in their heavy metal tolerance

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Seeds of *Arabidopsis thaliana*, *A. arenosa*, and *A. halleri* were collected in metallicolous and non-metallicolous localities. Root characteristics of their seedlings growing on agar medium with 10 μM Zn (control) and 1000 μM Zn concentrations were compared with the model A. *thaliana* ecotype Columbia. Root tissue patterns of all three species from both types of localities were similar to *A. thaliana* Columbia. Quantitative differences concerned root and stele diameter, and the number of cells in tissue layers. Under 1000 μM Zn the root growth and the distance of root hair initiation from the root tip were reduced while length of root hairs increased. Root hair morphology was disturbed only in the sensitive *A. thaliana*. Root responses to Zn were similar in the plants originating from metalliferous and non-metalliferous localities.

Keywords: *A. thaliana*, *A. arenosa*, *A. halleri*, zinc, tissue pattern, root hairs

# Late season root profile development of two contrasting vine rootstocks

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Two years old vine stocks of *Vitis vinifera* cv. Grenache grafted on rootstocks 41-B and 161-49 were placed in a rhizotron in July 2008. New root formation, growth and lignification at different depths were followed from grape harvest (September) to leaf senescence onset (November), along with soil matric water potential (Ψm) and final biomass of shoots and roots. Both rootstocks showed a large amount of new roots in September, apparently ageing to growing and lignified roots before leaf senescence, but only partially for 41-B (root mortality). Ψm reflected differences in root depth profiles: in 41-B, with most roots in the shallowest levels, water uptake was only evident at 20cm, while 161-49, with roots more evenly distributed, affected both depths similarly. However, no differences were found in total root length, total root biomass or root:shoot ratio. No evidence of growth in cool seasons was found. These results suggest contrasting soil exploration strategies in these and other rootstocks, that could be used as an ecophysiological tool to improve water use efficiency under Mediterranean conditions.

# Fine root biomass and morphology of *Pinus densiflora* under different conditions of aboveground growth

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The fine root (diameter ≤2.0 mm) biomass and morphology of Japanese red pines (*Pinus densiflora*) grown under different aboveground conditions (*i.e.*, high and low competitive environments) were investigated in a pine–cypress mixed forest. All *P. densiflora* subject trees were approximately 40 years old, and the aboveground condition (*i.e.*, size) of red pines appeared to be influenced by the surrounding Japanese cypress (*Chamaecyparis obtusa*). Smaller pines exhibited lower fine root biomasses, shorter root lengths, and lower root tip densities, but longer specific root lengths and higher specific root tip densities relative to larger ones. These results suggest that *P. densiflora* may adjust the morphological traits of fine roots at different biomass allocation to fine roots in relation to aboveground conditions.

Keywords: fine roots, Japanese red pine, root biomass, root morphology, aboveground growth

# Quantitative study of the root system and sprouts of the antierosional plant vetiver (*Vetiveria zizanioides,* L. Nash)

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In order to study the quantitative dynamics of the root system and sprouts of the anti-erosion plant vetiver (*Vetiveria zizanioides,* L. Nash) scientific studies were carried out in hothouse, in Israel in 2004-2008 and in field conditions on a vetiver plot in Georgia.

Taking into consideration the principal geological, ameliorative, hydrological and climatic factors of the soil, the irrigation norms and watering of vetiver, the coefficient of evaporation and transpiration were determined, as wall as the dynamics of growth of the height and root system of vetiver.

Using the theory of reliability and risk and taking into account the basic characteristics of the slope and soil, the soil antierosional effect of the so-called biological wall formed of vetiver has been determined, taking into consideration the principal parameters of the maximum intensity of rainfall, the washout rate of the soil particles and other biological, hydrological and hydraulic parameters.

Keywords: vetiver plant, root system, Evapotranspiration, erosion

# Impact of soil compaction on the tracheid diameter and the theoretical hydraulic conductivity of Norway spruce seedlings

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Soil compaction was brought about by the long-term load of soil in root containers planted with 2-year-old Norway spruce seedlings. After finishing the experiment the high of seedlings were measured. Sections for histology were carried out behind the root tip and also proximally from older places. The lumen diameter along and across root radii were measured. The theoretical potential hydraulic conductivity was calculated using the modified Hagen-Poiseuille equation. Statistical analyses were carried out using program R. Control seedlings were statistically higher and had bigger lumen diameter along and across root radii than experimental seedlings. We can conclude that seedlings, which growth under impact of pressure, were smaller and develop narrower tracheids. The lower growth (ie shorter water path) of the experimental seedlings enabled them the same or even higher theoretical potential hydraulic conductivity than was calculated for control seedlings. Shortening of water path is general characteristic of plant, which growth under influence of stresses.

Keywords: anatomy, fine roots, metaxylem, soil compaction

# Gibberellin-mediated regulation of major cell-wall proteins in pea roots

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Gibberellin (GA), a shoot growth-promoting hormone, is known to regulate root growth in the presence of ancymidol (Anc), an inhibitor of GA biosynthesis. We have analyzed cell wall proteins of pea roots (*Pisum sativum* L.) in view of suggested importance of cell walls during morphological change of root cells by GA and Anc. Major protein bands on SDS-PAGE were compared between Anc-treated and (Anc+GA)-treated roots. The most remarkable was the down-regulation by GA, *i.e.* up-regulation by Anc-treatment, of 35 kD protein band which had 100 % homologous partial amino acid sequences to peroxidase of white clover (*Trifolium repens*). Other down-regulation by GA were chitinase class III. Up-regulated proteins by GA were pectin methylesterase and another peroxidase. As far as major protein bands from cell walls are compared, Anc-treated (GA-starved) thick roots accumulates peroxidase in the cell walls suggesting the higher level of cell-wall stiffening by peroxidase-mediated cross-linking of cell-wall components. GA may keep more extensible root cell walls by decreasing the peroxidase content and by regulation of pectin methylesterase.

Keywords: apoplast proteins, cell wall, gibberellin, pea, peroxidase, root growth

# A meta-analysis of QTLs controlling root growth and the response to abiotic stresses in maize

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There is no doubt that breeders indirectly selected for more efficient root systems whilst selecting for yield. However, there is comparably little information about the root morphology they selected for, nor about its response to abiotic stresses or the genes controlling it. This paper aims for a meta-analysis of four recent QTL studies performed by us using the following maize populations: CML444 x SC-Malawi RILs (C6), Ac7643 x Ac7729/TZSRWM RILs (C5) (both CIMMYT), Lo964 × Lo1016 $F_{2:4}$ families (Lo; Experimental Institute for Cereal Crops, Bergamo, Italy) and an association mapping panel of 74 temperate maize inbred lines (UOH; University of Hohenheim) (see poster of Reimer et al.). Two studies aimed to map temperature tolerance (Lo and UOH) the other two aimed for desiccation tolerance (C5) and drought avoidance by altered root morphology (C6). Root morphology was assessed non-destructively in growth pouches and destructively in sand columns (Lo) before the second leave had fully developed. In all population the same basic characteristics were measured, *i.e.* the growth of axile and lateral roots as well as their ratio. A consensus map will be presented and the most promising target regions controlling root morphology in these populations will be discussed.

Keywords: *Zea mays* L., root growth, corn, quantitative trait loci, stress tolerance

# Anatomical analysis of *lrt1* maize mutant

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Lateral roots form the major part of the root system, which interact with plants rhizosphere. One of very limited number of maize lateral roots mutants is lrt1 (lateral rootless 1). Gene, which is related to its fenotype, was mapped to the short arm of the second chromosome, but it hasn´t been still characterized (Hochholdinger & Feix, 1998). The mutant is deficient in early postembryonic lateral roots formation beside other. Exogenous application of auxin does not, while phosphate addition and/or mycorrhiza symbiosis and other environmental factors caused partial revert to original fenotype (Hochholdinger & Feix, 1998; Hochholdinger et al., 2004; Paszkowski & Boller, 2002).

The work is aimed to detailed anatomical analysis of lrt1 mutant. Exodermis development and cell wall modification during differentiation was shown to be affected and related to cultivation mode. This fact seems to be related with changes in synthesis of extracelular phenolic substances detected in lrt1 mutant proteome (Hochholdinger et al., 2004). Structural changes and modifications of exodermal cell walls were correlated with permeability of the root surface and its boundary properties. Aerenchyma formation in the middle cortex of the maize root depends upon the environmental factors. Extent of its formation differs between mutant and wild type. Spatial relationship between exodermis and aerenchyma formation is discussed.

Keywords: lateral root, maize, *lrt1*, exodermis, permeability, aerenchyma

# Effects of lateral mannitol treatment on the development of tissues in rice seminal roots

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Plants modulate their body plan through modulation of cellular developmental processes in response to environmental changes. However, it is not easy to determine whether time-course of cell differentiation process was changed under a certain environment in an organ *in situ*. We previously proposed a unique method to monitor changes in the rate of cell differentiation by monitoring cell production rate. However, measuring cell production rate needs a laborious anatomical procedure. To avoid this difficulty, we have developed another convenient method in this study. Rice seeds were sandwiched between two agar plates, only one of which contained 270 mM mannitol solution, and roots were allowed to grow for four days attaching to both agar plates. Cross sections were cut basipetally from the root apex and they were observed under a fluorescence microscope to examine whether there are any differences in the cellular developmental state between the two sides, the mannitol side and the control side. As a result, indicators of cell differentiation, such as, widening of the Casparian strip in the radial wall of the endodermal cells, suberization of the inner tangential wall of these cells, and formation of aerenchyma were promoted in the mannitol side while appearance of the Casparian strip as fluorescent dots did not differ between the two sides.

Keywords: rice, endodermis, Casparian strip, aerenchyma, osmotic stress

# The endodermal cell to cell contact is required for the spatial control of Casparian band development

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The aim of this study was to elucidate the development of apoplastic barriers in endodermal cells of Arabidopsis thaliana primary roots based on comparison of 7-days old plants of the wild type Ler and genotypes with changed endodermal development.

The apoplastic barriers develop in two stages. In the first the Casparian bands develop on the anticlinal cell walls closer than 2 mm from the root apex. Detail TEM analysis of this process was performed. The most important data is that the endodermal cell to cell contact is required for the spatial control of Casparian band development. This finding is based on scr3 genotype analysis. In the second stage suberin lamellae develop on the inner surface of primary cell walls. This process starts either with position effect opposite to the phloem poles in the distance of 8-10 mm from the root apex or even earlier preferentially opposite to the xylem pole where the lateral root primordia develop. Thereafter on the base of lateral root the endodermal cells of morphologically different shape form a collet, which connects the endodermis of lateral and primary root.

Keywords: *Arabidopsis thaliana*, Casparian band, development, endodermis, suberin lamellae

# Allometric relations between roots and shoots based on the root atlases

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The data gathered by Kutschera and coworkers as presented in different volumes of the rootatlas suggest a number of analyses. One of the more straightforward is to analyze relations between the shoot height, maximum root depth and maximum lateral root system extension which are constant descriptors in all the quoted Atlases. In another step these parameters can be correlated to soil profile descriptions, and location parameters also described in the Atlases. Results of these analyses will be presented, and allometric coefficients discussed in the light of theoretical considerations regarding shoot-root partitioning

Keywords: allometry, root-shoot, image analysis

# Fractal dimensions of rooting systems – the case of the Wurzelatlas mitteleuropäischer Ackerunkräuter und Kulturpflanzen

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The drawings in the Wurzelatlas mitteleuropäischer Ackerunkräuter und Kulturpflanzen (Root atlas of central European Weeds and Crops, and also in other Atlases by Kutschera and others) offer a unique opportunity to analyze rooting patterns of very different crops and herbs determined using a consistent methodology. Using 203 drawings, the fractal dimension of the drawings are determined. Results are presented and suggest that the fractal dimension of a rooting system increases with the length scale characterizing the root volume.

Keywords: fractal, image analysis, rooting system

# Lignification commencement in roots is controlled by the time after elongation completion

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Common event is that deceleration of root growth results in cell differentiation closer to the root tip. In tree roots, autumn appearance of xylem behind several remained meristematic cell is an extreme case. This phenomenon is usually considered an acceleration of cell differentiation. To verify this opinion, the time course of lignification was investigated in rapidly growing roots of maize seedlings as compared with roots slowly growing in chloramphenicol solution (0.05 mg/ml) and roots irradiated by X-rays (10 kR) which extended only a day and then stopped. The appearance of lignin precursors (free coniferyl and syringyl groups) was examined histochemically. Lignification started in protoxylem (both groups), in Casparian strips and middle plates of endodermal cell walls (coniferyl groups) and then in exoderm (coniferyl groups).The slower root growth was, the nearer to root tip lignification began. However, we related the commencement of these processes to the completion of cell elongation. The time scale showed that in fully-elongated cells lignin precursor appearance is almost similar in all treatments. Therefore, the deceleration or cessation of cell division in root meristem results in elongation deceleration, but after completion of elongation the lignification occurs at almost the same rate. No acceleration of cell differentiation was observed, its program starts to progress independently of root growth rate, just after root cells fully elongated.

Keywords: growth rate, cell differentiation, lignification, completion of elongation

# Influence of galactoglucomannan oligosaccharides on cell elongation in primary and lateral roots of intact mung bean plants

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Galactoglucomannan oligosaccharides (GGMOs) influence elongation growth of plants. The aim of this work was to determine the effect of GGMOs and their modified form (GGMOs-g – GGMOs with reduced galactose content) on root elongation growth accompanied by variations in elongation or division of rhizodermal and primary cortical cells. GGMOs alone as GGMOs+IBA stimulated primary and lateral root elongation growth compared with the control and IBA, respectively. This effect of GGMOs was accompanied by rhizodermal cells elongation and primary cortical cells division. On the other hand GGMOs-g alone or in the presence of IBA inhibited root elongation growth compared with GGMOs and GGMOs+IBA, respectively. The activity of these oligosaccharides in root cells elongation and division is obviously determined by the oligosaccharides structure.

Keywords: elongation growth, galactoglucomannan oligosaccharides, lateral roots, primary cortical cells, primary root, rhizodermal cells

# The symplastic cell interconnection changes during maize and reed root cortex differentiation

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Symplastic connection via plasmodesmata (PDs) takes essential role in transport as well as in plant morphogenesis (for review see Oparka 2005). Electron microscopy based plasmodesmograms generally do not cover root symplast as complex system changing along the axis of differentiation (Ma *et* Peterson 2000, 2001, Zhu *et al.* 1998, for review see Gunning *et* Robards 76). Presented method based on immunolabeling of fixation induced callose synthesis enabled us to investigate active PDs in wider set of samples than electron microscopy routine. Current paper is focused on changes of PDs distribution within differentiating root cortex.

# Gibberellin regulation of root growth and flowering in tea plant (*Camellia sinensis* L.)

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We investigated the growth-regulating functions of GA in the adventitious roots (AdR) of tea plants cultivated in hydroponics. Anc suppressed root growth and promoted thickening of AdR in the elongation zone. Development of suberin layer in root exodermal cell walls was promoted by Anc, but delayed by GA. Anc also promoted flower bud formation, and turned all new buds into flower buds in the typical case. All these effects of Anc were suppressed by the exogenously applied GA in hydroponics. We also investigated sugar composition of cell walls. By comparing soil-, hydroponics- and mist-cultured AdR and GA-starved (Anc-treated) AdR, it was found that the most apical part of the roots (0-2 mm behind root tip) responded most remarkably to the growth conditions. Mist-cultured roots, under the least mechanical stress, had the softest cell walls with the highest content of pectin and with the lowest content of cellulose. Gradient of cellulose content along root axis in GA-starved mist-cultured roots were similar to that of soil-grown roots with slowest growth rate. These results show that GA regulates also the root growth of woody plant with changes in cell wall components.

Keywords: cell wall, exodermis suberinization, flowering, gibberellin, root growth, tea root

# Interaction of galactoglucomannan oligosaccharides with auxin and activity timing in seminal root growth

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Galactoglucomannan oligosaccharides (GGMOs) control various plant processes and interactions with the environment which are under the regulation of growth hormones. The aim of this work was to prove the interaction of GGMOs with IBA in seminal root elongation growth during 24 hours of mung bean (*Vigna radiata* (L.) Wilczek) seeds germination. The activity of exogenous GGMOs in seminal root elongation was connected with the regulation effect of exogenously applied IBA. The effect of GGMOs was dependent on their timing with IBA application. A significant impact of the concentration of IBA in this process has been demonstrated and GGMOs proved also in this case their antiauxin activity accompanied by changes in cell wall-associated peroxidase activity presumably connecting with restucturalization and changes in physical properties of cell walls.

Keywords: elongation growth, galactoglucomannan oligosaccharides, peroxidase activity, seminal root, timing of action

# Root morphology and dynamics in yeheb (*Cordeauxia edulis* Hemsley) plants

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Yeheb (Cordeauxia edulis Hemsley) is a hardy and drought tolerant multipurpose plant that is endemic in the dry border area between Ethiopia and Somalia. Yeheb seedlings were grown in greenhouse with temperatures and humidity mimicking yeheb's natural habitat. Different number of seedlings were transferred to containers with soil and supplied with fertilizer and water. Plants were growing for 5 years when they were harvested and different morphological parameters were measured on the roots. The results from these measurements will be presented at the Symposium.

Keywords: Yeheb, root morphology, fine root biomass, root form

# Several factors relating on rooting of strawberry young plants

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Most of strawberry cultivars are clonally propagated. Although Sashinae is a nursing method suitable to raise simultaneously a large amount of young plants, it is disadvantageous for smooth rooting. We examined effects of pretreatment, 3-day reservation under 5°C (RT), 3-day wilting under a wet and dark condition (WT) and 3-hour dipping into different concentrations of NAA solution (NT), on rooting of young plants in late June 2008.After each pretreatment, they were nursed for 10 days under shading and sprinkle water condition. All plants including the control rooted well. It was concluded that protecting the young plants from drought by in the early stage of nursing was significant for rooting.

Keywords: Clonal propergation, Rooting, Strawberry young plant

# Root morphology of two modern high-erucic acid oilseed rape varieties (*Brassica napus* var. *oleifera*) in response to reduced agricultural inputs

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Oilseed rape (*Brassica napus* var. *oleifera*) is considered a multifunctional crop, as a source of food, feed and several industrial compounds. It includes low erucic varieties (*i.e.*, Canola) and high erucic ones (*i.e.*, HEAR, High Erucic Acid Rapeseed), very rich in this fatty acid, and mainly destined for non-food applications. This experiment examined root responses of two new commercial HEAR varieties (Hearty, Maplus) to marked reduction of agricultural inputs. Two input levels (high, low) were compared. Root growth was studied, to check its possible key role in low input adaptation. Profiles of volumetric root length density (RLD) were revealed by the auger sampling method, at phase G1 (onset of pod formation) in 2006 and 2007 in a silty-loam soil at the experimental farm of the University of Padova (NE Italy). Root densities of both Maplus and Hearty were much higher, especially in deep layers, compared with older Canola varieties at the same location. High inputs led to significantly higher RLD compared with extensive management, without substantial differences between varieties. In view of the obtained results, we conclude that modern HEAR varieties, with denser root systems, are more suitable for low input management, for greater N uptake and seed yields.

Keywords: erucic acid, low input, nitrogen fertilization, root length density

# Insights into fine root development patterns of Perennial Ryegrass (*Lolium perenne* L)

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Since the initial report that roots finer than a given diameter are determinate in growth habit, little research has been done on the concept of diameter mediated growth patterns. An investigation into this phenomenon with a common pasture grass (*Lolium perenne* L.; Perennial ryegrass [Lp]), using very high resolution imaging (effective pixel size < 5 micron), provides some additional insights. Cultivars of this cross pollinating species have extensive variability in rooting patterns. Several different types of fine lateral roots (<0.5 mm diameter) have been documented: Long indeterminate, short indeterminate, long determinate, short determinate. Short vs. long determinate appears a plant determined characteristic since mixtures have not been observed. Only long indeterminate lateral roots have lateral branching. There appear to be two types of long indeterminate roots, frequent and atypical. The frequent type of indeterminate lateral root are typically half the diameter of the parent root. The atypical type may be as large as the parent root diameter, and may appear at any location along the parent root. Short indeterminate roots differ from long ones in not having branching, growing slowly, and being smaller in diameter.

Keywords: fine roots, developmental patterns, indeterminate, determinate, short laterals

# SESSION 2

# ROOT UPTAKE, USE EFFICIENCY AND COMPETITION

Oral Presentations

# Individuality of roots

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A root system develops in a dynamic three dimensional soil volume and therefore has to cope with environmental unevenness and unpredictability. This is achieved, in part, by the formation of various types of roots that express different traits. Such, differences in traits of various roots, are based on inherent characteristics of the plant. In spite of that, most physiological investigations continue to use root assemblages in their studies, without distinction between root types and without determination of the fraction that each root type may comprise.

Different functions of roots are activated, by the specific conditions that prevail in their immediate environment and the specific responses of the roots to such conditions. Differences in responses are manifested in the structure of the roots, in their growth pattern, in their composition and hormone content, in the activity of some of their key enzymes, in their capability for water and nutrient acquisition, in their tolerance to environmental stresses and in their effect on their rhizosphere.

Are the traits of each root type permanent characteristics or transient and may change in time? Is it possible to forecast the development of different types under different conditions? Those and other questions will be discussed.

**The take home message is:** A root system is comprised of various root types that function in concert, but still preserve their individuality.

Keywords: root types, Individual behavior

# Utilization of plant growth regulators for improving the recovery rate of fertilizer in rice-effect of L-β-Phenyllactic acid on growth of rice seedlings

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We investigated the effects of L-β-Phenyllactic Acid (LBP) on growth of both shoot and root in rice seedlings. Rice seedlings were cultured in the seed packs$^{TM}$ containing 1/100 strength MS nutrient solution with or without 100 mg/L LBP. Agronomical parameters were measured and the total root area was calculated according to the method proposed by Kimura (2001) after two weeks seeding. The plant age and plant height of rice seedlings were markedly enhanced by LBP treatment than those of control. The seminal root length of seedlings was also significantly ($P<0.05$) increased by 26% compared with that of control. In contrast, the root number per seedling was not affected by LBP treatments. Correlation between the total area of root, and the number of root or the seminal root length were not observed. It should be noted that LBP significantly ($P<0.05$) increased the total area of root of seedlings by increasing those of the thinner lateral root (less than 0.757 mm in diameter), not of the thicker one. In conclusion, the high recovery rate of fertilizer in *co-situs* application using a CRF (controlled-released fertilizer) is possible by using LBP.

Keywords: controlled-released fertilizer, L-β-Phenyllactic acid, recovery rate of fertilizer, rice, root system, seedling

# Phenotypic plasticity of *Pinus pinaster* to water stress: Biomass allocation and root architecture

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In a context of climate change, adaptation of perennial plantations to water constraints becomes a major concern for wood productivity. Scenario of climate change predict severe summer drought in south-western France. Our project plans to describe adaptive mechanisms of the species. The phenotypic plasticity of *Pinus pinaster* ait. to water availability is tested in the field by planting 1-years-old trees under a greenhouse open at its borders for rainwater exclusion. Water is provided to compensate evapo-transpiration to half the plants by aerial irrigation. One well growing and one slow growing half-sib family, both of the local improved provenances were compared. The soil is a sandy spodosol. The soil water content, water table level, air temperature and humidity were monitored. Shallow soil water content decreased to 6% in the dry treatment in late summer. After an inventory of height and diameter, 40 saplings were uprooted in March July September and March for aerial and root biomass and architecture assessment. Surprisingly, water shortage did not affect total biomass of the saplings. However, the water stressed trees showed slimmer stems, more biomass allocation to needles (+18%), and distinctly less allocation to roots (-30%), especially distal roots. Water constraints did not affect taproot length and rooting depth or maximal root radial distance. Selection for height at age 10-years resulted in saplings with a better harvest index for the stem. We hypothesize that *P. pinaster* saplings stop root growth when the soil is too dry, but maintain their productivity by setting more needles.

Keywords: root system architecture, water-stress, plasticity, genomics, *Pinus pinaster*

# Belowground interspecific competition in mixed boreal forests: The effect of stand developmental stage and soil fertility on the ectomycorrhiza and fine root characteristics

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The role of the belowground interspecific competition in the formation of the stand structure is poorly understood. In boreal forest soils, fine roots and ectomycorrhizas acquire together the soil resources, and therefore have to be studied simultaneously in the same stands.We studied fine roots and ectomycorrhizas in five mixed *Betula pendula* Roth, *Picea abies* (L.) H. Karst., and *Pinus sylvestris* L. stands in Southern Finland. The stands formed continua of developmental stage (15-, 30-, and 50-year-old stands) in the stands of medium fertility, and of site fertility in the young stands (30-year-old fertile, medium fertile, and infertile stands). The biomass of the external hyphae of ectomycorrhizas was the highest, and the diversity of the fungal community the lowest, in the most fertile stand. The vertical distributions of fine roots of the three tree species were mostly overlapping, indicating high inter-specific belowground competition in the stands. We did not find any clear trends in the fine root biomass across the developmental stages of stands. The fine root biomass of the conifers increased towards lower site fertility, whereas in *B. pendula* it was almost constant. In contrast to the conifers, the specific root length (SRL) of *B. pendula* clearly increased from the most fertile to the least fertile stand. This may indicate differences in the primary nutrient acquisition strategy between conifers and *B. pendula*.

Keywords: ectomycorrhizal diversity, fungal biomass, fine root biomass, root morphology

# Variability in root apoplastic barriers relates with variability of cadmium uptake and translocation

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Root apoplastic barriers, endodermis and exodermis represent cell layers with specific wall modifications. One of their functions is regulation of radial transport of water and ions. In response to cadmium influence these layers mature closer to the root tip. Differences in the development of endodermis were found in clones of the same species differing in cadmium translocation from the root to the shoot. Specific additional layer of lignified cells the peri-endodermal layer is formed in one of the hyperaccumulator species *Thlaspi caerulescens* syn. *Noccaea caerulescens*. Suberinization, lignification and cell wall thickening may occur in reaction to Cd treatment in roots of various plant species. Even wound periderm in monocot roots can be formed.

Keywords: apoplast, cadmium, endodermis, exodermis

# Root plasticity to water and its relevance for drought tolerance

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The manner in which roots explore the soil is a key ability for plants to survive and compete. Root plasticity to exploit nutrient patches is well documented, however the responses to localised water is less well understood. Compacted layers in the soil, either natural e.g. at horizon boundaries or resulting from compaction associated with the passage of machinery, often impedes the access of roots to the subsoil. In these cases access to subsoil water is controlled by the numbers of roots that find and follow a crack or biopore through the compacted layer and then have the plasticity to exploit the water resource. Recently we have used field experiments controlling the access of roots to water in the subsoil as a way to screen a limited number of barley genotypes for their ability to cope with drought stress.

We have modified our technique of controlling access to the subsoil and applied it in controlled growing conditions with dry surface soil and water available at depth. Measurements of root length, mass and branching are obtained after washing the roots from fixed depths in the soil. This enables us to measure the proliferation of roots of different barley genotypes and to compare them with control samples and thus quantify their plasticity to subsoil water.

Keywords: Barley, root plasticity, drought tolerance, biopores, subsoil water

# Root respiration and carbon metabolism in response to self/non-self competition

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Carbon metabolism is a basic process essential for plant growth and survival that encompasses mainly photosynthesis, and respiration. Although they are many studies on photosynthesis, they are still limited studies on plant respiration in general and specifically on root respiration which plays a major role in whole plant carbon metabolism. In the current study, we investigated the affect of non-self competition stress on the performance of root respiration in the model species field pea (*Pisum sativum* var. *arvense* Poir. cultivar Dunn). Split root plants were planted in triplets so that each pot contained either two roots of the same plant (self) or of two different plants (non-self). The plants were watered with ample water (moist treatment) or salt-solution (0.1 mol NaCl $L^{-1}$; salinity treatment). As response to non-self competition shoot mass significantly decreased by 20%, while the root mass remained similar, resulting in an increase of the root:shoot ratio by about a third. Thus relatively more biomass and carbon was allocated belowground. But SRA of plants with non-self competition stress decreased significantly. A significant reduction of leaf dark respiration by a half, accompanied by a significant increase of root $O_2$ uptake by 27% in non-self plants. non-self plants were less affected by salt stress than self plants, indicating on a possible acclimation to future stress in non-self plants in a feed-forward acclimation mechanism.

Our results provide new information on root respiration, which indicates that carbon emission through root respiration may have been underestimated by up to 30%. Therefore it is essential to continue and explore the effects of self vs. non-self on carbon metabolism in order to produce more accurate climate change models that currently neglect respiratory changes in general and specifically root respiration, especially in such a wide phenomena in nature such as self vs. non-self.

# Root-depth profiles of important agricultural crops

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Based on a literature review we describe root density profiles in terms of a logistic dose-response function for important global agricultural crops (wheat, maize, rice, barley, soybean, pulses, cotton, potato, sunflower, rye, rapeseed, and sugarbeet). These root density profiles can be used in 1-D macroscopic root water uptake models. For use in 1-D microscopic root water uptake models, we analyze root density data in terms of the half mean distance between roots. Based on the database there is little support for a predictive relationship between parameters of the root density distribution of agricultural crops and climate or management factors. Constancy of the shape of the root density distribution with time is shown not to hold in some experiments, but evidence is anecdotical. At present the basis to describe rooting profiles with depth only seems to allow profiles which are constant in time and with depth. The correlation between half mean distance and drought sensitivity is investigated and conclusions will be presented.

Keywords: modelling, root length density

# P depletion in the rhizosphere of *Brassica napus*: Diffusive gradients in thin films (DGT) in comparison to conventional extraction methods

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Several methods are available to estimate plant-available phosphorus in soil (e.g., Olsen method, Ca-lactate-acetate method, etc.). However, many studies have shown that the correlation between extractable P and P accumulation in plant was hardly significant. Additionally, P depletion in rhizosphere soil could not be fully assessed. Thus, there is a need for new methods which provide more detailed insight into P availability and P depletion in rhizosphere soils. The method of "diffusive gradients in thin films" (DGT) has been developed to assess the effective soil solution concentration of major and trace elements. Additionally, DGT can be used to determine the kinetics of resupply. Therefore, we have conducted a pot experiment with three soils having similar pH, but different levels of total and extractable P. *Brassica napus* L. was planted on each soil and grown for 60 days. After harvesting, roots were separated from soil and shoots were separated from roots. Biomass and P concentration were determined in order to calculate the total P content in plant. The rooted soil was treated as rhizosphere soil and compared with non-planted control soils. CAL-extractable P as well as the effective soil solution P concentration using DGT ($C_E$) were determined for rooted and non-rooted soils. Only for one of the three soils, CAL-extractable P concentration was clearly different between rooted and non-rooted soils. For two soils, the soil solution P (determined using soil solution samplers) was higher in planted soils. In contrast to CAL-extractable and soil solution P, the effective P concentration in soil solution ($C_E$) was clearly decreased in all rooted soils. Thus, the difference of $C_E$-P between rooted and non-rooted soils had a better correlation with P concentration and total P content in shoots compared to the difference of CAL-P.

Keywords: phosphorus, Brassica, rhizosphere, DGT, soil solution

# Is callose a barrier that does not enable penetration of the root cell protoplast in *Lemna minor* L. by lead ions?

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Plants have developed various resistance strategies: for example formation of physical and/or chemical barriers, which partly or completely limit the penetration of the organism by the stress factor. One of the common barriers used in plant cells is a callose layer. It can form a barrier protecting against both abiotic and biotic stress factors. Induction of synthesis of this cell component was also observed under the influence of trace metals: Al, Co, Ni, and Zn. In roots of *Lemna minor* treated with $Pb^{2+}$ ions, in spite of induction of callose synthesis in the root apex, Pb very quickly appeared in protoplasts. That is why the present study attempts to explain the cause of this phenomenon. The treatment of *Lemna minor* L. plants with $Pb^{2+}$ resulted in intensified deposition of β-1,3-glucan (callose) in roots. It was localized in the protoderm and in the centre of the root tip (procambial central cylinder). Callose distribution in *Lemna* root cell walls was only partly corresponded to lead localization. Very often, in walls containing numerous Pb precipitates, callose was not detected, and even if it was detected, then the number of signals for callose was much smaller than for Pb. A continuous callose bands were formed only local and they prevented the penetration by Pb only in a small area of the protoplast located in the immediate vicinity. Most of Pb deposited in walls was not separated from the protoplast by a callose layer. As a result, Pb was present in the protoplast. In conclusion, callose, whose synthesis is induced in *Lemna* root cells under the influence of Pb, does not prevent effectively the penetration of the protoplast by Pb ions. The major, although not the only reason for this is certainly the rather limited, local distribution of callose in walls of individual cells.

Keywords: callose, lead ($Pb^{2+}$), root cell, duckweed, *Lemna*

# Variation in rooting habit of potatoes: Potential for improving resource capture

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Potatoes are important to Scottish agriculture but are also a major crop globally. Relative to cereals they are inefficient in their acquisition and utilization of water and minerals using a disproportionate amount of irrigation and fertilizer which conflicts with environmental protection measures and agricultural sustainability. We are screening potato cultivars for root traits associated with resource capture to develop an understanding of their genetic control. The present study was undertaken to assess variation in rooting traits of a range of potato genotypes including the European tetraploid potato (*S. tuberosum* Group Tuberosum), diploid Phureja potatoes (*S. tuberosum* Group Phureja) and Neotuberosum lines (selected from *S. tuberosum* Group Andigena) under field and glasshouse conditions. Significant differences in root number, length and surface area were found. Total root length per plant varied from 38m for the Tuberosum variety Pentland Dell to >100m for the Phureja variety Mayan Twilight. There was significant correlation between glasshouse and field measures; stolon root number from the glasshouse screen could be used to indicate total root length in the field. Our data demonstrate that there is significant variability in root characteristics amongst potato genotypes. In the future, molecular characterisation for genetic markers associated with improved rooting characteristics could enable resource capture improvement through genotypic and/or phenotypic selection of appropriate root traits and their expression in relevant commercial germplasm.

Keywords: *Solanum tuberosum*, Phureja, root, nutrient-use, sustainability, water-use

# Poster Presentations

# Silicon deposition in roots of forage grasses

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Silicon (Si) is deposited in specific root and shoot tissues at various concentrations depending on plant species. In this study, we compared location and quantity of Si deposition in the roots and leaf blades of four forage grasses using X-ray microanalysis. Seedlings of two C3 temperate grasses (timothy, tall fescue) and two C4 tropical grasses (sudangrass, rhodesgrass) were grown in sand culture with application of potassium silicate under the green house condition to analyze Si deposition in seminal roots. The grasses were also grown in pots filled with an Andosol soil for the analysis of Si deposition in nodal roots and leaves of mature plants. At the seedling stage, Si deposited in endodermal cell walls in primary seminal roots of timothy and sudangrass, but not in those of tall fescue or rhodesgrass. In mature plants, Si deposition in endodermal cell walls of nodal roots was detected in all the species except rhodesgrass. The Si content (wt%) in the root endodermis was 0.7% in timothy, 0.8% in tall fescue, and 3.6% in sudangrass, respectively. Sudangrass formed Si aggregates on the inner cell walls of endodermis. Aged nodal roots of rhodesgrass sometimes accumulated Si in the cell walls surrounding the aerenchyma. The pattern of Si deposition on leaf surface was also much varied among four grass species. These differences could be related to the degree of Si effects to stress tolerance and forage quality of each grass species.

Keywords: *Chloris gayana*, EDX-type X-ray microanalyzer, ESEM, *Festuca arundinacea*, *Phleum pratense*, *Sorghum sudanense*

# Root pruning reduces root competition and increases crop growth in a living mulch cropping system

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Living mulch systems may decrease pest attacks. However, the below-ground competition from the living mulch may decrease the growth of the cash crop. Here growth of white cabbage in living mulch systems and in pure stands was compared. Root pruning of the living mulch increased the above-ground biomass of white cabbage, with two prunings giving higher cabbage yields than one. Below-ground growth and competition were examined by measuring root distribution in minirhizotrons and uptake of $^{15}N$ placed at different soil depths. These studies showed that the ability of mulch species to compete for resources at depth was restricted by pruning.

Keywords: living mulch, N competition, root distribution, root pruning, white cabbage

# Genotypic variation in root traits involved in phosphorus utilization by barley

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In Scotland the major cereal crop is barley and here we investigate the variation between barley mutants in relation to root characteristics and their ability to respond to phosphorus deficiency. A screen of a mutant population in an Optic genetic background has identified variation in rooting characteristics (root hairs, root length and root angle) and a sub sample of mutants demonstrating variation in root hair characteristics (no root hairs, short root hairs and long root hairs) has been grown in a pot experiment to establish links between specific root hair characteristics and phosphorus utilization. This will help us to identify candidate genes for root traits which improve phosphorus use efficiency in barley allowing their introduction into commercial varieties which will be beneficial to the long term sustainability of agriculture.

Keywords: agricultural sustainability, forward genetics, *Hordeum vulgare* L., mutant population, root hairs

# Absorbing roots and leaves distribution in studies based on whole tree approach in large pines and oaks

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Roots represent one of the most important parts of trees similarly like their foliage and naturally deserve high attention in tree water relation studies. However, whole tree approach has been rather rarely applied in routine, landscape applicable forest tree studies. Here we show some examples of such approach, where both below and aboveground parts of trees were examined together. Operative biometric parameters and seasonal transpiration were studied in two contrasting specie/sites. Mature Scots pine (*Pinus sylvestris* L.) plantation growing on sandy soil (Brasschaat, northern Belgium) and a mixture of species in the floodplain forest (Lednice, southern Moravia) growing on heavy soil, mostly consisting of pedunculate oak (*Quercus robur* L.), ash (*Fraxinus excelsior* L.) and lime (*Tilia cordata* L.) were compared. Vertical leaf distribution in canopy layers at different height above ground, relative vertical absorbing root distribution in soils and seasonal transpiration of stands was estimated using specific technologies. Similarities and differences in tree and stand structure and behavior are discussed. The above results represent only a small part of similar studies, however they illustrate rather wide background of the research, applied for practical forestry purposes, which must not be yet crucial for our present scientific activities, but it reasonably seems, that most probably such needs will occur in the nearest future.

# Breeding for root system shape in perennial ryegrass (*Lolium perenne* L.)

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Root dry weight (DW) distribution was measured in the progeny of four contrasting root shape pools. Shoot DW, root DW, and root/shoot DW ratios did not differ among the progeny. Type 2 (high surface root mass, roots to 1m) progeny had a significantly higher percentage of total root DW between 0-10 cm than type 1 (low surface root mass, roots to 1m). The root type 2 progeny had a lower percentage of total root DW between 10 -20 cm than the other root types, and also, type 2 had a significantly lower % of root DW 20-30 cm than types 1 and 4 (high 0-10 cm root mass, shallow).The probability of the root type 4 plants having roots at 1m depth was 0.67 – a significantly lower probability than for the other progenies.

Keywords: breeding, root depth, root shape, ryegrass, *Lolium*

# Root development of maize as affected by weeds in tropical major an minor seasons

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Field studies determined the impact of two aggressive tropical dicot weeds *Mimosa pudica* – Fabaceae and *Acalypha indica* Euphorbeaceae) on root development of maize seedlings over the first 30 days after planting and on seed yields, in major and minor seasons of the tropics. Weeds were sown with maize seeds at a density of 8 plants per sq. Meter. Root length densities were determined and subsamples of roots were used to determine the proportions of monocot (maize) and dicot (weed) roots by examining the vascular bundles. Seed yields were determined at crop maturity. In the major wet season, there were more maize roots in the soil profile, and seed yields were greater than in the minor dry season. In the minor season, there was greater total RLD and the roots of weeds were in a greater proportion in all depths. The roots of acalypha, the upright weed was more prominent at all depths than that of mimosa, a prostrate weed and seed yields of maize were affected to a greater extent by acalypha. The importance of weed management during early growth to reduce competition and obtain greater seed yields was observed.

Keywords: maize, weeds, root growth, tropical seasons

# Maize (*Zea mays* L.) root architectural plasticity in response to critical nitrogen stress using an aeroponics system

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Nitrogen (N) is a crucial macronutrient that influences maize yield and development both above and below ground. Previous studies on maize root architecture have focused on seedling roots. Since adult, post-embryonic adventitious roots are the major root organs in maize responsible for N capture, this study examined root plasticity at post-embryonic developmental stages in response to low N. To dynamically quantify the maize post-embryonic root system, which is extensive and developmentally complex, we engineered an aeroponics system, where the roots are suspended in the air and misted at regular intervals with a nutrient solution. We detected that adult maize, upon low N stress exposure, ceases the elongation of metabolically expensive, pre-existing crown roots and/or makes shorter *de novo* crown roots, in favour of allocating more energy to support less expensive lateral root growth and branching. Our results reveal a novel adaptation to low N in adult maize: induced root architecture plasticity to maintain soil exploration while reducing the internal metabolic resources required.

Keywords: *Zea mays*, root architecture, nitrogen, aeroponics

# Effects of Cd treatment on root activity in tea plants

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The present study investigated effects of one of toxic metals – cadmium - on tea plants (*Camellia sinensis*). After appearance of the new white roots in one-year old rooted cuttings of cultivar `Yabukita` cultivated with Konishi's hydroponics medium, they were treated with cadmium solution using $Cd(NO_3)_2 \cdot 4H_2O$ at the concentration of $10^{-5}$, $10^{-4}$, and $10^{-3}$M for 1 week, respectively. Root activity was evaluated by triphenyl tetrazolium chloride (TTC) method for visualizing the activity points of succinic acid dehydrogenase related with respiratory system and $O_2$ uptester method which measures the consuming $O_2$ volume by roots. By TTC method, the root activity was inhibited partially in the $10^{-5}$ M Cd-treated roots and completely in $10^{-4}$ and $10^{-3}$ M Cd-treated ones. Respiratory activity of tea roots treated with $10^{-5}$, $10^{-4}$, and $10^{-3}$ M Cd measured by $O_2$ uptester method was 22.30±12.38 (n=11), 18.73±8.57 (n=7), and 18.78±10.70 (n=7) ($\mu molO_2\ h^{-1}\ gDW^{-1}$), respectively. In the control roots (without Cd treatment), respiratory activity was 35.54±14.41 (n=13) ($\mu molO_2\ h^{-1}\ gDW^{-1}$). The results showed that Cd inhibited the root activity. In our previous study, Cd could hardly be detected in leaves of $10^{-5}$ M Cd-treated tea plants. We suggested that early development of Casparian bands in exodermis may function as a barrier against toxic metals including Cd. Moreover, according to the present study, it results that the inhibition (decrease) of root activity by Cd treatment may affect Cd uptake in roots.

Keywords: tea roots, Cd, respiration

# Study of root zone restriction by transplanting cultivation for suppression of cadmium content in Spinach

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In order to make the method for reduction of Cadmium (Cd) risk on spinach grown in the Cd polluted fields with non-contaminated soil dressing, we studied about the effect of the transplanting cultivation with plug seedlings on the root distribution and the Cd uptake on spinach. It was shown that the using of the transplanting on spinach cultivation suppressed the development of the spinach roots in contaminated soil and reduced the Cd uptake of spinach. It was verified that the application of transplanting with plug seedlings on spinach cultivation was effective to reduce the Cd risk on spinach grown in the Cd polluted fields with non-contaminated soil dressing.

Keywords: spinach, cadmium, transplanting cultivation, plug seedling, root distribution

# Root growth and N uptake to 1.6 m soil depth by babyleaf rucola on sandy soil

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Little is known about root growth and N uptake of field-grown babyleaf rucola. However, the quality of the babyleaf product is very sensitive to decreases of N fertilisation despite high application of up to 250 kg N $ha^{-1}$ over the first 8 weeks growing period. This may be due to leaching of nitrate below the root zone on sandy soils, and subsequent losses of nitrate to the environment. Therefore a field experiment was performed to investigate 1) the root growth and N uptake of rucola on sandy soil; 2) the effect of N fertilisation and seeding density on soil N availability, deep root growth, N uptake activity and product quality. Root growth was studied by use of minirhizotrons and deep N uptake by isotope $^{15}N$ placement at two subsequent harvests. Rucola was found to have a root depth of 0.8 m at the first harvest (eight weeks), and of 1.6 m at the second harvest after additional four weeks. The deep root growth was confirmed by uptake of $^{15}N$ placed at 0.6 and 1.1 m depth. The deep N uptake was not affected by N fertilisation, but total N uptake and product quality were increased by higher N fertilisation and seeding density. In average more than 200 kg nitrate-N $ha^{-1}$ was lost from the 0-2.5 m soil profile during the 12 weeks of growth and another 200 kg N/ha was left in the soil after harvest. The apparent contradiction between the development of a deep root system, high N inputs and suboptimal quality at harvest was indicated to be due to high irrigation intensity at seeding. This caused low availability of nitrate in the early root zone, and extreme N losses from this sandy soil.

Keywords: rucola, deep root growth, N uptake, minirhizotrons, nitrate leaching

# Modification of $NH^+$ ions transport into *Zea mays* germ roots by means of exogenous amino acids

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Influence of certain amino acids on ammonium uptake by corn shoots' roots was investigated.

Short-term treatment of roots with amino acids resulted in changes of ammonia transport into plant roots. Maximum inhibition of ammonia transport system was observed upon addition of D- and L-Asp, L-Gln, and L-Glu into experimental solution.

Changes in ammonium transport into seedling roots of *Zea mays* are caused by changes in qualitative and quantitative contents of amino acids in cell cytoplasm after treatment of seedling roots by exogenous amino acids.

Keywords: *Zea mays*, ammonium transport, free amino acids

# Mercury uptake kinetics by white lupin roots

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Kinetics of Hg uptake by white lupin roots was studied at 20ºC and ice-cold conditions. At 20ºC, Hg uptake showed two components, active influx of Hg and passive accumulation of Hg, which can be monitored at ice-cold conditions. Ice-cold Hg-uptake showed a linear behaviour. The difference between Hg uptake at 20ºC and ice-cold conditions was best fitted to a hyperbolic curve, which would indicate the presence of an active transport of Hg across the root membrane mediated by a carrier. Values obtained are $K_m$ = 149 µM and $V_{max}$ = 3.6 µmol Hg $g^{-1}$ FW $h^{-1}$. Data obtained at 20ºC were best fitted to a hyperbola with linear compound, giving the kinetic parameters the values of $K_m$ = 218 µM and $V_{max}$ = 3.8 µmol Hg $g^{-1}$ FW $h^{-1}$, quite similar to those obtained from the corrected hyperbolic function. On the other hand, Hg is somehow accumulating in plant material under ice-cold conditions. Further investigations are needed to elucidate whether Hg is entering inside plant cells at < 2ºC, by way of an ionic channel or just an adsorption phenomenon is taking place.

# A study of glutamine uptake by rice roots

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We present uptake and metabolism of glutamine by rice plant roots. Rice plants were cultured in a gel, each containing different kind of 20 amino acids as nitrogen sources under sterile condition. There was a large difference in root development according to the kind of amino acids. Especially in the case of glutamine, the seminal roots and lateral roots were developed well. Therefore, the glutamine absorption manner was analyzed applying $^{14}$C-labeled glutamine, using the real-time imaging system. The uptake amount of glutamine was steadily increased at the root tip. However, in the middle of the root, glutamine uptake curve reached plateau after 10 hours, suggesting that the glutamine accumulation was active at root tip, while the glutamine was only passing through the middle part of the root. To analyze metabolism of glutamine in the plant, doubly labeled amino acids with stable isotopes was applied. In the case of glutamine uptake, the ratio of free amino acids in root was rather constant compared to those when valine were supplied. The mass analysis indicated that absorbed glutamine was metabolized to the other amino acids, suggesting the smooth assimilation of absorbed glutamine.

Keywords: glutamine, rice, root development, uptake, metabolism, real-time imaging system

# Effects of root trenching of overstorey Norway-spruce (*Picea abies*) on root growth of underplanted beech (*Fagus sylvatica*) and Douglas fir (*Pseudotsuga menziesii*) seedlings

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The impact of root competition by the overstorey Norway spruce on soil water potential and on root growth of the underplanted seedlings of beech and Douglas-fir over two growing seasons was investigated using a trenching experiment.

Keywords: root trenching, Fagus sylvatica, Pseudotsuga menziesii, root growth response

# Root distribution of winter wheat cultivars as affected by drought

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Drought stress is one of the main environmental factors limiting crop yields. Choice of drought-resistant cultivars may minimise yield-losses under water-limited conditions. The development of a deeper root system contributes to increased drought resistance.

Based on this information, the genotypic variation in root system distribution in winter wheat was examined in a field experiment either under natural rainfed conditions or with an induced water deficit. The distribution of roots was quantified at the wax-ripe stage (EC 83).

Root length densities were highest in the top 20 cm. Drought-stressed plants tended to produce less overall root length, and cultivars differed significantly in overall root lengths produced. Cultivars seemed to differ in their reaction to drought stress, but the difference was not significant.

In conclusion, data from additional growing seasons will be necessary to confirm variation in root distribution between cultivars in their response to drought-stress.

Keywords: wheat, drought, root distribution, genotypic variation.

# Application method of green manures affect root development of field grown maize and mungbean in tropical minor seasons

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A field experiment evaluated the impact of two green manures (leaves of *Gliricidia sepium* or *Tithonia diversifolia*) on root development characteristics of maize (*Zea mays*) and mungbean (*Vigna radiata).* The organic matter was either incorporated 14 days prior to planting or placed on the surface at planting. The root length densities (RLD) and root weight densities (RWD) were determined upto a depth of 60 cm at 30 days after planting and the final yields of crops and N contents of seeds and residues. Incorporation of organic matter stimulated root development, especially the RLD, N use efficiency (NUE) and seed yields. Tithonia promoted root growth to a greater extent and the beneficial effect was greater on roots of maize than in mungbean. Incorporation also enhanced NUE and seed yields irrespective of the green manures.

Keywords: green manures, placement, root growth, tropics

# Cd accumulation in roots and nitrogen-fixing activity of root nodules in leguminous plants

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The Cd content in roots and the nitrogen-fixing activity (NFA) of root nodules were determined under soil and soilless culture conditions in species of leguminous plants depending on Cd concentration in the medium. The possibility of NFA stimulation by low Cd concentration was shown.

Keywords: Cd, *leguminous* plants, accumulation, roots, nodules, nitrogen-fixing

# Effect of root structure on root cadmium uptake in maize

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This study compares the architecture and the structure of maize roots grown in hydroponics, aeroponics and soil. No significant differences were found in number of root apices per unit of weight and root surface per unit of weight between the three cultivation methods. The only difference was found in distances from the root apex where root apoplastic barriers are being formed. Formation of barriers in hydroponics is more distant from the root apex, resulting in higher proportion of barrier-free areas comparing to aeroponically and soil grown roots. This may explain previously found differences in cadmium uptake between the different cultivation conditions.

Keywords: Cadmium uptake, endodermis, exodermis, root architecture, *Zea mays*

# SESSION 3

# RHIZOSPHERE AND SOIL ORGANISMS

Oral Presentations

# Rhizosphere and Mycorrhizosphere interactions – Selection, detection, selectivity and function

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Soil microorganisms (symbionts, saprotrophs & pathogens) are key determinants of soil fertility and plant health. Better understanding of the interactions of these microorganisms with each other and with plants is a prerequisite for the efficient, sustainable management of soil fertility and crop production. Although bacteria, pathogenic, saprotrophic and symbiotic fungi may exist in intimate association with each other and interact directly, they have traditionally been studied separately by separate groups of scientists, working within different research traditions. The rhizosphere has been studied intensively since the term was first used by Hiltner in 1904 but the study of the mycorrhizosphere is still in its infancy. Symbiotic mycorrhizal hyphae provide the main direct route for carbon flow from plant roots to the soil microbial community, accounting for between 10 and 20 % of the total plant photosynthate in natural and semi-natural ecosystems. The surface area of these hyphae is the ultimate plant-soil interface, typically exceeding that of the roots by 1-3 orders of magnitude. These hyphae provide the main pathway for nutrient uptake from soils by plants. In conventional, intensive agriculture the biomass and functional importance of mycorrhizal associations is reduced by high fertiliser inputs, disturbance and agro-chemicals. However in low input, sustainable systems symbiotic mycorrhizal mycelia may play a crucial role in maintaining productivity by improving plant access to nutrients and water, reducing the negative impact of pathogens, and providing an important niche for plant growth promoting or other beneficial bacteria.

Different examples of rhizosphere and mycorrhizosphere interactions in both forest and agricultural systems will be examined. Many systems are characterised by high overall diversity and appropriate methods are sometimes required to enrich the relevant microbial populations and to examine the selective effects of different plants or mycorrhizal symbionts.

New high throughput sequencing methods provide novel opportunities to examine the metagenomes or transcriptomes of different systems but relevant questions and appropriate temporal and spatial levels of sampling must be identified.

Keywords: bacteria, carbon flow, fungi, mycorrhiza, mycorrhizosphere, rhizosphere

# Plant species with different competitive abilities affect microbial growth in rhizosphere

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The aim of this study was to examine how different competitive abilities of two plant species, *Fragaria vesca* and *Duchesnea indica,* alter the functions of rhizosphere microorganisms in dependence on N availability. By intraspecific competition of the plants, significantly lower microbial biomass was observed in the rhizosphere of weak competitive *F. vesca* as compared with strong competitive *D. indica* under N-limiting conditions. However, microbial specific growth rates were 2.4 folds greater in rhizosphere of *F. vesca* than of *D. indica*. By interspecific competition of both plants, microbial growth rates were similar to those for *D. indica* indicating that strong competitive plant species control microbial community in the rhizosphere. The competition of both plant species and the dominating effect of *D. indica* on microbial specific growth rates disappeared after N fertilization. We conclude that competitive ability of *F. vesca* and *D. indica* and their effects on microbial growth rates in rhizosphere are pronounced mainly under N-limitation.

Keywords: plant – microbial interactions, growth strategies, N limitation, rhizosphere

# Analysis of determining factors on community structure of soil bacteria in volcano ash soil (Kanto Loam) farming field using PCR-DGGE method

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Soil bacteria were analyzed to discuss factors affecting structure and diversity of their community in two farming fields with different soil types (red loam and Andosol) originated from volcano ash soil, Kanto Loam, in Japan. Soybean, barley and maize were grown in rotation with different fertilization from 2007 to 2008. The bacterial 16S rDNA sequences extracted from the individual soil sample was amplified by PCR and detected by denaturing gradient gel electrophoresis (DGGE). Similarity of bacterial community structure among the samples was analyzed by principal component (PC) analysis on the detected DNA band patterns. The crop species affected much on the detected band patterns. The largest number of bands was detected from maize soil, suggesting high diversity of bacterial species in the community, while the smallest number of bands was from soybean soil. Mapping of the soil samples by the PC1, PC2 and PC3 also demonstrated the clear differences in structure of bacterial communities among three crop species. In maize and barley, growth stage of crops was the primary major factor determining the structure of bacterial communities, and the soil type was the second one. In soybean soil, the band pattern was rather stable comparing with maize and barley. The effects of fertilization were not obvious in any crops. The results indicate that the large effects of plant species in crop rotation and their growth stages have large effects on the communities of soil bacteria, while there also were rhizosphere effects.

Keywords: barley (*Hordeum vulgare* L.), maize (*Zea mays* L.), PCR-DGGE method, soil bacteria, soybean (*Glycine max* (L.) Merr.)

# Resilience of rhizosphere bacterial populations during phytoextraction of heavy metal polluted soil with poplar

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As the heavy metal (HM) content in remediated soils may be reduced due to the metal uptake by plant roots, continual monitoring of key bacterial communities might be useful to assess the resilience of the microbial structures and to find indicators for the removal of the HM. Here, we studied the response of *Pseudomonas* spp. and ammonia-oxidizing bacterial (AOB) populations during phytoextraction. Hybrid poplars were grown in compartmented root containers with an aged HM contaminated soil for 13 weeks. Bulk and poplar rhizosphere soils were analyzed by denaturing gradient gel electrophoresis (DGGE) of *Pseudomonas* (*sensu stricto*) 16S rRNA and *amoA* gene fragments. DGGE patterns revealed that *Pseudomonas* and *amoA*-containing populations in the contaminated soils were markedly different from those in the uncontaminated soils. *Pseudomonas* and *amoA* profiles appeared to be stable over time in the bulk soils. In contrast, contaminated rhizosphere soils revealed a clear shift of populations with removal of HM. Rhizosphere *Pseudomonas* spp. and AOB populations of the HM-contaminated soils became similar or at least shifted from HM-stressed back to the populations of the uncontaminated soils during phytoextraction. The effect of phytoextraction was, however, not evident in the bulk samples, which still contained large amounts of HM. Cloning and sequencing of dominant DGGE bands revealed that *Pseudomonas* were phylogenetically related to the *Pseudomonas fluorescens* cluster and the *amoA* sequences to *Nitrosospira* spp. This study suggests that two taxonomically different populations are able to recover after the relief of HM stress by phytoextraction practices and the use of simplified root container experiments provides valuable information for risk assessment of heavy metal polluted soils.

Keywords: heavy metal, phytoextraction, root container, rhizosphere bacterial populations

# Microbial community structure in the rhizosphere of tobacco plants engineered to release phytase from their roots

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Transgenic plants that release microbial phytase from their roots have been developed and offer potential for improving the utilisation of inositol phosphates, which are the major form of organic P found in most soils. However, the efficacy of interaction between enzyme and substrate in the rhizosphere is dependent on various microbial, biochemical and physical interactions. In this study, the effect of the presence of soil microorganisms on P-accumulation by transgenic tobacco plants that express a fungal phytase (along with control plants) was investigated in a P-deficient soil following various treatments designed to perturb the soil microbial population. The structure of microbial communities within the rhizosphere was assessed using a TRFLP-based approach on amplified 16S rDNA genes. Whilst an interaction between the presence of soil microorganisms and plant P nutrition was evident, expression of the fungal phytase in the transgenic lines had little or no impact on the structure of the microbial community. Although soil microorganisms have an implicit role in the availability of P to plants, the community around roots appears to be resilient to the impact of single-gene changes that are designed to specifically modify the biochemistry of the rhizosphere in relation to mechanisms associated with nutrient cycling.

Keywords: bacteria, fungi, inositol phosphate, phytase, transgenic plants

# Alteration of plant metabolites and root exudate-mediated interactions by pathogenic and mycorrhizal fungi in tomato

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Over the past years, the knowledge on signaling in plant–microbe interactions has increased to a great extent. However, the signal communication of roots is still not satisfactorily understood. Our work was initiated to elucidate the plant response in a biological system consisting of the crop plant tomato, the arbuscular mycorrhizal fungus *Glomus mosseae* and the soil borne tomato pathogen *Fusarium oxysporum* sp. *lycopersici* in monoculture and mixed cultivation. Among the effects of mycorrhizal and pathogenic fungi on the growth and development of tomato in single and combined inoculations we will point out the response of soilborne fungi on root exudates. Moreover, based on chemical analyses of the above- and below-ground plant organs by HPLC-PDA and quadrupol GC-MS we will provide data on alterations in the profile of plant metabolites in various organs and root exudates which are specifically caused by pathogenic and mycorrhizal fungi. The main classes of focused metabolites include sugars, sugar alcohols, organic and amino acids, and secondary metabolites, such as phenolic acids, flavonoids, and terpenoids. Our research will provide improved insights about metabolic dynamics in leaves, roots, and root exudates of tomato. The extent of correlation of detectable in the metabolite profiles in various organs of tomato to the inoculation with a specific mycorrhizal and pathogenic fungus, or a combination of both, will be explored.

Keywords: tomato, *Fusarium oxysporum*, mycorrhiza, plant metabolites, root exudates

# Arbuscular mycorrhizal fungi systemically compensate crude oil effects on root biomass

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The arbuscular mycorrhizal (AM) symbiosis beneficially effects plant growth and enhances plant tolerance toward biotic and abiotic stresses, mainly due to improved plant water uptake and nutrient supply. Environmental pollution such as crude oil soil contamination is of major concern as organic pollutants in general may harm human health particularly because of mutagenic and carcinogenic capacities. Moreover toxicity and persistence in soils may lead to a lack of vegetation on polluted areas. Several investigations confirm AM fungi to improve the establishment and maintenance of plants on contaminated soils resulting in an amelioration of soil rhizosphere and vegetation cover. But there is little known about the systemic impact of AM fungi in response to organic soil contaminants although systemic effects have already been confirmed regarding biotic stresses such as plant pathogen infestations. A pot experiment was set up to determine the impact of both crude oil pollution and mycorrhizal symbiosis on growth of *Phaseolus vulgaris*. Plantlets were grown in a split-pot system, exposed to either polluted or non-polluted soil, supplemented or not with viable propagules of Glomus spp. (Symbivit$^{R}$). The experimental soil derived from an arable land in Austria and was spiked with crude oil four years prior to the experimental setup. Plants were cultivated in a green house for 6 weeks, each treatment carried out in 4 replicates. At harvest leaf, stem and root biomass were determined. Roots were further stained and AM colonization quantified. Morphological root characteristics of bean were analyzed by means of WinRhizo computer program. Significant effects of both crude oil pollution and mycorrhiza colonization were observed. These treatment effects are particularly discussed regarding a

systemic impact of AM symbiosis in response to the a-biotic stress of crude oil soil contamination.

Keywords: systemic effect, *Glomus* spp, hydrocarbons, environmental pollution, rhizosphere

# Strigolactones as signalling compounds in the rhizosphere

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In the rhizosphere a multitude of communication processes takes place, however, although many substances released by plant roots have been identified, only relatively little data are available on their possible function as signalling compounds in the rhizosphere. Strigolactones are apocarotenoids exuded by roots in extremely low concentrations and stimulate the seed germination of the parasitic weeds *Striga* and *Orobanche.* Recently, strigolactones have been identified to act also as important signalling molecules for the establishment of the arbuscular mycorrhizal (AM) symbiosis due to their activity on AM hyphal branching. Moreover, due to their role as plant hormones regulating shoot branching, strigolactones have been suggested to be present in all plant species. This ubiquitous presence of strigolactones in plants could mean that these compounds not only play a signalling role in the interaction between plants and parasitic plants (such as *Striga* and *Orobanche*) and plants and AM fungi, but are more general signalling compounds in rhizospheric plant microbe interactions. Presenting recent results on the role of strigolactones in rhizospheric plant-microbe interactions we will discuss this hypothesis.

Keywords: plant-microbe interactions, rhizosphere, signalling, strigolactones

# Poster Presentations

# Differences in common bean root colonization by distinct PGPRs and their fluorescent marked derivatives

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PGPRs (Plant Growth-Promoting Rhizobacteria) play an important role in the promotion of plant development by several mechanisms, but the beneficial effect may be hampered due to constraints imposed by biotic and abiotic rhizosphere soil conditions. Thus, salinity and/or the presence of other microorganisms can modify early events of root colonization. Moreover, if the positive plant effect of several PGPRs is intended to be used for the elaboration of microbial inoculants, it is necessary to determine their mutual compatibility in the rhizosphere.

Keywords: *Phaseolus vulgaris*, *Rhizobium etli*, PGPRs, root colonization

# Root area index of Lucerne affected by Rhizobia and Mycorrhiza under dry organic farming conditions

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This experiment has been done to investigate effect of dual inoculation of rhizoba and mycorrhiza on Root Area Index (RAI) changes in lucerne under water deficit condition. Three factors included Rhizobium inoculation*;* Mycorrhiza inoculation and Irrigation, each one at two levels (with and without application) have been studied in a factorial experiment in the form of complete randomized block design. The trial was located on the organically managed fields of the University of Natural Resources and Applied Life Sciences, Vienna (Rassdorf) in April 2007. This index is defined as a new index in root studies for crops. RAI is calculated with the following formula: RAI= Root Surface Area / Soil Surface Area. First, root surface is measured by WinRHIZO instrument. Results of mean comparisons by Duncan's multiple range test showed that root area index was higher when rhizobia and mycorrhiza used individually in compare without their application. Effect of double interaction of Rhizobium x Mycorrhiza on root area index ranged from 13.147(R0M0) to 14.697 (R1M1).Effect of double interaction of Rhizobium x Irrigation on this parameter varied from 11.040 to 14.509 and R0I0 was at the lowest group. In double interaction of Mycorrhiza x Irrigation all of treatments were at the same group. Effect of using irrigation was higher than the effect of using mycorrhiza. In triple interaction of Rhizobium x Mycorrhiza x Irrigation , root area index was higher than other treatments .Root area index had a positive and significant correlation with mycorrizal colonization (MC), water use efficiency (WUE), root dry weight (RDW) and shoot dry weight (SDW).

Keywords: root area index, mycorrhiza, rhizobia, lucerne

# Identification and pathogenicity of the fungi species causing root rot on pepper in West Azarbaijan province, Iran

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Typical populations of soil microorganisms near the root surface contain bacteria, actinomycetes, fungi, protozoa and algae. Fungal species are among the known casual agents of soil born disease on cultivated plants. In present study, we investigated on the fungal agents involved in pepper wilt in West Azarbaijan province of Iran. Pepper fields were checked in Orumieh, Mahabad, Oshnavieh and Piranshahr in August and September during 2006-2007. Fungal and pseudo-fungal agents were isolated on acidified PDA, PCA and CMA as well as baiting from the infected plants rhizosphere. Eighty two isolates were recovered from infected plants and were subjected to a subsequent taxonomic study; hence, were identified at species level. These isolates were identified as *Phytophthora capsici, Pythium aphanidermatum, Rhizoctonia solani, Fusarium oxysporum, F. solani, F .chlamydosporum, F. sambucinum* and *Verticillium dahlia*. Pathogenicity test was carried out at greenhouse using 34 selected isolates on two pepper cultivars (Bell and native cultivars) and the percentage of the infected plants was calculates after a definite time from inoculation depending on the fungi species. Among the selected isolates, one isolate from *F. sambosinum* and another from *F.clamydosporium* had no pathogenicity effect on Bell pepper, while four isolates from *Rhizoctonia solani*, one from *Verticillium dahlia*e and another from *Pythium aphanidermatum* had a higher pathogenicity effect. The rest were placed between these two groups. Three isolates from *F.cladmydosporium* and two from *F. sambosinum* had no pathogenicity on native cultivar, while two isolates of *R. solani* had the highest pathogenicity and the rest were between these mentioned groups. Furthermore, *F. solani* showed very low

pathogenicity on the native cultivar. According to Koch rules, pathogens were isolated from infected plants again.

Keywords: rhizosphere, fungi, pathogenicity, pepper, root rot

# Effect of Thiobacillus and Mycorrhiza fungi under different levels of sulfur on yield and yield components of soybean

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Phosphorus (P) and Sulfur (S) are two necessary nutrients that increase the growth and yield of the plants. Deficit of these nutrients in the soil, usually compensate by use of chemical fertilizers and but these fertilizers have harmful effects on the environment and decrease the quality of agricultural products therefore biological fertilizers are more interested for using in agricultural ecosystems (Nadian, 2005).

It is well documented that application mycorrhiza fungi caused increase water absorption and nutrients special phosphorus and transmission those to host plants cells and improve growth and photosynthesis and produce more assimilate. Also mycorrhiza has synergistic effects with most of other microorganisms that have increasing effect on yield and yield components most of crops (Lukiwatid et al., 2002; Marulanda et.al, 2003).

Thiobacillus cause increase oxidation sulfur and decrease soil pH and increase produce sulfat in soil therefore caused increase absorption some nutrients especial phosphor in soil. (Messick & Fan, 1999)

Use of thiobacillus and sulfur together in soil significantly positive affected in 1% level on weight of thousand seed and soybean yield because of thiobacillus increase oxidation sulfur and decrease soil pH therefore caused increase absorption some useable nutrients. (Sharma, 2003)

# Effects of biota on bio- and physicochemistry in the rhizosphere of deciduous tree species and its impact on carbon flow to the soil

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The rhizosphere is a region of high activity between roots, fungi, microorganisms and animals. In the environment of roots the turnover of biomass is very high. Therefore, in the rhizosphere many different carbon and nitrogen compounds arise. The main object of the study is highlighting the influence of two deciduous tree species, beech *(Fagus sylvatica* L.) and ash *(Fraxinus excelsior* L.), on the carbon and nitrogen dynamics in this highly active zone. Beside the effects of the tree species, the influences of other biotas, especially earthworms, litter and mycorrhiza, on the soil are examined.nover in the rhizosphere are studied. In addition, the C and N input into the soil by litter decomposition is examined. Different experimental approaches investigate the effects on $CO_2$ efflux, $O_2$ consumption, and pathways of $N_2O$, low molecular organic acids and other compounds in the root-soil interface. This study emphasizes the rhizosphere mainly in a laboratory experiment using novel two-species double split-root rhizoboxes at defined soil temperature and soil moisture. In these rhizoboxes the root-soil interface can be analyzed highly resolved. The spatial and temporal patterns of the above mentioned parameters can be detected on a small scale. For measuring $O_2$, $CO_2$ and pH, novel optical noninvasive sensors (optodes) are used. The poster will introduce the novel rhizobox system equipped with noninvasive optical sensor technology for bioprocess analysis in the rhizosphere. The intention of the project is bringing a better understanding of bio- and physicochemical processes driven by the rhizobiota network of two contrasting temperate tree species. This can contribute to our knowledge of plant- and litter-mediated C cycling and C storage in forest soils, in regard to estimate their possible role as long-term carbon sinks.

Keywords: rhizosphere, carbon flow, soil biota, beech, ash

# Bioprotection against the root parasite *Orobanche crenata* is induced in pea roots inoculated with *Rhizobium leguminosarum* bv viceae defective in Nod factor production

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*Orobanche crenata* is a root holoparasitic plant which constitutes the major constraint for pea (*Pisum sativum* L.) (Fabaceae) cultivation in the Mediterranean area and Middle East. The most feasible method of control is breeding for resistant plant genotypes, although little resistance is available within cultivated pea.

Pea is able to establish a species-specific symbiosis with *Rhizobium leguminosarum* bv. viceae. In compatible *Rhizobium*-legume interactions transitory increases in defence mechanisms are induced in the legume plant, and it has been demonstrated that the activation of some molecular and biochemical mechanism of defense in rhizobial peas decrease the infection by *Orobanche*. To our knowledge nothing is known yet about the effect of incompatible *Rhizobium*-legume interactions on *Orobanche* infection.

In the *R. leguminosarum* mutant (*nodC*$^-$) the production of the protein NodC which regulates the synthesis of the Nod factor is altered. This results in an incompatible interaction with pea. In this incompatible pea/*R. leguminosarum* mutant interaction, it has been demonstrated that SA levels increase in plant roots and this could be related with the induction of a SA-mediated defence. In the present work, inoculation of peas with *R. leguminosarum* 248 (mutant *nodC*$^-$) in presence of *O. crenata* reduced infection of *O. crenata* by 74%. Our data suggest that the *Rhizobium* mutant *nodC*$^-$ stimulates an specific active mechanism of resistance against *Orobanche* in plant roots.

# Mycobioindication method simplified: Sclerotia of *Cenococcum geophilum* Fr. as indicators of stress in forest soils

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*Cenococcum geophilum* Fr., an ubiquitus ectomycorrhizal fungus, forms frequent and detectable ectomycorrhiza and sclerotia in temperate forests. It shows proliferation in stress conditions, in situations in which other types of ectomycorrhizae usually diminish in abundance. We tested its applicability as an indicator of the chronic increased ambiental ozone-induced stress. In our experimental system beech seedlings were planted into 20 containers (6 plants per 30 L container) filled with soils from the plot and exposed for two vegetation periods in the sun part of crowns (on towers) or in the shadow (at ground level) in the Kranzberg ozone fumigation system (www.casiroz.de). At the end of the second vegetation period twelve 2x2x2 $cm^3$ substrate cubes at every 2 cm depth were taken in four replicates per sun-exposed container, from which five were from the fumigated $2xO_3$ and three from the control $1xO_3$ fumigation system. The total number of sclerotia in 2 cm depth cubes in the volume of ca. 8 $cm^3$ per depth layer was higher in the fumigated containers (at $P<0.001$), and their distribution showed a statistically significant difference in the peak number of sclerotia in the upper 2-8 cm layers (Fisher LSD at $P<0.001$, comparisons for factor ozone within each depth layer). Their numbers have shown a clear distribution along depth layers and differed among the fumigated and ambient ozone exposed containers. We propose that *C. geophilum* can be considered as an applicable bioindicator of air pollution in different forest ecology studies.

Keywords: mycobioindication, *Cenococcum geophilum* Fr., sclerotia, ozone, drought, stress

# Auxin-regulation of hyphal elongation and spore germination in arbuscular mycorrhizal fungus, *Gigaspora margarita*

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Hormonal effects of auxins, IAA, 2,4-D and NAA, on spore germination and hyphal elongation of arbuscular mycorrhiza, *Gigaspora margarita,* were investigated on agar plate in order to unveil the function of auxin in growth regulation of mycorrhizal fungi. All three auxins enhanced spore germination and hyphal elongation at $10^{-9}$ M concentration. However, at higher concentrations over $10^{-5}$ M, these auxins strongly inhibited spore germination and hyphal elongation. These dose-response relationships were identical to that of plant root elongation. Aromatic amino acids, phenylalanine and tyrosine, showed little effects at $10^{-7}$ ~ $10^{-3}$ M, whereas tryptophan strongly inhibited them at $10^{-3}$ M. The effective concentration range of auxin was consistent with the reported endogenous level of IAA in plant roots and also with IAA level in rhizosphere. These results indicate the possible function of auxin to regulate spore germination and hyphal elongation of mycorrhizal fungus *Gigaspora margarita*.

Keywords: auxin, *Gigaspora*, hyphal elongation, IAA, mycorrhiza, spore germination

# Influence of rhizosphere bacteria of African oil palm (*Elaeis guineensis*) on calcium, iron, and aluminum phosphate in vitro mobilization

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*In vitro* calcium-phosphate mobilization was caused by acidification of the nutrient medium and the production of different carboxylic anions. Under highly buffered soil conditions (neutral or alkaline pH), only citrate can release remarkable amounts of P from $Ca_3(PO_4)_2$. Citrate can prevent halo zones on calcium-phosphate agar by precipitation of calcium citrate. This effect reduces the use of such plate tests remarkably!

Down to a pH of 3.5, solubilization of iron and aluminum phosphate cannot be explained by proton release. These phosphates are efficiently mobilized by citrate, malate and tartrate. Common plate tests can fail to detect really effective P solubilizing strains. Therefore, liquid culture or genetic characterization are more reliable methods to elucidate citrate, malate and tartrate producers.

# Use of model plants for monitoring colonization of several PGPR isolated from an organic olive grove

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Indol acetic acid (IAA) production is a common PGPR feature. It has been reported that bacteria producing IAA can promote rooting and their effects on plants mimic that of exogenous IAA, a common practise in nursery industries. In a previous work, 500 strains were isolated from an organic olive grove and tested for PGPR activities. Some of them were selected by their ability for auxin production and checked for rooting induction on olive cuttings.

The goal of this work is the monitoring of bacterial root colonization through a green protein fluorescence marker (GFP) using model plants under axenic conditions. For that, we have designed rooting induction assays on *Vigna radiata* (mung bean) cuttings and *Brassica napus* (canola) seeds. Number and root length, as well as bacterial colonization were determined. In both model plants, root colonization has been observed by means of Laser Scanning Microscope.

Keywords: olive cuttings, organic agriculture, PGPR, IAA, root colonization, GFP

# Biological nitrification inhibition as a novel approach for enhancing nitrogen use efficiency in crops

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Nearly 70% of the applied N fertilizer from managed ecosystems is lost through nitrification and associated processes. The lost N contributes to environmental pollution due to $NO_3^-$ leaching and global warming due to $N_2O$ emission. Additionally, the rising costs of fertilizers are making the crop production more costly than before. For these reasons, Nitrogen use efficiency (NUE) is the key factor in nutrient management for most of the crops. The phenomenon termed as Biological Nitrification Inhibition (BNI) offers an alternative way to enhance NUE in crops as indicated by experiments carried out with *Brachiaria humidicola* at CIAT. A bioassay using a recombinant *Nitrosomonas europaea* strain it was proved that root exudates of this tropical grass can strongly inhibit nitrification. Experiments conducted in the field further confirmed that roots of *Brachiaria* species release BNI compounds in soils. Various tropical grasses with varying degree of BNI activity were selected along with soybean and bare soil, which are believed to lack such BNI capacity, as controls. The soil samples of controls (bare soil and soybean) exhibited the greatest amount of *amoA* genes of Ammonia-Oxidizing Bacteria (AOB) and Ammonia-Oxidizing Archaea (AOA) as compared to soils where *B. humidicola* genotypes were grown. Thus, these results provided a convincing evidence of the occurrence of the BNI phenomenon in the field. The bioluminescence assay and soil chemical measurements have revealed genetic diversity for BNI activities in *Brachiaria* and also in rice genotypes.

Keywords: biological nitrification inhibition, *Brachiaria humidicola,* environmental pollution, nitrogen use efficiency, rice, root exudates

# Biodiversity of Arbuscular Mycorrhizal Fungi (AMF) in some forest tree species in Bangladesh

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Status of Arbuscular Mycorrhizal Fungal (AMF) colonization in seven tree species (*Albizia saman*, *Acacia auriculiformis*, *Albizia lebbeck*, *Chickrassia tabularis*, *Eucalyptus camaldulensis*, *Gmelina arborea*, *Swietenia macrophylla*) collected from the Chittagong University Campus (CU), Bangladesh, was investigated. Roots and rhizosphere soil samples were collected from the different slopes in different seasons. Percentage of AM colonization in the roots, intensity of root colonization and number of spores/100gm dry soil were assessed. All the samples were found to be colonized by AM fungi. Percent root colonization varied widely irrespective of seasons (before, during and after rainy season) and slopes (steep, gentle & plain land). The result of the investigation reveals that the intensity and percentage of AMF infection varied in different forest tree species. The intensity of colonization was maximum in *C. tabularis* (74.43%) and minimum in *A. auriculiformis* (53.75%) before rainy season. During rainy season, *A. lebbeck* showed the maximum AM colonization (69.45%) whereas *A. saman* was minimum (24.4%). After rainy season, it was found highest in *S. macrophylla* (67.8%) and lowest in *A. saman* (19.36%). The AM infection was also varied in different slopes in various seasons. Analysis of the rhizosphere soils showed that mycorrhizal spores were present in all locations from where the plant roots were collected. The number of spores found per 100g dry soil ranged between (164-376) before rainy season whereas it was (27-310) during rainy season and (194-299) after rainy season. *Glomus* was the common species in the soil samples. Out of six recognized genera of AM fungi, *Glomus, Sclerocystis*, *Entrophospora*, *Scutellospora* and other unidentified spores were observed. The possibility of indigenous AM fungi has been ensured for the primary establishment of nursery seedlings.

Keywords: Bangladesh, arbuscular mycorrhizal fungi, root colonization, spore population

# Arbuscular Mycorrhizal Fungi increase pharmaceutically active compounds in Valerian roots

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Root colonization by symbiotic arbuscular mycorrhizal fungi (AMF) improves mainly the phosphorus (P) acquisition but additionally alters a range of biological and chemical parameters in plants. In the present study the effect of root colonization by AMF on pharmaceutically active compounds in valerian (*Valeriana officinalis* L., Valerianaceae) such as sesquiterpenic acids and essential oils was determined.

Keywords: *Valeriana officinalis,* Valerianaceae, arbuscular mycorrhizal fungi, sesquiterpenic acids, essential oil, pharmaceutical active compounds

# Field versus laboratory studies - comparing turnover rates of $^{14}$C-labelled citrate in soil

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Compound specific mineralization studies as well as soil respiration measurements provide a powerful tool to trace the fate of various carbon substrates in soil and to estimate changes in carbon fluxes and turnover rates as a response to anthropogenic perturbation such as climate change, pollution and agriculture. These measurements of carbon (C) turnover are frequently made in the laboratory where it is easier to control the experimental conditions. However, factors such as the absence of plants and associated mycorrhizas, physical disturbance (sampling and sieving), alteration in redox status, exposure to light and changes in temperature might potentially alter microbial activity and consequently $CO_2$ production. Therefore the aim of this study was to compare in-situ biodegradation rates in the field on three contrasting land use regimes (arable, woodland, grassland) with mineralization rates in laboratory using $^{14}$C labelled citric acid as a model LMW carbon substrate. In both the laboratory and the field we showed that $^{14}CO_2$ evolution followed a bi-phasic pattern that conformed well to a double first-order kinetic model. While the first rapid mineralization phase showed a similar half-life for citrate under all laboratory and field conditions (4.93 ± 0.74h), the second slower mineralization phase had a significantly longer half-life when performed in the field. Overall, our results suggest that citrate depletion from the soil solution was largely independent of our experimental conditions whilst the turnover of the citrate-derived C immobilized in the microbial biomass was significantly affected by the incubation conditions. We conclude that laboratory incubation studies may lead to a significant overestimation of soil organic matter turnover rates and that the laboratory provides a poor surrogate for field experimentation.

Keywords: bias, biodegradation, carbon models, decomposition, carbon turnover

# Interaction between alfalfa (Medicago sativa L.) mycorrhizal roots traits and heavy metals (Cd, Co and Pb)

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There are contrast ideas about interaction of plant roots and heavy metals. Therefore, for investigation of root reaction to inoculation with mycorrhiza in contaminated land an experiment was conducted under greenhouse conditions in a 2×8 factorial completely randomized design, with three replicates in 2007. First factor was without inoculation (I0) and inoculation (I) with *G. mosseae*. Second factor was seven levels of heavy metals contaminants (Cobalt (Co)=50 mg $kg^{-1}$, Cadmium (Cd)=8 mg $kg^{-1}$, Lead (Pb)=400 mg $kg^{-1}$ dried soil, CoCd, CdPb, PbCo and PbCoCd) plus control (C) (without contamination). Results indicated inoculated plants with *G. mosseae* had produced more mycorrhizal root dry weight and mycorrhizal root length in heavy metals contaminated soil. This topic showed under heavy metal stress mycorrhiza caused enhancement of root biomass and length that can help to root in stressful soil condition. Our findings were agreed with view of point that mycorrhiza by increment of length and biomass of root supports plants in heavy metals contaminated land.

Keywords: mycorrhiza, Alfalfa, heavy metals, root traits

# Do earthworms affect the utilization of nutrients and the mycorrhizal colonisation of grassland plants?

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Earthworms and arbuscular mycorrhizal fungi (AMF) are key-organisms in grassland ecosystems and are known to individually affect the diversity and functioning of these systems. However, there still exists little knowledge on the ecological interactions of earthworms, AMF and plants. The objectives of this study were to investigate whether (i) plant species can utilize nutrients and/or AMF present in subsurface earthworm casts, (ii) the activity of vertical burrowing (anecic) and soil dwelling (endogeic) earthworms differentially affect the distribution of nutrients and/or AMF, and (iii) earthworm activity affects the productivity and structure of grassland ecosystems. We tested this in a full-factorial mesocosm experiment (mesocosm diameter 45 cm, volume 40 l) in a greenhouse with a patch of earthworm cast material inserted in 25 cm depth in each mesocosm. Mesocosms were planted with 11 low-fertile grassland species representing grasses, non-leguminous herbs and leguminous herbs. In order to be able to trace the functional links between ecosystem components, we labelled casts with stable isotope tracers ($^{13}C$, $^{15}N$) and inoculated them with a mixture of four widely distributed AMF species (*Glomus intraradices*, *G. mosseae*, *G. geosporum*, *G. claroideum*). Earthworm species used were the anecic *Lumbricus terrestris* and the endogeic *Aporrectodea caliginosa*. Nutrient uptake, root colonisation by AMF and earthworm activity was monitored every third week. After six months, the mesocosms were destructively harvested and plant biomass, root AMF colonization and isotopic signals in plant tissue measured. Possible species-specific colonisation of plant roots by *Glomus* species was determined using polymerase chain reaction (PCR). Preliminary results indicate that earthworm activity specifically altered the nutrient utilisation and AMF colonisation of plant species. The impact of earthworm

activity together with AMF symbiosis on the productivity and structure of grassland ecosystems is discussed.

Keywords: arbuscular mycorrhiza fungi (AMF), earthworms, greenhouse experiment, mesocosms, plant-animal-fungi interaction, stable isotope tracing, PCR

# Alteration of root growth caused by heavy forest machinery on Osankarica

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Impact of heavy forest machinery on soil properties is well described. However, there is still a lack of surveys of root growth impacts, although available data suggest that development and turnover of fine roots significantly differ among undisturbed sites and sites, affected by forest operations including mechanized harvesting and skidding. Operational limitations are needed for sustainable forest management concerning long-term effects of soil compaction on soil physical properties and root growth caused by heavy forest machinery. Although some recommendations were given recently (e.g. from project EcoWood), both Slovenia and the rest Europe do not possess any standards or limitations with regard to mechanized harvesting and skidding. Additional relevant indicators are required from field measurements. Investigation of the machinery impacts on root growth using minirhizotrons was set up in autumn 2007 and autumn of 2008 after forest operations at a beech-dominated forest site at Osankarica (Pohorje mountain range, 1250 m/sl). First picture taking sessions begun in summer of 2008 and to date 5 assessments at monthly intervals in the vegetation season 2009 were analyzed. The differences in fine root turnover have not reached a statistical significance yet although tendencies have been detected.

Keywords: mechanized forest operations, soil compaction, minirhizotrons, root growth and turnover

# SESSION 4

# ALLOCATION AND PARTITIONING IN ROOTS, CONTRIBUTIONS TO SOIL C SEQUESTRATION

Oral Presentations

# Spatial distributions of plant root carbon storage capacities within soil aggregates

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Soils are large carbon (C) reservoirs that mitigate global warming by removing greenhouse gases from the atmosphere and sequestering them as soil organic matter (SOM). SOC represents one of the major pools in the global C cycle. Therefore, even small changes in SOC stocks cause important $CO_2$ fluxes between terrestrial ecosystems and the atmosphere. The composition and distribution of plant root soluble C impacts the formation, stability and function of soil aggregates. Little is known about the spatial distribution and variable composition of these root-C compounds which are absorbed within individual soil aggregates. Both the rates or intensities of drying or wetting, and the differences or severity in water contents alter the transport of water, C and N through micro and mesofaunal habitats at both the micro and mesoscales. These changes alter gaseous compositions, C and N storage capacities and microbial communities among different regions within soil aggregates. Recent advances in X-ray microtomography enable the examination of intact pore networks within soil aggregates at resolutions as small as 3 microns.

In collaboration with the Advanced Photon Source near Chicago, we compared pore geometries of similar air-dried aggregates from the same soil type which were subjected to multiple drying/wetting (DW) cycles. DW cycling developed greater spatial correlation ranges that paralleled the sorption of $^{13}C$ away from respiring microorganisms resulting in significant shifts in the abundance of unique microbial ribotypes within exterior and interior regions of macroaggregates subjected to 0 and 5 DW cycles. Past research indicates that microbial activities within the soil aggregate matrix are spatially heterogeneous due to complex pore geometries within aggregates. Illumination of the "blackbox" interiors of soil aggregates by synchrotron microtomographic 2D and 3D imaging provide visual evidence of biophysical and biogeochemical regulated pathways controlling flow

rates of soil solutions through intra-aggregate pore geometries. This presentation includes a discussion of natural and anthropogenic alterations of root-based C solution flow, sequestration and reduced respiration by soil aggregates containing biological, chemical and physical gradients.

# Fine roots of Scot pines with sparsely foliated crowns are not necessarily less vital, and irrigation influences its fine roots only marginal

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Scots pine (*Pinus sylvestris*) forests in inner-Alpine dry valleys of Switzerland have suffered in recent decades from drought and elevated temperatures, resulting in a higher tree mortality rate than in average. In the present study, we investigated the fine roots of two types of pines, high-productive Scots pines having a densely foliated crown, and low-productive Scots pines having a sparsely and scantily foliated crown. The analyses of the biomass and of the physiological and morphological properties of the fine roots revealed, that the two types of pines did not differed significantly from each other. In order to observe whether and how trees would react to an additional water supply, water from a nearby river was irrigated during three vegetation periods. This additional supply of water, although it improved the density of the pine crowns, did not influence the biomass of the fine roots or its physiological and morphological properties, except the root tissue density, which was significantly reduced. Using in-growth cores to observe the responses of newly produced fine roots, no differences between the fine roots of high- and low-productive pines were observed, except the length of the fine roots, which was significantly improved. The lack of a difference between the fine-root biomass of high- and low-productive pines and the lack of a strong response of the fine-roots physiology and morphology to irrigation suggests that fine roots of Scots pines have a high priority for within-tree carbon allocation in order to maintain an optimal water and nutrient uptake from the soils, also under unfavourable conditions.

Keywords: fine root physiological and morphological properties, fine root standing crop, high- and low-productive pines, in-growth cores, irrigation, *Pinus sylvestris*

# A global analysis of fine root biomass and biomass production in forest stands

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Fine roots are the most significant components contributing to carbon cycling in forest ecosystems. Here, we refined estimates of total fine root biomass (≤ 2 mm) (FRB) and biomass production (FRP) in different forest biomes using the database of forest stands compiled from literature, and elucidated what is the effect of variation in root diameter class and sampling depth on the estimates. The mean total FRB (g $m^{-2}$) did not differ significantly between the biomes; for the boreal forests it was 419±253 (N=81), and those for the temperate and tropical forests 487±335 (N=176) and 465±365 (N=68), respectively. When the FRB estimates were reevaluated for the whole rooting depth the differences became significant ($p$=0.031), and the extrapolated FRB estimate for the boreal forests (526±321 g $m^{-2}$) was smaller that those for the temperate (807±632 g $m^{-2}$) and tropical (776±522 g $m^{-2}$) forests, respectively. The mean FRP (g $m^{-2}$ $a^{-1}$) was significantly ($p$=0.013) smaller for the boreal (307±286, N=33) and temperate (397±308, N=64) forests than that for the tropical (595±470, N=33) forests. Also the fine root turnover rate (FRP/FRB) was significantly smaller in the boreal (0.8) and temperate (1.3) forests than in the tropical forests (1.5). We found significant positive correlations between the ≤ 1 and ≤ 2 mm and between the ≤ 2 and ≤ 5 mm FRB and FRP. These relationships were used to standardize the estimates, and the ≤ 1 mm FRB was 0.7 times smaller and the ≤ 5 mm FRB 1.6 times higher than the ≤ 2 mm FRB. The corresponding figures for the FRP were 0.5 and 1.3. Our results indicate there are differences in FRB and FRP between the different biomes and the FRB and FRP estimates are much dependent on the sampling depth and fine root diameter class.

Keywords: below-ground biomass, biome, turnover, rooting depth, root diameter

# Potential contribution by cotton roots to soil carbon stocks in furrow-irrigated Vertisols of NW New South Wales, Australia

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Historically, soil organic carbon dynamics in Australian Vertisols have been analysed in terms of inputs from above-ground crop residues but not by roots. Potential contribution by cotton roots to soil carbon stocks was evaluated between 2002 and 2008 in two experiments near Narrabri, north-western NSW. Experiment 1 consisted of cotton monoculture sown either after conventional tillage or on permanent beds and a cotton-wheat rotation on permanent beds, and Experiment 2 consisted of four rotation systems sown on permanent beds: cotton monoculture, cotton-vetch, cotton-wheat and cotton-wheat-vetch. A Roundup-Ready™ cotton variety was sown until 2005, and a Bollgard™ II-Roundup Ready™-Flex™ variety thereafter. Root growth in the surface 0.10 m was measured with the core-break method, and that in the 0.10 to 1.0 m depth with a minirhizotron and I-CAP image capture system. These measurements were used to derive root C added to soil through intra-seasonal root death ($C_{lost}$), C in roots remaining at end of season ($C_{root}$) and root C potentially available for addition to soil C ($C_{total}$). Average $C_{total}$ ranged between 0.5 and 4 t/ha, with $C_{lost}$ contributing 25-70%. $C_{total}$, $C_{lost}$ and $C_{root}$ were reduced by cool/wet seasons, cotton monoculture, high insect pest numbers and Bollgard II varieties, but increased by warm/dry seasons, non-Bollgard II varieties and wheat rotation crops. Permanent beds increased $C_{root}$.

# Carbon and nitrogen release from tree stumps in boreal clear-cut forests

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Stumps are the biggest coarse woody debris component in managed forests. Their role in nutrient cycling is, however, poorly understood. Recently the request for such information has grown since the use of stumps as energy wood increases rapidly. We studied C and N dynamics in Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), and silver birch (*Betula pendula* Roth.) stumps, which had decomposed for 0, 5, 10, 20, 30 and 40 years after clear-cutting in southern Finland. We found that in 40 years conifer stumps lost 80 % and birch stumps 90 % of their initial C. The amount of N in stumps increased during decomposition. After 40 years of decomposition, the amount of N was 1.7 and 2.7 times higher than the initial amount in pine and spruce stumps, respectively. Nitrogen was released from birch stumps, but not until they had decomposed for 20 years or longer. The increase of N amount in stumps could result from the translocation of N by fungi from the surrounding soil and from the fixation of atmospheric N by bacteria living in stumps. The results indicate that the stumps of the major tree species in Fennoscandian forests are long-term C and, especially, N pools, and they act as N sinks potentially diminishing N leaching into ground water and watercourses after clear-cutting. This suggests that the removal of stumps may markedly affect the nutrient status and nutrient cycling of boreal forests.

Keywords: carbon, coarse woody debris, decomposition, energy wood, nitrogen, stump

# The age of fine root carbon may not indicate the age of root

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For root carbon age estimation by bomb radiocarbon method, the fine root samples from ingrowth cores with known maximum root age (1 to 6 years) from three Scots pine (*Pinus sylvestris* L.) stands from boreal forests of Finland were collected and analyzed. The stands were 1) Ilomantsi (maximum root age one year), 2) Jämijärvi (maximum root age one year), 3) Punkaharju (maximum root age 2, 4 and 6 years). The ingrowth core root samples originate from the years 1985 to 1993. Two root diameter classes were selected; i) < 0.5mm, and ii) 1.5-2.0 mm.

The overall goal of this study was to assess whether or not the root C age estimated by $^{14}C$ method coincides with the known maximum root age. For this purpose, we analyzed the bomb root C age of carefully sorted live and dead fine roots by bomb radiocarbon method and compared it with the known maximum fine root age. Since the structural carbon (cellulose) is not replaced after the root is formed, the root cellulose C age should represent the real age of the root, with the assumption that the cellulose C originates from recent photosynthesis. Hence, the bomb $^{14}C$ was analysed both in bulk roots (*i.e.* without removing any structural or non structural compounds from the roots) and in only root cellulose (other root constituents removed).

In our study, the radiocarbon content of the archive roots of known maximum age and corresponding atmospheric air $^{14}C$ values from the years when the ingrowth cores were in soil were supportive to each other in most of the cases but not in all. For Jämijärvi and Ilomantsi sites, both $^{14}C$ age and known maximum root age supported each other. However, this was not the case for the Punkaharju site. At this site, the ingrowth cores were placed in soil in 1987, and sampled in the years 1989, 1991 and 1993. The radiocarbon content of *bulk* live fine roots (Ø < 0.5 mm), sampled during 1989-93, was in the range of 187-147 ‰, close to that of recorded atmospheric levels (175 - 123 ‰). However, the radiocarbon content of bulk

live fine roots (339 - 156 ‰) of larger diameter class (1.5 - 2 mm) sampled during 1989-1993 remarkably exceeded that of recorded atmospheric levels. This means that the $^{14}C$ age of these fine roots was up to 12 years older than the known maximum age of roots.

The live root *cellulose* of both diameter classes had similar root $^{14}C$ content as in the atmosphere, except the roots sampled in May 1989 with extremely high values of 262 ‰ (for the roots < 0.5 mm) and 296 ‰ (for the roots 1.5 - 2mm in diameter). These values substantially exceeded the atmospheric air $^{14}C$ value of 160 ‰; *i.e.* fine root cellulose had older C dating to 1980-81 than the known root age of 1987-89. While it can not be completely excluded that the non-supportive results were caused by sampling error or contamination, it is more likely that the $^{14}C$ signature of fine roots is not always indicative of root age, e.g. because of addition of C from storage, retranslocation within the root system, organic C uptake, or incorporation of older respired $CO_2$.

Keywords: cellulose, fine root age, ingrowth core, *Pinus sylvestris,* radiocarbon, root carbon

# Contrasting phenology of roots and shoots in Arctic Tundra plant communities

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Phenology is an important component of models which predict the response of vegetation to global warming. However, despite the large contribution of fine roots to overall vegetation production (c. 50-80% of primary production in some vegetation types), phenology measurements are usually made only on shoots. Consequently, understanding of root phenology and of the extent to which root and shoot phenology are synchronous is limited. This is especially true of arctic ecosystems, which also have high ratios of below-ground to above-ground biomass and which are expected to experience the greatest climate change over the next century.

Recent research has shown a decoupling of fine root and shoot phenology in temperate deciduous forest, compared with adjacent grassland, which may be explained by the greater difference between atmospheric and soil warming in forests, and the competitive advantage of early leaf expansion in a forest canopy. We therefore hypothesised that in the low-stature, nutrient-limited tundra vegetation, root and shoot phenology are closely coupled.

We tested this hypothesis by measuring bud burst, shoot growth, leaf senescence and root growth of the dominant species in five arctic vegetation communities in northern Finland throughout the 2008 growing season. The communities comprised two wet sedge communities, dominated by *Eriophorum angustifolium* and *Carex rostrata* respectively, two dwarf shrub communities with a mixture of evergreen and deciduous shrubs (predominantly *Empetrum hermaphroditum*, *Vaccincium* spp. and *Betula nana*), and mountain birch (*Betula pubescens* subsp. *tortuosa*) forest with an understorey of evergreen shrubs. Mini-rhizotrons inserted at 45$^{o}$ and a CID-600 root scanner were used to collect data on root growth, and both above and below-ground measurements were made weekly throughout the growing season.

Our results showed a close coupling of root and shoot phenology in the graminoid dominated communities but a decoupling in shrub and birch forest communities, where peak root production occurred a month after peak shoot production. In graminoid dominated communities the period of root production exceeded that of shoot production. Soil temperature throughout the season did not differ significantly between communities and therefore does not explain the observed differences in root phenology.
This study supports the finding that shoot phenology is not an adequate representation of overall vegetation phenology, and the results may have implications for the prediction of the response of arctic ecosystems to warming, especially in view of the expansion of shrubs in this region and the potential impacts on below-ground processes.

Keywords: root, shoot, phenology, production, arctic, tundra

# Poster Presentations

# Factors influencing the rate of senescence of clover roots following permanent excision of the shoot

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Clover roots can survive for periods in excess of 6 weeks after permanent excision of the shoot when grown in sand culture and left undisturbed. Experiments were conducted to investigate whether the rate of root senescence is affected by soil and crop management factors. Cutting roots to simulate mechanical damage and shading the shoot prior to excision resulted in an earlier loss of root cell viability. Viability was also lost much sooner when roots were grown in soil rather than sand culture. The results suggest that in the field, clover roots may be relatively short-lived following soil cultivation, especially if the clover is grown as an understory in a crop mixture.

Keywords: Red clover, root senescence, shading, mechanical damage

# Influence of soil compaction on the dynamics of root growth and mortality in spring barley

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A controlled environment experiment was conducted to investigate the effect of soil compaction on the dynamics of root growth and mortality in spring barley. Plants were grown in soil packed to a dry bulk density of 1.10 (loose soil) or 1.45 g $cm^{-3}$ (compacted soil) and the appearance and disappearance of roots recorded at an observation window. Compaction reduced the total length of root produced, but did not alter the dynamics of root death and decay following removal of the shoot during grain filling, nor the proportion of root length that died and decayed before shoot excision. The results suggest that models of C and N cycling should consider the effects of soil compaction on root production, but not specifically those on root death and decay.

Keywords: Barley, root mortality, decomposition, C and N cycling, soil compaction

# Stem girdling effect on soil respiration in 35 and 65 years old Norway spruce (*Picea abies*) stands

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The soil is considered to be the major C sink in boreal forests, thus determination of soil carbon fluxes is essential for reliable C budgets. Especially partitioning of soil and root respiration is a major challenge. Soil respiration ($R_s$) consists of autotrophic respiration ($R_a$, respiration of plant roots and of microorganisms living on root-derived organic C in the rhizosphere) and heterotrophic respiration ($R_h$, respiration of free-living microorganisms during their decomposition of soil organic matter.

In our study we attempted to estimate the contribution of roots to soil respiration by a girdling experiment. The study was established in two Norway spruce (*Picea abies*) stands, 35 and 65 year old, at Nordmoen, southeast Norway. Four quadratic plots (21m x 21m) were chosen within each of the two stands in spring 2006 and within two plots all trees were girdled. To estimate the contribution of root respiration, we measured $CO_2$ efflux within each plot with a PP EGM-4 gas monitor for $CO_2$, at permanently marked spots during two years (2006 and 2007).

In the youngest stand in 2006, $R_s$ in the control plots was higher than in the girdled plots at all measurement occasions. During this period, the mean $R_s$ in the girdled plots was 64.9 % of the mean $R_s$ in the control plots. In 2007, the $R_s$ was highest in the girdled plots on most occasions, but the difference was never significant. In the oldest stand, $R_s$ was also highest in the control plots in 2006 and highest in the girdled stand in most cases in 2007, but the difference was never significant. The implications will be discussed.

# Root and shoot growth and yield of different grass-clover mixtures

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The aim of the field experiment was to determine the yield and growth of different grass-clover mixtures. The results should contribute towards optimizing grass-clover in terms of shoot and root development, the total yield, the range of varieties as well as the health of livestock and animals.

# Evaluation of biologically active organic exometabolite content in rhizosphere of meadow agrocenoses of different species composition

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The organic products of plant exometabolites and vital activity of plant-attendant microflora in rhizosphere of meadow agrocenoses were studied. It was revealed that more of phenolcompounds (by a factor of 1.5-3) and nitrogenous ones (by a factor of 1.5-2) were involved in a small biological turnover through a soil medium under 2-fold mowing of herbage than under 4-fold one.

Keywords: meadow plants, rhizosphere, root exometabolites, content

# Belowground carbon allocation: Recovery of $^{13}C$ in root growth and respiration after in situ $^{13}CO_2$ pulse labelling

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Allocation of assimilated carbon among organs is controlled by the environment and the phenology, and it affects the growth of tree, the contribution of each organ to autotrophic respiration, the transfer of carbon to the rhizosphere and in fine, carbon sequestration in ecosystems. Our aim is to quantify the amount of carbon which is allocated to root growth and root respiration in *Pinus pinaster*. Short term pulse labelling with almost pure $^{13}CO_2$ (99%) was applied on 2 trees. $^{13}C$ recovery in root respiration is measured by incubating roots sorted from soil cores collected at different dates after labelling, and by continuously monitoring soil respiration and root respiration of intact roots enclosed in a soil free chamber connected to a tuneable diode laser spectrometer. The use of recently fixed carbon for new root growth is evaluated from the isotope composition of roots that are growing in ingrowth cores installed after the labelling of the tree. Preliminary results showed that root respiration was enriched in $^{13}CO_2$ about two days after labelling, showing a pattern similar to that of soil respiration.

Keywords: carbon isotope, labelling, root respiration, soil respiration

# Roots of understory species in maritime pine forests

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Unfortunately there is commonly an overemphasis on dominant trees in forest studies that ignores an important functional component of the forest ecosystem: the understory species. In maritime pine (*Pinus pinaster*) plantation forests, previous work had shown that it could make up 6.7 % of total aerial and 28 % of total ecosystem root biomass. We conducted a study on four different dominant understory species with varying density of the understory species of interest. In all of the twenty stands (five per understory species) number and dimensions of the pine trees were recorded permitting estimations of aerial and coarse root biomass of the pines. Biometrical measurements of the understory vegetation as well as destructive harvests were carried out in six 1 $m^2$ plots for each of the twenty stands for: aerial, coarse root and fine root biomass. The first results show that understory represents on average 4.9 % of total ecosystem aerial biomass and 29.8 % of total ecosystem root biomass. The use of Root/Shoot ratios together with biometrical data and average nutrient concentrations will be explored to derive tools for estimating carbon and nutrient pools in the understory vegetation from easily accessible variables.

# Pattern of aluminium-induced efflux of organic acid anions in root tips differs between *Cryptomeria japonica* and *Pinus thunbergii* seedlings

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Differential resistance of forest trees to aluminium (Al) may alter carbon flow to the soil. One of the well-known physiological mechanisms of the resistance to Al includes internal detoxification and exclusion of Al via root organic acid anions (OA) exudation. The objective of this study was to clarify whether Japanese plantation tree species such as *Cryptomeria japonica* grown in acidic soils and *Pinus thunbergii* in alkalized soils have similar functions. We hypothesized that roots of *C. japonica* exude more amounts of OA than those in *P. thunbergii*. Seedlings of *C. japonica* and *P. thunbergii* were incubated with Al solutions for 24 h under controlled conditions. Different patterns of OA exudation were observed between two species. Oxalates and citrate exuded by both species in the presence of Al. Malate was exuded only by *C. japonica* in the presence of Al. The amount of exuded oxalate was higher in *P. thunbergii* than in *C. japonica*, whereas with citrate it was the opposite. We conclude that OA exudations in these species might serve for the exclusion of Al but we cannot conclusively support the hypothesis that OA play a critical role in the resistance mechanism against Al.

Keywords: aluminium, citrate, *Cryptomeria japonica*, organic acid anion, oxalate, soil acidity

# Seasonal changes in fine root respiration and morphological traits in a broad-leaved forest in Japan

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We examined the seasonal acclimation of fine root respiration to temperature associated with the morphological traits in *Quercus serrata* and *Ilex pendunculos*a trees. The root respiration rates in both species increased with increasing temperature and those of the roots < 0.5 mm in diameter were higher and more variable than the roots > 0.5 mm. In addition, with increasing temperature, the variation in the respiration of the smaller roots widely increased. We conclude that seasonal acclimation of fine root respiration to temperature should be considered not only the diameter but also root life span.

Keywords: root $CO_2$ efflux, mean root diameter, $Q_{10}$, temperature

# Direct measurement of heterotrophic decomposition respiration from root litter in warm-temperate secondary deciduous forest in Japan

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We developed the measurement of heterotrophic respiration rate from root (*Quercus serrata*) litter ($R_{rl}$) using direct measurement method in natural forest condition. $R_{rl}$ increased with increasing temperature and with decreasing root diameter. We found that $R_{rl}$ using our direct measurement method was influenced by temperature and root diameter. These results imply that the $R_{rl}$ is important indicator to clarify real root decomposition process in root turnover in natural forest condition.

Keywords: heterotrophic respiration, root litter, *Quercus serrata*, temperature, root diameter

# Fine-root biodegradation measurements in controlled OxiTop system

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Degradability of fine roots ($d \leq 2$ mm) of Norway spruce (*Picea abies*) at moderate and high soil copper concentrations was studied in a laboratory incubation experiment. The OxiTop (WTW) system used enables to assess soil respiration by measuring $O_2$ consumption of samples. Soil was collected in a fertile Norway spruce forest site. Fine roots were picked out of soil, weighed and cut in 0.5-1.0- mm pieces. The treatments were 'soil', 'soil + roots', 'soil + roots + Cu 100 ($mg\,kg^{-1}$)', and 'soil + roots + Cu 500 ($mg\,kg^{-1}$)'. The amendment with Cu100 increased respiration up to 160% compared with the 'soil + roots' treatment. Estimates of root biodegradation ($O_2$ consumed per carbon content of the sample) were 16% ('soil + roots'), 45% ('soil + roots + Cu 100'), and 31% ('soil + roots + Cu 500'). The preliminary results suggest that the amendments with Cu increased microbial respiration and had an enhancing effect on the fine root decomposition. The OxiTop system may perform as a useful and feasible means for studying plant litter degradation under variety of controlled conditions.

Keywords: fine-root degradability, copper, laboratory incubation, OxiTop, soil microbial respiration

# Assimilate partitioning towards the roots at increased nutrient solution concentration affected by tomato fruit size and origin

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To improve tomato quality nutrient solution concentration (electrical conductivity, EC) is increased. One reason for an enhancement is the raised carbon assimilate influx into fruits. This results in an increased root/shoot ratio. The literature indicates that average root size is diminished in modern cultivars compared with landraces, tomato included. Therefore, we wanted to test the hypothesis if dry matter partitioning towards the roots is reduced in newly bred cultivars also at higher EC levels. Four modern greenhouse cultivars and four landraces selected for their fruit size. EC in the effluent solution was controlled at 2 and 9 dS $m^{-1}$. Total dry mass production amounted to 550 g $plant^{-1}$ after 100 growing days. Neither EC nor cultivar significantly influenced dry mass produced. Ratio of vegetative to generative plant parts was manifold higher for the newer cultivars (1.0 g $g^{-1}$) compared with the landraces (7.4 g $g^{-1}$). Though, EC levels did not influence the ratio (4.8 g $g^{-1}$). Root/shoot ratio and thus dry matter partitioning toward the roots was significantly enhanced at the higher EC level. Landraces had also a significant higher root/shoot ratio compared with modern cultivars. No treatment interactions were determined for the allometric relationships. Root dry mass portion related to the total plant dry mass decreased with plant age (beginning: 30 %; end: 10 % and 15 % at EC2 and EC9). Results indicate that modern cultivars have really smaller root systems compared with landraces. However, a higher supply of nutrients counteracts the reduction of smaller root systems of new cultivars. Thus, regulation of dry mass partitioning in response to EC establishes or restores allometric growth among plant parts and functional balance between the supply and use of carbon in a way that tomato root systems at higher EC levels can better encounter stress conditions.

Keywords: electrical conductivity, *Lycopersicon esculentum*, landraces, root size, shoot/root ratio

# Siliceous lignin as promoter for root system development of coniferous trees seedlings

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Siliceous lignin (LSi), synthesized and produced in IWC on the basis of hydrolysis lignin was widely tested as a plant growth and development activator. There are no data regarding LSi influence on the development of ectomycorrhizal fungi which interaction with plant roots leads to the multisided effect close to that observed at LSi application. The aim of the present study was evaluation of the influence of LSi on wood seedlings root system incl. effect on mycorrhizal fungi. The most pronounced effect was obtained for 1 year old pine seedlings growing in glasshouse: root length, volume, number of tips increased by 23%, 37%, 13%, respectively, against control. In 2 years biometric parameters of pine seedlings growing in microfield conditions on the LSi background were better than for spruce and intensity of mycorrhizae development increased by 1,5 times.

Keywords: pine seedlings, roots, mycorrhiza, siliceous lignin

# Spatial variation of fine root biomass in a lowland dipterocarp forest, peninsular Malaysia

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Distribution of fine root biomass is studied at a mature, lowland dipterocarp forest. To clarify the variability of fine root biomass in surface soils we established quadrats of 1m x 1m, 2m x 2m and 4m x 4m each in area in the Pasoh Forest Reserve, Peninsular Malaysia. We systematically collected 16 soil cores with 25 $cm^2$ x 10 cm in size at each quadrat. We extracted fine root with a diameter thinner than 5 mm and separated the fine root into three diameter classes, 0 to 1 mm, 1 to 2 mm and 2 to 5 mm. Fine root biomass with a diameter of 0 to 5 mm was estimated as 3.0 to 5.0 mg $cm^{-3}$ at the top 10 cm soil. The coefficient of variation (CV) was higher in the 2-to-5 mm class than in thinner classes showing that the distribution of thicker fine root was more heterogeneous than thinner classes. The CV of fine root biomass with a diameter of 2 to 5 mm ranged 63 to 98%. On the other hand, the CV of fine root with a diameter of 0 to 2 mm ranged 27 to 47%. That the total fine root biomass significantly correlated with the 2-to-5 mm class, not with thinner classes, suggests that the biomass of thinner fine root shows relatively homogeneous distribution and that the variation of total fine root biomass is mainly dependent on that of the 2-to-5 mm class.

Keywords: carbon storage, diameter class, Pasoh Forest Reserve, surface soil, tropical forest

# SESSION 4.1

# COST ACTION: BELOWGROUND CARBON TURNOVER IN EUROPEAN FORESTS

Oral Presentations

# Roots and carbon allocation – quantity, quality, and controls?

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The ability to quantify the amount of carbon plants allocate to fine roots (and their mycorrhizas) and its below-ground C residence time is a major missing link in efforts to quantify and describe forest C cycles (Joslin et al. 2006). Quantification of the role of roots in carbon cycling requires estimating root biomass, turnover rate, and C concentrations. More data is available on fine root biomass (e.g. Finér et al. 2007, Helmisaari et al. 2008), whereas the estimation of root turnover rates and their relationship to environmental factors still remains poorly known. Total C concentrations in roots are relatively well known, but the composition of different C compounds need to be studied more as they have important roles, and affect soil processes through root exudates and litter.

Since the belowground and aboveground parts of plants are closely linked, a whole-tree and ecosystem approach is necessary for estimating and understanding the role of fine roots and their mycorrhizas in carbon cycling. The rate of growth, as well as the longevity of fine roots and mycorrhizal mycelia, are affected by the availability of carbohydrates and nutrients (e.g. Nilsson et al. 2005, Withington et al. 2006), and by environmental factors such as soil temperature and moisture (e.g. Majdi & Öhrvik 2004). The relationships between these factors and fine root dynamics are poorly known for most species and sites.

Recently, there has been an active debate on the accuracy of different methods for investigating fine root longevity (e.g. Strand et al. 2008). Estimates of root turnover and longevity have been obtained through sequential coring and measuring root growth into root-free ingrowth cores, minirhizotrones allowing in situ observations of root growth and mortality, or isotopic methods. Despite the variability in field methods, mean ages of fine roots in ecosystem models have reflected a consensus that the majority of tree fine roots grow and die within a few years, though some studies report

turnover times of several years. The age of rhizomes of clonal dwarf shrubs (e.g. *Vaccinium genera*) can be tens of years, but their fine root turnover may be rapid, and the ericoid mycorrhizal fungi significantly contribute to soil C stores (Olsrud & Christensen 2004).

Measurements of mean age of fine root C using radiocarbon isotopic methods (Gaudinski et al. 2001, Matamala et al. 2003) indicated that $^{14}C$-values measured in live, dead, and mixed fine roots from temperate forests corresponded to a longer time elapsed since C was fixed from the atmosphere than estimates of root lifetime previously reported using other methods. Part of this discrepancy was caused by root sorting problems, and careful sampling and sorting yielded more comparable root age results with other methods (Tierney & Fahey 2002). Later studies (Luo 2003, Vargas et al. 2009) also showed that the assumption of isotopic methods that root growth only uses recently fixed photosynthetic carbon may not hold in all situations, as stored, non-structural C can be retranslocated, and used for new root growth.

There exists no single method that has proved to be best in all situations for root longevity determinations, as most of the methods have their strengths and error sources. Studies involving several methods for turnover determination on the same sites are valuable. All empirical studies, as well as any literature-based regional or global analyses of fine root turnover, should report not only which methods were used but also how and under which environmental conditions the studies were performed, and exactly which species, and components were analysed.

Nobody is demanding an aboveground researcher to point out a single value for needle/leaf turnover. Modellers have, however, asked this for fine root turnover, but root researchers should point out that there exists no single value, since many factors affect root turnover time, e.g. plant species, climate and weather, soil nutrient status, the root component in question and the mychorrhizal status. Answers to these questions can best be found through continuing empirical and experimental research.

# Factors affecting fine root and rhizome contribution to soil carbon sequestration in Norway spruce stands

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The aim of the study was to analyze the factors affecting the turnover rate (TRate) of < 2 mm fine roots (FR) and understorey rhizomes, both <2 mm in diameter, of spruces, deciduous trees, shrubs and herbs, and to estimate the respective carbon (C) inputs into forest soils. FR and rhizome bio- and necromasses were measured in ingrowth cores after 3 years after inserting; 4 times a year in a pole (28 yr) and a mature (84 yr) Norway spruce stand; and once in soil cores. Stand density was 2315 and 698 stems $ha^{-1}$, and basal area 15.5 and 29.0 $m^2ha^{-1}$ in pole and in mature stands, respectively. The annual FR and rhizome production in the ingrowth cores was calculated according to Fairley and Alexander (1985); TRate was calculated dividing the annual production by the mean biomass. FR (and rhizome) turnover was calculated multiplying the TRate from ingrowth cores by the respective mean FR (and rhizome) biomasses from soil cores. In the pole stand, tree FR comprised 97.4% (11.8 t $ha^{-2}$) of the fine belowground plant biomass in soil cores and 99.2% (13.3 t $ha^{-2}$) in ingrowth cores; the rest was shrubs and herbs. In the mature stand, tree FR biomass formed 92.4% (9.4 t $ha^{-2}$) in soil cores; and shrubs and herbs 6.5%, and 0.8%, respectively; in ingrowth cores tree FR formed 94.7% (6.8 t $ha^{-2}$). In the pole stand, the turnover of tree FR was 6.9t $ha^{-2}$ $year^{-1}$ (97.5% of the whole FR and rhizome turnover) and in the mature stand 7.1t $ha^{-2}$ $year^{-1}$ (80.7%). In the mature stand the turnover rate was: 0.68; 1.58; 2.12 and 2.72 $year^{-1}$, for spruces, deciduous trees, shrubs and herbs, respectively. The main factors affecting fine root and rhizome contribution to soil C were plant species composition, environmental conditions and stand age.

# Role of root dynamics in soil organic carbon

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Forest ecosystems are important in carbon sequestration, and assessing the effect of landuse changes on carbon pools requires a good understanding of what drives soil organic carbon (SOC) levels. Numerous observations have indicated that SOC levels in the mineral soil do not decline significantly following forest harvesting, despite lower aboveground litterfall inputs. In addition, soil respiration losses seldom decline in clearcut sites. The processes underlying this stability of SOC following clearcutting are not well understood. Roots have been implied as the possible source of C, but there is only sparse and indirect evidence of the role of root dynamics in SOC.

In this study, we investigated how the dynamics of fine and coarse tree roots (fragmentation, decomposition) can stabilize SOC levels in the upper mineral soil of a spruce forest. Based on existing data from a high-elevation spruce forest at Achenkirch, Tirol and literature values, a model of fine and coarse root dynamics and their feedbacks to SOC levels was formulated that was consistent with current field observations. This modelling exercise was further augmented with experimental data on decomposition and fragmentation of fine and coarse tree roots obtained during a 5-month laboratory incubation experiment using soil and root samples from the same site.

This combination of field and laboratory observations and modelling provides new insight into the importance of roots and root turnover as a source of soil C, and also highlights some of the methodological challenges in accurately assessing SOC pools.

# Fine root seasonal pattern and turnover: A case study of beech stand (*Fagus sylvatica* L.) in Southern Alps, Italy

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Root turnover is a critical process of ecosystem's nutrient dynamics and carbon sequestration. It is also an important sink for primary productivity of plants. By using the root coring technique, we estimated fine root (d < 2mm) seasonal pattern and turnover rate for 1 yr growing season. The experimental site was located in a beech forest stand of Lombardy Southern Alps. Samples were collected at three soil dephts, each 10 cm tick. Live and dead roots were separated. The results show that mean Annual Fine Root Mass was 2.2 $t\,ha^{-1}$ (1.53 $t\,ha^{-1}$ biomass and 0.68 $t\,ha^{-1}$ necromass) and its seasonal pattern was bimodal. Moreover, fine roots were up to 60% located in the uppermost soil layer (0-10 cm). Finally, the overall turnover rate was 1.04 $yr^{-1}$ and increased with soil depth.

Keywords: root seasonal pattern, turnover rate, *Fagus sylvatica* L.

# Belowground turnover rate and carbon sequestration of fine roots in forest soil

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Data on the seasonal growth dynamics of fine-root biomass (live), necromass (dead) and standing crop (live + dead) roots and live/dead ratios in forest ecosystems are compiled from literature and from own investigations. Dry weight estimates of fine roots from sequential core sampling, ingrowth cores, and minirhiztrons or observation windows are included as examples. The highest live/dead ratio of tree fine roots (<1 mm in diameter) is usually found in the upper part of the soil profile and the ratio is decreasing with depth. The live/death ratio of the fine roots seems to reflect the vitality of the fine roots, both spatially and temporarily in the soil profile. Data in the literature from about 90 different data sets in forest ecosystems, suggest turnover rates of live, dead and standing crop of tree fine-roots in the range of 0.1-4.8 $yr^{-1}$. The annual turnover rates are frequently higher than the average amount of fine-roots. The fine-root growth is dependent on assimilated products produced in abundance by the green photosynthezing parts of the tree and translocated to roots and stored as starch reserves in the root systems. The substantial rates of below-ground production, mortality and decomposition of fine roots suggest that they are far more dynamic than would be predicted from growth patterns in above-ground tree structure.

Keywords: fine roots, fine-root growth, live/dead ratio, root distribution, root turnover

# Tracing the transfer of recently assimilated carbon into the soil after in situ $^{13}CO_2$ pulse labelling of trees

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The fate of carbon in the soil plant system was followed by using pulse-labelling of 10 m tall trees in the field with $^{13}CO_2$ for a short period of time. The study is conducted on three tree species (beech, oak and pine) that are among the major species in European forests. Trees are labelled at three distinct phenological phases during the growing season. The assimilated $^{13}C$ by plants during the pulse labelling was then tracked in soil $CO_2$ efflux with a high temporal resolution using tuneable diode laser absorption spectrometry and in the microbial compartment from soil cores (root + mycorrhiza transfer) and in mesh cores that permit the ingrowth of mycorrhiza hyphae but exclude roots (no-root cores).

Keywords: carbon allocation, *Fagus sylvatica*, *Pinus pinaster*, *Quercus petraea*, residence time, soil $CO_2$ efflux

# Poster Presentations

# Seasonality in growth of ectomycorrhizal hyphae in *Fagus*, *Quercus* and *Pinus* in France

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Fine roots and associated mycorrhizal partners are the major pathway for uptake of water and nutrients into forest trees. In turn, fine roots and mycorrhizal structures contain significant amounts of carbon and nutrients but sound scientific research underpinning our understanding on the dynamics of production, maintenance and turnover of these structures is still limited. In particular, assessing how much carbon is allocated to the finest structures, *i.e.* mycorrhizal hyphal networks, for construction and maintenance, is still a key challenge for *in situ* research in forest ecosystems. In the present work, our objective is to quantify the production of ectomycorrhizal hyphal structures throughout the growing season in three forest sites with different tree cover, *i.e. Fagus sylvatica*, *Quercus petraea* and *Pinus pinaster*. At each of the study sites $^{13}CO_2$ labelling experiments [1] will be carried out by combining a canopy labelling chamber on trenched trees with a tuneable diode laser absorption spectrometry method to trace the fate of the $^{13}C$ in the trees and the soil. This will be done throughout 2009 using three different seasons for labelling. At each of the three labelling periods, ingrowth mesh bags (30 µm mesh filled with quartz sand) will be installed in the top soil around the

labelled trees. Ectomycorrhizal hyphae that grow into the mesh bags will be evaluated upon retrieval after three months for biomass, length and $^{13}C$ signature. Preliminary data and their interpretation will be available in early summer 2009.

Keywords: ectomycorrhizal hyphae, forest trees, growth dynamics, ingrowth bags, labelling

# Belowground allometric relations in Norway spruce growing in soils with contrasting skeleton and water content

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An increasing importance is assigned to the estimation and verification of carbon stocks in forests. Forestry practice applies several long-established and reliable methods to assess the aboveground biomass; however we still miss accurate predictors of belowground biomass. A major windthrow event, exposing the coarse root systems of Norway spruce trees in the Tatra mountains, has allowed us to assess the effects of contrasting soil conditions on root system development. Four sites representing a gradient of boulder content (from 25% to 65%), as well as water-logging, were selected within the windthrown area. The volume of all coarse roots and belowground stumps of selected spruce trees was established and linked to aboveground stem parameters. Increasing soil skeleton content had negative impact on root/shoot ratio, while soil water-logging led to an increase in this ratio. We have constructed allometric relationships for belowground biomass prediction and were able to show that boulder content does not alter the allometric relations. Soil water-logging, on the other hand, significantly impacts model parameters. We showed that diameter at breast height is a reliable predictor of belowground biomass and once site-specific parameters have been developed it is possible to accurately estimate belowground biomass in Norway spruce.

Keywords: belowground biomass, *Picea abies*, soil skeleton, water-logging, allometric relation

# Long-root growth dynamics, bio- and necromass, turnover rate, NPP and its proportion of fine root production in a fertile Norway spruce forest

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Long roots (LR) are functionally significant for the spreading and stability of the fine root system and for nutrient transport within the plant. Woody roots of diameter < 2 mm develop from fast-growing or slow-growing long-roots with a primary structure and conical root apex (Salyayev, 1959), which occupy free soil volume quickly and create the option to form more ectomycorrhizal short roots on them later. The LR growth dynamics, bio- and necromass, turnover rate, net primary production (LRNPP) and its proportion of fine root production (FRNPP) was measured in a fertile Norway spruce (Picea abies) forest. Soil and ingrowth core and soil monolith (50x50x20 cm3) method was used for estimation of in 1996-1999 and 2008, respectively. The yearly average increment of fast-growing LR in study area was $295 \pm 53$ mm in 1982 (40 yr-old), $224 \pm 79$ in 1994 and $115 \pm 19$ mm in 2008, and their growth was seasonally most rapid from mid-June until mid-July. In the first half of the growth period the growth of LR depended mainly on soil temperature, and in the second half, on the soil moisture content.

LR occupied the root-free soil volume in ingrowth cores first. The mean LR biomass was 55.8 (12.7 % of total fine root biomass), 25.6 (4.9 %) and 7.3 kg $ha^{-1}$ (1%) in the first, second and third year ingrowth cores, respectively; 6.4 kg $ha^{-1}$ (0.5 %) in soil cores and 5.7 kg $ha^{-1}$ in soil monoliths. The LRNPP was 7.8 and 9.4 kg $ha^{-1}$ $year^{-1}$ estimated by ingrowth cores (third year after inserting) and soil monoliths, respectively. Turnover rate of LR was 1.1 $year^{-1}$ for third-year ingrowth cores and 1.7 $year^{-1}$ for soil monoliths. Hence LR dynamics is affected by their age, status (fast- or slow-growing) and limiting environmental conditions.

# Influence of high salinity on root biomass and sap flow of adult olive trees

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Olive is one of the most economically valuable trees in the Mediterranean countries especially because of its drought and salt tolerance.

Two drip-irrigated varieties of 11 yrs-old olive (*Olea europaea* L.) trees, 'Barnea' and 'Proline', considered as tolerant and sensitive to salinity respectively, were examined in the Negev desert, Israel. Three levels of salinity (1.2, 4.2 and 7.5 dS $m^{-1}$) were applied on 'Barnea' trees, and two salinity levels (1.2 and 4.2 dS $m^{-1}$) on 'Proline' variety. Bio- and necromass of fine and coarse roots and fine root surface area were determined and correlated to water content and salinity respectively to soil patches. A tetrazolium test was used to confirm the applied criteria of root sorting into living and death. Sap flow rates and xylem sap osmolality were measured on coarse roots.

Fine root biomass of both olive varieties was highly correlated to soil moisture and salt concentrations. Whereas there were no major differences in root sap flow rates, Barnea variety possessed a much higher root biomass and subsequently a larger absorbing root surface area than Proline variety under moderate salt stress. Furthermore, fine root biomass of Barnea variety was still considerably high under severe salinity. Xylem sap osmolality was found to be significantly higher in salt-stressed Proline roots.

The ability of Barnea variety to sustain a high root biomass under salinity and the higher salt exclusion capacity are likely to contribute to the high salt tolerance of this variety. Influences of root biomass on water uptake and a possible mechanism of Proline to compensate the biomass loss partially by increasing root axial conductivity are discussed.

Keywords: *Olea europaea*, root biomass, root sap flow, salt stress, xylem sap osmolality

# Dynamics of fine-root, rhizosphere and soil parameters in a silver birch stand chronosequence on reclaimed oil shale mining area

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The alkaline and stony abandoned opencast oil shale mining area (OSMA) needs reclamation. Planting of trees, especially fast-growing deciduous species as silver birch (Betula pendula) on OSMA is the best means to help a new forest ecosystem to develop rapidly. A chronosequence of silver birch stands of different ages (1, 2, 3, 4, 7, 31, 43) on reclaimed OSMA was investigated to reveal changes in short root morphology and activity of microbial communities in the soil root interface (Rhiz) and in the bulk soil (Bulk) during stand development to sustain and improve plant nutrition in harsh conditions. Short root morphological parameters were measured using WinRHIZOTM. Biolog Ecoplates were used to determine community-level physiological profiles (CLPP) of culturable bacteria in Rhiz and Bulk. Soil pH decreased and organic matter % increased logarithmically with increasing stand age (from 8.1 to 7.0 and from 1.8% to 15%, respectively); $pH = 8.0 – 0.29*\ln(\text{stand age})$, $r^2 = 0.97$, $p < 0.01$. Mean short root tip frequency per root length (RTFL), mass (W), diameter (D), and tissue density (RTD) increased, and short root length (L), short root tip frequency per root mass (RTFM), specific length (SRL) and specific area (SRA) decreased according to a power function with stand age ($0.85 < r < 0.98$, $p < 0.05$). Soil N% was negatively correlated with SRL, L and RTFM ($-0.88 < r < -0.82$, $p < 0.05$) and positively with D, W and RTFL ($r < 0.9$, $p < 0.01$ for both). Microbial biomass in soil was positively correlated both with soil N% ($r = 0.96$, $p < 0.01$) and stand age ($r = 0.91$, $p < 0.05$). Rhiz/Bulk AWCD ratio indicating the plant support of rhizosphere microbial communities was low after planting, reached the maximum after two years

and decreased thereafter hyperbolically with age. In conclusion, 1) silver birch on reclaimed OSMA supported rhizosphere microbial communities to improve mineral nutrition; 2) among short root morphological parameters RTFL, characterizing root ramification, responded most strongly to stand development.

Keywords: chronosequence of Silver birch stands, fine root morphology, rhizosphere processes, mining area reclamation

# SESSION 5

# CLIMATE CHANGE AND ENVIRONMENTAL STRESSES

Oral Presentations

# Climate change and belowground processes in forests

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For vegetation, climate change is a complex interaction of physical and chemical changes in the environment, such as changes temperature and precipitation, increased inputs of nitrogen and increased concentrations of ozone and carbon dioxide. Many of these effects of these factors on roots are mediated by changes in rates of photosynthesis and carbon allocation. The effects of these factors, with emphasis on elevated carbon dioxide, on roots and mycorrhizas and below ground carbon inputs will be reviewed.

Keywords: elevated carbon dioxide, root turnover, trees

# Effectiveness of roots in preventing metal leaching in EDDS-assisted Phytoextraction with *Brassica carinata* A. Braun. and *Raphanus sativus* L. var. *Oleiformis*

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In metal phytoextraction, soil amendment with chelators can improve metal uptake and translocation (to shoots) by increased mobilization. Due to their persistence, chelates may also cause metal leaching, increasing the risk of groundwater contamination. In this study, the influence on metal leaching of dose and application time of EDDS, a more recent and less persistent chelator, was evaluated at pot level in Ethiopian mustard (*Brassica carinata* A. Braun) and fodder radish (*Raphanus sativus* L. var. *oleiformis*) by cultivating plants in severely metal-contaminated pyrite wastes (As, Co, Cu, Pb, Zn). Plant growth parameters were analysed in relation to water percolation and its metal content. Compared with untreated controls, four EDDS treatments were examined: doses of 2.5 and 5 mmol EDDS $kg^{-1}$ soil applied one week before harvest, and 1 mmol EDDS $kg^{-1}$ soil repeated five times at 5- and 10-day intervals. To increase root growth, fodder radish treated with 1 mmol at the 5-day interval was also added with 1 mg IBA (indole-3-butyric acid) per kg of soil. Shoot biomass, leaf area and root length, which were generally reduced in EDDS-treated plants of both species, were negatively correlated with volumes of percolated water. Roots played an important role in reducing metal concentrations in percolation water, due to increased uptake and retention of pollutants. These results suggest that, compared with controls, EDDS applied at harvest increases neither water percolation nor metal leaching, regardless of the dose used, unlike earlier low-dosage treatments.

Keywords: ethylene diamine disuccinic acid (EDDS), Ethiopian mustard, fodder radish, heavy metals, metal leaching, root growth

# Physical limitations to root growth: Screening, scaling and reality

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Climate change predictions are for increased variability of rainfall in many regions worldwide, resulting in greater fluctuations in soil water regime. Crop root systems will be subjected to increased physical stresses – specifically the incidence of intermittent water stress, soil mechanical impedance, and hypoxia. We need to understand the relative importance of these stresses to target particular crop cultivars to soil physical conditions. Frequently, a single root system (and even a single root tip) experiences a combination of physical stresses, presenting a challenging fluctuating environment for root growth coordination. Our data suggest that water stress rarely acts in isolation from mechanical impedance, whereas mechanical impedance frequently limits root growth even in relatively wet soils, often increasing by an order of magnitude as the soil dries. We found that penetrometer resistance exceeded 2MPa in more than one third of arable topsoils that we examined, at water contents approaching field capacity. Plant scientists are responding to these environmental threats with increased interest in screening crops for particular root phenotypes. However, there are three major difficulties: seedling root system properties may not scale to root system properties of more mature plants; root systems are very plastic in relation to environmental conditions; and different types of root system are required for particular soil stresses. The electrical capacitance techniques offer a rapid glasshouse or field-based method for estimating root mass. Good correlations were obtained for barley seedlings grown in soil, and mature wheat plants of 35 varieties grown in sand columns. More information is needed on how root mass distribution in soil contributes to root capacitance.

Keywords: abiotic stress, drought, root growth, scaling, mechanical impedance, root-soil interactions

# Interactions between root and stem growth in *Pinus sylvestris* exposed to drought - assumptions based on tree ring analysis

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Radial stem growth indices of trees are frequently applied to identify the climatic factors limiting tree growth. Based on several tree-ring studies conducted within a dry inner Alpine valley it is well established that growth of Scots pine (*Pinus sylvestris* L.) is primarily limited by spring precipitation and severe drought results in increased tree mortality. To examine short-term influences of drought stress on growth processes more closely, we determined the influence of climate variables and soil moisture and temperature on intra-annual dynamics of tree ring development and stem radial growth in *Pinus sylvestris*. We found that bud-break and shoot growth recommenced in May at the earliest. Root growth, however, is assumed to precede above ground growth for several weeks that is why we hypothesize that growth reductions seen in ring-width series, which coincide with drought periods in early spring, are related to an extensive growth inhibition or even damage of the fine root system and associated symbiotic mycorrhizal hyphae in the upper soil layer. Higher tree mortality and reduced growth of shallowly rooted trees support our reasoning. Dendrometer records revealed that although fluctuations in stem radius were closely related to soil moisture throughout the growing season, an influence of soil temperature on initiation of radial stem growth was detected. These results suggest that in *Pinus sylvestris* exposed to severe soil dryness, a threshold root-zone temperature rather than soil moisture is involved in triggering onset of above ground stem growth in spring. Hence, our results suggest a close linkage between root and stem growth in *Pinus sylvestris* exposed to drought. Therefore, we conclude that combined studies considering both, above and below ground growth processes are needed to elucidate more comprehensively the influence of environmental stresses on tree physiology and successional forests shifts in the course of climate change.

Keywords: cambial activity, drought, root-shoot interaction, Scots pine, tree ring

# Root adaptations of Mediterranean species to hypoxia and anoxia

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Mediterranean species are popular ornamentals in the UK. Originating from climatic zones of hot dry summers and mild wet winters they exhibit features of drought adaptation, and are therefore suited to the predicted climate change scenarios of hotter drier summers. This work investigates how these species will respond to the predicted wetter winters and increased frequency of spring and summer flooding. Initial work on flooding of four Mediterranean species in a pot experiment, showed that the detrimental effects of waterlogging were only severe when the temperature was high and flooding prolonged. To examine the response of roots to oxygen deprivation over a range of conditions from total absence of oxygen (anoxia), low oxygen (hypoxia) and full aeration, small plants of *Salvia officinalis* were grown in a hydroponics-based system and mixtures of oxygen and nitrogen gases bubbled through the media. When the plants were subjected to a period of 5 days of hypoxia they responded by increasing the production of lateral roots in the upper part of the root system. This enabled them to acclimate and survive a subsequent period of 5 days anoxia. A rapid onset of 5 days of anoxia from full aeration caused serious loss of root and inhibited further lateral root production. There was no evidence that these species increased their root porosity, during periods of hypoxia as hydrophytes readily do, so it is concluded that a rapidly developing flexible root system is their strategy for surviving periods of waterlogging.

Keywords: waterlogging, flooding, lateral roots, root porosity

# Seasonal dynamics of *Picea abies* and *Fagus sylvatica* fine roots in an acidified cambisol

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The study focused on Norway spruce (*Picea abies* L. Karst) and European beech (*Fagus sylvatica* L.) grown in Kysucké Beskydy Mts., North-Western Slovakia. In the growing season 2006, the following fine root (upper diameter of 1 mm) traits were studied: biomass and necromass seasonal dynamics, vertical distribution, production, mortality, fine root turnover and production-mortality ratio including soil depth 0-35 cm. Results indicated that spruce had a lower standing stock of fine roots than beech, and fine roots of spruce were more superficially distributed than those of beech. Furthermore, we estimated higher seasonal dynamics and also higher turnover of fine roots in spruce than in beech. Production–mortality ratio was higher in beech than in spruce, which was hypothetically linked to the effect of the drought episode occurred in July and August. The results suggest that beech fine roots may resist the physiological stresses better than that of spruce.

Keywords: biomass, mortality, necromass, production, stress, turnover

# Identification of genes expressed during aerenchyma formation in maize roots using laser microdissection and a microarray

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Laser microdissection (LM) is a new method that makes it possible to obtain large homogeneous populations of cells from tissue sections in one step. LM in combination with microarray analyses can monitor changes in transcript levels in specific cell types, in which morphological or physiological changes are observed. In this study, we used LM and a microarray to monitor genes expressed during aerenchyma formation in maize (*Zea mays*) roots. In maize, hypoxia stimulates ethylene biosynthesis, which induces cell death in the root cortex, thereby forming aerenchyma in the roots. Roots of 3-d-old maize (inbred line B73) seedlings were waterlogged for 6 h and then were fixed and embedded in paraffin. We isolated root cortex cells from the paraffin-embedded sections using LM, extracted RNA and carried out a maize cDNA microarray. Finally, we identified several genes that were expressed specifically in the root cortex during aerenchyma formation. Possible roles of these genes in aerenchyma formation are discussed.

Keywords: Aerenchyma, Laser microdissection, Maize, Microarray, Root aeration, Waterlogging

# Impacts of climate change on root demography and soil respiration of a perennial grassland

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Direct and indirect effects of temperature, drought and elevated $CO_2$ on grassland ecosystems have been well established when considering one or two abiotic factors, but rarely when considering the interactions of the three factors. For example, the positive effects of elevated $CO_2$ and temperature on growth and plant C balance may be counterbalanced by drought effects, depending on the thresholds. For the below-ground compartment, experiments on grassland ecosystems have shown that elevated atmospheric $CO_2$ can affect root dynamics in terms of production, life span, and mortality and decomposition rates. Then it is expected that C cycling is fast and C accumulation is small in soil of grassland subjected to elevated $CO_2$. Here, we report results of dynamics and demography of roots and soil respiration of perennial grassland monoliths exposed to four different treatments: Control (C), Temperature (T, +3°C in comparison with control), Temperature x Drought (TD, +3°C and 20% lower summer precipitations than in control) and Temperature x Drought x $CO_2$, according to A2 scenario (IPCC, 2001) ($TDCO_2$, +3°C, -20% summer precipitations and $CO_2$ 200ppm above control). Root dynamics was measured by minirhizotron method and soil respiration was measured by a closed chamber technique. Results obtained for the three first years showed a significant increase of root growth (+33%) and new roots mean diameter (+6%) in the $TDCO_2$ compared to control. Under TD and $TDCO_2$ soil respiration was 35% higher than in control. These first results confirm higher root activity under A2 scenario ($TDCO_2$).

Keywords: Root dynamic, Climate change, Respiration, Minirhizotron

# Does the removal of the snow layer enhance the adverse effects of soil frost on *Picea abies* (L.) Karst. ?

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Snow is known to act as an important insulator of forest soils against frost in northern latitudes. Consequently, the lack of a snow layer may result in more severe soil frost, thereby increasing freezing injuries to tree roots. Frozen soil may cause stress in spring, when the demand for evapotranspiration is high. We studied the effects of the timing of soil frost thawing on the roots and foliage of Norway spruce. A snow manipulation experiment was conducted in a 47-year-old Norway spruce stand in eastern Finland during winter 2005-2006 and 2006-2007. The treatments (with three replicates) were: 1) CTRL with natural snow accumulation and melting, 2) OPEN: artificial snow removal during two consecutive winters, and 3) FROST: same as OPEN, but the ground was insulated with a layer of hay between plastic sheeting in early spring in order to delay soil thawing until July. The growth and physiology of nine trees per treatment were monitored in 2006 and 2007. FROST reduced shoot and needle growth, but not fine root biomass. FROST also delayed bud development and interfered with carbohydrate metabolism. FROST reduced the proportion of healthy buds and increased resource allocation to male flowers. The foliar nitrogen concentration in the current year needles was lower in the FROST treatment than in the control in 2006. Chlorophyll fluorescence and electrical impedance of current-year needles were affected by FROST in 2006, but not in 2007. Ion leakage measurements on the needles indicated no damage in 2007. Trunk diameter growth and bud burst were delayed in the FROST treatment in 2006, but not in 2007. Overall, the results indicate that the physiology of Norway spruce responded in varying ways to delayed soil frost melting.

Keywords: soil frost, snow, *Picea abies*, root growth, needle physiology

# Drought-induced plasticity of root specific conductivity and vulnerability to cavitation

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Studies concerning plant adjustment to drought have highlighted the importance of plastic xylem adaptations. However, few comparisons of tree species grown under contrasting moisture regimes exist; our knowledge is particularly limited regarding the adjustment of tree root hydraulic properties. The aims of this study were to test if (i) fine roots are more vulnerable to cavitation than shoots, (ii) root specific conductivity decreases upon drought stress, and (iii) the root systems of Quercus are better adapted to drought stress than those of Fagus. We studied specific conductivity (ks), xylem anatomy and vulnerability to embolism in roots of saplings and mature trees of drought-sensitive *Fagus sylvatica* L. and relatively drought-tolerant *Quercus petraea* (Matt.) Liebl. which were exposed to experimental summer drought. Mature Fagus and Quercus trees had 3 to 15× higher ks values than saplings, indicating a large increase in root specific conductivity with age. Axial root conductivities of water-stressed Quercus saplings were more variable than Fagus saplings' roots ks. Roots of both species were much more vulnerable to cavitation (water potentials causing 50% conductivity loss, ΨPLC50: -0.3 to -0.5 MPa) than shoots (-2 to -3 MPa). Furthermore, water-stressed Quercus roots cavitate earlier than well-watered roots. In Quercus, drought led to an increase in root ks, which contrasts with shoots where conductivity generally decreased. A decrease in root conductivity was found in severely water-stressed Fagus saplings and adult trees. Small-diameter roots of Fagus and Quercus with their high cavitation susceptibility are much more drought-sensitive than shoots and are thus likely to act as hydraulic 'fuses' in the soil-plant-atmosphere continuum. Root ks can adapt to soil drought, but magnitude and direction of these adaptations are more variable than in shoots. Drought-adapted tree species such as Quercus petraea seem to be capable of partly compensating for drought-induced root conductivity losses by increasing axial root conductivity.

Keywords: Axial conductivity, *Fagus sylvatica*, *Quercus petraea*, roof experiment, summer drought, vulnerability to cavitation

# Transcriptional profiling of root hypodermal tissues during formation of a barrier to radial $O_2$ loss in rice (*Oryza sativa* L.)

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Internal aeration is crucial for plant growth in waterlogged soils. A barrier to radial $O_2$ loss (ROL) can enhance longitudinal diffusion of $O_2$ via the aerenchyma to the root tip, and thus promote root elongation into anoxic substrates. In rice, the barrier to ROL is inducible, forming in adventitious roots in stagnant or waterlogged conditions, but not in aerated conditions. However, the genes involved in regulating barrier formation have not been identified. The present study: (i) identified the timing of barrier formation in rice, using cylindrical root-sleeving $O_2$ electrodes, and (ii) identified candidate genes involved in barrier formation. We isolated root hypodermal tissues during formation of the barrier to ROL using laser microdissection, which is a technique for isolating specific cell-types from heterogeneous tissues. RNA extracted from these tissues was analyzed with a rice 44k oligo microarray. We 137 genes that were significantly up-regulated or down-regulated (*P* value of log ratio $< 0.01$) in the outer root cell layers during barrier formation. The up-regulated genes included some peroxidase and transporter genes that might be involved in forming putative suberin or lignin deposits, compounds that are considered to be involved in barrier formation.

Keywords: Barrier to radial $O_2$ loss, Hypoxia, Laser microdissection, Rice 44k oligo microarray, Root aeration, Waterlogging

# Root responses to soil physical constraints: Quantitative gene expression analysis

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Root elongation and exploration can be constrained by soil that is too hard for roots to penetrate through, soil that contains too much water (which results in hypoxyia due to too little oxygen) or because as the soil dries the water potential falls. Studies of the impact on gene expression in relation to soil water, soil strength and porosity are limited, partly because of the difficulty in doing quantitative studies on roots that have been grown in soil. Many drought gene expression studies use root material grown in hydroponics containing osmotic compounds to simulate drought conditions, while other more recent studies have used material grown in soil amended with sand and peat.

We have harvested seedling root material of Barley (*Hordeum vulgare*) plants grown in a wide range of soil conditions. Soil conditions have been quantified (e.g soil strength, soil macroporosity, water content) using measurements related to the least limiting water range approach. Using quantitative RT-PCR we are analysing the gene expression of DHN4 (a gene previously shown to be up regulated in drought conditions), an aquaporin and other candidate genes. Future work may include candidate genes that are potentially involved in root penetration, such as those involved in the production of mucilage and border cells.

Keywords: Barley, Soil strength, Drought tolerance, qRT-PCR, Least limiting water range

# Poster Presentations

# Seedling growth and aluminum distribution in root of sago palm under low pH condition

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To determine the aluminum (Al) tolerant ability of sago palm, seedlings were grown in culture solution at pH 3.6 including different level of $AlCl_3 \cdot 6H_2O$ corresponding in 0, 10, 20, 100 and 200 ppm Al. Total dry weight, plant length and total leaf area tended to be largest at treatment with 10 ppm Al followed by 0, 20, 100 and 200 ppm Al. The root system treated with 200 ppm Al was apparently different from the other plots, which the critical toxic level to inhibit sago palm growth was considered to be around 200 ppm Al. The $Al^{3+}$ concentration tended to be lower in the leaflets at higher leaf position and the stele of adventitious roots, while it tended to be higher in the cortex of adventitious roots. Furthermore, the observation of Al localization in the roots stained with hematoxylin showed that Al was accumulated in the cell wall of exodermis. From fluorescent observation of roots stained with berberine-aniline blue, the development of suberin lamellae was found in the exodermis, which might suggest the suberin lamellae as the first barrier to restrict the radial movement of Al in sago palm roots under acid conditions.

Keywords: adventitious root, aluminum localization, exodermis, sago palm, suberin lamellae

# Root dynamics and nitrogen uptake in a future climate

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Climate change has great impact on natural ecosystems, and plant root responses are a major part of whole-plant responses to climate change. Little information is available on below-ground plant responses as to how root growth and turn-over, root morphology and nutrient use efficiency change in response to climate change. In the CLIMAITE experiment root biomass and nutrient uptake have been studied in different treatments with higher $CO_2$, temperature and a drought period. Preliminary results show a decrease in root biomass with increasing temperature, while the root biomass was increased under elevated $CO_2$ concentrations. Nutrient uptake in *Deschampsia flexuosa* is higher in the $CO_2$ treatments and lower in the combined Temperature*Drought treatment.

Keywords: CLIMAITE, root growth, $NH_4$, bioassay, *Calluna vulgaris*, *Deschampsia flexuosa*

# Effects of sewage sludge application on the arbuscular mycorrhizal colonization of selected grassland species in Austria

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A long-term field experiment was conducted to study the effects of sewage sludge application on the arbuscular mycorrhizal (AM) root colonization of 14 selected grassland species. The sewage-sludge-treated soil was enriched primarily with inorganic P, lactate-soluble K, aqua regia-extractable Ca and Mg as well as aqua regia-extractable heavy metals (Zn, Cu, Cd, Pb, Hg) in the uppermost 10 cm. In the sewage-sludge-treatment and in the untreated control percentage AM root colonization of the grassland species investigated varied from 17 to 45 %. In the sewage-sludge-treated soil mycorrhization was highly significant lower than in the unfertilized soil. The results suggest that a long-term application of sewage sludge leads to a decrease in percentage AM root colonization of grassland species primarily due to a P accumulation in the soil.

Keywords: mycorrhiza, field experiment, phosphorus, heavy metals

# Effect of deep-flood irrigation on grain quality, yield and root activity in rice

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To minimize the deterioration of grain quality caused by the high temperature stress in ripening stage is an important agronomical issue in rice cultivation. Field trial was conducted to investigate effects of deep-flood irrigation on growth and quality of rice under high and normal ripening temperature. The experiment was carried out at the paddy field in Niigata, Japan, using three rice cultivars (Hatsuboshi, Sasanishiki and Koshihikari). Two water management regimes were prepared: DFI (deep-flood irrigation; water level was kept in 18 cm from active tillering to maximum tiller stage) and CWI (conventional water irrigation). DFI decreased inferior tillers, resulting in higher percentage of tillers that produce mature grains. Although DFI decreased the number of panicles, it increased the number of grains per panicle and thousand grain weight of brown rice, hence yielded equal to the CWI plot. In addition, DFI decreased occurrence of milky white grains rather than white belly or basal white. This effect was observed both high temperature and normal temperature conditions, suggesting to be an effective method to overcome deterioration effect of high ripening temperature. The more sensitive the cultivar is to high temperature, the higher the DFI effect is to reduce grain deterioration. However, it should be noted that DFI start after production of enough number of tillers. Otherwise, yield will be decreased for a shortage of tillers. 330 tillers/$m^2$ may need to get equal level of yield to the conventional cultivation while reducing deteriorated grains. The effect of DFI on the root activity will be also discussed in the present study.

Keywords: Chalky grain, Cultivar, Deep-flood irrigation, High temperature stress, Rice, Root activity

# Ameliorating effects of aluminium on low pH-induced structure damage to *Lotus corniculatus* root cells

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Ultrastructural responses of *Lotus corniculatus* root cells to solutions with low pH 4.0 alone or with 2.0mM $AlCl_3$ were compared. The low pH induced special modifications of cell nuclei and disintegration of cytoplasmic organelles. Importantly, no cell wall thickenings were present. $Al^{3+}$ at the same pH did not induce as severe damage as the acidity alone. Increased vacuolation and irregular cell wall thickenings were most frequent. The effect of $Al^{3+}$ on cytoplasmic structure depended not only on severity of stress and on the position of a particular cell within the root, but also on the occurrence of stress-induced cell wall thickenings.

Keywords: low pH, proton toxicity, aluminium, cell wall thickenings

# Role of root to avoid salt stress in sago palm (*Metroxylon sagu* Rottb.)

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Sago palm, a starch producing palm, grows in swampy and peaty soils. Since sago palm can grow in brackish water areas, it is considered to be salt-resistant. Ion concentrations in different plant parts and some physiological features under NaCl treatment (342mM) were measured to investigate salt resistance of sago palm. Under the NaCl treatment for one month, sago palm maintained a low $Na^+$ concentration in the leaflets at higher leaf positions by storing $Na^+$ mainly in the roots and the petioles at lower leaf positions. The $Na^+$ concentrations in the adventitious roots were lower in the stele than in the cortex under the NaCl treatment, which suggested the existence of a mechanism in the endodermis to restrict excessive influx of $Na^+$ from the cortex into the stele. From X-ray micro-analysis, the dense distribution of Na in the adventitious root was found around its endodermis. The change in the $Na^+$ concentration in the roots and leaves did not affect $K^+$ distribution to the leaves. Regardless of the decrease in transpiration rate and slight delay new leaf emergence with the treatment, there was no significant difference in dry matter weight of leaves. It was therefore considered that the nature of salt resistance of sago palm might consist of salt avoidance by mechanical restriction of excessive $Na^+$-distribution to the cortex.

Keywords: adventitious root, endodermis, $Na^+$, NaCl treatment, sago palm, X-ray micro-analysis

# Soil compaction and root growth controlling factors in cropland, semi-arid of South Bulgaria

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Soil compaction is recognized as an important problem in croplands. The main objective of this study was to evaluate soil factors controlling root development of maize grown on field with subsoil compaction in semi-arid area of South Bulgaria. Two treatments were examined: deep loosening in combination with drainage and control without meliorations. Root observations to 1 m depth were made on vertical and horizontal planes covered with 2 x 2 cm grid mesh at silking. For analysis of root spatial pattern, the variance: mean ratio (VMR) test was also applied. Results for root densities expressed as dry mass and proportions of "full" squares consisting at leas one root were similar in the topsoil, but significantly higher in the subsoil of the meliorated plot showing deeper root allocation there. The control plot had more squares with lots of roots at the top-subsoil boundary owing to grouping of roots in pores and cracks. The horizontal planes in the control generally consisted less "full" squares, showing larger soil areas without roots and great distances for water and nutrient transmission. Consequently, an inhibited water extraction from subsoil, a delay in the crop ontogenesis and less biomass production was established there during the observed period. The VMR test at small (2 cm) scale was close to 1 in the topsoil of the meliorated plot indicating lack of clustering. At all other positions and scales examined, the VMR's were considerably higher than 1 indicating different levels of root clustering. The strongest positive correlation was found between the root data and the soil hydraulic conductivity, which can be used as an indicator for root density distribution.

Keywords: Maize, Soil compaction, Root density and spatial distribution patterns, Semi-arid climate

# Root characteristics of *Lotus corniculatus* L. and *Bromus inermis* L. grown on eroded rangeland in a semi-arid area of South Bulgaria

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The supportive role of plant roots for slope stabilisation is identified. Nevertheless, data on root characteristics and their effects in controlling soil erosion are seldom. The main task of this study was to evaluate site effects (slope, soil parameters, fertilisation) on root characteristics and thus in return to identify of the erosion-reducing potential of two cover crops in semi-arid conditions of South Bulgaria. To achieve this, root morphology and density distribution, biomass production of a mixture of Bird's-foot trefoil and Bromegrass grown on gentle ($6^{o}$) and steep slopes ($12^{o}$), and relevant soil characteristics were measured. The experiment included plots without and with 11 different rates of NPK fertilisation. In was observed that the effect of the fertilisation on shoot and root development was stronger on the gentle than on the steep slope. The shoot: root mass ratios were higher for the steep slope and for the treatments without or minor rate of fertilization. On these plots, less root biomass occurred in the topsoil due to root relocation in deeper soil depths. Compared to mass, root length and surface area densities did not consistently increased with increasing the NPK fertilisation rate. Extra Ca applications, however, apparently supported the root elongation. No significant differences in mean root diameters were found between the treatments, except of the highest N applications affecting primarily the growth of the main roots rather than their branches. A high erosion-reducing potential of the topsoil roots was estimated in all treatments on both slopes.

Keywords: Rangeland, Slope, Soil fertility, Cover crops, Root morphology, Erosion-reducing potential

# Formation of aerenchyma in seminal root of wheat under nutrient starvation and transcriptome analysis

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Excess moisture injury in wheat and barley is one of agricultural constraints. In Japan, over 60 % of wheat in area is grown in drained rice paddy fields. To overcome the wet injury in wheat, modification of the aerenchyma forming capacity in wheat root using genetic engineering is expected. However, the molecular mechanisms associated with aerenchyma formation are still unclear.

We observed the growth of primary seminal roots of wheat seedlings under two culture conditions, control and starvation. Root aerenchyma was found under starvation until 7 day after sowing. Transcriptome analysis showed the different gene expressions between the roots under two nutritional conditions.

Keywords: Excess-moisture injury, *Triticum spp*., aerenchyma, nutrient starvation, transcriptome

# Frost hardiness of mycorrhizal and non-mycorrhizal scots pine (*Pinus sylvestris l.)* roots

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There are many studies about mycorrhizal associations but only few about their survival and functioning at low temperatures. The aim of this research was to compare the frost hardiness of mycorrhizal and non-mycorrhizal roots of pine (*Pinus sylvestris* L) seedlings. The effect of daylength and temperature on the frost hardiness of roots was also studied. Seedlings were cultivated in four blocks for 17 weeks. Every block contained both mycorrhizal (*Hebeloma sp.)* and non-mycorrhizal seedlings. After 13 weeks growth in long day and warm temperature growing chamber, half of the mycorrhizal and non-mycorrhizal seedlings were taken to a chamber with short day and low temperature to cold-acclimate. The study was done with low nutrient contents. The frost hardiness of the roots was assessed with electrolyte leakage tests. From each block three parallel root samples from four treatments were prepared for 6-7 frost exposure temperatures. Analysis of variance was used to compare the results of the electrolyte leakage tests, dry weights and nutrient concentrations of the roots, stems and needles. The inflection point of the temperature response curve for non-mycorrhizal roots with hardening treatment was -6.8°C, mycorrhizal roots with hardening treatment -7.5°C; non-mycorrhizal roots without hardening treatment -9.8°C and mycorrhizal roots without hardening treatment -8.9°C. No difference was found between frost hardiness of mycorrhizal and non-mycorrhizal pine roots. Also the interaction of mycorrhiza and hardening treatment was not statistically significant. Unexpectedly, the roots without the hardening treatment were more frost hardy than the roots with the hardening treatment. In this study the nutrient contents were very low and that has probably affected also the frost hardiness of the roots. More information about functioning of mycorrhizas at low temperatures is needed especially with different nutrient contents and different mycorrhizal fungi.

Keywords: Ectomycorrhiza, Frost hardiness, Roots, Nutrients

# Growth and vitality of fine roots of Norway spruce as influenced by experimental and natural drought

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The presented project deals with drought effects on the dynamics of fine roots of Norway spruce. A study on pure spruce stands along a precipitation gradient is carried out in order to investigate the adaptations of adult trees to natural differences in soil drought conditions. The research plots represent a transect in central Germany from the Solling Mountains in the state of Lower-Saxony along the southern border of the Harz Mountains (state of Thuringia) to Halle in the state of Saxony-Anhalt. The annual rainfall on these sites decreases from West to East from 1000 mm to about 500 mm of precipitation per year. By determining the fine root bio- and necromass using an inventory depth profiles of fine root distribution are created and the effect of drought on live:dead ratio of fine roots can be evaluated. Furthermore fine root morphology is analysed and used to calculate root area indices on stand level. An application of the minirhizotron method as well as the ingrowth core method will allow for monitoring fine root growth and turnover.

Additionally, above ground biomass and productivity are analysed measuring aboveground stand structure, stem increment and leaf litter production.

Our presentation will give an overview on the planned experiments as well as an account of some preliminary results.

Keywords: fine roots, Norway spruce, drought, minirhizotron, ingrowth cores

# The effect of different Si concentrations on antioxidative response in young maize roots

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During our studies of drought, salt and cadmium stresses we have compared also the effect of various Si concentrations (3.5 mM, 17.5 mM and 35 mM). There is no generally accepted concentration of Si with positive effect known for various plant species. Activities of some antioxidative enzymes (ascorbate peroxidase, catalase, quaiacol peroxidase and superoxid dismutase) and root growth parameters were studied in young roots of maize *Zea mays* L. cv. NK-Alpha grown under salinity stress with and without Si treatment.

# Carbon accumulation in fine roots of soils of a Mediterranean oak forest growing under different levels of thinning and drought conditions after fire disturbance

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International reports like IPCC predict an increase in drought of at least 20% in the Mediterranean basin. In this scenario, which will be the contribution to the carbon balance of the soil plus root system as $CO_2$ sequestration agents?

In a Mediterranean oak forest under regeneration after a fire (1998) located at Castelltallat range, Barcelona (Spain), two treatments were applied in 2003: forest management with two levels (thinning and no thinning) and rainfall inputs with two levels (natural and artificially decreased). In 2007, a dry year, no effect of managing was seen either in root density or total root carbon. In 2008, a rainy year, there was an increment in root density; however, this increment only resulted in higher root carbon concentration in the soil in the artificially decreased rainfall treatment, managing having no effect in this parameter.

# Root biomass of eighteen alfalfa (*Medicago sativa* L.) cultivars in two different environments under organic management

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Roots play an important role, especially in low input farming system such as organic farming, in maintaining water and nutrient supply to plant tissues, and they also contribute to the maintenance of soil organic matter content and structure. Our objectives were to (a) study final root biomass and (b) effect of drought stress on root biomass production in different alfalfa (*Medicago sativa* L.) genotypes. Eighteen Iranian and European alfalfa cultivars were evaluated in an α-lattice design with two replications in two environments in September, 2007. The experiments were located on two organically managed fields (Raasdorf and Gross-Enzersdorf) of the University of Natural Resources and Applied Life Sciences Vienna, Austria, both under dry site conditions. In Gross-Enzersdorf, soil moisture was kept at field capacity with drip irrigation, while the only water source in Raasdorf was rainfall. A soil core method (Ø 9.1 cm) was used to determine root biomass in 0-30 cm depth. The cultivar effect was significant ($P < 0.05$) for root biomass (t $ha^{-1}$) and root mass density (mg $cm^{-3}$) in both environments, indicating genetic variation among the tested genotypes for these traits. In Gross-Enzersdorf, the highest root biomass belonged to cv. NS-Banat (10.58 t $ha^{-1}$), Ghargholog (9.74 t $ha^{-1}$), Shorakat (9.70 t $ha^{-1}$) and Ordobad (9.40 t $ha^{-1}$). Under rain-fed conditions in Raasdorf, Vlasta (9.51 t $ha^{-1}$) and Shorakat (8.83 t $ha^{-1}$) had the highest root dry matter. The average root biomass and root mass density differed significantly ($P < 0.05$) between the two environments. Drought stress conditions reduced similarly root biomass and root mass density in the rain-fed experiment by 19.6 %.

Keywords: Alfalfa, organic farming, root biomass, root mass density, drought Stress

# Contribution of root systems on soil $CO_2$ efflux in a tropical rainforest in Borneo, Malaysia

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Recently published data suggests that contribution of root systems is significantly important for the variation of soil $CO_2$ efflux in an Asian forest. In this study, we aimed to examine the contribution of root systems on soil $CO_2$ efflux in a tropical rainforest in Borneo, Malaysia, by 1) measuring fine root respiration using a root respiration chamber and 2) investigating variation of soil respiration according to the changes of distance from emergent trees, *Dryobalanops aromatica*. Our results indicate that fine root respiration varied from 0.3 to 6.5 nmol $g^{-1}$ $s^{-1}$, 2.4 nmol $g^{-1}$ $s^{-1}$ in average. We also found that soil $CO_2$ efflux 0.5 m apart from the emergent trees was significantly higher than those of 5 m and 10 m distances, suggesting that root systems could have a large impact on the fluctuation of soil $CO_2$ efflux in an Asian tropical rainforest.

Keywords: rhyzosphere, root respiration, soil respiration, spatial variation, temporal variation, tropical forest

# Wet injury in drained paddy fields and root Aerenchyma formation of wheat

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Excess soil moisture injury often occurs in Japanese wheat production area. Japanese farmers produce wheat in drained rice paddy fields because rice is overproduced in Japan. In such growth conditions, wheat plants often show wet injury. However, the detail of wet injury of wheat fields is not clear.

We observed wheat growth and soil conditions in paddy fields in 2007 and 2008 in Japan. Eighty observation points were set in a drained paddy field. Close relation was found between soil water content and plant height.

We observed root aerenchyma formation in wheat plants in the fields. The relationship between degree of wet injury of wheat plant and root aerenchyma formation was not clear.

Keywords: Excess-moisture injury, Triticum spp., Upland field converted from paddy field, Wet endurance.

# Association mapping for root traits of maize (*Zea mays* L.) grown at three temperature regimes: Allelic response pattern of root traits suggest specificity of alleles to optimal conditions vs. temperature-extremes

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While considerable research has been devoted to unravel the genetic basis of cold or heat tolerance, little has been done to trace the effect of an allele across the whole temperature range a maize plant is exposed to during its lifetime. We used a germplasm set comprising temperate flint and dent inbred lines to tackle this question. Seedlings were grown at 16°C, 28°C and 36°C. Associations were tested between the root traits at the V2-stage and 1415 AFLP markers. Markers with main effects and with environment interaction effects were found. Root traits were controlled by alleles responding to both temperature extremes, indicating general response pathways.

Keywords: corn, QTL, abiotic stress

# Oxygen transport to flooded roots for respiration via Aerenchyma in Soybean (*Glycine max*)

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In soybean plants, secondary aerenchyma derived from a phellogen is formed in flooded stem, root and nodule. It is suggested that the aerenchyma is an oxygen pathway and aerial oxygen is transported to roots and nodules, so we investigated that oxygen from stem to root via aerenchyma was used for roots respiration using stable isotope $^{18}O$ as a tracer. Stem with or without aerenchyma just above water level was exposed by the $^{18}O_2$ gas for 3 h, and then the water was extracted from sampled root. Water samples were analyzed for oxygen isotope ratios on an isotope ratio mass spectrometer. In control plants, after the basal region of the no aerenchymatous stem was applied by $^{18}O_2$ gas, $\delta^{18}O‰$ of extracted water indicated little increase. In contrast, when the basal region of the aerenchymatous stem was exposed to $^{18}O_2$ gas, $\delta^{18}O‰$ significantly increased. Therefore, aerenchyma transports oxygen for respiration and its formation is morphological adaptation to flooding in soybean plants.

Keywords: Aerenchyma, Flooding stress, Oxygen transport, Root respiration, Soybean

# Factors responsible for diurnal and seasonal changes in the reduction of stomatal conductance in paddy rice caused by elevated $CO_2$

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Understanding of leaf stomatal responses to the atmospheric $CO_2$ concentration, $CO_2$ is essential for accurate prediction of plant water use under future climates. Elevated $CO_2$ generally reduces stomatal conductance ($g_s$), but the magnitude of the reduction in $g_s$ varies. Limited information is available for the diurnal and seasonal changes of $g_s$ under elevated $CO_2$. We examined the factors responsible for diurnal and seasonal changes of $g_s$ under elevated $CO_2$ with three rice cultivars grown in an open-field environment under flooded conditions for two years. Conductance of all cultivars was generally higher in the morning and at noon than in the afternoon, and was significantly decreased by elevated $CO_2$ at most times of day for all cultivars by 0-63% (25 out of 38 days in two years). There were no significant interactions of $CO_2$ × cultivar, $CO_2$ × time of day, $CO_2$ × cultivar × time of day at all measurement days excepting for one time of day. Ball, Woodrow & Berry model (1987) well explained the $g_s$ responses in the morning and at noon over years, days, cultivars and $CO_2$ conditions, but the model could not well explain the $g_s$ responses in the afternoon especially under ambient $CO_2$. Leaf water potential was reduced in the afternoon especially under ambient $CO_2$. This suggested a need for incorporating factor of plant water status into the model for improving accuracy for simulating $g_s$ responses under future climates.

Keywords: Elevated atmospheric $CO_2$, Free-air $CO_2$ enrichment (FACE), Global change, Leaf water potential, Rice, Transpiration

# Root anatomical responses of two *Salix caprea* isolates growing in different environmental conditions

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Root anatomic characteristics of cuttings of two *Salix caprea* isolates exposed to zinc (Zn) and cadmium (Cd) or both are compared to growth and heavy metals accumulation behavior.

Keywords: Willows, Heavy metal accumulation, Cadmium, Zinc, Root anatomy, Casperian band

# Shoot and root phytotoxicity by EDDS in relation to dose and application time in *Brassica carinata* A. Braun and *Raphanus sativus* L. var. *oleiformis*

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This study examines the effects of the chelator EDDS on plant growth and phytoextraction of *Brassica carinata* A. Braun (Ethiopian mustard) and *Raphanus sativus* L. var. *oleiformis* (fodder radish) grown in metal(loid)-polluted pyrite wastes (As, Co, Cu, Pb, Zn). Plants were cultivated for 75 days in pots. Four EDDS treatments were tested: 2.5 and 5 mmol EDDS $kg^{-1}$ soil applied one week before harvest and 1 mmol $kg^{-1}$ soil repeated five times at 5- and 10-day intervals. Fodder radish treated with 1 mmol at the 5-day interval was also added with 1 mg IBA (indole-3-butyric acid) $kg^{-1}$ soil to prevent root phytotoxicity.
EDDS caused shoot and root phytotoxicity in both species, especially when it was applied earlier (repeated treatments). Ethiopian mustard was less sensitive than radish to EDDS application. EDDS enhanced metal concentrations in shoots at any dose in both species, but not metal removal, except for dose 2.5 mmol in mustard.

Keywords: EDDS, root and shoot phytotoxicity, *Brassicaceae*

# SESSION 6

# ROOT – SOIL INTERACTIONS: MODELLING CONCEPTS

Oral Presentations

# Modelling plant soil interaction: From the soil particle to plant scale

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In this talk I will present models that deal with plant nutrient uptake. In particular I will discuss the role plant exuded organic acids and mycorrhizae can have on this process. I will begin by describing our recent work on modelling exudation of 2'-deoxymugineic acid (DMA) and the effect this has on plant acquired zinc. We assume that DMA and zinc are both present in two forms in the soil, in the soil solution phase and bound to the soil particles. We will develop a model that describes this competitive binding reaction and then link it up to a model for plant exudation and zinc uptake. In particular we will investigate the effect of the diurnal DMA exudation pattern on the zinc uptake. The second model I will describe deals with the uptake of nutrients, such as phosphate, that in addition to binding to the soil particle surfaces can also diffuse into the soil particle micropores and bind to their internal surfaces. This leads to a so called dual porosity models for the soil and we will show how the results for nutrient uptake by plants differ when one considers simple particle surface binding in comparison to dual porosity nutrient binding. We find that the results are qualitatively and quantitatively very different. This highlights the need for the simultaneous measurement of soil properties and root nutrient uptake properties. A third model I will discuss deals with modelling the effect mycorrhizae have on phosphate uptake by plants. We consider the phosphate movement within the soil, uptake by roots and fungus, and transport of phosphate within the fungus to the root surface. We find that the model predictions for phosphate depletion profiles in the soil differ significantly for two plausable and experimentally reported fungal phosphate uptake rates. Whilst both depletion profiles have support within the literature clearly, only one of them has to be correct. I will suggest a controlled experiment which has not yet been performed that can decide between the two scenarios. In the concluding section I will discuss different approaches on modelling whole plant nutrient uptake.

Keywords: plant-soil interaction, plant modelling, soil modelling, organic acid exudation

# RACINE2: A software application for processing spatial distribution of root length density from root intersections on trench profiles

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A field method has been developed to quantify root length density (RLD) from root intersection density (RID) measured on a trench-profile, using modelling RID-RLD relationships. For 2D spatial distribution mapping of RID (at 5-cm scale for example), the large amount of data is processed and converted into RLD and root distances (ARD) through modeling. Calculations and RLD mapping can be performed quickly using a new freeware: RACINE2*,* tailored to this field method. The software also allows a simple modeling of potential root exploration ratio in the soil (PRER) taking ARD into account. The software contains published models calculating RLD from RID for several crops (maize, sorghum, sugarcane, rice), ARD from RLD and PRER from RD. Models may be changed or added into RACINE2. RLD, ARD and PRER are calculated for each spatial unit. They can be mapped. Data can be exported to a spreadsheet or a surface mapping software for further analysis. It is also possible to import data into RACINE2 from a spreadsheet. RACINE2 thus makes studies about root-soil interactions, root growth and root uptake easier. Some examples of field results calculated by RACINE2 are presented (RLD, ARD and RER profiles and maps). They point out differences of PRER when taking (or not taking) into account 2D spatial root distribution. Taking into account spatial variability of root system in relation with soil characteristics may be important for root water and nutrient uptake in field conditions.

Keywords: Trench-profile method, Root study software, Root length density, Root distribution

# Modeling the root system of maize to predict water and phosphorus uptake

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Our aim was to develop a model for the dynamic simulation of root morphology and architecture. The model intended to support the identification of root traits maximizing the capture of resources from soil. The effects of mechanical constraints in the soil were implemented as well as the distribution, availability, uptake characteristics and dynamics of water and phosphorus. Maize was used as a model crop and the implemented model was tested using contrasting maize genotypes. The model predicted the response of root growth to mechanical soil constraints and the uptake of phosphorus reliably. We are currently testing and improving the model for water uptake.

# Comparison of nutrient uptake between an averaged root system model and true 3D simulation

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Simulation is an important tool when analysing the mechanisms within the rhizosphere. In this work we discuss the impact of individual roots and rhizosphere traits on nutrient uptake by a whole root system.

Due to the complexity of large root systems 3D simulations are often not feasible. Thus the use of up-scaling techniques such as averaging or homogenisation is of major importance. The scope of this work is to present a method that compares these approximations to true 3D simulations for small parts of a root system.

In order to obtain realistic 3D uptake models, root architecture models are coupled with soil models where the interactions between plant roots and soil are described by boundary conditions at the root surfaces. In averaged models, the root system uptake is represented by a sink term which is dependent on the local root length density. However, effects which are dependent on local root geometry like overlapping depletion zones are neglected. In order to estimate the error which is introduced by this simplification we compare the averaged root system model to true 3D simulation. For the dynamic root system growth we use a model based on L-Systems which returns segments of individual roots. We use the mesh generator Distmesh, which uses a force-based smoothing procedure to optimize the node locations, to obtain a finite element mesh of the geometry. The mesh is then imported in Comsol Multiphysics, a finite element solver for the solution of partial differential equations, to calculate nutrient uptake by a 3D root system.

Finally we discuss the differences of the simulated nutrient uptake by a whole root system as calculated by the averaged model and true 3D simulation.

# A split-pot experiment with sorghum to test a root water uptake partitioning model

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Correct modeling of root water uptake partitioning over depth is a relevant issue in hydrological and crop growth models. We describe an experiment performed in split-pot lysimeters with sorghum plants. Both compartments were submitted to different irrigation cycles resulting in contrasting water contents. Observations of root water extraction were compared to matric flux potential based model predictions. Following model prediction, plants should prefer water uptake from wetter compartments according to the respective matric flux potential of both compartments, the root matric flux potential, and a root length density related parameter. In order to obtain reasonable agreement between model and experimental results, a correction factor had to be included accounting for heterogeneity of root length density and root activity as well as imperfect soil-root contact. Including this correction factor, model predictions of root water extraction were in reasonable agreement with observations. Release of water from roots to soil was observed on several occasions during the experiment, but model predictions it suggested a higher frequency and intensity than observed. This is probably due to not considering internal root system resistances, thus overestimating the ease with which roots can act as conductors of water.

Keywords: Root water uptake, split pot, root length density, matric flux potential

# Experimental and modelling studies of drought-adaptive root architectural traits in wheat

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Yield improvement in drought-prone environments based on selection for yield per se has been slow due to large genotype by environment interactions (G x E). In this paper, we present an interdisciplinary approach to crop improvement that links physiology with plant breeding and simulation modelling to enhance the selection of high yielding, drought-tolerant varieties for the water-scarce environments.

In a series of field experiments in Queensland, Australia, we found that the yield of CIMMYT wheat line SeriM82 ranged from 6 to 28% greater than the current adapted cultivar Hartog. Physiological studies on the adaptive traits underpinning this advantage revealed that SeriM82 and Hartog differ in root architectural traits. In large soil-filled chambers, SeriM82 had a narrower root system architecture and extracted more soil moisture per soil volume, particularly deep in the profile, late in the growing season when marginal water use efficiency (WUE) is high. To quantify the value of these adaptive root traits, we conducted a simulation analysis with the cropping systems model APSIM for a range of rain-fed environments contrasting in soil water-holding capacity in southern Queensland using long-term historical weather data. The analysis indicated a mean relative yield benefit of 14.5% in water-deficit seasons and that each additional millimetre of water extracted during grain filling generated an extra 55 kg $ha^{-1}$ of grain yield. Further root studies of a large number of current Australian and CIMMYT wheat genotypes in small gel-filled chambers revealed that wheat root system architecture is closely linked to the angle of seminal root axes at the

seedling stage - a trait which is suitable for large-scale and cost-effective screening programmes.

Overall, our results suggest that an interdisciplinary approach to crop improvement based on identification of root traits conferring tolerance to drought stress, evaluation of drought-adaptive traits in the target population of environments using simulation modelling, and development of simple and efficient screening methods is likely to enhance the rate of yield improvement in rain-fed crops in a changing climate.

# New methods for examining the effects of matric potential and root-soil contact on crop root growth and function

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This paper describes the effects of plant species, growth medium and matric potential on root elongation. Maize and lupin were grown in vermiculite and soil for 96 h at matric potentials ranging from −0.03 MPa to −1.6 MPa. Root elongation decreased with decreasing matric potential. Plants showed sensitivity to the growing medium. Root elongation of maize was greater in soil than in vermiculite at matric potentials greater than −1.6 MPa. X-ray computed tomography was used to investigate the root-particle contact of lupin and maize in vermiculite and soil. Greater root-particle contact was found in soil than in vermiculite, which might be correlated with a greater root elongation rate in soil.

Keywords: X-ray computed tomography, 3-D visualization, root growth, root-soil contact, matric potential

# Structural diversity of roots: The comparative analysis and modelling

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During 1985-2009, we compared morphological and anatomical specific features of underground organs in 900 plant species belonging to 6 divisions: Psilotophyta, Lycopodiophyta, Equisetophyta, Polypodiophyta, Pinophyta and Magnoliophyta. Root structure was compared in plant habitats in Ural mountains, in West, Central and East Siberia, and in Far East. In a number of russian botanical gardens, 767 introduced species were also investigated. To estimate common traits and the range of their variation in roots of these species, on cross sections under microscope we evaluated the variability of root anatomical traits, and then calculated variation coefficient (CV%).In roots with primary structure we measured the ratio of cortex to stele. In the case of secondary structure, we measured the sizes of periderm, phloem, wood and pith, and then calculated their proportions. Basing on root micro photos in computer, we have drawn their structural models. Their analysis permitted us to determine most stable, systematically important structural root features typical of plants belonging to the same taxons (divisions, classes), families and subfamilies. For example, for 4 species of the subfamily of Pyroloideae, a single common anatomical model of root structure was presented, although the plants were collected in 45 biocenoses located in european and asian regions of their areas. Due to quantitative evaluation of the variability of anatomical traits in species belonging to different taxons, we revealed the stability and systematic importance of the traits and constructed 137 structural models basing on microscopic examinations of root cross sections. Such modelling facilitates the insight into root structural commonness and diversity.

Keywords: roots, anatomy, intraspecific variability, structural model

# Poster Presentations

# Model based assessment of barley root ideotypes for breeding strategies in water limited environments

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A simulation study of root effects on barley biomass production under Austrian and Iranian climate conditions was performed using the DAISY model. In Iran deep rooting cultivars provide a general advantage for crop growth. In Austria a rooting depth of 70 cm was sufficient to realize the year specific growth potential. Above a threshold of around 350 mm rainfall, competition for assimilates between roots and shoots even resulted in a lower biomass production of deep rooting cultivars.

Keywords: drought, root ideotype, modeling, barley

# Depth and vertical distribution of roots in tropical maize inbred lines

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We need a better understanding about the distribution of roots in soil and the genetic variation available to alter this distribution. There is evidence that root traits are indirectly selected by breeders. For example, indirect selection for a deeper root system may improve drought avoidance (Hund et al., 2009) and even be related to historic yield increase (Hammer et al., 2009) in maize. We investigated a diverse panel of 33 tropical maize inbred lines for basic root characteristics. Leaf area increments did not increase beyond root elongation rates above 200 cm $d^{-1}$. Genotypes were separated into those with a relatively deep or shallow root system given their leaf area. This knowledge may be utilized to select model genotypes for the mapping of quantitative trait loci (see posters of Hund et al. and Reimer et al.) and for simulation studies (poster of Herter et al.).

# Root growth and leaching of nitrogen of catch crops – Results from a lysimeter project

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Following cereals, catch crops can reduce the leaching loss of nitrate ($NO_3$-N). In a three-year experiment a bare soil fallow and *Phacelia*, sunflower and a brassica catch crop succeeded spring wheat at two levels of nitrogen (N) input with the aim of investigating the relationship of $NO_3$-N leaching loss with the root growth, rooting depth and N uptake of catch crops and if these relationships depended on N input and years. The main N input was applied to the preceding spring wheat crop at 2 and 27 g N $m^{-2}$. Water percolation from the lysimeters and nitrate concentration in the leachate were measured on weekly intervals from the sowing until the harvest of the catch crops to calculate $NO_3$-N leaching loss. N uptake was calculated at the frost killing of the catch crops from biomass yield and N concentration. Minirhizotrons were used to assess the spatial and temporal patterns of root growth from 0.10 to 1.00 m. The time course of root length density and rooting depth were fitted to a logistic and a piecewise regression model, respectively. The parameters of these models and N uptake were studied by means of correlations to asses their relationship with $NO_3$-N leaching loss.

Catch crops species differed in N uptake, root growth and rooting depth. The brassica species were the most effective reducing $NO_3$-N leaching loss despite having intermediate N uptake. Fast growth of the roots in deep soil layers was the main characteristic of catch crops reducing $NO_3$-N leaching loss. Consequently, the parameters that indicated earliness of root growth associated relatively stronger and more consistently with $NO_3$-N leaching loss than N uptake or parameters that indicated static characteristics of the root system.

# Root halotropism? Salinity effects on Kochia (*Bassia indica*) roots

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Roots are responsible for the acquisition of nutrients and water from the soil, and possess an important role in establishing plant tolerance to stress conditions. Roots control their growth orientation by displaying differential growth (*i.e.* a tropism) in response to environmental cues such as gravity and water content. Gravitropic responses are widely studied; however other tropisms in roots have not been studied extensively. Salinity is a major environmental stress for plants in general and especially for roots that have major effects on the response of the whole plant. Our observations on root architecture of Kochia (*Bassia indica*), offer that roots may exhibit tropism cued by salinity ("halotropism").

We found Kochia roots in the field growing horizontally towards saline soil. In our greenhouse experiments Kochia plants were grown in 100 L pots with artificial soil salinity gradient, achieved by irrigation of saline and tap water. We found that roots grown in low or no salt areas were growing horizontally towards the salt gradient peak. In the salt peak area roots were growing vertically towards the salt. Plants growing in hydroponic solution showed higher growth rates in 80 mM NaCl compared to tap water. This study presents a novel finding of halotropism in which roots grow towards salt and seem to require salinity for growth.

Keywords: root tropism, halotropism, salinity, Kochia (*Basia indica*)

# Modelling rooting depth of trees in boreal forests

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We evaluated two nonlinear functions to estimate the tree rooting depth for incompletely sampled profiles. The functions were a hyperbolic curve, $Y = (Y_{max}\ X)/(K_d+X)$, and an exponential curve, $Y = Y_{max}(1-e^{-KX})$, where Y is the cumulative root biomass (g $m^{-2}$) at depth X (cm), $Y_{max}$ the fitted maximum root biomass, and $K_d$ and K parameters describing the form of the vertical root distribution curve. The functions were fitted to fine (<2 mm), coarse (2-10 mm) and total (<10 mm) tree root biomass data (g $m^{-2}$) from the organic, 0-5 and 5-20 cm layers of a Norway spruce dominated stand in eastern Finland (63° 51'N, 28° 58'E). Values for the mineral (till) soil layers were corrected for stone content (0.28 v/v) of the bulk soil. The fitted functions were used to calculate the depths at which 50% ($D_{50}$) and 95% ($D_{95}$) of maximum root biomass, $Y_{max}$, were achieved. Compared to the exponential model, the hyperbolic model gave higher $R^2$ (>0.9), $D_{50}$ and $D_{95}$ values for all three root diameter classes. $D_{95}$ values with the hyperbolic model averaged 75.7 cm while those with the exponential model averaged 14.3 cm. With both functions, $D_{50}$ and $D_{95}$ values were greater for fine roots than for coarse roots (by 21% and 35% with exponential and hyperbolic models, respectively). Such models can be used not only to describe the vertical distribution of roots but also to objectively estimate maximum rooting depths.

Keywords: root biomass, rooting depth, soil water use, curvilinear functions, modelling

# SESSION 7

# METHODS FOR ROOT OBSERVATION AND MEASUREMENT

Oral Presentations

# Measuring root system architecture: Opportunities and challenges

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Root architectural traits are important for the selection of crops and cultivars that are most efficient in the acquisition of nutrients and water from soil. Increasingly laboratory-based methods are being used to screen large numbers of plants and to measure selected architectural traits. Our research with temperate cereals demonstrates that while such methods may allow numbers of root axes and angular spread to be determined reliably, the ranking of other traits such as length may be markedly influenced by the growing medium. For example, root length of dwarfing wheat lines grown on agar plates was increased by about 40% relative to wildtype and semi-dwarfing lines, while in a sandy loam soil under well-watered conditions it was decreased (by 24-33%). Similarly while the ranking of particular growth traits (root number, root angular spread) of 5 barley genotypes grown in gel plates, soil sacs and small soil-filled pots was similar, those grown in gel chambers had a different order of ranking for root length to the soil-grown plants. Recent developments in x-ray microtomography have facilitated the 3D non-invasive measurement of small root systems grown in solid media allowing angular distributions to be obtained in addition to numbers and length. Developments in software and instrumentation mean that quantifying root architectural traits is becoming easier but the significant soil environment-genotype interactions mean that it is important to consider the typical soil conditions and stresses present in the environment where a crop is to be grown.

Keywords: barley, genotypic variation, root length, wheat, x-ray tomography

# How to statistically treat disappeared fine roots for longevity estimates from minirhizotrons

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Minirhizotrons, transparent acrylic tubes inserted in the soil, are well suited for long term, non destructive, *in situ* observations of fine roots. In minirhizotrons, the fine roots are regularly photographed and the root images are visually evaluated according to their status as living, dead or disappeared. This evaluation gives the background for further statistical treatment to estimate the fine root longevity. It is inherent in the minirhizotron technique that a large group of roots will be described as "disappeared" due to grazing, overgrowing by other roots, unclear images or other reasons. Because the fraction of disappeared roots is substantial in some cases, this has consequences for the interpretation of the longevity results.

We processed three years of minirhizotron images from Norway spruce stands in southeast Norway (30 yr old) and northern Finland (70 yr old). Of all processed fine roots 32 and 23 % was evaluated as disappeared in Norway and Finland, respectively. When roots labeled as disappeared were pooled together with dead ones, the fine root longevity estimates, using the Kaplan-Meier method, decreased almost by a factor of two (401 and 433 days), as opposed to labeling them as *censored observations* (770 and 777) days for Norway and Finland, respectively).

Here we demonstrate how the early decision making on the fine root status bears consequences on the resulting longevity estimates.

Keywords: fine root longevity, Kaplan-Meier survival analysis, minirhizotrons, Norway spruce, *Picea abies*

# Seasonal patterns of fine-root production and respiration of oak seedlings and dwarf bamboo

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Understanding the temporal pattern of fine-root dynamics is important for evaluating fine-root turnover and production. We separately examined the temporal patterns of fine-root production by oak (*Quercus crispula*) and dwarf bamboo (*Sasa veitchii*), which is the major component of fine-root biomass in a cool-temperate forest. We grew 5 oak seedlings and 5 *Sasa* stocks (*i.e.*, the rhizome and connected culms) in organic-free sand in rhizoboxes and then scanned roots that were visible through the sides of the rhizoboxes to measure the length of each root in the images. We defined the fine-root production rate as the total increase in root length measured during each observation interval. We also measured root respiration and whole-plant assimilation in a closed dynamic chamber system. Oak root production peaked in July, but *Sasa* root production peaked in both July and October. Soil temperature was highly correlated with oak root production, but less so with *Sasa* root production. Leaves of *Sasa* expanded in late summer, and the photosynthetic rate of *Sasa* was highest in September, suggesting that aboveground phenology influences the seasonality of fine-root production. The timing of oak root production was synchronized with root respiration, and the root respiration rate increased exponentially with increasing soil temperature. These results demonstrate different temporal patterns of fine-root production by oak seedlings and understory species (*Sasa*), even under similar environmental conditions.

Keywords: oak, understory vegetation, *Sasa*, fine-root production, root respiration, rhizobox

# Assessing the root-soil contact in biopores

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Biopores are preferential ways for root growth in the subsoil, especially due to reduced mechanical resistance. In case of biopores formed by anecic earthworms, biopore walls are often covered with linings rich in soil organic matter and nutrients. However, it remains unclear, to which extent roots penetrate the drilosphere and exploit the nutrients stored therein. Precise quantification of the contact area between roots and soil in biopores is of particular interest for future modelling of nutrient uptake from subsoil.

Observations of roots growing in biopores undertaken with "classical" destructive methods, such as the profile wall method, suggest that roots often grow within the biopore lumen without touching the biopore wall. However, these findings may be based on dislocations of roots by excavation tools and therefore displaying artefacts. We suppose that the use of minimum-invasive imaging *in situ* techniques based on endoscopy can extend our knowledge on the soil-root interface. Preliminary endoscopic investigations were undertaken in a field experiment on a Haplic Luvisol from loess (loamy silt; Klein-Altendorf near Bonn, Germany). Continuous biopores below the plough-layer were excavated by removing topsoil down to 30 cm soil depth and visually investigated using a flexible videoscope with an outer diameter of 3.8 mm. We were able to differentiate four categories of root segments growing in biopores: (1) vertical without contact to the biopore wall, (2) vertical in contact to the biopore wall, (3) lateral branching from vertical roots and (4) entering the biopore horizontally from the bulk soil.

Keywords: endoscopy, root-soil contact, biopores, nutrient uptake

# High resolution determination of soil solution phosphorus concentrations in the vicinity of *Brassica napus* L. roots

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Modelling of the dynamics of phosphorous uptake shows that its gradients within the rhizosphere are very steep, making their determination challenging, as high spatial resolution is required. Major constraints include the difficulties of sampling extremely low volumes at defined localized positions. The diffusive gradients in thin-films (DGT) technique can potentially overcome these problems. High resolution (sub-mm) measurements of ion concentrations in sediments have already been performed using this method. In the present work it is applied to rhizosphere soil adjacent to plant roots. Brassica napus L. plants were grown in rhizotrons to obtain roots growing directly on the surface of a soil block. When several roots were visible at the soil surface, rhizotron cover plates were removed and Fe-oxide DGT gels were applied onto the soil surface. The layered gel sheets were placed so that they directly overlaid vital roots and the adjacent rhizosphere soil. After removal, DGT binding gels were dried and analyzed for P contents by LA-ICP-MS. P concentrations at the soil-gel interface (CDGT) and effective soil solution P concentrations (CE) were calculated for each ablation spot. Photographic images of the roots and the soil surface subjected to sampling were overlaid by CDGT and CE concentration maps. By these means, soil solution P concentration gradients in the rhizosphere were visualised and quantified for the first time at submillimeter resolutions. Knowledge of soil solution P concentrations in close vicinity to roots provides a better understanding of nutrient uptake processes and can be used directly to test and refine mathematical models of nutrient acquisition by plant roots. The method presented here for the determination of solute concentrations in the rhizosphere is not restricted to phosphorus. It

should be applicable to all elements that can be sampled using DGT and measured by LA-ICP-MS.

Keywords: rhizosphere, soil solution, phosphorus, DGT, LA-ICP-MS

# PlantVis: A new software tool for analysis of root growth dynamics

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Root growth is highly dynamic and responds quickly to changes in environmental conditions. Using a combination of confocal laser scanning microscopy and *Arabidopsis thaliana* genotypes expressing a plasma membrane targeted GFP, growth associated motion can be captured in short time-lapse image datasets (e.g. at 1 min intervals). We have developed a new image analysis software tool (*PlantVis*) to estimate displacements at pixel locations in these images to 0.1 pixel resolution, including a confidence measurement for each estimation.

Analysis of the *PlantVis* output using the statistical package R, allows extraction of biologically meaningful information. For example, motion estimates can be calculated relative to the central axis of a root and can be presented graphically as motion at specific distances along the root from the quiescent centre. Furthermore, the length of the division and elongation zones, and the position of maximum expansion can be calculated for individual datasets. Finally, depending on the magnification used during microscopy, elongation can be estimated for individual cells.

Using this methodology we have imaged and analysed root growth under a range of growth conditions, for example with differences in carbon supply and different physical conditions. Currently we are exploring the interaction of roots with their physical environment using glass ballotini beads that impose different physical stresses on the elongating roots.

Keywords: PlantVis, cell expansion, elongation, confocal microscopy, motion, root

# Digital image analysis: Simplifying quantification of traits for root morphology and architecture for different sorghum varieties

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Rhizotrons are effective for screening traits of root morphology and architecture prior to field experimentation. The objectives of this study were to improve the Rhizotron method by comparing digital imaging of root systems with conventional root scans and to apply it to five different sorghum varieties. Plants were grown in duplicate in inclined, slim rhizotrons filled with a sandy top and subsoil at field capacity (FC) and 50% available water content (AWC) in a split-plot design in the glasshouse (16/24 °C). Root growth was monitored weekly and roots were washed out after 42 and 90 days using a pin-board (25 mm grid). After digital imaging of the root architecture the roots were sub-sampled for scanning with WinRHIZO to quantify the baseline root parameters. Undisturbed rhizotron images showed differences in root advancement rates but revealed little of root architecture. Digital images of increasing resolution (9.1 to 12 Megapixel) and optimized contrast between roots and background, improved the recovery rate of scanned roots from <50% ($r^2$=0.12) to >70% ($r^2$=0.70). Root size distributions from pin-board images moved towards larger root diameters when compared to the root scans. Sorghum varieties bred for rainy and post-rainy season showed very different rooting patterns (angle of adventitious roots; root distribution in the profile) but similar root development (1$^{st}$ and 2$^{nd}$ order roots). Further analysis, e.g. links and development, using the permanent records of pin-board images, is discussed.

Keywords: Digital image, Root morphology, Root architecture, Sorghum, Rhizotrons

# Dynamics of air gap formation around roots with changing soil water content

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Most models regarding uptake of water and nutrients from soil assume intimate contact between roots and soil. However, it is known for a long time that roots may shrink under drought conditions. Due to the opaque nature of soil this process could not be observed in situ until recently. Combining tomography of the entire sample (field of view of 16 x 16 cm, pixel side 0.32 mm) with local tomography of the soil region around roots (field of view of 5 x 5 cm, pixel side 0.09 mm), the high spatial resolution required to image root shrinkage and formation of air-filled gaps around roots could be achieved. Applying this technique and combining it with microtensiometer measurements, measurements of plant gas exchange and microscopic assessment of root anatomy, a more detailed study was conducted to elucidate at which soil matric potential roots start to shrink in a sandy soil and which are the consequences for plant water relations. For *Lupinus albus* grown in a sandy soil tomography of the entire root system and of the interface between taproot and soil was conducted from day 11 to day 31 covering two drying cycles. Soil matric potential decreased from −36 hPa at day 11 after planting to −72, −251, −429 hPa, on day 17, 19, 20 after planting. On day 20 an air gap started to occur around the tap root and extended further on day 21 with matric potential below −429 hPa (equivalent to 5 v/v % soil moisture). From day 11 to day 21 stomatal conductivity decreased from 467 to 84 mmol $m^{-2}$ $s^{-1}$, likewise transpiration rate decreased and plants showed strong wilting symptoms on day 21. Plants were watered by capillary rise on day 21 and recovered completely within a day with stomatal conductivity increasing to 647 mmol $m^{-2}$ $s^{-1}$. During a second drying cycle, which was shorter as plants continuously increased in size, air gap formed again at the same matric potential. Plant stomatal conductance and transpiration decreased in a similar fashion with decreasing matric potential and appearance of air gap as during the first

cycle. Microscopic assessment of the tap root at day 31 showed that secondary thickening of the taproot occurred all along the region of interest observed during X-ray tomography. A large part of the cross sections consists of lignified tissue; no root hairs could be observed along the tap root. Gaps are expected to reduce water transfers between soil and roots. Opening and closing of gaps may help plants to prevent water loss when the soil dries, and to restore the soil-root continuity when water becomes available.

# 3-D modeling of tree root systems – a fusion of 3-D laser scans and 2-D tree-ring data

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Most studies addressing woody plant roots deal specifically with geology, topology or biomass approximations, and estimations for root biomass remain particularly rough. To address questions such as what role tree roots play in the carbon budget, accurate estimates of root biomass are essential. Biomass models that include information about root development through time are also needed, as most biomass models represent only the present state of a tree's developmental stage. The aim of this study is to develop an annually resolved 3-D growth model for tree root systems. A 3-D surface model of a root system was first captured, and then combined with tree-ring width data. Different scanning methods, including terrestrial laser scanning, Scan-Arm and Inhand-scanning, were used and evaluated as devices to acquire a 3-D image of the root surface. Once the root surface was successfully modelled, we calculated root volume with a volume-computation algorithm. Moreover, a first attempt to add age information to the 3-D surface model by integrating tree-ring data was made. The accuracy of the volume calculations for the surface models varies depending on the complexity of the scanned objects, the used scanner type and the modelling techniques. While volume computations for simple shapes (e.g., cylinders) differed by less than 5 % from the actual volume the calculations for complex root structures differed by up to 15 %. The most accurate root model differed by < 5 %. The first models demonstrate that distances can readily be surveyed within the models using point to point computations. Hence, root length and distribution patterns can be measured virtually and no longer need to be performed manually. In addition, surface models with integrated ring borders enable reconstruction of root development and provide additional information on bifurcation and root length patterns.

Keywords: laser scanning, root development, root biomass, tree rings

# Detection of buried tree root samples by electrical measurements

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Trees growing on earth dikes generate safety problems and reduce dikes durability. Root systems generate internal and external erosion risks which can be important on wooded dikes. The aim of this study was to differentiate various root samples of trees rooted in dikes by geo-electrical measurements.

Before proceeding to roots detection in situ, it is necessary to make tests in laboratory. The objective of this experiment is to characterize exactly the electrical signal of buried roots according to root samples orientation and depth and to materials type.

Root samples were buried in plastic boxes in different type of dyke materials. Electrical conductivity measurements were carried out on buried root samples with their complete structure.

Keywords: earth dikes, root samples, detection, electrical measurements

# Poster Presentations

# Fine root biomass and dynamics in a mature broad-leaved deciduous forest differing in tree species composition

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In this project we want to analyse effects of various tree species compositions on fine root biomass and root growth in a mature broad-leaved deciduous forest of the Hainich National Park (Thuringia, Central Germany). In order to investigate effects of tree species identity on the fine root system, we selected 100 study plots ("tree clusters") consisting of three canopy tree individuals in the forest area. The clusters consist of one, two or three different tree species. Tree species included in this approach were *Acer pseudoplatanus, Carpinus betulus*, *Fagus sylvatica, Fraxinus excelsior* and *Tilia cordata*. All possible species combinations (25 options) were realised and each combination had four replicates.

We conducted an inventory of fine root biomass (< 2 mm in diameter), at three different sampling dates. The various tree species were distinguished by morphological attributes. Furthermore, we investigated differences in fine root morphology among the species.

This poster presentation will give an overview on the study approach and preliminary results.

Keywords: fine roots, mature broad-leaved deciduous forest, biomass

# Vitality and turnover rates of tree fine roots affected by competition and drought

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Roots and their turnover play a vital role for individual plant growth, the interaction and competition between different tree species and the carbon and nutrient cycle in the soil. However the dynamics of fine root turnover are not fully understood. Our project analyses the interactions of beech *(Fagus sylvatica* L.) and ash *(Fraxinus excelsior* L.) in the rhizosphere. In particular the relation between longevity, branching order and nutrient availability of fine roots will be explored. The poster will present the methods used in the project and preliminary results. Methods include a container experiment with beech and ash. By using the minirhizotron technique, we monitor the roots over selected time intervals. Thereby the longevity and mortality of fine roots can be viewed and compared through image analysing. The above-and belowground biomass production will be determined annually. In an additional microcosm experiment with an integrated split root system we will trace the C- and N-allocation and partitioning with stable isotopes marked leaf litter. Small rhizoboxes serve as a tool to implement competition and manipulation experiments. Biochemical tests in comparison to morphological analyses are applied to investigate root vitality and turnover. Thus the allometric relationship between fine root diameter, branching order and metabolic activity is investigated. Another drought and nitrogen experiment is established in the Gottingen Rhizolab. The rhizolab is an outdoor laboratory with eight containers of 8 $m^3$ volume each covered with a mobile roof, which excludes rainfall. Minirhizotrone tubes are installed horizontally in several heights. The 3 year old trees are supplied with different water and nitrogen concentrations. The outcomes of the project will help to understand the dynamics of root turnover, the parameters affecting the lifespan of roots and the complexity of the rhizosphere dynamics.

Keywords: fine roots, turnover rates, minirhizotron, rhizobox, split root system, drought

# Spatial root interaction of maize and two important weed species

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Roots are essential for growth, survival and fitness of plants. Most often roots of different plants share a certain soil volume, for example when weeds establish within a crop canopy. The study of the co-location of roots in such plant mixtures is, however, not trivial, because it is not easy to assign single roots to the respective plants. To overcome this limitation, we conducted an experiment in which one transgenic line of maize (*Zea mays* L.) expressing the green fluorescent protein (GFP) was grown together with either redroot amaranth (*Amaranthus retroflexus* L.) or lambsquarters (*Chenopodium album* L.). We used minirhizotrons (*i.e.* transparent tubes installed in the soil) and a suitable imaging system to detect those roots which are fluorescing, to screen the roots of the plant species being grown in each mixture and to classify them as maize or weed roots. The approach was suitable for studying how maize and the selected weed species interact in a shared soil volume. Preliminary results indicate that the number of roots of maize was significantly reduced by the presence of weeds. Furthermore, the effect of maize on the number of roots of the weeds was the opposite of that on shoot biomass; it increased for lambsquarters, whereas it decreased for redroot amaranth. The results suggest a different competition strategy of redroot amaranth than maize and lambsquarters.

# Electric capacity as a measure of the intact root system size in the soil

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When alternate electric current is put into the soil where a plant is growing and the second electrode is linked to the basal part of the plant and electric capacity measured then its size is positively related to the root system size (RSS). The measuring current frequency is 1 kHz (Chloupek, 1977; Dalton, 1995).

Comparable is only RSS:

- Of plants of the same species – RSS of different species are not comparable.
- When measured in the same time.
- In the same substrate (soil, hydroponics etc.).
- When the same instrument preset on measurement of parallel capacity is used.
- When the aerial part of the measured plants is dry.

The relation between RSS and its electric capacity is obvious from:

- The significant correlation between the electric capacity of the root system and its weight, volume and surface - not only in our experiments.
- Higher yield of varieties with greater RSS in dry environment (barley and wheat).
- The reaction of plants on drought which was similar as the reaction on small RSS (lower content of starch and higher content of nitrogen substances in barley and wheat grain). However the measurement cannot evaluate distribution of the RSS in soil profile.

Keywords: Root system size (RSS), electric capacity, barley, wheat

# Green fluorescent protein (GFP) - A tool to identify roots in mixed plant stands

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Although roots take up most of the resources required by the plant, the lack of efficient research tools hinders the understanding of the root system. This is even more evident when research focuses is not on the single plant but on plants, which share the same soil resources. None of the available methods enables the desired simple, inexpensive, and objective assignment of the observed roots to a target plant in a mixture. Here we demonstrate that transgenic plants expressing the GFP, combined with the minirhizotron technique, are the key to overcoming the methodological limitation to investigate root interactions in situ. We planted transgenic maize (Zea mays L.) together with either its corresponding wild type or Italian ryegrass (Lolium multiflorum Lam.). The fluorescence enables the observation of the relative distribution of the roots of each plant type and, thus, their interaction with each other. The selected plants are suitable for model experiments to unravel fundamental belowground ecological processes. Because the genetic transformation of plants is an established technique, which can be applied to a large set of plant species, this method is of wide scope.

Keywords: root interactions, green fluorescent protein (GFP), root research methodology, plant communities

# Methods for wheat root observation in field conditions

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Principal methods to study root system of a winter wheat crop in field conditions are reviewed. Methods observations of root system after sampling are also presented. The method for study wheat root system actually developed at Gembloux to conduct a PhD research is detailed.

# The role of plant roots in formation of soil humus

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The bulk volume of rhizospheric soil (soil penetrated by plant roots) under individual tree can occupy up to 3-10 $m^3$. However, the bulk volume of soil in immediate contact with plant roots constitutes only 1-6% of the bulk volume of a soil layer. Only a thin layer of soil, not more than 3-5-mm thick, is capable of interacting with roots. Only in this soil layer one can observe the immediate effect of plant roots on soil properties: humus formation, lower content of nutrients and some acidification of the substratum. In a larger bulk volume of rhizospheric soil, the effect of roots on soil properties is neglectable. Therefore, such soil characteristics as pH, content of humus and the sum and composition of exchangeable cations do not correlate to the mass of plant roots, including any of their fractions.

Keywords: plant roots, humus formation

# Analysing of fine root growth from digital images

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In this study, we developed new techniques that analyze continuous scanner image of roots in order to determine characteristic of fine root growth in a forest ecosystem. In our method, the growth of fine root is detected by temporal changes of pixel color information in the root images. Growing speeds and direction of fine root tips was extracted semi-automatically using commercial software.

Keywords: fine root, image analysis, *Quercus serrata,* root growth, tracking

# Mapping QTLs for root morphological traits in durum wheat

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Durum wheat (*Triticum turgidum* L. var. *durum*, 2*n*=4*x*=28, AABB) is an economically and nutritionally important cereal crop in the Mediterranean region and its production is largely influenced by environmental stresses, such as drought, heat and nutrient deficiency. Roots are an important part of the plant architecture that is involved in foraging for the available water and nutrients in the rhizosphere. A deep and thick root system is generally considered as a more favourable element allowing the crop to maintain its water status even under water stress. Nonetheless, little is known about the molecular and genetic basis for root growth in durum wheat. The availability of molecular marker technology has provided plant breeders with a new set of tools to evaluate plant diversity at a DNA level. In the present study, chromosome regions involved in the control of root architecture were investigated by testing a recombinant inbred lines (RIL) population consisting of 123 $F_{8:9}$ lines derived from the cross between two durum wheat varieties (Creso and Pedroso) contrasting for root traits. The genetic map comprised more than 500 molecular markers spanning greater than 1800 cM. QTL analysis showed that a relatively limited number of chromosome regions were involved in the root morphology. The most relevant regions were identified on chromosome 2A, 6A, 5A and 1B for traits related to length, area and volume of roots.

Keywords: Durum wheat, Root morphology, QTL, Recombinant inbred lines

# Use of near-infrared reflectance spectroscopy to predict the percentage of dead versus living grass roots

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We tested the potential of near-infrared reflectance spectroscopy (NIRS) to predict the percentage of dead versus living roots of five grass species grown in monocultures in container and in a grassland community in field condition. Root death was induced after total severance of aboveground vegetation according to Picon-Cochard et al 2009. Root samples were collected immediately after this treatment to obtain predominantly live roots (L), and dead roots at three dates: T0, T1 and T2, corresponding to date of aerial cut, one and two months after the cut, respectively. NIRS spectra of live and dead roots were compared with measurements of root vital coloration, root and soil respiration and minirhizotron. These results show the potential of NIRS to predict the percentage of dead and live roots for grass monocultures and for a grassland community in field conditions and open up new opportunities in estimating more accurately below-ground net primary production of grasslands.

Keywords: grassland, NIRS, root mortality, vital coloration, root and soil respiration, minirhizotron

# Root sampling and analysis in lucerne (*Medicago sativa L.*) field trial

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Use of reliable method for estimation of root biomass is crucial in organic farming system. The main objective of this study was to compare two common root sampling methods using soil corer (9 cm diameter) and soil monolith (12.5 cm wide) in order to determine their suitability for estimation of root biomass. A randomized block experiment with four replicates was carried out on organically managed fields at Raasdorf, Eastern Austria, for two consecutive years (2007 & 2008). Root biomass of Lucerne cultivar Sitel was determined in the top 30 cm soil layer. With the soil corer, two samples were taken per plot, one sample on the row and one between the rows. Calculations of root biomass were based on the percentage of "on" and "between"-row area. Monolith samples were taken from each of the harvest areas per plot integrating over the whole "on" and "between"-row area. Results revealed that the root biomass differ significantly ($P \leq 0.05$) due to the sampling method, and it also differed significantly ($P \leq 0.05$) between the two years. The soil monolith method yielded slightly more root biomass than the soil corer method in both years, suggesting its better suitability for estimation of root biomass in large field experiments.

Keywords: Lucerne, Root biomass, Soil Corer, Soil Monolith, Sampling methods

# Livestock identity effects on belowground biomass, fine root morphology, and nitrogen allocation in pastures differing in species diversity

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In Europe, extensively managed semi-natural agricultural meadows count among the most species rich ecosystems. Over the last 50 years, a decline of these important habitats occurred due to land use intensification. Much research focusing on the relationship between biodiversity and productivity demonstrated a positive influence of species richness on aboveground productivity, nutrient retention and ecosystem stability. These positive biodiversity effects could occur via complementary resource use (e.g. by different rooting depths) and by different disturbance responses. Most research has focused on aboveground biodiversity effects ignoring the root compartment despite its importance for water and nutrient resource uptake. We investigated the impact of different livestock identities (cattle, sheep, cattle & sheep) on belowground biomass and nitrogen allocation as well as fine root morphology within two biodiversity classes in mesothrophic pastures. Biomass and nitrogen concentrations in the aboveground parts of the plants was measure from 6 grazed plots per treatment. Root samples (< 2 mm and > 2 mm in diameter) were taken from two soil depths (0-10 cm, 10-20 cm) to investigate the specific root length and the root length density as well as the root nitrogen concentration was measured. For four target species, additional analyses of specific root length and tissue density were conducted. Although aboveground biomass was reduced up to 80 % by livestock grazing, belowground biomass was not reduced as compared to ungrazed control plots in high diversity pastures. In the low species diversity treatment, sheep grazing significantly reduced belowground biomass. Fine root C/N ratio was lower in grazed than in not grazed plots and higher in the upper soil depth. Sheep grazing led to higher specific root lengths but fine root tissue densitiy was not affected by livestock identity.

Keywords: grassland, shoot/root ratio, fine root morphology, nitrogen, biodiversity

# Tree and understorey fine root growth and longevity in a Norway spruce stand in northern Finland

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Tree and understorey fine root growth and longevity were determined by minirhizotron (MR) research in northern Finland. The study was made in a 70-year-old Norway spruce stand, growing on a mesic mineral soil site in the Kivalo experimental forest. Three replicate plots were established, and three vertical and two horizontal MR tubes installed in June 2003 in soil of each of the three plots. The images were taken at monthly intervals (altogether 11 sessions) during the growing seasons 2004, 2005 and 2006. The lengths, diameters and status (new, living, dead, disappeared) of Norway spruce fine roots and understorey (mainly shrub) fine roots and rhizomes were recorded. For both trees and understorey, the frequency of new born roots was comparatively higher in the first two growing seasons (2004 and 2005) after the tube inserting, and then considerably decreased in 2006. The primary reason may be root growth stimulation by cutting them by soil coring for tube inserting. Another contributing factor may be that roots growing into the limited space between the MR tube wall and soil the first years left little space for new roots in the following years. Root elongation rate was highest during late summer and early autumn. The reason for reduced root growth during shoot elongation is possibly attributed to greater carbon demand by the canopy, and reduced carbohydrate translocation to the roots. Both for horizontal and vertical tubes, the overall means of root elongation rate in all plots was slightly higher for understorey roots/rhizomes than for tree roots. Tree and understorey roots did not differ much in their longevity, disappearance and decomposition duration, and are not affected by either soil depths or the tube placement (horizontal and vertical tubes). The mean root longevity, time from emergence to death, was 14-16 months. Roots of both trees and understorey born in 2004, one year after installing the tubes, died and

disappeared proportionally more within a year than roots born in 2005. Also, root longevity was lower for those roots which were born in early summer (June 2004) than roots born later (July and August 2004). We observed a large number of living roots disappearing without being dead, sometimes only after a few months after they were born. Root decomposition (duration from death to disappearance) ranged from 4.6 to 7.4 months for trees and from 3.2 to 6.1 months for understorey, the longer durations involving one winter period.

Keywords: fine root, longevity, death, disappearance, minirhizotron, Norway spruce, understorey

# No-tillage direct seeding cultivation in rice with single basal application of controlled release fertilizer in poorly drained paddy soil

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No-tillage direct seeding cultivation of rice using single basal application of controlled release fertilizer (CRF) is efficient to reduce labor costs and environmental degradation in poorly drained paddy soils. The nitrogen release patterns of CRF are synchronized with the growth rate of the crops, and the recoveries of CRF by the crops are considerably higher compared with rapidly available fertilizer (RAF). Therefore, sufficient amount of CRF for the entire growing season can be applied together with seed (so called, "co-situs application"). The objective of this study is to investigate growth characteristics and yield of rice plant grown under no-tillage direct seeding culture with single basal application of CRF.

Keywords: Controlled release fertilizer, No-tillage direct seeding cultivation, Recovery rate of fertilizer, Rice, Root, Seedling

# Methods for thresholding minirhizotron root images

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An approach to thresholding root images taken from minirhizotrons was tested on maize, based on the decomposition of an image into N sectors. A range of luminance thresholds was tested for binarizing each sector, and the most suitable depended on root age, whereas the best correlation between manual and automatic measurements of roots was obtained with N=64. At this level of fragmentation, the best threshold was also determined automatically by maximizing between-groups variance when luminance distribution was divided into two pixel groups, without achieving improvements in analysis. However, this last approach can work as the basis for a method which approximates an image histogram as the sum of two weighted normal distributions, one for background and one for roots.

Keywords: minirhizotrons, image analysis, local thresholding, luminance distribution

# Ground penetrating radar can detect roots of *Pinus thunbergii* in a coastal forest

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According to the Kyoto protocol, root biomass of forest trees must be evaluated to determine carbon storage in forest ecosystem. Recently, non-destructive method using ground penetrating radar (GPR) can be used to detect coarse roots of forest trees. However, the successful application of GPR in root detection has been site specific and we still need to clarify which site conditions are available for root detection using GPR. The experiment was carried out in a coastal forest of 10-yr-old *Pinus thunbergii* grown in coastal sandy soils. Three 1 × 4 m plots were set and three transects 4 m long were established in each plot. Radar profiles were collected along transects using a field-portable GPR system with a 1.5-GHz antenna. After GPR scanning, the vertical distributions and diameters of all roots were recorded down to a depth of 30 cm. We clearly detected more than 70% of the roots greater than 10 mm in diameter but only 6% of the roots less than 10 mm. These results support the previous results that can be detected roots greater than 5 mm in diameter but the detection rate of these sized roots is only about 20%.

Keywords: ground penetrating radar, *Pinus thunbergii*, root biomass, root distribution, coastal forest

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