P7 - Plant responses to Belowground Stresses

P7.1

Root adaptations to waterlogged soils: internal aeration and nutrient acquisition

Timothy D Colmer (University of Western Australia)

Waterlogging impedes oxygen movement into soil, so that roots become oxygen deficient. Potentially-toxic reduced soil constituents can also accumulate during waterlogging. Internal oxygen transport, via root aerenchyma, is crucial for waterlogging tolerance. Dryland species suffer damage during waterlogging; formation of adventitious roots containing some aerenchyma can only partially compensate for the damaged seminal root system. Oxygen movement via aerenchyma in adventitious roots enables some growth and nutrient uptake in dryland species (e.g. wheat). Many waterlogged soils are also saline; root aeration is essential for maintenance of K/Na selectivity. Wetland species (e.g. rice) form a large adventitious root system. In addition to extensive aerenchyma, roots of many wetland species also contain a barrier impermeable to radial oxygen loss (ROL) in basal zones. The aerenchyma and ROL barrier act synergistically to enhance oxygen diffusion to the root apex. Such oxygen movement would promote root growth and nutrient uptake, enabling productivity of wetland species in waterlogged soils.

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09:05 Saturday 3rd July 2010

P7.2

Drought and water stress of crops: a look at the soil-root system interplay

Claude Doussan (INRA - EMMAH), Srayeddin Iyad (INRA - EMMAH)

Climate change may induce in parts of the world a decrease of rainfall. Such a change is already at work in the Mediterranean region where a decrease in rainfall rate seems to have started 40 years ago. Likewise, drought and particularly extreme drought could increase in a near future, like the 2003 heat and drought wave over Europe. As a consequence, rainfed crops or natural ecosystems will be more often drought stressed but, also, irrigated crops because of the increasing pressure over renewable water resource. There is always a need to increase the efficiency of water uptake by plants. In the different components of water efficiency of plant or crop, the soil-root system is less known and much remains to be gained in the efficiency of water use by a better knowledge of the soil-root system interplay.

With experimental data of two crops, Maize and Sorghum which exhibit different susceptibility to drought stress, we will show the difference in development of root systems of the two crops in conjunction with water use for variable water stress levels. Some emphasis will be given to the spatial variability of uptake, with the use of new imaging techniques like Electrical Resistivity Tomography. We will conclude by a look on new experimental or modelling avenues that could be helpful in improving our knowledge and optimisation of crops (and soil) in facing drought stress.

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P7.3

Pushing through hard soil - do root hairs grip the soil and aid root penetration?

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Mechanical impedance to root growth is often the major physical limitation to root growth in soil, as suggested by recent surveys of soil physical properties and seedling assays of root growth in Scotland. Roots often exploit cracks and biopores present in the soil, but are then faced with penetrating the bulk soil - for example, at the base of a loose seedbed. Root hairs serve a major role in improving root-soil contact, and enabling water and nutrient uptake. In this talk we consider the pressures exerted by root tips during soil penetration, the tensile strength of root hairs, and the possibility that root hairs provide significant mechanical anchorage to enable root tip penetration. We performed experiments using a hairless root mutant to test whether the presence of root
hairs enabled maize roots to penetrate soil after growing down artificial biopores (2mm diameter). Root mutants elongated approximately 25% slower than the wildtype roots in the absence of any physical impedance. When grown in biopores in relatively loose soil (dry bulk density, 1g/cm\(^3\)), mutant roots tips penetrated only 3 mm into the soil below, as compared with 12 mm for the wildtype roots. In dense soil (1.5 g/cm\(^3\)), root penetration was about 1mm for both wildtype and mutant roots. Where root elongation exceeded root penetration, seedlings were forced out of the soil - this was particularly the case for the hairless roots, suggesting that root hairs can afford significant mechanical anchorage for roots growing within biopores, so aiding root growth and penetration.

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P7.4

Inositol-Phospholipid signaling coordinates plants adaptation to environmental stress: from stress perception in plasma membrane to gene expression in the nucleus

Alex Levine (The Hebrew University of Jerusalem)

Plants have remarkable ability to adapt to adverse environments. Adaptation involves removal of multiple proteins, lipids and other macromolecules from their locations and replacement with new, better suited ones. The process involves multiple metabolic alterations that require coordination between gene expression and trafficking to final destinations. The plasma membrane constitutes first barrier to outside conditions. It is ideally positioned for stress perception and inwards signaling. Phospholipids, particularly phosphatidylinositides (PtdIns) were shown to regulate intracellular signal transduction by phosphorylation of specific sites in the inositol ring by specific kinases and phosphatases. We studied the role of PtdIns 5-phosphatases (At5PTases) in salt and drought stress, using reverse genetics. From 9 mutants tested, only At5ptase7 was sensitive. Surprisingly, it was tolerant to osmotic stress. Analysis of stress responses showed reduced accumulation of reactive oxygen species and Ca\(^{2+}\) in cytosol and nucleus in At5ptase7. Mutants also showed decreased endocytosis and expression of salt-responsive genes. Subcellular localization of At5PTase7 showed it in plasma membrane and nucleus, in line with locations of above activities (ROS production, endocytosis, gene expression). In summary, our results reveal a major stress signaling pathway that involves inositol lipids. Regulation of abiotic stress responses by phosphatidylinositol 5-phosphatases, described here, is associated with phosphatidylinositol 3-kinase activity, described before, further supporting the role of inositol lipids in stress responses. Taken together, our results suggest that the phosphatidylinositides coordinate different responses to salt and osmotic stress on several levels: by affecting ROS production, endocytosis and gene expression, through regulation of membrane and protein trafficking.

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P7.5

A new screening method identifies genetic variation in root response to salt and water stress

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Salinity as well as drought are increasing problems in agriculture. Durum wheat is relatively salt sensitive compared to bread wheat, and yields poorly on saline soil. Field studies indicate that roots of durum wheat do not grow as deep as bread wheat in saline soil. In order to look for genetic diversity in root growth within durum wheat, we developed a screening method to identify genetic variation in rates of root elongation in saline solution. Plants were grown in rolls of germination paper (25 x 38 cm) with a gradient of increasing salt concentration from base to top. Rolls were placed in PVC tubes 37 cm tall, with salinity at the base ranging from 50 to 200 mM NaCl, with complete nutrients. Seedlings were grown for 5 days in the light to the two leaf stage, and transpiration and evaporation were minimised so that the salinity gradient was maintained. NaCl concentrations of 100 mM or 150 mM were found a suitable salinity to differentiate the elongation of the seminal roots of the genotypes. These correspond to a level of salinity in the field that reduces growth 50% or more. Significant genetic variation was found. This method can be extended to other species to identify variation root elongation in response to salinity or water stress.

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P7.6

Response of the halophyte Atriplex nummularia to non-uniform root zone salinity

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Salinity in soils is often heterogeneous, yet the physiology of halophytes has typically been studied in media with uniform salinity. We examined the growth and physiology of the halophyte *Atriplex nummularia* when exposed to non-uniform salinities in the root-zone. 6-week-old cuttings were exposed either to uniform (10, 500 or 1500 mM NaCl) or non-uniform salinities (one half in 10 and the other in 500 or 1500 mM NaCl). Shoot growth was severely inhibited by 1500 mM NaCl when applied to both root halves. By contrast, in both non-uniform treatments, shoot dry mass was similar to that of control plants (uniform 10 mM NaCl). In the non-uniform treatment 10/500, root dry mass was no different from that of uniform treatments at 10 and 500 mM NaCl. However, with 10/1500 there was an increased allocation (1.5-fold) of dry mass in the low NaCl side. Despite most water being taken up from the low salinity side, in both non-uniform treatments, a reduction in stomatal conductance was observed, and such reduction was more pronounced at 10/1500. Midday water potentials in non-uniform treatments were similar to those of control plants but leaf osmotic potential became more negative due to solute accumulation. In summary the low salinity side enabled plant growth and water uptake but the salinity of the high salinity side impacted on stomatal conductance.

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**P7.7**

**Can drought adapted Mediterranean plants acclimate against anoxia?**

Claire M King (University of Reading), Ross W Cameron (University of Reading), Steve J Robinson (University of Reading)

Principle adaptations to flooding induced anoxia by hydrophytes and some mesophytes, include the formation aerenchyma and the development of shoot borne roots. Less is known about xerophytes, including drought adapted Mediterranean species widely grown in UK gardens, and whether they will withstand the wetter winters predicted by climate change scenarios. *Salvia officinalis* showed a response to hypoxia in experiments that manipulated the oxygen status of the root zones of hydroponically grown plants using oxygen/nitrogen gas mixtures. Five days of hypoxia caused a proliferation of lateral roots in the upper parts of the root system, which allowed the plants to survive 5 days of subsequent anoxia. Conversely, in plants that received 5 days anoxia from full aeration, roots died back and lateral root production ceased. To consider flooding in soil-plant systems, an experiment growing *Salvia* in Perspex columns filled with soil-based growing media (diameter 200 mm, depth 400 mm) investigated root production and longevity by counting roots on a 10 mm square grid at the column edge, whilst altering the water table height. Raising the water table to 200 mm doubled the rate of root production and reduced the loss of white roots in the unsaturated zone, compared to columns where the aeration was maintained. This ability to rapidly assemble new lateral roots in the upper parts of the root system is a response that allows these plants to survive short periods of anoxia, rarely noted by other workers.

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**P7.8**

**Wheat genotypes differ in ability to extract soil water from deep soil layers**

Eric S Ober (Rothamsted Research), Chris J Clark (Rothamsted Research), Anne Perry (Rothamsted Research)

Drought limits wheat yields in the UK and in many regions globally. The ability of roots to penetrate the subsoil and extract moisture is a critical component of maintaining yield potential and stability. However, the extent of genotypic variation for rooting depth and drought tolerance in wheat breeding lines is not known. Twenty-one genotypes were compared under managed drought conditions in the field under large rainout shelters from 2007-2009. Root activity was inferred from patterns of water extraction from the soil profile measured using a capacitance-type soil moisture probe. Results showed significant genotypic differences in rates of post-anthesis water uptake at 80 cm from the soil surface. Total crop water use was negatively correlated with leaf rolling and positively correlated with drought tolerance, total above-ground biomass and delayed canopy senescence. The data suggest that there is sufficient genotypic variation in root activity in elite germplasm to make breeding progress. With the development of appropriate screening tools, selection for genotypes that can better mine deep soil water should improve yield stability in variable rainfall environments.

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**P7.9**

**Physiology and evolution of aluminium resistance in plants**

Peter R Ryan (CSIRO Plant Industry), Emmanuel Delhaize (CSIRO Plant Industry)
Acid soils limit plant production around the world and especially in the tropical and semi-tropical regions of Asia, America and Africa where agriculture varies from industrial scale production to subsidence farms. The application of lime can ameliorate acidity but changes to sub-soil pH can take many years and the costs are prohibitive for many producers. Aluminium (Al\(^{3+}\)) toxicity is the major stress to plants on acid soils and species and genotypes displaying greater resistance to Al\(^{3+}\) toxicity tend to perform better on acid soils. Our understanding of the physiology and genetics Al\(^{3+}\) resistance in plants has increased enormously over the last 10 years. We now know that Al\(^{3+}\) resistance is a multigenic trait, which relies on excluding Al\(^{3+}\) from the plant or detoxifying it once it enters the cytoplasm. However in certain species resistance is dominated by a single mechanism. The genes controlling some mechanisms, as well as their regulators, have been isolated and characterised in detail in heterologous expression systems. Several of these genes are members of two different families (ALMT and MATE) and encode Al\(^{3+}\)-activated transport proteins. These transporters release organic anions into the apoplasm to bind the harmful Al\(^{3+}\) ions. Other transporters involved in resistance are members of the ABC family and these appear to be releasing sugars into the apoplasm to modify the cell wall or are transporting Al\(^{3+}\) out of the cell. We will summarise the recent developments in the area, discuss the evolution of this trait in plants and suggest directions for future research.

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P7.10

Root cells react to cadmium toxicity to reduce the radial transport of ions

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To regulate radial transport of ions, roots are equipped with apoplastic barriers. These occur in the endodermis and, in most angiosperms, also in the exodermis. Initially, they develop by local impregnation of radial and transversal cell walls with a mixture of lignin and suberin in the form of Casparian bands. Subsequently, suberin lamellae are deposited on the entire inner surface of the walls of endodermal and exodermal cells. In many aspects these cells resemble those of the wound periderm. Both growth conditions and plant genotype can influence the development of these apoplastic barriers. Upon exposure to toxic metals, development of these apoplastic barriers is accelerated and they occur closer to the root tip. The distance at which these barriers occur from the root tip is directly correlated with metal (Cd) uptake and translocation to the shoot. Under severe toxic-metal (Cd) stress, ectopic lignification of cortical and pericycle cells may also occur. In some monocots development of a wound periderm can be induced in the outer cortical layers under severe Cd stress. When only one side of a root is exposed to Cd, there is accelerated asymmetrical deposition of suberin lamellae in the endodermis close to the root tip on the exposed side. We propose that this acts as an apoplastic barrier, preventing radial Cd transport both to the xylem and to the healthy unexposed side of the root.

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P7.11

Stagnant deoxygenated growth conditions reduce the overall permeability of rice (Oryza sativa L.) roots for solutes but not for water.

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When grown in stagnant medium (0.0-0.2 O\(_2\) mg l\(^{-1}\)) for 2 weeks, rice (Oryza sativa L. cv. IR64) roots developed strong apoplastic barriers in their peripheral cell layers very close to the root tip. These barriers minimized radial oxygen loss (ROL) from aerenchyma to the anaerobic substrate and significantly reduced the oxygen permeability (\(P_{\text{oxy}}\)) compared to the roots from hydroponics. To check whether these barriers affect transport of water and solutes, hydraulic conductivity (\(L_p\)) and solute permeability (\(P_{sr}\)) of excised adventitious roots were measured with a root pressure probe, whereas a pressure chamber was used for the whole root systems. Different from oxygen permeabilities, stagnant growth failed to decrease the \(L_p\) of either excised adventitious roots or whole root systems. In contrast, when grown in stagnant medium, root \(P_{sr}\) for NaCl decreased 13-fold compared to the plants from hydroponics and the reflection coefficient (\(\sigma_{sr}\)) increased 2-fold. It is concluded from these results that, even though, stagnant medium induced well-developed apoplastic barriers such as suberized exodermis and lignified sclerenchyma very close to the root tip, they couldn’t effectively block the radial flow of water in rice roots. However, different from water, these barriers significantly decreased roots’ permeability for NaCl as did for oxygen.

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14:50 Saturday 3rd July 2010
**P7.12**

**Root Phenotypes for Infertile or Hostile Soils**

Philip J White (SCRI), Tim S George (SCRI), Lionel Dupuy (SCRI), Alison Karley (SCRI), Tracy Valenentine (SCRI), Lea Wiesel (SCRI), Jane Wishart (St Andrews)

Plants require fourteen mineral elements (N, P, K, Ca, Mg, S, Cl, B, Fe, Mn, Cu, Zn, Ni, Mo). Crop production in many areas of the world is restricted by the availability of these elements in the soil solution. For example, the availability of N, P and K often limit low-input agriculture, and, irrespective of their concentration in the soil, the availability of Fe, Mn, Zn and Cu to crops often limits production on calcareous or alkaline soils. Magnesium availability is restricted on coarse-textured, calcareous or strongly acidic soils. Toxic concentrations of mineral elements in the soil solution also limit crop production. Constraints to crop production on acid soils include proton, Al and Mn toxicities together with P, Mn, Mg, Ca and K deficiencies, and saline or sodic soils contain toxic concentrations of Na, Cl and/or B. In addition, Mn and Fe toxicities occur on waterlogged or flooded soils. Since mineral elements are acquired by the root system, it has been suggested that the development of genotypes with appropriate root traits will improve crop yields on infertile and hostile soils. This paper first examines root traits required for the acquisition of essential mineral elements individually, before considering the trait tradeoffs required to address the multiple mineral constraints of hostile soils.

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**P7.13**

**Exploring roots - selective root placement in nutrient-rich hotspots**

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Nutrient hotspots in otherwise poor soils can trigger the outgrowth of lateral roots to facilitate the uptake of these resources. This selective root placement may occur in response to either nitrate or phosphate patches, but appeared to be highly sensitive to the concentrations of nutrients in the patch and in the background. We developed a sand culture based system in which Arabidopsis plants can be screened for their changes in root architecture when experiencing locally different nutrient conditions. Our results also indicate that phosphate-triggered outgrowth of lateral roots may be regulated via the interaction of miRNA399, a microRNA that is exported from the shoot when the plant is P-stressed, with UBC24/PHO2 in the roots. Arabidopsis pho2 mutants showed selective root placement in response to patches with high phosphate concentrations, whereas wildtype plants only responded to patches with relatively low concentrations, and not to high concentrations of phosphate. Next to a function of UBC24/PHO2 in the regulation of high-affinity phosphate transporters, this protein may therefore also regulate initiation and/or outgrowth of new lateral roots.

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**P7.14**

**Progress and prospects of increasing drought tolerance in pearl millet using genetics and genomics approaches**

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Pearl millet is a staple cereal grain and fodder crop grown by subsistence farmers in the hottest, driest regions of sub-Saharan Africa and the Indian subcontinent. Post-flowering drought stress is one of the major factors reducing its yield and yield stability drastically. This presentation will cover progress made so far towards identification, characterisation and breeding of drought tolerance quantitative trait loci (QTLs) in pearl millet using genotypes adapted to drought stress conditions of Africa and Asia. It will particularly focus on the fine-mapping of a validated major quantitative trait locus (QTL) for terminal drought tolerance mapping to linkage group 2, which explained up to 32% of variation in grain yield under multi-environment terminal drought screening using mapping population testcrosses of F2:3 segregants from two independent crosses. Results will be presented on the genetics and physiology dissected of this QTL, as well as on the successes of its marker-assisted backcross transfer into elite pearl millet hybrid parental lines. Data will be presented on the added advantage offered by this drought tolerance QTL in saline and alkaline stress conditions. Current efforts being taken towards fine mapping and towards developing gene-based markers for targeted saturation mapping of this major drought tolerance QTL will be discussed. Genetic stocks (QTL-NILs, high resolution genetic cross, and inbred germplasm panel for association genetics studies) and genomic resources (gene sequences, gene-based markers and comparative genomics information) currently assembled for these purposes will be discussed in length.

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P7.15

**Improvement of drought and heat tolerance in chickpea (Cicer arietinum L.) by induced mutation**

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Chickpea is traditionally sown at the end of spring rains and grown in the spring- and summer-period in the Mediterranean region, including Turkey. The crop suffers from drought and high temperature stresses in these periods. Resistance to drought or water stress can be achieved by drought escape or tolerance. The present study was aimed at selecting drought and heat tolerant lines by induced mutations. ICC 552, ICC 4951, ICC 4958, ICC 6119 were irradiated with 200, 300 and 400 Gy of gamma rays from a 60Co source. M1 plants were grown at Antalya and harvested individually in 2004-05. M2 generation was raised in separate rows at Antalya in 2005-06. Putative mutants were confirmed M3 generation in 2006-07. Selected mutants were compared for earliness, yield and reaction for ascochyta blight from 2008 to 2009 under late sown conditions to take advantage of drought and heat stresses. In 2009, mutants were compared with their parents and drought susceptible checks, ILC 3279 and ILC 8617. Selection was done after susceptible checks died due to drought and heat stresses. Some mutant lines were selected for resistance to ascochyta blight under natural epidemic conditions. Furthermore, some of them were found to be more resistant to drought and heat stresses than their parents. The mutants had higher yield than their parent under drought and heat stresses conditions, and mutants tolerated 41.8°C. The results clearly suggested that mutation techniques could be effectively used to develop drought and heat tolerant chickpeas.

Key words: root, xylem, drought

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16:45 Saturday 3rd July 2010

P7.16

**How does deficit irrigation affect root growth in tomato?**

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The anatomy of root plays an important role in understanding physiological events during plant growth and development, especially under drought conditions when root signalling induces many plant adaptations. In this study, we performed morphological and anatomical characterization of tomato root and its responses to drought stress using wild type and two ABA deficient tomato mutants. A split-root technique was used to divide the root system of the plants in two parts, and exposed simultaneously to different water regimes: (1) control with both root compartments well-watered, and (2) RDI with both compartments partially irrigated and (3) PRD with one compartment fully irrigated, while the other was kept dry to allow production of the root signals. Root length and weight were measured. Samples of lateral root were cross sectioned, examined by using light and fluorescent microscopy and hydraulic conductivity was calculated based on number and diameter of xylem vessels. In all genotypes root length was increased by PRD and not affected by RDI. Root weight was not affected by RDI and PRD in mutants, was but increased in wild type. This effect is more expressed in PRD than in RDI. Since reduced-irrigation treatments do not significantly affect hydraulic conductivity in lateral roots, increased root weight in PRD is probably consequence of longer and/or more numerous lateral roots.

Key words: root, xylem, drought

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.17

**Effects of deficit irrigation on phenological growth stages in ABA-deficient tomato mutants**

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Regulated deficit irrigation (RDI) and partial root-zone drying (PRD) are water saving techniques with positive effects on yield and water use efficiency. This research aimed to compare the effectiveness of these two techniques on phenological growth stages and the possible role of ABA in these effects using ABA deficient tomato mutants. Three tomato genotypes (wild type Ailsa Craig and ABA deficient mutants: *notabilis* and *flacca*) were grown in growth chamber conditions. The plants were exposed to three water regimes: control plants were well-watered, plant exposed to RDI treatment got
50% less water than considered optimal to the entire root-zone, while plants exposed to PRD treatment got the same amount of water as RDI but unevenly distributed to the root system so that part is irrigated while the remainder is allowed to dry the soil. During plant development phenological growth stages were observed. Our results showed that even when the same volumes of water were applied, the effect of PRD on the acceleration of the phenological phases in all genotypes is more expressed than in RDI. The magnitude of these effects differs between genotypes indicating the possible role of ABA: PRD accelerates flowering and ripening the most in the wild type.

Key words: tomato mutants, partial root drying, regulated deficit irrigation, flowering, ripening

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.18

OXI1 kinase mediates ionic stress tolerance during Arabidopsis germination and seedling establishment

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The most vulnerable stage of the plant’s life cycle is the transition from dormant seed, through germination, to seedling establishment. Whilst complex metabolic and hormonal shifts initiate cell expansion and reactivate the meristems, emergence from the protection of the testa exposes plants suddenly to the prevailing environmental conditions. Survival depends upon the seedling’s ability to sense and respond to biotic and abiotic environmental cues. Cells generate reactive oxygen species (ROS) as a signal, both during normal development and in response to various environmental cues, including salt stress and pathogen attack. OXI1 kinase is part of the ROS-associated signal relay which integrates a diverse range of stress responses in Arabidopsis (Rentel et al. 2004). Transcripts of OXI1 are elevated in response to salt stress, but not the osmolar equivalent of mannitol, implicating OXI1 in ionic toxicity rather than osmotic tolerance. Loss-of-function mutants at this locus have enhanced sensitivity to salt during germination and seedling establishment, but not at later developmental stages. A more detailed analysis suggests a role for OXI1 at two specific stages; initial testa rupture, and the transition to de-novo organ synthesis in the emergent seedling. These stages correlate with the timing of OXI1 promoter-reporter activity. We report progress in the characterization of the oxi1- mutant phenotype during early development.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.20

The adaptive mechanism of Secale cereale plants to high light condition

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The light condition of photosynthetic organisms can highly vary in intensity and quality on a broad time scale, which ranges from minutes up to hours, days and even months. These variations influence directly the efficiency of photosynthetic processes and therefore plant productivity. Short- or long-term plant illumination with high light intensity frequently leads to degradation of the
PSII structure. However, in the aim of the optimization of absorbed energy utilization plants have developed several regulatory mechanisms operating at the molecular level. In our experiment Secale cereale plants were cultivated under light intensity of 150 µmol m⁻² s⁻¹ and next exposed to light intensity of 1200 µmol m⁻² s⁻¹ for 3 h. The responses of plants to high irradiance were examined at the level of the structure and function of the photosynthetic apparatus. We observed that under high light condition leaves adaptation was based on the balance between the quantity of absorbed energy by the antenna complexes and light utilization in the form of photosynthetic electron transport. The plants reaction to high light intensity was also connected with a decrease in the yield of dark phase reactions which was accompanied by significant fall in the level of thermal dissipation of excitations within the energetic antennae.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

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**P7.21**

**Effect of cadmium on growth and mineral composition of Dianthus carthusianorum plants**

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Cadmium (Cd) is a widespread, naturally occurring element present in soil, rock and water, however, it may be accumulated in substantial amounts in these environments due to anthropogenic activity. Physiological effects of Cd toxicity in plants include inhibition of growth, chlorosis or necrosis, changes in photosynthetic efficiency, respiration and other metabolic processes. Many toxic effects of Cd action result from interaction with essential elements, especially those with the same valence as Cd, such as Zn, Mn, Cu, Mg, Ca and Fe. In the present study, differences in Cd uptake, translocation and its influence on the growth and mineral composition in two ecotypes of Dianthus carthusianorum varying in Cd-tolerance were investigated. Plants of a tolerant ecotype, originating from a Zn-Pb waste heap in Southern Poland (calamine ecotype), and these of a control ecotype, originating from unpolluted site (control ecotype), were cultivated in hydroponics at 5-100 µM Cd. Both ecotypes accumulated similar concentrations of Cd in their roots, however, higher Cd concentrations were found in leaves of the calamine ecotype. Cd treatment had no influence on root dry biomass and root mineral composition. Shoot biomass was reduced at higher Cd concentrations, a significant decrease in the shoot Fe content was also found in both ecotypes. Ca, Mn and Zn concentrations were higher in the control ecotype. In general, higher variability in Cd and mineral content as well as biomass and water content was found within the control ecotype suggesting high selection pressure in the ecotype colonizing metal polluted sites.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

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**P7.22**

**Adaptation of photosynthetic apparatus of Dianthus carthusianorum under Zn, Pb or Cd stress conditions**

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Dianthus carthusianorum is one of the dominant plant species developed spontaneously on calamine (Zn-Pb-Cd) waste heaps near Olkusz, southern Poland. The calamine ecotype of this species was shown to exhibit higher metal tolerance in comparison with ecotypes from unpolluted sites; however, it has not been examined with respect to photosynthetic apparatus efficiency under metal stress conditions so far. Adaptation of the photosynthetic apparatus to Zn, Pb and Cd was investigated in two ecotypes of *D. carthusianorum* (calamine and control ecotypes) cultivated hydroponically. Non-metal treated plants of both ecotypes showed similar photosynthetic activity. There were no differences in the carotenoids level in both ecotypes, whereas the chlorophyll a+b level in Cd-treated plants from the control ecotype and the Pb-treated plants from the calamine ecotype decreased. The photosynthetic apparatus of the control ecotype plants was more sensitive to metal toxicity, especially to Cd, as determined on the basis of the significantly decreased Rfd, Fv/Fm, qP parameters. At the same time, NPQ, LNU and %X increased in the metal treated plants of the control ecotype in a much higher degree than in the calamine ecotype. Metal toxicity in the plants of the control ecotype was well seen in the dark phase of photosynthesis; the plants
showed low adaptation to Cd and weak photoprotective mechanisms. The plants from the calamine ecotype were resistant to Cd and Zn, but despite the chlorophyll a+b decrease and rather the decline of the light phase activity of photosynthesis after Pb treatment, they maintained effective photoprotective mechanisms.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.23

What are the implications of variation in root hair length on P-limited yield in barley (Hordeum vulgare L.)?

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Phosphorus (P) is one of the essential nutrients required for plant growth, and is commonly applied as fertilizer to enhance crop yield, however supplies of quality rock phosphate are diminishing. Plants have evolved a number of mechanisms to increase their P efficiency and it is a greater understanding of the genetics behind these traits that will help us to identify candidate genes that can be introduced into commercial varieties with benefits to the long term sustainability of agriculture. The screening of a mutant barley population for root traits associated with improved resource capture has resulted in the identification of genotypes with differing root hair phenotypes. Here we utilise a sub-sample of this population to investigate the implications of root hair length on phosphorus (P) limited yield. Mutants were pot-grown in soil under two P treatments in identical parallel experiments, one harvested at 7 days, the other at 14 weeks. Results confirmed the robustness of an initial controlled environment screen for root hair phenotypes in-vitro, while also establishing the importance of the presence and/or length of root hairs in relation to P accumulation and yield. Our results suggest that the presence of root hairs was important for yield but the length of the root hairs was not significant. In addition, data establishing the impact of root hair length on P accumulation under varying levels of water stress will be presented.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.24

Effect of salinity on germination and seedling growth of four medicinal plants

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This experiment was conducted in Germinator in order to study the effects of water potential on seed germination, rate of germination and seedling growth of four medicinal plants named Coriandrum sativum, Plantago psyllium, Discorinia sophia, Portulaca oleracea. Four water potentials including distilled water as control (0), -0.37, -0.59 and -0.81 MPa which made by different salts (NaCl, CaCl$_2$ and NaCl+CaCl$_2$ in 5 to 1 molar ratio). The experiment was carried out based on completely randomized design with six replications. Results of variance analysis showed that effects of water potential, type of salt composition on germination percentage, rate of germination, root and shoot length were significant. With decreasing water potential, germination percentage and rate of germination declined but the response of plants differed so that seed germination of Portulaca oleracea was not affected by decreasing water potential where as others significantly decreased. The effect of salt composition was significant on rate and percentage germination. The percentage germination at lower water potential which made by NaCl + CaCl$_2$ significantly was higher than the same water potential made by only NaCl and CaCl$_2$.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.25

Plasticity of root architecture in response to external nutrients

Fabian Kellermeyer (University of Glasgow), Anna Amtmann (University of Glasgow)

Plant root system architecture (RSA) is highly plastic and responds to environmental cues such as nutrient conditions in the external medium. Therefore RSA can be used as a quantifiable output to study sensing and signalling of mineral nutrients. In addition to that the genotype of the plant has to be taken into account controlling root development and stress responses. Here we measured spatial and temporal root architectural parameters of A. thaliana in several nutritional and genetic backgrounds using the software tool EZ Rhizo (Armengaud et al., 2009). A strong response to the external potassium concentration was observed. For example low K induced the emergence of higher order lateral roots at about 10 days after germination. This effect was more or less pronounced in different Arabidopsis accessions. Other RSA parameters also changed differentially between accessions when grown on high and low K medium. Moreover interactions of low K responses with other external conditions such as concentrations of nitrate, sulfate and calcium could be
observed. These results suggest the applicability of QTL analysis to find novel regulators of nutrient sensing and signalling using natural variation of Arabidopsis as the genetic source.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.26
Genotypic variation in the ability of barley to tolerate multiple abiotic stresses

Timothy S George (SCRI), Lawrie K Brown (SCRI), Gracie Barrett (SCRI), Lionel Dupuy (SCRI), Philip White (SCRI)

With global environmental change and finite resource availability it is important to increase the ability of crops to cope with multiple abiotic stresses. Here we investigate variation amongst barley genotypes in their ability to tolerate combined stresses of water and phosphorus (P) deficit. Firstly, we studied a population of elite spring and winter barley genotypes (~150) grown in field trials throughout the UK. We demonstrated a large variation in P acquisition between lines and related this to prevailing climatic conditions. Further investigations into the rooting characteristics were carried out using split-pot growth systems. These revealed that roots of a traditional Scottish landrace were less plastic in their response to the combined stresses of water and P deficiencies than a commercial variety, Optic. This was manifest in the traditional landrace coping with combined stresses more effectively. Finally, we screened a limited population of genotypes for response to combined stress in glasshouse and field experiments. Genotypes exhibited a range of response to combined stresses and there was a greater ability to cope in those with more variable growth under optimal conditions. Our research indicates that there is significant variation in tolerance to combined stresses across a range of barley genotypes and that, historically, breeding varieties under optimal conditions may have reduced their ability to cope with multiple abiotic stresses. Understanding the genetic control of traits involved in tolerance to multiple abiotic stresses will allow the production of crop varieties better able to cope with future agroenvironments.

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P7.27
Genetic architecture of phenotypic traits in world sesame collection regenerated in Mediterranean climate

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In order to identify the genetic architecture of phenotypic traits and bring new varieties suitable for Mediterranean type of environments, 12 qualitative and 9 quantitative descriptors were analyzed by using the data recorded from 345 sesame genotypes representing for 29 different countries from all over the world. Qualitative traits were analyzed for principal component analysis. The first third PCs with eigen values ≥ 1 contributed 70.62% of the variability amongst accessions. PCA1 explained 33.88% of the total variance and positively correlated to first flowering date and 50% flowering date. PCA2 explained 25.79% of the total variance and mainly correlated to stem length to the first capsule and plant height. PCA3 explained 10.95% of the total variance and mainly correlated to number of seeds per capsules and seed yield. Qualitative traits were analyzed for percentage distribution. Maximum variation was observed for seed coat color. Prominent traits in sesame which are early flowering, number of capsule, seed yield and number of branches showed wide spectrum of variability. We suggested a core set of 103 accessions (30% base collection), accounted for 56% variance (score) of the base collection. This core collection was compared with the whole collection using Shannon-diversity index (SDI). The similarity between the collections according to SDI values indicated that diversity of the entire collection was well represented in the core subset. The entire and suggested core collections represent a valuable source of different phenotypic traits that is expected to be important for sesame breeding programs.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.28
Effect of temperature drop on potato plant responses to biotrophic pathogens

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Cold temperatures often combine with nematode invasion of plants in the North. The most significant pest of potato plant is potato cyst-forming nematode (PCN) Globodera rostochiensis Woll. Infection by this
Aluminium and low pH induced physiological changes in the antioxidative response system of Plantago algarbiensis and P. almogravensis

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Plantago almogravensis Franco and P. algarbiensis Samp. are Portuguese endemic species in risk of global extinction that colonize acid soils. In previous studies we observed that in vitro cultures and plantlets of both Plantago species accumulate high Al concentrations without showing visible symptoms of toxicity. The aim of this study was to evaluate the response of the antioxidant enzymes, superoxide dismutase (SOD), catalase (CAT) and ascorbate peroxidase (APX), to low pH and Aluminium (Al). Cultures of P. almogravensis and P. algarbiensis [1] were grown for 24 h, 48 h and 7 days in 1/4MS liquid medium (pH 4.0) containing 0, 2.5, 5 or 10 mg l\(^{-1}\) Al. Medium at pH 5.75 without Al was used as control. Overall, a significant (P<0.05) stimulation of SOD activity (up to 2-fold) was observed in both Plantago species after 24 h of culture at pH 4.0 (with or without Al). This was followed by an increase (P<0.05) on CAT (up to 2-fold) and APX (up to 3-fold) activities after 48 h and 7 d exposure. The results obtained indicate that the enhancement of antioxidant enzymes may contribute to Plantago tolerance by suppressing oxidative damage.


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P7.30
Aluminum tolerance in wheat/barley introgression lines and in their parental genotypes

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Aluminum (Al) toxicity is one of the major limiting factors for the production of most cereals in acid soils. The evaluation of the Al tolerance of six wheat and three barley genotypes and of eleven hybrid derivatives demonstrated that: (1) the genotypes possessed narrow genetic variance with a relatively high level of tolerance to acid soil and a wide range of tolerance to Al; (2) the high root growth rate of the wheat Mv9kr1 did not affect the Al tolerance level; (3) some of the barley genotypes (Manas, Betzes) had Al tolerance at least as high as that found in the Al-tolerant wheat genotypes Atlas 66 or Chinese Spring; (4) barley chromosome 4H may contain genes responsible for root elongation, independently of its Al tolerance; (5) the 2DS.2DL-1HS translocation line exhibited higher Al tolerance than was observed in the parental lines, indicating that either the lack of the distal part of the 2DL chromosome or the presence of the distal part of 1HS improved the Al tolerance level.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.31
Photosynthetic rate, elemental analysis, and antioxidant activities of ascorbate peroxidase and glutathione reductase in salt-stressed Echinacea pupurea, E. pallida and E. angustifolia

phytonematode reduces potato productivity and quality of tubers. The aim of the study was to characterize potato plant responses to short-term temperature drop combined with PCN invasion. Potato plants (cv. Nevsky) were grown at 23°C with 12-photoperiod during 14 days in a climatic chamber and exposed to short temperature drop from 23 to 5°C for 2 h at the end of the night for 6 days (DROP treatment) and at 23°C (control). Then plants were infected by PCN and remained under optimal growth conditions (23°C) for 2 months. Dry weight, Chlorophyll fluorescence parameters (MINI-PAM, Walz, Germany) and expression of the nematode resistance genes (PCR in real time) has been analyzed.

It has been established that temperature drop did not affect plant dry weight. The Fv/Fm of infected plants had lower values compare with control. In contrast, DROP-treated plants and control Fv/Fm had similar values and was constant during all the experiment. qP was higher in DROP-treated plants than in control, on the contrary NPQ showed a reduction. Moreover, short-term temperature drop promoted to induction of expression of resistance gene H1 and Gro1-4. It is concluded that temperature drop treatments increased potato plant resistance to infection by G. rostochiensis. Study was supported by RFBR, No.; 10-04-00097.

Sylvie Renault (Department of Biological Sciences University of Manitoba), A Sabra (Department of Biological Sciences University of Manitoba)

A greenhouse study was designed to investigate the effects of different NaCl concentrations (0, 50, 75 and 100 mM) on photosynthetic rates, elemental contents and antioxidant enzymes of three Echinacea species (E. pupurea, E. pallida and E. angustifolia). Six-month old plants were transferred to nutrient solutions supplemented with NaCl in aerated hydroponic systems for two weeks. Photosynthetic rates were decreased with increasing salt concentrations in all species. Calcium content was decreased in both shoots and roots of salt-stressed E. pallida and E. angustifolia, while it was not changed in E. pupurea shoots. The Na+ and Cl- contents were increased in the shoots and roots of all Echinacea species at all salinity levels, however E. pupurea retained more Na+ in the roots than the shoots. Glutathione reductase (GR) activity was increased in the leaves and roots of E. pupurea and E. pallida by 50 and/or 75 mM NaCl, whereas GR activity in E. angustifolia was decreased in the shoots and increased in the roots by 75 mM NaCl. Ascorbate peroxidase (APX) activity was increased at 50 and 75 mM NaCl in E. angustifolia leaves. In E. purpurea, APX activity was enhanced by 75 mM NaCl, but was not altered by salt treatments in E. pallida. These results indicate that Echinacea species exhibit different responses to salt; while E. purpurea limits Na+ toxicity by retaining it in the roots, E. pallida has higher antioxidant activities of both APX and GR.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.32

Mapping rhizosphere solutions using glass microcapillaries.

Deni Tomos (Bangor University), Susan Tandy (University of Copenhagen), Grail Barry (Bangor University), Brittain Susan (Sheffield University), Eric Paterson (Macaulay Institute Aberdeen), Cameron McLeod (Sheffield University)

We used glass microcapillaries to obtain samples for quantitative measurement of the dynamic behaviour of soil and rhizosphere solutes at fine spatial resolution. Initially, crystals of uranyl salts and fragments of shrapnel of spent Uranium anti-tank projectiles were placed in flat microcosms with removable "windows" to allow sampling of 2-5 nanoliter droplets of soil solution at different distances and directions. The density of the Uranyl solution appeared to result in a downward plume away from crystals. Doping the soil with citrate before insertion of the shrapnel resulted in much higher concentration of U in the solution around and below the fragment. Finally shrapnel fragments were placed next to the developing cluster roots of Lupin seedlings. The transient efflux of citrate and malate from these roots (measured using capillary zone electrophoresis) was measured and shown to correlate with a transient solubilisation of U (measured using ICPMS). These measurements provide an illustration of not only of the way that depleted uranium waste may behave in the “living” soil, but also of the process by which roots “mine” minerals as they grow. They also illustrate that micro-sampling is a practical way of studying below ground plant responses.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.33

Potential of arsenic accumulation in plants growing on old mining sites

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High concentration of pollutants is often present in the material from waste heaps, dumps, mine tailings and in the water from old mine works. Arsenic (As) belongs to the dangerous elements present in some of these localities. Although As is non-essential element, its content in the plants growing in polluted sites often considerably exceeds the values typical for non-contaminated sites. The aim of present contribution is to show the accumulation and translocation of arsenic in plants from the soils and contaminated substrates in two old mining regions of Slovakia. Material on heaps coming from ancient mines of Sb-ores, mine tailings and soil in the surrounding, contains extremely high amount of As (up to 1700 ppm). Accumulation and translocation potential of As of dominant plant species on both localities were investigated. Majority of the species exhibited low As translocation to the shoots. Some of these plants, especially woody species, can be possibly used for phytostabilization of contaminated substrates. Few species showed increased accumulation of this element in the shoots. It may be important for potential toxicity for herbivores and in the case of medicinal plants also for humans.

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P7.34

Does supplementary silicon enhance the saline tolerance of tomatoes beyond the enhancement provided by naturally occurring background silicon?

Catherine Keeling (Writtle College Chelmsford Essex CM1 3RR UK), Clive Ireland (Writtle College)

Silicon has been shown to enhance saline tolerance in cereals, however, the efficacy of stress amelioration by Si in non-cereal crops is unclear. While Si may increase saline tolerance in tomatoes by enhancing plant water status, most studies have employed “minus-silicon” control plants. Consequently, it is uncertain whether the benefit to salt-stressed tomatoes is met entirely by the background Si present in irrigation water and growing media, or whether additional silicon can produce further benefit. Si was applied hydroponically to 5-week-old tomato plants at 0mM (“minus”), 0.4mM (“background”), and 2.5mM (“supplementary”) in the absence/presence of 80mM NaCl. 0.4mM Si increased fresh weight by 10% compared to the minus-Si plants, in both saline and non-saline conditions. There was no significant effect on dry weight. Supplementary Si (2.5mM) significantly ameliorated the water and chlorophyll contents of salt-stressed plants, but did not further increase total fresh weight. Saline plants treated with 2.5mM Si suffered a more severe decrease in leaf K⁺ content than in other Si treatments. Under conditions of high water stress, supplementary silicon clearly has a strong ameliorating effect on the water content of salt-stressed tomatoes, leading to a significant improvement in yield. However, in cool temperate conditions the magnitude of this effect is much reduced compared to previously reported effects in warm-grown tomatoes. Indeed, increasing the Si supply above naturally occurring background levels may negatively affect the growth of salt-stressed tomatoes by further decreasing the leaf K⁺ content.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010

P7.35

Defensive redistribution of photoassimilate, and changes in root growth, after attacks on roots or shoots by herbivores and soil pathogens

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Plants survive attack by pathogens and herbivorous insects in part by diverting new carbon into reserves for later growth. Within split-root barley, allocation of carbon tracer when some roots were challenged with Fusarium graminearum, or with jasmonic acid (simulating root herbivory) fitted the above paradigm: allocation of C-photosynthesis to the challenged roots reduced, to the benefit of non-challenged roots. Nevertheless, a known effect of leaf herbivory is to inhibit root elongation, in marked contrast to the afore-mentioned beneficial changes in carbon distribution. We therefore imaged carbon import (using 13C) to a much higher spatial resolution, since the difference in measurement locations of root elongation and carbon import may explain the apparent contradiction.

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Poster Session 17:00 – 19:00 Friday 2nd July 2010
pressure deficit) were conducted in growth chambers and greenhouses. The modelling part was based on experimental data and used a light-sensitive, parametric Lindenmayer-System.

Salt-induced reductions in leaf area were significantly altered by the different environmental conditions. The leaf angle between the stem and intersection of the petiole with the first leaflet (epinasty) increased with salinity, whereas the angle between the stem and the tip of the leaf (bending) decreased under the same conditions. Related to leaf area, both angles were significantly larger under salinity, but showed a decreasing trend over time. The percentage of rolling leaf area increased with time and salinity. Simulation runs showed that up-scaled on the whole plant level these alterations resulted in different plant volumes, light interception profiles and biomass productions. Thus, this study highlights the significance of architectural traits such as epinasty and leaf bending for explaining salt-induced reductions in plant biomass.

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P7.37

Cadmium tolerance mechanism in *Wedelia trilobata* (L.) Hitchc. (Asteraceae) plants

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Cadmium is a widespread nonessential toxic heavy metal released into the biosphere mostly by modern industry. The aim of the present work is to evaluate the responses of different Cd concentrations (5, 25 and 50 \( \mu M \)) exposure in *W. trilobata* plants kept in hydroponic nutritive solution for 96 h, to diagnose the potential use of this plant specie in phytoremediation. Cd content in tissues increased proportionally with concentration; the accumulation was 1306, 193 y 52 mgKg\(^{-1}\) in roots, stems and leaves respectively. The bioconcentration factor was higher than 1 in all organs at any [Cd], which is an indication that *W. trilobata* is Cd accumulator plant.

Root dry biomass was reduced 40.3% at 50 \( \mu M \) Cd. Increase in GSH, cistein and phytochelatins content (PCs) at 50 \( \mu M \) was observed, six different PCs types were detected. Lipid peroxidation increased at 0.5, 5 y 25 \( \mu M \), but not at 50 \( \mu M \). The PCs increase at 50 \( \mu M \) is related to the sequestration mechanism which reduced the toxic Cd effect on lipid membranes. These results indicate that *W. trilobata* is a Cd accumulator and tolerant specie throughout the PCs mechanism sequestration, allowing Cd phytoextraction in Cd contaminated soil.

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