WORKING PARTY ON ENVIRONMENTAL APPLICATIONS OF POPLAR AND WILLOW

NITRATE LEACHING AND BIOMASS PRODUCTION FROM SHORT ROTATION COPPICE FERTILISED WITH DAIRY SLURRY

Ruth Copeland[1]

Short rotation willow coppice (SRWC) has been identified as one of the most viable energy crops for the United Kingdom. A field trial of SRWC was grown on a farm in Northamptonshire to investigate growth and productivity. Twenty-four plots were fertilised with eight different nitrogen-based slurry applications (0, 50, 100, 150, 200, 250, 300 and 300 kg N ha^{-1} yr^{-1}). In addition sixteen lysimeters were established to quantify and compare nitrate leaching from grassland and SRWC in relation to nitrogen-based slurry applications (250 kg N ha^{-1} yr^{-1}). The viability of SRWC on dairy farms was investigated in relation to management and financial implications.

Yields of 13,147 to 25,168 od kg ha^{-1} were obtained from the field trial with annual growth rates of around 9,000 od kg ha^{-1} yr^{-1}. There were no significant differences between plots in relation to the nitrogen-based slurry applications ($p>0.05$). The high nitrogen content within the leaves ($p>0.05$ for treatments) implied that the willows were well supplied with nitrogen and the nitrogen within the slurry was surplus to requirements. NO_3-N (mg l^{-1}) leaching was significantly greater ($p<0.05$) from the willow lysimeters and the uptake of nitrogen by the willows (159-179 kg N ha^{-1} yr^{-1}) was significantly greater than by the grass (116-117 kg N ha^{-1} yr^{-1}). A partial nitrogen budget was established for the lysimeters.

An appraisal of the costs incurred during the establishment and management of the field trial suggested that the projected financial viability of SRWC is not as promising as expected. However, the effective management of SRWC within agriculture could lead to added benefits such as enhancement of biodiversity and an alternative to traditional crops for the application of slurry.

Key Words: willow, dairy waste, slurry, leaching, nitrate, nitrogen, yield.

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MANIPULATION OF BROWNFIELD CONTAMINATION USING WILLOW AND POPLAR

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Soil contamination is a frequent constraint to sustainable redevelopment of brownfield land. Mass balance data from field trials are used to assess the feasibility of influencing contaminant hotspots through uptake and harvest of short-rotation coppice. The potential for planting trees to extract or to immobilise mobile pools of heavy metals in soil is evaluated. The results are one part of six years of experimental fieldwork at more than 50 trial plots at 18 sites in North-West England. In these experiments, twelve trial plots each 30m x 30m (2-3 plots per site) were located at seven sites with differing former land uses (landfill, industrial waste, sewage sludge) and types and ranges of contamination.
Metal levelMDispersion patterns of heavy metals were measured at sites variously contaminated with As, Cd, Cu, Ni, Pb, Zn and B, planted with five species, hybrids and clones of *Salix* and two *Populus* hybrids, comparing performance with *Alnus*, *Betula* and *Larix*.

Significant toxicity to plants was only recorded in the cases of extremely high concentrations of B and As. Contaminant hotspots were targeted for experimental work; the sampling pattern was designed to identify 1% area hotspots. H
eavy metal mobility was quantified as the tree cover became established and for three growth seasons. Attention was given to assessing the toxicity of contaminant hotspots in relation to the potential for site clean-up, and to risks of increasing mobility and dispersal of contaminants into the wider environment. Toxicity to plants was seldom an important issue, and was only recorded in the cases of extremely high concentrations of B and As. Overall mortality was low (mean 11%) and was not related to contamination, except at one site with over 4,000 mg As kg^{-1}. Bioavailability of metals in the hotspots was also quantified, both spatially and temporally. Plants themselves affect metal mobility; for example, metals are returned to the surface through uptake and leaf fall. In supporting pot experiments, mobility was also significantly influenced by soil conditions created by plant growth, rhizosphere processes and earthworm activities.

Evidence was provided that selected phytoextraction of cadmium is feasible, and may resolve risks associated with its widespread and ubiquitous contamination of soils and restoring soil health within a realistic time. Key factors are clone selection, targeting of hotspots, timing of harvest and removal of the root bole. There is probably very limited scope for other metals on brownfield land, although there may be an opportunity to reduce phytotoxic concentrations of Zn from agricultural soils. Where the concentration of Cd in soil is just above guideline values, or where annual inputs are small, phytoextraction by *Salix* may provide an efficient and cost-effective method of clean-up. However, there are also outstanding gaps in knowledge relating the long-term success of ensuring there is no risk to human health (from re-entrainment of particulates or increased downward movement of metals to water bodies), or to the wider environment (e.g. to food chains).

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The probable outcome of current research effort will be that both phytoremediation strategies using trees will form part of an integrated solution to brownfield land, alongside natural attenuation, soil washing and chemical and biological additives to contaminated soils. Community forestry using willows and poplars offers the potential of restoration of healthy soils in degraded and contaminated land.

Key Words: Brownfield, heavy metals, cadmium, phytoremediation.

FULL-SCALE PHYTOREMEDIATION SYSTEMS COMBINED WITH WOOD FUEL PRODUCTION USING SHORT ROTATION WILLOW COPPICE

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Short rotation willow coppice (SRWC) has been grown in Sweden for bioenergy purposes since the 1970's. Commercial plantations of willow (*Salix spp.,* mostly different clones of *S. viminalis, S. dasyclados*, *S. schwerinii* and hybrids) are established for intensive production of wood fuel, grown in double rows for short rotation periods (harvest every 3-4 years). The biomass produced is burned in district plants for combined production of heat and electricity.

It was soon realized that SRWC could also be used as an effective nature-friendly system for treatment of different waste products. The basic idea behind such phytoremediation systems on SRWC, which involve application of, for example, municipal wastewater, landfill leachate (water percolating from landfills), industrial wastewater or municipal sludge, is the reduction of pollutants or nutrients in waters and soils by plant uptake or the facilitation of microbial transformation. Willow has a number of advantages as a phytoremediation crop, such as high biomass yield, high evapotranspiration rate, good coppice ability, tolerant roots during anoxic conditions and high efficiency in taking up substantial amounts of heavy metals. These properties, combined with the environmental benefits of using willow biomass as a fuel, plus the relatively low cost of establishment compared to conventional waste treatment methods, show the potential of SRWC for phytoremediation.

There are currently around 50 such large-scale systems in Sweden treating the different kinds of wastewater mentioned above, and more than 10,000 hectares with SRWC fertilized with municipal sludge. In the case of wastewater, sprinklers or pipes for drip irrigation are placed in the field and the irrigation is conducted during the growing period. Lined ponds are constructed for water storage during the winter period. Sludge in most cases is mixed with wood-fuel ash in order to have a more nutrient-balanced fertilizer. The benefits of using SRWC for phytoremediation are manifold: the fertilization cost for the farmer is minimal, waste treatment costs for the municipality are reduced, and the treatment is conducted locally on-site which provides the district heating plants with wood fuel at low transport costs.

Despite the obvious advantages of the system, environmental hazards such as nitrogen and phosphorus leaching, plant toxicity, greenhouse gas emissions, accumulation of heavy metals in soils and sanitary aspects could be some of the challenges for successful performance if the applications are not conducted with caution. Research has been conducted to evaluate possible environmental problems as well as the rationalization of waste applications when SRWC is used for phytoremediation purposes.

Key Words: phytoremediation, willow, *Salix*, short rotation willow coppice, Sweden.

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HEAVY METAL TOLERANCE IN HYDROPONICALLY-GROWN *SALIX* SPECIES: PERSPECTIVES FOR PHYTOEXTRACTION

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Remediation of metal-polluted soils by metal-accumulating plants (phytoremediation) is an environmentally friendly and low cost approach. In recent decades, numerous plants with hyper-accumulating potential have been discovered by scientists around the world. However, most of these plants achieve only low shoot biomass, which consequently results in a considerably long time period necessary for the remediation of polluted soils by phytoextraction until an acceptable level of metal concentration in soil is achieved.

Based on screenings, it has recently been found that fast-growing woody plants with high biomass such as *Salix* and *Populus* are capable of accumulating metals. The requirements of a *Salix* clone used to remediate soils by removing metals during harvest are quite different; however; a higher rate of uptake and translocation may be particularly relevant to clones in contaminated soils and the metal concentration in the harvested plants should exceed the metal concentration in the soil.

An hydroponic study was set up in order to investigate the metal tolerance and metal accumulation potential of willow species from Europe and Chile to evaluate their potential for phytoextraction.

Cuttings of 20 *Salix* species were grown in pots containing 4L of modified Hoagland's nutrient solution for approximately two weeks under controlled environmental conditions. After the equilibration period, cuttings were exposed to: (a) 0.5 mg L^{-1} of Cd or Cu, (b) 5 mg L^{-1} of Zn or Pb and (c) mixture of Cd, Cu, Pb and Zn at the same concentration in the nutrient solution. Treatments were carried out in four replications and untreated control plants were included in the experiment. After a growth period of 30 days in the metal-enriched nutrient solution, plants were harvested and separated into leaves, roots, cuttings and twigs. The fresh weight was recorded and plants were dried at 80°C to constant weight. Samples were digested in a closed microwave system and analysed for metals using AAS-GF. The tolerance index (TI) in this experiment has been calculated from the final root biomass using the following formula: TI (%) = (root dry weight in metal solution/root dry weight in control solution) x 100.

Metal concentrations in all parts of the plants were lower when willows were simultaneously exposed to Cd, Pb, Cu and Zn compared to the single metal treatments, which is likely due to metal competition mechanisms and adaptation to toxic conditions. The tolerance to heavy metals varied considerably between species. There was no obvious relation between tolerance indices and uptake in the individual treatments. However, the observed drastic reduction

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of metal uptake from the cocktail treatments may be a tolerance mechanism associated with a switch from a high- to a low-affinity uptake system. The root morphology was also affected by the metal treatments. Further data on heavy metal uptake will be presented.

Future studies are needed to establish the relationship between metal accumulation in hydroponically and soil-grown willow species to assess the suitability of hydroponics as a screening tool.

Key Words: phytoremediation, metal pollution, *Salix*, *Populus*, phytoextraction.

DEGRADATION OF ORGANIC ENVIRONMENTAL POLLUTANTS BY POPLAR

Sharon L. Doty[1], Allison L. Moore, Azra Vajzovik, Joel D. Nishimura, Richard Meilan, Milton P. Gordon, Stuart E. Strand

Contamination of soil, groundwater and air by halogenated hydrocarbons such as trichloroethylene (TCE), carbon tetrachloride (CT), and chloroform has become a common problem around the world. Our laboratory studied the uptake and degradation of halogenated hydrocarbons by a variety of plants. It was demonstrated that poplar cells had the capacity to degrade these pollutants to non-toxic metabolites. By using axenic cell cultures and hydroponically-grown plants, the phytoremediation potential of poplars apart from the actions of soil microbes was shown.

The uptake and degradation of these environmental pollutants can be greatly enhanced, however, by the introduction of genes encoding cytochrome P450s. These versatile enzymes have been well-characterized and can attack a wide range of pollutants. Cytochrome P450 2E1 was expressed in tobacco and *Atropa belledonna* as test systems for *Agrobacterium tumefaciens* and *A. rhizogenes* plant transformations. The gene was expressed and functioned well in the transgenic plants. These plants had greatly enhanced degradation of TCE. Increased expression of P450 2E1 also led to an increase in the uptake and degradation of the toxic pesticide, ethylene dibromide (EDB), another substrate of P450 2E1. Because of the successes with these systems, transgenic poplar plants are being developed with increased expression of cytochrome P450s. Results with these plants will be presented.

Key Words: phytoremediation, TCE, CT, EDB.

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A WILLOW VEGETATION FILTER TREATING LANDFILL LEACHATE: PRELIMINARY FINDINGS FROM A FULLY-LINED, FIELD-SCALE SYSTEM IN THE UNITED KINGDOM

Jodie Duggan[1]

Landfill leachate poses a significant threat to water resources. Landfill operators in the United Kingdom are under increasing economic, environmental and regulatory pressures to find sustainable, environmentally passive and inexpensive methods of leachate treatment. It has been shown that landfill leachate is a suitable nutrient source for willows; however, there are relatively few facilities in the United Kingdom for the treatment of landfill leachate using vegetation filters, and none are fully lined systems. Lined systems offer complete containment of leachate, thus minimising pollution potential and allowing full analysis of influent and effluent within the system.

Two willow stands were established between May and July 2001 at Cranford Landfill, Northamptonshire, UK. They each contain approximately 2,000 willow trees of several different varieties. They are irrigated throughout the growing season, on a daily basis with a methanogenic leachate from a working landfill.

The aims of the project are to evaluate willow stands as a treatment for landfill leachate, to assess treatment efficiency and to determine the economic potential of willow vegetation filters to landfill operators as an alternative to conventional leachate treatments. Soil microbiological parameters are being analysed to assess treatment efficency in relation to soil health.

Preliminary results indicate that when a dilute leachate was applied to one of the beds, reductions in the parameters tested (total nitrogen, COD, sodium, potassium and chloride) ranged from 12 to 62%. When a full-strength leachate was applied, the percentage reductions were predominantly greater, ranging from 33 to 60%. There is also a substantial reduction in leachate volume with no detrimental effects on tree health to date.

Key Words: vegetation filter, landfill leachate, willow, treatment, soil microbiology, economic.

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ESTABLISHMENT OF BLACK WILLOW (*SALIX NIGRA* MARSH.) FOR RESTORATION OF BOTTOMLAND HARDWOOD FORESTS IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY, USA

Emile S. Gardiner[1]

Black willow (*Salix nigra* Marsh.) is a pioneer tree species on alluvial sites throughout the eastern United States and portions of Canada and Mexico, where it grows most extensively and attains its largest sizes on the moist and fertile alluvium of the Lower Mississippi Alluvial Valley. As a component in bottomland hardwood forests, black willow is physiologically capable of thriving on sites dominated by characteristically harsh conditions such as heavy clay soils, annual flooding of long duration and significant depth, and accretion of alluvial sediments. Structural and functional properties of the moist, mineral soil environments pioneered by black willow may be quickly altered by this species through processes including its stabilization of recently deposited alluvium, accretion of soil organic matter from inputs of leaf litter and woody debris, development of the evapo-transpiration process through the plant canopy, and development of vertical stand structure.

Black willow may be a desirable species to consider for forest restoration projects in bottomland areas because of its ability to reproduce vegetatively, rapid juvenile growth rate, flooding tolerance, value as wildlife habitat, and ecological role in early bottomland hardwood seres In spite of these favorable attributes, suitable cultural practices for the establishment of this species have not been described and consequently the use of black willow in afforestation programs has been limited.

This presentation will report first-year results from an experiment designed to study how cutting length and herbaceous competition interact to influence establishment, growth and above ground biomass production of black willow planted on former agricultural land. These results will be discussed in respect to restoration of bottomland hardwood forests functions and the potential for carbon sequestration on former agricultural fields in the Lower Mississippi Alluvial Valley.

Key Words: forest restoration, bottomland hardwoods, LMAV.

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EXPERIMENTAL SUSTAINABLE WASTEWATER PURIFICATION BY *SALIX* IN SMALL ESTONIAN COMMUNITIES

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In recent decades large efforts have been made by the Estonian Government, with the help of international foundations, to establish modern wastewater purification plants in Estonia. However, in many places there is still a shortage of purification systems, especially in rural areas, where wastewater is purified only poorly today. Local authorities still need effective but inexpensive methods of wastewater purification.

The first experimental purification plant based on willow as a vegetation filter was established in Estonia in 1995. From ten years of experience, it was learned that a willow plantation of 180 m^2 was too small for efficient purification of the sewage of 45 people. However, valuable data on willow biomass production and its allocation under conditions of unlimited water and nutrient supply was obtained. From this data it was possible to calculate the uptake of nitrogen and phosphorus by plants and to evaluate the influence of plants on the purification efficiency of the system.

In 2003 a new project of sustainable wastewater purification started in three communities of 200 to 1,000 persons. The prototypes established are: (i) combination of subsurface filter with small willow plantation for mainly N retention; (ii) vegetation filter for wastewater purification during vegetation season with additional facultative bioponds during winter; (iii) total wastewater purification in vegetation filter with storage ponds for winter sewage. After the first year of the experiment, first data is available about changes in sewage chemical composition in the pre-treatment stages (subsurface filters, ponds) under different climatic conditions. The field data permits evaluation of the possible load of wastewater in the vegetation filter and determination of the limiting factors in avoiding the risk of groundwater pollution. Improved knowledge of these topics will permit increased use of sustainable wastewater purification systems in the future.

Key Words: biomass, nitrogen, phytoremediation, *Salix*, subsurface filter, vegetation filter.

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SUCCESSIONAL COMPANION PLANTING OF *SALIX* FOR ENVIRONMENTAL APPLICATIONS IN CANADA

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Bioenergy from short-rotation coppice of willow (*Salix*) is not as economically viable in Canada as it is elsewhere. However, willows have been shown to effectively remediate a variety of contaminants, such as zinc, copper, nickel, perchlorate, petroleum hydrocarbons, and landfill leachate. Since Canada became a signatory to the Kyoto Protocol, there is also interest in afforestation to offset carbon emissions with carbon sinks, and plantings to remediate the tens of thousands of contaminated sites are not exclusive of carbon sink applications.

Phytoremediation currently relies heavily on *Populus* species to remediate certain contaminants. But because *Salix* has different ecological amplitudes than some of the hybrid poplars, it is useful in a wider variety of site conditions, and therefore more likely to effectively remediate contaminated soils and water where *Populus* species may not be as successful.

Canada was formerly the North American leader in the breeding and improvement of willows. However, support for willow breeding was withdrawn in the early 1990s, including the forestry stations where breeding stock was propagated. Despite the proven efficacy of willows in remediating contaminated soils, by 2000 hybrid and species willows were unavailable in commercial quantities in Canada. At this time, LandSaga Biogeographical maintains a 3.5 hectare research and propagation plantation containing nine willow clones planted in 1993-1994 and has begun a research program focused on the needs of the nascent phytoremediation industry.

Preliminary results from the plantation show that there are statistically significant and qualitative differences between growth and survival of individual clones in separate planting blocks, as well as between and within clones in each block. Data suggest that there are interactions between the various clones, in which there are both positive and negative effects on the growth of adjacent neighbours. Effects of different neighbouring species become more pronounced over time and are significant after 10 years. Final results may lead to improved design and management practices in which successional companion planting provides maximum growth and survival with minimum inputs for phytoremediation/afforestation applications.

Key Words: phytoremediation, afforestation, willows, carbon offset.

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FIELD EVALUATIONS OF PHYTOREMEDIATION OF VOLATILE ORGANIC COMPOUNDS WITH POPLARS AND WILLOWS IN THE MIDWESTERN USA

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Phytoremediation is an emerging technology in the United States for remediating brownfields, landfills, and other contaminated sites. Poplars and willows are two of the most common genera used for phytoremediation because they are adapted to riparian sites, grow rapidly, have extensive root systems, and take up large quantities of water. One of the challenges with phytoremediation is matching the proper species or clone to the contaminated site through field evaluations. Consideration must be given to soil, microclimate, region, pests and diseases as well as the contaminants to be remediated. A phytoremediation strategy that includes four phases has been used: plant material screening, verification, demonstration, and deployment. This conservative strategy allows time needed to assess the trees' remediation potential and for policy and administrative decisions related to phytoremediation applications.

Three successful case studies are presented where poplars and willows are used to remediate volatile organic compounds (VOC's) in the Midwestern United States. The first is a waste-solvent recycling facility in Wisconsin where acetone, methyl ethyl ketone (MEK), and methyl isobutyl ketone (MIBK) are higher in the groundwater than allowable limits; the second is a former Polychlorinated biphenyls (PCB) incineration site in Illinois where groundwater is contaminated with trichloroethylene (TCE) and perchloroethylene (PCE); and the third is a county landfill in Minnesota where leachate contaminated with vinyl chloride and heavy metals is leaking into adjacent wetlands. Each example has been successful to date and has presented unique phytoremediation challenges. Each represents a phytoremediation application that illustrates a promising environmental use of poplars and willows.

Key Words: *Populus*, *Salix*, brownfield, landfill, contaminant, wetland.

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METAL RESISTANCE AND ACCUMULATION IN NORTH AMERICAN WILLOW (*SALIX* L.) SPECIES

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The search for fast-growing woody species able to remove metals from contaminated sites has been a focus of recent research in both North America and Europe. Different species of willow, as well as some clones, vary considerably in their metal translocation patterns and their ultimate resistance to heavy metals. This research extends the study of willows' response to heavy metals to North American species.

The efficacy for phytoremediation of five willow species was tested by experimental copper and cadmium uptake in a greenhouse hydroponic system. The willow species used in the study were S. *discolor* Muhl., *S. eriocephala* Michx., *S. exigua* Nutt., *S. nigra* Marsh. and *S. lucida* Muhl. Five treatments included two concentrations (5 and 25 µM for each metal) and a control. Metal concentrations in solution and in plant tissues as well as solution uptake were monitored. Metal resistance was assessed through effects on dry weight of roots and shoots.

Metal uptake, translocation and growth response varied with metal, application levels, and species. The difference in sensitivity between species to high metal content ranged from the stimulation of root and shoot growth to their severe inhibition. Growth and transpiration were not decreased by 5 µM of copper and 25 µM of cadmium in the solution for most species. 25 µM copper caused foliar injury in *S. exigua* and *S. eriocephala* and reduced dry weight for all species after 21 days. Inhibition of growth in Cd treatments was evident only for *S. lucida*. In contrast, growth of *S. nigra* and *S. exigua* was stimulated even at high Cd concentration. The analysis of metal content in plant tissues revealed that the metals taken up by the plant go to the aerial tissues. The copper content of aerial tissues was relatively lower than that of cadmium while cadmium appears to be more mobile within the plant.

Results indicate that *S. exigua* exhibited resistance to Cd, but not to Cu, while *S. nigra* was resistant to both metals. *Salix nigra* is the most promising North American species for phytoremediation research because of its high total metal content, its ability to translocate Cu and Cd into wood and leaves, and its capacity to maintain high biomass during the experiment, especially in Cd treatments. Future field study should be conducted to confirm the findings and feasibility of phytoremediation technology using those species.

Key Words: contaminated sites, *Salix*, heavy metals, phytoremediation, translocate.

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SALICACEAE: BIOTECHNOLOGICAL TOOLS FOR THE RESTORATION OF STREAMS WITH TORRENTIAL FLUVIOMETRIC FEATURES

Enrique Matthei Jensen [1]

Fluvial biotechnology is used to restore streams to a more natural state, and aims to achieve infinite energy recycling. It not only protects the exposed river banks from undermining, but also makes possible recycling of sediments, both carryover and suspended, with good nutritional characteristics. These techniques have very low energy input and low costs.

Consolidation and stabilization of the sensitive adjoining soils and sites is assured, since the natural flood plains start working again as a very specific ecosystem, and the area becomes a damper to high water flow rates.

Paradigm changes are involved in replacing a labyrinth of banks and rocks through forest hydrological restoration. This should be done using streamside species, which are adapted to sites subject to flooding through use of their strong root systems.

The tree cover generates biomass - using short-rotation high-quality fibre - enhances the landscape, filters the air, and cleans the water of bacteria, chemicals and toxic heavy metals.

By using this clean technology, efforts have focused on cooperating with nature, instead of making an attempt to control it. Soon, a living stream can be created, with so-called (by biologists) “life support” functions.

Therefore, as happens with every natural activity through which on-going improvements may be created, such stabilizing, biomass-generating, air-filtering and water-cleansing activities, with enhanced landscape values should be given very high value, in order to encourage increased political awareness and assure a better future.

Key Words: Salicaceae, fluvial biotechnology, energy recycling, clean technology.

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EFFECTS OF POPLAR-WHEAT INTERCROPPING ON THE ATMOSPHERIC CO_2 CONCENTRATION ABOVE THE CROP CANOPY

Meng Ping[1], Zhang Jingsong, Zhang Qiwen

This paper takes the poplar-wheat intercropping system as an example for analysis of the effects of intercropping on atmospheric concentrations of CO_2. This is intended as part of a study of the ecological impacts of the agroforestry system and in order to provide theoretical support for agroforestry development in agricultural plain regions.

The experiment site was chosen on the Huang-Huai-Hai plain in China (115°33'E, 38°20'N), with a temperate continental monsoon climate. In the poplar-wheat intercropping system, the poplar plantation rows are 215 m long with a south-north orientation and spacing was 3 m × 30 m. Planted in the autumn of 1987, poplar trees, *Populus tomentosa* Carr, were 18.2 m in height with a crown width of 4.2 m and a DBH of 22.6 cm at the time of the study. The wheat was sown on 2 October 1997. Experiments were conducted using a wheat monoculture system as a control treatment.

The results indicate that during the period from wheat jointing to ripening, the daytime CO_2 concentration at 0.5 m above the wheat canopy on a clear day was about 7.53% lower in the intercropping system than in the control. The difference tended to increase with time, from 4.47% during the jointing stage to 7.48% and 11.87% during the flowering and ripening stages respectively. The daytime CO_2 concentration was always lower in the intercropping system than in the control and the difference was larger in the middle of the day than in the morning or evening. However, the daily pattern of changes of CO_2 concentration was almost the same in both systems.

The CO_2 concentration near the wheat canopy changed in a 'W' pattern with distance to the tree rows, i.e. the CO_2 concentration is higher near tree rows than in the centre of the intercropping system. The CO_2 concentration near the crop canopy at S1m and N1m was higher than that in the control, and was lower at S2m, S4m, S8m and N2m, N4m, N8m, but there was no significant difference in CO_2 concentration between SN15m and the control. The reduced daytime CO_2 concentration near the crop canopy in the intercropping system did not cause significant decline of photosynthesis in the wheat. Due to the limits of the experimental conditions, this study only considered temporal distribution of CO_2 concentrations along the horizontal dimension and the difference between the intercropping and the monoculture systems. More studies on the vertical (different locations above crop canopy) dimension will be needed.

Key Words: poplar-wheat intercropping system, atmospheric CO_2 concentration.

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MEETING REGULATORY REQUIREMENTS USING POPLAR AND WILLOW FOR WASTEWATER TREATMENT

Drusilla Riddell-Black[1], Jud G. Isebrands, Gill Alker

The use of poplar and willow in the management of wastewater has many technical and economic advantages and frequently is the most appropriate, sustainable technology for a given set of circumstances. However, regulatory agencies are generally unfamiliar with this approach to wastewater treatment and find it difficult to apply regulations developed for a more traditionally engineered approach. Equally, potential users of the technology are attracted to its green image and comparatively low capital cost, but despite these benefits, they require guaranteed, rather than estimated discharge quality standards. These can be difficult to quantify without extensive laboratory, glasshouse or field based testing, for which they are unwilling to pay.

Key criteria by which a proposed treatment facility or management strategy would be judged by a regulator are not necessarily relevant or applicable to a system employing willow or poplar. Similarly, key elements of tree based systems can fall outside regulatory terminology, and the need to categorise a facility within fixed boundaries such that unnecessary pre-treatment is demanded or inappropriate and costly licensing required. Even when a system is approved by a regulator, an excessively high level of monitoring may be called for because of a lack of confidence in the technology, reducing some of the cost benefits of a plant based treatment system and decreasing user confidence in the technical soundness of the approach.

The challenge is to provide both regulator and wastewater producer with information by which they can make a direct comparison between the merits of willow and poplar based wastewater treatment systems and conventionally engineered facilities. This paper will use site specific examples from landfill sites, a milk processing facility, a solvent recycling plant and a beef abattoir, to examine where regulation can potentially stop the development of facilities employing poplar and willow for wastewater treatment. It will then consider how these regulatory barriers may be overcome and look at where research needs to focus to facilitate greater regulatory acceptability of tree based wastewater management systems.

Key Words: willow, poplar, landfill leachate, regulation, wastewater.

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ENVIRONMENTAL ASPECTS OF BIOMASS PRODUCTION: THE "POPLAR FREE AIR CO_2 ENRICHMENT (POPFACE)"[1] EXPERIMENT AS A MODEL TO STUDY THE IMPACT OF THE INCREASING CO_2 ON AGROFORESTRY SYSTEMS

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The ecophysiological responses of trees and tree communities to global change, particularly in response to the predicted increase of atmospheric CO_2, will be crucial in determining the ability of woody plantations and natural forests to sequester carbon at the global scale. The few studies conducted at the whole-tree and community scale indicate that there will be a marked increase of primary production, but this increment will be mainly allocated into below-ground biomass. The present research combines a fast-growing, agro-forestry ecosystem, capable of elevated biomass production, with a large-scale FACE (free air CO_2 Enrichment) infrastructure (European FACE or EUROFACE), the only one available in the European Union in a forest tree stand.

The main objective of this experiment is to determine the functional responses of a cultivated multiclonal poplar plantation to actual and future atmospheric CO_2 concentrations, and to assess the interactive effects of this perturbation caused by human activities with the other natural environmental constraints on key biological processes and structures. Additionally, this project will yield relevant data to assess the potential for increasing the carbon sequestering capacity within the European Union, using such forest tree plantations. This project, therefore, combines the FACE technology with the study of mechanistic and process-based responses of a forest tree plantation, used as a model. Tree plantations represent a particular type of intensively managed ecosystem where the emphasis is placed on maximising biomass production over a relatively short time-scale.

The POPFACE experimental site was established near the city of Tuscania (Viterbo, Italy), on an agricultural field, 9 ha wide. The facility consisted of six circular experimental plots, each 314 m^2 wide. Three of these plots were treated at 550 ppm of CO_2 concentration, the forecasted concentration for the middle of this century, whereas the remaining plots were at ambient CO_2 concentration. The plantation was realized in spring 1999 utilising 30-cm long hardwood cuttings of three different poplar species, *Populus alba*, *P. nigra* and *P. x euramericana*; plant spacing is 1 x 1 m within the plots and 2 x 1 m in the remaining plantation, according to the principles of a high density, short rotation culture. The entire area was watered by drip irrigation throughout the project.

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Above-ground woody biomass of trees exposed to elevated CO_2 for three growing seasons increased by 15 to 27%, depending on species. As a result, light-use efficiency increased. Above-ground biomass allocation was unaffected, and below-ground biomass also increased under elevated CO_2 conditions, by 22 to 38%. *Populus nigra*, with total biomass equal to 62.02 and 72.03 Mg ha^{-1} in ambient and elevated CO_2, respectively, was the most productive species, although its productivity was stimulated least by atmospheric CO_2 enrichment. There was greater depletion of inorganic nitrogen from the soil after three growing seasons in elevated CO_2, but no effect of CO_2 on stem wood density, which differed significantly only among species.

The present study contributes to clarification of the implications of carbon allocation for long-term carbon storage on agro-forestry systems.

Key Words: poplars, short-rotation-forestry, agroforestry, global change, carbon sequestration, FACE facility.

VISUAL IMPACTS OF ENERGY-WOOD PLANTATIONS TO RURAL LANDSCAPE AS AN ATTRACTION FACTOR

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The concept of renewable resources has become an important factor in agriculture, forestry and related trade and industry. The intention to reach economic welfare and at the same time protect the environment and meet the social needs of areas is a challenging mission. Sustainable management includes the socio-cultural values that the landowners, local inhabitants and the public have for agriculture and forestry. One of those social values is the aesthetic value of rural areas. Landscape can also be considered as an indicator of cultural sustainability. The restructuring of agriculture has significant long-term impacts on rural landscape, biodiversity and recreational values.

Expanding demand of bioenergy causes large scale visible changes in the rural landscape. If the scenario of using 5 million hectares or even 1.5 million hectares for the cultivation of e.g. woody energy crops would realise in the EU, it could regionally mean a remarkably big change in the agricultural landscape. Short rotation forestry changes the appearance of the previously open agricultural landscape. The willows will grow to 6-7 m in height before harvest. It is often claimed that large uninterrupted short-rotation forests would lead to a decrease both in the landscape diversity and in the attractiveness of landscapes in most cases. The choice of land for short rotation forests is thus of significant importance and stresses the need for including landscape management when planning changes in agricultural land use.

In the future, the land-use decisions of landowners are increasingly affected by the preferences of potential recreation users, particularly in areas where a growing part of the income is based on eco-tourism. Landscape is one of the most important attractions of travelling and a factor affecting the rural livelihood, as a large proportion of tourist utility, may depend on the diversity and attractiveness of the rural landscape. The attitudes are generally negative towards new land-use forms that change the traditional agricultural landscapes. However, the visual impact of, for example, afforestation depends on the original quality of landscape, its familiarity, economic connections and many other things. On the other hand, the visual quality of afforested fields seems clearly to be a more desirable alternative compared to unmanaged set-aside fields. It is also important to notice that when asked, for example, Finnish people rank total positive effects (also other effects than effects on quality of visual landscape) of field afforestation as more important than negative impacts.

Key Words: rural tourism, attraction factors, visual impact, sustainability, renewable energy.

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