ICPEP-3

Global Climate Change and Food Security in a Growing World

Sagar Krupa
Professor, Department of Plant Pathology, University of Minnesota
St. Paul, MN 55108, USA

Global climate change is one of utmost international concerns. There is a perception among many that global climate change is simply global warming. In fact, global climate change is an integrated system of several atmospheric phenomena and their products. At the surface, concentrations of greenhouse or radiative gases such as carbon dioxide, chlorofluorocarbons, methane and nitrous oxide have clearly increased since the onset of the industrial revolution. These trace gases, in addition to warming the surface air temperature by trapping some of the energy from the outgoing radiation, when transported into the stratosphere (10-15 km above the surface), destroy the beneficial ozone layer naturally present at that height. Such a loss in the thickness or thinning of the ozone layer will permit the increased penetration to the surface of deleterious wavelengths of solar radiation (Ultraviolet or UV [B- band], 280-315 nanometers, 1 nanometer = one billionth of meter), with much concern for consequent increases in the incidence of melanoma or skin cancer.

Average global air temperature has increased by about 0.8° C above pre-industrial levels and a 2001 report by the Intergovernmental Panel on Climate Change projected a rise from 1.4° to 5.8° C by the year 2100. While this prediction is extremely important, there is a significant amount of spatial variability in the air temperature. Local climate in different geographic areas may very well become warmer and drier, cooler and wetter or remain unchanged. Any change in the climate is expected to manifest itself as increases in the frequency of extreme events such as hurricanes, blizzards, heat waves and the number of days without precipitation during the plant-growing season (drought).

Increases in air temperature can accelerate crop growth and consequently shorten the growth period. In cereal crops for example, such changes can lead to poor vernalization (e.g., hastened flowering) and reduced yield. There is also evidence that since the 1950s, in North America, in China and in the former Soviet Union, nighttime temperatures have increased much more than the daytime values (because of increased cloud cover due to air pollution and formation of hygroscopic, cloud-forming aerosols in the atmosphere), with the potential to reduce reproductive development in many crop species and consequently, their seed yield.

In developed countries, agriculture is supported by a complex system of research; education, finance and farm supply overlying the agricultural potentials of the arable soils. Public policy and agricultural management will attempt to develop strategies for maintaining crop production in areas with best soils, in spite of shifts in climate. Of equal or greater importance than the direct effects of rising air temperatures is the indirect effect on the hydrologic cycle, leading to shifts in the dependence on irrigation, where water is available. For example, projected drier summers in parts of the USA corn-belt will probably result in a shift from the production of corn to grain sorghum. This has serious economic consequences. Currently USA ranks #1 in the world in corn production (41% of the global production) and the area of its cultivation is on the rise, particularly since it is the largest source for ethanol (through fermentation) used as fuel in automobiles.

In as much as changes in air temperatures will have an impact on crop production, so will increases in the surface concentrations of carbon dioxide and ozone and elevated levels of ultraviolet-B radiation. Most unfortunately, much of our knowledge on these effects is based on experimental studies directed to changes in one variable at a time. Increases in the carbon dioxide concentrations are expected to increase the biomass in many crop species (particularly C3 plants such as soybean and rice, in comparison to C4 plants such as corn and sorghum). However, as seen in the greenhouse production of horticultural crops such as lettuce, increases in biomass may not always translate to acceptable nutritional quality of the consumed product, due to the increases in the accumulation of starch in the foliage at the expense of soluble carbohydrates and decreases in the protein content, unless nitrogen fertilization is practiced. In as much as the beneficial effects of increasing carbon dioxide concentrations on crop production are frequently cited, increasing levels of surface ozone (generated from precursor pollutant emissions, primarily from fossil fuel combustion) and ultraviolet-B radiation produce deleterious effects. Rapidly growing number of studies show that the adverse effects of ozone and ultraviolet-B radiation offset the beneficial effects of carbon dioxide. Since all three variables are on the rise (accounting, however, for their spatial variability), questions remain as to the outcome of their joint effects, superimposed on other climate variables such as shifts in air temperature and soil moisture availability and biotic factors (incidence of pathogens and pests).

While plant canopies serve as a sink for carbon dioxide during photosynthesis (daytime), they are a source during the night due to respiration. Furthermore, soils are a larger source for carbon dioxide due to increased microbial respiration and litter or biomass decomposition under increasing temperatures. Equally importantly agricultural emissions of greenhouse gases are governed by the use of nitrogen fertilizers (increased nitrous oxide emissions from the soil as a greenhouse gas) and animal husbandry (increased ammonia emissions from manure leading to atmospheric nitrogen fertilization by deposition, for example, in precipitation). Those are major concerns in the context of the contribution of agriculture to the climate change issue (warming air temperatures due to the former or shifts in biodiversity due to the latter). In addition, rice paddies are a major source of methane (a greenhouse gas). As populations grow in Asia (by some 29% in 2030), so will the area under rice production, to sustain the food supply.

Clearly the issues associated with deteriorating air quality are a global concern. Satellite data document the spread of aerosols all the way from West Africa to northeastern India to China. India and China rank among the top countries in net human consumption of primary food production. India also ranks at the top in the withdrawal of more than 40% of its total available fresh water supply, in comparison to China (20-40%) and the USA (10-20%). By the year 2050, a majority of the global population is projected to be at a high risk of suffering from water stress. Currently Asia supports more than one half of the global population, with a projected increase of 29% by the year 2030. In comparison, population is expected to increase in Africa by 65%, North America by 26%, and South America by 31% and in contrast, a decrease by 6% is predicted for Europe. The increases in the populations of Asia, Africa and South America are projected to be largely due the birth rates while increases in the US population would be mainly due to immigration.

It is very educative to examine the status of the present and projected global agricultural production within these overall scenarios. Currently the ratio of rural to total populations is for: the world - 52%, China - 65%, India - 71% and the USA - 20%. Similarly the ratio of agricultural to rural populations is for: the world - 80%, China - 94%, India - 73% and the USA - 10%. These are telling statistics of the major dependence of the two most populous countries in the world (China and India) and in addition, some others, on intense human labor for food production and sustainability, compared to the US.

China, India and the US account equally for some 40% of the total area in the world under crop production. Yet the agricultural production in metric tons per capita of the total population is for: the world - 0.26, China - 0.29, India - 0.20 and the USA - 1.4. The large difference between the statistic for the US and the others is due mainly to the use of complex and highly mechanized and managed crop production systems in the US, compared to the emphasis on manual labor elsewhere. In the US these types of statistics have led to some adverse, shortsighted consequences. There has been a progressive decline in the number of individual farmers and a converse increase in corporate mega-farming. In addition fluctuations in the commodity prices, the so-called surplus food supply and imports of foreign plant products have worked negatively against the profitability of individual US farmers and thus, the decline in their numbers.

The genetic base of domesticated or cultivated plants is very narrow compared to their wild relatives. Thus, many currently grown crops are considered to be genetically depauperate. Elite lines and hybrids derived from such germplasms are designed to yield well under relatively narrow and well-defined growing conditions. However, superior genotypes are used heavily in various crop-breeding programs, often resulting in considerable relatedness among cultivars grown across large geographic areas, although some cultivars may have more narrow distribution than others.

In general, the narrow genetic base and specific goals used in the breeding of virtually all modern crops make it unlikely that crop breeders will be able to accommodate large and rapid changes in the climate. On the other hand if climate change occurs gradually, production agriculture will be able to adapt to such changes as long as farm resources are not limiting. Nevertheless, if indirect selection of crops to climate change is practiced, it will prove to be an inefficient process. Thus, there will be an increasing need for regions able to sustain high crop production in the future to distribute their surplus food supply to others subjected to adverse impacts, particularly to populations in dire need. That might prove to be a critical determinant of future world populations.

The US agriculture is influenced by: (a) increased urbanization, (b) increasing population migration from rural to urban communities, (c) farming by increased mechanization and consequently decreased dependence on labor, (d) increased area under cultivation of crops developed through the application of biotechnology and consequently better disease, pest and weed control, (e) gain of higher yields and (f) farm consolidation through mergers (mega- corporate farms). In contrast, factors influencing food security in the developing countries include: (a) increasing population, (b) rapidly growing urbanization, (c) decreasing crop land, (d) decreasing farm resources, (e) continuing crop loss, (e) declining crop production and (f) declining biodiversity.

The number of mega cities (greater than 10 million population per city) has increased from 2 in 1950 to 28 in 2004. In 2001, the numbers of poor people (living on $1 or less per day) were concentrated primarily in East Asia, Sub-Saharan Africa and South Asia. During 1998, as equivalents of 1990 $, significant long-term growth in GDP (Gross Domestic Product) per capita was predominantly in Western Europe, Japan, US, Canada and the Oceania. Based on 2003 statistics, according to the Organization of Economic Cooperation and Development (OECD), additional foreign support needed for developing countries to reach 0.5 level of GDP in billions of $, among all developed countries, the US and Japan were the worst in giving aid. In contrast, Sweden and the Netherlands were the most generous with no additional aid required to reach the 0.5 GDP level. Thus, there is a major gap among the main nations of wealth and those that need support for sustainability of their society and their agriculture.

In the final analysis, scientists will continue to study the critical and important issues of the effects of adverse air quality and climate change on crop production. Unfortunately, some scientists have and will use socio-political reasons to further their own cause. Fortunately, in general, those types of activities are transient by nature (e.g., the rise and fall of the acidic precipitation research program in the US during the 1980s and 90s). At the end, sustaining the future global populations through food production and food security would require scientific integrity and a much broader and holistic understanding of the many coupled, but complex facets of our society and their feedbacks to the continuing process of environmental change and its impacts.

As the famous British born American writer, W.H. Auden once noted*:

"*Little upon his little earth, man contemplates the universe of which he is both judge and victim*"

(W.H. Auden, *Commentary*)

* According to the author of this article (SK), in a broader sense, the quotation from Auden should not be interpreted as being gender specific.

ICPEP-3

Environment & Biodiversity: Agenda for future

P. Pushpangadan & H. M. Behl
National Botanical Research Institute
Lucknow - 226 001, INDIA

India's economic growth is moving forward at seven to eight per cent a year, making it one of the fastest growing economies of the world. Fast and unregulated urbanization is threatening traditional ways of life and increasing pollution merely due to lack of understanding of sustainability, proper management, poor partnerships between industry, community and research & development.
Global efforts to eradicate poverty (income of less than US# 1 a day) are currently focused on the Millennium Development Goal (MDGs). The eight goals first articulated by the United Nations in September 2000 have been in place for five years.

UN Millennium Goals

1. Eradicate extreme poverty and hunger
2. Achieve universal primary education
3. Promote gender inequality and empower women
4. Reduce child mortality
5. Improve maternal health
6. Combat HIV/AIDS, malaria and other diseases
7. **Ensure environmental sustainability**
8. **Develop global partnership for development**

Goal # 7 and 8 are crucial that will lead to sustainability. India has achieved self-sufficiency in food yet several stomachs are still hungry. Out of these majority are those that till the land, produce food for others, are small landholders or rural landless.

The environment today

Environment covered water, air, land, and the inhabitants. The focus was on air and water pollution and its abatement. The **National Environmental Tribunals Act 1995** was enacted to provide for strict liability for damages arising out of any accident occurring while handling any hazardous substance and for the establishment of a National Environment Tribunal for effective and expeditious disposal of cases arising from such accidents, with a view to giving relief and compensation for damages to persons, property and the environment and for matters connected therewith or incidental thereto. Biodiversity was not emphasized while defining environment. Forest, wild life, agriculture, fishes etc. were considered as components of environment but the concept of biodiversity as defined by the Convention on Biodiversity is a recent introduction in the definition of environment. The country did introduce

Green Benches as constituted by the Chief Justice of the respective High Courts either on their own or on directions from the Chief Justice of the Supreme Court to constitute exclusively a bench (quorum consisting of more than one Judge) to deal with matters relating to environment. However, it did not focus on the issues related to sustainability that cannot be decided in courts.

The **Environmental Statement** is defined by the International Chamber of Commerce as "a management tool comprising a systematic, documented, periodic and objective evaluation of how well environmental organizations, management and equipment are performing with the aim of helping to safeguard the environment by **a)** Facilitating management control of environmental protection; and **b)** Assessing compliance with company policies which, would include muting regulatory requirements. Safeguard of biodiversity and sustainable development do not figure in the Environment Statement.

India is the first country in the world that has provided for constitutional safeguards for the protection and preservation of the environment. In the constitution of India, specific provisions for the protection of environment have been incorporated by the Constitution (42 amendment) Act, 1976. Now, it is an obligatory duty of the State and every citizen to protect and improve the environment. The Directive Principles of State Policy contain specific provisions enunciating the State commitment for protecting the environment. "The State shall endeavor to protect and improve the environment and to safeguard forests and wildlife of the country". Furthermore, duties of the citizens towards environment are contained in Article 5 1 -A(g), This Article says :- "It shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wildlife, and to have compassion for living creatures" However, the scenario of pollution and environmental damage is alarming. The natural resource base is under siege; poor water management degrades and squanders as precious resource, it is linked to the urbanization of poverty, UN secretary general Kofi Annan sustainable development

The other view on environment

There are contradicting reports on several issues such as global warming, climate change since these have international implications. Several climate scientists are divided on whether or not there is global warming. US scientists have a different view on the subject. "The core of the Bush policy was a voluntary goal of reducing emissions 'intensity' by 18 percent by 2012," says Aimee Christensen, executive director of Environment 2004, a political action group. Compare that to the targets set by the Kyoto Protocol, which would have mandated that by 2012 the U.S. return to emission levels 7 percent below those of 1990, or the McCain/Lieberman Climate Stewardship Act, which asked that the U.S. return to year 2000 levels of emissions. Both those plans would result in actual reductions, not just intensity reductions. However, these did not find approval of US government neither at home nor at international level.

Environment & Biodiversity: The paradigm change

Over the last century, population, market pressures and the development of new agricultural technologies have encouraged patterns of agricultural development tending towards agricultural intensification (i.e. increasing scales of monoculture production, intensive mechanical tillage, irrigation, and the use of synthetic fertilizer, pest control agents and a restricted diversity of crop and livestock varieties), often leading to natural resources degradation. The growing food demand by a wealthier and larger global population is expected to induce further encroachment of agriculture on unmodified ecosystems (10 billion hectares by 2050), with inevitable negative impact on biodiversity (WEHAB, 2002).

The majority of the human population increase is expected to take place in the biodiversity-rich developing countries of the tropics (e.g. the Caribbean, the Philippines, Sri Lanka and the Western Ghats of India), where 19 out of 21 regions of concentrated biodiversity ("biodiversity hot-spots") and human population in these areas is increasing faster than anywhere else). These areas of high population growth (many of which lie adjacent to protected areas) are also experiencing rapid changes towards urbanization where demand for agricultural products is expected to increase as income levels in these areas rise. The anticipated result of such demographic changes is that increased production pressures will be placed on both the wild lands and the agricultural production systems in and around protected areas.

A recent news item “Climate change threatens India: study” based on a study undertaken by Indian Institute of Management-Ahmedabad, TERI and NIO, Goa revealed that Teak and Sal forests may dry out due to higher temperatures, the production of wheat, rice and other major crops could fall and monsoon rainfall will rise, with a drastic impact of climate change in India. It said that 85 percent of India's forests will change due to climate change by 2030-2100 and that rising sea levels will impact coastal railways, roads, major river basin ecology, and rainfall. They also found that incidents of malaria could increase and climate change could introduce malaria in new areas. The NIO, Goa study clearly showed that "the southern peninsular coast will be the most vulnerable to sea level rise". They also observed that there could be large-scale loss of biodiversity. There will be large increase in net primary productivity" but "unique forest systems could suffer irreversible damage” (http://www.biodiv.org/headlines.aspx). Reports like this need a serious look into the management practices at local, regional, national and international level.

Biological diversity - or biodiversity - is the term given to the variety of life on Earth. The biodiversity we see today is the result of billions of years of evolution, shaped by natural processes and, increasingly, by the influence of humans.

CBD & Environment: Holistic approach

The Brundtland Commission established the conceptual link between biodiversity and sustainable development, reflecting a process of thought and international dialogue that led to the United Nations Conference on Environment and Development in Rio de Janeiro in 1992. Recognizing the fundamental role of biodiversity in supporting human life, the Convention on Biological Diversity, a legally binding landmark treaty, was opened for signature at the Rio Earth Summit and entered into force in 1993. Among the existing global biodiversity-related agreements, it was the first to cover all aspects of biodiversity and to acknowledge the role of biodiversity in sustainable development. The Convention presently has 188 members, reflecting nearly universal participation. The three main objectives of the Conventionthe conservation of biodiversity; the sustainable use of its components; and the fair and equitable sharing of the benefits arising out of the utilization of genetic resourcesare reflected in the text of the Convention, which contains both substantive commitments and provisions for the establishment of a framework for implementation.

SECOND GLOBAL BIODIVERSITY OUTLOOK meeting is scheduled in a few days. **2010 Biodiversity Targets** have been proposed in the provisional agenda. It has been realized that there is a threat to biodiversity from human activities. It has been reaffirmed that biodiversity is the living foundation for sustainable development, that the rate of loss is still accelerating, that threats must be addressed, and that the Convention remains a key tool for sustainable development. For these reasons, the Conference of the Parties adopted a Strategic Plan, in which Parties committed themselves to a more effective and coherent implementation of the three objectives of the Convention in order to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level, as a contribution to poverty alleviation and for the greater benefit of all life on earth. In order to achieve the Strategic Plan, and its 2010 biodiversity target, this plan has been proposed in the agenda to develop a framework.

The focal areas are:

1) Reducing the rate of loss of the components of biodiversity, including:
   (i) Biomes, habitats and ecosystems;
   (ii) Species and populations; and
   (iii) Genetic diversity;
2) Promoting sustainable use of biodiversity;

3) Addressing the major threats to biodiversity, including those arising from invasive alien species, climate change, pollution, and habitat change;
4) Maintaining ecosystem integrity, and the provision of goods and services provided by biodiversity in ecosystems, in support of human well-being;
5) Protecting traditional knowledge, innovations and practices;
6) Ensuring the fair and equitable sharing of benefits arising out of the use of genetic resources; and;
7) Mobilizing financial and technical resources, especially for developing countries, in particular, least developed countries and small island developing states among them, and countries with economies in transition, for implementing the Convention and the Strategic Plan.

People are having a major and growing impact on the biosphere, the long-term consequences of which are feared by many but are in fact not at all well understood. There are currently well over six billion people on the planet, and the human population is expected to reach nine billion by mid-century. Each person has the right to expect adequate food, clean water, safe shelter, and energy, the provision of each of which has profound ecological implications. Food must be grown on land or in water, water must be clean to drink, shelter must be constructed from ecosystem-derived materials, and energy must be harnessed from natural processes.

For the purposes of assessing progress towards the target to achieve by 2010 a significant reduction in the current rate of biodiversity loss, biodiversity loss is defined as the long-term or permanent qualitative or quantitative reduction in components of biodiversity and their potential to provide goods and services, to be measured at global, regional and national levels (decision VII/30, paragraph 2). The "current" rate is taken to be the rate in 2002, when the Strategic Plan was adopted.

This minimum demand is massively amplified however, by the wasteful consumption of resources over and above the level needed to meet basic human needs. This growing demand for luxury products among a relatively small segment of the world population is leading to a greater loss of biodiversity, with consequences for all. As biodiversity is lost, the provision of ecosystem goods and services may also be undermined, with a negative effect on human well-being. Recently, the Millennium Ecosystem Assessment concluded thatof the ecosystem services it assessed, and that make a direct contribution to human well-being15 of 24 were in decline.

Biodiversity loss can have indirect effects on human well-being as well. By disrupting ecosystem function, biodiversity loss leads to ecosystems that are less resilient, more vulnerable to shocks and disturbances, and less able to supply humans with needed services. The damage to coastal communities from floods and storms, for example, increases dramatically following conversion of wetland habitats, as the natural protection offered by these ecosystemsincluding regulation of water run-offis compromised. Recent natural disasters in Asia and North America serve to underline this reality.

The real costs of biodiversity loss are already recognized to pose a significant barrier to the achievement of the Millennium Development Goals (MDGs). Yet many of the actions that could be implemented most quickly to promote economic growth and reduce hunger and povertyfor example, intensification of agriculture, or conversion of forestsare harmful to biodiversity, and would undermine the long-term sustainability of any development gains. Recognizing the trade-offs and synergies that exist between poverty alleviation and biodiversity conservation will therefore be essential to achieving many of the targets of the MDGs.

Trends & progress towards the 2010 biodiversity target

Biodiversity indicators

Biodiversity indicators are information tools, summarizing data on complex environmental issues. They can be used to assess national performance and to signal key issues to be addressed through policy interventions and other actions. Indicators, therefore, are important for monitoring the status and trends of biological diversity and, in turn, feeding back information on ways to continually improve the effectiveness of biodiversity management programmes. Small sets of indicators that focus on key issues are referred to as headline indicators, and when used to assess national or global trends, build a bridge between the fields of policy-making and science.

Focal area: Reducing the rate of loss of the components of biodiversity, including: (i) biomes, habitats and ecosystems; (ii) species and populations; and (iii) genetic diversity

- Trends in extent of selected biomes, ecosystems and habitats
- Trends in abundance and distribution of selected species Change in status of threatened species
- Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socio-economic importance Coverage of protected areas

Focal area: Maintaining ecosystem integrity, and the provision of goods and services provided by biodiversity in ecosystems, in support of human well-being

- Fragmentation of ecosystems
- Water quality in aquatic ecosystems

Focal area: Addressing the major threats to biodiversity, including those arising from invasive alien species, climate change, pollution, and habitat change

- Nitrogen deposition
- Trends in invasive alien species

Focal area: Promoting sustainable use of biodiversity

- Area of forest, agricultural and aquaculture ecosystems under sustainable management Ecological footprint and related concepts

Focal area: Protecting traditional knowledge, innovations, and practices

- Status and trends of linguistic diversity and numbers of speakers of indigenous languages

Focal area: Ensuring the fair and equitable sharing of benefits arising out of the use of genetic resources Indicator to be developed

- Perhaps even more difficult than the identification and development of indicators on traditional knowledge is to develop such indicators on the status of access and benefit-sharing, the third objective of the Convention. Few countries have legislation in place on access to genetic resources and the sharing of benefits arising out of their utilization and established procedures to enforce this legislation. As the Ad Hoc Open-ended Working Group on Access and Benefit-Sharing develops options for an International Regime on Access and Benefit-Sharing, it will also consider ways to assess the degree to which this objective is achieved and seek to develop appropriate indicators.

Trends in invasive alien species

Ecosystems that are out of balance - for example as a consequence of fertilization/eutrophication - are particularly vulnerable to the establishment and spreading of non-native species, including pests and pathogens. Such invasive alien species can have devastating impacts on native biota, causing extinctions and impacting on valuable economic species. Invasive species can transform the structure and species composition of ecosystems by repressing or excluding native species. In the recent past, the rate and risk associated with alien species introductions have increased enormously because human population growth and human activities altering the environment have escalated rapidly, combined with the higher likelihood of species being spread as a result of increased travel, trade and tourism. A major source of marine introductions of alien species is hull fouling and the release of ballast water from ships, although other vectors, such aquaculture, and aquarium releases, are also important, and less well regulated than ballast water.

Conclusion

On the basis of the information available to date a common message emerges: that biodiversity is in decline at all levels and geographical scales, but targeted response options whether through protected areas, or resource management and pollution prevention programmes - can reverse this trend for specific habitats or species.

There should be no illusions. Achieving the 2010 biodiversity target requires not only a redoubling of efforts, but a firm commitment to act according to the priorities identified through the Strategic Plan. The conservation and sustainable use of biodiversity need to become an integral element of planning, policy, and practice for all economic and social sectors of society. We all derive benefits from biodiversity, and will all suffer from its loss. We do need to acknowledge however that failure to deal with biodiversity loss will burden the poor disproportionately. Proof of the compassion and care of the global community for the poor can be shown by ensuring that the basis for their livelihoods is conserved, used sustainably and the benefits shared equitably. These are heavy commitments. The burden however can be lessened and synergy realized at all levels through cooperation and the contribution of all.

ICPEP-3

How Air Pollution Can Change the Response of Plants to Other Environmental Stresses

JNB Bell
Professor of Environmental Pollution, Centre for Environmental Policy/Division of Biology
Imperial College London, Silwood Park campus, Ascot
Berkshire, SL5 7PY, UK.

Introduction

It has been known since the 17th century that air pollution can cause serious damage to vegetation, causing both visible blemishes on foliage and/or reductions in growth and crop yield. Research into this topic started in the late 19^{th} century, initially in Germany, but followed rapidly by the UK, USA, Canada and elsewhere. Initially interest was centred on the traditional pollutants in the form of coal smoke and SO_2, later it was realised that there were other phytotoxic pollutants present in the atmosphere. Thus in the period after World War II interest shifted to photochemical oxidants, particularly O_3, formed as secondary pollutants resulting from complex atmospheric chemical reactions involving nitrogen oxides and volatile organic compounds under conditions of high temperature and sunlight. The recognition of O_3 as a widespread pollutant, particularly in rural areas, occurred first in California, then elsewhere in North America, followed by Europe and Japan in the 1970s and much more recently in some parts of the developing world, although in the latter case the severity of the problem is largely unrecognised. Subsequently other pollutants became recognised as of major importance, notably NO_2 and NH_3 and their products. Widespread problems are not restricted to O_3, because acid rain and total nitrogen deposition are known to cause large scale problems of acidification and eutrophication, respectively.

The best example of an attempt to estimate the economic impacts of air pollution on crops was the National Crop Loss Assessment Network (NCLAN) carried out in the USA in the 1980s, followed by a similar programme in Europe. This concentrated mainly on O_3 and predicted a loss of $3 billion per annum for the 10 principal widely grown crops in the USA. It should be noted that this programme concentrated on the **direct** impacts of pollution on crop yield. However, there are a numerous other stresses, both abiotic and biotic, which cause enormous losses to agriculture, up to an order of magnitude higher than the estimates of NCLAN. Thus if the response of plants to these other stresses could be modified by air pollution, then the economic consequences could be substantial, including both negative and positive effects. In this article a brief overview will be given of the evidence for air pollutants impacting on these other stresses.

Abiotic stresses

There are a wide range of abiotic stresses which impact vegetation, including frost/low temperature, high temperature, drought, salinity, wind and mineral deficiency/toxicity. The best researched areas of interactions of abiotic stresses with air pollution are for frost and drought, with, to a much lesser extent, salinity.

Frost

There is abundant evidence that air pollutants can sensitise plants to frost damage, particularly in the case of SO_2 and O_3. Numerous controlled experiments have demonstrated that fumigated plants which are subsequently exposed to low temperatures show much greater frost injury than those that were previously exposed to charcoal-filtered clean air. Much interest in this issue was shown in both eastern North American and Europe during the 1980s, when major research programmes examined the possible role of O_3 in "forest decline". This followed observations that tree health showed particularly severe deterioration following harsh winters. It was demonstrated conclusively that a summertime fumigation with O_3 resulted in increased sensitivity to subsequent frost stress, including visible injury and delayed hardening in a number of tree species. Likewise it is now well known that heather in European heathlands, impacted by high levels of N deposition is sensitive to frost damage, leading to gaps in the canopy which permit the invasion of nitrophilous grasses and deterioration of these habitats of high conservation value.

Similar effects have also been demonstrated for herbaceous species, including grasses, cereals and clovers. In the UK the potential for SO_2 to exacerbate frost injury has been shown in both laboratory and field studies. In the latter case, of particular interest are observations at two open-air fumigation systems, where cereals were subjected to SO_2 in fields where different plots received different concentrations of SO_2 from computer controlled arrays of pipes. In such a situation the crop is subjected to all the local natural stresses, both abiotic and biotic. It was recorded in both systems that following periods of cold weather injury was significantly greater in the plots which had been fumigated with SO_2, with an indication of a dose/response relationship. My own research group has demonstrated a similar phenomenon, but this time caused by ambient pollution. In February 1986 we were carrying out an overwinter experiment in which four cultivars of red clover were grown in open-top chambers, ventilated with ambient or clean charcoal-filtered air, or else in outside chamberless plots. This month was exceptionally severe for the south of England, as the temperature fell below zero for four weeks. At the end of this period severe low temperature injury was seen on all the experimental plants, this being similar in the outside plots and the ambient air chambers, but significantly reduced in all cultivars in the charcoal-filtered chambers. Thus ambient air pollution had sensitised the clovers to frost injury. The pollutant(s) involved could not be identified unequivocally. O_3 can be dismissed as it is not elevated under winter conditions, but it is known that large areas of Western Europe, including the UK were blanketed in a cloud of high SO_2 concentrations at the time, although the role of NO_2 cannot be precluded.

Drought

It is generally held that drought reduces air pollution injury by reducing stomatal conductance, thereby inhibiting the uptake of pollutant gases into the leaf. However, this appears to be a complex situation, about which it is difficult to generalise, not the least because air pollutants have been demonstrated both to open and close stomata, depending on species, pollutant concentration and prevailing environmental conditions. In the case of soya beans in the USA and trees in the UK it has been shown that the nature of the O_3/drought interaction reverses, depending on pollutant concentration.

Of particular interest is a study in the UK, which showed that pretreatment with a SO_2+NO_2 mixture predisposed a grass species to drought stress. The grass was fumigated with a range of pollutant concentrations or else kept in clean air, before all plants being transferred to the latter treatment, with half being kept well-watered and the other half droughted. The watered plants showed no effect of pollution pretreatment, but the droughted plants showed a concentration-dependant reduction in growth, when pretreated with SO_2+NO_2. As in the case of frost injury, there has been considerable interest in the role of O_3/drought interactions in contribution to forest decline, in view of the latter apparently becoming worse following very dry summers. However, it is difficult to elucidate the respective roles of these two stresses in view of the fact that very dry summers always coincide with particularly high O_3 levels.

Biotic stresses

As in the case of abiotic stresses, their biotic equivalents are responsible for massive crop losses worldwide. These can take many forms, the principal being fungal pathogens, herbivorous insect pests, viruses, bacteria and nematodes. The interactions of air pollutants on all of these have been investigated, with emphasis on fungal interactions.

Fungal pathogens

Observations have been made for many years that the incidence of a range of fungal pathogens appear to be related, either positively or negatively, to elevated levels of air pollutants, most of these being in the vicinity of point sources. In general it appears that biotrophs (fungi not readily cultured in the absence of the host) were reduced in pathogenicity, while non-biotrophs showed a more mixed response. It was postulated that the former was a reflection of the intimate connection between the metabolism of the pathogen and the host, with pollutant-induced impairment of the latter resulting in damage to the fungus. In the case of stimulation it was suggested that injury to the host's surface provided courts of infection for the pathogen.

Many studies have been carried out on pathogen/pollutant interactions, although only a relatively small number of the vast range of potential combinations have been investigated. Thus only a selection will be given here, concentrating on the results of my own research group. One particularly interesting study of ours involved investigation of the natural infection of barley, growing in one of the open-air SO_2 fumigation systems mentioned earlier. This showed that in three successive growing seasons infection by powdery mildew was stimulated by SO_2, but the reverse occurred for leaf blotch. A controlled fumigation with the same concentrations of SO_2 in chambers confirmed the causal nature of the field system observations. The use of economic models for infection/crop yield reduction of these host/pathogen systems indicated that the combined net effect of them would be negative at all concentrations employed. Of particular interest here is the fact that powdery mildew is classed as a biotroph, indicating that the suggestion that biotrophs are reduced in infection by air pollution is certainly not a universal phenomenon.

There are two interesting cases where fungal pathogen incidence has been related to air pollution levels to the extent that they are considered to be (and in one case has been) employed as biomonitors. Both of these have been investigated by my group. The first of these is blackspot of roses a ubiquitous disease of rose leaves. In the past when SO_2 levels were very high in many parts of the UK, this disease was reported as absent from the more polluted areas. A study in the mid-1960s showed that its incidence was negatively related to the prevailing SO_2 concentration in a study of nurseries nationwide. The causality of this relationship was confirmed by controlled fumigation experiments.

Subsequently with the massive fall in concentrations, anecdotal evidence indicated that it had reinvaded locations where it was formerly absent. A study by a member of my group involved revisiting the locations of the 1960s survey and showed clearly that reinvasion had occurred everywhere and that there was no indication of any relationship with the residual SO_2 levels. The second disease was rather more controversial and studies have produced intriguing results. This was the tarspot of sycamore, which takes the form of large black lesions on the tree's leaves. A field study in cities of northern England in the mid-1970s showed a negative relationship between a calculated tarspot index (TSI: number of spots per leaf unit area) and SO_2 concentrations, which showed a similar cut-off level for total elimination as in the earlier blackspot research. Thus it was postulated that TSI was a good bioindication of prevailing SO_2 concentrations and it was incorporated into lichen biomonitor surveys in parts of northern England in the 1970s. However, a survey in the mid-1980s in Edinburgh failed to find the same relationship, and it was suggested that the earlier findings were an artefact viz. that in the more polluted areas towards the centre of cities the activities of street cleaners and park keepers increasingly removed the only source of inoculum in the form of spores overwintering on dead leaves on the ground. I used this example some years ago in a lecture I gave on a short course on environmental science for lawyers, as an exemplary lesson in the dangers of attributing causality to observed relationships. It was entitled “Correlation and Causality: Park Keepers or Pollution”! However, I had to eat my words! In the late 1980s some of the last controls on SO_2 emissions from domestic coal-burning were imposed around colliery villages in north-east England. A colleague from the local University of Newcastle upon Tyne observed that with falling SO_2 concentrations, not only did black spot of roses show reinvasion, but so also did tarspot of sycamore! Intrigued by this we studied the relationship between TSI and air pollution in the London area and a region of northern England (around the city of Sheffield). In the case of the Sheffield area tarspot had been recorded as absent in the mid-1970s in the more polluted places, in a biomonitoring study. When we resurveyed the area in 1999 the disease was prevalent in effectively all sites, and showed no relationship to the contemporary (much lower) SO_2 concentrations. Interestingly there was one site where it was absent: in the very middle of Sheffield, where a single tree was surrounded by concrete paving and there was no possibility of spores surviving overwinter to reinfect. Thus there was overwhelming evidence that SO_2 and TSI were negatively related and that the latter was potentially a good biomonitor. However, as part of the same study, the TSI of sycamore trees was measured along a transect of 50 km from a rural area into central London. It was found that the disease disappeared within London. Initially it was postulated that its relative short spore dispersal distance might have delayed reinvasion. However, this was refuted by a field study where saplings from a clean area were exposed along the same transect, together with inoculum in the form of infected dead leaves placed alongside. Again the fungus failed to reinfect within London. There would appear to be only two possible explanations: differences in climate along the transect and/or increasing NO_2 concentrations towards central London. The former can be dismissed as the changes in climatic parameters between the rural area and central London are far less than those around the UK, where the disease is ubiquitous (including Edinburgh). The most likely explanation is that the fungus is sensitive to NO_2, a pollutant which has its highest levels in the UK in London. This would suggest the potential for TSI to be used as a biomonitor for NO_2.

Insects

As in the case of fungal pathogens, for many years there have been field observations of changes in herbivorous pest (both sucking and chewing) infestation of vegetation in polluted areas. These have largely shown increases in incidence, but there are some opposite cases, particularly at very high pollutant concentrations. These observations have been made around point, diffuse and line scources (in the form of busy roads). Various studies have examined the causality and underlying mechanisms of these effects, employing field, filtration, fumigation and survey techniques. Some of the work of my research group on this topic will now be summarised.

Our initial work started as a result of discussions between myself and a colleague. The latter was an entomologist, interested in the relationship between host plant chemistry and herbivorous insect performance. My colleague was well aware that subtle changes in the amino acid composition of a plant could have major impacts on the performance of insects feeding on it. I was aware (from the literature) that air pollution could influence plant amino acid composition. Thus, *ipso facto*, we established the hypothesis that air pollution could alter pest infestations via changes in plant chemistry. We had no funding to test this hypothesis, but then in 1982 a gift arrived from Germany in the form of a student who wanted to carry out his Diplom Arbeit with us, and we suggested this topic. Probably one of the best decisions we ever made! As in other work, we developed a programme to verify the causality of field observations. For many years colleagues had worked on models to predict the outbreak of the serious sucking pest, black bean aphid, on crops in summer, by studying the number of eggs on its overwinter host in different parts of the country. Consistently these models underpredicted the outbreaks in areas impacted by the pollution plume downwind to the east of London. Thus we decided to investigate the impacts of SO_2 and NO_2 on this aphid. We fumigated the bean for short periods with SO_2 and NO_2 and then put the plants in clean air. Weighed aphids were caged on the leaves of fumigated plants and then reweighed three days later. It was demonstrated that the growth rate of aphids feeding on previously fumigated plants was increased above that of those on clean air controls. A parallel study examined the growth rate of aphids feeding on artificial diets, mimicking bean phloem sap, and showed no effect. Thus our hypothesis was confirmed that air pollution could change pest performance via effects on the host plant and most of our subsequent research has suggested that this is mediated via plant chemistry, particularly shifts in amino acid composition. Subsequently we have shown that this phenomenon is widely distributed across a wide range of pest/host plant systems. More confirmation of the relationship was determined by three further parts of the same investigation: a filtration study in central London showed the same effects, as did a transect exercise in which plants were exposed along a declining gradient of air pollution out from central London; finally an examination of aphid trap data around the UK showed that most species occurred at greater levels in areas with higher SO_2 pollution. The magnitude of the response of these insects which have a very short life cycle, indicates that they could readily escape the control of their natural enemies in the form of predators and parasites. Subsequent research has confirmed this, including measurements of infestation by aphids on barley in one of the field SO_2 fumigation systems discussed earlier. Ozone has also been shown to affect aphid performance, mediated via the host plant. Our own work has shown in chamber filtration experiments in a rural area that the pollution climate of a relatively low O_3 summer produced a substantial increase in colony size of black bean aphids feeding on beans. Other work has shown that O_3 levels only just above the natural background can produce substantial increases in aphid growth rates. In the case of O_3 there is evidence that there may be complex interactions with duration and temperature of exposure.

Conclusions

The subject of air pollution impacts on plant response to natural stresses remains relatively little studied. Yet it has potentially very significant implications for crop production not least in developing countries. It has so far been totally ignored in the establishment of air quality standards and guidelines, with the single exception of the United Nations Economic Commission for Europe's incorporation of extreme low temperatures into the critical levels for forests and natural vegetation, which are lowered by 25% in such circumstances. My conclusion is that the world is missing the opportunity to address a really serious threat to food security, notably in developing countries. Everybody understands the importance of frost, drought, insect pests and pathogens. Few understand the direct impacts of air pollution on crops. And fewer still understand the potential for the first of these to be impacted by the second!

Bibliography

Davison, A.W. & Barnes, J.D. (2002) Air pollutant-biotic stress interactions. In: Bell, J.N.B. & Treshow, M. (eds.) *Air pollution and plant life*. 2nd edition. John Wiley & son, Chichester. Pp 359-377.

Flückiger, W., Braun, S. & Hiltbrunner, E. (2002) Effects of air pollutants on biotic stresses. In: Bell, J.N.B. & Treshow, M. (eds.) *Air pollution and plant life*. 2nd edition. John Wiley & son, Chichester. Pp 379-406.

The Biotron: An Experimental Climate Change Research Facility

A. Singh[1], M. Dixon[2], B. Grodzinski[3], N. Huner[4*]
[1]*Chetna Research Institute, London, Ontario, Canada, www.chetnaresearch.com*
[2]*Dept. of Environmental Biology, University of Guelph, Guelph, Ontario, Canada, N1G 2W1*
[3]*Dept. of Plant Agriculture, University of Guelph, Guelph, Ontario, Canada, N1G 2W1*
[4]*Dept. of Biology, University of Western Ontario, London, Ontario, Canada, N6A 5B7*
**Corresponding author (nhuner@uwo.ca); Web: www.biotron.uwo.ca; www.ces.uoguelph.ca*

Overview

The Biotron is a modular, interdisciplinary, experimental climate change research facility developed through funding from the Canadian federal government, the Ontario provincial government, the University of Western Ontario (Western), the University of Guelph, Agriculture & Agri-Food Canada (AAFC), and several foundations and corporate contributors. Construction of the Biotron started in May 2005 and will be completed in 2007.

Major innovations of the Biotron include, first, the capacity to assess the impact of climate change on the interactions of plants, insects, and microorganisms. On the rooftop, six large, environmentally-controlled mesocosms or Biomes will provide a realistic location for testing concepts developed on the lab bench or in growth chambers. Thus, the Biotron enables the integration of experimental climate change research from the molecular scale to the mini-ecosystem scale. Second, the Earth Science Biome features a custom-designed, 6 meter high, controlled environment soil monolith system which will allow researchers to transport intact, 10,000kg soil columns from the field into the facility at experimental containment temperatures ranging from approximately -30°C to +40°C. Third, all imaging systems, analytical instruments, and growth chambers from each module will be integrated through an IT backbone that allows remote access and control from any web-browser. Last, the Transgenic Module includes two, federally certified, Containment Level 3 (CL3) laboratories for work on airborne biohazardous plant and microbiological pathogens, with a contiguous large, walk-in growth chamber.

The facilities summarized above represent Phase II of an ongoing multi-stage project. In 1999, Phase I of the Biotron Project was established as the Controlled Environment Systems Research Facility (CESRF www.ces.uoguelph.ca) located on the campus of the University of Guelph. The primary focus of the CESRF is the evaluation of plant-based life support systems for space travel and related terrestrial applications. Research partners associated with CESRF include the aerospace, chemical, and agricultural industries.

The research mission of the Biotron is to:

- accelerate our understanding of the responses to and consequences of global climate change on terrestrial and aquatic ecosystems;
- support and stimulate the shift of growth markets towards a "bioeconomy" in the areas of medicine and agriculture;
- assess and quantify the potential environmental benefits and risks associated with emerging biotechnologies on biodiversity and general ecosystem health.

The resulting deliverable will be a blueprint for long-term, ecosystem health in conjunction with sustainable economic growth in the medical and agricultural sectors of the global economy.

The research mission will be accomplished by:

- integrating research in environmental biology, medicine and agriculture;
- providing unprecedented experimental scale and flexibility with respect to controlled environment research on organisms as diverse as microbes, plants and insects in terrestrial and aquatic ecosystems.

Research Modules

The Biotron is a Level 2 containment facility designed on a modular basis. It serves as a premier research venue hosting unique Biomes and containment features in addition to several labs that provide the latest tools in plant, insect, and microbiological research. The facilities are designed with multiple air-locks and pressure cascades to prevent cross-contamination between modules or the release of organisms and pollen to the environment. Each module contains a fully equipped wet laboratory and serves as staging areas for experiments in the Biomes and they also support their own distinct research programs.

Biomes

Available in the Biotron are six large, custom-designed, environmentally-controlled, roof-top Biomes exhibiting enhanced Level 2 containment which are designed to allow multi-disciplinary teams to create and simulate integrated ecosystems including plants, insects, soil microbes, fungi, and algae. The biomes combine natural sunlight which either can be augmented by artificial lighting or reduced by activated, shading systems. Furthermore, all biomes are equipped with an array of micro-sensors to enable strict analysis and computer control over factors such as CO_2, temperature, light intensity, and precipitation.

The Biomes allow researchers working at the molecular level to scale up experiments to the mini-ecosystem level. Conversely, they allow ecologists to scale down experiments performed under variable field conditions to environmentally-controlled conditions within a biome. Thus, the biomes allow researchers to design various mesocosms and simulate pertinent climate change scenarios in order to assess the impact of an array of environmental factors on plant-soil-insect-microbe interactions, and bio-risk assessment of emerging biotechnologies and pollutants.

The Earth Sciences module contains a custom-designed, environmentally-controlled biome in which soil monoliths (1x1x6m) can be studied from regions as diverse as the Arctic tundra to modern agricultural fields. The Earth Sciences biome is suitable for the

investigation of climate change on soil structure, soil hydrology, soil microbiology, as well as plant-soil-microbe interactions. This specialized biome exhibits dual isolated temperature zones over two stories, individually programmable in the range of -30ºC to +40ºC with surface irradiance ranging from complete darkness to 80% full sunlight.
Ancillary facilities include a central analytical laboratory with state-of-the-art instrumentation including inductively coupled plasma, ion chromatography, gas chromatography-mass spectrometry, and X-ray fluorescence for soil and hydrological analyses.

Central Image Data Server (CIDS)

A unique feature of the Biotron, which strengthens its collaboration capabilities, is the capacity to provide researchers with real-time, world-wide experimental and data access and management. At the core of the Biotron's scientific functionality will be its secure, high-speed, web-accessible imaging database and data analysis system. The system will allow image acquisition and analytical systems data to be stored, annotated, retrieved, processed, and accessed on a central server from the initiating workstation, Biotron computer labs, or remotely through the internet. Additionally, Biotron computer labs will provide users with collaboration tools such as video and web conferencing, and access to high-end image analysis and processing software. Imaging technologies available in this suite feature the latest in confocal microscopy, digital light and fluorescence microscopy, transmission electron microscopy, and scanning electron microscopy. Contiguous with the Imaging suite is a spacious central laboratory for sample preparation, sectioning, coating as well as a cell tissue culture laboratory.

Plant Growth & Productivity

The components of this module located at the University of Western Ontario are contiguous with the newly relocated Environmental Stress Biology Group. The module houses 19 growth cabinets which include custom-designed, ultra-low growth cabinets which can attain temperatures as low as -20ºC at 80% full sunlight and -40ºC in the dark. In addition, specialized controlled growth facilities are available for modulating CO_2 concentrations, temperature, high light, UV levels and humidity singly or in combination in a constant or oscillating mode. Enhancing the functionality of these growth facilities are four new research laboratories that include a core instrument facility, a state-of-the-art flow cytometry facility, as well as a new fluorescence spectroscopy imaging facility. The CESRF component of this module includes 8 custom-designed, controlled environment growth rooms capable of providing temperatures ranging from - 20ºC to +40ºC, irradiance ranging from complete darkness to 80% full sunlight to assess plant canopy gas exchange. This enables the continuous and non-invasive measurement of plant growth and biomass production.

Insects

The Insect module is designed to allow research on the propagation and experimentation on a diverse array of insects such as drosophila, aphids, mites, mosquitoes, bees, moths, butterflies and caterpillars via a series specialized colony rearing and experimental growth chambers which can mimic habitats as diverse as the Arctic, desert, and tropical regions. The research enabled by this biome includes the study of the effects of environmental change on the interactions between plants, herbivores, and natural pest predators. In addition, this module provides a basis for the development of insect pest and disease vector control technologies through chemical ecology and/or biotechnology.

Transgenic Plants

The Transgenic Plant module provides facilities that will not only enable basic research in the use of transgenic plants to study plant growth, development, and productivity, but will also enable scientists and industrial partners to assess the ecosystem risks of genetically modified organisms (GMOs) on wild, endemic species. The facilities contain advanced tools for the development of novel GMOs in molecular farming, which consists of genetically engineering plants to produce therapeutic or nutritional substances such as vaccines, antibodies, proteins, enzymes and polymers. Included in this area are six walk-in transgenic growth rooms, a specialized pesticide delivery laboratory, a seed storage room, a general media preparation room, a cell transfer laboratory, a large transformation laboratory, and two Level 3 containment laboratories.

Microbiology

The Microbiology Module enables a diverse array of research including the examination of the origins of human pathogens and their progression from the soil to human diseases as well as microbial molecular ecology, biodiversity, and global biogeography. The laboratories provide excellent cryogenic facilities to culture and preserve newly discovered species of soil, airborne, as well as insect-borne fungi. A separately contained laboratory for mould research minimizes potential contamination of other micro-organisms with fungal spores. An important feature of this module is the presence of 48 specialized incubators providing unique temperature gradients for microbial growth. In the context of global warming, this is essential to establish a firm understanding of the role of temperature in determining the geographical distribution of large numbers of microbial isolates as well as the role of temperature in regulating microbe-insect-plant interactions important in maintaining natural vegetation, crop productivity and plant biodiversity.

The Future Phase III

Phase III, to be centered in Guelph adjacent to the existing CESRF, involves the development of larger scale autonomous robotic greenhouses. It endeavors to develop innovative robotics technologies that can be applied to the production of greenhouse crops for human consumption and molecular farming while augmenting controlled environment technologies toward the goal of completely sealed greenhouses. This has relevance in that it will seek to alleviate the significant labor and energy demands of the burgeoning greenhouse industry, while creating biological life-support technologies for manned interplanetary missions.

Growing Threats to Environmental Security

Prof. C.K. Varshney
Former Dean and Professor, School of Environmental Sciences, Jawaharlal Nehru University New Delhi- 110067.

Since the Stockholm Conference the concern for environmental security has rapidly grown and is now considered an important issue of global agenda for peace and security. In spite of its growing importance there is no unanimity among scholars about the meaning and content of environmental security. Traditionally, the notion of national security has been understood as a set of conditions that guarantees the ability of a State to protect its citizens, and pursue its national interests, free from both real and imagined impediments and threats. In contrast, environmental security is concerned with relative safety from environmental change caused by natural or human processes due to ignorance, accident, mismanagement or design and originating within or across national borders. Environmental change implies destabilizing the delicate ecosystem equilibrium developed and fine tuned over billions of years of evolution. Threats to environmental security are usually diffuse, unintended, trans-national, cause and effect often separated in time and space, have long term implications, and their resolution require commitment and cooperation from a wide range of actors.

Over exploitation and ecosystem degradation poses serious threat to environmental security. Environmental deterioration and degradation involving deforestation, decertification, reclamation of wetlands, damming of rivers, clearing of riverine and mangrove vegetation in coastal areas have frayed the natural safety net that healthy ecosystems provide. According to recent estimates environmental degradation is threatening the health and livelihoods of two billion people living in arid regions round the world.

Ecosystem disruption and over exploitation of natural resources are important drivers of violent conflict within and between States, leading to human misery and loss of life. Ecosystem disruption from natural disasters - Tsunami, floods in Mumbai, Hurricane Katrina - caused: large scale devastation, unprecedented misery and loss of human life. Weather related' disasters have growing economic and human toll. The economic losses from such type of disasters during 2004 were almost twice the total in 2003. Unless effective prophylactic and remedial measures are taken, tsunami and Katrina type of disasters will soon be common feature in the coming decades.

Instead of invading armies we must now contemplate the like of 'invading' pollution, rising sea levels, increased ultra violet radiation, and increased threat of diseases, such as malaria, HIV/AIDS, SARS, and bird flue that are as much threatening as any warfare. Reckless tampering with the earth's life support systems and habitat loss has taken heavy toll of the regions rich biodiversity resources. Continued loss of biological diversity threatens human health and undermines economic potential. Threats to environmental security are potential trigger of economic and political conflicts. Moreover, environmental security is a prerequisite for achieving the 'Millennium Development Goals'

To protect the citizens and to ensure their wellbeing, nations must plan and promote environmental conservation for safeguarding environmental security. Healthy ecosystems form the underpinnings of environmental security, sustainable development and long term wellbeing of people. Often causes and origin of threats to environmental security layout side the national borders. Trans-boundary issues remain out side the scope of national legislation and institutions. For pragmatic reasons cooperation between nations is vitally important. Innovative means and mechanisms have to be devised to take collective action for environmental protection through policies that are cooperatively defined and implemented.

Growing threats to environmental security demand promotion of 'collective security', a new form of diplomacy and international co-operation. Resolution of environment security threats will not only remedy the environmental constraints but will also serve as confidence building measure contributing towards peace making. In view of global ecological interdependence there is a need to design new forms of ecologically enlightened development, diplomacy and governance.

Insect Resistant Transgenic Crops: A major contribution of plant biotechnology to environmental sustainability

Rakesh Tuli and D.V. Amla
National Botanical Research Institute, Rana Pratap Marg, Lucknow-226001

During the course of evolution, a broad spectrum of metabolic activities have evolved in lower to higher organisms with an enormous capability to degrade any natural material. An unfathomable opportunity exists in understanding the complex matrix of pathways and deploying those in a sustainable manner for the degradation of man made agrochemicals, pollution abatement and bioremediation. Genetic engineering is poised to offer some of the most powerful approaches to develop novel life forms aimed at keeping the environment cleaner and sustainable. Plant biotechnology has already given an outstanding example in this direction in global commercialization of insect resistant transgenic crop plants the Bt-cotton, maize and soybean. The approach aims at doing away with tones of chemical pesticides used globally in agriculture. Since Indonesia imposed a ban in 1986 on the import of 57 insecticides used in rice, combined with IPM strategies, the government is officially known to save US$ 120 m annually. The WHO estimates a loss of about 20,000 lives midst some 20,00,000 cases of health hazard to farmers every year globally due to the widespread use of agrochemicals. Cumulatively, pesticides worth more than US$ 30 billion are estimated to be used worldwide annually. Technological shift from chemical to biological approaches is the unavoidable need for sustainable agriculture. Some of the biggest multinational agrochemicals corporations, including Monsanto, USA and Zeneca, UK have already reoriented their strategies to plant biotechnology.

Since the commercial release of transgenic crops in 1994, their adoption by farmers has increased impressively. In 2004, biotech crops were grown on nearly 80 million hectares in 18 countries. Global socio-economic and environmental impact of transgenic crops have been made by several groups in recent years; the most exhaustive study by Graham Brookes & Peter Barfoot was release in October 2005 by the PG Economics Ltd., U.K. The study shows that the global farm income contributed by GM crops increased by about US$ 6 billion in 2004. The use of herbicide and insect resistant GM soybeans, maize, cotton and canola made a major impact on environment by reducing the usage of herbicides and insecticides (active ingredients) globally by about 6% through 1996-2004. In terms of the environmental impact quotient, a 14% net gain is estimated. Less frequent herbicide and insecticide applications and reduced tillage operations further lead to the savings in greenhouse gas emissions and fuel usage. In 2004, a reduction of about 1 billion kg carbon dioxide is estimated due to reduced fuel usage. This is equivalent to removing nearly 0.5 million cars from the roads. The adoption of GM herbicide tolerant crops reduces a number of tillage operations related to seedbed preparation and weeding. Not only that the tractor fuel use for tillage is reduced, soil quality is enhanced due to low tillage and soil erosion is prevented. In turn more carbon remains in the soil, leading to lower emission of greenhouse gases. An extra 3 billion kg of soil carbon (equivalent to 10 billion kg of CO_2, not released to atmosphere) may have been sequestered in 2004. These enormous gains to environment are inspite of the fact that as yet only a few agronomic traits have been engineered, that too in a small number of crops and in a few countries.

In India, pesticides worth Rs. 10 billion are used on cotton crop alone, which is more than half of the total pesticide usage in the country. The development of transgenic cotton and paddy for resistance to insect pests is a major need in responsible applications of recombinant DNA techniques and transgenic crops in the country. In 2002, GM Bt-cotton was first released in the country. It was grown on about 1.2 million acres in 2004 which is about 6% of the total area under cotton cultivation in India. National Botanical Research Institute, Lucknow has made major contributions in developing indigenous technologies related to the development of Bt-cotton. The development of insect resistant transgenic crops has several technical challenges, if chemical pesticides have to be largely replaced, without sacrificing yield, safety and sustainability. Some of the areas full of inventive opportunities are: need to discover new genes targeted against locally relevant insect pests, pyramiding genes to guard against the evolution of resistance in insects, economical evaluation of biosafety and environmental risks following the release of the pesticidal proteins and transgenic crops, designing proteins against specific pests, expressing the pesticidal proteins specifically at the site of infestation by insect pests etc. Several of these issues have been innovatively pursued at NBRI for the development of transgenic cotton, pigeon pea, chick pea, castor, groundnut and tomato, jointly with laboratories at other institutes in India. A variety of novel genes and promoters have been designed to develop transgenic lines for resistance to locally prevalent insect pests. A hybrid -endotoxin protein was designed against a polyphagous lepidopteran insect pest *Spodoptera litura*, which is tolerant to most of the known -endotoxins. The hybrid -endotoxin was created by replacing amino acid residues 530-587 in a poorly active natural Cry1Ea protein, with a highly homologous 70 amino acid region of Cry1Ca in domain III. The truncated -endotoxins Cry1Ea, Cry1Ca and the hybrid protein Cry1EC accumulated in *Escherichia coli* to form inclusion bodies. The solubilized Cry1EC made from *E. coli* was 4- fold more toxic to the larvae of *S. litura* than Cry1Ca, the best known -endotoxin against *Spodoptera* sp. None of the two truncated toxins, solubilized from *E. coli* caused larval mortality. However, trypsinised Cry1Ca protoxin obtained from *E. coli* and solubilized from inclusion bodies caused mortality of *S. litura* with LC_{50} 513 ng/ml semi synthetic diet. A synthetic gene coding for the hybrid -endotoxin Cry1EC was designed for high level expression in plants, taking into consideration several features found in the highly expressed plant genes. Transgenic, single copy plants of tobacco as well as cotton were developed. The selected lines expressed Cry1EC at 0.1-0.6% of soluble leaf protein. Such plants were completely resistant to *S. litura* and caused 100% mortality in all stages of larval development. Hence, unlike in *E. colii,* the hybrid -endotoxin folded into a functionally active conformation in both tobacco and cotton leaves. The truncated Cry1EC expression in tobacco leaves was about 8- fold more toxic (LC_{50} 58 ng/ml diet) as compared to expression in *E. coli*. Some of our researches in this area have been published in Transgenic Research (2004), vol 13, page 397-410. The possibilities in discovering new genes and organisms and engineering those for the abatement of pollution through agricultural chemicals are endless.

ICPEP-3

Biodiesel: Hitting the target

Hm Behl
National Botanical Research Institute
Lucknow- 226001, INDIA

Countries have their own priorities and vision for growth. Energy, however, remains the mainstay for all civilized world. The priorities may lay in cost economics, environment friendliness, import substitution, or self-sufficiency as strategic objective. Energy is one of the priority areas for the Nation. Indian scenario is unique and different from other developed or developing countries. It has vast areas that are wastelands and are not being utilized for cultivation since these are unfertile, dry, sodic, saline, or alkaline. Majority of its population lives in villages. The country has state of art technologies with high tech establishments. Human resource is available in plenty. It has achieved self-sufficiency in food sector, however energy and environment are sectors that are of concern for policy makers and scientists.

The country is deficient in edible as well as non-edible oil resources (Table 1). Its imports of edible oil are increasing with ever increasing demand. Non-edible oil resources too are scarce and underutilized. Vegetable oil offers immense opportunity to substitute fossil fuel to meet energy demands.

Oil provides energy for 95 % of transportation in India and the demand for transport fuel continue to rise. The requirement of diesel (HSD) is expected to grow from 39.815 MMT in 2001-02 to 52.324 MMT in 2006-07 and about 66 MMT in 2011-12. The domestic supply of crude oil will satisfy only about 22 % of this demand and the rest will have to be met from imported crude. Current consumption of petroleum is 120 MMT as against nearly 18 MMT in 1970.

All countries of the world, including those with surplus energy are banking upon vegetable oil as alternative source of energy by way of biodiesel. Developing countries cannot afford to utilize edible vegetable oil or even used vegetable oil. However, many of these countries, like India, have large tracts of wastelands and tropical climate suitable for cultivating a variety of plants that yield non-edible oil. Cultivation for oil in degraded, waste, abandoned and abused lands will provide sustainability, employment generation, and much needed oil to replace fossil fuels. The development of the nation is intricately interwoven with sustainability in energy.

Dr. Abdul Kalam, Honourable President of India has given a vision for the country. It includes:

- Bringing an additional 10 million ha of land under assured irrigation
- Providing road-connectivity to all villages having a population of 1000 (or 500 in hilly/tribal areas)
- Providing drinking water to the remaining 74,000 habitations that are uncovered
- Reaching electricity to the remaining 1,25,000 villages and electricity connections to 23 million households
- Developing biodiesel from *Jatropha curcas* as alternative energy resource in the country

Jatropha curcas: the magic option

Bio-diesel, the renewable liquid fuel from biological raw material is a good substitute for petroleum diesel. The country has a ray of hope since there is a potential to grow a variety of plants in different habitats. *Jatropha curcas* is the first choice for it can grow at saline to alkaline soils, in arid to semi-arid conditions, low slopes of hilly areas, degraded and abused soils. It does not need protection from grazing and browsing animals that number five times the carrying capacity of the nation.

Bio-diesel is gaining worldwide acceptance as an environmental friendly solution to energy problem. It is an accepted option for energy security, reduction in imports, rural employment, and improving agriculture economy. Bio-diesel results in substantial reduction of unburnt hydrocarbons, carbon monoxide, and particulate matter. Indian Oil Corporation Ltd. (IOCL) reported that maintenance cost of vehicles run on Bio-diesel has reduced substantially. The Bio-diesel has no Sulphur, no aromatics and has about 10% built-in oxygen that helps it to burn freely. Higher cetane number improves the combustion.

USA uses soybean for Bio-diesel while many European countries are using rapeseed or sunflower, frying oil and animal fat in Ireland, castor oil is the option for Brazil, coconut oil for Malaysia, palm oil in Thailand and Philippines, cotton seed in Greece, linseed in Spain, and *Jatropha curcas* or *Pongamia pinnata* for India. It has several alternatives such as Neem (*Azadirachta indica*), Karanj (*Pongamia pinnata*), Meswak (*Salvadora* species), Mahua (*Madhuca indica*), Rubber (*Hevea* species), Castor (*Ricinus communis*), *Diploknema butracea*, *Garcinia* species, Tung etc.

Jatropha curcas produces 1 to 6 kg (there are reports of 15 kg) per tree and seeds have 30 to 40% (total seed with kernel basis) oil. Fruiting initiates in less than two years and the yield optimizes in the fourth to fifth year and the plant produces seeds for nearly 50 years. With 2 kg a tree one hectare will provide nearly 1.5 tonnes of biodiesel apart from 3.5 tonnes of cake biomass.

Current status of Bio-diesel in the country

1. The Ministry of Petroleum & Natural Gas has laid down a Bio-diesel Purchase Policy which will come into effect from January 1, 2006 which prescribes that companies shall purchase Bio-diesel of standard quality through its notified centers at Rs. 25 a liter (initially). Depending upon the market conditions, the Oil Companies shall be free to review the price every six months. The Policy recognizes the vital role that can be played by the Panchayati Raj institutions in promotion of Bio-diesel. The policy notes that the Panchayati Raj institutions may in consultation with National Oilseeds & Vegetable Oils Board (NOVOD), Department of Biotechnology (DBT) and National Botanical Research Institute (NBRI) who are working on a network program for making available good quality plants, prepare and consolidate plans for cultivation of oil (non-edible) bearing trees.
2. Petroleum Conservation Research Association (PCRA) has opened a National Biofuel Center (NBC) at its headquarter in New Delhi that has information from “root-to-canopy” information to educate masses and information sharing www.pcra-biofuels.org.
3. PCRA has also introduced a Bio-diesel Bank that recognizes efforts of various bodies in promoting Bio-diesel. The Bank awards credit points for the work done on propagation, promotion, R&D efforts, imparting training, developing plants & machinery to promote Bio-diesel.
4. Uttranchal state has constituted Bio-fuel Board (UBB) for promotion of Bio-diesel in the state. Chhattisgarh ha formed a Biofuel Development Authority (CBDA). Andhra Pradesh government has set up a Task Force. Several other states have either formed task forces or promoted NGOs to take up plantation.
5. National Oilseeds & Vegetable Oils Board (NOVOD) has implemented an R&D network program in the country to develop practices for cultivation in nearly 1800 hectares in the country.
6. Department of Biotechnology (DBT) has initiated a Biofuel Mission and Jatropha micro mission to select good germplasm, develop quality planting material and

standardizing agro techniques.

7. CSIR has initiated a network program for genetic enhancement in association with industry under its prestigious NMITLI program.
8. National Botanical Research Institute Lucknow in association with Biotech Park, Lucknow has initiated efforts to educate farmers, industry and entrepreneurs, develop a model nursery, model plantation and certification of seeds for their oil. It has also partnered with IIP, Dehradun for providing end-to-end technology to industry. It is providing consultancy to several companies including Tatas.
9. Shatabadi trains are using B5 since December 2002 for their test runs.
10. Indian Oil Corporation (IOC) has tested passenger cars in association with Tatas. HPCL has carried out tests with BEST in Mumbai.
11. Gujarat State Road Transport and Haryana state is running its buses (Rewari depot) using B5.
12. Southern Railway is using 100% bio-fuel for running heavy vehicles like trucks, cranes, forklifts, jeeps and tractors.
13. Daimler Chrysler has taken a 5000 km test run of Mercedes using B5 in collaboration with CSMCRI.
14. D1 of U.K. has drawn enthusiastic plans to develop Bio-diesel in the country.
15. Several NGOs have plunged into Bio-diesel program and are cultivating *Jatropha curcas* for seed production.

The approach

The country ahs nearly 63 million hectares of wasteland, out of which 33 million hectares of wasteland have been allotted for tree plantation. Collective effort of farmers, NGOs, contract farming, industry and international promoters can produce sufficient feedstock to achieve Bio-diesel mix of 5 % in conventional diesel. The PURA concept of Dr. Abdul Kalam, Honourable President of India provides a good model for *Jatropha curcas* plantation and production of Bio-diesel. The President proposes that Bio-diesel plants grown in 11 million hectares of land can yield a revenue of approximately Rs. 20,000 crores a year and provide employment to over 12 million people both for plantation and running of the extraction plants. This is a sustainable development process leading to large-scale employment of rural manpower. Also, it will reduce the foreign exchange outflow paid for importing crude oil, the cost of which is continuously rising in the international market. He further states, “Can there be a better project than this for coherent development of our rural sector and sustainable business preposition for industry?”

Dandeli Ferro alloys [Karnataka] established in 1955 is a heavy consumer of electricity. It converted all five of their 1 MW diesel engines to run on biodiesel in Feb. 2001 and generated 760,000 kWh of energy entirely from *Pongamia* oil. *Pongamia pinnata* is another viable option as the country has large number of *Pongamia pinnata* trees in almost all the states.

Energy Independence: Vision of President of India

Energy is the lifeline of modern societies. But today, India has 17% of the world's population, and just 0.8% of the world's known oil and natural gas resources. We might expand the use of our coal reserves for some time and that too at a cost and with environmental challenges. The climate of the globe as a whole is changing. Our water resources are also diminishing at a faster rate. As it is said, energy and water demand will soon surely be a defining characteristic of our people's life in the 21st Century.

Energy Security rests on two principles. The first, to use the least amount of energy to provide services and cut down energy losses. The second, to secure access to all sources of energy including coal, oil and gas supplies worldwide, till the end of the fossil fuel era, which is fast approaching. Simultaneously we should access technologies to provide a diverse supply of reliable, affordable and environmentally sustainable energy.

With 114 million tonnes of annual requirement of oil we produce only about 25 % of our total requirement. The import cost today of oil and natural gas is over Rs. 1,200,000 million. Oil and gas prices are escalating; the barrel cost of oil has doubled within a year. The projections are that these might cross $100 a barrel.

Dr. Abdul Kalam, Honourable President of India defines Energy Security, which means ensuring that our country can supply lifeline energy to all its citizens, at affordable costs at all times, is thus a very important and significant need and is an essential step forward. He challenges that it must be considered as a transition strategy, to enable us to achieve our real goal that is - Energy Independence or an economy, which will function well with total freedom from oil, gas or coal, imports. He identifies that "Energy Independence has to be our nation's first and highest priority. We must be determined to achieve this within the next 25 years i.e. by the year 2030".

Vision for the oil sector, Dr. Abdul Kalam, Honourable President of India believes, "has to aim at providing to the nation at least 50% of its annual oil and gas need. Since we are dealing with fossil material resources, it may not be possible to meet this requirement fully from conventional oil exploration and extraction alone".

Bio-fuel Enterprises & Societal Missions

Panchayats have nearly 4.3 lakhs of surplus land. Similarly Railways, industry and Public sector has and that is not put to optimum use. Large tracts of wastelands, rural human resources, tropical climate and ready (never to be saturated) market for the finished product makes Bio-diesel industry as a very attractive business. However there has to be a different paradigm and approach. There is a win-win situation for industry as well as society.

Bio-diesel also has to compete with diesel in prices even though it is environmentally clean and technically more efficient. There may be huge costs of transportation of seeds, extracted oil, finished bio-diesel, managing cake (nearly 70% of seed production) etc. Ideal set up will be one where transportation of these products except that of finished product is least. PURA concept of Dr. Abdul Kalam, Honourable President of India where clusters of villages produce feedstock, extract oil; purify it to make it ready for trans-esterification; and convert seed cake to energy and good fertilizer will be a paradigm shift. It will shift the industry to villages and not otherwise. It not only fulfills the dream of Dr. Abdul Kalam, Honourable President of India in providing economic connectivity in the village clusters but also perhaps is the only option for the country.

Value addition by way of secondary products from oil & seed cake; alternative technologies and perfection of transesterification process involving least energy and least pollution till enzymatic conversion becomes feasible; and strategic and premeditated planning can take us to energy security. Indian model of bio-diesel production will be unique and will set a trend.

OILWISE / MONTHWISE IMPORT OF NON-EDIBLE OIL FOR THE MONTH OF NOV. '04 TO APRIL '05 WITH COMPARATIVE PERIOD FOR PREVIOUS YEAR (6 MONTHS) IN BRACKET (in M tonnes)

Month	*P.K.F.A.D.*	*P.F.A.D.*	*OTHERS*	*C.P.S.*	*C.P.K.O*	*Total*
Nov. 2004	- (900)	2,491 (6,577)	- (4,700)	11,536 (15,900)	3,849 (-)	17,876 (28,077)
Dec. 2004	- (-)	5,678 (11,235)	- (-)	8,718 (4,221)	3,501 (-)	14,396 (15,456)
Jan. 2005	- (1,007)	8,844 (6,049)	- (2,500)	11,555 (8,198)	1,500 (-)	20,399 (17,754)
Feb. 2005	1,704 (-)	7,647 (12,686)	- (-)	17,982 (4,432)	6,499 (-)	27,333 (17,118)
March 2005	- (-)	4,089 (14,185)	1,000 (1,000)	12,498 (6,131)	4,584 (-)	27,333 (17,118)
April 2005	500 (-)	5,800 (7,040)	- (-)	20,584 (10,725)	4,000 (-)	30,884 (17,765)
Total	2,204 (1,907)	34,548 (57,772)	1,000 (8,200)	82,873 (49,607)	23,933 (-)	144,559 (117,486)
2003-04	7,117	97,144	24,011	106,891	-	235,163
2002-03	5,665	123,991	27,767	121,945	-	282,463
2001-02	3,492	112,111	10,595	160,991	49,539*	338,529

P.K.F.A.D. - Palm Kernel Fatty Acid Distillate, P.F.A.D. - Palm Fatty Acid Distillate, C.P.S.- Crude Palm Stearin, C.P.K.O. - Crude Palm Kernel Oil

Source: http://www.seaofindia.com/alltables/sea_imports%202004-05.htm

Phytoremediation of Selenium and Other Toxic Trace Elements Norman

Terry and Danika LeDuc
Department of Plant and Microbial Biology, 111 Koshland Hall, University of California, Berkeley, CA 94720-3102, U.S.A.

Soils and waters in many areas of the world are polluted with toxic trace elements. These include metalloids such as selenium (Se) and arsenic (As), as well as heavy metals, e.g., cadmium (Cd), lead (Pb), chromium (Cr) and mercury (Hg). Because of the acute toxicity of these elements, there is an urgent need to develop technologies to remove or detoxify them. Phytoremediation, the use of plants and their associated microbes, offers an effective, low-cost and sustainable means to achieve this end. For contaminants present in soils, there are several different approaches of which three are presented here. *Phytoextraction* utilizes the ability of certain plants to take up contaminants from the soil and water and accumulate them in their tissues, which can then be harvested and removed from the site. *Phytovolatilization* makes use of the plant's ability to convert pollutants into volatile forms, which then escape to the atmosphere (e.g., Se, mercury). *Phytodetoxification* involves the ability of plants to change the chemical species of the contaminant to a less toxic form, as occurs when plants take up toxic hexavalent chromium (Cr) and convert it to non-toxic trivalent Cr. For contaminants present in wastewaters, *constructed wetlands* provide an effective, low-cost treatment system to remove a wide-range of contaminants from municipal wastewater as well as effluents from electricity generating facilities and oil refineries. Although this is not phytoremediation in the sense used above, plants nevertheless play a critical function in this form of pollutant removal. In this brief review, we highlight different aspects of our research on the phytoremediation of Se, as well as some heavy metal pollutants.

Constructed wetlands

Constructed wetlands are artificial wetlands specifically designed to improve water quality. Like natural wetlands, they are a complex mixture of water, sediments, living and dead plant materials, fauna and microbes. In essence, constructed wetlands act as giant biogeochemical filters able to remove contaminants present at very low concentrations from very large volumes of wastewater (e.g., Se from oil refinery wastewater). The filtration of contaminants that occurs in a wetland ecosystem takes place mostly in the layer of dead, partially decomposed plants, known as “fallen litter”, and in the fine sediment layer beneath the litter layer. These two layers provide habitat for microbes and other organisms able to transform contaminants into less bioavailable and therefore less toxic chemical forms. In addition to their role in generating the fallen litter and fine sediment layers, plants provide the fixed carbon that supports these microbial populations.

Much of our research has focused on Se, a pollutant present in wastewater from industrial and agricultural enterprises. In California, soils on the west side of the San Joaquin Valley were formed from the natural weathering of Se-bearing Cretaceous shales of the surrounding California Coast Range and are therefore enriched in Se. Since these Se- and salt-laden soils must be heavily irrigated to leach away the salts, large amounts of subsurface drainage water are produced, which is highly contaminated with dissolved Se. This drainage-water Se has been shown to be responsible for mortality, developmental defects, and reproductive failure in migratory aquatic birds and fish.

In an experiment designed to test whether constructed wetlands could be used to filter Se from irrigation drainage water, we constructed 10 quarter-acre wetland cells at the Tulare

Lake Drainage District in the San Joaquin Valley. Specifically, we wanted to know whether varying plant species influences the efficiency of wetlands for Se removal. Each cell was planted with one or a combination of the following plant species: sturdy bulrush (*Schoenoplectus robustus* (Pursh) M.T. Strong), baltic rush (*Juncus balticus* Willd.), smooth cordgrass (*Spartina alterniflora* Loisel.), rabbitfoot grass (*Polypogon monspeliensis* (L.) Desf.], saltgrass [*Distichlis spicata* (L.) Greene], cattail [*Typha latifolia* L.], tule [*Schoenoplectus acutus* (Muhl. ex Bigelow) Á. Löve & D. Löve), and widgeon grass (*Ruppia maritima* L.). One cell was left unplanted as a control. On average, the wetland cells removed approximately 69% of the total Se mass from the inflow. The presence of plants improved the efficiency of Se removal over the unvegetated cell but the particular choice of plant species was found to have no significant effect on Se removal. Rates of biological Se volatilization on the other hand, varied substantially with the type of species planted, with the highest rates of biological Se volatilization being recorded when the wetland cell was planted with rabbitfoot grass.

Most of the Se filtered out by the wetland cells was trapped in the upper sediment layers, which could present a serious ecotoxic risk over the long term. One way of alleviating the buildup of Se in the upper sediment layers of constructed wetlands is to increase the efficiency by which wetlands convert the Se into volatile forms. Plants and microbes are both capable of absorbing inorganic and organic forms of Se and metabolizing them to volatile forms, e.g., dimethylselenide (DMSe), which is 500-700 times less toxic than SeO_4^{-2} or SeO_3^{-2}. In this way Se is removed from the sediments, and its entry into the food chain diminished. Even though the volatilized Se may eventually be redeposited in other areas, this is not a problem in California where much of the state is deficient in Se with respect to the nutrition of animals, which require Se in low concentrations.

Genetic modification of plants to enhance phytoremediation

Because of the potential importance of biological Se volatilization to Se phytoremediation in both wetlands and uplands, research in our laboratory has focused heavily on genetic engineering strategies to improve Se volatilization by plants, as well as on increasing the ability of plants to extract and remove Se from contaminated soil. A useful approach for increasing phytoremediation efficiency is to overexpress enzymes catalyzing rate-limiting steps. Tagmount et al. (2002) showed that S-adenosyl-L-methionine:L-methionine S-methyltransferase (MMT) is the enzyme responsible for the methylation of selenomethionine to Se-methylselenomethionine and that this enzyme was rate limiting with respect to the production of volatile Se. Overexpression of MMT in Arabidopsis and Indian mustard (*Brassica juncea*) increased the rate of Se phytovolatilization approximately twofold over wild type.

Another, quite different approach is to use hyperaccumulator plant species as a source of plant genes to enhance phytoremediation. Milk vetch (*Astragalus bisulcatus*) is a hyperaccumulator that accumulates Se in its leaves to concentrations in excess of 4000 ppm. However, because it grows very slowly, it is of limited value for phytoremediation. It is able to accumulate Se to very high levels partly through the presence of the gene encoding selenocysteine methyltransferase (SMT). SMT converts the amino acid, selenocysteine (SeCys), which can cause toxicity when incorporated into protein, into the non-protein amino acid, methylselenocysteine (MetSeCys), thereby diminishing Se toxicity. Transgenic plants overexpressing SMT show enhanced tolerance to Se, particularly selenite, and produced 3- to 7-fold more biomass than wild type. SMT plants accumulated up to 4-fold more Se than wild type, with higher proportions in the form of MetSeCys. Additionally, SMT Arabidopsis and SMT Indian mustard volatilized Se 2 to 3 times faster when treated with SeCys and selenate, respectively.

Our greatest success in using genetically engineered plants for phytoremediation has been in the phytoextraction of Se from soil with high levels of Se, boron (B), and salt. Three transgenic lines of Indian mustard were used in the first transgenic phytoremediation trial in the U.S. One line overexpressed the enzyme ATP sulfurylase (APS), which facilitates the reduction of selenate to selenite and is rate limiting with respect to the production of reduced, organic Se compounds. Indian mustard plants overexpressing APS have increased tolerance and accumulation of Se. APS Indian mustard may tolerate metals better because it has higher concentrations of the thiol, glutathione (GSH), than wild type. Glutathione (γ-Glu-Cys-Gly) plays an important role in heavy-metal detoxification. GSH can directly form GSH-metal complexes and, as part of the active oxygen-scavenging system, can protect the plant cell from oxidative stress. GSH is also the direct precursor of phytochelatins (PCs), which bind, detoxify, and sequester metal ions to the vacuole. The other two lines tested in the field trial expressed genes in the GSH synthesis pathway, γ-glutamylcysteine synthetase (γ-ECS) and glutathione synthetase (GS). Overexpression of these enzymes in Indian mustard was first shown to confer increased tolerance to Cd in solution culture. This tolerance was correlated with 1.5 to 2.5 higher levels of GSH and PCs. In the field, all three lines accumulated more Se in their shoots than wild type. In fact, the APS line accumulated over four times as much Se as wild type. Additionally, the GS line was significantly more tolerant of the high Se, B, and salt sediment than wild type.

Phytodetoxification

The toxicity of the heavy metal, chromium (Cr), is of increasing concern because of its heavy use in many different industries, including metallurgy, electroplating, production of paints and pigments, tanning, wood preservation, Cr chemicals production, and pulp and paper production. It is especially toxic in its hexavalent form, Cr(VI). In this form, it is a highly toxic carcinogen, which may cause death to animals and humans if ingested in large doses. Chromium, in the trivalent form (Cr(III)), on the other hand, is an important component of a balanced human and animal diet, and its deficiency disturbs the metabolism of glucose and lipids in humans and animals. Plants have the ability to detoxify Cr(VI) by reducing it to nontoxic Cr(III). Using high energy X-ray absorption spectroscopy, research in our laboratory showed that many plants including water hyacinth and various vegetable crop species can convert Cr(VI) to Cr(III) in root and shoot tissues within hours after uptake. The ability of *E. crassipes* (water hyacinth) to reduce Cr(VI) to non-toxic Cr(III) could provide a significant approach for the *in situ* detoxification of Cr(VI) contaminated wastewater. Water hyacinth has an excellent potential for the phytoremediation of Cr in wastewater because (i) it has the ability to absorb and remove toxic Cr(VI) and then reduce it to nontoxic Cr(III); (ii) it can accumulate Cr in high concentrations in its tissues, especially roots; (iii) it produces very large amounts of biomass (106-165 $t\ ha^{-1}\ yr^{-1}$); and (iv) since the whole plant can easily be harvested, Cr accumulated in both shoots and roots can be removed.

Conclusions

Our research has shown that plant-based technologies for removing and detoxifying toxic trace elements from contaminated soil and water are effective, and more importantly, can be improved substantially using modern scientific approaches. One such approach is genetic engineering. Laboratory-produced transgenic plants can be effective in field scale cleanup, as shown by our recent research with transgenic Indian mustard, which more efficiently removed Se from highly contaminated sediments. Thus, genetic improvement of plants for phytoremediation has a great potential for improving environmental quality. Nevertheless, there are very few examples where genetic