G.J. Heij and J.W. Erisman (Editors). Acid Rain Research: Do we have enough answers?

Future of acidification research

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Abstract

Acidification is not a simple process operating separately from other geochemical, biochemical and biological processes. It is a part of an extremely complex ecological development of our nature influenced by energy - hungry ever growing human population. Acidification as a general biogeochemical process will be implicitly studied in most of the future ecological research projects dealing with global climate changes and land use changes There are many scientific, technological and even political questions to be solved to fight acidic pollution effectively. It is just a question of the significance of acidification with respect to other environmental processes and issues. The most important questions to be answered by the future research fall into following topics: (1) Questions related to the effects of reduction of emissions and mitigation practices on ecosystem development and present status of improvement of water and soil quality, (2) acidification impact on climate change, (3) acidification during land-use changes and organic matter transformations, (4) acidification and its influence on trace metal toxicity, (5) acidification during biogeochemical cycles of nitrogen, carbon and sulfur (6) socioeconomic factors with respect to environmental acidification. Other miscellaneous topics should be subject to future investigations before the process can be fully controlled and its harmful effects eliminated.

1. INTRODUCTION

Future of the research into environmental acidification will be determined by the past development of the subject. The occurrence of acid rain has a long history. It has been discussed since 1661 (Cowling, 1982). Smith (1852) wrote about air and rain of Manchester. An systematic monitoring and research of the process and its consequences to ecosystems started in seventies of this century following a news release and a scientific paper by Odén (1967, 1968). The history of the development of the environmental topic is well documented by Gorham (1981, 1991). Internationally, acidification was recognized as a serious environmental problem in Europe through the United Nations Convention on Long Range Transboundary Air Pollution signed in 1979. Within this Convention, research was lunched to learn more about causes and consequences of acidification in Europe. The National Acid Precipitation Assessment Program (NAPAP) in the U.S.A. was created by Congress in 1980 (Irving ,1992). Almost $400 million have been invested in sponsored research by NAPAP till 1989 (NAPAP, 1989). Acidification of water and forest soils has been an important research topic during the last 25 years by individual researchers, many government sponsored research programs, especially in Sweden (Anonymous, 1992), as well as by joint efforts of environmental programs lunched by the Commission of European Communities. The investigation of acidification has began later in Asia (Ogura N., 1992, Environmental Agency, 1993). Acid rain was reported even in an Amazon rain forest (Haines et al., 1983). During the last 25 years, detail knowledge has been gained about relationships between acidifying emissions of pollutants and physico - chemical and biological state of surface water, ground water and soil. It has been recognized that the intensified environmental acidification due to human activity is detrimental to aquatic and terrestrial ecosystems (e.g. Schindler, 1988, Schneider, 1992, Ulrich and Pankrath, 1983, Steinberg and Wright, 1994, Teller et al., 1992).

The most important information for future development of the topic is that acidification is not a simple process operating separately from other geochemical, biochemical and biological processes. To the contrary, it is a part of an extremely complex ecological development of our nature influenced by energy - hungry ever growing human population. Acidification is not a global problem, however, it is a regional phenomenon occurring frequently in industrial districts with a high intensity. The process has a character of a time chemical bomb. Often, it proceeds unnoticed, until a buffering capacity of nature is exhausted, and acids become detrimental to various natural and man made materials as well as to organisms. It is phenomenon which will stay with us as far as people will burn fossil fuels. During the last two decades, scientists have gained a solid understanding of the process (Teller et al., 1992, Steinberg and Wright, 1994, Anonymous, 1993). In spite of that, there are still many scientific, technological and even political questions to be solved to fight acidic pollution effectively.

2. ACIDIFICATION IN A FRAMEWORK OF OTHER ENVIRONMENTAL ISSUES

Acidification is a physico-chemical and biological process which will be always active part of our dynamic environment. An excellent example of the position and significance of acidification within a broad range of other environmental issues was presented in a Dutch publication "Concern for Tomorrow" (Langeweg, 1989). Acidification is just a part of the complex interaction between biota, bedrock, soils, sediments, water and air and the interaction is influenced by social and economic factors. These relationships are illustrated in Fig. 1.

Most of the past effort focused on the acidification as a result of burning of fossil fuels and the interaction of SO_2 and NO_x with water and soils. Acidification in Scandinavia has been attributed not only to emission sources but also to natural processes connected with changes in forestry practices (Rosenquist et al., 1980, Rosenquist I.Th., (1985). Attention was paid to the physiological influence of acid water on fish (Hultberg, 1983) and acid atmospheric deposition on forests (Ulrich and Pankrath, 1983). The importance of depletion of base cations in soils and toxicity of aluminum ions has been stressed by Ulrich (1981) and others. Much less is known about the response of organic matter to acidification, namely about the rates of release and fixation of

CO_2 due to accumulation and decomposition of humic substances in soils.To what extent acidification reduces biodeversity in aquatic and terrestrial ecosystems is known only in few cases.It is often assumed, that the changes in land use and climate can influence the rates of environmental acidification. Unknown is, whether regional acidification can influence the global climatic changes and future land use changes significantly. There is an uncertainty whether acidification is still a social and economic issue. Do people and decision makers care about acidification any more? What are the differences in the opinion within rich countries where substantial reduction of acid emissions has taken place and poor countries where such measures cannot be implemented because of insufficient funding? Who is going to finance future research into acidification, critical loads of acidifying compounds and regional exceedences of the loads?

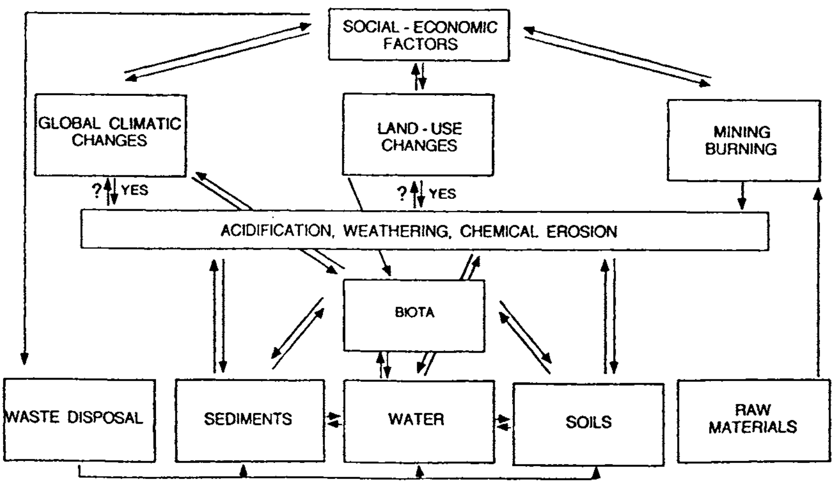

Fig. 1 Acidification within the broad scope of environmental and socioeconomic relationships. **YES** indicates where the relationship is assumed to be significant. **?** indicates an uncertainty whether the feedback is significant or not.

3. ACIDIFICATION WITHIN FUTURE RESEARCH PROGRAMS

Terrestrial ecosystem research initiative of European scientists (Manaut, 1994) introduces 6 major topics for future environmental research:

1. Land-use change
2. CO_2 atmospheric concentration and climatic drivers

3. Soil organic dynamics
4. Biogeochemical cycles
5. Biodiversity and ecosystem functioning
6. Modeling and other integration activities.

These topics should be developed across geographical gradients from boreal to Mediterranean European environments and from maritime to continental climate gradients. The research effort should be interdisciplinary between biochemical, biophysical and socioeconomic fields. Another important feature will be the transition between various scales of resolution and global perspective of changing environment. Manipulation field experiments and long-term monitoring schemes will be necessary to reach meaningful results. Research focus will shift from sulfur cycle to carbon and nitrogen cycle and to the role of trace elements and trace organics.

In the United States, the relations between the acid emissions and their effects have been presented to U.S. Congress in 1990 (NAPAP, 1993). The summary indicates that the understanding of acidification and its influence on forests, aquatic ecosystems, human health and materials and cultural resources is considered to be sufficient to reach meaningful policy-oriented assessments (NAPAP, 1991). The research and monitoring strategy will be probably directed towards answering questions contributing to the evaluation of a particular acid deposition control approach. The research should be directed towards better understanding of the impacts of pollutants on forest and ecosystem nutrient cycling along climate gradients, and towards regeneration of damaged ecosystems and forest resources. Ozone-acid rain interaction should be also an important research topic as well as the plant responses to complex impact of atmospheric ozone, NO_x,NH_3, SO_2, CO_2 and trace metal toxicities and deficiencies. It has been recognized, that we have an insufficient knowledge on the biochemical role of antioxidants and free radicals scavengers in oxidative metabolism. There is a general opinion among scientists that there is a need for a continual long-term monitoring program on sensitive ecosystem parameters. As stated by Rask and Hendershot (1992), "the researchers should adapt to changing priorities for research while granting agencies should recognize the benefit of uninterrupted time series". Small catchment studies are the tool to better understanding of the causes of the observed long-term changes in well defined ecosystems (Paces, 1992, Moldan and Cerny, 1994, Cerny et al., in print). The catchment and plot experimental manipulations are a new tool which has been well developed in Europe (Rasmussen et al., 1992) and has been considered for operation in the United States too (NAPAP 1991). Acidification as a general biogeochemical process will be implicitly studied in most of the future ecological research projects. It is just a question of the significance of acidification with respect to other environmental processes and issues.

Future research should concentrate on quantification of nitrogen and carbon cycles at different scales from soil-water micro systems via small and large catchment studies toward continental and global scale synthesis of field data. More information is desirable on proton generation and consumption during the water pathways in order to interpret dynamics of biogeochemical reactions. The use of environmental isotopes D, ^{18}O, ^{13}C, ^{15}N, ^{34}S, $^{87/86}Sr$ can be helpful in this respect (Cerny et al., in print). Biogeochemical studies will most probably relay more on manipulation experiments on more diverse vegetation types, particularly on deciduous woodlands, grasslands and wetlands. Acidification should be considered together with the impact of temperature and variable levels of ozone and nitrogen. Reversibility of acidification should be studied in combination with the impact of increased summer draughts and winter rapid decreases in temperature. Future research should focus more towards combined effects of air pollutants and climate change (Beier and Cummins, 1992). Soil sinks for sulfur should be better understood to explain commonly found imbalance of sulfur in catchment budget studies and possible irreversibility in lowering the buffer capacity of acid soils.

Acidification of water and soils is a recognized problem and it is sometimes considered as scientifically well understood process. Still many important aspects need further development. A recent Dahlem Conference addressed explicitly this topic (Steinberg and Wright, 1994). A summary of the most important topics for future research which appeared at the Conference is given in the Appendix.

4. CONCLUSIONS

Future acidification research will not be an isolated effort. It is expected that it will become an integral part of research into aquatic and terrestrial ecosystems and that it will be more integrated with economic and political assessments. In spite of that acidification is a regional problem, it will be considered as one of the factors contributing to global climatic changes because of its impact on behavior of soils and forests. Acidification will be implicitly considered in the research dealing with biogeochemical cycling of potentially toxic trace elements, within nitrogen and carbon biogeochemical cycles and in studies of biodiversity. Ecological research along transects across Europe will necessary include acidification gradients. It will be especially important in transects including the Black Triangle of central Europe with acidification maxima at the German - Czech - Polish borders.

Goal oriented research organized by individual governments and intragovernmental bodies, should be supported by an independent individual basic research. The new and often most important discoveries in the acidification and other ecological problems were reached by individual efforts by dedicated scientists (Odén, 1968) or small scientific teams (Likens and Bormann, 1974, Douglass and Hoover, 1988) rather than through large costly projects. On the other hand only the continuous, interdisciplinary and well organized projects are able to describe the environmental problems on continental and global scale. Such projects, when analyzing the behavior of the global systems, should apply the knowledge gained through basic research on local scale.

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5. APPENDIX

Topics for future research into environmental acidification (selected from Steinberg and Wright ,1994 and supplemented by the author).

5.1 Questions related to the effects of reduction of emissions and mitigation practices on ecosystem development and the status of improvement of water and soil quality:

Sites responses to reduction of SO_2 and increase in NO_x and O_3

Effect of liming on pool of exchangeable base cations and acidity in soils

Ecological effects of substantial decrease in SO_2 deposition in central Europe.

5.2 Acidification and climate changes:

Relationships between climate change and changes in hydrological pathways to environmental acidification.

Strong acid anion pulses due fluctuation in climatic conditions (e.g. changes in wetting and drying periods) as an analogue of some expected global climate changes.

Release of N_2O during denitrification and nitrification influenced by acidification and global warming. N_2O is more radiatively active than CO_2 and CH_4.

Scaling-up of local or small catchment acidification studies to regional or even global scale ecological changes.

5.3 Land-use changes and organic matter:

Changes in quantity and quality of organic acids with changes in land use and changes in anthropogenic acid deposition

Vegetation changes or management other than afforestation as a cause of chronic (more than 5 years) surface water acidification in the absence of acidic deposition?

Organic acidification due to production, transport and behavior of organic acids in ecosystems

Impact of acidic deposition on production and release of dissolved organic carbon (DOS) Does acidification by inorganic acids influences metal completing with organic carbon significantly?

Incorporation of DOS to critical load calculations.

5.4 Acidification and trace metals and other element toxicity:

The response of trace, potentially toxic metals to acidic deposition and its relationship to general physico - chemical properties of ions (ion ratios, Pauling's negativity).

Toxicity of trace metals enhanced by acidification in water and soil with respect to fish, aquatic invertebrates, soil and sediment microorganisms and to sensitive plants.

Methylation of mercury and other elements in environment due to changes in pH and DOC

5.5 Acidification and cycling of nitrogen:

Acidification effect of increased nitrogen input on N cycling and physiology of soil - plant system before and after the nitrogen saturation of forests.

Historical status of nitrogen in acidified and non-acidified surface waters derived from paleoecological observations.

5.6 Acidification and cycling of sulfur:

Forms of sulfate which accumulates in soils. Reversibility of fixation of sulfate in connection with release of toxic aluminum.

Reduction of the buffering capacity of geological materials in hydrologically important source areas due to deposition of SO_2 and products of its oxidation..

5.7 Socioeconomic factors and environmental acidification:

Do people care about acidification any more? What are the differences in opinions in rich "non-polluting" countries and poor polluting countries? Who is going to finance future research of acidification, critical loads and the state of exceedences of the load? Past Communistic governments were notorious for hiding fats about environmental deteriorations in their countries. However, there are strong indications that even the new democratic governments in central Europe do no support sufficient research of environmental acidification and the exceedences of critical loads in their countries.

There is a general agreement among environmental scientists about the need of long-term data on behavior of aquatic and terrestrial ecosystems, especially on changes in biodiversity due to acidification, changes in temperature and land use. How such long term monitoring projects can be financed? Comparative data are needed along climatic and pollution transects.

Important issue is the reversibility of ecosystem damages due to acidification under conditions of reducing emissions. Will the present emission control measures be cost effective and ecologically sufficient?

5.8 Miscellaneous topics:

Differentiation between biological responses to natural and to anthropogenic acidification.

Importance of acidic episodes due to sea salt in combination with acidic deposition. Is it important or unimportant phenomenon?

Episodic vs. chronical effects of acidification on ecosystems.

Full explanation of why species are lost from acidified environment. Multiple stress impact is not fully understood. We refer to it usually in cases when we do not know the exact cause of an ecological damage.

Reduction of emissions is probably the single most important factor to lead to ecosystem recovery. Yet, are existing predictive models reliable? do they reflect real processes of acidification and its recovery? Are not they sets of equations which after proper calibration just mathematically simulate observed trends without any real predictive power?