Sustainable agriculture in the Baltic Sea Region in times of peak phosphorus and global change
Introduction

Dear Reader,

EcoRegion is an important project that supports the realisation of sustainable development approaches in the whole Baltic Sea Region and contributes to making it a sustainable and prosperous place.

In recent years, progress has been made to advance sustainable development in the Baltic Sea Region. These efforts are now supported by the EcoRegion project, which seeks to turn this area into the world’s first EcoRegion, where economical growth goes hand in hand with environmental integrity and social justice.

The project is based on the unique multi-stakeholder network of Baltic 21, which was created for the realisation of the Agenda 21 for the Baltic Sea Region. By way of eight sectoral platforms, Baltic 21 members carry out joint actions and cross-sectoral activities to pursue Sustainable Development in the Baltic Sea Region and the implementation of the Council of the Baltic Sea States Strategy on Sustainable Development 2010–2015. Furthermore the project is aligned with the Aalborg Commitments, through which regional governments voluntarily commit to defining clear targets and implementing concrete actions for Sustainable Development.

Through the EcoRegion project, ten model regions prepare strategic sustainability plans and implement a selected set of concrete measures designed to reach these Sustainable Development targets. This process is supported by a capacity building programme on Integrated Sustainability Management Systems. Numerous workshops foster the inter-regional, cross-sectoral and sectoral-regional dialogue and understanding on Sustainable Development within the Baltic Sea Region. In addition, public materials, including a good practices database, provide information on how to foster Sustainable Development on a regional level.

One of the publications produced by the project is the series EcoRegion Perspectives. It presents policies, projects and practices for the sustainable development of the Baltic Sea Region from various perspectives such as tourism, spatial planning and climate change.

We hope this periodical will give readers an insight into the diversity and potential of innovation and education for sustainable development, and trust that you will find it both interesting and informative.

Dörte Ratzmann,
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

EcoRegion Project Lead Partner

Sustainable agriculture in the Baltic Sea Region
Foreword

Dear Reader,

Every individual is responsible for a sustainable living. With a view to food this affects in particular one’s dietary habits and food management. A major problem of industrialisation has been the introduction of frozen and processed food and an elevated demand for prime meat parts as it led to an unbalanced diet with too much fat, sugar and salt, and the disposal of unpopular animal parts. The Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) estimates that in relation to the produce 20-75% of the food is disposed, which equals 20 million tonnes of groceries only in Germany. FAO valued the dumping of foodstuff to one third of the total production worldwide.

Personal deficits in the handling of foodstuff need to be compensated by adequate educational programmes for awareness rising and finally behavioural change. This is an important contribution to global food security and a sustainable use of the resource phosphorus (P) which is otherwise dissipated in the environment. Yet another problem that arises is the export of P in cheap feedstuff and energy crops from developing countries as increasing world market prices for P may hamper a balanced supply and thus favour P mining in these areas of the world.

But why care about P? The answer to this question is simple. Because P is a non-renewable resource, geogenous P deposits are limited, P is an essential nutrient for all living organisms and thus is indispensable for food production.

Agriculture is the largest consumer of P. In principle it does not matter whether the global resources satisfy the demand for another 50 or 150 years. It is a matter of fact that food production will be compromised for future generations if the anthropogenic and agricultural P cycle is not closed timely. These are facts that can not be denied and it is five minutes to midnight to develop a global concept on how to deal with P scarcity in a socially just way.

The Baltic Sea Region could be among the first regions worldwide to implement new strategies and technologies for closing the P cycle on farms. Here, the responsibility of farmers is given a turn. What can they do? It starts with a profound agronomic education and the transfer of local knowledge to optimise crop production in a sustainable way. With a view to P, the required knowledge comprises for instance aspects of plant nutrition, soil biology and soil physics with regard to the P demand of crops, organic P cycle and P losses through erosion and run-off, respectively.

Diffuse P losses from agriculture are a major contributor to eutrophication of water bodies such as the Baltic Sea. Other relevant issues for a sustainable use of P which avoids equally P mining and P surplus are the assessment of a site-specific optimum P status to satisfy the P demand of crops, the development of algorithms to match the small-scale spatial variation of plant available P in soils with variable rates of organic and mineral fertilisers.

It can be expected that recycling of P and thus the use of recycled P fertiliser products will play a key role in a sustainable P management. However, conditions need to be strictly defined for their use in order to foreclose negative environmental impacts. Such negative impacts range from charging soils with organic and inorganic xenobiotics for instance if sewage sludge is directly applied on agricultural soils to yet unknown effects on soil fauna, wild life and the putative introduction of pathogens if residues from biogas production are used that were generated by co-fermentation with sewage sludge or slaughterhouse wastes. Another important aspect is the speciation of P in the recycled product as it is imperative that only products are used as P fertiliser materials if P exists in a plant available form. This implies that MBM (meat-and-bone meal) may not be used directly as fertiliser material as the prevailing P form is apatite which is more or less insoluble on arable soils. Advanced technologies eliminate all those problems by incineration of waste products in combination with a chemical treatment to allow for the required plant availability of P.

International experts assigned to agricultural stewardship for sustainable phosphorus use contributed to the presented Perspectives and offer significant advancement of turning the Baltic Sea Region into the first EcoRegion of the world!

Silvia Haneklaus and Ewald Schnug,
Institute for Crop and Soil Science, Julius Kühn-Institute
CBSS Expert Group on Sustainable Development - Baltic 21 / Task Force on Sustainable Agriculture
Content

Baltic Sea Region policies for reducing P loads to the Baltic Sea
8 „Peak times“ for urban agriculture
12 Need for action in the Baltic Sea area
16 Task Force Sustainable Agriculture of Baltic21
19 Nutrient losses from agriculture in Estonia
21 Effects of algae blooms on coastal tourism
23 Agriculture and the Baltic: A local approach

Global perspectives on limited P resources
26 Global TraPs: An international effort to promote sustainable use of phosphorus
29 Legal perspectives of sustainable P use in agriculture

Baltic Sea Region perspectives on limited P resources
34 The inorganic P pathway - constraints for 100 % P utilisation
37 Fate of P fertiliser in soils - the organic pathway
39 Variability of P uptake by plants
44 Higher phosphorus utilisation in cropping systems
46 Setting standards for organic and mineral P fertilisers
50 Phosphorus management in organic farming
56 Phosphorus from recycled organic fertilisers - a Norwegian perspective
58 How energy from livestock manure can reduce eutrophication
63 Sustainable Agriculture - Truly Multidisciplinary Cross-Cutting Themes

Annex
65 References
Perspectives

Baltic Sea Region Policies for reducing P loads to the Baltic Sea

“Peak times” for urban agriculture¹

Nowadays humans are the main driver of change to the earth’s ecosystems. We have reached the “man-made world” – the Anthropocene – era.¹ Science defines nine planetary boundaries that “humans need to respect in order to avoid catastrophic environmental change at continental to global scale”². Some of these boundaries we have already crossed. This will have a tremendous impact on the livelihood of our societies and planet in the future.³

The global phosphorus cycle

One of these planetary boundaries relates to the global phosphorus and nitrogen cycles. Large-scale conventional agricultural systems are totally dependent on the continuous input of phosphate fertilisers produced from naturally available phosphate rock. Yet, we are currently hitting “peak phosphorus”. While its exact timing is controversially debated, it is a certainty that “phosphorus is an exhaustible resource with no substitutes. Shortages will occur.”⁴

The harmful effects of excessive phosphorus application

Natural supply of phosphorus is not harmful to our biospheres. However, it becomes a harmful pollutant when mined and added to fine-tuned ecosystems by excessive use of fertilisers in order to stimulate crop growth as practised in conventional agriculture.⁵ As a consequence phosphorus, the friend of life on earth, turns into an enemy, causing algae blooms and oxygen depletion in lakes and seas, killing water species, threatening fresh water supplies and triggering other chain reactions in the bio-system.

The necessity to save phosphorus

As one solution to this dilemma, Stephen R. Carpenter suggests the conservation of phosphorus instead of the continuation of its waste.⁶ Amongst others, he highlights farming as well as food production, distribution and consumption as main areas in which conservation of phosphorus is not only needed but also possible.

While farming is mainly done in the countryside, food production and distribution takes place in semi-urban and urban areas. In addition, main consumers of agricultural products can be found in cities and towns. In 2008 the urban percentage of the world’s population reached 50 %. The global urban population of currently 3.3 billion is expected to grow to 4.9 billion by 2030.⁷ How will we feed all these city dwellers in the future?

Localised farming as a solution

Food production in the Baltic Sea Region and other parts of the world, past peak oil and peak phosphorus, will depend upon more localised farming that is relatively resilient to extreme weather events, can operate effectively with reduced inputs, and is adaptable to likely increases in weed, pest and disease problems.⁸ We have to realise that we are living in a post-food surplus era and adapt our production and consumption in a post-peak oil and peak phosphorus, “man-made world” era.⁹

¹ In this article urban farming, urban food production and urban agriculture are used synonymously.
⁴ Climate change, rate of biodiversity loss, nitrogen-phosphorus cycles
⁶ “P is a finite fossil mineral mined for human use and added naturally into the Earth System through geological weathering processes. The crossing of a critical threshold of P inflow of the oceans has been suggested as the key driver behind global-scale ocean anoxic events, potentially explaining past mass extinctions of marine life” in Rockström, Johan et al. 2009: Planetary boundaries: Exploring the safe operating space for humanity in Ecology and Society 14(2):32
⁸ The urban percentage of the world’s population is projected to reach 60 percent by 2030. The 3.3 billion global urban population is expected to grow to 4.9 billion by 2030. Growth in smaller cities and towns is expected to account for most of the urban population increase. http://www.prb.org/Articles/2007/UrbanPopToBecomeMajority.aspx

Maxi Nachtigall
Project Officer, Council of the Baltic Sea States (CBSS) Expert Group on Sustainable Development, Baltic 21, CBSS Secretariat

Innovative solutions for urban farming. © Maxi Nachtigall

Allotments in Stockholm city center. © Maxi Nachtigall
Urban food production can provide these added values at the same time as it is taking off the nitrogen and phosphorus pressure from our farmlands. Although cities themselves show symptoms of biochemical imbalances and are hotspots of accumulation of nitrogen, metals and phosphorus they also harbour a pool of […] resources […]”. 10

How can we cut down waste on phosphorus, conserve this valuable resource and at the same time secure food supply? We need better planning for better food which can mean many different things: a healthier and more sustainable agricultural policy as well as sustainable agriculture that better addresses modern urban consumption patterns. It would also mean better integrated sustainable food systems that take into account the impacts of climate change, increasing food prices and the need for balancing food and energy security.

We need urban consumers that are able to make informed decisions on what and how to eat and have clear demands on how and where food should be produced. Consequently, we need to (re)define the possibilities for urban farming and create better urban-rural linkages to ensure food supply in urban environments for future generations. “A just and sustainable food system protects the land which produces the food, supports the local community, through local production, empowers communities through self-reliance and gives them increased food system security.” 11

Urban food production can provide these added values at the same time as it is taking off the nitrogen and phosphorus pressure from our farmlands. Although cities themselves show symptoms of biochemical imbalances and are hotspots of accumulation of nitrogen, metals and phosphorus they also harbour a pool of […] resources […]”. 10

The multifaceted benefits of urban farming
Increased urban farming would result in greener cities that would naturally trigger other benefits such as decreased energy costs, water use and drainage, reduction of urban heat islands, absorption of pollutants, increased urban ecology and biodiversity as well as certain social and health aspects. “When you start growing more food on public lands in cities you increase both a lot of social cohesion, you deepen democracy but also you create a sense of protecting the environment. It is no longer only bushes along the road it means a food supply.”13 Wherever it is we are living we have to (re)start thinking in a place-based manner. More practical measures need to be taken in order to reduce the ecological impact by the average urban citizen.

Some possible solutions to produce urban ecosystem services can be listed as follows:

- Rethinking the concept of community gardens and urban allotments
- Creating more locally supported farms in metropolitan areas, roof top gardens and greenhouses
- City planning for planting of edible plants in parks and other urban open green spaces (including residential housing balconies), even animal husbandry
- Establishment of food share systems and community supported agriculture, e.g. farmers markets
- Development of broad educational programmes on small scale farming, urban agriculture and permaculture in urban settings in order to enable community members to implement measures in a short time frame on a local scale
- Less consumption of pre-processed and packaged food

These solutions would give urban citizens environmentally sound alternatives to conventional farming and abounded food systems. This would help us to stay within our planetary boundaries. The promotion of sustainable lifestyles and creation of sustainable agriculture would not only generate employment opportunities in the eco-innovation and green technology sectors as well as in local community work.

The Baltic Sea Region could become a forerunner region of sustainable cities and towns in symbiosis with vibrant rural landscapes and a home to people with clear sustainable demands and lifestyles. Thereby, one could improve the quality of life in urban-rural settings and strengthen urban-rural links. “Cities themselves do present both the problem and solutions to sustainability challenges in an increasingly urbanised world”. Urban farming is one of the most important features of urban resilience and sustainability.

12 Grimm, Nancy B. et al., 2008: Global challenges and the ecology of cities in Science magazine, Vol 319, 8 February 2008
The state of the Baltic Sea water has drastically deteriorated over the recent decades. Human activi-
ties both at sea and throughout its catchment area are placing rapidly increasing pressure on the marine ecosystem. Of the many environ-
mental challenges, eutrophication is one of the major problems for the sea and for the lakes and rivers in its catchment area, especially in the southern and eastern parts of the Baltic Sea. It is caused by excessive nitrogen and phosphorus inputs. This leads to problems like increased algal blooms, murky waters, oxygen depletion and a lifeless sea bottom.

Nutrients enter the Baltic Sea via rivers, through atmospheric deposition and in direct discharges from pollution sources located along the coastline. The riverine discharges originate both from point sources, such as industrial or municipal wastewater plants, and from diffuse sources, such as agriculture and forestry, scattered dwellings, traffic and atmospheric deposition within river basins. The Baltic Sea is connected to the North Sea and to the Atlantic Ocean through the narrow Danish Straits and Sound areas. Inflows of fresh seawater occur rarely, and poor oxygen conditions release phosphorus accumulated in the bottom sediments.

Agriculture is the main source of phosphorus and nitrogen inputs to the Baltic Sea accounting for about 50 % of the total diffuse loads. Managing emissions from agricultural land and livestock operations is critical to restore the ecological balance of the Baltic Sea. Putting an end to further destruc-
tion of the Baltic Sea marine envi-
ronment and avoiding an irrevers-
able disaster calls for immediate wide-scale cross-sectoral action. Failure to react now would under-
mine both the prospects for future recovery of the sea and its resilience against the climate change and the risk of increasing nutrient loads. Fur-
thermore, inaction will have an im-
pact on resources vital for the future economic prosperity of the whole region and would cost tenfold more than the cost of action. Efforts to combat eutrophication have already been and continue to be made in many different fora at various levels but it is a complicated task to curb nutrient loads from diffuse sources.

The Helsinki Commission

The Baltic Marine Environment Protection Commission, more usually referred to as the Helsinki Commission or HELCOM, is an international or-

ganisation made up of the nine Bal-
tic Sea coastal countries and the Eu-

ropean Community, working to pro-
tect the marine environment of the Baltic Sea. HELCOM is the governing body of the “Convention on the Protection of the Marine Environment of the Baltic Sea Area” - also known as the Helsinki Convention, which was signed by all Baltic Sea countries in 1974 and came into force in 1980. A new updated convention was signed in 1992 by all states border-
ing the Baltic Sea, and the European Community and it entered into force in 2000. The Convention covers not only the Baltic Sea, but also the sur-
rounding catchment area within the coastal countries. The whole catch-
ment area covers 1 600 000 sqkm, which is about four times the area of the sea itself.

The Baltic Sea Action Plan

HELCOM has had several approaches in its history for enhancing the state of the Baltic Sea but the objectives have not been reached yet. The latest is the Baltic Sea Action Plan (BSAP). Its ambitious target is to restore the good ecological status of the Baltic marine environment by 2021. The Plan was adopted by all nine Baltic Sea States within the Helsinki Com-
mission (HELCOM) and the European Community at the ministerial meet-
ing on November 15, 2007 in Krak-

ow, Poland. The cross-sectoral plan identifies the specific actions needed to achieve the agreed targets within a given timeframe for the main en-
vironmental priorities: 1) combating eutrophication, 2) curbing inputs of hazardous substances, 3) ensuring maritime safety and response capac-
ity to accidents at sea, and 4) halting habitat destruction and the ongoing decline in biodiversity. The HELCOM Member States are cur-
rently developing national plans to implement the Action Plan.

The BSAP has strong links to global legislative frameworks and is also seen, for those Parties who are also EU Member States, as a contribution to the implementation of key EU directives, in particular the Marine Strategy Framework Directive, the Water Framework Directive and the Nitrates Directive.

Reducions in nutrient inputs have primarily been achieved through improvements at major point sources, such as municipal sewage treatment plants and industrial wastewater outlets. Achieving further reductions, such as run-
off from agriculture, is a tougher task considering the rapidly growing agricultural sector in the region. Reducing nutrient losses from agriculture is much more complicated than curbing loads from point sources and will involve several measures. Due to retention in soils, groundwater and inland surface waters, a reduction of nitrogen or phosphorus in local emissions will result in less reduction to the Baltic Sea. Additionally, there is a considerable time-lag between the implementation of agricultural water protection measures and any observed effects in lakes and rivers, and even more so for marine water bodies. This means that load reductions in marine water bodies will not be observable for years or even decades after water protection...
Sustainable agriculture in the Baltic Sea Region

To decrease phosphorus and nitrogen discharges into the Baltic Sea, the losses from agricultural activities and scattered dwellings to inland surface waters have to be reduced most probably by at least 50% from the 1997-2003 average levels, depending on the retention in different catchments.

The role of EU legislation
In the future, like up till now, the EU legislation and agricultural policy will play a major role in the state of the Baltic Sea. When entering the agricultural subsidy system, the new EU member countries like the Baltic states and Poland will increase their agricultural production. This will also increase the intensity of farming with higher risks of nutrient leaching. Around the Baltic Sea, rising living standards in the new EU member countries and Russia will probably increase the proportion of animal-sourced food in people’s diets. The increasing animal production may require an expansion of the cultivated area, leading to increasing nitrogen and phosphorus leaching. At the EU-level there is no direct regulation to prevent phosphorus discharges from agriculture. The Nitrates Directive only regulates the nitrogen discharges from agriculture.

To reduce phosphorus and nitrogen losses from countless individual field plots and animal production units is a huge task that calls for identification of high-risk areas and implementation of cost-efficient and targeted agri-environmental measures. Such measures could for example be cultivation of catch crops, establishment of buffer zones, restoration and construction of wetlands, reduction in mechanical treatment of soils, lime application, construction of higher storage capacity for manure and application of less than yield-optimal fertiliser amounts. Enlarged and clustered animal farms require more effective methods to store, process and distribute manure. Slurry could for example be used for bioenergy production.

To this end, there is a need for interdisciplinary research and advisory services and for recognition of economic, social and political constraints.

There is a need to take actions both for point and diffuse sources in the following areas:

- Waste water: municipalities, scattered settlements and single family homes
- Agriculture
- Transboundary air- and water-borne pollution

Objectives of the Baltic Sea Action Plan to combat eutrophication

The BSAP objectives cover the following targets: no excessive nutrient concentrations, clear water, no excessive algal blooms, natural oxygen levels, and natural distribution and abundance of plants and animals. HELCOM has estimated that for a good environmental status to be achieved, the maximum total allowable annual nutrient inputs into the Baltic Sea would be 21,000 tonnes of phosphorus and about 600,000 tonnes of nitrogen. Over the period 1997-2003, average annual inputs amounted to 36,000 tonnes of phosphorus and 737,000 tonnes of nitrogen. Therefore, annual reductions of some 15 000 tonnes of phosphorus and 135,000 tonnes of nitrogen would be required to achieve the Plan’s crucial ‘clear water’ objective. However, a slightly decreasing trend in the point-source and riverine loads of both P and N can be seen between the years 1990 and 2006 but the short-term development has not been satisfactory.

To decrease nutrient inputs into the Baltic Sea to the maximum allowable levels, the HELCOM countries have agreed to take actions no later than 2016 to reduce nutrient loads in waterborne and airborne inputs, aiming to reach good environmental status by 2021. To reach these reduction targets, each Member Country is encouraged to choose the most appropriate and cost-effective measures for its special needs. The Action Plan duly proposes provisional country-wise annual nutrient input reduction targets for both nitrogen and phosphorus (see table 1).

For addressing the problems of the large agro-industrial clusters, contracting states also agreed to identify individual hotspots such as major intensive cattle, poultry and pig rearing facilities, where actions should be prioritised in order to comply with revised requirements for prevention of pollution from agriculture (Annex III of the 1992 Helsinki Convention). The designation of these new “hot spots” has not been accomplished yet. Environmentally sound manure management has to be assured via construction of adequate manure storages, proper agri-environmental measures and advisory services and via identification of agricultural areas that are critical for nutrient pollution of the Baltic Sea such as designation of relevant parts of agricultural land as nitrogen vulnerable zones and performance of risk assessments of nutrient leaching from agricultural areas. More comprehensive research and new innovations are needed to solve the problems.

Current progress is slow
According to the data on total nutrient loads into the Baltic Sea by 2008 it seems that there has been relatively little progress in the reduction of losses of nutrients from agriculture within the Baltic Sea catchment area since 2000. In fact, losses from agriculture appear to have increased in some BSAP member countries although load figures for source loads many countries have a significant (p< 0.05). For direct point and diffuse sources are uncertain due to the impact of climatic factors and different methodologies applied, making comparisons of loads between years difficult.

The first HELCOM Initial Holistic Assessment of the Environmental Status of the Baltic Sea based on data from the period 2003-2007 concludes that in addition to selective extraction of fish, eutrophication is the other most dominant human pressure on the Baltic Sea. Previous measures have been taken too late or have been insufficient to help curing the environmental damages. The assessment also points out that yet. Environmentally sound manure management has to be assured via construction of adequate manure storages, proper agri-environmental measures and advisory services and via identification of agricultural areas that are critical for nutrient pollution of the Baltic Sea such as designation of relevant parts of agricultural land as nitrogen vulnerable zones and performance of risk assessments of nutrient leaching from agricultural areas. More comprehensive research and new innovations are needed to solve the problems.

Current progress is slow
According to the data on total nutrient loads into the Baltic Sea by 2008 it seems that there has been relatively little progress in the reduction of losses of nutrients from agriculture within the Baltic Sea catchment area since 2000. In fact, losses from agriculture appear to have increased in some BSAP member countries although load figures for source loads many countries have a significant (p< 0.05). For direct point and diffuse sources are uncertain due to the impact of climatic factors and different methodologies applied, making comparisons of loads between years difficult.

The first HELCOM Initial Holistic Assessment of the Environmental Status of the Baltic Sea based on data from the period 2003-2007 concludes that in addition to selective extraction of fish, eutrophication is the other most dominant human pressure on the Baltic Sea. Previous measures have been taken too late or have been insufficient to help curing the environmental damages. The assessment also points out that

<table>
<thead>
<tr>
<th>Country</th>
<th>Phosphorus (tonnes)</th>
<th>Nitrogen (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>16</td>
<td>17,210</td>
</tr>
<tr>
<td>Estonia</td>
<td>220</td>
<td>900</td>
</tr>
<tr>
<td>Finland</td>
<td>150</td>
<td>1,200</td>
</tr>
<tr>
<td>Germany</td>
<td>240</td>
<td>5,620</td>
</tr>
<tr>
<td>Latvia</td>
<td>300</td>
<td>2,560</td>
</tr>
<tr>
<td>Lithuania</td>
<td>880</td>
<td>11,750</td>
</tr>
<tr>
<td>Poland</td>
<td>8,760</td>
<td>62,400</td>
</tr>
<tr>
<td>Russia</td>
<td>2,500</td>
<td>6,970</td>
</tr>
<tr>
<td>Sweden</td>
<td>290</td>
<td>20,780</td>
</tr>
<tr>
<td>Transboundary Common pool*</td>
<td>1,660</td>
<td>3,780</td>
</tr>
</tbody>
</table>

Table 1: Country-wide reduction targets for N and P in tonnes (HELCOM BSAP 2007).

The assessment also points out that destruction of the Baltic Sea will fur- thermore have a severe impact on the comparison of loads within the area. Compara- son of flow normalised loads during 1997-2003, which is the reference period for setting provisional reduction targets in the BSAP, with flow normalised input during 2006-2008 indicates a reduction of less than 1900 tonnes of nitrogen (2 %) and more than 3,300 tonnes of phospho- rus (10 %).

A statistical analysis on flow normal- ised riverine load data to the Bal- tic Sea shows no significant overall decrease in nitrogen and phospho- rus waterborne inputs during 1994- 2008. Some countries have obtained a significant decrease in these loads, while others show increases or decreases, although not statistically significant (p<0.05). For direct point source loads many countries have a significant reduction in emissions of nitrogen and phosphorus during these 15 years.

Pressures should be progressively re-duced because only further signifi- cant, targeted and cost-effective reduction of phosphorus and nitrogen will result in improved ecosystem health of the Baltic Sea.
The actual condition of the Baltic Sea is alarming. In particular, nitrogen and phosphorus losses from agriculture, which result in eutrophication, have a strong impact on the highly sensitive ecosystem. On November 15, 2007 the member states of the Helsinki Commission (HELCOM) for protecting the Baltic Sea decided on a Baltic Sea Action Plan for reducing nutrient inputs into the Baltic Sea. This implies, among others, the distribution of country-by-country quota for upper nutrient loads. The Task Force Sustainable Agriculture (TFSA) of the Agenda 21 for the Baltic Region (Baltic 21) elaborates strategies other than a political administrative limitation of nutrient surpluses and fertiliser use in order to reduce negative impacts of agriculture on the Baltic Sea.

Since 2000, the Working Group Agriculture of HELCOM (Helsinki Commission for the protection of the Baltic Sea) and recently the Task Force Sustainable Agriculture (TFSA) have dedicated their work to adopting and refining good agricultural practices in relation to regional specifics in order to reduce nutrient losses from agriculture. At the moment Germany is in charge of TFSA, represented by the Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) within the scope of its marine protection politics. Prof. Dr. Dr. Ewald Schnug is chairman of the group and head of the Institute of Crop and Soil Science of the Federal Research Centre for Cultivated Plants, Julius Kühn-Institute (JKI) in Braunschweig.

In the line of work of TFSA/Baltic21 expert meetings have been organised on a regular basis in the form of international symposia in the series Protection of Water Bodies from Negative Impacts of Agriculture. Milestones are summarized below.

Consensus existed at the symposium Challenges of Precision Agriculture and Remote Sensing that modern technologies such as precision agriculture, which employs satellite navigation systems (GPS) and remote sensing, will yield fertiliser savings and consequently improve environmental quality. The introduction of new technologies in agricultural production will have a significant potential for reducing nutrient losses from agriculture. Experts expect that their proposed investment into future technologies will find broader acceptance by farmers rather than further legal confinements.

An enforcement of bio-energy in agriculture sounds like a promising concept to cope with global change, scarcity of energy and unemployment. However, there is concern about whether this development will comply with the principle of sustainability, which postulates “a development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. This issue was addressed during the symposium Sustainable development of bio-energy production with special view to soil protection. Our society’s hunger for energy faces limitations to the
perspectives sustainable agriculture in the Baltic Sea Region

baltic Sea Region policies for reducing P loads to the Baltic Sea

nutrient losses from agriculture in Estonia

The territory of Estonia is 45,227 km², of which 43,200 km² is land area. Forests cover nearly 50% of the land, the rest being wetlands (22%) and agricultural land (23%). The sown area of field crops is 560,000 ha, of which about half is under cereal production, nearly 40% is used for production of forage crops and the rest is under potato, vegetable and industrial crop production (Põllumajandusministeerium 2011). The share of permanent grasslands and pastures is rather high, forming more than 7% of the total land area.

The Baltic Sea Action Plan and the need for nutrient input reductions

The HELCOM Baltic Sea Action Plan (HELCOM 2007) foresees considerable annual nutrient input reductions country-wise, based on the principle of maximum allowable nutrient inputs to the sea. These were set up at the level of about 21,000 tonnes of phosphorus and 600,000 tonnes of nitrogen. Estonia agreed to annual reduction target levels of 220 tonnes of phosphorus and 900 tonnes of nitrogen. In 2000 Estonia was responsible for about 27,000 tonnes of nitrogen and nearly 1,000 tonnes of phosphorus, which formed, respectively, 3.6% and 2.8% of the whole Baltic Sea pollution load. Load entering the sea via rivers amounted to 25,273 tonnes of nitrogen and nearly 877 tonnes of phosphorus (HELCOM 2004). By 2007 the levels decreased to about 20,000 and 800 tonnes, respectively (Loigu and Leisk 2008).

Most wastewater passes advanced tertiary treatment and only about one percent is released to the environment without any treatment. A study estimating reduction capacity from point sources revealed that phosphorus load can be decreased by 68 tonnes and nitrogen about 352 tonnes compared to 2007, if one follows the most stringent HELCOM recommendations with regard to wastewater treatment (Pachel et al. 2011). Thus, quite a considerable reduction is required from diffuse sources, especially from agriculture.

In many Eastern European countries, including Estonia, the highly industrialised and centralised agricultural production system collapsed in the late 1980s and early 1990s. Fertiliser use dropped six times in Estonia and in 2005 constituted only about 13% of the peak in 1987-1988. The decrease in livestock units (LU) was about twofold, the level today being 0.41 LU ha⁻¹ of arable land, although there are considerable variations among regions. The area of arable land (crop fields and cultural grasslands) decreased from about one million ha in the early 1990s to less than 0.6 million ha by 2003. It is now about 0.6 million ha (Statistical Office of Estonia 2006, 2007). Despite lowered fertilisation rates, improved agricultural management practices and changes in land use, agriculture still remains the main source of diffuse pollution of inland surface waters, comprising 59% of total nitrogen (TN) and 30% of total phosphorus (TP) input in 2009. The average annual area-specific load of nitrogen and phosphorus was on the level of 13.9 kg N ha⁻¹ and 0.23 kg P ha⁻¹ in agricultural landscapes and 2.4 kg N ha⁻¹ and 0.09 kg P ha⁻¹...
Baltic Sea Region Policies for reducing P loads to the Baltic Sea

Effects of algae blooms on coastal tourism

Every summer time tourists and domestic coastal areas are troubled by news about poisonous algae. It might be a catastrophe for the beach destinations, because the public health authorities are forced to barricade the beach areas to guarantee public safety. This phenomenon is an example of the complicated interaction between algae blooms, climate change, and nutrient flows at the global and regional level, as well as their influence on tourism and leisure activities and the perception of visitors concerning these problems.

Algae blooms – groups, sources and annual appearance

Algae are a large group of autotrophic organisms ranging from unicellular up to large brown algae (“kelp”) with a length of more than 50 metres. Algae are found in fossil dated back to 3 billion years and have a wide range of reproductive strategies. The oxygen in the early atmosphere of the Precambrian era is the result of algae photosynthesis. Nowadays two groups of algae blooms are typical for the Baltic Sea Region: the diatoms bloom in spring and the cyanobacteria bloom during the summer. It occurs both in coastal waters and in lakes.

Algae carpets are a result of the interaction between nutrient circulation (phosphorus), sunlight, water temperature, wind, waves, salt water inflows and carbon dioxide. There is no doubt that cyanobacteria blooms are caused by high water temperature and low wind speed; the appearance of blooms has been above average after winters with no ice coverage. It can be assumed, that the North Atlantic Oscillation (NAO) affects algae blooms in general.

However, the influence of nutrients (phosphorus, nitrogen) on algae blooms is under debate. There is no doubt that algae blooms are a result of the nutrient input; but there are additional effects of internal eutrophication caused by the release of phosphorus from sediments.

In any case, the effects of climate change and anthropogenic nutrient input are evident – and seem to become more and more difficult for the water quality.

Tourism and algae blooms

Bathing tourism is the most popular use of destinations around the Southern Baltic Sea. For more than 50 % of tourists “bathing” is the only reason to visit in Mecklenburg-Vorpommern. In addition, the coastal areas, with their landscape diversity, are a favourite background for water
sports. The algae blooms influence the leisure activities as follows:

- Some cyanobacteria species produce toxins. The high reproduction rate in summer times can be harmful for other species with direct contact to algae (e.g. bathers or scuba divers with a constricted immune system)
- Macrophyte carpets at the beach cause an olfactory harassment; sometimes the beach and water surface are covered with foam produced by algae.
- Algae reduce the visibility under water and the permeation of sun light. It causes a feeling of insecurity, makes scuba diving more uncomfortable and limits the adventure character.
- Macrophytes can be obstacles for navigation in shallow water areas.

It is well known from several field studies that tourists wish safe and clean beaches and clear water with a very good visibility; that’s why they prefer coasts bordered directly to the sea. Lagoons with a reduced water visibility (but without health hazards) are not very popular. But there are differences in relation to the age of the tourists, the level of education and the experiences with coastal tourism destinations in general.

Algae blooms and the future of Baltic bathing tourism

Concerning the current discussion about carrying capacity in European beach destinations the development of lagoon destinations could be worthwhile, also with regard to the effects of climate change, the potential shift in travel behaviour and the growing demand for beaches. The international legal framework (European Water Framework Directive; European Bathing Water Directive) and the national law provide the guidelines for such developments. Even if the influence of nutrient inflow of rivers on algae blooms is not proven, improved wastewater management and reduced fertilisation in agriculture are important steps towards better water quality. Furthermore, there are promising approaches to reduce nutrients in the water column and the sediment generally: The mussel Dreissena polymorpha can bind a lot of nutrients, is domestic in European coastal lagoons and can be cultivated easily. The potential of that form of aquaculture has just been discovered.

Additionally, the problem of algae blooms is a good starting point for various forms of education. The need for further awareness raising about potential hazards is evident, but there is a chance to expand and combine it with general topics like eutrophication and climate change.

Agriculture is probably the most important polluter of the Baltic Sea. Nitrogen and phosphorus are transported into the sea from agricultural land as surface runoffs or via airborne sedimentation. This influx radically changes the underwater ecosystem, promoting a strong growth of algae and indirectly leading to oxygen deficiencies in large sea areas.

Local effects of marine pollution

Wieck municipality, as a coastal village, is directly affected by marine pollution. The community lies on the shore of a chain of lagoons subject to regular inflow of Baltic Sea water. During summer, the lagoon’s water is often strongly green in colour due to a vast amount of freely floating microscopic algae. Although there are no known health concerns related to these algae, it is definitely not the most pleasant environment for bathing. Most locals and tourists therefore stay away from the small bathing beach of the village and the pleasantly warm water. Wieck is an attractive community nonetheless, boasting antique houses and a magnificent national park, but life quality in the village and its touristic attractiveness could be even higher with a cleaner and more natural marine ecosystem.

Developing good practices - promotion of sustainably produced food

Wieck municipality has decided that this is enough reason to act and take steps to reduce marine pollution. While one village alone cannot radically change the situation, it is very well possible to make a start by developing better – or even best – practices that might be valuable for...
larger-scale application. This is what Wieck municipality is undertaking in the EcoRegion project. As Wieck is not an area of industrial agriculture, but is rather covered by pastures and woodland, opportunities to act may seem a bit limited at first sight. But food consumption in the village is another way to approach the issue. The intention is to increase the share of sustainably produced food coming largely from organic agriculture in the region. Organic crop production usually produces fewer nutrient emissions compared to conventional agriculture, so this is a well-fit approach to relieve the Baltic from polluting substances.

Involving stakeholders and improving consultation

To push regional and organic food, Wieck has partnered with a regional initiative called „LändlichFein“ („FinestRural“) which has taken its seat in the village this year, happy to find both a home and a platform. Its growing membership consists of gastronomers and hotel keepers from Wieck and the coastal region who try to serve both organic and regionally produced meals instead of „normal“ supermarket groceries. Some of them offer only organic food, others as much as it proves possible. Getting organic and regional resources for quality cooking can actually be quite a problem, as producers are often small and distribution channels are not always well developed, especially in far-off and rural areas like Wieck. Improved consultation for consumers (where and how to get it) and producers (which channels to use to bring the produce to where the demand is) could change this. Increased supply and demand have been promoted by having organic products sold locally at a small market in the village center twice a week. Currently this is only happening during the tourist season, but this may well change in the future.

To make the mission complete, cooperation with another organisation has begun. The „Landaktiv“ initiative informs and educates on the topics of organic farming and food processing as well as on sustainable fishing practices. It is planned to synchronize the activities of the two involved organisations and Wieck’s own informational and marketing activities by establishing a professional consulting point that could complement the already existing national park information center. Current plans see it not only focusing on professional agricultural production, but also addressing and informing the many tourists that visit the region about sustainable home gardening. Tourists taking good ideas home are a fitting prerequisite for a better Baltic Sea ecosystem, as agricultural use on the vast land areas far away from the seashore (but still in the catchment area) is a decisive factor for water quality.

Improving water quality locally - regenerating the natural coastline

Improving water quality is also something that Wieck is undertaking locally. Most of the rather flat ground around the lagoons was regularly flooded in former times. This was terminated 50 years ago by a huge dike building programme in the region. The lagoons thereby lost most of the sedimentation areas where floating eutrophic debris could settle. Regenerating this natural purification process by breaching some dikes will not only be beneficial for water quality. Floodlands are a paradise for ducks, geese, cranes and waders – birds that are of interest for ornithologists visiting the national park region. Tourists are the main source of income in the village, so giving them good reasons to visit and stay in the municipality economically appealing. Wieck is therefore anticipating reinstating 400 ha of floodland east of the village – one of the largest coastal dike breaches in Europe and definitely one of the future highlights in the national park. The project still needs some detailed planning and some financing issues will have to be solved. But major steps and decisions have been taken, promising a more attractive environment for Wieck, a better ecological performance for the Baltic and the birth of many further activities.
Global perspectives on limited P resources

Global TraPs: An international effort to promote sustainable use of phosphorus

Scientists and natural resource managers are concerned about unsustainable management of phosphorus (P) because not only is phosphate rock a finite natural resource, but its inefficient management can result in contamination of water bodies. It is an established fact that P shortage will threaten global food security. An international effort, called the Global TraPs project, is bringing together knowledge and perspectives from science, industry, NGOs and other important stakeholders to assess the current state of knowledge, identify gaps and develop options for sustainable P management.

Why the focus on phosphorus? Phosphorus is an essential element of life: it is an indispensable element in human and animal bodies, natural and agricultural systems and in numerous natural and industrial processes and products. Phosphorus is present in various compounds in all living cells, in the cell membranes and in life-maintaining materials such as DNA, RNA and ATP. This portends that without phosphorus there would be no life on earth.

The essential nature of P in food production and the finite amount of natural P resources (phosphate rock deposits) have resulted in concerns about the medium- to long-term availability, accessibility and quality of phosphate rock for fertiliser production. Specific concerns relate to the timing of a “peak” in phosphate rock production, after which it will become more expensive to extract phosphate rock and produce P fertiliser. Although recent reports suggest that current resources and reserves (the latter defined as the currently exploitable phosphate rock, given today’s economic and technology contexts) are larger than previously indicated (by the data used to predict a peak in production this century), phosphate rock is a non-renewable element on which humankind is already highly and increasingly dependent. Even though concerns about a potential P scarcity exist, farmers in many developed regions of the world use more P fertiliser than annual crops require. Excess soluble P in the environment resulting from industrial, agricultural and non-agricultural uses can contaminate groundwater and surface water resources, causing the well-known problem of eutrophication.

It has been estimated that humans have roughly doubled or tripled global P cycling through mining and processing into fertiliser and industrial products and through the inefficient use of these products. Phosphate rock exploration, mining and processing into fertiliser are likely to increase in the foreseeable future given the current increase in food demand to feed the ever increasing global population. According to the International Fertilizer Industry Association (IFAI), to keep up with agricultural production, an annual increase of approximately three percent in global P demand is expected by 2050/16, with further increases likely. Due to a growing number of factors contributing to erosion, runoff and waste discharge, P typically absorbed by soil particles can easily escape to contaminate natural water resources, as in the case in the Baltic Sea. Both the contamination and availability problems around unsustainable P use call for closed-loop approaches requiring, among others, increased recycling efforts. Models and technologies for environmentally sustainable P management exist and are being practiced in many locations, including effective erosion control and manure management, use of urban and municipal wastes as fertiliser, and processing of P from sludge and manure as struvite (magnesium phosphate) for agricultural and industrial use.

The Global TraPs Project: Transdisciplinary Processes for Sustainable Phosphorus Management

Concerns and opinions about inefficient P use have been voiced in both scientific and non-scientific media by individuals or groups often representing only the view of a single stakeholder group. What has been lacking is a multi-stakeholder forum involving differing viewpoints, knowledge and concerns. This kind of dialogue is needed to guide and optimise future P use through an assessment of the current knowledge and gaps as well as the development of options for the way forward.

The Global TraPs Project (Global Transdisciplinary Processes for Sustainable Phosphorus Management; 2010–2015) is addressing this broad need. Participants have met for the third time in August 2011 to consider the guiding question for the project: “What new knowledge, technologies and policy options are needed to ensure that future phosphorus use is sustainable, improves food security and environmental quality and provides benefits for the poor?” Global TraPs will bring together knowledge and know-how from “practice” (producers and users of phosphorus, along with those facilitating their efforts, such as extension and development organisations) and “science” (researchers from various disciplines with an interest in phosphorus). This international project has broad participation from scientists, industry, NGOs and other groups from around the world. The project is co-led by the Swiss Federal Institute of Technology (ETH-NSSI) and the International Fertilizer Development Center (IFDC), each assuming responsibility for leadership of one facet – “science” (ETH-NSSI) and “practice” (IFDC). It is expected that a large number of stakeholders (as many as 300) will be involved and participate in the project.

The project employs transdisciplinary (Td) methodology to facilitate a dialogue of mutual learning. By integrating diverse knowledge and perspectives from various stakeholders and through consensus building, the Td processes results in development of socially robust options for future policy. While focusing on the global situation, TraPs draws from location-specific case studies designed to address specific issues of interest. Study
Sustainable agriculture in the Baltic Sea Region

and discussions will be organised into ‘node’ groups with each node focusing on a part of the global phosphorus supply chain (shown in Figure). Node groups focus on, for example, exploration of phosphorus resources (Exploration Node), production of fertiliser from phosphate rock (Processing Node) and the fate of phosphorus after it is used (Recycling and Dissipation Node). Each node will have two leaders, one from “practice” and the other from “science”. These leaders are cooperating with a transdisciplinary coordinator with in-depth experience in transdisciplinary methodology. Ideally, participants in each node will represent “science” and “practice” in equal proportions. In the spirit of transdisciplinary methodology, the Global TraPs project seeks to create an open, transparent platform for all participants to respectfully share and exchange knowledge and viewpoints. Exchanges on views and values are integral to the process, which operates in a pre-competitive and non-politicised arena. This means that, rather than focusing on policy making, the goal of the Global TraPs project is to develop recommendations about policy options for supporting sustainable P use and management.

Broad topics of the Global TraPs project are the following:

• The current state of knowledge about P cycling and use
• New knowledge necessary (knowledge gaps) to promote sustainable P use
• New approaches and technologies needed to optimise P use and re-use
• Areas for policy intervention that have the greatest potential to promote sustainable P use

A report describing project outcomes will be made available globally for high-level decision makers in policy, industry, science and development. Specific case studies and their outputs will benefit particular locations.

This article broaches the legal treatment of the non-substitutable nutrient phosphorus (P), which is indispensable for life and its major modern, non-renewable source, phosphate rock. Not only is the highly important P resource problem relevant, which has hitherto received little attention in the legal discourse, but also the excessive and wasteful entry of P into the environment. This leads to significant harmful effects on ecosystems, particularly evident in the long-term, as well as subtle impacts of P accumulation in waters and soils. The European and German fertiliser and soil regulations are at best weak when opposing the existing resource and pollution trends. Regulations in the above mentioned legal domains are insufficient and lack concreteness and real enforcement. They do not prevent the relocation of problems nor provide a safeguard for absolute quantity reductions in phosphorus use.

Hoping for a free play of actors and markets without government control in respect to the P question has proven unsuccessful. Our root cause analysis strives to explain why. One way of dealing with this issue could be to demand stricter, more ambitious and more concrete command and control legislation, which appears to make sense at first from a transparency, motivation and ecology perspective.

The national level

Similar steps could be required at the national level, for instance a re-definition of the term "code of good practice", since the boundary between fertilisation and over-fertilisation has so far been drawn where further yield and quality increase are no longer possible by simply applying more fertiliser. The amount of fertilisation required from an ecological and resource-policy point of view is then already exceeded because that limit stands below the agriculturally-defined optimal fertilisation intensity. This should be standardised accordingly.

The consumption perspective

From a consumption perspective, decreased yields are defensible in the face of wasteful food handling in western societies (disposal rate, high meat consumption). Moreover, instead of using surface balance in order to measure nutrient balance, the more comprehensive and implementation-friendly enterprise balance should be applied, since the latter includes all nutrients going into and leaving the pool, such as seeds, feed, livestock, crop yield and fertiliser.
Global perspectives on limited P resources

Last but not least, slurry as a by-product of factory farming, as well as P use in feed, ought to be reduced structurally. As an alternative, lower limits in applying farm fertiliser as well as refraining from using additional mineral fertiliser could be discussed in order to encourage faster closed-loop cycles such as those in organic agriculture. In addition, it would be necessary to improve enforcement of the respective regulations. This could be achieved by introducing concrete norms, stricter monitoring and a legal basis not subject to administrative discretion.

Such (and perhaps also other) reform options in respect to P fertilisation would be quite welcome, and have been discussed in part for a long time (of course without implementation).

Why the administrative regulatory approach might not succeed

There are a number of reasons for assuming that the administrative regulatory approaches will eventually not succeed in solving the resource and environmental problems related to phosphorus:

• First, the enforcement problem in agriculture can hardly be solved with a command and control regulatory approach, since an endless multitude of minimal processes would need to be monitored. The vision of a “policeman on every tractor” is hardly realistic. Also, as has been shown, one cannot solely count on self-regulation in agriculture and elsewhere.

• Administrative approaches (command and control) often have the disadvantage that they unexpectedly shift environmental problems to other areas. If the EU were to decrease P use, this might trigger intensified cultivation outside the EU – or a massive increase in the likewise problematic use of green genetic engineering.

• There is one more problem inherent to all similar command and control solutions: administrative legal systems are often prone to individual case-based exceptions, discretion or weighting. These expectations can often thwart the spirit of the legal norm through frequent application.

• Further, it is difficult to translate aspects such as “long-term preservation of food security” into administrative legal criteria (command and control) since they do not directly correspond to individual fertiliser application.

• This leads to our central point: The essential problem concerning ecological impact and resource issues is demonstrated not so much with one single fertiliser application. Rather, it is the accumulation of many - insignificant when taken separately – fertiliser applications and the resulting excess fertilisation. Intensive livestock farming also adds to the problem. This also holds true for the significant contribution of agriculture to climate change by energy-intensive fertilisation, methane-releasing livestock farming and other environment-affecting issues. From an individual perspective, the single adverse effects on the natural and aquatic environment often seem not to be sufficiently relevant, yet in total, they add up to substantial adverse effects.

The holistic perspective - focusing on reduction of total P quantity

It is therefore necessary to find a regulatory approach that captures the required holistic perspective. Only a real decrease in the total quantity of all phosphorus used (ultimately on a global scale) and at the same time much more enhanced P recycling can actually achieve the necessary resource conservation while alleviating ecological impacts. Absolutely central to this thinking is the realisation that creating regulations solely focusing on efficient P application will not be sufficient. Indeed, any reduced P application “per plant” in the current food crop system represents prima facie a gain. However, if at the same time the area of currently unused land is increasingly used for example for feed crop cultivation (triggered by globally rising meat consumption) or for bioenergy plants, the required absolute reduction in P use cannot be met. This problem of impending rebound effects is currently reflected in the climate change discourse - and even here not often enough - yet it also exists within the resource problem complex. It should further be pointed out that the resource issue can ultimately only be solved on a global scale. A reduction of P in the EU would certainly help the ecological problem of waterways and soils, yet the resource issue would remain – finite global phosphate rock supplies would likely be used elsewhere.

Our global food security would not be put at risk, because any genuine quantity regulation that included manure measurement would make the production of food of animal origin unattractive (one calorie of food from animal origin requires four to twelve plant-based calories), and so food security would probably be stabilised (also as a result of gained P savings). This is likely to result in the promotion of ecologically advantageous, cycle-oriented forms of land use, such as organic farming. Apart from natural circulation systems on farms, the agenda could be set for consistent efforts to recycle P from residues, such as from the sewage sector or the waste industry, back into agriculture. From an ecological and health perspective, this implies clearly counteracting the impending overload of soils with heavy metals and organic pollutants through new recycling and treatment concepts, a task which has not been sufficiently integrated in the past.

The fact that thoughts on small-scale regulatory improvements almost exclusively dominate the debate despite the obvious frictions presented, might seem more remarkable than it actually is. The previously described individual types of motivation for the public, entrepreneurs, legal practitioners and politicians do indeed promote approaches which may demand no substantial behavioral changes of those involved. Rather, they seemingly
provide “technical problem solving”. Apparently, most people involved fear nothing more than some sort of debate on “abidation”, in which the durability and global spread of our occidental resource use (for example our high meat consumption) would need to be discussed in depth and not only in the language of euphemistic speeches. If one (usually reasonably) many administrators, lawyers and others try to avoid the debate by pointing out that such a new approach might not be “politically enforceable”, and thus cannot be further discussed, the majority of existing options in western countries are, of course, correctly described. Admittedly, this would then (1) not be an objective practical constraint, but an explainable behavior of concrete people in politics, administration, the public and farming community, for which all would need to take responsibility, especially with respect to resulting consequences. Further, one should then (2) plainly admit that a real solution to the P problem complex can thus probably not be attained, with all the highly negative long-term consequences of such a “business as usual” policy.

A global approach to limit P use

A global approach to quantity control is simpler to enforce, prevents shifts in location – because the normative addressees cannot avoid quantity control anyway – removes the rebound problem and ideally tackles a given problem (also in the case of P) at its roots. Global quantity control can therefore be, where necessary, less bureaucratic and democracy-friendly since the legislative body makes the real decisions and not the administration with its multifaceted actions for concretisation. Further, quantity control potentially provides more freedoms since, within a given quantity frame, it leaves the freedom of decision to the citizen. However, what is not implied is that such a quantity regulatory approach should generally replace any other soil protection. Even in those areas where it would be appropriate to have such an approach (such as in the context given), it might become necessary to develop additional legal regulations, as for instance for the use of sewage sludge, which on the one hand should be increasingly used, yet on the other hand this is only possible under certain ecological and technical premises.

Phosphorus and EU subsidies

An obvious tool for P quantity regulation could be a clear rearrangement of EU subsidies for the agrarian sector towards subsidies of environmental services, away from mass production and livestock farming. This stands to reason also from a fiscal perspective and for world trade legislative reasons. An alternative or even better cumulative effect would be the introduction of a fee on mineral fertiliser. Such a possibility has been discussed for some time already for the nutrient nitrate, but it is also plausible for P. Instead, one could practice friendly enforcement with respect to fertiliser producers. In the case of P resources, if implications other than ecological ones are to be covered, generally taking also into account the global agrarian market and the extremely important animal feed market, then certainly a European or even global fee would be appropriate. Due to the time lag of effects it is important to start as soon as possible with these suggested measures. First results, particularly in respect to eutrophication, are likely to be visible only in several years or decades. Also the resource problem demands quick action.

Phosphorus and taxes

An approach focusing on raising taxes would simultaneously tackle many other problems beyond the P issue. The same effect as that provided by a tax could perhaps be achieved with a certificate-approach similar to the European greenhouse gas emission trading system, by creating entitlements to P quantities and by gradually reducing P certificates on a global scale. A further alternative might be provided by a general certificate approach on land use, which could be linked to a completely newly designed European and global greenhouse gas emission trading system. The latter approach would establish different, typified land use type certificates depending on the degree of their ecological relevance and would then again gradually reduce them on a global scale. From a climate policy perspective, including land use in is any case on the agenda. However, severe enforcement difficulties are expected, including on the operative level given the difficulty in determining the ecological value of certain areas and land use types. These difficulties will be even more apparent in administrative and legislative global solutions. The easiest approach might well be to establish a parallel global certificate market for phosphorus and for greenhouse gas emissions. A resulting price and cost pressure and resulting changes in land use would certainly also be indirectly beneficial to other land use problems.

In European law, article 9 of the European Water Framework Directive (WFWD) on the imperative of rendering tasks economical already suggests an economic solution for the P issue, especially with respect to waterways. According to current prevalent belief, fertilisation is considered only as a form of water use, not as a water service since it does not comply with the definition given in article 2 no. 38 WFWD. Article 9 of the WFWD demands that also those which are not water services take on an appropriate share for the cost recovery of such water services if they are to some degree responsible for these costs. Accordingly, sectors such as for example agriculture in fact need to bear the latter and costs resulting from over-application of fertilisers in wastewater treatment for the provision of drinking water (including extracting e.g. uranium). Finally, water quality impairments linked to fertiliser production could also be taken into account.

Phosphorus and social justice

P use and, in general, any administrative or quantity control approach eventually leads to implications for social distributive justice. This not only refers to conflicts between economic freedom and the protection of physical preconditions of freedom (in parts also guaranteed by fundamental human rights), which are always present in environmental protection. Rather, it refers to secondary effects that arise from the resulting compromises between these different rights in environmental policy. In other words, harm and benefits arising from P application do not always align. This problem has a national and global dimension. Eventually declining phosphate rock reserves are likely to result in higher prices and quality degradation due to higher heavy metal loads. While industrialised countries are still able to pay prices for higher quality and fertiliser in general, developing countries can face severe availability, accessibility and quality issues. Moreover, soils in the southern hemisphere are currently exposed to substances such as heavy metals (including extracting e.g. uranium). Finally, water quality impairments could, for instance, distribute the revenues arising from a charge or from a certificate system auctioning per capita to the citizens of every state. Another option would be to partially or completely frame them as North-South transfers.
A minimum solution P concentration is needed to facilitate plants’ P uptake from soil solution. This concentration varies between plant species and cultivars. In acid soils, P released from minerals upon weathering is readily adsorbed on the surfaces of iron and aluminium (oxy)hydroxides by ligand exchange reactions or, in calcareous soils, precipitated as sparingly soluble calcium phosphates. In soils never fertilised with P, these solid phases maintain a very low P concentration (<0.02 mg/l) in the soil solution, and the vegetation is taking up P actively from this very dilute solution. Together with shortage of N, this low P concentration is commonly the limiting factor for growth. When solution P concentration is elevated, P uptake is increased, but after a threshold value, further increase in solution P concentration does not contribute to increased yield or P uptake. The sufficient concentration needed for 95 % of yield varies widely (0.01–0.3 mg/l), depending on the crop and soil properties.

The primary objective of P fertilisation is to increase the P concentration of soil solution to a level sufficient to cover the demand of crops. However, almost all soils initially have a large buffer capacity against any change in the P concentration in the soil solution through the sorption and precipitation reactions mentioned above. In soils never fertilised with P, almost all sites capable of adsorbing P are free for capturing P from the solution. In a pristine soil reclaimed for agriculture, even a large P dose is nearly completely adsorbed (fixed) by the mechanisms mentioned above, with very little increase in solution P concentration. In such soils, P adsorption is rapid, taking place in hours. At the advent of P fertilisation, it was common to have no obvious response to added P, because it was so effectively immobilised in the soil and the availability to plants was rapidly lost. Until recently it has been a common belief that P limitation to crop growth can be avoided only by applying several times more P than is taken up by the crop. This way the sorption sites in the vicinity of the applied fertiliser are saturated with P, which contributes to a higher dissolved P concentration in the nearby solution. Apparently irreversible sorption to soil is the principal reason that in soils low in P the recovery of fertiliser P by crops is very low.

Abundant P fertilisation by mineral fertilisers and manure and strongly positive P balances in large parts of the industrial world have gradually elevated the P status of soil. The tendency of soil to fix added P has also decreased as an increasing number of the potential sites for P sorption are already occupied. Gradual filling of sorption sites has contributed to higher soluble P concentrations and decreased the need of additional P fertilisation. A large surplus of P has accumulated in soils, a large part of which remains available to plants. It is often estimated that only 10-20 % of P contained in the crop originates from the most recent fertilisation, the remaining 80-90 % coming from the reserves accumulated in the soil in earlier fertiliser applications. If matched with P uptake, apparent utilisation of fertiliser P can be 100 % in these soils. Furthermore, it is common to have only minor or non-existent short-term responses to P fertilisation in most field experiments carried out in intensive agriculture.

Most P in common mineral P fertilisers is readily soluble. After application to the soil the fertiliser granule starts to dissolve and a concentrated P solution diffuses into the surrounding soil. Different calcium phosphates, predominantly dicalciumphosphate, are precipitated in that zone as their solubility products are exceeded. Later, upon dilution of the soil solution, these precipitates are gradually dissolved and fertiliser P enters the different pools of soil. Even though this fertiliser P is not distinguishable from the bulk
of the rest of secondary P reserves of soil, recently applied P maintains a somewhat higher solubility. Since fertiliser P moves only a few millimetres a year, localised P application can create environments of substantially higher solution P concentrations than in the bulk soil and therefore contribute to higher utilisation of P by the crop. Over time, P diffuses further into the soil pores, and is bound more strongly onto the oxide surfaces. Continuous weathering of soil minerals produces new aluminium and iron oxide faces so that new sites for P sorption are generated. P can even be embedded (ocluded) and lose contact with the soil solution. These processes slowly decrease the availability of fertiliser P.

Degree of P saturation (DPS), a concept developed by Lookman et al. (1995; Geoderma 66, 285-296), can be used to explain the distribution of P added to soil between the adsorbed and dissolved pool. The concept is valid in acidic soils where aluminium and iron hydroxides are mainly responsible for the sorption of added P. It is assumed that there are a certain number of sites capable of adsorbing P.

The DPS is originally operationally defined as the molar ratio of oxalate-extractable P to the sum of oxalate-extractable aluminium plus iron:

\[
\text{DPS} (%) = 100 \times \frac{\text{Pox}}{0.5 \times (\text{Alox} + \text{Feox})}
\]

The coefficient 0.5 stands for the assumption that half of the potential sorption components are actually active and in contact with soil solution. The lower the DPS, the more readily and more strongly added P is adsorbed. Upon repeated applications and positive P balances, an increasing number of the potential sorption sites become occupied with P. At the same time, the bonding strength of successively adsorbed P decreases and a higher P concentration is maintained in soil solution. A DPS value of 25 % has been set for a soil where solution P concentration becomes excessive from the environmental point of view, allowing P leaching in dissolved form or substantial P release from eroded soil material.

Even though the DPS concept has been primarily developed for environmental assessment, it can to a certain extent be utilised roughly in estimating the sufficiency of P supply to a crop. In many parts of intensive agriculture, with a long history of abundant P fertilisation with mineral fertilisers or manure and highly positive P balances, the DPS values are considerably high. In these soils solution P concentration meets or exceeds the threshold value needed by the crop plants for maximum growth. A prerequisite for apparently 100 % utilisation of fertiliser P is thus a rather high soil P status and thereby a substantially decreased fixation tendency. Even though P is continuously subjected to processes that slowly decrease its solubility also in soils of high P status, their P supply power is sufficient to meet the crop needs for several years, even decades.

Soil P status is, however, not the only variable regulating P uptake by the crop. An incomplete utilisation of fertiliser P, in spite of abundant supply, can result from adverse edaphic and climatic conditions. These include soil acidity, poor drainage, temporal water logging, soil compaction, drought, or deficiency of other nutrients.

**Fate of P fertiliser in soils – the organic pathway**

This overview addresses the following questions:

i) Are phosphate ions that get through the soil’s ‘organic pathway’ – that is, those that are found at some point in time in an organic form or within soil organisms or plant residues – totally plant available (100% use by plants)?

ii) Do they remain in the soil/plant system (zero losses to the environment)?

Positive answers to these questions would lead to the conclusion that P management in agro-ecosystems and more specifically plant P nutrition could be optimised by in-cr easing soil organic P content and soil biological activity. More specifically we hypothesise that by re-moving P from the soil solution, soil microorganisms or plants will store it in different forms within biological membranes and prevent P from being strongly sorbed onto soil particles, and that the mineralisation of microorganisms or plant residues and the hydrolysis of organic P will lead to the release of P to the soil solution from which it will be taken up by plants or microorganisms.

The above stated hypotheses will for the following reasons probably not be verified completely. Many forms of organic P are found in soils, some being rapidly and strongly stabilised on soil particles such as myo-inositol hexakisphosphate and others being rapidly hydrolysable, such as RNA, ATP or glucose-P. Whereas steady-state release of P from the microbial biomass might happen in synchrony with plant P demand, pulses of P release from microorganisms to the solution seem to be rarely in phase with active plant demand, rather leading to P sorption on soil particles. The coefficient of use of organic P, manure P or P in plant residues by plants as measured with radiotrace techniques is always lower than 100% of the added P and reaches rarely the P use efficiency measured for a water-soluble P source as super triple P. The results obtained from a P budget study of the DOK I field experiment show, however, that the addition of a unit of P either as organic fertilizer or as water soluble fertilizer leads to the same increase in soil available P. This suggests that in the long-term the P added as organic fertilizer...
Phosphorus (P), in addition to nitrogen (N) and potassium (K) belongs to the group of macro-nutrients that are essential for plant growth. A deficiency of P may limit plant growth and yield, reducing the uptake of other nutrients such as N and creating a surplus that is subsequently at risk of leaching into ground and surface waters. On the other hand, over-application of P can directly contribute to losses to water bodies and result in eutrophication. Therefore, farmers need to choose fertilisation strategies that minimise the environmental and economical risks. Fertiliser recommendations have to be based either on soil analysis or on expected P uptake by plants with the aim of providing a balanced P fertilisation to exactly meet crop growth requirements.

Concentrations of P in plants vary between different crops, growth stages and plant parts, for example grain and straw for wheat. The calculation of P uptake by plants is common practice and involves knowledge of actual or expected yield as well as the P content of all plant parts. Depending on the agricultural management, after harvesting several plant parts remain in the field (e.g. stubble, straw or sugar beet leaves), and therefore remain within the nutrient cycle. Other major plant parts (e. g. grains, potatoes and beets) are removed from the field and transported off site. Consequently, understanding the variation of P concentrations in plants is a prerequisite for sustainable P management.

The DOK1 field experiment in Switzerland compares since 1978 the effect of conventional and organic farming practices on crop productivity and soil fertility. © Astrid Oberson

Variability of nitrogen © Susanne Schroetter

8 Experiment on bio-Dynamic, bio-Organic and Conventional (K) farming systems, since 1978

The exact mechanisms for these long-term transformations are unknown: on the one hand P added as water soluble fertilizer can become less available while on the other hand organic P from the organic fertilizer can be mineralised with time. The importance of the "organic pathway" to plant P nutrition is probably relatively limited in cropped systems where microbial P content and turnover are low compared to the high plant P demand that is concentrated over a few weeks (e.g. during stem elongation for cereals) and to the large P exportations by crop products. In grasslands, however, this "organic pathway" might play a more important role in plant nutrition as microbial P content and turnover can be very high compared to a relatively constant P uptake during the season and in relation to P exportations. Finally, besides orthophosphate, organic P compounds as well as organic P rich colloids (plant debris, micro-organisms) can also be lost from the soil either in runoff or by leaching.

The fact that organic P is not always as available as the water soluble form of P, or that organic P can be lost from the soil, is no reason to neglect soil organic matter input. Organic matter is not only important as a source of nutrients (N, S, P), but is also important for the cation exchange capacity of the soil and for the development of an optimal soil structure which favours water-holding capacity, plant root development and finally nutrient uptake.
Systematic analysis of plant P concentrations started more than 100 years ago, but is currently no standard farm management practice. Table 1 provides some examples of P contents for wheat available in the literature. It can be seen that reported P concentrations vary substantially. Certain factors influence P uptake by crops resulting in variable P contents. This variability can be observed spatially, temporally, due to species and variety characteristics, as well as management practices, or can be a combination of all of these.

As an example of the variation in grain contents between varieties of winter wheat, Table 2 provides some values from a variety trial carried out by Barrier-Guillot et al. in 1992, published in 1996.

Such results demonstrate that calculating reliable estimates of nutrient uptake by plants is challenging. Nevertheless, gross nutrient balances for P are calculated on an annual basis for all OECD countries. Coefficients used to calculate the input and output of a farm or a country are mostly static values averaged across years and varieties. Most OECD countries use their own generated coefficients (Table 3). The data sources and methodologies used to do this are not always well understood and reduce the validity of comparisons of such balances between countries.

The German gross P balance (Figure 1) shows that the average P balance has in recent years fallen towards zero. But, whilst the reduction of average P surplus at the country scale is a positive development, a national P balance does not provide any insight into the variation in surpluses or deficiencies at a local or even small scale, which can have major effects on yields, P availability in agricultural soils, and P losses to water resources.

The variability at such a small scale is due to the heterogeneous nature of agricultural fields with regards to soil texture and organic matter and the fact that the land is often undulating. Such heterogeneity can be minor, with little effect on yield and nutrient uptake, but can also be extreme and substantially impact plant growth. The most influential parameters are topography and soil texture, which contribute to the availability of water and nutrients.

Whilst sandy soils have a higher risk of nutrient leaching into ground waters, clay soils as well as soils with low pH have a high potential to adsorb P. Therefore, such soils can have a high total P content but a low P availability.

Figure 2 demonstrates the spatial variation for winter barley in the year 2000 for a) yield, b) grain P content, c) calculated P uptake and d) soil P availability. P uptake was calculated using spatially recorded P concentrations in grain and straw. In this example, barley grain P content varied spatially between 0.30 - 0.36 % P across the 25 ha field (Figure 2b). Such significant variations in P content question the validity of the method for...
calculating plant P uptake using defined P coefficients, as is required by German law. Using this approach, German farmers have to prove that their holding has not exceeded an average annual nutrient surplus of 8.7 kg P per hectare over the last six years of fertilisation.

The P coefficient used for winter barley in Germany is defined as 3.52 kg P per tonne of grain, whilst Figure 2b shows major areas which are well below this value. Using the static P concentration value to calculate P uptake by the plant biomass of this field will most likely overestimate P removal. Consequently, the risk of excessive P application will be increased, at least in parts of the field. The result of uniform P applications over many years onto a heterogeneous field can be seen in Figure 2d, showing the accumulation of available soil P in areas of the field with lower yield potential caused by sandy soils as well as lower lying parts of the field where P was transported from higher areas. Future spatially variable P applications that take into account available soil P as well as variation in yield potential could reduce the risk of P losses into water bodies by wind and water erosion.

Table 3: P contents used in some OECD countries to calculate P-balances in 2004 for spring & winter wheat grain.

<table>
<thead>
<tr>
<th>OECD member state</th>
<th>P in wheat grain [kg t⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>spring wheat</td>
</tr>
<tr>
<td>Australia</td>
<td>2.60</td>
</tr>
<tr>
<td>Korea</td>
<td>2.82</td>
</tr>
<tr>
<td>Sweden</td>
<td>3.10</td>
</tr>
<tr>
<td>Japan</td>
<td>3.36</td>
</tr>
<tr>
<td>Italy</td>
<td>3.49</td>
</tr>
<tr>
<td>Germany</td>
<td>3.52</td>
</tr>
<tr>
<td>Switzerland</td>
<td>3.66</td>
</tr>
<tr>
<td>Canada</td>
<td>4.21</td>
</tr>
<tr>
<td>Spain</td>
<td>4.80</td>
</tr>
</tbody>
</table>

Figure 1: German gross P balance calculated according to OECD standards using common P coefficients for Germany as well as the mean P input and output between 1990-2008.

Figure 2: (a) winter barley yield, (b) P content in grain, (c) P uptake and (d) soil P availability in Mariensee (Lower Saxony, Germany), 2000.
Higher phosphorus utilisation in cropping systems

An economical use of phosphorus (P) is a key issue for sustainable agriculture. The integration of P-mobilising plant species in crop rotation is one of the most promising agronomic measures to improve P utilisation in cropping systems.

Plants respond to their soil environment and are able to influence the nutrient availability in the rhizosphere. This has special importance for P given its low mobilisation in soils. Crop plants have different strategies to influence the P uptake. Some plants adapt to low availability of P mainly by changing their root morphology, others are effective due to the high excretion of P-solubilising compounds. There are major differences in P uptake efficiency not only between plant species, but also between genotypes.

Under P deficiency plants usually increase their root length in relation to the shoot biomass. Due to this increased root to shoot ratio, the nutrient requirement and influx per single root decrease. Mainly monocotyledonous plants, such as cereals and grasses, have large root length and surface. Thus, they can utilise a greater soil volume, which is of vital importance with a view to P utilisation.

Plant root exudates mainly consist of a complex mixture of amino acids, organic acids, organic and inorganic ions, vitamins, sugars, nucleosides and enzymes which have direct or indirect effects on the acquisition of nutrients. The capacity to excrete organic acids is very pronounced for plants with so-called proteoid roots like lupine. Another example is oilseed rape, which excretes high amounts of malate and citrate which cause a better solubility of Ca phosphates. This happens due to a decrease of soil pH values while the chelating compounds bind cations and thus release P. Not only the excretion of organic acids, but also the amount of inorganic ions absorbed by plant roots can influence the soil pH value. Root exudates also contain molecules that control the development of mycorrhizal fungi, which contribute significantly to the P nutrition of various crops.

Organic P may comprise up to 80 % of total soil P. Mineralisation and the subsequent release of phosphates makes organic P plant-available. This process is promoted by enzymes, like acid and alkaline phosphatases. Environmental conditions and plants' growth affect the activity of phosphatases in soil. High activities of acid phosphatase were found for example in soils during cultivation of amaranth and maize.

Catch cropping is the cultivation of plants with a short vegetation time between the cultivation of two main crops. Catch crops are mainly used as green manure and cover the soil until late autumn or until the next spring. This has a positive influence on soil fertility and can reduce nutrient losses from soil. Furthermore, these plants can improve the P supply of the following main crops directly by modifying soil properties and mobilising P, or indirectly after their decomposition, when P is released from the plant material and provides an easily accessible P pool to succeeding crops. Very promising results were obtained for phacelia and buckwheat cultivation by the author.

Thus, it can be concluded that the combination of many different crops in a crop rotation is an important contribution to sustainable food systems and will not only have positive effects on the biodiversity in cropping systems, soil fertility and plant health, but may also help to improve the P utilisation in soils and save P fertilizers.
Phosphorus (P) is an essential plant nutrient. A sufficient supply for crops is important to warrant crop productivity. P deficiency will not only reduce plant growth, but also impair soil fertility. A surplus of P in soils is not desired either. Erosion of P-rich topsoil results in increased P input into water-bodies which is a major cause of eutrophication – a serious and consistent condition in the Baltic Sea.

To prevent soil P surpluses in agricultural soils, the German Fertilisation Ordinance limits the annual surplus for phosphate to 20 kg P₂O₅/ha. To meet this aim, old recommendations for the agricultural use of organic and mineral fertilisers have to be evaluated and advanced, site-specific fertiliser algorithms need to be developed for a demand-driven input of the resource. Then a reduction of P losses to water bodies can be expected.

Besides preventing P surpluses in the nutrient balance, the input of organic and inorganic pollutants by mineral and organic P fertilisation including recycled products has to be considered since those products may contain considerable amounts of these substances. Once added to the soil, they can accumulate and enter the food chain. Hence, to ensure a safe and sustainable use of P-containing inorganic and organic fertilisers, it is important to gain an advanced understanding of the properties of different organic and inorganic fertilisers.

Standards for P-containing fertilisers and recycled products

With view to the scarcity of rock phosphate reserves and increasing prices for mineral fertilisers, the use of organic P from waste materials such as manure, sewage sludge or slaughterhouse wastes is of high interest. One current trend is the rapid expansion of biogas facilities for energy production. The residues from these facilities are regularly applied on agricultural soils as fertiliser material. In this case it is important to enact regulations that guarantee food safety by setting norms for recycled products. These imply that such commodities must not contain any organic xenobiotics and their heavy metal content should...
not lead to an accumulation in soils; another relevant issue is that they are not contaminated by human toxicologically-relevant pathogens. These constraints are essential as co-fermentation of plant products with sewage sludge or slaughterhouse wastes is a common procedure in biogas plants. However, recycled products for instance on the basis of farmyard manure and sewage sludge ashes will play a major role in closing the P-cycle on farms. Standards for (recycled) fertiliser products need to address the speciation of P and to define a minimum content of plant-available P, besides the general norms set for food safety.

Assessing plant-availability of P by different extraction methods

To ensure both a sufficient P supply and prevention of a P surplus on agricultural soils, an estimate of the plant-available amount of fertiliser P is needed. To distinguish between instantly available, medium and long-term available P fractions, several chemical extraction methods with different strengths are applied. The German Fertiliser Ordinance contains 11 methods to assess phosphate solubility; most of them are equal to the methods given by EU Regulation 2003/2003 on fertilisers (Kratz et al. 2010). Experiments in the laboratory and pot trials showed that it is possible to reduce the number of standard methods to assess P-solubility of mineral as well as organic fertilisers to three or four: while water extractability describes P-forms with a high solubility having an initial effect, the mid-term effect of non-water soluble P-forms can be best described by an extraction with ammonium citrate. For the estimation of tradable total P content of a fertiliser, it is suggested to apply the mineral acid extraction (Kratz et al. 2010).

Adjusting P-fertiliser rates for maintaining an optimum P status of soils

Agriculture has to strive for a balanced P-input which replaces P taken off by harvest products. In order to do so it is relevant that the only P applied is plant-available and takes part in the soil P-cycle. This means that the plant-available amount of P in the fertiliser material has to be determined next to the current and optimum P status in soils. In addition, it is necessary to assess changes in soil P status in relation to management practices.

Calculation of the so-called P-index takes into account the local condition parameters for P uptake capabilities of the agricultural area (e.g. soil quality, slope of the field, and distance to a watercourse) and helps to determine the risk of P losses to water-bodies in the studied area when P is applied to the soil. The P-index can be applied to evaluate which fields are predestined to P loss and to decide if on the particular field further P application is arguable. It can also help to decide if rather an organic than an inorganic P-source should be applied since this will have a positive influence on soil porosity, aggregate stability and infiltration capacity - all of these being factors which decrease soil erosion and thus reduce P losses from agricultural land.

Variable, site-specific rate application of inorganic and organic P sources

The use of inorganic multi-nutrient fertilisers simplifies nutrient application on cropland. However, the use of these products causes major problems since the spatial variability of optimum fertiliser rates between different nutrients is not correlated and the nutrient ratio remains constant during the complete application. This might lead to an undesired surplus or deficiency in different areas of the field. To solve this problem, the spatial variability of soil and crop characteristics should be correspondingly converted into a spatially variable application of fertilisers that matches the local demand on the field. For mineral multi-nutrient fertilisers, a strategy for site-specific fertiliser application has already been designed. However, it is advisable to also develop advisory models for a variable, site-specific rate application of organic fertilisers. Thus, it can be expected that by this means non-point nutrient losses will be efficiently reduced at the field level.
Phosphorus management in organic farming

Organic Farming acts on sites with different P fertilisation history

Primarily crop production in organic farming aims to optimise use of soil-borne phosphorus (P) and of fertiliser P applied. Several long-term experiments have shown only slightly lower crop yields after decades of omitted P fertilisation compared to P-fertilised plots (Gransee and Merbach 2000) showing that P mobilisation from the solid phase of the soil can cover crop demands especially when yield levels are lower compared to mainstream agriculture. Soil P-reserves are dependent on specific site conditions and former fertiliser inputs. For Germany a tremendous additive surplus of P input with fertilisers and feedstuff imports in agriculture is calculated on the basis of statistical data. For the time between 1950-2000 additive P input exceeded P removal of crops by about 800 kg/ha P in the new and 1400 kg/ha P in the old German federal states (Köster and Nieder 2004). Also in other regions of the world decades of P fertilisation higher than crop removal have increased soil P levels. At the same time, 30 % of the worldwide agricultural area has negative P-balances (McDonald et al. 2011). It is estimated that 40 % of worldwide crops are affected by P deficiencies (Vance 2001).

Organic farming is currently benefiting from the history of P over-fertilisation. Nevertheless, with negative long-term budgets organic farming will increasingly depend on P amendments in the future (Loes and Oegaard 2001). The questions are then: when will organic farms run into a definite deficit resulting in yield losses and what measures and strategies can be used to replenish the plant available P pool in soils?

P budgets of organic farming systems are often negative

Due to fodder imports and manure management, organic livestock farms are normally described as having balanced or even positive P budgets (Berry et al. 2003) although their P export via milk products and bones of slaughtered animals is higher when compared with arable organic farms. Livestock systems benefit from the intensification of nutrient cycling with animal keeping indicated by feed crop production, nutrient transfer from grassland and use of manures. But if they are using 100 % organic feed from farm-own production and have no other P imports they will reduce their P reserves by product export in the long-run. In closed arable organic farming systems specialised on cash crops a nutrient transfer between fields via biogas-manure could be introduced, but generally lower capacities exist to increase the on-farm nutrient cycle. Organic vegetable production often relies on high amounts of nitrogen and P imported by organic manures or green waste composts. These organic inputs can generate surplus P in soils.

Generally, soils under long-term organic farming have lower available P contents than those under conventional agricultural use (Oehl et al. 2002). This does not necessarily mean that yields are limited due to lack of P. Soils under organic and conventional farming mostly differ in inorganic P fractions but seldom in organic fractions except microbial P, which is often higher under organic than conventional farming conditions (Oehl et al. 2001). Extensive analyses of recent P fertilisation trials showed the limited possibility to predict P supply to crops by soil analysis values. It was shown that even if nutrient contents in the top soil classified by CAL and DL method are ‘very low’ (A) or ‘low’ (B) there is only little probability to increase yields by additional P fertilisation (Kuchenbuch and Buczko 2011). Thus, P mining in soils with low available P contents indicated by negative P budgets might be tolerable even in the medium or long-term, especially when the lower yield expectations of organic farming are considered.

Soil tests on P for organic farming

A deeper interpretation and active P management is only possible when the availability of P soil reserves can be described. The role of organic and inorganic P and/or microbial parameters for P supply in organic plant production has to be defined and quantified by suitable soil tests. The common fertiliser recommendations in organic farming indicates that the soil test level “low” (B) is sufficient for the typical low yield expectations. Up to now, no systematic relation of P from organic farming acts on sites with different P fertilisation history
Sustainable agriculture in the Baltic Sea Region

Astrid Oberson
Senior Scientist, Group of Plant Nutrition, Institute of Agricultural Sciences at ETH Zürich, Switzerland

Gerold Rahmann
Head of the Institute of Organic Farming, Johann Heinrich von Thünen-Institute (vTI), Trenthorst, Germany

Mixed cropping of P-efficient white lupin with safflower. © Hans Marten Paulsen

fractions in the soil to P nutrition of crops has been found. However, in organic farming this source is claimed to be of utmost importance in supporting the aim of basing organic production on nourishing plants primarily through the soil ecosystem.

It is assumed that methods of soil analysis used in the past have underestimated the available P resources in central European soils. Also special soil tests for organic farming have been developed (Haneklaus et al. 2005), but the usability of these methods for organic agricultural practice has not been described and verified.

Organic farming systems are usually predominantly N-limited and the crop P needs for yield level under organic growth conditions are not well defined. Furthermore, the available threshold values used to describe P supply in plant tissue are derived from systems fertilised with sufficient mineral N and might not be adequate for lower yield levels. It is obvious that a real P budget management is not possible without further information on these basic parameters.

Mobilising soil P reserves by biological measures

Using suitable root systems and adapted crop rotations

Root geometry, root-length density and active root surface area, increased by mycorrhiza in certain species, are important factors influencing the ability of plants to unlock nutrients from the solid phase of the soil. The enhancement of active root surface to assure an intensive P exploration of plants in soil should be an inevitable goal of agricultural production.

P management in organic farming should entail a composition of crop plants displaying different root systems and capacities for P uptake. For example white lupin and buckwheat are described as having an efficient P uptake and different species can access different soil P reserves (Mat Hassan 2010). Also other dicots displaying taproot systems combined with intensive rhizosphere activity – like lucerne or pea – can be introduced into organic crop rotations to strengthen organic P flow.

When grown in mixed cropping, P efficient crops can directly enhance the P nutrition of the cropping partner. On the other hand, effective P uptake by these plants might also limit P that is available for the following crops. Also the cultivation, mulching and redistribution of more common cover crops like grass clover may enhance biological P cycling on farm. The nutrient (and P) value and nutrient relations of the plant tissue can be influenced by crop type and plant age.

Enhancing soil microbial activity

Soil microbes colonise the rhizosphere, enhanced by root exudates. P mobilisation from insoluble inorganic and organic soil reserves takes place by soil acidification or exudation of phosphatases by plants and microbes. Mycorrhiza and their activity increase with increasing depletion of P soil reserves. But microbes and plants are also competing for the orthophosphate available in the soil solution. Thus, the net balance of available P from these biological processes is difficult to quantify. It depends on several environmental conditions as well as substrate attributes, e.g. the C:P ratio of organic materials (Oberson et al. 2010).

Organic inputs can stimulate soil microbial activity and soil P mobilisation. But since the factors driving microbial P release are not completely understood the prediction of plant available P coming from soil microbes is difficult to quantify.

Organic farming relies on this biological P mobilisation and targeted P fertilisation is often neglected, without knowing the real potential of these processes for an efficient nutrient management. Due to the sometimes high, but in the short-term
P in the deeper layers is considered to range from 25 to 70 % of the total amount of P in the soil profile. In the subsoil, roots have been reported to grow predominantly in macropores either formed by physical processes such as swelling and shrinking, or biogenically (old root channels and earthworm borrows). The area around biopores, the so-called drilosphere, is considered as a preferred site for nutrient acquisition in the subsoil. Thus, crop-species that can enhance earthworm population should be preferred in organic agriculture. Earthworm excreta are characterised by higher biological activity and higher content of microbial P and alkaline phosphatase activity. Thus, roots growing in earthworm biopores meet higher P contents in the tapestries of the walls coated with worm cast (Pankhurst et al. 2002).

P delivery from the subsoil is enhanced when P content in the topsoil is low, as demonstrated by long-term field trials (Oehl 2002; Wechsung and Papel 1993). Already before topsoils were extensively fertilised with P, it was shown by means of 32P tracer methods that the subsoil substantially contributed to plant P nutrition. In a degraded prairie soil it was shown, that continuous alfalfa growth can restore lost P reserves by P mobilisation and it is still unclear to what extent plants, and soil and root microbes can mobilise the P reserves and feed them into the active soil-plant farm P cycle (Guppy et al. 2009). So these biological measures to enhance P mobilisation are far from confirmed knowledge which can be used in management advice. Due to the complex factors determining P mobility in soil, each component of the P cycle in organic farms should be analysed to decide on the necessity and the right place for P imports. Of genuine importance for organic systems might be the role of P for rhizobial N fixation with legumes (Römer and Lehne 2004). In any case, a hidden depletion of available P in soils under long-term organic management by use of P sources with low availability in the soil/plant P circle should be avoided.

Suitable fertilisers must be discussed

After estimating possible capacities of biological P mobilisation - and available P in soils, suitable P fertilisers and fertilising strategies that can be applied in organic farms to correct P imbalances have to be identified.

Use of P fertilisers – especially rock phosphate, which is widely used in organic farming – is potentially linked to soil contamination with Cadmium as well as Uranium (Kratz and Schnug 2005). Furthermore, the use of rock phosphate is often inadequate because most P enters the P budget in more or less insoluble form. When the soil pH is higher than 6, P mobilisation from this source is doubtful and unforeseeable (Arcand and Schneider 2006). Attempts to increase P availability of rock phosphate by mixtures with slurry, manure or compost, or to increase initial P mobilisation by application to plants with high P efficiency improved P usage only little and under controlled conditions. Also, the frequently discussed use of rock powders – e.g. of basaltic or volcanic origin – as fertiliser in organic farming is ineffective, due to low nutrient availability. Special developed rock phosphate or bone meal fertilisers generating acid phases to dissolve P have not yet been introduced in practice and are currently not acceptable by EU regulation. At least in special cases, the use of soluble P fertilisers such as superphosphate should be allowed. The recycling of P containing residues from industry and households should also be reintroduced in organic farming under consideration of closed nutrient cycles and under strict limitation of possible pollutants in the sources, e.g. in sewage sludge and composts (Rahmann et al. 2009). Ethical aspects concerning the use of conventional sources and residues from animal production with low animal welfare standards must also be discussed. Therefore farm collaborations that are shifting plant nutrients, among these also P, by livestock and biogas manure from conventional to organic systems should be prepared to face public debates on the consistency of nutrient cycling in organic farming.
Phosphorus from recycled organic fertilisers – a Norwegian perspective

Food production is the largest consumer of mined phosphorus (P) worldwide. P is introduced to food production from mineral fertilisers and feedstuffs, with fertiliser as the most important source. Only a small part of this P ends up on our forks. During production, processing, trade and intake of food, P is directed to various organic wastes, by-products and wastewater. Manure makes up the largest of these secondary P resources, containing around 13,500 tonnes per year on a national basis in Norway. In comparison, Norwegian farmers use around 8,000 tonnes of P in mineral fertilisers per year. 6,000 tonnes of P from food production is found in organic waste and wastewater from processing, trade and consumption of food. One third of this P is returned to agricultural land with recycled organic fertilisers and soil amendments, mainly by sewage sludge and meat-and-bone meal (MBM). MBM is processed low risk slaughtering waste and is utilised as a fertiliser. In addition, around 60 % of the sewage sludge produced in Norway is used in agriculture as soil amendment.

Recycling of products based on waste and wastewater represents a potential risk connected to sanitation and contaminants. The last decade there have been national risk assessments for biosolids and meat-and-bone meal based on low-risk slaughtering waste, concluding that these products can be safely used on agricultural land as long as they follow the process- and product quality standards set in current legislation. As these products are regarded as safe and beneficial to the soil, incineration with possible P recovery from the ashes has so far not been regarded as an alternative. There are restrictions on loads and areas where waste-based products can be used. Restrictions on loads are related to heavy metal content in the products and there are no explicit restrictions on P loads. As application loads for these materials are often decided by nitrogen (N) fertiliser effect or soil improvement effects, the P load often tends to be higher than the plants’ P demand.

When MBM is applied in order to supply the crop with nitrogen, more P than the annual plant demand is also applied. Experiments have estimated the effect of P from MBM during the first year to be 40-50 % compared to the effect of P from mineral fertiliser. Release of P from the bone fraction of MBM is a long-term process and MBM has proven to have a residual effect of P supply that lasts for several years in Norwegian soils. It is, however, important to note that the solubility of MBM is pH dependent and the P fertiliser effect can be expected to be best on acidic soils.

It has been recommended not to apply any P the year after application of MBM as N fertiliser. In organic farming systems, MBM is recommended at 80 kg N per hectare to a nitrogen-demanding crop once in a four or five year crop rotation in order to maintain the P balance. An organic fertiliser based on meat-and-bone meal and wood bottom ash is being developed in Norway at present.

Biosolids originating from sewage sludge are typically applied as soil amendments once in a 10-year period in an amount of 20 tonnes dry matter per hectare. Such application represents a large amount of total P (150 – 600 kg per hectare), but due to the low plant availability of P, farmers commonly apply the same amount of mineral P as usual both in the application year and the following years. P from biosolids will therefore often be poorly utilised in the soil-plant system.

Also for manure, efficient P recycling has proven to be problematic. The animal density in Norway is regulated as a ratio between animals and land for application of manure (manure animal unit, MAU). One MAU represents around 14 kg P, which should be applied to 0.4 hectares or a larger area. However, the amount of manure on a farm basis is often applied according to the crops’ demand for nitrogen, leading to higher applications of manure at areas close to the farm, and almost nothing at more distant fields. Such practice results in build-up of high concentrations of readily available P in soils, increasing the risk for P loss from agricultural land by erosion and leaching.

In areas with high animal density, a combination of biogas treatment and separation of P from the liquid digestate is regarded as an interesting alternative. Norwegian experiments with liquid digestate made from mixtures of manure, fish silage and food waste have shown a very good effect as fertiliser, often at the same level as mineral NPK fertiliser. The challenge with liquid biogas residue is high transport costs, which put an economic limitation on use in areas distant from biogas plants. Although different solutions for precipitation and concentration of plant nutrients in digestes are being investigated, there are so far no obvious and profitable methods available.

Developments in processing technology to convert waste and by-products into recycled fertiliser products are key factors for more efficient P recycling. What we are still waiting for are the legal and economic incentives to start the process.
How energy from livestock manure can reduce eutrophication

The problem of phosphorus recovery from a manufacturer's point of view

60% of phosphorus losses to the Baltic Sea originate from non-point sources, 90% thereof from agriculture or, more precisely, from factory farming. Notwithstanding the regulatory and voluntary efforts for higher environmental compatibility, animal husbandry remains a key emitter of excessive phosphorus applications to soils and subsequent losses to aquatic bodies.

Ecologists claim that only a radical system and management change can solve the problem. Experience teaches, however, that radical changes do not happen without emergency. As a consequence, an evolutionary technological approach that does not substantially interfere with current agricultural practices may be a meaningful option.

Biomass waste is generally acknowledged as a sustainable option for energy generation. Livestock manure in Germany has a gross energy potential of about 100,000 GWh per year, two times the currently installed wind power capacity. Still, only 15% of it is used, mainly for biogas production. Animal excreta are used as a fertiliser, because of their significant nutrient concentrations and other benefits to pasture and cropland. However, excessive phosphorus applications on farmland enhance the risk of nutrient losses to water-bodies by run-off and erosion. Soils in the vicinity of animal husbandry farms usually receive excessive phosphorus loads because there is no cheaper and easier way of disposing biomass waste than to spray it on agricultural land. As long as waste may be declared as fertiliser independently from fulfilling a meaningful function or not, excessive nutrient loads to soils will continue.

The main problem behind the non-sustainable practices is the high water content of most biomass wastes, depending on its origin and varying between 80% and 97%. This fact reduces the economic transport range of these materials to just a few kilometres.

So what to do? The key is energy generation together with nutrient recovery. No doubt that biomass waste is an adequate renewable energy source. As long as manure is used for biogas generation, moisture is not a problem. But it does not solve the nutrient problem, because the waste from biogas production, digestion residues, contains as much water as the input. However, biogas is only a first step to a sustainable solution. Digestion residues and waste biomass that is not suitable for digesters should be incinerated.

Incineration of biomass waste, independent from preceding biogas production, solves two problems simultaneously. Firstly, it makes use of the full energy potential of biomass, as digestion residues still have an energy potential of 15,000 MJ per tonne (Arndt 2009). Secondly, it concentrates the nutrients and facilitates their transport to the soils where they are needed and do not harm the environment.

However, to make this vision come true, coordinated efforts and research and development are needed.

Framework conditions

Phosphorus (and other nutrients) originating from livestock manure and sewage sludge is unevenly distributed in Germany as shown in the example of the Federal States Schleswig-Holstein, Mecklenburg-Vorpommern and Brandenburg – draining to the Baltic Sea in comparison to Germany as a whole (see table 1).

Accumulated phosphorus applications in Schleswig-Holstein probably exceed sustainable fertilisation needs. It has been observed that farmers apply relatively high loads of mineral phosphates though they use manure. Breaking down the figures to applications by region, as intended during the Baltic Manure Project (http://eu.baltic.net/ProjectDatabase.5308.html?&contentid=5&contentaction=single), will bring to light disparities.

The examples of the three German Federal States Schleswig-Holstein, Brandenburg, and Mecklenburg-Vorpommern show that not only the nutrients from animal excretions but also from human excretions (sewage sludge) are disposed of on agricultural land as fertiliser materials. Schleswig-Holstein, a Federal State with one of the highest P-loads from livestock manure in Germany, prefers agricultural application of sewage sludge rather than alternative, sustainable pathways.

Hypothetically, a large proportion of phosphorus taken up by crops in Germany could be covered in a safe way by renewable sources – livestock manure, sewage sludge and slaughterhouse residues – if these resources could be applied in those regions where they are required and not where they can be disposed of at low cost. Pre-conditions to nationwide (phosphorus) fertiliser application rates in line with sustainable farming recommendations are that new fertiliser products be dry and contain phosphorus in sufficiently high concentrations, and that the agronomic phosphorus efficiency be proven.

According to the conversion factors in use in agricultural policy, each livestock unit produces about 15 m³ of livestock manure per year, with an average dry substance concentration

<table>
<thead>
<tr>
<th>Table 1: Livestock, agricultural land and P₂O₅ applications in 3 States and Germany (Source: Destatis 2009 statistical data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandenburg</td>
</tr>
<tr>
<td>Livestock units</td>
</tr>
<tr>
<td>Agricultural land (ha)</td>
</tr>
<tr>
<td>P₂O₅ from livestock manure and sewage sludge applied per ha in kg per year</td>
</tr>
<tr>
<td>P₂O₅ from mineral fertilisers per ha in kg per year</td>
</tr>
<tr>
<td>Total P₂O₅ per ha in kg per year</td>
</tr>
</tbody>
</table>
of 10 %, of which about 80 % is organic. During anaerobic digestion, it yields at least 3 MWh in the form of biogas. Because of the degradation of organic matter into biogas, the resulting digestion residues contain only 7 % dry matter, of which 70 % is organic. Tests at the University Hohenheim (Germany) have demonstrated that dried digestion residues with 10 % humidity yield 15.000 MJ or 4.16 MWh per tonne in the form of heat (Arndt 2009).

Hypothetically, 13.5 million livestock units in Germany could thus yield energy in the order of 95.000 GWh and more if the total waste from animal husbandry is considered. This is twice the energy output of all wind power plants at present in operation and may be a significant contribution to future energy supplies.

Most of this energy potential has not been considered yet because of the inefficiency of drying processes in use. The key to accessing the total energy potential of livestock manure, other wet biomass and even sewage sludge is in recycling the energy that is necessary to evaporate water. Whereas at present most of the energy yielded is used for internal processes and in particular for drying, recent developments are promising regarding the technical feasibility to significantly increase drying efficiency. However, a net energy yield from livestock manure remains a prerequisite for the widespread implementation of the proposed concept.

### Innovative approaches

The highest phosphorus concentration in a recycled fertiliser product can be achieved by mono-incineration of the targeted waste biomass. Besides phosphorus, potassium, calcium, and sulfur, micronutrients will be accumulated in the ash. Nitrogen is lost during incineration, but half of the original N-content can be separated before incineration by an effective solid-liquid separation.

Almost all waste biomass and in particular manure contains large amounts of water, up to 97 %. Energy generation by anaerobic digestion does not require dewatering. About 15 % of livestock manure in Germany is already used to produce biogas and this share should increase substantially in the near future. Generating energy by anaerobic digestion, however, has no effect on the regional distribution of phosphorus because the digestion residues are again sprayed on cropland in the vicinity of animal husbandry farms.

Only mono-incineration can solve the problem. There are good reasons to assume that all targeted biomass could yield a net surplus of energy on top of covering the additional expenses for material preparation, de-watering and drying.

Assuming that the highest energy yield can be achieved by anaerobic digestion and subsequent mono-incineration, all larger animal husbandry farms should be equipped with biogas facilities where between 30 % and 50 % of organic substances of livestock manure will be degraded (Arndt 2009). These facilities will yield digestions residues with the characteristics shown in table 2.

State-of-the-art solid-liquid separation yields a solid phase with 20-30 % dry substance and a liquid phase with 2-6 % dry substance. On average, about 75 % of phosphates and 50 % of each nitrogen and po-tassium may be concentrated in the solid phase (Arndt 2009) (see also table 3). The nutrients remaining in the liquid phase will continue to be used for fertilisation in the vicinity of the animal husbandry farm – with only 25-50 % of the traditional nutrient application rates.

The solid phase should be shipped to larger mono-incineration facilities where it will be dried and combusted. Whereas fluidised bed combustion has proven to be appropriate for sludge and residues with high moisture content, energy-effective drying is not state-of-the-art. However, a few examples of very effective drying systems exist in the area of biomass-fueled combined heat and power (CHP) plants, for instance in Hedensbyn and Storuman, northern Sweden, engineered by GreenExergy AB. GreenExergy is one of the few companies that have managed to recycle most of the energy needed for evaporating water from forestry and sawmill residues. The dryer has a net energy consumption of only 150 kWh to evaporate one tonne of water, in comparison to 1200-1400 kWh for traditional drying processes. If this system could be transferred to sludge and manure drying, mono-incineration of these materials would yield net energy surpluses and contribute significantly to energy supplies.

The main task for the dryer is to reduce the moisture content in the raw material from feed moisture content down to 8-12 %, depending on the final use of the product. The system shall also facilitate the feeding and the extraction of material to, and from the pressurised dryer. An important task is to recover the evaporated steam from the raw material through regeneration of low pressure steam to other low temperature usage.

<table>
<thead>
<tr>
<th>Digestion residue</th>
<th>Dry Substance</th>
<th>N\text{\textsubscript{total}} kg/m\textsuperscript{3}</th>
<th>NH\textsubscript{4} kg/m\textsuperscript{3}</th>
<th>P\textsubscript{2}O\textsubscript{5} kg/m\textsuperscript{3}</th>
<th>K\textsubscript{2}O kg/m\textsuperscript{3}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min.</td>
<td>2.9</td>
<td>0.74</td>
<td>0.15</td>
<td>0.09</td>
<td>2.0</td>
</tr>
<tr>
<td>Max.</td>
<td>13.2</td>
<td>2.4</td>
<td>1.5</td>
<td>0.9</td>
<td>10.6</td>
</tr>
<tr>
<td>Average</td>
<td>6.7</td>
<td>5.4</td>
<td>3.5</td>
<td>2.5</td>
<td>5.4</td>
</tr>
</tbody>
</table>

Hypothetically, 13.5 million livestock units in Germany could thus yield energy in the order of 95.000 GWh and more if the total waste from animal husbandry is considered. This is twice the energy output of all wind power plants at present in operation and may be a significant contribution to future energy supplies.

Most of this energy potential has not been considered yet because of the inefficiency of drying processes in use. The key to accessing the total energy potential of livestock manure, other wet biomass and even sewage sludge is in recycling the energy that is necessary to evaporate water. Whereas at present most of the energy yielded is used for internal processes and in particular for drying, recent developments are promising regarding the technical feasibility to significantly increase drying efficiency. However, a net energy yield from livestock manure remains a prerequisite for the widespread implementation of the proposed concept.

### Innovative approaches

The highest phosphorus concentration in a recycled fertiliser product can be achieved by mono-incineration of the targeted waste biomass. Besides phosphorus, potassium, calcium, and sulfur, micronutrients will be accumulated in the ash. Nitrogen is lost during incineration, but half of the original N-content can be separated before incineration by an effective solid-liquid separation.

Almost all waste biomass and in particular manure contains large amounts of water, up to 97 %. Energy generation by anaerobic digestion does not require dewatering. About 15 % of livestock manure in Germany is already used to produce biogas and this share should increase substantially in the near future. Generating energy by anaerobic digestion, however, has no effect on the regional distribution of phosphorus because the digestion residues are again sprayed on cropland in the vicinity of animal husbandry farms.

Only mono-incineration can solve the problem. There are good reasons to assume that all targeted biomass could yield a net surplus of energy on top of covering the additional expenses for material preparation, de-watering and drying.

Assuming that the highest energy yield can be achieved by anaerobic digestion and subsequent mono-incineration, all larger animal husbandry farms should be equipped with biogas facilities where between 30 % and 50 % of organic substances of livestock manure will be degraded (Arndt 2009). These facilities will yield digestions residues with the characteristics shown in table 2.

State-of-the-art solid-liquid separation yields a solid phase with 20-30 % dry substance and a liquid phase with 2-6 % dry substance. On average, about 75 % of phosphates and 50 % of each nitrogen and po-tassium may be concentrated in the solid phase (Arndt 2009) (see also table 3). The nutrients remaining in the liquid phase will continue to be used for fertilisation in the vicinity of the animal husbandry farm – with only 25-50 % of the traditional nutrient application rates.

The solid phase should be shipped to larger mono-incineration facilities where it will be dried and combusted. Whereas fluidised bed combustion has proven to be appropriate for sludge and residues with high moisture content, energy-effective drying is not state-of-the-art. However, a few examples of very effective drying systems exist in the area of biomass-fueled combined heat and power (CHP) plants, for instance in Hedensbyn and Storuman, northern Sweden, engineered by GreenExergy AB. GreenExergy is one of the few companies that have managed to recycle most of the energy needed for evaporating water from forestry and sawmill residues. The dryer has a net energy consumption of only 150 kWh to evaporate one tonne of water, in comparison to 1200-1400 kWh for traditional drying processes. If this system could be transferred to sludge and manure drying, mono-incineration of these materials would yield net energy surpluses and contribute significantly to energy supplies.

The main task for the dryer is to reduce the moisture content in the raw material from feed moisture content down to 8-12 %, depending on the final use of the product. The system shall also facilitate the feeding and the extraction of material to, and from the pressurised dryer. An important task is to recover the evaporated steam from the raw material through regeneration of low pressure steam to other low temperature usage.

<table>
<thead>
<tr>
<th>Digestion residue</th>
<th>N\text{\textsubscript{total}}</th>
<th>Ammonium</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min.</td>
<td>52.2 %</td>
<td>46.8 %</td>
<td>50.0 %</td>
<td>47.9 %</td>
</tr>
<tr>
<td>Max.</td>
<td>67.0 %</td>
<td>52.8 %</td>
<td>89.3 %</td>
<td>50.0 %</td>
</tr>
<tr>
<td>Average</td>
<td>57.6 %</td>
<td>46.8 %</td>
<td>73.3 %</td>
<td>49.3 %</td>
</tr>
</tbody>
</table>
The technical challenge for the dryers will be the physical state of livestock manure and sludge before and during the drying process. It will be difficult to prepare the material for the kind of steam dryers used in the GreenExergy CHP plants. Moreover, sludge is entering into a sticky state at a certain stage of the drying process that has always been a challenge to sludge dryers. Manure drying has not been tested yet.

Compared to drying incineration should not present any problem. State-of-the-art fluidised bed furnaces such as those from Outotec Oyj will safely handle the material. However, high loads of nitrogen, chlorines and sulfur in manure increase the risk of flue gas and material corrosion. They are challenging with respect to the flue gas and material corrosion. The Vietnam University yielded an ash with 24 % P2O5 and 21 % K2O as primary nutrients and 23 % Calcium as secondary nutrient (Arndt 2009). It is evident that a fertiliser with an original nutrient concentration of 45 % may be evenly distributed across Germany. If and when heavy metal concentrations exceed the limits for sustainable fertilisers, the ASH DEC heavy metal separation process may be installed together with the incinerator.

Even if the proposed approach would significantly reduce the excessive application of nutrients in regions with high livestock concentration, it does not automatically entail higher plant nutrition efficiency if the ash-based product is not plant available. Consequently, as a last step, the plant availability of renewable fertilisers needs to be tested and improved, if necessary. Pot and field tests during the FP-6 Programme “SUSAN” have demonstrated that the formation of magnesium-phosphates during a thermal process can produce phosphate fertilisers with high plant availability on neutral to acidic soils. The Julius Kühn Institut (JKI), German Federal Research Center for Cultivated Plants has successfully tested in-situ inoculation of phosphate rock with sulfur and Thiobacillus. Both methods could significantly increase fertiliser efficiency of renewable phosphate fertilisers. Product development must not stop when renewable products can achieve similar efficiency levels as traditional, water-soluble phosphate fertilisers. There is still potential to further increase the plant availability of renewable products to obtain high crop yields with adequate fertiliser applications.

The same rule applies to renewable materials as to renewable energy: our planet is not big enough to sustain multiple replacement of one source by the other. The key to sustainability is closing nutrient and energy cycles and making the use of resources more effective.

Sustainable agriculture? This is one of the key questions for the future. In 1998 the Baltic 21 Agriculture Sector answered this question by elaborating a goal and definition for sustainable agriculture:

“Sustainable agriculture is the production of high-quality food and other agricultural products and services in the long run, with consideration taken to economy and social structure in such a way that the resource base of non-renewable and renewable resources is maintained.”

Important sub-goals are:

- The farmers’ income should be sufficient to provide a fair standard of living in the agricultural community.
- Farmers should practice production methods that do not threaten human or animal health or degrade the environment, including biodiversity, and at the same time minimise the environmental problems that future generations must assume responsibility for.
- Non-renewable resources should be gradually replaced by renewable resources and re-circulation of non-renewable resources should be maximized.
- Sustainable agriculture should meet the needs of food and recreation, preserve the landscape, cultural values and historical heritage of rural areas, and contribute to the creation of stable, well-developed and secure rural communities.
- The ethical aspects of agricultural production should be secured.

A series of three books in the final stage of production and will soon be available. They are the concrete outcome of the Ecosystem Health and Sustainable Agriculture project. Here the importance of an ecosystem approach as regards sustainable agriculture is highlighted. Sustainable agriculture is a means of securing the necessary resources for safeguarding global food production, biodiversity reserves, recreation needs, water quality and well developed rural and wildlife areas. It can also be an effective means of reducing poverty and achieving the Millennium Development Goals, as well as mitigating climate change. It is also about health, welfare, respect and ethics regarding animals and man, as well as quality of food and feed. In other words, the books are truly trans-disciplinary and represent a new holistic outlook on ecosystem health and sustainable agriculture.

These three books are based on experience from the Baltic Sea and Great Lakes Regions and are written by prominent experts and scientists from the two regions. Two networks have been involved in the production of the books, The Baltic University Programme (BUP) and the Envirovet Baltic Networks. The BUP is a network of approximately 220 universities in the drainage basin of the Baltic Sea, which cooperates on sustainable development and studies of the region, its environment and its political changes. The programme, founded in 1991 at Lunds University, Sweden, operates by producing courses, holding conferences and seminars. In 2010, the BUP network delivered courses at more than 100 universities serving nearly 9,500 undergraduate and graduate students.
graduated students. The Envirovet Baltic, a network of environmental health scientists and educators from the USA and the nine countries bordering the Baltic Sea, was founded in 2001 on an initiative of the College of Veterinary Medicine at the University of Illinois and the Centre for Reproductive Biology in Uppsala at the Swedish University of Agricultural Sciences, along with scientists from universities in the Baltic Sea Region (BSR).

The production of these books was managed by BUP and included several educational seminars, training courses, conferences and meetings on Ecosystem Health and Sustainable Agriculture. These were held in St. Petersburg and Kaliningrad, Russia, in Tallinn and Tartu, Estonia, in Jelgava, Latvia, in Warsaw, Poland, in Uppsala, Sweden and in Urbana-Champaign, Illinois, USA. The project has also achieved large international recognition as it was awarded the status of a United Nations partnership for Sustainable Development and the status of a Baltic 21 Lighthouse project. The latter was awarded by Baltic 21- an Agenda 21 for the Baltic Sea Region as a good example of an international project on sustainable development within the Baltic Sea Region. As a result, it has been presented at many conferences, such as the United Nations Commission for Sustainable Development 16 Meeting in May 2008, AgroRus 2007 and 2008, Baltic 21 Ten Year Anniversary at the Riga Summit in June 2008, and Baltic Sea Days in March 2009. The production of these books was financed by SIDA, SEPA and SI.

We strongly recommend that readers study all three volumes in this educational series:

- **Sustainable Agriculture** (ed. Christine Jakobsson, 500 pp.)
- **Ecology and Animal Health** (ed. Leif Norrgren and Jeffrey Levengood, 400 pp.)
- **Rural Development and Land Use** (ed. Ingrid Karlsson and Lars Rydén, 300 pp.)

The first two books will be printed in October/November 2011 and the third book a few months later.

It is our firm belief that agriculture and related activities can, if well managed, be positive for ecosystems and biodiversity. Alternatively, agricultural activities can also have disastrous effects on the environment including humans living in the area. Often national goals are not only to sustain the country’s food security, but also to keep an open landscape and a rural lifestyle. A sustainable rural development has its backbone in a sustainable agriculture.

## Annex

Baltic Sea Region perspectives on limited P resources

### References


(2002): Phosphorus budget and P availability in soils under organic and conventional farming. In: 
Nutrient Cycling in Agroecosystems 62(1), 25-35.


of soil associated with macropores at different depths in a red-duplex soil in NSW. Australia. In: 
Plant Soil 238, 11-20.


Rahmann, G. / Oppermann, R. / Paulsen, H.M. / Weismann, F. (2009): Good, but not good enough? 
Research and development needs in Organic Farming. In: Landbauforschung Völkenrode 59(1), 
29-40.

and grain yield in a red clover-oat rotation. In: Journal of Plant Nutrition and Soil Science 


and grain yield in a red clover-oat rotation. In: Journal of Plant Nutrition and Soil Science 

and grain yield in a red clover-oat rotation. In: Journal of Plant Nutrition and Soil Science 

and grain yield in a red clover-oat rotation. In: Journal of Plant Nutrition and Soil Science 

Rahmann, G. / Oppermann, R. / Paulsen, H.M. / Weismann, F. (2009): Good, but not good enough? 
Research and development needs in Organic Farming. In: Landbauforschung Völkenrode 59(1), 
29-40.


im Statischen Dauerversuch Lauchstädt – Betrachtung der P-Bilanz nach 84 Versuchsjahren. 
The EcoRegion Perspectives’ series is published as part of the EcoRegion project funded by the Baltic Sea Region Programme 2007-2013.

It documents experiences and concepts which show how sustainable development in the Baltic Sea region can become a reality. Each issue focuses on a specific sustainability topic such as tourism, territorial cohesion, education and innovation, transport and energy.

EcoRegion Perspectives support relevant regional fora such as the CBSS Expert Group on Sustainable Development – Baltic 21 as well as the implementation of the EU Strategy for the Baltic Sea Region.

The different EcoRegion Perspectives’ issues are coordinated by the EcoRegion partners and reflect a wide range of stakeholders with expertise on the respective topics.