Proceedings of the 5th Vietnamese-Hungarian International Conference on „Animal Production and Aquaculture for Sustainable Farming”
Can Tho University, Can Tho, Vietnam, 11-15 August, 2007

# POTENTIAL OF AQUACULTURE VERSUS AGRICULTURE IN SUSTAINABLE RESOURCE UTILISATION

*Maria Takacs-Hajos – Lajos Szabo – Janos Olah*

Tessedik Sámuel College, Faculty of Agricultural Water- and Environment Management
1-3. Szabadság str., Szarvas, H-5540, Hungary

hajos.maria@mvk.tsf.hu; szabo.lajos@mvk.tsf.hu; olah.janos@mvk.tsf.hu

## Abstract

We are approaching rapidly an age of diminishing resources and there is a global need to conserve the remaining natural products and services and use them in more sustainable technologies of aquaculture, agriculture and animal husbandry. The new applied discipline of ecotechnology both in aquaculture and agriculture is emerging from the basis of the rapidly growing quantitative ecology. Ecological engineering applies the tools and principles of ecotechnology and helps to develop, to introduce and to practice environmentally sustainable technologies in meat production processes. Coupling ecotechnology with biotechnology has a real perspective, where the protein production traditionally applies the technologies of living processes. This new way of producing products and services is already realized in integrated aquaculture practices relying mostly on microbial processing of nutrient and on the manipulation of energy transfer rates. Based on ecotechnological principles the nitrogen pathways, fluxes and cycles were selected to quantify the biotechnological processes of protein production in integrated aquacultural and ecosystems of animal husbandry.

Nitrogen retention have been quantified in fish-cum-livestock, livestock, arable and mixed ecosystems with potentials of farm inputs and consumable farm outputs. Environmental cost of farming with the parameters of nitrogen leached to soil, water or lost to the atmosphere have been also quantified in the same types of meet producing farms.

## Potential of aquaculture versus agriculture

An eco-eco concept of the landscape nitrogen metabolism has been elaborated and adopted to describe the economic and ecologic processes in the natural resource consumption with the nitrogen atom. The resulted national nitrogen budget and calculated landscape nitrogen metabolism was verified with the trend of riverine nitrate concentrations (Oláh and Oláh, 1996). Following this approach and applying it to quantify the protein producing potential, we have collected and compared the consumable farm nitrogen output in almost all agroecosystem types of agriculture and aquaculture (Figure 1). Detailed nitrogen cycling data were collected and evaluated by Frissel (1978) for 65 agricultural agroecosystems of various intensity including dairy and meat production, arable land, forestry as well as horticulture. Here we present the nitrogen output from each particular agroecosystems grouped on the line of similar intensity of the same protein producing ecosystem. The wide range of intensity from shifting agriculture to the intensive dairy or arable farming required the presentation on logarithmic scale. Similar evaluation of the protein production potential we have already published for aquaculture (Sinha and Oláh, 1982). By plotting our 30 published production values against stocking figures in a wide range of fish rearing ecosystems, we have got a near linear response. Taking into account the various latitudes where these experiments were conducted, we had to convert all the fish production values to 365 days. Fish production was dependent primary on stocking density if environment and food were sufficient.

If we compare the production of aquaculture systems with those of agricultural ones, it is surprising that natural waters may compete with the majority of agricultural systems. This means that properly managed natural waters have the potential to produce protein as efficiently as agriculture, but with a much more sustainable consumption of the environment. Protein production in natural waters is coupled actually with the production and not with the consumption of the environment. What a great strategic surplus! The constructed fishpond ecosystems may produce animal protein, on an areal basis, as much or even more than the peak yields of plant protein produced in any of the analysed arable ecosystems. The industrial aquaculture, this wastefull trend of the last two decades, proved to be the same sinful trial of the profit oriented blind scenario for the natural resource consumption, than the western industrialized agriculture. In these industrialized fish factories the production potential is almost unlimited, at least theoretically. In practice however, there are questions: what is the energy cost and how much environment we have to consume to produce one ton of protein in such food producing factories.

## Farm input and consumable output

Applying the eco-eco concept of the landscape nitrogen metabolism we have also quantified the relationship between farm input and consumable farm output using Frissel's data for agricultural farms and our own data of five Hungarian aquacultural farming systems. The input and output of each food producing terrestrial and aquatic farming systems were expressed in nitrogen atom (Figure 2). Solid line plots indicate the nitrogen efficiencies from l percent to 200 percent. In the case when output was higher than input the nitrogen fixation was not quantified properly or the soil or sediment organic nitrogen pool was consumed. As it was predictable the farm output from arable systems is much higher than the output from livestock systems. All arable systems are between 30 and 100 percent of the input. Up to farm input of 150 kg N ha$^{-1}$ y$^{-1}$, the output efficiencies are often close to the 66 percent efficiency curve. There are slightly lower efficiencies at higher farm inputs. In livestock systems the range and scattering of data points is much wider. About half of the farms are within the efficiency range of 10 to 30 percent. As could be expected, the results in mixed systems are intermediate between those of arable and livestock systems.

Contrary to the agricultural ecosystems analysed by Frissel, in all of the five Hungarian aquacultural technologies included in this study, only manure, as the byproduct of the appropriate integrations, was applied for building block molecules of the fish protein synthesis. There was no inorganic fertilization applied. This cheap and effective food producing biotechnology is realized through bacterial plus algal based aquatic food chains. The industrialized aquaculture technologies were not plotted into this input output analysis. First, because their unfeasible nature due to the highly artificial procedures and the environmentally unacceptable by products. The fish-cum-goose ponds produced consumable farm output with the most efficient nitrogen transfer machinery. In this ecosystem the significant streamflow and baseflow transported and supplied the bulk of the nitrogen. The groundwater nitrate nitrogen content ranged between 8-19 ppm. If we do not count this nitrogen input, the nitrogen transfer efficiency is around hundred percent. Another advantage of this animal protein producing system is its high nitrate removal capacity from the ground and stream water. This is an environmentaly very important landscape function.

The highest consumable farm output was produced in the fish-cum-duck integration with nitrogen transfer efficiency of above 50 percent. On experimental scale the fish and duck consumable output together, has reached the very high value of 620 kg N ha$^{-1}$ year$^{-1}$ (Pekár et al. 1993). The fish-cum-pig ponds represent an indirect integration. The pigs are not kept directly on the ponds, only their manure was introduced daily into the ponds. An example of the mismanaged aquaculture in Hungary is macrophyte choked carp pond ecosystem. In this shallow and large pond on the Hortobagy Puszta, the specialized transfer routes direct the nirtogen into the macrophyte biomass of *Potamogeton pectinatus*, instead of to the fish protein synthesis (Oláh and Szabó, 1986). The efficiency is well below three percent. The aquacultural rotation system of the fish-cum-duck-alphalpha-rice we have placed and analysed among the mixed systems. This comlex agroecosystem utilizes the input nitrogen with 30 percent efficiency. Its consumable output is the second highest among the quantified mixed systems.

## Environmental costs of farming

Beside the high consumable farm output and nitrogen efficiency, the most important inherent advantage which characterizes these aquacultural ecosystems, as compared to the terrestrial agroecosystems, is that they are able to receive, to process and to retard waste nutrients generated on the agricultural landscape. They behave and function similarly to the true natural wetlands. Consequently they are able to substitute at least partly the original nutrient processing activity of the intact wetland system existed once on the floodplain of the Carpathian Basin.

The dotted line plots in the input and output relations indicate the equal absolute losses of the nitrogen from the analysed food producing systems (Figure 2). This relation is very indicative quantitatively. It clearly documents how significant is the nutrient loss in most of the open agricultural technologies. Without its recycling how the whole biosphere is getting supersaturated and choked very soon in the near future. The signs of ozone depletion, warming, drying and acidifying are the result of the nutrient overproduction together with farming abuses. Their daily impacts are already visible and sensible on our own skin. The absolute nitrogen loss in certain farming system at the intensive end of the range may reach the extremely high value of 500 kg N ha$^{-1}$ y$^{-1}$. In livestock rearing systems the absolute nitrogen loss is usually higher than in arable systems. The direct or indirect integration of livestock production with the aquacultural wetlands would help again, decreasing this loss significantly. Completing and closing the open cycle of the industrially produced nitrogen molecule is a great challenge for the near future.

The absolute total nitrogen loss is composed of several fluxing pathways. Plotting the nitrogen leached to surface and groundwater or lost to the atmosphere gives further details about the environmental fate of this agricultural byproduct (Figure 3). The leaching of nitrogen on terrestrial farming ecosystems in the form of surface and subsurface runoff may reach the value of almost 100 kg N ha$^{-1}$ y$^{-1}$ at higher farm input, but scattered on a wide range according to soil texture and gradient. In the investigated five Hungarian aquacultural farming systems the values actually represent the nitrogen content of the draining water. On the solid clay texture the seepage is minimal. The amount of drained nitrogen ranged between 28 and 81 kg N ha$^{-1}$ y$^{-1}$. The highest value was measured in the fish-cum-goose ponds due to the short water retention time. An important research project (Szabó, 1994) has clearly demonstrated that the Hungarian fishponds have received more nitrogen from the water supplying rivers than released back during the autumnal draining for harvest.

The nitrogen loss to the atmosphere is usually surpasses the values of the leached or drained nitrogen. The highest value reaches the amount of 200 kg ha$^{-1}$ y$^{-1}$. In the terrestrial agroecosystems the loss to the atmosphere comes from denitrification and ammonia volatilization. The later process is frequently dominating. The atmospheric loss from aquacultural ponds is mostly the result of the denitrification. Volatilization may occur only under a very limited condition, at high pH values. Fortunately the high pH situation is usually accompanied with a very low ammonia concentration. As a result, volatilization, poisoning the atmosphere with nitrogen, is negligible in fish producing ecosystems.

A final conclusion may be arrived that aquaculture even on the dried floodplain area of the Carpathian Basin is able to eliminate and to retard the polluting nitrogen which comes from the nitrogen releasing processes of the industrialized terrestrial farming. It may come directly with filling river water, in which the nitrate concentration has reached the annual average value of 15.6 ppm at the peak period of the agriculture industrialization, in 1984. The agricultural waste could be processed also through direct or indirect integration with animal husbandry. Aquaculture receives agricultural waste also with the nitrogen rain. The annual nitrogen retention per hectare was measured and calculated in detailed research projects. It was 218 kg in fish-cum-duck (Oláh et al. 1994a), 294 kg in fish-cum-pig, 12 kg in fish-cum-goose (Oláh et al. 1990), 125 kg in macrophyte choked carp pond (Oláh and Szabó, 1986) and 93 kg in fish-cum-duck-alphalpha-rice rotation system (Oláh et al.1994b).

## Reconstruction of floodplain aquaculture

Thus, augmenting food production through aquaculture in the Carpathian Basin is the most sustainable consumption of the unrenewable energy and the most wiseuse of the natural resources. It has several advantages: (1) the high protein producing potential, (2) the complete nutritive value of fish protein, (3) the energy cost effective as well as (4) the healthy environment creating nature. Priority has to be assigned for proper nutrient and organic waste recycling through fish farming on larger landscape scale, in order to make these systems of aquaculture still more energy and environment effective for protein production.

Enlargement of fish and wildlife rearing areas both with constructed fishpods and with restoring reasonable part of the dried floodplain, would somehow substitute the former function of the inland riverine delta. The nutrient processing, removing or retarding natural resource function of the floodplain wetlands is even more vital today, as compared to the situation before the river regulation in the second half of the last century. The industrialization of the formerly closed agriculture resulted in an enormous increase of the nitrogen fertilizers. We have calculated the national nitrogen budget for the peak industrialization period and for the year of 1993 as well as reconstructed, at least the nitrogen input sources, which characterized the nitrogen load condition before river regulation that is on the intact riverine floodplain network (Table 1). There was almost a tenfold increase of the nitrogen input. This huge nitrogen load on the present agricultural floodplain landscape is accompanied by the dramatic decrease of the nitrogen retarding wetland area from 39 000 km$^2$ to 67 km$^2$. This deformed landscape metabolism results in an overall toxic condition on the Hungarian Lowland. The restoration of a planned and well-designed floodplain aquaculture is a very actual strategy, which can be realized only together with nature protection, wildlife production and with the development of the rapidly spreading ecotourism.

Floodplain aquaculture should yield cheaper and nutritious foods within reach of the poorer section of society. Development of floodplain aquaculture on this sound direction will help achieving economic progress and generating substantial employment for the countryside section of the Hungarian population. It has also potential for exports, as fish consumption in developed countries is on the increase. However, with the reconstruction, at least part of the former nitrogen processing capacity along the River Tisza and its tributaries, a more important target would be achieved, that is the restoration of the healthy environment.

## References

Prissel M.J., 1978. Cycling of mineral nutrients in agricultural ecosystems. Development in agricultural and maneged-forest ecology 3. Elsevier, Amsterdam.

Oláh J. and P. Szabó, 1986. Nitrogen cycle in a macrophyte covered fish pond. Aquacultura Hungarica, Szarvas 5:165-178.

Oláh J., G. Vörös, S. Körmendi and F. Pekár, 1990. Groundwater nitrate biomanipulation in typha-covered ponds with goose-cum-fish cultura. EIFAC/FAO Symposium on Production Enhancement in Still-Water Pond Culture. Prague, Czechoslovakia, 15-18, May 1990. 1:107-113.

Oláh J. F. Pekár and P. Szabó, 1994a. Nitrogen cycling and retention in fish-cum-livestock ponds. J. Appl. Ichthyol. 10:341-348.

Oláh J., P. Szabó, A. A. Esteky and S.A. Nezami, 1994b. Nitrogen processing and retention on a Hungarian carp farm. J. Appl. Ichtyol. 10:335-340.

Olah J. and M. Olah 1996. Improving landscape nitrogen metabolism on the Hungarian lowland. Ambio 25(5):331-335.

Pekár F., L. Kiss, P. Szabó, and J. Oláh, 1993. Pond processing of high organic load in a fish-cum-duck culture system in Hungary. In: From discovery to commercialization. Abstracts of contributions presented at the International Conference Worlds Aquaculture 1993, Torremolinos, Spain, May 26-28, 1993. p. 253.

Sinha V.R.P. and J. Oláh, 1982. Potential of freshwater fish production in ecosystems with different management levels. Aquacultura Hungarica (Szarvas) 3:201-206.

Szabó P. 1994. Quality of effluent water from earthen fish ponds in Hungary. J. Appl. Ichtyol. 10:326-334.

***Table 1.*** National nitrogen budget measured for the years of 1988, 1993 in Hungary and reconstructed for the intact floodplain of the 19th century, $10^3$ t $y^{-1}$

| Balance | Before regulation | 1988 | 1993 |
|---|---|---|---|
| *Input* | | | |
| Nitrogen rain | 19 | 146 | 105 |
| Inorganic fertilizer | 0 | 617 | 124 |
| Industry | 0 | 10 | 8 |
| Totol input | 115 | 495 | 425 |
| | 134 | 1268 | 662 |
| *Output* | | | |
| Food export | - | 60 | 45 |
| Outflowing rivers | - | 600 | 480 |
| Total output | - | 660 | 525 |
| Accumulation, kg $ha^{-1}$ $y^{-1}$ | - | 65 | 15 |

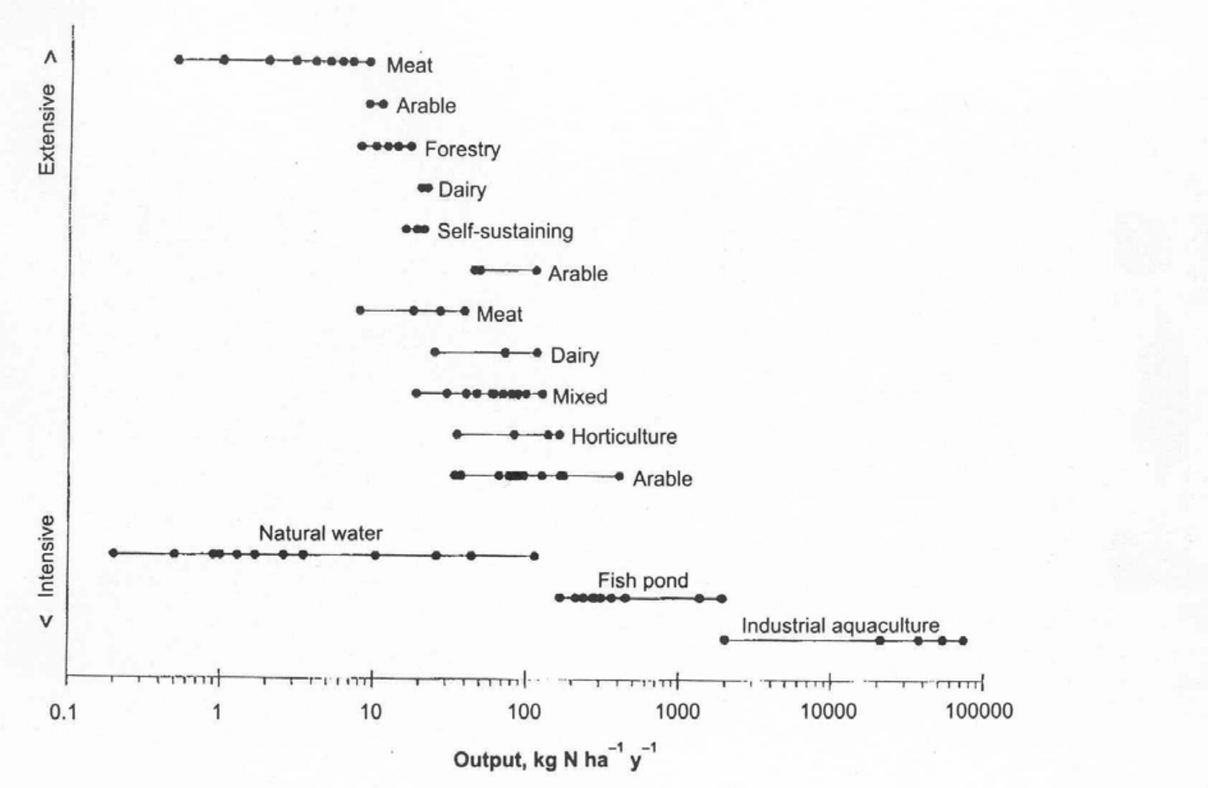

***Figure 1.*** Nitrogen output from agriculture and aquaculture agroecosystems based upon Frissel (1978) for agriculture and Sinha and Oláh (1982) for aquaculture.

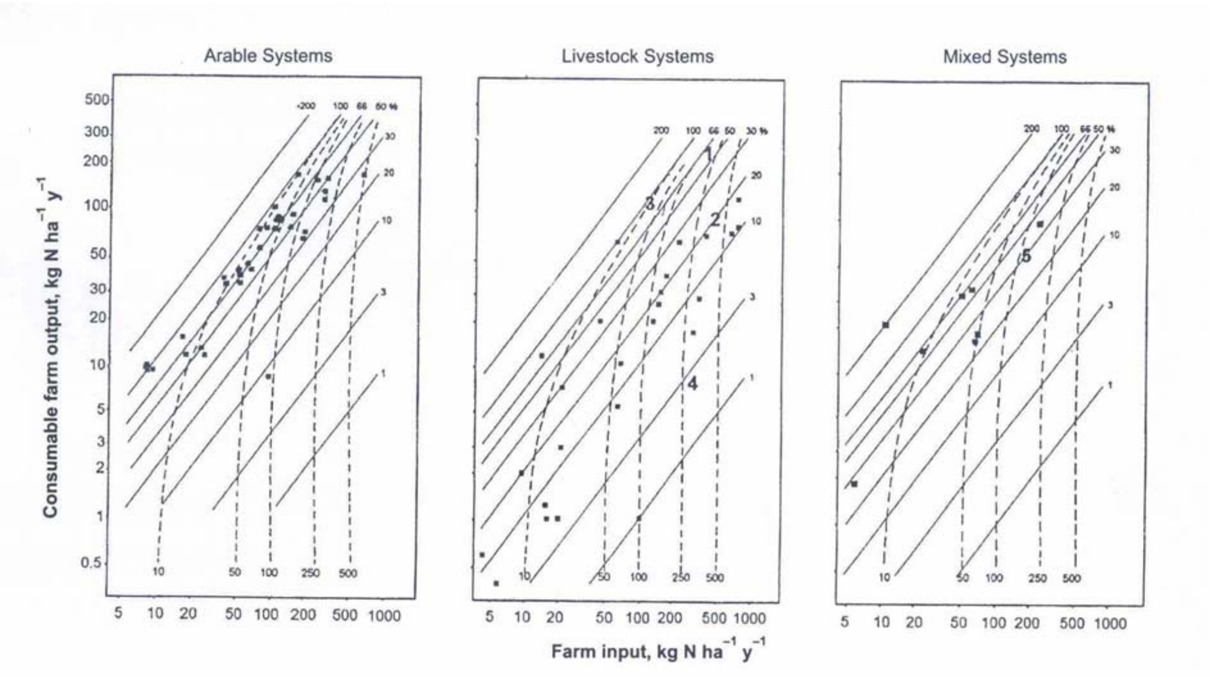

***Figure 2:*** Nitrogen efficiency (solid line %) and environmental load (dotted line kg N ha$^{-1}$ y$^{-1}$) as functions of farm nitrogen input and consumable output (1. Fish-cum-duck, 2. Fish-cum-pig (Oláh et al. 1994a), 3. Fish-cum-goose (Oláh et al. 1990), 4. Macrophyte choked carp pond (Oláh and Szabó, 1986), 5. Fish-cum-duck, alphalpha and rice rotation (Oláh et al. 1994b)

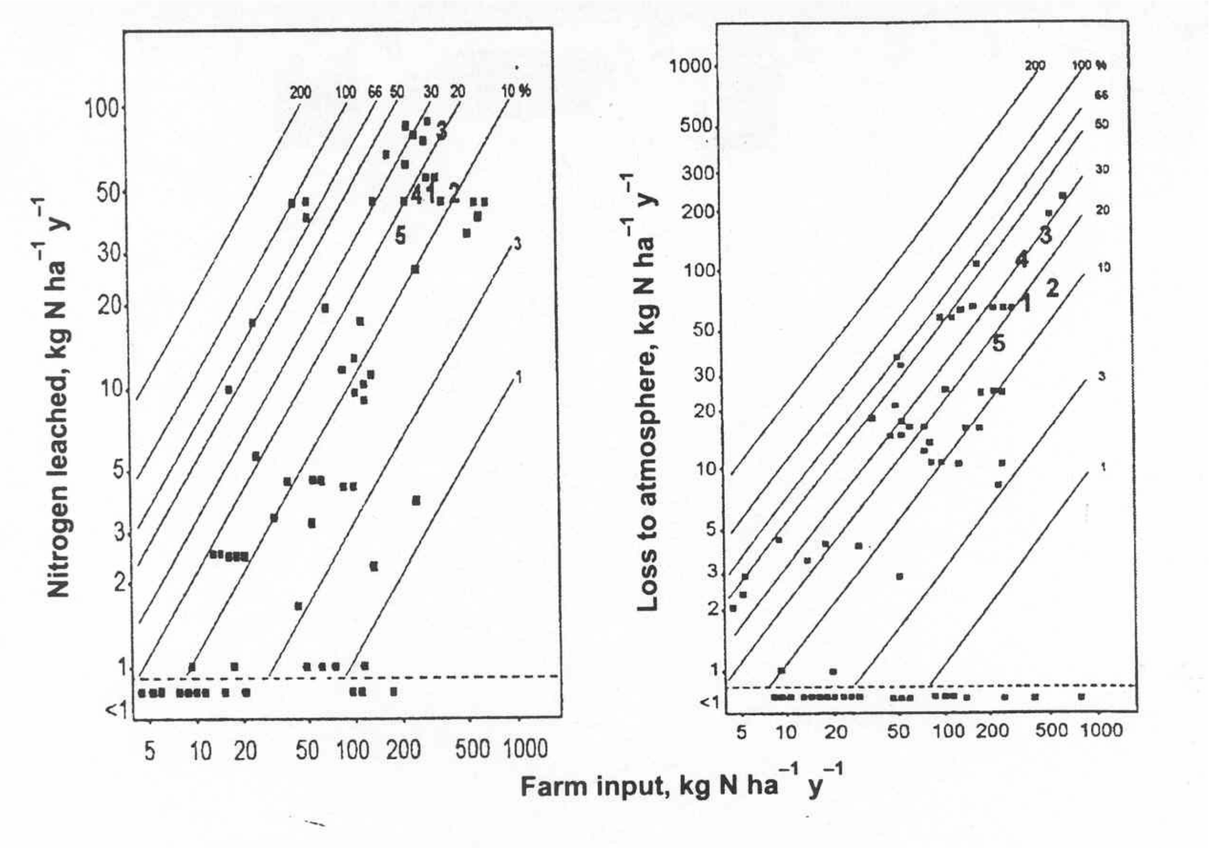

***Figure 3.*** Nitrogen leached and loss to atmosphere as function of farm nitrogen input in arable, livestock and mixed agroecosystems (Oláh et al. 1994a), 3. Fish-cum-goose (Oláh et al. 1990), 4. Macrophyte choked carp pond (Oláh and Szabó, 1986), 5. Fish-cum-duck, alphalpha and rice rotation (Oláh et al. 1994b).