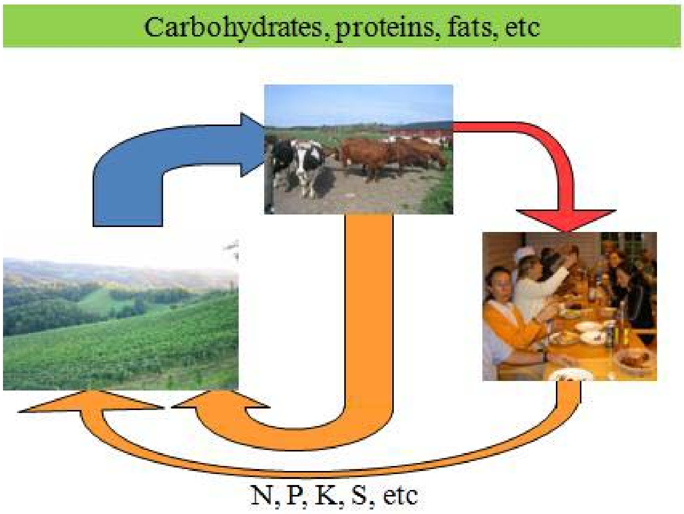
Lecture 4.1 Cycles of plant nutrients and water

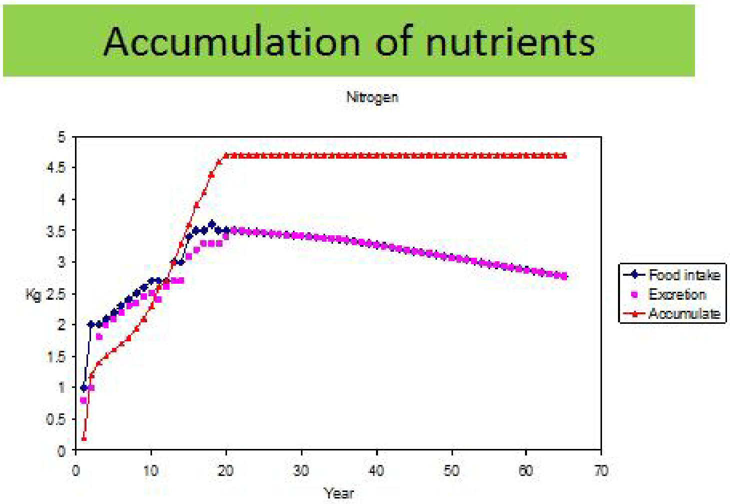
How do plant nutrients and water flow in nature? How has these flows been changed by society?

Goal: To be familiar with the natural cycles of plant nutrients and water and to know how different sanitation systems affect these cycles.

Ecological Alternatives in Sanitation



Most natural ecosystems are sustainable over long time periods. The flow of nutrients are stable within the system as the consumed nutrients mainly are circulated on the field/forrest level with a smaller stream leaving for carnivores. The traditional flow for all is that the nutrient come back to the soil. Examples of such ecosystems are the savannah, the rain forest, the temperate forest etc. These systems have been running for very long time period and the losses have been small. However in last hundred years this natural internal flow of nutrients has been redirected and the nutrients from the main carnivore of today, the human are ending up in the water streams and lost into the ocean.

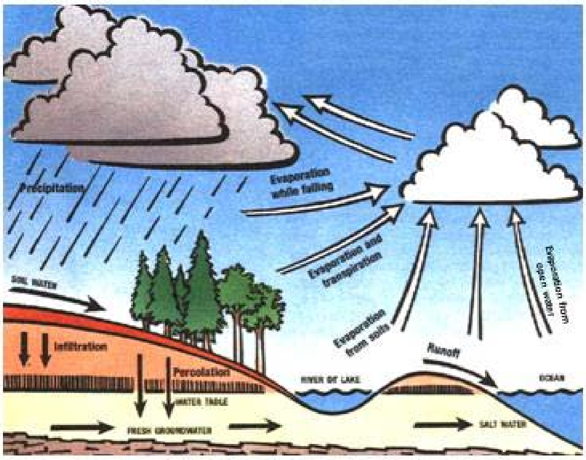


Note that while growing animals need to consume nutrients in the form of carbohydrates, proteins, fats etc., grown animals do not accumulate plant nutrients, like nitrogen, phosphorus, potassium and sulphur etc. Growing animal accumulates some of these nutrients in its body tissue, e.g. nitrogen in the form of proteins in the muscles and phosphorus in the skeleton, but even during this period only a very small fraction of the intake of these elements is accumulated. Once the animal is fully grown, it excretes as much of the plant nutrients as it consumes.

This is exemplified with this slide that shows the amount of nitrogen found in a average size human 80kg and an approximate consumption, excretion and accumulation of nitrogen during one life span.

Here we can see that small amounts of nutrients are accumulated during the first 20 years and after that the consumed nutrients are excreted as the body have reached a mass balance.

Hydrological cycle



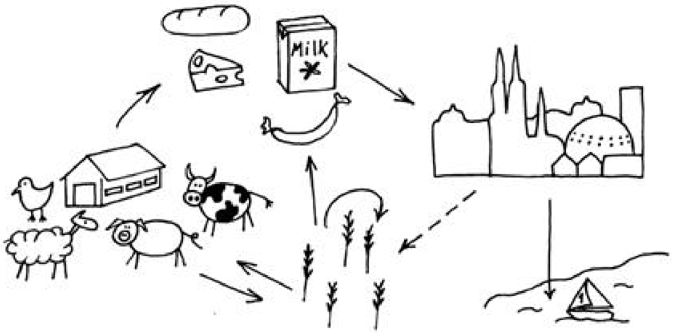
www.fao.org/docrep/U8480E/U8480E3k.jpg

The natural hydrological cycle is driven by the sun. Water is evaporated and the precipitation, the rain, supplies fresh water to the soil and to the streams and lakes. In the soil, fresh ground water is formed and this feeds, together with surface runoff, streams and lakes.

While in a geological time frame, there is a clear coupling between the cycles of water and plant nutrient, the stable sustainable ecosystems are developed, and have evolved, to decouple these cycles as much as possible. The reason for this is that if the ecosystem looses a lot of plant nutrients by leaching, then it will be depleted of these and thus its production of plants will not be sustainable. Therefore, stable terrestrial ecosystems have developed to trap and utilise as much of the dissolved plant nutrients as possible. It is largely thanks to their efficient trapping of dissolved plant nutrients that fertile and productive terrestrial ecosystems so often coexist with clear streams and lakes which are not eutrophicated.

More about this is found in Chapter##

Linear flow of plant nutrients in present food chain

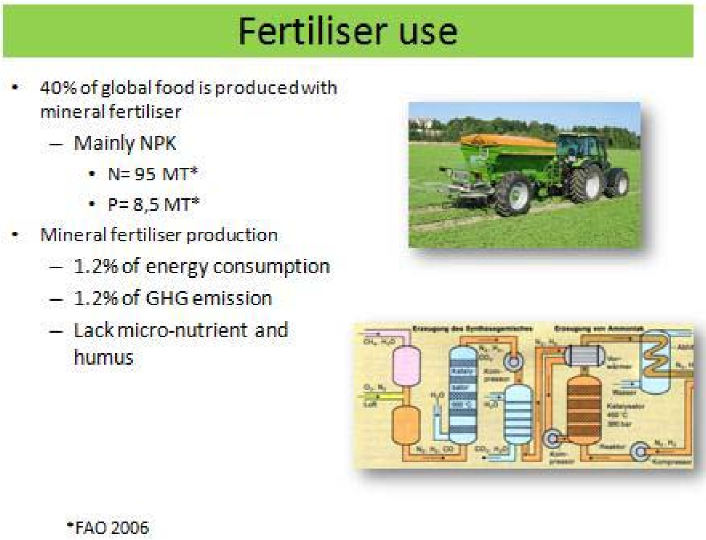


Contrary to the cyclic flow of plant nutrients in stable ecosystems, the flow of plant nutrients in our human society is almost entirely linear, at least as far as the flow of plant nutrients in food goes. The food plant nutrients flow, as constituents of the food, from agriculture to society. However, with conventional sanitation systems this flow is linear, not cyclic. When a water flushed sanitation system is used, the plant nutrients end up either in surface water causing pollution and eutropication. When a conventional pit system is used, the plant nutrients end up extremely concentrated in soil, far too concentrated for vegetation to be able to utilise them in any reasonable time. This is also the case when sewage sludge from well functioning sewage treatment plants are put in landfills. Usually this leads to a large part of the nitrogen leaching out, while the phosphorus mainly remains in the close vicinity of the deposit. In both cases, there is a severe risk of contaminating the ground water with nitrogen in the form of ammonium and nitrate and with pathogens.

The linear flow of plant nutrients from the agricultural system leads to the soil being depleted of plant nutrient. Thus, to sustain good harvests, this linear flow of plant nutrients out of the agricultural system has to be counteracted by a linear flow in of plant nutrients and this flow is normally supplied by chemical fertilisers produced from non-renewable resources, e.g. raw phosphorus, natural gas and oil (for producing nitrogen fertilisers) and potassium deposits.

The losses due to leakage and erosion have to be counteracted by use of cultivation practises which minimize these losses. The loss of nutrients due to harvested crop and food should be counteracted by recycling the safely sanitised excreta and kitchen waste.

Thus, for improving the sustainability of food production it is important both to recycle the food lost with the harvested crop, which is done by recycling of safely sanitised excreta and kitchen waste and to use crop cultivation practices which minimize the nutrient losses due to erosion and leakage.



The large part of the flow of fertiliser nutrient into agriculture is lost on the way and does not end up in the amount of plant nutrients actually found in the food we consume. The main part of the nitrogen is lost in agriculture, mainly as nitrate leaching from the fields and nitrogen gas being denitrified in the fields. Some is also lost as N_2O, nitrous oxide and ammonia. The main part of the phosphorus remains in the soil and thus helps to improve its nutrient status. However, some is also lost from the fields mainly due to erosion but also leakage.

Details on the data: Data given in million tonnes of pure nitrogen (N) and phosphorus (P) for year 2002/03 (Produced fertiliser. International Fertilizer Association (http://www.fertilizer.org/ifa/).

The amount of phosphorus, 8,5 Mton, corresponds to 20 Mton of P_2O_5.

If we look at the global scale regarding the nutrient content of the excreta from humans we have used an average number for food consumption. In this case we used the diet of one Indian person. The food consumption is based on the FAO statistics on food consumed in per person in India www.fao.org

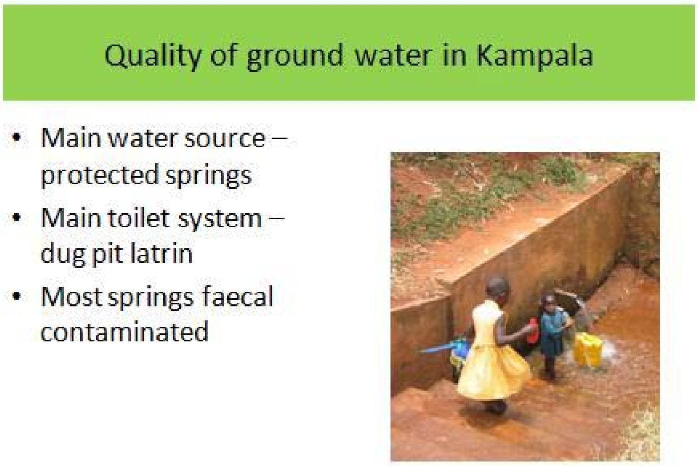
Nitrogen: 0.13*total protein supply per person

Phosphorus: 0.011*(total protein+vegetal protein supply per person)

Equations from: Jönsson et al. 2004

To compare the different costs for the plant nutrients in the wastewater the price of one kilogram of nitrogen have been compared for production and for removal. The production is the average retailer price in Sweden 2010 (no subsidies) that the farmer pay for nitrogen fertilizer. The fertilizer market is global and the price is similar wherever you by the fertilizer. Many countries subsidies mineral fertilizers and the farmer pay lower prices. Often is this price the price that organic fertilizers are compared with when discussing the market for human derived fertilizers.

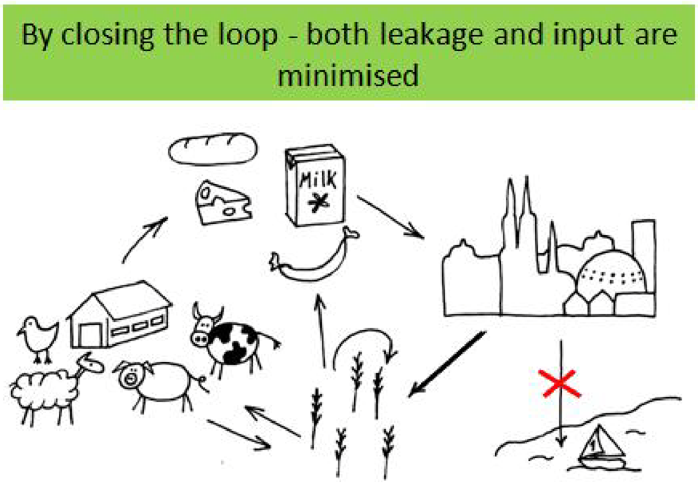
One alternative for this calculation is to include the cost of management of the consumed nitrogen also. In this calculation the price for nitrogen removal is based upon the treatment cost in an average Swedish sewage treatment plant where nitrogen are removed by nitrification and denitrification in a highly advanced treatment process. This can also be included in the calculation for fertilizer cost. If the system don’t have the advanced treatment process it should not be included in the calculation, however, if it is possible environmental effects from pollution should be included.



Kampala, the capital of Uganda is located on seven hills, on these hills there are several springs coming to the surface. In the valleys of the hills there are wet lands where standing water is found. The springs are the main water source for the majority of the inhabitants.

The main sanitation system for the area is dug pit latrines that are dug into the hills close to the houses. The placement of the latrines have not been associated with where the springs are located, so it is usual to find latrines just uphill to the spring.

This have lead to decreasing water quality from the springs and in an evaluation of the water quality of ten protected springs, faecal coliforms were found in all sampling of the springs and in 90% of the cases the count of faecal coliforms exceeded the WHO guidelines for drinking water quality (Haruna et al., 2005).



If the produced wastewater, that today are polluting the water recipients, are redirected from pollutant of the water bodies to a resource in food production there are two main gains.

First of all the pollution of the water recipients decreases as no more eutrophying nutrients enters. Together with this, also other pollutants in the water are stopped, e.g. pathogens and organic micropollutants that have major effects on the general water quality and specific on the drinking water quality.

Secondly as the nutrients are recycled back to agriculture the net loss of plant nutrients from agriculture will decrease and thereby will also the requirement for compensating nutrients decrease, this means that the need for virgin mineral nutrients to the fields is decreased and less fossil resources will be consumed.

Crop nutrient removal

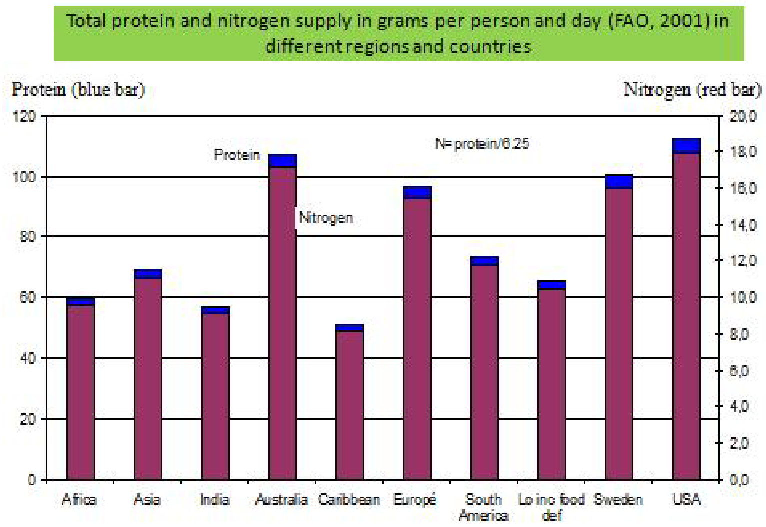
Crop	Yield, kg/ha	Dry matter	N, kg/ha	P, kg/ha
Cereals				
Maize	4000	88%	51	9
Rice	4000	88%	45	11
Sorghum	4000	88%	56	9
Wheat	3000	88%	55	10
Wheat straw, crop above	4000	85%	16	2
Tubers etc				
Cassava root	20000	36%	32	1
Potatoes	25000	23%	83	13
Sweet potatoes	10000	59%	49	12
Others				
Banana fruit, ripe	25000	31%	67	8
Ground nuts, peanuts	1000	94%	37	4
Soybeans	1000	91%	54	5

The table shows the amount of the plant nutrients nitrogen (N), phosphorus (P) and potassium (K) removed by the usable (as food or feed) crop with the given yield. This means that the amount of nutrients in removed crop residues is in addition to the amounts given in the table. The nutrient content in the table includes peels for crops with high moisture (bananas, potatoes, sweet potatoes & cassava root) but not for the others. Thus, the nutrients in the peels are neither included for groundnuts nor soybeans.

As shown by the table the amounts of nutrients removed by the crop are large, making it obvious that in the long run the nutrients of the soil will deplete, if the soil is not replenished with these elements.

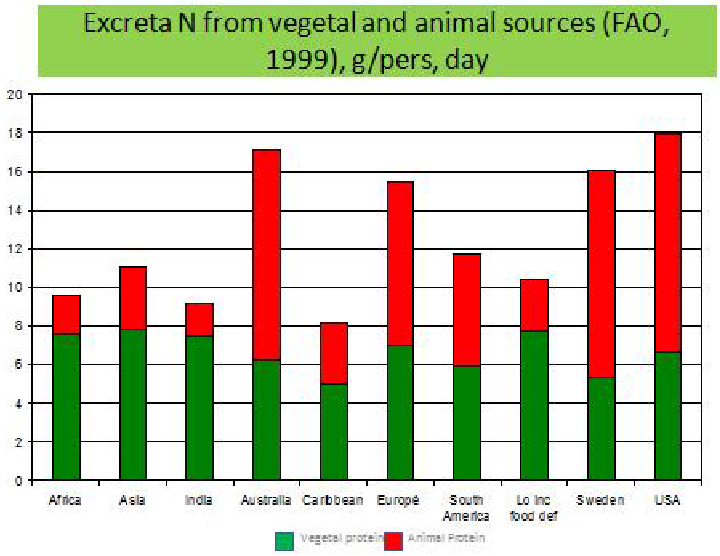
The recommended fertilisation for certain crops and especially on certain soils can be radically larger than the amounts given in the table, especially for phosphorus, due to differing soil status and differing ability of the soil to deliver or immobilise nutrients. Many soils around the world are poor in phosphorus and to a large extent immobilises the phosphorus applied. The immobilised phosphorus is not lost, but can be seen as an investment towards a more fertile soil. However, on such soils the fertilisation recommendations for phosphorus can be up to 10 times as high as the amount removed by the usable crop.

References for composition of crops: Machin. D.H., 1991; Simonsson, A. 1991; Leung, W.-T.W. 1968.



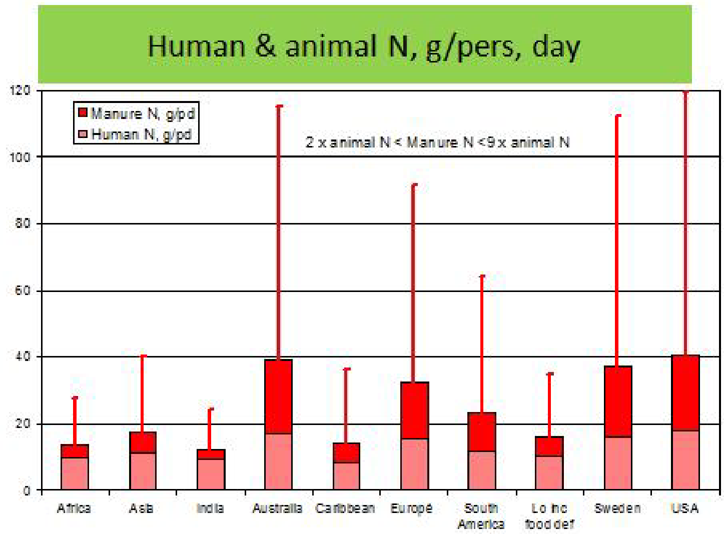
The consumption of protein differs by approximately a factor of 2 between different countries and regions. E.g. the supply of proteins in the Caribbian is around 50 grams per person and day, while the corresponding figure in the US is around 110 grams. Protein is normally calculated by multiplying the amount of nitrogen in the food stuff and then multiplying it by 6.25. Thus, the amount of nitrogen supplied to inhabitants in different countries and regions has been calculated by dividing the amount of protein supplied by 6.25. The food supplied does not entirely end up as food actually eaten as part of it ends up as kitchen waste, and thus the bars in the above diagram indicate slightly larger quantities than what is actually consumed and thus slightly more than what will be found in the excreta.

The diagram clearly shows that the amount of nutrients supplied by person and day is much larger in the developed regions of the world than in the developing. The amounts of protein, and thus of nitrogen, supplied is far larger in e.g. Australia, Europe, Sweden and the US than in e.g. Africa, India and the Caribbean. The amount of nutrients in the excreta is one argument stressing the urgency to close the nutrient loop in the developed countries. However, as seen in the next diagrams, it is even more urgent to close the nutrient loop in the developing regions.



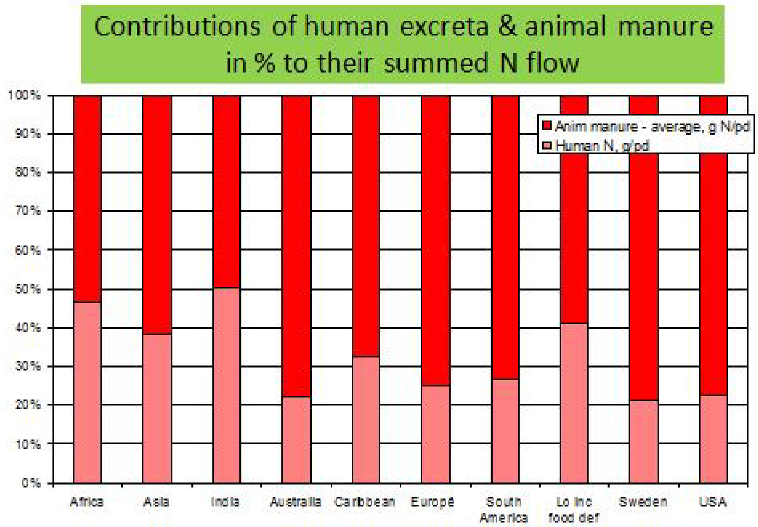
The diagram shows that the amount of vegetal protein (in green) supplied per person and day is fairly constant in different regions, between approximately 35 and 50 grams per person and day. And it is higher in most developing regions than in the developed regions. In the developed regions the vegetal protein is supplemented by large amounts of animal protein. The animal protein (in read) has accumulated in the animals and the efficiency for this accumulation is low. Its variation can be approximated as usually between 10 and 30%, meaning that 2 to 9 times the amount of nitrogen in the animal protein has been excreted as manure from the growing animal. Thus, the total flow of nitrogen in animal manure and human excreta in society can be calculated.

You can get the data for your country/region from www.fao.org, FAOSTAT-Nutrition, Food Supply, Crop Primary Equivalents.



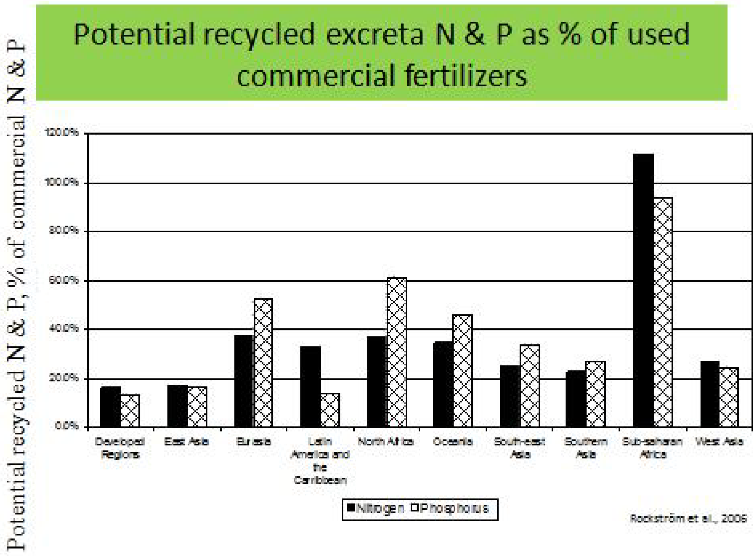
The total flow of nitrogen in animal manure and human excreta in different societies. In the calculation, imports and exports has been neglected, i.e. it has been assumed that the food supplied in a region also is produced in the same region.

As seen from the diagram, the proportion of the nitrogen flowing with human excreta to the flow of nitrogen in excreta and manure is far less for the developed regions than for the developing regions, due to the large flows of nitrogen with animal manure in the developed regions. Thus, the excreta nutrients are far more important for the plant nutrient flow in the developing regions than for the developed regions. This is even more so, as the farmers in the developed regions can afford to use chemical fertilisers and thus they can replace the losses of plant nutrients from the fields. In the developing regions however, many farmers can not afford chemical fertilisers, which means that the soil can rapidly be depleted of nutrients. This, together with the data in the above diagram strongly indicates that it is of utmost importance for food security to close the nutrient loop in the developing regions, that it is of utmost importance to introduce Ecosan sanitation systems in these regions.



As seen from the diagram, the contribution by the human excreta flow to the combined flow of N is far larger in the developing regions of the world, 40-50% in Africa & Asia and in countries with low income and food deficiencies. In the developed regions on the other hand, Australia, USA and Europe, the contribution from the human excreta is far less, 20-25%, which indicates that it is far more crucial to close the nutrient loop in the developing regions than the developed ones. This is especially so, as the farmers in the developed regions supplement the nutrient flow in manure and excreta with chemical fertilisers, while many farmers in many developing regions can not afford chemical fertilisers.

On the data: the flow of N in animal manure has been calculated as 5.5 times the amount of N consumed in the form of animal protein.



The above diagram gives another argument why it is of utmost importance to introduce Ecosan in the developing regions. In many of these regions, the excreta nutrients corresponds to, and thus theoretically can replace, a larger fraction of the chemical fertilisers used, than in the developed regions. E.g. in North Africa, Euroasia and Oceania, the plant nutrient content of the excreta corresponds to approximately 40 to 50% of the chemical nitrogen and phosphorus fertilisers used and in Sub-saharan Africa the excreta nutrients even corresponds to more than 100% of the chemical plant nutrients used, while in the developed regions the excreta nutrients corresponds to approximately 15% of the chemical fertilisers used.

References

Haruna R., Ejobi E., Kabagambe EK. 2005, The quality of water from protected springs in Katwe and Kisenyi parishes, Kampala city, Uganda

Jönsson, H., Richert Stintzing, A., Vinnerås, B. & Salomon, E. 2004. Guidelines on use of urine and faeces in crop production. Report 2004-2, Ecosanres, Stockholm Environment Institute. Stockholm, Sweden. Download: http://www.ecosanres.org/PDF%20files/ESR%20Publications%202004/ESR2%20web.pdf

Machin. D.H., 1991. Overview of needs and justification for use of roots, tubers, plantains and bananas in animal feeding In:Machin, D. & Nyvold S. Roots, tubers, plantains and bananas in animal feeding, FAO Animal production and health paper 95

Simonsson, A. 1991. Fodermedel till svin. Husdjur Rapport 69, SLU Info.

Leung, W.-T. W. 1968. Food composition table for use in africa. Nutrition Program, National Center for Chronic Disease Control, Health Services and Mental Health Administration, Public Health Service, U.S. Department of Health, Education, and Welfare, 9000 Rockville Pike, Bethesda, Maryland 20014 U.S.A.

Rockström, J., Nilsson Axberg, G., Falkenmark, M., Lannerstad, M., Rosemarin, A., Caldwell, I., Arvidson, A. & Nordström, M. 2005. Sustainable Pathways to Attain the Millennium Development Goals. Stockholm Environmental Institute, Sweden.