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Substance flow analyses in arable production

Substance flow analyses in the form of farm input balances can provide valuable, environmentally relevant information on agricultural production of basic materials. Methodological procedures and feasibility of such balances are demonstrated with the example of a wheat production method. Farm input balances are an excellent calculating basis for energy balances. Especially if substance flow information is to be used further in connection with environmental valuation instruments such as the input/output balance, there remain areas which cannot be represented with the procedure usually adopted in process chain analyses. This relates for instance to emissions such as nitrous oxide or nitrate elutriation.

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Surveying substance and energy flows in agricultural production is particularly important when assessing the associated environmental impacts, for instance in the ecological valuation of differing modes of nutrition or of biomass provision procedures for obtaining energy, for example with the instrument of Life Cycle Assessment of products.

The substance groups to be described within the context of the inventory analysis can be characterised with the collective terms „Substances“, „Pollutants“, „Wastes“, „Energy input“ and „Emissions“ (*fig. 1*). Aspects which will motivate the preparation of substance flow analyses in agriculture in future, particularly in connection with food production are, for instance, the requirements of product liability, which according to the will of the European Union are to be expanded to agriculture. Quality and environmental management systems built on such farm information [1]. In agriculture, the term „substance balance“ has so far meant on the one hand a description of nutrient flows in the farm, and on the other hand the drawing up of input balances, but not so much a complete process chain analysis.

Balancing method

The standards DIN-EN-ISO-14.040 ff [2, 3] are suitable as a framework for the methodology. In these a combination of process chain analysis and input-output analysis is recommended, which is therefore often used in such agricultural valuations.

In addition to the quantities of farm inputs such as fuels or mineral fertilisers used, the quantities of substance flows generated to provide of these is also to be appraised for a comprehensive agricultural substance flow analysis. As well as the basic materials, semi-finished or finished products produced for further use, these also include solid, liquid and gaseous emissions from or in soil, water and air, in addition to wastes.

A distinction can be made between the following life path levels of agricultural products:
- Obtaining raw materials
- Construction and maintenance of infrastructure and factories
- Production of agricultural inputs
- *Agricultural production*
- Further processing
- Use, consumption
- Waste disposal, recycling of residual materials

Multisectoral levels:
- Transport
- Energy provision
- In-farm substance cycles (plant/livestock production)

In addition to the agricultural target product produced, incidental and coupled products and residual materials occur. Thus, for instance, it makes a difference in the balance whether straw is picked up from the field and used for livestock production as litter, or whether it is then sold. In the former case it is an in-farm substance cycle between farm sectors, and in the second case an export from the farm, which makes it necessary to allocate the preceding substance flows between two products. However, if the straw remains directly on the field and is worked in, it represents a substance cycle in the same farm sector.

Provision chains for farm inputs

Energy sources

In agriculture diesel fuel, fuel oil and electricity are generally used in the pre-chains for the farm inputs. Pre-chains include exploration, extraction, conditioning, storage and all transport operations up to the farm, and – in the case of electricity – in addition the specific energy source mix, the degree of efficiency and transmission losses.

Seed and plants

The provision process should be included on

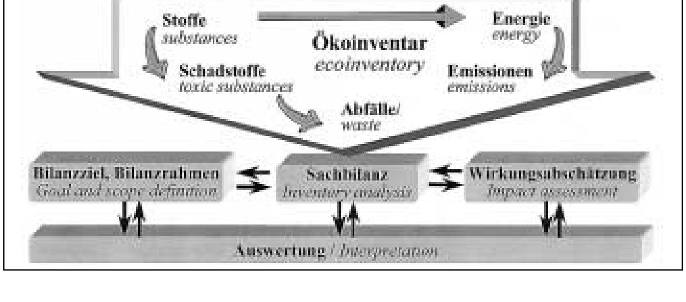

Fig. 1: Substance flow analysis and its connection to life cycle assessment (LCA)

the basis of a „typical“ agricultural production situation. In addition, specific expenditures for seed production are to be taken into account, the generally lower yield by comparison with cash crop production, higher losses due to more intensive cleaning, and distribution.

Fertilisers and pesticides
The pre-chains consist of extracting raw materials, producing active agents or mineral fertilisers, formulation and packing, and all transport operations up to the farm. In the case of mineral fertilisers the nutrients N, P, K, Mg and Ca are taken into account.

Nutrient flows additionally occur in arable farming in the form of farm-produced fertilisers, harvest residues and green manuring – generally as on-farm substance cycles – and to a lower extent as secondary raw materials generated outside the farm, which are used for agricultural purposes. Parts of the fertilised nutrient quantities – especially nitrogen – are released unused as emissions in water or air. These and the aforementioned nutrient flows are difficult to quantify via organic raw materials, since they are generally not measured.

Capital investments (machinery and buildings)
The associated substance flows for production, use, repair and waste disposal must be allocated proportionately to a production process. Allocation to area unit, harvest quantity or time is generally carried out on the basis of rough assessments, mainly only at farm level.

Sample calculation: Production process for wheat production

The data used and the assumptions made originate from the Göttingen System Experiment INTEX [5], System Ordnungsgemäss, location Reinshof, 1998 harvest. The following farming measures were implemented (P = pass): rotary spade harrow (stubble working, 1 P); ploughs (1 P); cultivators (wing shear, 1 P); seed bed preparation (1 P); rotary harrows (+ sowing, 1 P); N-fertilising (3 P); pesticide spreading (4 P); harvest (threshing, pickup, storage, ventilation).

For the purpose of simplification only nitrogen flows which are directly connected with the agricultural production method are taken into account here. For machine weights, working times, machine use profiles and fuel consumption data from [4] were used and we carried out our own calculations. The green manuring is assumed on a pro-rated basis, the fertiliser quantities are calculated on the basis of the yield from the mean nutrient withdrawal [6].

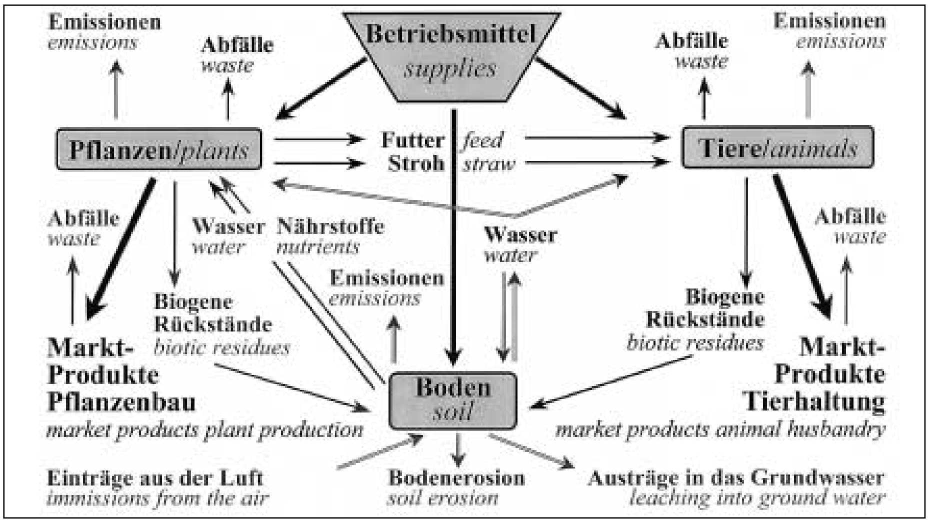

Fig. 2: Simplified overview on substance flows in agriculture (substance flows,which are hard to quantify, are shown in grey)

Results

While the input balance on the farm and the quantities of cash crops produced (*fig. 2*) can be calculated easily from the field file, barn bookkeeping or the farm bookkeeping, other substance flows, especially in the field of emissions, wastes and water regime, are difficult to quantify (shown in gray in figure 2). A further difference by comparison with industrial production consists in the processes occurring in the soil, such as the dynamics of nitrogen or humus formation. These are dynamic operations which vary with local conditions.

It is clear from *table 1* that the farm input outlays can be described with the aid of a few additional assumptions on an area-related or yield-related basis, and that other substance flows such as field emissions can generally not be mapped at farm level in figures, even if there is a good data base available.

Conclusions

In agriculture too, comparative environmental valuations of different nutritional methods are only possible with the aid of comprehensive substance flow balances in which the direct and indirect share of agriculture can be mapped adequately. However – at any rate today – the individual farm quantification of some environmentally relevant substance flows is still problematic in agriculture, even as an open production system. By contrast, substance flow balances in the meaning of a farm input balance represent an important data basis for calculating energy balances which can also be provided by farms.

Table 1: Aggregated substance flow balance for winter wheat 1997/98

Category	Input	Amount/ha	Remarks
Seed	winter wheat	200 kg	
Mineral fertiliser	P_2O_5	73.4 kg	proportion from rotation, subtracted
	K_2O	51.8 kg	proportion from rotation, subtracted
	CaO	300 kg	proportion from rotation
	MgO	17.3 kg	proportion from rotation, subtracted
	N	180 kg	as CAN
Plant protection	active ingredients	2.6 kg	active ingredient total
	total materia	5.3 kg	total plant protection material
End energy-carrier	diesel	67.3 kg	80.6 l (density 0.835)
	engine oil	1.4 kg	2 % of fuel
	electricity	37.4 kWh	storage requirements
Machinery		33.7 kg	one-part writing-off material
Working time		6.4 mh	machinery hours only
Yield	wheat	8.73 t	85% dry matter, average threshing sample
Not quantified here:			
water		l/m^2	subtraction, leakage
buildings			one-part writing-off material
refuse		kg	spay containers, seed sacks
emissions, immissions		kg	solid, liquid, gas
material flow from preliminary operations			