Int. Agrophysics, 1998, 12, 13-24

AGRICULTURE IN A SUSTAINABLE ENVIRONMENT - A HOLISTIC APPROACH

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A b s t r a c t. Based on a holistic definition of land use, including the six main functions of soil and land, five of them competing with agriculture in space and time, new approaches in the conceptualization and perception of sustainable land use are developed. Sustainable land use is explained as a local and/or temporal harmonization of all main uses of land, minimizing irreversible ones. Agricultural land use depends on all the other uses of soil and land and can only be sustainable when these are sustainable as well.

K e y w o r d s: agriculture, sustainable environment, holistic definition of land use, agricultural land use

INTRODUCTION

A look into international literature reveals considerable differences in the interpretation an perception of the terms "sustainability" and "land use" [10,16,18,22,29]. Based on the definition of the World Commission on Environment and Development [30], the term "sustainability" aims at maintaining or even improving environmental, social and economic conditions for future generations, and therefore includes environmental, technical, social and economic dimensions, as well as the dimension of time. Under the aspect of land use, sustainability means using land and soil in such a way that the quality and multifunctionality of both is maintained or even improved, thus leaving options for future generations.

However, on an operational basis, it is impossible to define sustainability without exactly defining the land use system (including its socio-economic dimensions) and the time horizon for which sustainability is aimed.

"Land use" is defined by most scientists as "agricultural land use" without taking into consideration the five main other uses of soil and land, which competitively interact with agriculture in space and time.

In the following, an attempt will be made to define sustainable land use through a holistic approach, distinguishing between "sustainable land use" and "sustainable agricultural land use", thus defining new approaches in the conceptualization and perception of sustainability in agricultural and rural development. On a worldwide level, the spatial relation of agriculture to other land uses is quite different, comparing different continents or countries.

Therefore, it seems necessary to begin with the question: "What is land use?" The definition of land in this context is more comprehensive than soil, and includes the aspects of topography, landscape, biodiversity, and others.

THE SIX MAIN USES OF SOIL AND LAND

A definition of land use based only on agriculture is incomplete, because at least five further types of land use interact competitively with agriculture in space and time. Therefore, land use is defined as the temporarily and spatially simultaneous use of at least six main functions of soil and land. Three of these functions are more ecological, three others more linked to human activities, defined as technical, industrial and socio-economic functions [2,3,5,6].

The three ecological functions are:

1) Production of biomass, ensuring food, fodder, renewable energy and raw materials; these well-known functions are the basis of human and animal life.

2) Filtering, buffering and transformation capacity between the atmosphere, the groundwater and the plant cover, strongly influencing the water cycle at the earth surface as well as the gas exchange between terrestrial and atmospheric systems, and protecting the environment, including human beings, against the contamination of groundwater and the food chain.

This last function becomes increasingly important, because of the many solid, liquid or gaseous, inorganic and organic depositions on which soils react through mechanical filtration, physico-chemical absorption, and precipitation on its inner surfaces, or microbiological and biochemical mineralisation and metabolisation of organic compounds, as shown in Fig. 1. The latter may also contribute to global changes through the emission of gases from the soil into the atmosphere (see dotted line in Fig. 1), because globally the total pool of organic carbon in soils is three times higher than the total organic carbon in the above-ground biomass and twice as high as the total organic carbon in the atmosphere [17]. Therefore, soils are a central link in the biotransformation of organic carbon and continually play a role in releasing CO_2 and other trace gases into the atmosphere. These gases are very important for processes of global change, which, in this case, involve large-scale feedback of many localized small-scale processes. As long as these filtering, buffering, and transformation capacities can be maintained, there is no danger to the groundwater or to the

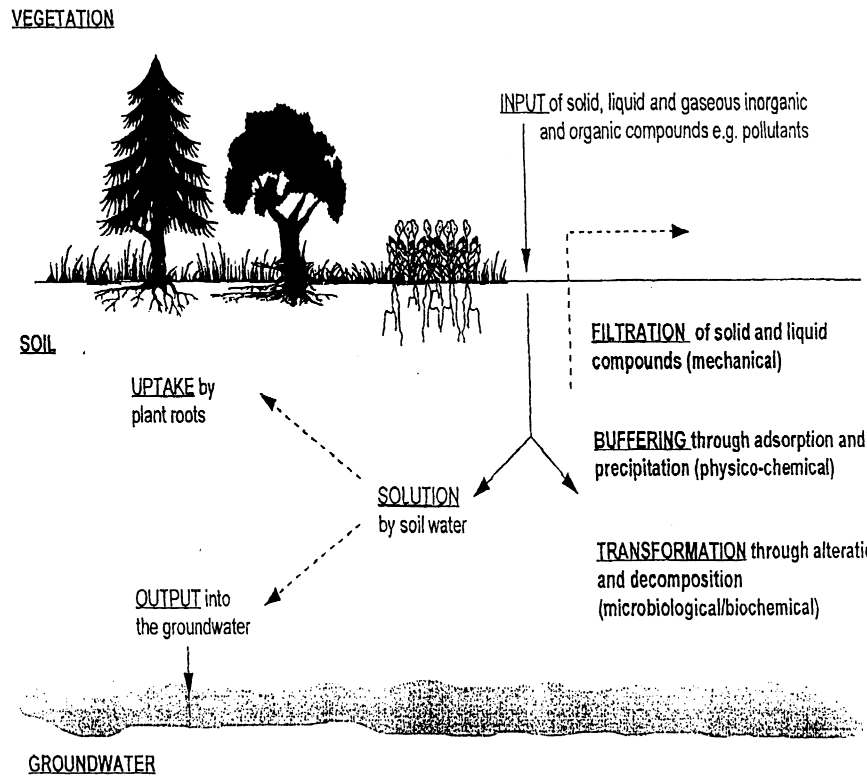

Fig. 1. Soil as a filter, buffer and transformation system between atmosphere, biosphere and hydrosphere.

food chain. However, these capacities are limited, and vary according to individual soil conditions.

3) Biological habitat and gene reserve, with a large variety of organisms in and above the soil. Soils contain more species in number and quantity than all other above ground biota together. Soil use is directly linked to the question of biodiversity. Human life is extremely dependent on this biodiversity, considering, e.g., the fact that the antibiotic penicillin was developed from the penicillium fungus, ubiquitous in the soil. We do not know if we will need new genes for maintaining human life in the near or the remote future. Moreover, genes from the soil become increasingly important for many technical processes, especially biochemical, biotechnological and bioengineering ones.

In addition, soils have three technical, industrial and socio-economic functions and uses:

4) They are the spatial base for technical, industrial, and socio-economic structures and their development, e.g., industrial premises, housing, transport, sports, recreation, dumping of refuse, etc.

5) They are a source of raw materials, (e.g., clay, sand, gravel, and minerals in general, as well as a source of energy and water).

6) Soils are a geogenic and cultural heritage, forming an essential part of the landscape in which we live, concealing and protecting paleontological and archeological treasures of high value for the understanding of our own history and that of the earth.

Therefore, a definition of land use should include all these six main functions of land and soil, which are often used concomitantly in the same area. Figure 2 shows the six functions and uses schematically. On this basis, land use can be defined as the temporarily or spatially

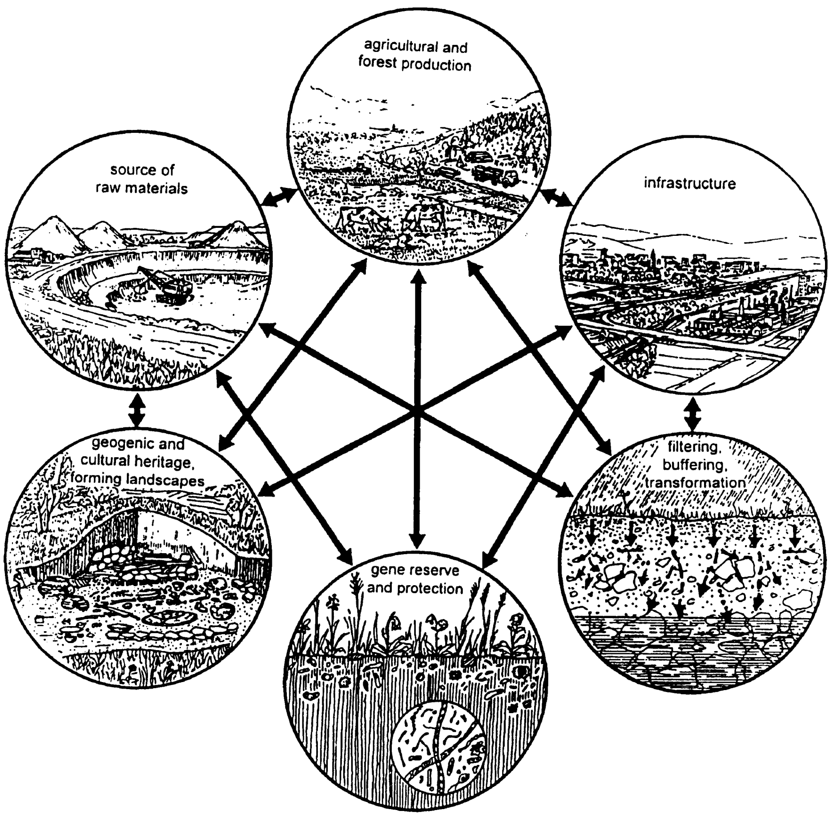

Fig. 2. The six different functions and uses of soil and land and the competition between them.

simultaneous use of all these functions, although they are not always complementary in a given area. However, where specific conditions on a regional or local scale exist, this very broad and holistic definition can be reduced and adapted accordingly.

INTERACTION AND COMPETITION BETWEEN THESE FUNCTIONS

To develop a comprehensive definition of sustainable land use, it seems necessary to define all the interactions and competitions which exist among these functions and their uses.

In this context, three different categories of competition can be distinguished:

1) Exclusive competition exists between soil uses for infrastructure, as a source of raw materials and as a geogenic and cultural heritage on the one hand and soil uses for biomass production, filtering, buffering and transformation activities and as a gene reserve on the other hand. This becomes evident, when soils are sealed through urban and industrial development, e.g., the construction of roads, of industrial premises, houses, sporting facilities, or when soils are used for the dumping of refuse, all this being known as the process of urbanization and industrialization, excluding all other uses of land and soil.

The growth of urban population on a world-wide level and the measure of urbanization and industrialization is shown in Table 1, demonstrating urban population increase from 1970 - 1990 on the different continents, and indicating that by 1990 South America had a higher degree of urbanization than Europe, see also Blum [6].

Table 1. Increase of urban populations from 1970-1990 [28]

Area	1970	1990
	(%)	
Europe	67	73
South America	60	76
North America	58	71
Africa	23	34
Asia	24	29
World	37	43

This means that in Europe the different forms of land use are less separated but more closely interrelated with clear consequences for the second category of competition, through intensive interactions between infrastructural land uses and their development, and agriculture and forestry.

2) A second category of competition exists through intensive interactions between infrastructural land uses and their development, and agriculture and forestry, as shown by Fig. 3, which indicates roads and settlements in southern Germany. The scale of this figure indicates the density of this technical infrastructure, which significantly contributes to the problem of soil contamination and pollution, because all these linear and point sources are loading local soils with contaminants on three different pathways: through atmospheric deposition, on waterways and through terrestrial transport (see Fig. 4).

Figure 4 illustrates the many possible interactions between infrastructural land use on the one hand and agriculture and forestry on the other hand. This is especially true for densely populated areas in Europe and other regions of the world. In this context it also seems necessary to point out that soils are the last but one sink for many inorganic and organic depositions, the last one being the bottom of the oceans.

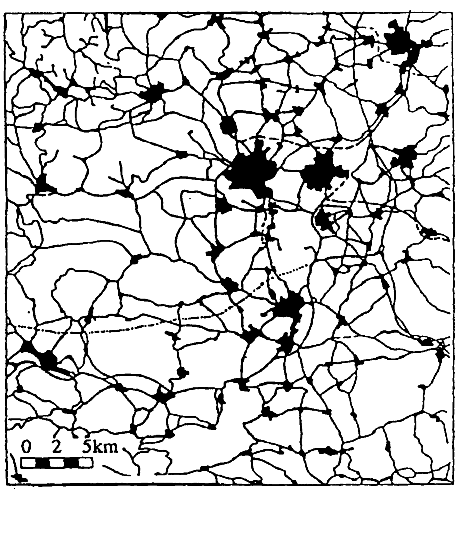

Fig. 3. Sealing of soils and landscape by settlement and roads [11].

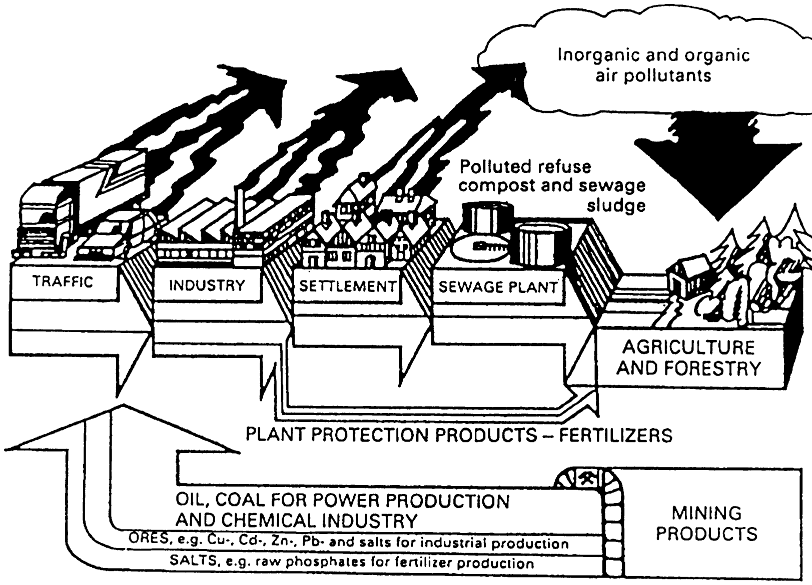

Fig. 4. Soil pollution through excessive use of fossile energy and raw materials [2].

In Fig. 4, different forms of loads can be distinguished: inorganic and organic depositions from traffic and transport, as well as those from urban and industrial activities. Most of these loads, such as severe acidification, pollution by heavy metals and other elements, pollution by xenobiotic organic compounds, deposition of non-soil materials, severe salinization and alcalinization, are more or less irreversible, because soils act as a sink [4,7,8,12]. Irreversibility is defined as the non-reversibility by natural forces or technical remediation measures within 100 years, which corresponds to about four human generations.

Only few processes of soil degradation, such as compaction or contamination by biodegradable organics or by small amounts of heavy metals, can be regarded as reversible by technical measures or natural remediation, e.g., bioturbation and bio-accumulation processes.

In the following, some of the adverse effects of transport, urbanization and industrialisation on agricultural and forest land will be exemplified, compare also Fig. 4, and Blum [9].

Figure 5 shows some of the impacts of traffic and transport on soils along highways and roads, indicating soil contamination through lead and hydrocarbons, as well as through cadmium and other compounds.

Soil degradation through urban activities is mainly due to the enormous consumption of air, water and other goods within towns, which can be analyzed by the flow of materials through urban agglomerations (e.g., in t/day or t/year). An example for the city of Vienna, with 1.6 mill. inhabitants is given in Fig. 6. From this figure it can be seen that each day the town consumes 560 000 t of water, 100 000 t of air and undefined amounts of energy, of construction materials, and other durable goods, producing 550 000 t of sewage and emitting 127 000 t of gas every day, which does not include about 8 000 t of solid wastes and undefined quantities of consumer goods [14], see also [12].

Looking at the flow of copper in the same city, in t/year (see Fig. 7), estimated by Lohm and Brunner, 1996, on the basis of data from Stockholm, Sweden [1], it can be seen that approximately 8 000 t of copper/year are used in the city. Only approximately 100 t/year are leaving the city as solid waste, and a little bit more than 10 t/year as sewage, and less than one ton as gas exhaust. The rest is added to the already existing stock of 320 000 t.

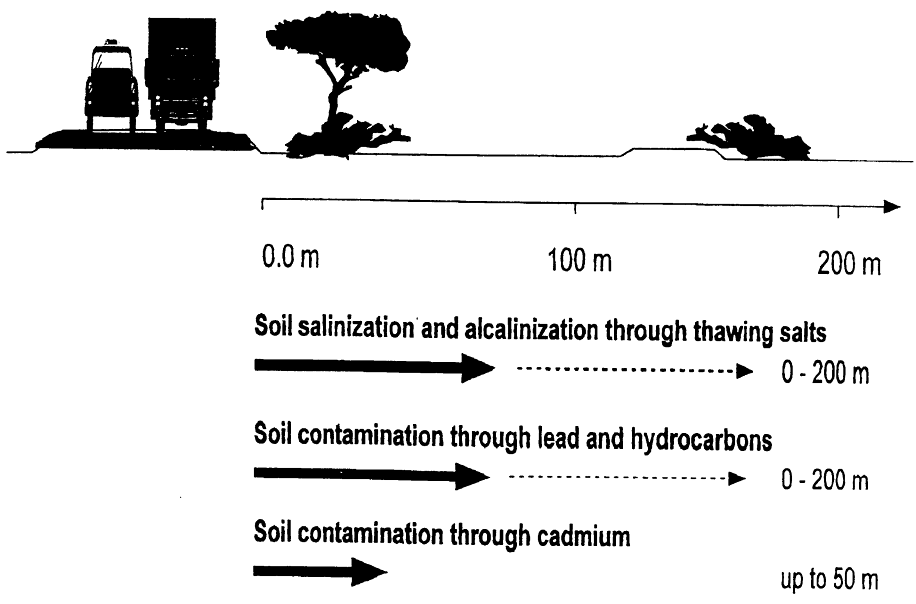

Fig. 5. Deposition of pollutants near traffic routes.

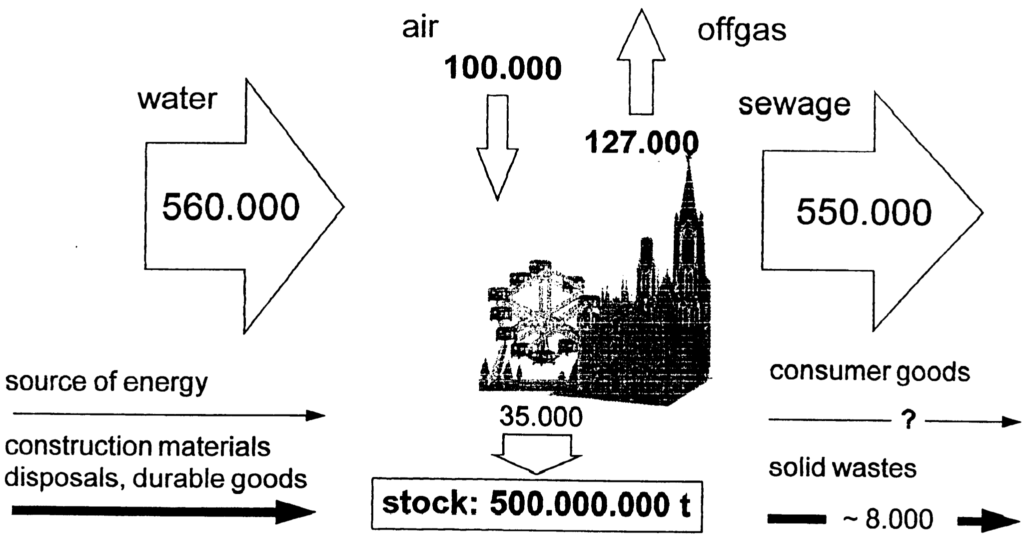

Fig. 6. Flow of goods through the city of Vienna in t/day [14].

The distribution of the copper emissions from the city can be found in the agricultural soils around the city, by depositions up to approximately 40 km [21]. The copper content in this area diminishes from 100 mg/kg top soil in the city center to approx. 20 - 30 mg/kg top soil at a distance of about 40 km (see Fig. 8). From this figure, it becomes also clear that other elements, such as zinc and lead are deposited from town activities in the close environment.

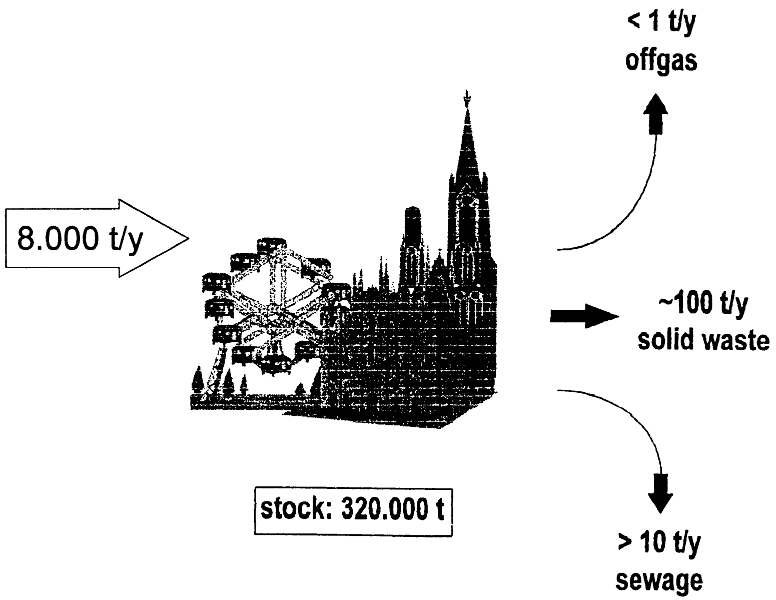

Fig. 7. Flow of copper through a city in t/year (estimated by Lohm and Brunner, 1996 on the basis of Bergbäck *et al.*, [1].

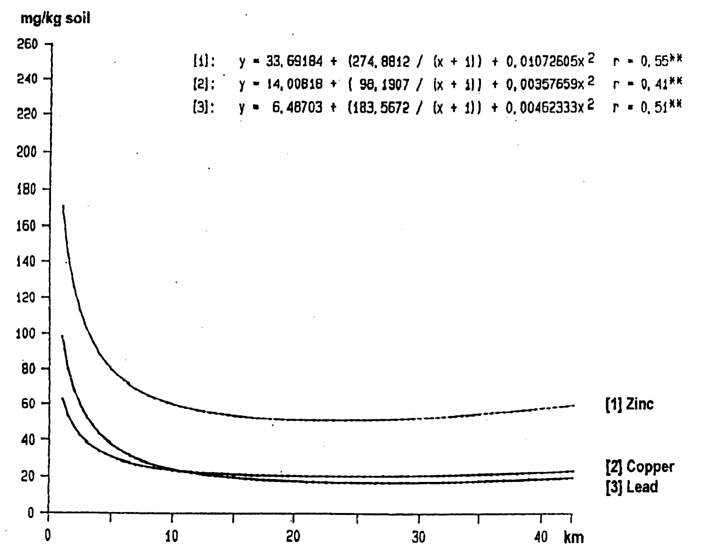

Fig. 8. Distribution of copper in top soils (0-20 cm), between metropolitan Vienna and the eastern state border, in a distance of 40 km [21].

The same is true for other parts of the world, as can be seen from Fig. 9 [26], indicating the distribution of As, Cd, Hg, and Pb in the metropolitan area of Manila, Philippines.

Soil degradation through industrial activities occurs in a more concentrated form than that from urbanization. Looking into large-scale industrial accidents, prompting public concern, indicates that chemical escape and hazardous wastes were the cause for Seveso (1976), Bhopal (1984), and Basel (1986). Release of radioactive material occurred on Three-Mile-Island

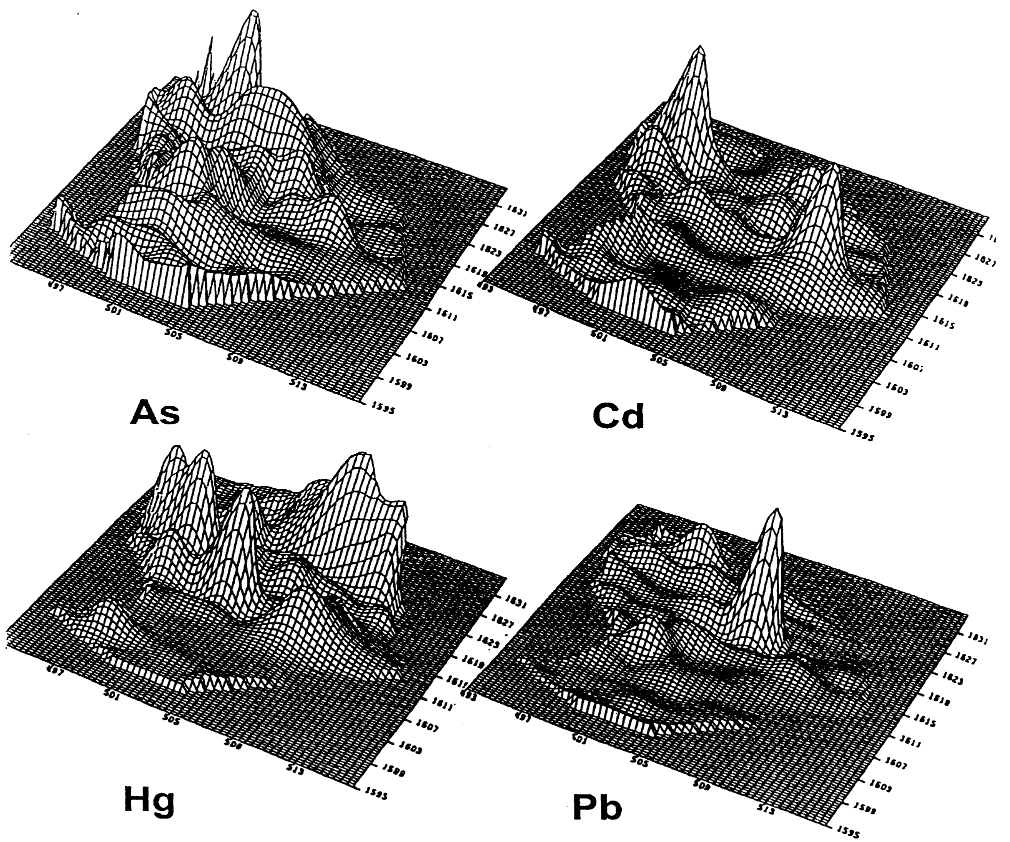

Fig. 9. Distribution of As, Cd, Hg, and Pb (mg/kg) in 373 topsoils (0-5 cm) of metropolitan Manila (Manila, Caloocan, Quezon, and Pasay) Philippines [26].

(1974), and Tchernobyl (1986). Such spectacular accidents show only the peak of the iceberg, whereas minor contamination and pollution problems occur each day around industrial sites, through the processing of pulp and paper, organic petro-chemicals, fertilizers, petroleum, foundries, metal works and many other industrial processes emitting heavy metals and other compounds, at a near and medium distance from the industrial production sites, as can be seen from the industrial area of the south-eastern part of Hamburg, Germany, according to Lux ([24], modified), see Fig. 10, showing the distribution of Cd, Sn, As, Cu, and Pb in mg/kg soil at two different distances from the industrial plant. Such contaminations are often also manifested in sediments of rivers, which are contaminated by sewage water.

3) A third form of competition also exists among the three ecological soil uses themselves, as shown in Fig. 11. Waste and sewage sludge deposition on soils as well as intensive use of fertilizers and plant protection products, in addition to the deposition of air pollutants (comp. Fig. 4), may have a negative influence on groundwater and the food chain, surpassing the natural capacity of soils for mechanical filtering, chemical buffering and biochemical transformation. This has to be taken into account, when implementing or using high input agricultural systems. In this context, it should be remembered that agriculture and forestry not only produce biomass above the ground, but also influence the quality and quantity of the groundwater production underneath, because each drop of rain falling on the land has to pass the

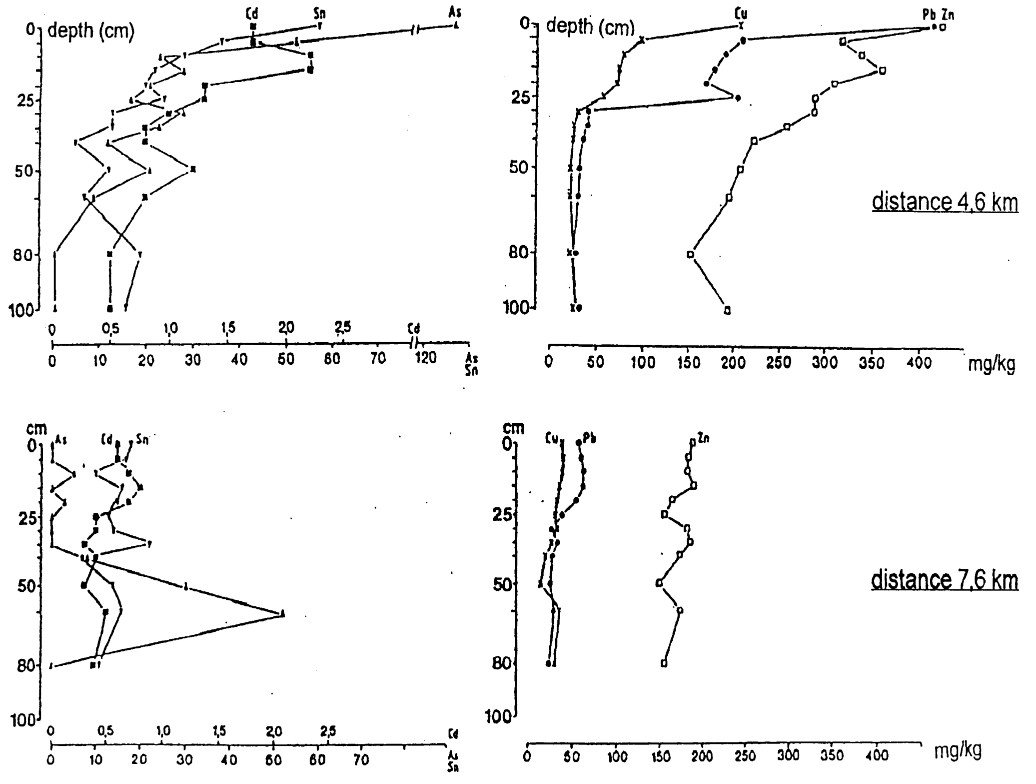

Fig. 10. Content of Cd, Sn, As, Cu, Pb and Zn (mg/kg) in soils at two distances from an industrial area in the south-eastern part of the city of Hamburg/Germany (Lux, [24], mod.).

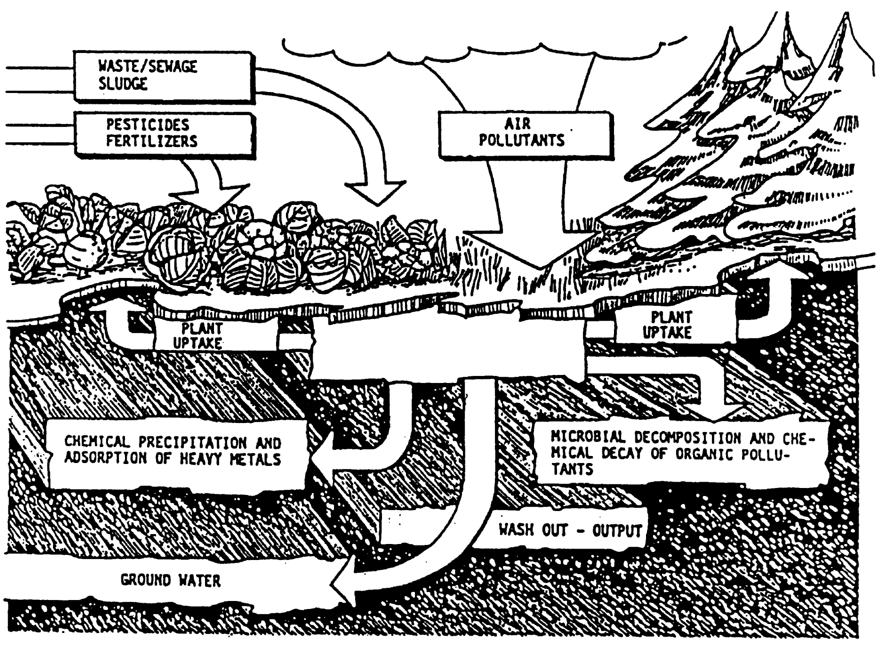

Fig. 11. Competition between agricultural production and groundwater quality through soil contamination from different sources.

soil before it becomes groundwater. Such problems are well known for many parts of the world, where contamination of the groundwater as drinking water through nitrate, pesticides and chemical compounds from the deposition of sewage sludge and waste compost are analyzed.

When the groundwater is used as drinking water, the competition between the production of food and fibre on one side and the production of groundwater on the other side is a competition between the satisfaction of basic human needs. In many areas of the world, especially in Europe, conventional agricultural production becomes increasingly controlled by quality standards for drinking water. It is easier to transport and sell food and fodder than to do the same with the necessary amount of drinking and household water.

WHAT IS SUSTAINABLE LAND USE?

Based on these facts, sustainable land use can be defined as the spatial (local or regional) and temporal harmonization of all six soil functions, through minimizing irreversible uses, e.g., sealing, excavation, sedimentation, acidification, contamination or pollution, salinization and others. This definition includes the dimensions of space and time. Therefore, the harmonization of soil functions is not only a scientific question, but also a political one, which means that all people living in a given area or space have to decide which soil functions they may use at a given time. Scientists only have the possibility to develop scenarios and to explain which causes and impacts may occur when different options are exercised. One important conclusion that can be drawn from this, is that the maintenance of soil multifunctionality is a precondition for the welfare of future generations.

CONCLUSIONS FOR THE DEFINITION OF AGRICULTURE IN A SUSTAINABLE ENVIRONMENT

The general definition of sustainable land use given above, shows clearly that agricultural land use is only one of several possible land uses and therefore depends on all other uses in a given area or region. Thus, sustainable agricultural land use is only possible when all the other land uses are sustainable as well. This means that an intensive linkage exists between sustainable agricultural use and the sustainability of all possible uses of soil and land. Sustainable agriculture is only possible, if no adverse impacts from other land uses are in existence. Looking into the specific spatial distribution of agriculture and other land uses, e.g., in Europe, such as settlements, industry, transport and others, it becomes clear that this concept of land use is holistic enough for being the basis of all future developments.

When determining the sustainability of agricultural land use, we must also take into account that socio-economic factors exist, which in many cases are more important than ecological considerations. Whereas ecological factors should be defined on a local scale, regarding specific topographical, climatic, physical, chemical, biological, and other conditions of terrestrial ecosystems, especially soils, socio-economic factors are determined on a regional or even on a world wide basis. They are governed by market conditions, terms of tariffs and trade (e.g., the General Agreement on Tariffs and Trade, GATT), and are in many cases reflected by the cost of energy, raw materials and labour. Often, these are the predominant factors for conventional agricultural systems. Ecological factors on the one hand and socio-economic and cultural ones on the other hand, should be clearly differentiated and not mixed up. However, the question is, if and how indicators for sustainable agricultural land use can be defined.

There are many possibilities for defining indicators for sustainable agricultural land use, see Doran and Jones [15], Hamblin [19], Karlen *et al.* [20], Larson and Pierce [23], Papendick and Parr [25] . The a.m. holistic approach to land use may be helpful in defining the suitable indicators for future sustainable agriculture for the different local or regional conditions in Europe or elsewhere.

CONCLUSIONS

In the 21st century, agricultural land use will occur under quite different ecological, technical and socio-economic conditions than in the centuries before. This is not only due to increasing competition for space, e.g., through the growth of urbanization and industrialization, with all its socio-economic and environmental impacts, especially in Europe, but also through increasing and severe competition between biomass production on one side and groundwater production on the other side, including problems of biodiversity and global change, e.g., through the emission of gases from agricultural areas into the atmosphere.

In many countries of the world, land surfaces for agricultural production are decreasing, due to the spreading of urban and peri-urban areas, to severe soil deterioration and the loss of soil quality, which means that in the future, sustainability in agricultural land use has to be reached on increasingly reduced areas and will only meet the challenge of sufficient production by intensification. For the increase of productivity and efficiency, new concepts are needed, compare Constanza *et al.* [13].

This holistic approach to sustainable land use may be helpful in order to define ecological, socio-economic and technological problems, thus enabling science to develop more comprehensive scenarios for sustainable development in the next century.

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