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SUSTAINABLE LAND USE FOR FOOD PRODUCTION IN THE TROPICS AND SUBTROPICS – A HOLISTIC APPROACH

Abstract

A definition of land use only based on agriculture is incomplete, because at least five other main 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 six main functions of land. Within this concept, biomass production and especially the production of food is one important function of land.

Due to severe competition between the six types of use, sustainable land use is defined as spatial and/or temporal harmonization of all main uses of land, minimizing irreversible ones. From this, the conclusion is drawn that sustainable agricultural land use depends on all the other types of land use and can only be sustainable if all others are sustainable as well. This is also true for food production as one specific target of land use.

Based on this approach, some specific constraints for food production in the tropics and subtropics are discussed on a strategic, tactical and operational level, aiming at the definition of principles for sustainable use of natural resources in these regions.

1. Introduction

During the last few years "Sustainable Land Use" has become a keyword within the discussion about agricultural land use and specifically for food production in the tropics and subtropics. Discussions at international congresses, seminars or workshops on this topic reveal considerable differences in the interpretation and perception of "sustainability" and "land use" (Blum 1993, Blum 1994, Blum and Aguilar Santelises 1994, Ensa 1992, Scope 1994). Most soil scientists define "land use" as "agricultural land use", without taking into consideration the five other uses of land, which interact competitively with agriculture in space and time.

Therefore, 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" and defining actual problems on a strategic, tactical and operational level for sustainable food production in the tropics and subtropics.

2. Definition of Land Use

In a holistic approach, six main uses of soil and land can be distinguished, three of them ecological ones and three others mainly related to human activities, such as technical, industrial and socio-economic ones.

The three ecological uses are:

- Production of biomass, ensuring the supply of food, fodder, renewable energy and raw materials; a function which is basic for human and animal life.
- Filtering, buffering and transformation capacity of soil between atmosphere, groundwater and plant roots. Soils act as a protective medium, preventing the uptake of harmful substances by plantroots or their wash-out into the groundwater, at the same time producing gases through biochemical transformation processes. – These filtering, buffering and transformation activities are shown in fig. 1, which depicts three main processes:
  - mechanical filtration, e.g. in the pore space;
  - physico-chemical buffering through absorption and precipitation processes at the surfaces of inorganic and organic soil components;
  - transformation by microbiological and biochemical processes, especially the decomposition and alteration of organic compounds.
- Moreover, soil is acting as a biological habitat and a gene reserve, as a large variety of organisms live in or above the soil. Therefore, soil use is directly linked to biodiversity, which is also an important factor for human life, considering for example that the antibiotic Penicillin was developed from the ubiquitous penicillium fungus, present in the soil. In addition, genes from the soil are used increasingly for biotechnology and biogenetic engineering.

Three further soil functions, linked to technical, industrial and socio-economic activities are:

- Soil as a spatial basis for technical, industrial and socio-economic structures and their development, e.g. industrial production, housing, transport, sports and recreation, dumping of refuse, and others.
- Soils serve as a source of geogenic energy, raw materials such as clay, sand, gravel and others and as a source of water.
- Moreover, soils are a geogenic and cultural heritage, forming part of the landscape and concealing paleontological and archeological treasures of high importance for the understanding of the history of earth and mankind.

Fig. 2 depicts all these six main uses of land schematically, indicating that land use should be defined as the temporarily and spatially simultaneous use of all these soil functions, which are of course not always complementary in a given area. Moreover, this figure shows clearly that severe competition and interaction exist between these six main uses of land.

3. Competition Between the Six Main Uses of Land

Three main types of competition and interaction between these six uses of soil and land can be distinguished:

3.1 Exclusive competition exists between the use of land for infrastructure, as a source of raw materials and as geogenic and cultural heritage on one hand and for agricultural and forest production, filtering, buffering and transformation activities and as a gene reserve on the other hand. – This means that between the technical soil uses and the ecological ones exclusive competition exists. For example, the construction of a road or a factory excludes all ecological uses.

3.2 Further intensive interactions exist between infrastructural land uses and development on one hand and agriculture, forestry, filtering, buffering and transformation activities and soil as a gene reserve on the other hand, especially in urban and peri-urban areas, spreading exponentially into agricultural and forest areas around the world. Tab. 1 shows the constant increase of urban population from 1970 – 1990, which is most pronounced in developing countries. This can also be seen from tab. 2, which shows the world's 35 largest cities, most of them in tropical and subtropical regions.
Therefore, large areas can no longer be considered as agricultural regions but as urban or periurban ones, with intensive and concurring influences on ecological, especially agricultural land uses.

2.3 Intensive competition also exists between the three ecological soil and land uses themselves. Farmers are producing biomass (food, fodder and renewable energy) on their land, and at the same time groundwater underneath, as each drop of rain falling on their land has to pass their soil before it becomes groundwater. Therefore, farmers are not only influencing the food chain, but also the quantity and quality of groundwater production, through their agricultural practices, especially the use of agrochemicals. Moreover, through intensive agricultural land use, the gene reserve and the biodiversity can also be influenced.

Summarizing, it can be said that in many parts of the world, also in many tropical and subtropical regions, agricultural land use is influenced by urbanization and in part also by industrial production. Therefore, a more comprehensive definition of "sustainable land use" is needed.

4. Definition of Sustainable Land Use

Sustainable land use can be defined as spatial and/or temporal harmonization of all six main uses of land, minimizing irreversible ones, e.g. sealing, excavation, sedimentation, contamination or pollution, salinisation and others. This definition includes dimensions of space and time and aims at maintaining a maximum of uses in a given area, thus leaving options of land use for future generations.

Spatial and temporal harmonization of all six main land uses, minimizing irreversible ones, has to be attempted in a local or regional approach, depending on the specific uses of land in a given area. This is not primarily a target of science, but rather a political one. Scientists should develop scenarios in order to facilitate sound political decisions.

5. Definition of Sustainable Agricultural Land Use

According to the definitions described above, agricultural land use is only one of six possible uses of land and therefore depends on all other uses in a given area or region. This can clearly be seen in fig. 2 and the subsequent explanations of the different land use functions.

Therefore, sustainable agricultural land use is only possible if all the other land uses are sustainable as well. – In this definition, sustainability is determined by ecological as well as by socio-economic and cultural factors.

Ecological factors are mainly defined on a local or site scale (e.g. topographic, climatological and others, as well as specific physical, chemical and biological soil parameters).

In contrast, socio-economic and cultural factors are mostly defined on a regional or global level, e.g. through international market conditions, the General Agreement on Tariffs and Trade (GATT) and others. Those are often reflected by the costs for energy, raw materials and labour.

Ecological factors on one hand and socio-economic and cultural ones on the other hand should be clearly differentiated and not mixed up. This seems to be very important for strategic, technical and operational procedures in order to find new approaches in sustainable land use for food production in tropical and subtropical regions.

The actual global food supply is reported by Borlaug and Dowswell (1994), indicating that:

- Worldwide cereal production, since 1950 has increased by 2,7% per annum, with virtually all of these gains coming from yield increases, while population has grown by 1.9% over the same period.
- Real prices of agricultural commodities are the lowest ones in history.
- The increases in yield and production have made it possible for per capita consumption in developing countries to increase by 27% since 1960. As a result, between 1961–63 and 1987–89, the per capita supplies of food have increased from 1,725 to 2,394 calories per day in East Asia and the Pacific Region, from 1,970 to 2,194 calories per day in South Asia, and from 2,370 to 2,725 calories per day in Latin America and the Caribbean Region.

  The only area of severe trouble is the Sub-Saharan Region of Africa. Only very small increases in per capita/calories/day supplies occurred during the 1960s. During the last two decades, however, per capita/calories/day supplies have actually decreased as population has increased by 3% per annum while food production has grown only by 2%.

6. Problem Identification for Sustainable Food Production in the Tropics and Subtropics, with Special Regard to Africa

The identification of problems for sustainable food production in these regions can be achieved on three different levels: a strategic, a tactical and an operational one.

6.1 Strategic level

6.1.1 Definition of goals

Based on the holistic approach developed above, several important goals in relation to food production are not considered in existing approaches in the tropics and subtropics:

- The growth of urban and periurban areas with regard to sustainable soil and water management. – Urbanization in developing countries of the tropics and subtropics has reached a very dynamic stage, and a magnitude which is without any historical precedent. Two thirds of the total population growth occur exclusively in urban and periurban areas. If this development continues, it will cause further severe losses of population in the farmland areas and other drawbacks with important consequences for agricultural production.

- The question of the extension of agricultural land (cropping areas and pastures) and its influence on soil protection: Regarding to recent international literature, it is evident that there are no more soil reserves for agricultural use available in the tropics and subtropics with very few exceptions, e.g. the Cerrado-areas in South America, especially in Brazil, because any further extension of agricultural and pasture land would lead to the destruction of terrestrial ecosystems and soils. Therefore, an increase in food production is only possible by intensification on existing surfaces which diminish constantly, as revealed by recent publications on human-induced soil degradation (based on GLASOD inventory, see Oldeman et al. 1991), indicating that heavy loads are put on soils and high losses already exist and still more have to be expected (e.g., for Africa, Tab. 3).
- In several areas of the tropics and subtropics, a competition of food and groundwater production exists. Therefore, primary goals have to be established in order to maintain an equilibrium in the satisfaction of basic needs.

Besides the definition of these and further goals, which have to be reached in order to achieve sustainable food production in these regions, the procedures have to be redefined as well, based on the essential governing principles of the biosphere.

6.1.2 Definition of procedures based on the essential governing principles of the biosphere

Basic long term requirements for sustainable agricultural land management and food production can be defined as follows:

- Maintenance of the greatest possible variety of species in and upon the soil (biodiversity) and protection of water resources. The old and traditional land use techniques, which were developed in the tropics and subtropics and are adapted to their specific ecological conditions, should be given priority and the many techniques that are imported from other ecological regions should be adapted accordingly.
- Solar orientation and the use of energy from renewable resources with minimization of the use of fossile energy and non-renewable raw materials. In the medium run, solar orientation and the use of energy from renewable resources will be the only way of promoting sound and

sustainable food production in the tropics and subtropics, because the exclusive use of fossile energy is simply too expensive and not feasible in many areas. New techniques have to be developed.
- Optimal use of energy and raw materials through the combination of different land use systems (e.g. agroforestry) and closed-cycle production with a reduction of material intensity and an increase of resource productivity is another important target, which has to be defined as a basic procedure for sustainable food production in these regions.
- Decentralization in combination with ecological land management systems, with maintenance of ecologically stable landscapes: This principle seems to be very important in order to maintain soil fertility and landscape productivity, avoiding the destruction of landscapes and soils.
- Agreements on specific market conditions, tariffs and terms of trade for agricultural products, avoiding eco-dumping. This principle is very important and is far beyond science, reflecting problems in the socio-economy of many developing countries in the tropics and subtropics.

Based on these principles, the targets of entropy reduction, minimization of entropy production and increase of ecological stability can be reached. Therefore, it seems necessary to increase our efforts for the development of new concepts in this sense in the near future, even regarding warnings, indicating that improvement of soil fertility management is only possible by introduction of improved seed, fertilizer and weed control technology (Borlaug and Dowswell, 1994).

6.2 Tactical level

Whereas the strategic level is mainly based on a continental approach, the tactical level is rather dealing with regional problems. Within this level ecological, socio-economic and technical constraints have to be considered.
- *Ecological constraints:* Ecological constraints for sustainable food production in the tropics and subtropics are the limited soil surface and constant loss of soils through soil destruction, especially erosion by water, wind and salinization. This means that the conservation and maintenance of soil fertility is one of the most important tactical targets in food production. Other constraints are: topography, adverse climatic conditions, a lack of water resources, a lack of natural vegetation (e.g. forests and bushland) for the protection of agricultural land, due to deforestation and other types of severe mismanagement in tropical and subtropical landscapes (Sombroek, 1993).

- *Socio-economic and technical constraints:* Under this aspect, a lack of administrative and technical infra-structures on the level of countries and within regions of specific countries can be observed. This also means that administrative and technical support of farmers, especially in Sub-Saharan Africa, is strongly underdeveloped.
  The same is true for legal instruments, protecting landscapes and soils and promoting agricultural production for example through maintenance of certain price levels for agricultural products.
  Economic instruments, e.g. incentives for the stimulation of agricultural production are also rarely available. Moreover, research is also insufficient in many countries and not available at the farmers' level. The same is true for education and information, which are basic tools in promoting sustainable food production in the tropics and subtropics.

6.3 Operative level

Operative procedures have to focus on local or site conditions. Under such conditions, different constraints can be identified in relation to sustainable food production in the tropics and subtropics. Such constraints are for example availability of information, e.g. through extension.

The availability of labourers is already becoming scarce in certain regions, which means that mechanization would be needed in order to counterbalance the loss of manpower, especially in those rural areas where migration to urban and periurban centres is common.

Moreover, the availability of finances and products, e.g. fertilizers and agrochemicals to provide favourable conditions for growth and to protect crops and products in general, should be drastically improved (Van Reuler and Prins 1993).

Such constraints at an operative level have to be recognized. They cannot generally be solved on a scientific level, as they are mostly based either on socio-economic or on legal conditions (Swegle 1993).

7. Conclusions

In the 21st century, food production will occur under quite different ecological, technical and socio-economic conditions than in the decades before. There is not only increasing competition for the space for food production through the exponential growth of urban and periurban areas and socio-economic problems, radiating from them into the adjacent rural surfaces, but also severe competition between food production on one side and ground water production on the other side, without counting problems in biodiversity through large scale monocultural approaches.

Land surfaces for agricultural production in many developing countries of the world are decreasing, due to severe soil deterioration, e.g. erosion by water and wind and the use of fertile land for infrastructural development. This means that in the future, food production will occur on increasingly reduced areas and will only meet the challenge for sufficient production by intensification. For the increase of productivity and efficiency, increasing support from renewable resources of energy will be needed as well as other inputs, including recent advances in molecular biology and biotechnology.

Looking into this overall situation, a more holistic approach to food production in the tropics and subtropics will be needed, including ecological, scientific and technological as well as socio-economic aspects.

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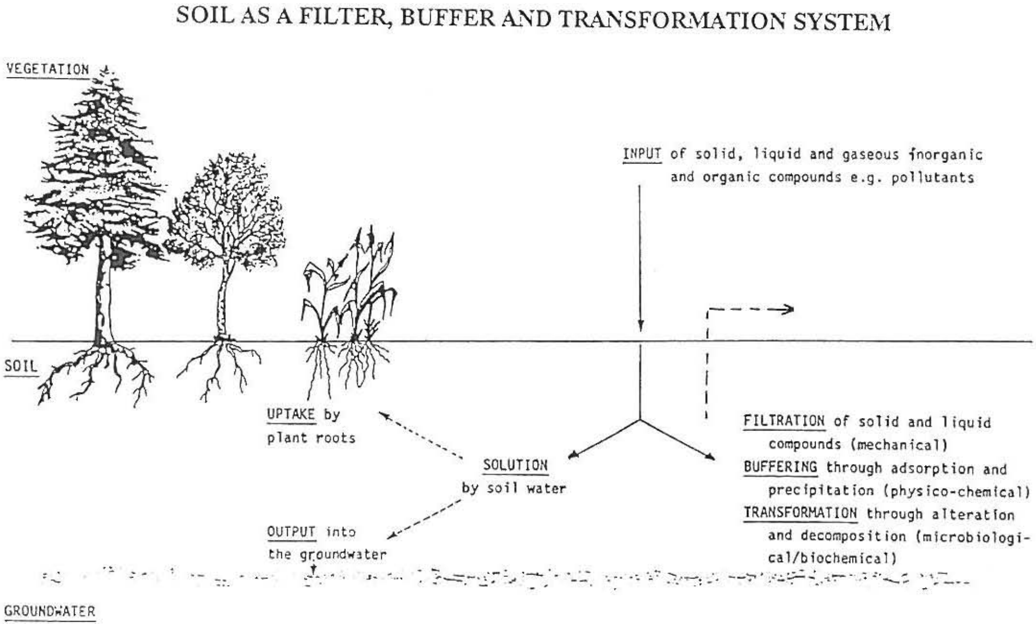

Figure 1: Soil as a filter, buffer and transformation system

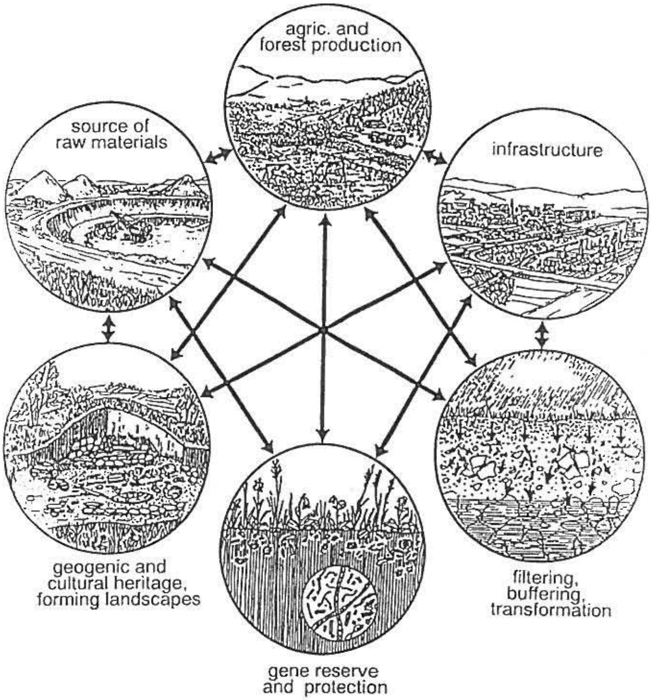

Figure 2: Competition between the 6 soil functions

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

United Nations Environmental Data Report (3rd Ed.) 1991/92

Table 1: Urban Population

Rank	Country	City	1970	1990	Added	% Growth
1	Japan	***Tokyo***	14.91	***20.52***	5.61	37.626
2	Mexico	***M. City***	9.12	19.37	***10.25***	112.39
3	Brazil	S. Paulo	8.22	18.42	10.2	124.09
4	USA	***N. York***	***16.29***	15.65	-0.64	-3.9288
5	China	Shanghc	11.41	12.55	1.14	9.9912
6	India	Calcuttc	7.12	11.83	4.71	66.152
7	Argentina	B. Aires	8.55	11.58	3.03	35.439
8	Korea	Seoul	5.42	11.33	5.91	109.04
9	India	G. Bomk	5.98	11.13	5.15	86.12
10	Brazil	Rio de J.	7.17	11.12	3.95	55.091
11	UK	London	10.59	10.57	-0.02	-0.1889
12	Japan	Osaka/K	7.61	10.49	2.88	37.845
13	USA	Los Ang.	8.43	10.47	2.04	24.199
14	China	Peking	8.29	9.74	1.45	17.491
15	Indonesia	Jakarta	4.48	9.42	4.94	110.27
16	Russia	Moscow	7.07	9.39	2.32	32.815
17	Iran	Tehran	3.29	9.21	5.92	179.94
18	Egypt	Cairo	5.69	9.08	3.39	59.578
19	France	Paris	8.34	8.75	0.41	4.9161
20	India	N Delhi	3.64	8.62	4.98	136.81
21	Philippines	Manila	3.6	8.4	4.8	133.33
22	China	Tianjin	6.87	8.38	1.51	21.98
23	Italy	Milan	5.52	7.9	2.38	43.116
24	Pakistan	Karachi	3.14	7.67	4.53	144.27
25	Nigeria	***Lagos***	1.44	7.6	6.16	***427.78***
26	Thailand	Bangkok	3.27	7.16	3.89	118.96
27	USA	Chicagc	6.76	6.89	0.13	1.9231
28	Peru	Lima	2.92	6.5	3.58	122.6
29	Bangladesh	Dhaka	1.54	6.4	4.86	315.58
30	India	Madras	3.12	5.69	2.57	82.372
31	Colombia	Bogota	2.37	5.59	3.22	135.86
32	Hong Kong	H. Kong	3.53	5.44	1.91	54.108
33	Russia	S Peterst	3.96	5.39	1.43	36.111
34	Iraq	Baghda	2.1	5.35	3.25	154.76
35	Spain	Madrid	3.37	5.06	1.69	50.148
		Total	215.13	338.66	123.53	
		Max	16.29	20.52	10.25	427.78

Table 2: The world's 35 largest cities

Type	Light	Moderate	Strong	Extreme	Total
	(million ha)				
Loss of topsoil	53.9 (1.8)1	60.5 (2.0)	86.6 (2.9)	3.8 (0.1)	204.9 (7.0)
Terrain deformation	3.6 (0.1)	6.9 (0.2)	11.7 (0.4)	0.4 (0.001)	22.5 (0.7)
Water	57.5 (1.9)	67.4 (2.2)	98.3 (3.3)	4.2 (0.1)	227.4 (7.7) (46%)
Loss of topsoil	79.1 (2.7)	84.2 (2.8)	7.4 (0.2)	-	170.7 (5.8)
Terrain deformation	9.2 (0.3)	5.1 (0.2)	-	-	14.3 (0.5)
Overblowing	-	-	0.5 (0.002)	1.0 (0.03)	1.5 (0.005)
Wind	88.3 (3.0)	89.3 (3.0)	7.9 (0.3)	1.0 (0.03)	186.5 (6.3) (38%)
Loss of nutrients	20.4 (0.7)	18.8 (0.6)	6.2 (0.2)	-	45.1 (1.5)
Salinization	4.7 (0.1)	7.7 (0.2)	2.4 (0.08)	-	14.8 (0.5)
Pollution	-	0.2 (0.007)	-	-	0.2 (0.006)
Acidification	1.1 (0.03)	0.3 (0.01)	+	-	1.5 (0.05)
Chemical	26.0 (0.9)	27.0 (0.9)	8.6 (0.3)	-	61.6 (2.08) (12%)
Compaction	1.4 (0.04)	8.0 (0.3)	8.8 (0.3)	-	18.2 (0.6)
Waterlogging	0.4 (0.001)	0.1 (0.003)	-	-	0.5 (0.002)
Subsidence organic soils	-	-	-	-	-
Physical	1.8 (0.006)	8.1 (0.3)	8.8 (0.3)	-	18.7 (0.6) (4%)
Total	173.6 (5.8) (35.1%)	191.8 (6.5) (38.9%)	123.6 (4.2) (25.0%)	5.2 (0.2) (1.0%)	494.2 (16.7) (100%)

1. Figures in parentheses are percentages of total land area of Africa (excluding water bodies). Percentages within degraded lands are shown by category in bold numerals, also within parentheses.

Table 3: Human-induced soil degradation Africa (based on Glasod inventory; see Oldeman et al. 1991)