Natural resource use by agricultural systems

Linking biodiversity to poverty

Fred Tonneijck, Huib Hengsdijk & Prem S. Bindraban
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Preface

This project was funded by the Netherlands Environmental Assessment Agency (MNP) under contract number E/555020/01/MO. The final results were brought about after many discussions with our colleagues of MNP and others. Project results were presented at a national workshop on ‘Generic global modelling of the linkages between biodiversity and human well-being’ (February 16-17, 2006; Zeist, Netherlands) and an international workshop on poverty-biodiversity linkages (March 6-11, 2006; Turrialba, Costa Rica). Both workshops were organized by the MNP. We gratefully acknowledge the support and the discussions with Dr. Tonnie Tekelenburg and Dr. Ir. Rob Alkemade from MNP during various stages of the project.
Summary

Agricultural development is a well-known threat to the conservation of biodiversity and the loss and fragmentation of native habitats. It also is considered to be an important engine of economic development in developing countries. Changes in agricultural production systems might affect directly and/or indirectly both biodiversity and aspects of livelihood such as poverty and hunger. The Netherlands Environmental Assessment Agency (MNP) has recently developed the global biodiversity model GLOBIO 3. This model focuses mainly on the relationships between the changing environment and biodiversity. There is a need to further develop this model and to incorporate livelihood aspects and their linkages with biodiversity and the sustainable provision of goods and services. In this study we attempt to describe, as quantitatively as possible, the direct relation between species diversity within agricultural production systems and the productivity of these systems. A line of thought also is presented on how to link livelihood (poverty and hunger) to agricultural outputs.

Following the concept of production ecological principles, agricultural production systems can be fully characterized by their inputs and outputs, i.e., input-output combinations. To assess the relationships between agricultural production, biodiversity and livelihood, detailed information on inputs and outputs has been gathered for the current production systems world-wide. Typical or predominant production systems (crops and livestock) were selected for each of 72 farming systems as have been described by Dixon et al. (2001), and inputs (nitrogen and labour) and outputs (yield) were quantified on the basis of available statistics, literature and models. Nitrogen balances of production systems were qualitatively assessed on the basis of yields and nitrogen inputs. Formulas have been presented to calculate self-sufficiency in terms of food quantity (dietary energy balance) and quality (protein content) depending on quantity (i.e. yield) and type of produce. For important services such as water and soil fertility, equations have also been described to assess water balance and soil organic matter. Data on diversity of species in response to an increase of nitrogen input were derived from a quick scan of the literature.

To improve their livelihoods, farm households can intensify the existing production systems, can diversify production and processing, and can expand their land holding or herd size. These strategies all have different effects on biodiversity. Our study indicates that expansion of land to increase agricultural production would result in the greatest loss of biodiversity. Up to 80% of species diversity might be lost due to full conversion. Species diversity is lower in high-input production systems than in low-input systems, though at absolutely low levels in both systems (<20%) compared to the diversity in natural systems. The challenge is to intensify agricultural production on converted lands which ultimately has a minor impact on biodiversity rather than to clear natural lands for cultivation.

Our study can principally be regarded as a technical exercise to explore the relations between agricultural production, biodiversity and livelihood on the basis of available information. One of the major problems was that the farming systems classification by Dixon et al. (2001) was not compatible with available yield statistics. Furthermore, data on livestock productivity and external nitrogen inputs were hardly available on a global scale. Variation in input-output relations within production systems apparently is very high because of differences in biophysical and socio-economic characteristics and applied technologies within the same farming systems class. These classes cover large areas and variation in input-output relations can be addressed only by more detailed analysis (downscaling) of farming systems. The linkage between biodiversity and production systems obviously applies to the field scale where (natural) resources are converted into goods and services. The farm level is the level where aspects of livelihood of farm households can be determined. Upscaling and downscaling of information is one of the most important challenges in agricultural sciences. Despite the problems in quantifying inputs and outputs of production systems, their estimates are a first step in improving the characterization of identified farming systems, enabling to better differentiate farming systems and helping to link biodiversity, livelihood and production systems.
1. Introduction

1.1 General introduction

Assessment of the impact of human activities on world's natural resources is important to understand the limits of our claims on those resources and to set out strategies for sustainable use. Biodiversity is considered of eminent importance for life, while its use is at the base of the provision of goods and services to mankind. Unsustainable use can however lead to overexploitation and jeopardize the sustenance of the resource base itself. Therefore seeking ways to balance the use and sustenance of biological diversity is and will remain an act that needs careful monitoring and assessments.

Agricultural development, conversion of nature for agriculture, and conversion of agricultural land into urban sprawl are widely recognized as very serious threats to the conservation of biodiversity and the loss and fragmentation of native habitats. Many of the richest and most endangered biodiversity hot-spots are concentrated in those areas in which rural poverty prevails. The use and conservation of biodiversity on local scale in developing countries is therefore inherently linked to the international debate on sustainable development, poverty and hunger. More progress in reducing biodiversity loss can be achieved through the better integration of biodiversity goals into broader development and poverty reduction strategies. Major challenge is the translation of various international agreements (for instance WSSD, Convention on Biological Diversity, Millennium Development Goals) into tangible activities in developing countries to support the sustainable development and the use and conservation of biodiversity. Tools and methods to support this process may contribute to improved policy formulation at different levels: Local initiatives can be better tuned to international developments, while global contributions (including those of the Dutch government) in the field of sustainable development, biodiversity and poverty can be better matched to the needs of developing countries.

Since agricultural development is considered a major threat to biodiversity but at the same time an engine of economic development in many developing countries, agricultural production systems are the level where biodiversity and development goals unite. Many of the costs of changes in biodiversity due to agricultural development have historically not been accounted for in decision-making. Current agricultural development is closely linked to the international trade in agricultural products, which increasingly is subject to rules, grades and standards as result of changing consumer demands. Although such regulations can be interpreted as market protection mechanisms, they also may offer opportunities to better reward the use of biodiversity (ecosystem services) and the equitable and sustainable development in producing countries. However, insight in how to relate commodity chain standards with the performance of agricultural production systems is still scarce.

Analyses to formulate recommendations on biodiversity use and conservation for decision making have up to now hardly emphasized the relation of biodiversity with land use, poverty and wealth creation. Poverty and wealth creation are the result of activities determined by a myriad of factors including biophysical properties of for instance soil, water and biodiversity, economic conditions which stimulate or discourage certain activities, socio-cultural attitudes and the political environment. It is clear that changes in agricultural production systems might affect directly and/or indirectly both poverty and biodiversity. Our ultimate goal is to enhance the insights into the relations between biodiversity use and poverty and hunger of farm households.

1.2 The Globio 3 model

The Netherlands Environmental Assessment Agency (MNP) has recently developed the global biodiversity model GLOBIO 3 (Figure 1; see also Ten Brink et al. 2006). GLOBIO 3 focuses mainly on the relationships between the changing environment and biodiversity. The model is linked to the integrated environmental assessment model IMAGE 2.2 (IMAGE team, 2004), which enables analyses of the effects of different socio-economic scenarios on biodiversity. The core of the GLOBIO3 model is formed by general dose-response relationships between environ-
mental factors and biodiversity. Further developments of GLOBio aim at the incorporation of aspects of well-being (hunger and income poverty) and their linkages with biodiversity and the sustainable provision of goods and services.

Figure 1 presents the linkages between the environment, biodiversity, the goods and services as provided by biodiversity, and human well being and poverty for an agricultural production system. It is hypothesized that the production of goods and services is determined by biodiversity in its broad since. Biodiversity includes all available stocks and the variation of living organisms and it is primarily determined by the state and the quality of all ecological processes. Both the ecological processes and biodiversity are influenced by human activities. Two types of human activities have been distinguished: (1) restoring investments and (2) harvest investments. Restoring investments are directed to the enhancement and maintenance of the production ability of a production system and include measures such as erosion prevention and water management. Harvest investments relate to the harvesting of products themselves and to improved production of one of the goods. These latter investments include removal of the original vegetation, ploughing, application of fertilizers and pesticides, and removal of the product of interest. The yields of the different goods and services are basic to the livelihood of the people who depend on the particular production system. It must be realized that livelihoods do not only depend on the goods and services which are provided by their farms, but also on external earnings.

Figure 1. Schematic representation of the Globio 3 Model. Source MNP 2005.

1.3 Aim of the project

The aim of the proposed project is to develop and apply an analytical methodology to quantitatively assess the relations between the production of goods and services by agricultural systems, and biodiversity, poverty and hunger.

In this study we attempt to describe, as quantitatively as possible, the direct relation between the species diversity (% of natural) within agricultural production systems and the productivity of these systems on the basis of literature data and expert judgment. To link biodiversity to poverty, a line of thought is presented on how to link poverty to agricultural outputs (goods and services).
1.4 Outline of the report

Chapter 2 presents our general concept of the linkages between biodiversity, poverty (further referred to as livelihood) and agricultural production systems. The quantitative relationship between species diversity within production systems and increase of agricultural production is described in Chapter 3. Chapter 4 explores the linkages between production systems and livelihood and presents some useful indicators for assessing various aspects of livelihood. Subsequently, detailed information has been gathered for the current production systems world-wide as these have been described by Dixon et al. (2001). These data which refer to the inputs into the production systems and the outputs in terms of goods and services have been combined with estimations of percentage species diversity and livelihood aspects. The results of this activity are presented in Chapter 5. Project results are evaluated in Chapter 6 with an emphasis on future activities that are considered necessary to further develop our knowledge on the linkages between biodiversity, livelihood and agricultural production systems.
2. Linking biodiversity and poverty to agricultural production systems: development of a general concept

Agricultural development provides an effective means for both reducing poverty and accelerating economic growth but might adversely affect biodiversity. Thus, we introduce a set of concepts to explore the relationships between agriculture, biodiversity, poverty and hunger that is based on the approach of production ecological principles (Lövenstein et al., 1995; Van Ittersum and Rabbinge, 1997). According to these principles, agricultural systems can be fully characterized by their inputs and outputs, i.e., input-output combinations. This approach has proven to be generally applicable and has been used to analyze, for example land quality indicators (Bindraban et al., 2000), the world food production (WRR, 1995), and the regional allocation of production and natural areas (WRR, 1992).

Figure 2 presents the concept of agricultural production systems with respect to their inputs and outputs in more detail and links these inputs and outputs to the GLOBIO 3 model (see also Figure 1). Agriculture can be defined as the human activity in which energy from the sun is utilized for the production of sugars that are used in the plant to construct carbohydrates, proteins, lipids and other compounds (Van Ittersum and Rabbinge, 1997). These substances can be used for animal and human consumption or as a basis for industrial products. Ecological processes and biodiversity stocks including for example the quality of soils (chemical, physical, biological) together with labour and capital are inputs to production systems. Often, external inputs (capital) are used to manipulate the growth of a crop or animal in such a way that desired productivity levels are realized. Goods and services are the outputs of these systems and these outputs may have positive and/or negative feedbacks on biodiversity stocks, ecological processes and farmer livelihood. Agricultural produce can be used for home consumption (self-sufficiency) or can be marketed (income). The production of goods and services may have undesired consequences such as emissions to the environment as a result of nutrient losses, pesticide spills and soil erosion. Services relate for example to the on-farm use of crop residues and manure that result in an increase in soil organic matter and soil nitrogen content and improved retention of water. Furthermore, it is clear that societal and economic objectives that have their origin outside the agricultural sector need to be considered when evaluating the effects of agricultural production systems on biodiversity and livelihood.

In general, the level of output increases with increasing input. The production level of agricultural systems depends on the absolute and relative levels of production factors. When all production factors are present in optimal amounts and proportions, meeting the needs of the crops, the production level will be determined by solar radiation, temperature and CO₂ and potential yields will be obtained. Under inadequate availability of water and/or nutrients growth will be limited, while it will be further reduced by weeds, pests and diseases. Going from more optimal conditions to less optimal, yields generally decrease, while the occurrence of other species, both flora and fauna, within the production system may increase. Thus, production systems differ in the levels of inputs and outputs. These inputs and outputs have a direct relation with biodiversity within the systems themselves and also have an indirect effect on biodiversity at a higher scale level (regional) due to the claims of these systems on (natural) resources, primarily land. Production systems as described by their inputs and outputs are location specific. The location can be characterized by the physical production environment that refers to climate factors, soil characteristics and abiotic factors in soil and atmosphere. The production system is further defined by the applied production techniques and the selected crop species or variety.
Production systems, inputs and outputs

Inputs
- Nutrients, pesticides, fuel
- Seeds/plants, water, organic matter
- Labour, machinery

Production systems
- Water, organic matter
- Soil fertility, mycorrhization
- Soil respiration, nitrification

Outputs
- Erosion, sedimentation, emission
- Crop residues, organic matter
- Biodiversity, desiccation

Biodiversity stocks and processes

SE Cycles

Figure 2. Presentation of the linkages between the production of goods and services by agricultural production systems as defined by their inputs and outputs and biodiversity, poverty and hunger. SE cycles refer to Social and Economic cycles. White boxes relate to boxes as presented in the Globio 3 Model (see also Figure 1).

The linkage between biodiversity and production systems obviously applies to the field scale where (natural) resources are converted into goods and services, expressed in physical terms. The farm level is the first level where physical and socio-economic information meet and aspects of livelihood of farm households can be determined. Thus, at least two levels of analyses are required, namely the field level and the farm level, to link biodiversity and livelihood to agricultural production systems. Various production systems (input-output combinations) can exist within one farm and consequently the livelihood of a single farm household might be based on different outputs (goods and services).

The field level must be linked to the farm level when we want to evaluate the relation between biodiversity and livelihood. The concept of farm household as schematically presented in Figure 3 describes the relevant linkages at the level of a farm household. Generally, poor farmers operate more under sub-optimal production situations where growth-limiting and reducing factors predominate, while rich farmers are able to control growth factors in such a way that potential yields are within reach. In other words, poor farmers rely heavily on resources (mainly natural) which are cheap and available within the production system, such as the occurrence of natural enemies to protect crops against pests or the availability of nutrients in soil organic matter. Wealthier farmers substitute natural resources by capital inputs, e.g. the supply of nutrients through artificial fertilizers rather than from soil organic matter, while at the same time are able to improve the resource base for farming through such interventions. Reliance of poor farmers on natural resources also includes the dependency on biodiversity in terms of land (e.g. slash-and-burn, common grazing systems) and crop genetics (local crop varieties, which are often low-yielding but stress tolerant), while this reliance tend to decrease with improved management.

Chapter 3 describes the relation between biodiversity and agricultural production systems in more detail and this relationship is assessed quantitatively on the basis of gathered data. The relation between production systems and livelihood is explored in Chapter 4.
Figure 3. Schematic presentation of the linkages at the level of a farm household.
3. General relationship between species diversity and increase of agricultural production

3.1 Introduction

Results of studies that have examined biodiversity across a wide range of agricultural intensification are scarce. There are abundant studies that relate productivity and diversity of ecosystems. From studies on animal and plant communities, a general relationship emerges in which diversity first increases and then decreases as productivity increases (Rosenzweig and Abramsky, 1993). Similar hump-backed, unimodal relationships have been found between disturbance and species diversity and between stress and diversity (for instance Grime, 1979). These patterns seem to hold for a wide range of organisms and environments.

The relationship between species diversity and agriculture is complex. Agriculture has been noted as the major cause of natural habitat loss world-wide. Agriculture competes for land with nature. The accompanying effects on biodiversity will depend strongly on the intensity with which this clearance and/or conversion takes place. Agricultural production on partially and completely converted sites might also affect biodiversity adversely. Next to fragmentation, the abundant use of pesticides and chemical fertilizers is considered an important threat to existing biodiversity. Other relevant impacts of an increase in agricultural production relate to for instance changes in climate, hydrology, and soil erosion. Agriculture can also act as a source for biodiversity increase since new plant and animal genotypes (number of crop species and varieties, types of livestock) are introduced and new environments for invading species are created.

This Chapter describes a first attempt to generally relate species diversity within production systems to an increase in agricultural production. The replacement of nature with crop species generally is the first step in obtaining space for agricultural production. Brown and Brown (1992) have evaluated the effects of various forms of destruction of Brazilian forests on species loss. They presented a general relationship between species diversity response to habitat alteration including agriculture (Figure 4). From this hump-backed, unimodal relationship, the following can be concluded:

1. A slight disturbance generally leads to an increase in diversity as species diversity usually peaks in points of high environmental heterogeneity;
2. Except for field and edge species, biodiversity strongly decreases with increasing disturbance by agriculture;
3. Biodiversity response to disturbance quantitatively differs among groups of species.

Although this figure describes the relationship at the regional scale, it can be used as a basis to present a hypothetical relation between biodiversity and disturbance at the level of production systems i.e. agricultural fields. At field level, changes in biodiversity in response to the existing production system can be quite severe whereas these severe changes might be masked at the regional level. Two strategies exist to support agricultural production:

1. The stage of clearance of nature followed by subsequent partial or complete conversion to agriculture.
2. The stage of intensification after conversion leading to an increase in yield per unit area that is converted.
It is logical to suspect that both stages have different impacts on biodiversity loss. A hypothetical relationship between biodiversity and input increase (that is production increase) is presented in Figure 5. We assume that complete conversion has the largest impact on species diversity and diversity loss will continue when agricultural input and hence crop yield increase at converted sites.

Figure 4. Tropical forest biodiversity versus degree of habitat alteration in more homogeneous or low-productivity, and (dotted lines) more complex or high-productivity systems in Brazil at the regional scale.

Figure 5. Hypothetical relationship between species diversity and input increase of agricultural production systems at the field (production) scale.
3.2 Literature data on the relationship between species diversity and agricultural production

Based on a quick scan of the literature, data on species diversity in combination with the described habitat modification (rate of conversion or production system) are gathered for four groups of organisms: plants, vertebrates, invertebrates and soil nematodes (see Appendices 1-4). Production systems are generally not described explicitly in terms of the input level. We therefore classified the input level for each of these systems on the basis of the estimated production level. The resulting data for the selected groups of organisms are presented in Figure 6.

No loss of species diversity

In analyzing biodiversity in response to disturbance quantitatively, the question is relevant at what point disturbance and subsequent conversion to agriculture will start to result in initial loss of biodiversity. Analysis of ecosystem (tropical forests) responses to logging disturbance have suggested that, globally, a loss of up to about 50% of trees during felling and management operations may not cause permanent damage (cited from Johns, 1992). Although there is a considerable initial impact in terms of reduction of numbers of some species of plants and animals, the level of resilience shown by the community is remarkably high. The observation that low-intensity systems with existing trees do not always affect biodiversity negatively supports this suggestion. Donald (2004) evaluated the biodiversity impacts of some agricultural commodity production systems (cacao, coffee, rice, oil palm and soybean). He found that an approximate equal number of quantitative studies demonstrated no loss of biodiversity following conversion of natural habitat to low-intensity production as demonstrated an adverse effect. This comparison did not take into account the types of taxa involved.

Based on these findings, we assumed that species diversity for all groups of organisms is generally not affected up to 50% conversion and modification of natural area to production systems. Species diversity losses occur at higher rates of conversion. Conversion rates of 50% or higher are quite normal even for production systems where agriculture is performed at partially converted sites such as the cultivation of coffee and cacao in the shade of existing trees. Thus, almost any type of agriculture that is performed actively on partially and fully converted fields will result in a reduction of natural biodiversity at the field scale.

Plant species diversity

As result of the clearance of natural habitats, plant species are the first organisms to respond. Other groups of organisms will follow and might be less responsive to man-made disturbance and logging than vegetation. Plant species diversity at completely cleared sites is the result of the planned diversity (number of crop species), the number of plant species that invade the production sites and the number of species that originates from the existing seed bank. As shown in Appendix I, the total number of plant species on cultivated sites is rather low and varies from 6 to 130 in the cited studies. Irrigated rice in Sri Lanka is considered to sustain a high level of species diversity because it offers much variation over time with alternatively wet, semi-wet and dry conditions. A preliminary study on flora of an irrigated rice field has documented 34 species of plants (cited from Bambaradeniya and Amerasinghe, 2003). A total number of five species was found in sugarcane in Rio Cauto, Cuba, and plant species diversity was 21% compared to the number of species in a non-diverse (not natural) and nearby forest (Ponce-Hernandez, 2004). We estimate that plant species diversity within productions systems at completely converted sites is less than 10% as compared to the diversity in natural systems. Within this range, agricultural management can affect plant species diversity in production systems. Thus, it has been shown that plant species diversity in extensive systems is up to four times higher than in intensive systems, though at absolutely low levels in both systems.

Vertebrate species diversity

The effects of replacing natural forests with oil palms were reviewed by Henson (1994) with respect to amongst others the potential impact on mammal species diversity (Appendix II). Species diversity was less than 50% in disturbed forests and less than 20% in oil palm and rubber plantations. He concluded that ‘oil palm cultivation in general poses little direct environmental impact per se; rather it is during the forest clearing operations where
problems arise'. The main impact of the latter is the loss of biodiversity. This conclusion might also hold for other completely cleared tree plantations such as teak, rubber, coffee and cacao. Bird species diversity (60-100%) apparently is less responsive to partial disturbance but is about as responsive (5-25%) to complete conversion as mammal species diversity. We estimate that vertebrate species diversity within productions systems at completely converted sites is less than 25% as compared to the diversity in natural systems.

Invertebrate species diversity

Lawton et al. (1998) reviewed studies in Cameroon where species diversity of several groups of invertebrates was determined in response to various levels of habitat modification ranging from undisturbed forests to completely converted sites. In comparison to undisturbed tropical forest, average species diversity was 87% in partially converted forests (circa 60% removal of trees) and 51% at completely converted sites (Appendix III). In the Indo-Australian Tropics, Pinus and Acacia plantations retained 47% diversity after complete conversion (Holloway et al., 1992). In irrigated rice in Sri Lanka, mosquito breeding species richness decreased by only 20% from 49 species in the forested phase to 39 by the third year under irrigation (cited from Bambaradeniya and Amerasinghe, 2003). Certain mosquito species are favoured by the change of tropical forests to irrigated rice production systems. This might explain the relatively low biodiversity loss of mosquito species in Sri Lanka as compared to the observed losses of invertebrate species diversity in Cameroon. This explanation points to a general problem in evaluating literature data on biodiversity losses in response to habitat alteration. In many studies, the focus is on specific (groups of) species which are expected to respond to habitat changes in terms of species diversity rather than on random selection of species.

Soil nematodes

Soil is the habitat of plant roots and of a vast array of organisms (bacteria, fungi, protozoa, nematodes, invertebrates) which contribute to the maintenance and productivity of agricultural production systems. Our knowledge of the biodiversity of soils is very poor. Hooper et al. (2000) assessed the evidence for correlation between aboveground and belowground diversity and concluded that a variety of mechanisms could lead to positive, negative, or no relationship depending on the strength and type of interaction among species. Bloem et al. (2006) also concluded that there is no simple quantitative relationship between aboveground and belowground diversity. While species have a functional role in ecosystems, biodiversity per se does not. A great loss in soil biodiversity might occur without a concomitant loss of relevant functions.

We focused on soil nematodes since some data were available relatively easily. As presented in Appendix IV, the percentage of species diversity in completely converted soils ranges from circa 40 to 90%. As reviewed by Hole et al. (2005), there exists no clear difference in nematode abundance between organic and conventional arable and grassland systems. Percentage diversity in temperate agricultural habitats is about 20% of the diversity in temperate forests (cited from Bloemers et al., 1997). Yeates presents an overview of the number of nematode species in widely differing habitats (Table 1). The number of nematode species varied from 1 in reed beds to 80 in a mixed prairie system.
Table 1. **Total number of nematode species identified in different habitats (from Yeates, 1979).**

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Number of species</th>
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<tbody>
<tr>
<td>Mixed prairie</td>
<td>80</td>
</tr>
<tr>
<td>Oak-hornbeam forest (summer)</td>
<td>92</td>
</tr>
<tr>
<td>Beech forest</td>
<td>75</td>
</tr>
<tr>
<td>Oak forest</td>
<td>22</td>
</tr>
<tr>
<td>Mixed fen</td>
<td>13</td>
</tr>
<tr>
<td>Alder-buckthorn carr</td>
<td>20</td>
</tr>
<tr>
<td>Dune sand</td>
<td>50</td>
</tr>
<tr>
<td>Sedge</td>
<td>17</td>
</tr>
<tr>
<td>Buckthorn carr</td>
<td>12</td>
</tr>
<tr>
<td>Reed bed</td>
<td>1</td>
</tr>
</tbody>
</table>

### 3.3 Quantifying the relationship between species diversity and agricultural production

Species diversity data for the four groups of organisms are presented in relation to the estimated input level of the systems in Figure 6. This figure clearly supports the conclusion by e.g. Henson (1994) that conversion of natural habitats to agriculture *per se* has a dramatic impact on species diversity. Up to 80% of species diversity may be lost due to full conversion irrespective of the studied group of organisms. This also holds for sites which were situated at close distance from the original and natural habitats: a coffee plantation without shade trees in Ecuador (75-95% loss of bird species) and oil palm plantations in Malaysia (more than 80% loss of mammal species).

![Species diversity (percentage of natural) for various groups of organisms in relation to conversion and input increase. Data represented by open circles are disregarded from the regression since plant diversity in both cases (Rio Cauto, Cuba) was compared to diversity in a non-diverse and non-natural forest nearby. Data represented by an open triangle is disregarded from the regression since the response of the studied invertebrate group (mosquito species) might not be representative for the response of invertebrates as a whole (irrigated rice, Sri Lanka).](image)

*Figure 6.** Species diversity (percentage of natural) for various groups of organisms in relation to conversion and input increase. Data represented by open circles are disregarded from the regression since plant diversity in both cases (Rio Cauto, Cuba) was compared to diversity in a non-diverse and non-natural forest nearby. Data represented by an open triangle is disregarded from the regression since the response of the studied invertebrate group (mosquito species) might not be representative for the response of invertebrates as a whole (irrigated rice, Sri Lanka).*
On most agricultural land, species diversity generally is less than 20% as compared to the diversity in natural systems. This seems to apply to all production sites after complete conversion irrespective of the level of input. Below this level of 20%, farm management can affect biodiversity. Observations showed that extensive management improved species diversity within the production systems as compared to intensive systems.

**Table 2.** Species diversity (percentage of natural) in relation to nitrogen input levels for production systems at completely converted sites. Data on input level and species diversity have been deduced from Figure 6.

<table>
<thead>
<tr>
<th>Input level</th>
<th>Amount of external nitrogen (kg/ha)</th>
<th>Species diversity (% of natural)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No input</td>
<td>0</td>
<td>15,0</td>
</tr>
<tr>
<td>Low input</td>
<td>0 - 75</td>
<td>12,5</td>
</tr>
<tr>
<td>Medium input</td>
<td>&gt;75 - 150</td>
<td>10,0</td>
</tr>
<tr>
<td>High input</td>
<td>&gt;150</td>
<td>7,5</td>
</tr>
</tbody>
</table>

As information stands, there is no need to distinguish between the various groups of organisms. All studied organisms are about equally responsive to habitat modification and subsequent intensification of agricultural production. Species diversity in various production systems can be represented by one score for the overall response of organisms to an increase of agricultural production. Table 2 summarizes the data for percentage species diversity in relation to the various levels of input as we have deduced from Figure 6. We use the amount of nitrogen input as a proxy for the increase of external input. Nitrogen as a major nutrient is crucial for crop and animal production and often is one of the limiting production factors in low input farming, while most ecosystems’ productivity depends to a large extent on available nitrogen. Once depleted, soils deprived of nitrogen can be replenished by leaving it fallow for a long time, by using leguminous crops, or by using external inputs such as fertilizers and manure. A site is considered to be completely converted when nature has been cleared and converted for more than 80% of the area. This applies to almost all existing production systems. The summarized data have been used to estimate the level of species diversity for the current production systems (see Chapter 5).

In many studies, the focus is on specific (groups of) organisms which are expected to respond to habitat changes in terms of species diversity rather than on random selection of species. The consequence of non-random selection of species for the overall species diversity response to changes in production systems as shown in Figure 6 is as yet unclear.
4. Exploring the link between production systems and livelihood

4.1 Introduction

The first MDG calls for a 50% reduction of people living on less than $1 a day in 2015 relative to 1990, i.e. from 28% to 14% of all people in low and middle income economies. The Goals also call for halving the proportion of people who suffer from hunger between 1990 and 2015. Hunger and poverty are intertwined. Geographically most poor and hungry are found in rural areas despite the fact that these are the areas of food production. While the lack of sufficient income to purchase food is clearly a major factor causing household food insecurity, hunger itself contributes to poverty by lowering labour productivity, reducing resistance to disease and depressing educational achievements. In linking biodiversity and poverty, hunger should be considered in addition to agricultural use of land.

Poverty can be defined as the extent to which households or individuals have sufficient resources or abilities to meet their needs. This definition links to the concept of sustainable livelihoods in which individuals or households rely on a basket of assets (resources or abilities) which determine their activities (or livelihood strategies). The basket comprises human (health skills, education), natural (resources), physical (infrastructure, housing), financial (earnings, savings, etc.) and social (networks, influence) assets. A livelihood is sustainable when it can cope with and recover from stress and shocks, and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base. Poor rural households rely heavier on few assets only, primarily natural resources and social capital, compared to wealthier people with a more comprehensive and balanced basket, which makes the poor rather vulnerable to change and pressures. The high reliance on few assets, the high vulnerability and the unequal wealth distribution link poor households closely to biodiversity.

The farm level is the prime level where physical and socio-economic information meets, and thus where aspects of livelihood (poverty and hunger) as related to production systems can be determined. At the farm level decisions are made with respect to the use of (natural) resources. Farm households rely on a basket of assets (see above), which determine their activities (or livelihood strategies), including the type of agricultural production systems and non-farm income activities. These assets together with the goals of farm households determine how available resources are applied resulting in a certain level of well-being and an impact on biodiversity.

4.2 Indicators for livelihood of farm households

In linking biodiversity and poverty, hunger should also be considered in addition to agricultural use of land. Poverty relates to the monetary income of farm households while hunger relates to the availability of sufficient food of good quality. Thus, relevant indicators to determine the livelihood of farm households should measure the crop yields that have been obtained, the monetary income and the level of self-sufficiency at least.

Total income of a farm household consists of the monetary value of total agricultural production (crops and animals) at the farm and income from off-farm employment. It is beyond the scope of this project to gather data on total income of farm households. If necessary, the income of agricultural produce can be calculated by multiplying the total amount of produce (yield of cash crop, milk, meat) and the price per unit product. This is only possible if information on local prices for the various agricultural products is available.

Self-sufficiency can be characterized by a dietary energy balance (MJ), which is the difference between energy contained in all produce for home consumption and the household energy requirements. Food quality is expressed as the protein content (%) of the subsistence crop. Data on the caloric value and the protein content of agricultural produce can be calculated and is incorporated in the analyses of the current production systems (see Chapter 5).
5. Linking biodiversity, livelihood and current production systems world-wide

5.1 Introduction

The farm household is the pivot to link biodiversity and livelihood. The household is the prime level where physical and socio-economic information meet, and thus where aspects of livelihood (poverty and hunger) as related to farming systems can be determined. In addition, biodiversity is one of the major assets of rural households, which depend on one or more production activities as their major livelihood strategy. These production activities (or production systems) use biodiversity as one of the inputs to realize economic outputs, which contribute to the livelihood of farm households. Analysis of the relationship between inputs used in production systems and the generated economic outputs improves insight in the linkages between biodiversity and livelihood. Although such an analysis appears straightforward, each farm household is unique in its assets and associated production systems used as part of livelihood strategies. It is impossible to analyze at global scale each individual farm household and associated production systems in terms of inputs and outputs. Some kind of classification of farm households and production systems is required to identify populations of farm households with broadly similar ‘basket of assets’ and related constraints and livelihood strategies. Only then major differences among household and production systems can be identified and a global assessment of the linkages between biodiversity and livelihood is possible.

Here, we have used the farming systems classification as developed by Dixon and colleagues as starting point (Dixon et al., 2001). This classification is based on the availability of natural resources (including climate and site-specific factors such as soil, altitude and slope, and farm size, tenure and organization) and the dominant pattern of production systems (including field crops, perennials, aquaculture, hunting and gathering, processing and off-farm activities taking into account the main production technologies used). Based on these criteria eight broad categories of farming systems were distinguished:

- Irrigated farming systems
- Wetland rice based farming systems
- Rainfed farming systems in humid areas of high resource potential
- Rainfed farming systems in steep and highland areas
- Rainfed farming systems in dry or cold low potential areas
- Dualistic (mixed large commercial and small holder) farming systems
- Coastal artisanal fishing
- Urban based farming systems

Dixon et al. (2001) applied the criteria and broad grouping of farming systems to six main regions in the developing world and in this way identified 72 farming systems with an average agricultural population of 40 M, although individual systems range from less than 1 M to several hundred million agricultural inhabitants. In our study we omitted the urban based farming systems since we are interested in rural farming systems only. Based on the farming systems classification, we have identified typical, - which are often the predominant, - production systems (crop and livestock types with associated technology) for each farming system. In general, most farming systems comprise various production systems including off-farm activities as part of their livelihood strategy. However, such an analysis in this stage is not possible. Hence, farming systems that comprehend a range of biophysical and socio-economic characteristics are ‘dissected’ and represented by their most representative production system only. Subsequently, these production systems are described in terms of relevant inputs and outputs (goods and services).

In Appendix V major characteristics of farming systems and inputs and outputs of associated production systems are described. In addition to a description of the production systems in terms of inputs and outputs and consulted references in this Appendix, the results also are presented in detail in tabular format (Appendix VI, separate Excel file). Major characteristics of the farming systems are provided by Dixon and colleagues, such as total area, cultivated area and the agricultural population depending on these systems for their livelihood. The pressure on
farming systems is characterized by the percentage share of cultivated area in total farming systems area, and the
ratio between the agricultural population and the cultivated area. However, for livestock-oriented production
systems, which also comprise an area of land cultivated with crops, both indicators may be misleading since land
used by animals and the agricultural population hardly depend on the cultivated area, but often on extensively grazed
range land with unknown size. Inputs and outputs of crop production systems are quantified on a hectare basis. For
livestock production systems productivity is expressed per tropical livestock unit (TLU), while other inputs are
expressed on a hectare basis as in crop production systems.

During the literature search some inconsistencies between Dixon et al. (2001) and other sources were discovered.
For example, rice-wheat farming systems in South Asia cover a cultivated area of 62 Mha according to Dixon and
colleagues, while the rice-wheat consortium (http://www.rwc.cgiar.org/Rwc_Crop.asp) and Timsina and Connor
(2001) estimate the cultivated area with rice-wheat systems only 13.5 Mha. Here, we only identify such discrepan-
cies in data but are not able to analyze the reasons or their consequences for final conclusions.

5.2 Indicators of production systems

Major indicators of livelihood are income and self-sufficiency in terms of food quantity and quality. Income consists of
the monetary value of agricultural production (crops and animals) at the farm and income from off-farm employment.
Self-sufficiency can be characterized by a dietary energy balance (MJ), which is the difference between energy
contained in all produce for home consumption and the household energy requirements. Similarly, the food quality
component of self-sufficiency can be characterized by the difference in the amount of proteins contained in the crop
for home consumption and the protein requirements of household members. Here, we quantify the economic output
of production systems, which either can be sold (monetary value) or used for self sufficiency purposes. In Appen-
dix V, conversion factors are provided to convert the economic output of food products into energy and proteins.
Economic products refer to the freshly harvested main product. However, these data should be used with care: used
information sources often do not specify well the type of economic product. For example, yields of grain maize can
refer to the cleaned product (grains) but may also refer to the entire (dried) maize cobs. Also differences in water
content of the fresh product may result in differences. Similar comments refer to energy and protein contents of
economic products as given in Appendix V, i.e. the products often are poorly specified. Information sources have
been cited so that users can verify them and assess their merit. Information on productivity of livestock systems in
terms of milk production and live weight gain at global scale is scarce, fragmented and poorly standardized.
Therefore, information on productivity of livestock systems should be used with care and preferably be checked in
dedicated case studies.

Since income is closely related to labour productivity also labour requirements for each typical production systems
have been estimated. Labour requirements depend on the technology and management level of farming systems.
Within the same farming systems different technologies may prevail, such as the transplanting or seeding of rice,
which may result in considerable variation of labour requirements. As much as possible such variation is indicated on
the basis of available literature. Especially, non-mechanized harvesting operations are labour intensive and conse-
quently, associated labour requirements depend on the yield level. Therefore, labour requirements for manual labour
operations have been separated from labour required for other field operations. For mechanized harvesting
operations labour requirements are much less related to the yield level and therefore not further specified. Labour
requirements for livestock systems have not been further specified as economies of scale are evident, for example.
one person may herd 1 or 5 animals with little or no difference in labour input. In addition, more than in crop
production systems, the type of management of livestock is important in specifying related labour requirements. For
example, nomadic systems vs. sedentary systems, grazing systems vs. cut-and-carry systems, type of milking
technology used, etc. Information on the type of management in livestock production systems on global scale is
hardly available.

An important indicator of biodiversity use is the external nitrogen input in production systems. Nitrogen input refers
to the externally applied nitrogen sources, i.e. fertilizer and manure. However, global information on nitrogen use in
production systems is limited. Especially information on used amounts of manure and associated nitrogen content is
scarce. Since nitrogen losses are not considered in this study, a nitrogen balance (nitrogen input \textit{minus} nitrogen output) is only described qualitatively with ‘-’, ‘±’ or ‘+’ indicating most likely depletion, equilibrium or enrichment of soil nitrogen stocks, respectively.

Approaches to estimate water requirements and water balances of production systems enabling to address other services provided by production systems are also indicated in Appendix V. Estimation of these indicators as done for other indicators would result in meaningless and little differentiated ranges of indicator values. More accurate estimation of these indicators requires detailed biophysical data on climate and soils. A similar description is given in Appendix V to estimate the soil organic matter content within the identified production systems. This could be a starting point to estimate the effect of other services of production systems, for example, relating to the contribution of crop residues to the soil organic matter reserves.

Variation in input-output relations within production systems is sometimes very high as these relations depend on biophysical (spatial and temporal aspects) and socio-economic characteristics and applied technologies within the same farming systems zone. Therefore, in Appendix VI frequently ranges of inputs and outputs of production systems are presented. Only a more detailed analysis of farming systems may result in further specification of production systems and smaller uncertainty ranges. For other systems consisting of two or more crops such as the lowland rice farming systems in SE Asia variation in shown inputs and outputs may be a consequence of different cropping seasons (dry and wet season).

Despite the cautionary remarks made, estimated indicators of the production systems improve the characterization of identified farming systems, allow to better differentiate farming systems and help to link biodiversity, livelihood and production systems.

5.3 Results of input-output characterization

In general, production systems in South Asia and East Asia and the Pacific are characterized by high man-cultivated land ratios indicating high population pressure on land resources in this part of the world. The same ratios for production systems in Eastern Europe and Latin America belong to the lowest values in this study suggesting the presence of large scale production systems.

Production systems with commercial crops, i.e. crops not for self-sufficiency, such as coffee, banana and cotton receive highest nitrogen inputs. Mainly in South Asia and East Asia and the Pacific also production systems aimed at the production of bulk crops such as wheat and rice receive large amounts of nitrogen reducing local biodiversity. Only in few production systems (i.e. commercial crops and rice and wheat-based systems in Asia) we expect large scale enrichment of soil nitrogen stocks and associated risks of nitrogen losses to the environment.

In general, production systems in which livestock husbandry dominates realize low milk and live weight gains which are associated by low nitrogen inputs. These results do not necessarily mean that livestock productivity at global scale is low. In many parts of the world, also in developing countries, intensive and highly productive livestock production systems exist, but in the used farming systems classification none of these intensive systems were predominant. In stead, in many parts of the world extensive livestock production systems prevail in marginal areas from an arable cropping point of view. In these areas, livestock production systems are often one of the few available livelihood strategies. Although external nitrogen inputs are low in these areas, still biodiversity can be severely affected by over-grazing (Darkoh, 2003). However, in our analysis livestock production systems scored better with respect to biodiversity (species diversity) than crop production systems because of the low external N input in livestock systems.

Labour requirements associated with the management of production systems can be considerable and total up to 300 labour days (ld) per ha for double rice systems (with two rice crops per year). Since labour requirements are unevenly distributed over the year with labour peaks often at the start and the end of the growing season such labour intensive systems can not be managed by family labour only. This may explain the prevailing small farm
holding sizes in South Asia and East Asia and the Pacific, which often are less than 1 ha. Farmers are not able to manage much more land. In contrast, mechanized production systems in Eastern Europe may reduce labour requirements to less than 5 labour days per ha in wheat production systems.

5.4 Data bases

As much as possible used information sources for quantification of inputs and outputs of typical production systems have been indicated per production system in Appendix VI. Here we briefly discuss the most important databases, their major characteristics and limitations. Some specific remarks made in Section 5.2 concerning the poorly defined terminology is valid across the different discussed databases.

The most extensive database on agricultural production is FAOSTAT (http://faostat.fao.org/). Yield data are country-wise collected and thus do not allow to identify variation within countries. Similar information is provided by the United States Department of Agriculture -USDA (http://www.fas.usda.gov/curnwmt.asp and links) for fewer countries. However, this source often includes forecasting reports and information on why yields and production areas deviate from other years. Also regional differences within countries are sometimes specified in production reports when relevant. Very detailed yield information is available for the US. The USDA through its Production Estimates and Crop Assessment Division (http://www.pecad.fas.usda.gov/cropexplorer/) also provides access to global remote sensing images (SPOT, MODIS), weather images, spatial aggregate production estimates (but unfortunately no yield data maps), production reports, soil moisture status, etc. FAO’s GeoNetwork provides access to various global maps such as the FAO’s soil map, global elevation maps and MODIS and LANDSAT remote sensing images (http://www.fao.org/geonetwork/srv/en/main.home). Other land use maps are available on SAGE website maintained by the Centre for Sustainability and Global Environment (http://www.sage.wisc.edu:16080/iamdata/). Some detailed maps from South and North America are available with crop yields (e.g. coffee and maize) based on the year 2000. Based on various sources mentioned before and others, the most complete regional (sub-national) database on crop yield, area and total production for the entire world became available just recently at the end of the study: http://www.fao.org/landandwater/agll/agromaps/interactive/index.jsp.

Global information on the amount of nitrogen (and P and K) applied per crop is scarce and no systematically collected database exists. The most complete database is a joint publication by FAO, the International Fertilizer Industry Association (IFA), the International Fertilizer Development Centre (IFDC), the Phosphate and Potash Institute (PPI) and the International Potash Institute (IPI) of which the most recent version is available at http://www.fertilizer.org/ifa/statistics/crops/fubc5ed.pdf. Only few countries collect such data and often only for a few crops, therefore estimation procedures for countries are different. In addition to the average nitrogen input, the total crop area and the percentage of the area which is fertilized is provided. Recently, FAO started to publish reports on fertilizer use in individual countries, which also have been used in Appendix VI. These reports give a broader view on fertilizer production and use, which sometimes is specified per region. However, these reports also proof that information on the use of fertilizers is not collected systematically. Instead, sometimes recommended nitrogen inputs per crop are provided. In none of these publications, grassland is taken into account. In few FAO country reports information is given on manure inputs.

No systematically information is available for labour requirements associated with different operations in production systems. For mechanized farming in temperate zones the Dutch KWIN handbook is a detailed source and many data will be valid for mechanized farming operations outside the Netherlands (Dekker, 2002). For manual farming operations in (sub) tropical crops such a source is lacking and information must be derived from publications which often do not provide accurate descriptions of the management operations. This is an important source of variation in found data on labour requirements.
For various regions or production systems more detailed studies and data are available but we do not know to what extent these information sources are consistent with the farming systems approach by Dixon and colleagues. For example, The International Livestock Research Institute (ILRI) did a mapping exercise of poverty in developing countries in relation to livestock systems (http://www.ilri.cgiar.org/InfoServ/Webpub/Fulldocs/Mappoverty/index.htm). In the study 11 global livestock systems are identified and described, though no productivity estimates of these systems are provided. Detailed poverty mapping of livestock systems in East Africa is available. A less defined classification of mixed farming systems exists for Asia identifying 5 production systems (Devendra, 1995) on the basis of which landless livestock production systems have been added in a later stage (Mäki-Hokkonen, 2006). However, none of the livestock classifications provide quantitative information on the performance of the identified systems. The Rice-wheat consortium addresses the intensively managed rice-wheat systems in the Indo-Gangetic plains (http://www.rwc.cgiar.org/Rwc_About.asp) and is the knowledge base concerning this farming system. The rice-wheat farming system is part of the classification made by Dixon and colleagues. The Consultative Group on International Agricultural Research (CGIAR) is the entrance to crop-specific information world-wide (http://www.cgiar.org/). Its International Research Centers often have mandates for different crops which can be linked to the typical productions systems as we have identified for the different farming systems. Some of the Institutes collect and maintain own crop statistics, such as on rice, but data are often presented at national scale only.
6. Evaluation

The relationship between biodiversity and agricultural production is quite complex. For instance, it involves competition for land between agriculture and nature, positive and negative feedbacks of production increase and introduction of new species on production sites. In this study, we quantified the relationship between species diversity and input increase of existing agricultural production systems. Up to 80% of species might be lost due to full conversion of natural areas to production fields irrespective of the studied group of organisms. After full conversion, species diversity is generally less than 20% in production systems compared to the diversity in natural systems. Habitat loss and degradation are considered to be the most important threats to species, affecting 23% of all assessed vertebrates, 57% of assessed invertebrates, and 70% of assessed plants (IUCN, 2004). Full conversion is basic to most of the agricultural production systems that currently exist worldwide. If the rate of biodiversity loss due to an increase in agricultural production must be reduced, we need to avoid the conversion of natural land to agriculture as much as possible.

The evidence is overwhelming that it is essential to accelerate agricultural growth if poverty is to decline rapidly. Agricultural development provides an effective means for both reducing poverty and accelerating economic growth. This is achieved not only by increasing incomes for producers and farm workers but also by creating demand for non-tradable goods - namely services and local products. It is this indirect effect on demand, and the associated employment creation through the off-farm sector of rural areas and market towns that can make a major contribution to the reduction of rural poverty.

According to Dixon et al. (2001), there are five main strategies for farm households to improve their livelihoods three of which pertain to agricultural activities, (1) intensification of existing production systems, (2) diversification of production and processing and 3) expansion of land holding or herd size. These strategies all have different effects on biodiversity. It is clear from our study that expansion of land to increase agricultural production will result in the greatest loss of biodiversity. Thus, the main strategy to increase agricultural production and hence to improve farmers’ livelihood is intensification of existing production systems. Intensification means that comparable or higher yields are attained with the same amount of land that has already been converted, and a higher and improved use of inputs (such as fertilizer, improved varieties, better farm management). Our study shows that species diversity is lower in high-input production systems than in low-input systems, though at absolutely low levels in both systems compared to the diversity in natural systems. Thus, the challenge is to intensify agricultural production on converted lands with a minimum impact on biodiversity as a result of input increase.

Biodiversity response to intensification within production systems will differ from that on the landscape or regional level. The greater the area, the more species can generally be found. Consequently, species diversity at the regional scale is less sensitive to local habitat changes as compared to the field scale, i.e. the site of agricultural production (compare for instance Figures 4 and 5 in this report). Furthermore, processes which determine local biodiversity differ from those which control biodiversity within a region or a landscape. Heterogeneity of the environment (mosaics, patchiness) is an important determinant for biodiversity and increases in heterogeneity lead to increases of biodiversity. Agricultural intensification often leads to homogenization and local loss of biodiversity but may provide room for biodiversity elsewhere. Thus, landscapes and regions are generally more heterogeneous and hence accommodate more species than agricultural fields.

The linkage between biodiversity and production systems obviously applies to the field scale whereas the farm level is the first level where physical and socio-economic information meet and aspects of livelihood of farm households can be determined. The question is important how to upscale the data that are obtained at the field and/or farm scale for global analyses. In the up-scaling issue information from both biophysical and socio-economic disciplines need to be addressed. Figure 7 illustrates some of the up-scaling issues in more detail. The blue boxes represent the socio-economic domain; the green boxes the biophysical domain and the yellow boxes the farm household level and the steps/information required for scaling up household information.
The left side of Figure 7 illustrates how resource use decisions of individual households are influenced by, on the one hand, the policy environment through markets, services and infrastructure and on the other hand the availability of natural resources, which determine the potential performance of production systems. Subsequently, farm household objectives, resource availabilities and constraints determine the mix of production systems (production structure) and allocation of resources among production systems. Since each farm household is unique in terms of objectives, resource availability and constraints also resource allocation decisions among households will be different. A farm household typology may help to identify relatively homogenous classes of farm households which can be used for up-scaling purposes, indicated with the yellow box in the center of Figure 7. Important is to know the size of each farm household class (mainly for economic purposes) and the spatial allocation of farm households (mainly for biophysical purposes). In the right hand side of Figure 7, feedbacks in the system are indicated as a consequence of aggregating socio-economic and sustainability effects. In the socio-economic domain feedback mechanisms relate, for example, to the aggregate supply of agricultural products and their demand. Changing supply-demand relationships affect prevailing product prices and thus the attractiveness of production: Low aggregate supply may result in high farm gate product prices, while a high aggregate supply may result in low farm gate product prices. In the biophysical domain feedbacks relate, for example, to the eroded soil ending up in rivers or water reservoirs which can not be estimated simply by summing up the soil loss of individual fields or farm households in a region. In both domains spatial aggregation issues can be identified, which often also relate to temporal aspects. Changing supply-demand relationships may have consequences for the area to be sown in the following year, while eroded soil may decrease soil fertility in areas where soil is lost and increase in areas where eroded soil is deposited. Depending on the type of process involved dynamics differ and determine whether such temporal effects need to be taken into account in an analysis of the system. In general, upscaling (and downscaling) issues are poorly understood and few data and tools are available to address them properly. Upscaling and downscaling of information is one of the most important challenges in agricultural sciences (Rabbinge and Van Ittersum, 1994).

Given the complexity in the interrelated issues of spatial scaling and dynamics, in this study static production systems have been used as starting point to quantify their relevant inputs and outputs. Based on the farming systems classification of Dixon et al. (2001) we have identified typical or predominant production systems (crops or livestock) for which we have quantified inputs (N and labour) and outputs (yield) as much as possible on the basis of available statistics, literature and models. Nitrogen balances of production systems were qualitatively assessed on the basis of yields and nitrogen inputs. Obviously, one of the major problems encountered is that the farming systems classification as described by Dixon et al. (2001) is not compatible with yield statistics, which are mainly...
collected on national basis, sometimes on sub-national (regional) scale. Although national and regional statistics and case-study data on crop yields are readily available, information on livestock productivity is much less available or collected less systematically hampering comparison among systems. Therefore, we have used frequently simple models to estimate livestock productivity, which preferably should be verified in dedicated case studies. Global data on external nitrogen input in production systems are poorly available but low productivity of production systems is often an indicator of low nitrogen inputs. In addition, quantification of inputs and outputs of production systems often requires implicit assumptions about the spatial and temporal scale of the system. Although we used well-defined units/scales to express inputs and outputs, i.e. inputs and outputs of crop production systems were expressed per hectare and livestock productivity per TLU, for some inputs economies of scale prevail and therefore are hard to quantify, such as for labour requirements in livestock production systems. Finally, variation in input-output relations within production systems is sometimes very high as these depend on biophysical (spatial, temporal) and socio-economic characteristics and applied technologies within the same farming systems zone. Since used farming systems zones cover large areas, obviously there is large variation in such conditions. Such variation can be addressed only by more detailed analysis (downscaling) of farming systems resulting in more specific characterization of farming systems and production systems and in smaller uncertainty ranges of inputs and outputs. Despite these problems in quantifying inputs and outputs of production systems, their estimates are a first step in improving the characterization of identified farming systems, enabling to better differentiate farming systems and helping to link biodiversity, livelihood and production systems.
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Appendix I.

Plant species diversity within various
production systems
<table>
<thead>
<tr>
<th>Location</th>
<th>Organism</th>
<th>Undisturbed</th>
<th>Partial conversion</th>
<th>Complete conversion</th>
<th>Remarks</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td></td>
<td>3000</td>
<td></td>
<td>20-30</td>
<td>1 Intensive Number of species in percentage of estimated total number of fern- and higher plants (3000) in Germany (Becker, 1997)</td>
<td>Bathon, 1997</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td></td>
<td>130</td>
<td>4 Extensive</td>
<td></td>
<td>Biodiversity is affected positively by temporal variation within the agro-ecosystem (aquatic, semi-aquatic and terrestrial dry)</td>
<td>Bambaradeniya et al., 1998</td>
</tr>
<tr>
<td>Rio Cauto, Cuba</td>
<td></td>
<td>13-34</td>
<td>6-12</td>
<td>38 Grassland</td>
<td>Number of species in percentage of the total number of species (13-34) in nearby non-diverse forests</td>
<td>Ponce-Hernandez, 2004</td>
</tr>
<tr>
<td>Various</td>
<td></td>
<td></td>
<td></td>
<td>5 Sugarcane</td>
<td>Number of species in percentage of the total number of species (13-34) in nearby non-diverse forests</td>
<td>Cited from Hole et al., 2005</td>
</tr>
</tbody>
</table>

Density of noncrop flora in conventional cereal fields was around a third of that in organic fields (Hald, 1999)
<table>
<thead>
<tr>
<th>Location</th>
<th>Organism</th>
<th>Undisturbed</th>
<th>Partial conversion</th>
<th>Complete conversion</th>
<th>Remarks</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Various</td>
<td>Cereals</td>
<td></td>
<td></td>
<td></td>
<td>Mean number of weed species in both margins and cereal fields was more than twice as high under organic management (Frieben and Kopke, 1995)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grasslands</td>
<td></td>
<td></td>
<td></td>
<td>Differences in number of plant species between organic and conventional grassland systems was less pronounced as compared to arable systems</td>
<td></td>
</tr>
</tbody>
</table>
Appendix II.

Vertebrate species diversity within various production systems
<table>
<thead>
<tr>
<th>Location</th>
<th>Organism</th>
<th>Number of species</th>
<th>Number of species</th>
<th>Percentage</th>
<th>Production system</th>
<th>Number of species</th>
<th>Percentage</th>
<th>Production system</th>
<th>Remarks</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameroon</td>
<td>Birds</td>
<td>45</td>
<td>28</td>
<td>62</td>
<td>60% removal of old trees, understorey clearance, planted with <em>Terminalia ivorensis</em> (Black afara)</td>
<td>4-8</td>
<td>13</td>
<td></td>
<td>Planted with <em>T. ivorensis</em> or weeded resulting in ground cover of dense <em>Chromalaena</em> (siam weed?)</td>
<td>Lawton <em>et al.</em>, 1998</td>
</tr>
<tr>
<td>Malaysia/Sabah</td>
<td>Birds</td>
<td>193-223</td>
<td>188-213</td>
<td>97</td>
<td>Forest logging</td>
<td>5-25</td>
<td></td>
<td></td>
<td>Coffee plantation after complete conversion, at 100m distance from edge of primary forest</td>
<td>Johns, 1992</td>
</tr>
<tr>
<td>Ecuador/Amazonia</td>
<td>Birds</td>
<td>5-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Canaday, 1997</td>
</tr>
<tr>
<td>Various</td>
<td>Birds</td>
<td></td>
<td></td>
<td></td>
<td>Organic versus conventional</td>
<td></td>
<td></td>
<td></td>
<td>Number of species up to two times greater in organic fields compared to conventional fields</td>
<td>Cited from Hole <em>et al.</em>, 2005</td>
</tr>
<tr>
<td>Various</td>
<td>Bats</td>
<td></td>
<td></td>
<td></td>
<td>Organic versus conventional</td>
<td></td>
<td></td>
<td></td>
<td>Number of species between 1.5 and 2 times greater in organic</td>
<td>Cited from Hole <em>et al.</em>, 2005</td>
</tr>
<tr>
<td>Location</td>
<td>Organism</td>
<td>Undisturbed</td>
<td>Partial conversion</td>
<td>Complete conversion</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Number of species</td>
<td>Number of species</td>
<td>Percentage</td>
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<td></td>
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<td>75</td>
<td>31</td>
<td>41</td>
<td></td>
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<td></td>
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<tr>
<td>Malaysia</td>
<td>Mammals</td>
<td>Disturbed forest</td>
<td>10</td>
<td>13</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Secondary forest</td>
<td>Numbers of species of mammals found in association with various vegetation types</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>12</td>
<td>16</td>
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<td>4</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Lalang (Parachela oxygastroides)</td>
<td>Cited from Henson, 1994</td>
<td></td>
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Appendix III.

Invertebrate species diversity within various production systems
<table>
<thead>
<tr>
<th>Location</th>
<th>Organism</th>
<th>Undisturbed</th>
<th>Partial conversion</th>
<th>Complete conversion</th>
<th>Remarks</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameroon</td>
<td>Butterflies</td>
<td>30-50</td>
<td>28-29</td>
<td>71</td>
<td>60% removal of old trees, understorey clearance, planted with Terminalia ivorensis (Black afara)</td>
<td>Planted with T. ivorensis or weeded resulting in ground cover of dense Chromalaena (siam weed?)</td>
</tr>
<tr>
<td></td>
<td>Flying beetles</td>
<td>22-112</td>
<td>35-40</td>
<td>56</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Canopy beetles</td>
<td>75</td>
<td>50-90</td>
<td>93</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Canopy ants</td>
<td>28-38</td>
<td>28-40</td>
<td></td>
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<tr>
<td></td>
<td>Leaf-litter ants</td>
<td>55-73</td>
<td>71-79</td>
<td>118</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Termites</td>
<td>45-52</td>
<td>52</td>
<td>107</td>
<td></td>
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<tr>
<td>Saba</td>
<td>Litter invertebrates</td>
<td></td>
<td></td>
<td>Selectively logged forest</td>
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<td>Abundance</td>
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<td>Indo-Australian Tropics</td>
<td>Macrolepidoptera</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Burghouts et al., 1992</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>Mosquito's</td>
<td>49</td>
<td></td>
<td>Forested phase</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Various (butterflies,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>spiders, beetles, other arthropods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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</table>
Appendix IV.

Soil nematode species diversity within various production systems
<table>
<thead>
<tr>
<th>Location</th>
<th>Organism</th>
<th>Number of species</th>
<th>Percentage</th>
<th>Production system</th>
<th>Number of species</th>
<th>Percentage</th>
<th>Production system</th>
<th>Remarks</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameroon</td>
<td></td>
<td>59-69</td>
<td>97</td>
<td>Undisturbed</td>
<td>60% removal of old trees, understorey clearance, planted with Terminalia ivorensis (Black afara)</td>
<td>52-65</td>
<td>90</td>
<td>Complete conversion</td>
<td>Planted with T. ivorensis or weeded resulting in ground cover of dense Chromalaena (siam weed?)</td>
</tr>
<tr>
<td>Cameroon</td>
<td></td>
<td>29</td>
<td>43</td>
<td>Slash-and-burn</td>
<td></td>
<td>34</td>
<td>48</td>
<td>Various</td>
<td>Cited from Bloemers et al., 1997</td>
</tr>
<tr>
<td>Various</td>
<td></td>
<td>&lt;200</td>
<td></td>
<td></td>
<td>&lt;40</td>
<td>&lt;20</td>
<td>Various</td>
<td>Temperate agricultural habitats</td>
<td>Cited from Bloemers et al., 1997</td>
</tr>
<tr>
<td>Various</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Various</td>
<td>No clear difference in nematode abundance between organic and conventional arable and grassland systems</td>
</tr>
</tbody>
</table>
Appendix V.

Description of farming systems and associated production systems

1. Sub-Saharan Africa

1.1 Irrigated

The irrigated farming system consist of areas with large scale irrigation schemes covering a total of 35 Mha of which 2 Mha is irrigated. Typical crop is flooded rice which supports an agricultural population of 35 M.

1.1.1 Rice

Prevalence of poverty: limited
Average yield (t ha-1): 2.3 in East Africa, 0.99 in Central Africa and 1.33 in West Africa
Nitrogen input (kg ha-1): 0-15 (Mali +Sudan)
Labour input: 84-143 ld ha-1 depending on method of sowing and land preparation and 11-45 ld t-1 for harvesting depending on the method of operation.
Cultivated/total land ratio (%): 5.7
Agric. pop./cultivated land ratio: 17.5
N-balance: -

Sources:

1.2 Tree crop

Tree crop farming systems are often mixed systems, in which industrial tree crops in the first five years of production are intercropped with some food crops used for subsistence (maize, cassava, plantain). These systems cover about 73 Mha of which 10 Mha is cultivated and supporting an agricultural population of about 25 M. Cocoa is a typical crop for these systems, which is planted after burning forests. Since hardly any fertilizers are applied, yields decrease after 20 years, though production is possible up to 50 years.

1.2.1 Cocoa

Prevalence of poverty: limited-moderate
Average yield (t ha-1): 0.2- 0.7; 0.3 (Ghana)
Nitrogen input (kg ha-1): < 5 (Ivory Coats, Gambia, Ghana)
Labour input:
Cultivated/total land ratio (%): 13.7
Agric. pop./cultivated land ratio: 2.5
N-balance: -
1.3 Forest-based

Forest-based systems are extensive and cover about 263 Mha. These systems have a high natural capital, of which a large percentage is in the vegetation (Brand and Pfund, 1998; Kanmegne, 2004). Only 6 Mha is cropped to feed a population of 28 M. Slash and burn agriculture prevails with cassava as a typical subsistence crop of this system. Yields generally decline after some years of production from a maximum of 10 t ha⁻¹.

1.3.1 Cassava

Prevalence of poverty: extensive
Average yield (t ha⁻¹): < 10
Nitrogen input (kg ha⁻¹): <5 (Zaire, Congo)
Labour input: 25 ld ha⁻¹ for field operations and 1.5-2 ld t⁻¹ (manual harvesting)
Cultivated/total land ratio (%): 2.1
Agric. pop./cultivated land ratio: 4.6
N-balance: -

Sources:

1.4 Rice-tree

These systems are typical for Madagascar and account 31 Mha with a cultivated area of 2.2 Mha. These systems consist of a mix of perennial and annual crops of which banana and rice are typical representatives. An agricultural population of about 7 M is supported by these systems.

1.4.1 Rice-banana

Prevalence of poverty: moderate
Average rice yield (t ha⁻¹): 2 - 3 (rice); banana ??
Nitrogen input (kg ha⁻¹): <5 (rice and banana)
Labour input: for rice, 84-143 days depending on method of sowing and land preparation and 11-45 days t⁻¹ for harvesting depending on method of operation.
Cultivated/total land ratio (%): 7.1
Agric. pop./cultivated land ratio: 3.2
N-balance: -

Sources:
1.5 Highland perennial

These systems are found in Eastern Africa and are based on perennial crops of which banana and enset (in Ethiopia) are the predominant representatives. These systems cover 32 Mha of which 6 Mha is cultivated and supply an agricultural population of 30 M.

1.5.1 Banana/Enset

Prevalence of poverty: extensive
Average yield (t ha⁻¹): 3.5 (enset)
Nitrogen input (kg ha⁻¹): 0 - 150 (lower limit, Stoorvogel and Smaling, 1990; upper limit, Amare Haileslassie et al., 2005)
Labour input:
Cultivated/total land ratio (%): 18.8
Agric. pop./cultivated land ratio: 5
N-balance: -

Sources:

1.6 Highland temperate mixed

These farming systems cover 44 Mha of which 6 Mha is cultivated. The agricultural population of these systems account 28 M mainly located in the altitudes between 1800 and 3000 m. Rainfed cereal production is predominating these farming systems with wheat as typical crop.

1.6.1 Wheat

Prevalence of poverty: moderate-extensive
Average yield (t ha⁻¹): 0.5 - 1.5
Nitrogen input (kg ha⁻¹): <5 (Ethiopia)
Labour input:
Cultivated/total land ratio (%): 13.6
Agric. pop./cultivated land ratio: 4.7
N-balance: -
1.7 Root crop

These farming systems account for 282 Mha of which 28 Mha is cultivated. The predominant crops in these farming systems are root crops of which cassava is a typical crop. These systems support an agricultural population of 44 M.

1.7.1 Cassava

Prevalence of poverty: limited-moderate
Average yield (t ha-1): 1.8 - 2.0
Nitrogen input (kg ha-1): <10
Labour input: 25 ld ha-1 for field operations and 1.5-2 ld t-1 (manual harvesting)
Cultivated/total land ratio (%): 9.9
Agric. pop./cultivated land ratio: 1.6
N-balance: -

Sources:
http://www.iita.org/crop/cassava.htm


1.8 Cereal-root crop mixed

These farming systems are predominantly in the dry subhumid zone accounting for 312 Mha of which 31 Mha is cultivated and supporting an agricultural population of 59 M. An important source of vulnerability is drought and therefore, millet is a typical and drought resistant crop for these farming systems.

1.8.1 Millet

Prevalence of poverty: limited
Average yield (t ha-1): 0.5 - 1.5
Nitrogen input (kg ha-1): <10 (Mali)
Labour input: 70 to 120 (ld ha-1) depending on mechanization level and bird scaring + 3-26 ld t-1 for harvesting operation depending on method of operation.
Cultivated/total land ratio (%): 9.9
Agric. pop./cultivated land ratio: 1.9
N-balance: -

Sources:
1.9 Maize mixed

Most important farming system in East and Southern Africa covering 246 Mha of which 32 Mha cultivated and providing food and income to and agricultural population of 60 M. The main staple crop is maize.

1.9.1 Maize

Prevalence of poverty: moderate
Average yield (t ha⁻¹): 1.0 - 2.5
Nitrogen input (kg ha⁻¹): 0-75 (upper limit Zambia)
Labour input (ld ha⁻¹): 30 to 50 depending on mechanization level + 3-14 ld t⁻¹ for harvesting operations.
Cultivated/total land ratio (%): 13.0
Agric. pop./cultivated land ratio: 1.9
N-balance: -

Sources:
http://www.iita.org/crop/maize.htm

1.10 Large commercial and smallholder

These farming systems consist of two distinct types, namely scattered smallholders and large-scale commercialized in the Southern Africa. These systems cover 123 Mha of which is 12 Mha cultivated and supplying an agricultural population of 17 M. Sorghum predominates in the west, while maize in the north and east.

1.10.1 Maize/sorghum

Prevalence of poverty: moderate
Average yield (t ha⁻¹): maize 2.8 - 6.0; sorghum 2.2 - 3.9 (upper range refers to irrigated)
Nitrogen input (kg ha⁻¹): 0-55 (maize); 0-30 (sorghum, estimate)
Labour input: 5-10 ld/ha (mechanized) for each crops.
Cultivated/total land ratio (%): 9.7
Agric. pop./cultivated land ratio: 1.4
N-balance: -

Sources:
1.11 Agro-pastoral: millet/sorghum

These farming systems occupy 198 Mha of which 22 Mha is used for crops and supplies an agricultural population of 33 M. Crops and livestock of similar importance. An important source of vulnerability is drought and therefore, millet is a typical and drought resistant crop for these farming systems. Production is somewhat lower than in cereal-root mixed crop farming systems (section 1.8).

1.11.1 Millet

Prevalence of poverty: extensive
Average yield (t ha-1): 0.4 - 1.2
Nitrogen input (kg ha-1): < 10
Labour input: 70 to 120 ld ha-1 depending on mechanization level and bird scaring + 3-26 ld t-1 for harvesting operations.
Cultivated/total land ratio (%): 11.1
Agric. pop./cultivated land ratio: 1.5
N-balance: -

Sources:

1.12 Pastoral

These farming systems are located mainly in the semi-arid Sahelian zone covering 346 Mha and supplying an agricultural population of 27 Mha. The main source of activity is nomadic herding of cattle. Quantified outputs refer to the secondary production, namely the amount of milk and live weight gain (including off-spring) per tropical livestock unit (TLU).

1.12.1 Cattle

Prevalence of poverty: extensive
Average yield: <0.2 (t milk TLU-1); 0.025-0.05 t live weight TLU-1)
Nitrogen input (kg ha-1): 0
Labour input:
Cultivated/total land ratio (%): < 100
Agric. pop./cultivated land ratio: ?
N-balance: -

Sources:
1.13 Sparse (arid)
This farming systems cover the largest part in Sub-Saharan Africa with 429 Mha but is of limited significance from an agricultural point of view. In addition, the area is sparsely populated with only 6 M. Nomadic pastoralists mainly graze cattle within the Wadis and therefore the actual cultivated area is very small but unknown.

1.13.1 Cattle
Prevalence of poverty: extensive
Average yield: <0.2 (t milk TLU-1); 0.025-0.05 t live weight TLU-1
Nitrogen input (kg ha-1): 0
Labour input:
Cultivated/total land ratio (%): < 1
Agric. pop./cultivated land ratio: ?
N-balance: -

Sources:

1.14 Coastal artisanal fishing
These farming systems are located along the coasts of East and West Africa and depend on sea fishing supplemented with crop production often in an agro-forestry type systems with root crops combined with perennials. These systems cover 38 Mha and supply an agricultural population of 13 M.

1.14.1 Cassava and oranges
Prevalence of poverty: moderate
Average yield (t ha-1): 1.8 -20 (cassava)
Nitrogen input (kg ha-1): 0
Labour input: 25 ld ha-1 for field operations and 1.5-2 ld t-1 (manual harvesting)
Cultivated/total land ratio (%): ??
Agric. pop./cultivated land ratio: ??
N-balance: -

Sources:
http://www.iita.org/crop/cassava.htm

2. Middle East and North Africa

2.1 Irrigated
Large scale irrigation schemes cover about 8.1 Mln ha and supply an agricultural population of 17 M. The high population density allows to grow labour intensive crops such as vegetables and fruits, though area-wise irrigated wheat covers by far the largest area. Small scale irrigation schemes are not included in these numbers as they are dispersed over the Middle east and north Africa and often only are of local significance.

2.1.1 Wheat
Prevalence of poverty: moderate
Average yield (t ha-1): 2.5-5; 3-3.9 (Syria)
Nitrogen input (kg ha$^{-1}$): 100-150
Labour input: 5-10 ld/ha (mechanized)
Cultivated/total land ratio (%): ??
Agric. pop./cultivated land ratio: 2.1
N-balance: ±

Source:
FAOSTAT data, 2006

2.2 Highland mixed

The highland mixed farming system is the most important system in the region in terms of population, i.e. it supplies an agricultural population of 27 M. However, the farming system covers only 75 Mha of which 22 Mha is cultivated. Rainfed cereals are typical for a large part of this farming system of which wheat is a typical representative.

2.2.1 Wheat

Prevalence of poverty: extensive
Average yield (t ha$^{-1}$): 0.7-1.7
Nitrogen input (kg ha$^{-1}$): 0-15
Labour input:
Cultivated/total land ratio (%): 29.3
Agric. pop./cultivated land ratio: 1.2
N-balance: -

Source:

2.3 Rainfed mixed

These farming systems occupy only 22 Mha, of which 14 Mha is cultivated, and supply an agricultural population of 22 M. Although these farming systems by definition are rainfed, increasingly they benefit from irrigation water supply allowing to grow other crops than wheat.

2.3.1 Wheat

Prevalence of poverty: moderate
Average yield (t ha$^{-1}$): 1.5-2.5; 0.7-1.7 (Syria);
Nitrogen input (kg ha$^{-1}$): 0-15
Labour input:
Cultivated/total land ratio (%): 63.6
Agric. pop./cultivated land ratio: 1.6
N-balance: -

Sources:

2.4 Dryland mixed

These farming systems are similar to the preceding rainfed mixed systems but are located in drier areas (annual rainfall up to 300 mm) constraining their production potentials. The systems supply an agricultural population of
13 M and encompass 22 Mha of which is cultivated 17 Mha. Typical crop of these systems is wheat. In Algeria about 50% of the cereal farmers practice fallow, while about 25% use N and P fertilizers, and 15% use herbicides.

2.4.1 Wheat
Prevalence of poverty: extensive
Average yield (t ha⁻¹): 1-2; 0.7-1.7 (Syria); 1-1.2 (Algeria)
Nitrogen input (kg ha⁻¹): 0-15
Labour input:
Cultivated/total land ratio (%): 77
Agric. pop./cultivated land ratio: 0.8
N-balance: -

Sources:

2.5 Pastoral
These pastoral systems cover an area of about 250 Mha. Scattered irrigated crop land (2.9 Mha) allow to boost the agricultural population supplied by these pastoral systems to about 8 M. The predominant feature of these systems are sheep.

2.5.1 Sheep
Prevalence of poverty: extensive
Average yield: 0.05-0.07 (t meat TLU⁻¹)
Nitrogen input (kg ha⁻¹): 0
Labour input:
Cultivated/total land ratio (%): 1.1
Agric. pop./cultivated land ratio: 2.8
N-balance: -

Sources

2.6 Sparse (arid)
These are the largest farming systems in terms of area in this region and cover about 660 Mha, but they supply an agricultural population of only 4 M. Pastoralists with cattle and other livestock are predominant in these farming systems, which also contain some 1.2 Mha of irrigated crop land.

2.6.1 Cattle
Prevalence of poverty: limited
Average yield: <0.2 (t milk TLU⁻¹); 0.025-0.05 t live weight TLU⁻¹
Nitrogen input (kg ha⁻¹): 0
Labour input:
Cultivated/total land ratio (%): <1%
Agric. pop./cultivated land ratio: 3.3
N-balance: -
3. Eastern Europe and Central Asia

3.1 Irrigated

These farming systems are scattered throughout the southern central and eastern area of the region and cover about 28 Mha, of which 10 Mha is cultivated supplying an agricultural population of 4 M. The majority of the cultivated area (8.6 Mha) is irrigated and used for the production of cotton.

3.1.1 Cotton

Prevalence of poverty: moderate-extensive
Average yield (t ha⁻¹): 2.2 (Uzbekistan)
Nitrogen input (kg ha⁻¹): 240-275 (Uzbekistan, including organic manure N)
Labour input:
Cultivated/total land ratio (%): 35.7
Agric. pop./cultivated land ratio: 0.4
N-balance: +

Sources:
FAO, 2003. Fertilizer use by crop in Uzbekistan

3.2 Mixed

3.2.1 Wheat

Widespread farming system in central Europe covering an area of 85 Mha of which 35 Mha is cultivated with crops. These farming systems provide a livelihood to an agricultural population of about 16 M. The main crop is wheat.

Prevalence of poverty: low-moderate
Average yield (t ha⁻¹): 2-4 (Poland); 4-5 (Czech); 3-4 (Slovakia, Slovenia); 1.5-3 (Rumania)
Nitrogen input (kg ha⁻¹): 30-90 (Poland)
Labour input:
Cultivated/total land ratio (%): 41.1
Agric. pop./cultivated land ratio: 0.5
N-balance: -

Sources:
FAO, 2003. Fertilizer use by crop in Poland

3.3 Forest-based livestock

3.3.1 Wheat

These farming systems are located in the northwest of the region and cover 72 Mha of which 25 Mha is cultivated and supplying livelihood to an agricultural population of about 5 M. Large scale production is predominant with wheat as a typical crop.
Prevalence of poverty: moderate
Average yield (t ha⁻¹): 2-3.3 (Estonia lower limit, Lithuania upper limit)
Nitrogen input (kg ha⁻¹): 0
Labour input:
Cultivated/total land ratio (%): 34.7
Agric. pop./cultivated land ratio: 0.2
N-balance: -
Sources:
USDA, 2004 (visited May 16, 2006)

### 3.4 Horticulture mixed

These systems cover 79 Mha of which is cultivated 24 Mha. These systems are typical for the Southern Balkans, Northern Turkey and the Caucasus and provide livelihood to an agricultural population of 10 M. Farm size is smaller and more diversified than previous farming systems in this region, still wheat is a major component of these systems.

#### 3.4.1 Wheat

Prevalence of poverty: moderate-extensive
Average yield (t ha⁻¹): 3 (Albania, Bulgaria); 2-3 (Rumania, Macedonia); 3-4.5 (Croatia); 2.7 (Bosnia); 2.5-3.5 (Montenegro)
Nitrogen input (kg ha⁻¹):
Labour input:
Cultivated/total land ratio (%): 30.3
Agric. pop./cultivated land ratio: 0.4
N-balance: -
Sources:
USDA, 2004 (visited May 16, 2006)

### 3.5 Large-scale cereal-vegetable

These systems cover 100 Mha in Ukraine, southwestern Russian Federation and Moldova. The agricultural population is about 15 M cultivating some 38 Mha. Despite the process of land privatization farms are still large and wheat is a typical crop.

#### 3.5.1 Wheat

Prevalence of poverty: moderate-extensive
Average yield (t ha⁻¹): 1.5-2 ((Russian Federation); 2-3 (Ukraine)
Nitrogen input (kg ha⁻¹):
Labour input:
Cultivated/total land ratio (%): 38.0
Agric. pop./cultivated land ratio: 0.4
N-balance: -
Sources:
USDA, 2004 (visited May 16, 2006)
3.6 Small-scale cereal-livestock

In contrast with the previous farming systems, these farming systems are much smaller and located in less favourable areas of Turkey. The total area covered by these systems is 35 Mha of which 8 Mha is cultivated and supplying an agricultural population of 4 M.

3.6.1 Wheat

Prevalence of poverty: moderate
Average yield (t ha\(^{-1}\)): 
Nitrogen input (kg ha\(^{-1}\)): 
Labour input: 
Cultivated/total land ratio (%): 22.8 
Agric. pop./cultivated land ratio: 0.5 
N-balance: -

3.7 Extensive cereal-livestock

These systems cover an area of 425 Mha of which 107 Mha is cultivated and supplying an agricultural population of only 14 M. These systems are located in the steppe, which traditionally were mainly used by transhumant herders but recently have been converted to cropping areas in which wheat plays a central role.

3.7.1 Wheat

Prevalence of poverty: moderate-extensive
Average yield (t ha\(^{-1}\)): 1 (Kazakhstan) 
Nitrogen input (kg ha\(^{-1}\)): 
Labour input: 
Cultivated/total land ratio (%): 25.1 
Agric. pop./cultivated land ratio: 0.1 
N-balance: -

Sources:

3.8 Pastoral

These systems are typical for the Southeastern Central Asia and cover about 82 Mha and supplying an agricultural population of 9 M. Herd management is based on spring and autumn grazing of communal pastures close to villages, summer grazing on distant and overgrazed mountain pastures, while in winter stall feeding predominates. In the valleys some 14 Mha are cultivated with cereals

3.8.1 Sheep

Prevalence of poverty: 
Average yield (t ha\(^{-1}\)): 0.08-0.13 t liveweight TLU\(^{-1}\) 
Nitrogen input (kg ha\(^{-1}\)): 
Labour input: 
Cultivated/total land ratio (%): 17.1 
Agric. pop./cultivated land ratio: 0.6 
N-balance: -
3.9  
Sparse (cold)

These farming systems cover the largest area in the region with about 1260 Mha of which only 23 Mha is cultivated. Also the agricultural population in relation to the total area is small with only 2 M. As a consequence of unfavourable climate conditions, crop choice is limited. Rye is one few crops that can be grown under prevailing conditions.

3.9.1  
Rye

Prevalence of poverty: extensive  
Average yield (t ha⁻¹): 1.4-1.5 (Russia)  
Nitrogen input (kg ha⁻¹):  
Labour input:  
Cultivated/total land ratio (%): 1.8  
Agric. pop./cultivated land ratio: 0.1  
N-balance: -

Sources:  

3.10  
Sparse (arid)

These systems cover 143 Mha in the southern part of Turkmenistan and Uzbekistan as well as a part of Kazakhstan. About 8 Mha is used for extensive cereal production (once in the two years fallow). An agricultural population of about 7 M depends on these systems.

3.10.1  
Barley

Prevalence of poverty:  
Average yield (t ha⁻¹): 1 (Kazakhstan)  
Nitrogen input (kg ha⁻¹):  
Labour input:  
Cultivated/total land ratio (%): 5.6  
Agric. pop./cultivated land ratio: 0.9  
N-balance: -

Sources:  

4.  
South Asia

4.1  
Rice

These systems are characterized by a high pressure on available land, 22 Mha out of the available 36 Mha is cultivated. In addition, these systems supply an agricultural population of about 263 M. By definition rice is the predominant crop of these systems and often grown twice or more per year under flooded conditions. Poverty is extensive and severe.
4.1.1 Rice

Prevalence of poverty: extensive
Average yield (t ha⁻¹): 4.3-7.1 (India)
Nitrogen input (kg ha⁻¹): 45-120 per crop
Labour input per crop: 80-120 ld ha⁻¹ depending on management and 5 ld t⁻¹ for harvesting operation
Cultivated/total land ratio (%): 61.1
Agric. pop./cultivated land ratio: 12.0
N-balance: ±/+ 

Sources:

4.2 Coastal artisanal fishing

These systems represent a relatively small area with 5 Mha of which 2.5 Mha is cultivated. Similar to the previous farming systems, population density is high as these systems supply an agricultural population of 18 M. In addition to fishing and off-farm activities, rice is a typical production systems and mainly used for subsistence purposes.

4.2.1 Rice

Prevalence of poverty: moderate-extensive
Average yield (t ha⁻¹): 3-4
Nitrogen input (kg ha⁻¹): 40-85
Labour input per crop: 80-120 ld ha⁻¹ depending on management and 5 ld t⁻¹ for harvesting operation
Cultivated/total land ratio (%): 50.0
Agric. pop./cultivated land ratio: 7.2
N-balance: ± 

Sources:
FAO, 2005. fertilizer use by crop in India.

4.3 Rice-wheat

These farming systems are extremely important for feeding the urban population in South Asia and encompass 97 Mha of which 62 Mha is cultivated. About 48 Mha of the cultivated area is irrigated. These systems supply an agricultural population of 254 Mha. Typical is the rice-wheat system in which rice and wheat are harvested in the same year, though wheat is sown in the preceding year.

4.3.1 Rice-wheat

Prevalence of poverty: moderate-extensive
Average yield (t ha⁻¹): rice: 2.4- 3.0 (Nepal); 2.9-5.8 (India); 2.8- 4.3 (Bangladesh), 2.9-3.7 (Pakistan); wheat: 1.6-2.7 (Nepal); 2.6-2.8 (India), 2.2-3.1 (Bangladesh), 2.0-2.1 (Pakistan)
Nitrogen input (kg ha⁻¹): rice and wheat, each 50 (Nepal), 70 (Bangladesh), 50-150 (India)
Labour input: rice: 20-120 ld ha⁻¹ and 5 ld t⁻¹ for harvesting; wheat: 20-135 ld ha⁻¹ and 6 ld t⁻¹ depending on mechanization level.
4.4 Highland mixed

These systems cover 65 Mha of which 19 Mha is cultivated and supplying an agricultural population of 53 M. Major crops are cereals mostly grown under rainfed conditions although this system also includes 2.6 Mha of irrigated land.

4.4.1 Wheat

Prevalence of poverty: moderate-extensive
Average yield (t ha$^{-1}$): 1.5-2.0 (Nepal); 2.0-2.5 (India), 1.7-2.2 (Bangladesh), 1.5-2.0 (Pakistan)
Nitrogen input (kg ha$^{-1}$): 25-50
Labour input: wheat: 135 ld ha$^{-1}$ and 6 ld t$^{-1}$ for harvesting
Cultivated/total land ratio (%): 29.2
Agric. pop./cultivated land ratio: 2.8
N-balance: -

Sources:
FAO, 2005. fertilizer use by crop in India.

4.5 Rainfed mixed

These systems cover the largest are in South Asia, 147 Mha of which 87 Mha is cultivated (including 14 Mha irrigated). They provide livelihood to an agricultural population of 227 M. Rice is one of the typical production systems.

4.5.1 Rice

Prevalence of poverty: extensive
Average yield (t ha$^{-1}$):
Nitrogen input (kg ha$^{-1}$): 40-50
Labour input:
Cultivated/total land ratio (%): 59.1
Agric. pop./cultivated land ratio: 2.6
N-balance: - to ±

Sources:
FAO, 2005. fertilizer use by crop in India.
4.6 **Dry rainfed**

In contrast to what the naming suggests, irrigation is an important component of these systems which are located in a drier zone than the preceding farming systems. About 3.5 Mha (36%) out of the 10 Mha cultivated land is irrigated. Total systems area is 18 Mha and providing a livelihood to an agricultural population of 30 M.

4.6.1 **Rice**

Prevalence of poverty: moderate
Average yield (t ha⁻¹): 40-50
Nitrogen input (kg ha⁻¹): 40-50
Labour input:
Cultivated/total land ratio (%): 55.5
Agric. pop./cultivated land ratio: 3.0
N-balance: -

Sources:
FAO, 2005. Fertilizer use by crop in India.

4.7 **Pastoral**

These systems occupy 55 Mha mostly used for transhumant herders keeping mixed livestock. About 6 Mln ha is cultivated of which 4.6 Mha is irrigated. However, the typical production system is cattle supplying an agricultural population of 21 M.

4.7.1 **Cattle**

Prevalence of poverty: moderate-extensive
Average yield (t ha⁻¹): <0.3 t milk/TLU; 0.075-0.1 t liveweight/TLU
Nitrogen input (kg ha⁻¹): 0
Labour input:
Cultivated/total land ratio (%): 10.9
Agric. pop./cultivated land ratio: 4.6
N-balance: -

Sources:

4.8 **Sparse (arid)**

These systems cover 57 Mha of which 1.7 Mha is irrigated and used for arable farming. However, pastoralists with livestock form the major production system providing a livelihood to an agricultural population of 9.6 M.

4.8.1 **Cattle**

Prevalence of poverty: moderate-extensive
Average yield (t ha⁻¹): <0.2 t milk/TLU; 0.025-0.05 t liveweight/TLU
Nitrogen input (kg ha⁻¹): 0
Labour input:
Cultivated/total land ratio (%): 3.0
Agric. pop./cultivated land ratio: 5.6
N-balance: -
Sources:

4.9  Sparse (mountain)

These systems are located in the high altitude zone of South Asia and occupy 34 Mha of which only 1.9 Mha is cultivated. The systems supply an agricultural population of 2.8 M which depend mainly on livestock husbandry.

4.9.1  Cattle

Prevalence of poverty: moderate
Average yield (t ha⁻¹): <0.2 t milk/TLU; 0.025-0.05 t liveweight/TLU
Nitrogen input (kg ha⁻¹): 0
Labour input:
Cultivated/total land ratio (%): 5.5
Agric. pop./cultivated land ratio: 1.5
N-balance: -

Sources:

5.  East Asia and Pacific

5.1  Lowland rice

These farming systems are extremely important for the rice production in this zone and elsewhere in the world. They cover 197 Mha of which 71 Mha (including 45 Mha irrigated) is cultivated and they supply an agricultural population of 474 M. Although these systems are rice-based (including double rice systems), diversification towards high value crops is increasing rapidly.

5.1.1  Rice

Prevalence of poverty: moderate
Average yield (t ha⁻¹): 5.3-7.0 (China); 3.4-6.8 (Vietnam); 3.5-5.4 (Thailand); 2.9-6.5 (Philippines)
Nitrogen input (kg ha⁻¹): 125-175 (China); 80-140 (Vietnam); 63-136 (Thailand); 60-150 (Philippines)
Labour input per crop: 80-120 ld ha⁻¹ depending on management and 5 ld t⁻¹ for harvesting operation
Cultivated/total land ratio (%): 36.0
Agric. pop./cultivated land ratio: 6.7
N-balance: +

Sources:
5.2  

Tree crop mixed

These systems cover 85 Mha of which 18 Mha (including 12 Mha irrigated) is cultivated mostly on soils to poor for growing rice. An agricultural population of 30 M depends on these systems for their livelihood. Perennial industrial crops grown in large plantations as well as smallholder farms are typical for these systems.

5.2.1 Oil palm

Prevalence of poverty: moderate  
Average yield (t ha⁻¹): 17-20 (Malaysia)  
Nitrogen input (kg ha⁻¹): 70-80  
Labour input (ld ha⁻¹): 35  
Cultivated/total land ratio (%): 21.1  
Agric. pop./cultivated land ratio: 1.7  
N-balance: ?

Source:  

5.3 Root-tuber

These systems cover about 25 Mha of which only 1.2 Mha is cultivated mainly with root crops of which yams are typical representatives. Although these systems from a regional point of view are of minor importance it is predominant in particular locations such as Papua Guinea and the pacific islands where an agricultural population of 1.5 M depends on these systems.

5.3.1 Yams

Prevalence of poverty: limited  
Average yield (t ha⁻¹): 9-15 (Papua New Guinea)  
Nitrogen input (kg ha⁻¹): 0  
Labour input: 100 ld ha⁻¹ and 3 ld t⁻¹  
Cultivated/total land ratio (%): 4.8  
Agric. pop./cultivated land ratio: 1.3  
N-balance: -

Sources:  

5.4 Upland intensive mixed

These systems are found in sloping land in humid and sub humid agro-ecological zones and occupy 314 Mha and an agricultural population of 310 M. The cultivated area is 75 Mha of which 25% is irrigated. The second largest system in terms of population is quite diverse in production but rice is typical as subsistence crop often grown in terraces under irrigation.
5.4.1 Rice (flooded)
Prevalence of poverty: extensive
Average yield (t ha\(^{-1}\)): 2.3 (Yunnan, China)
Nitrogen input (kg ha\(^{-1}\)): 100
Labour input: per crop: 80-120 ld ha\(^{-1}\) depending on management and 5 ld t\(^{-1}\) for harvesting operation
Cultivated/total land ratio (%): 23.9
Agric. pop./cultivated land ratio: 4.1
N-balance: ±/+

Sources:

5.5 Highland extensive mixed
Compared to the previous farming systems, these are located in mountain landscapes of higher altitude and lower resource qualities. They occupy 89 Mha of which 8 Mha is cultivated. An agricultural population of 47 M depends for their livelihood on these systems. Rice grown on slopes under rainfed condition is a typical production system.

5.5.1 Rice (rainfed)
Prevalence of poverty: moderate
Average yield (t ha\(^{-1}\)): 1.1.2 (Yunnan, China)
Nitrogen input (kg ha\(^{-1}\)): 69-84
Labour input: 80-120 ld ha\(^{-1}\) depending on management and 5 ld t\(^{-1}\) for harvesting operation
Cultivated/total land ratio (%): 8.9
Agric. pop./cultivated land ratio: 5.9
N-balance: +

Sources:

5.6 Temperate mixed
These systems occupy 99 Mha in central-northern China of which 31 Mha is cultivated. An agricultural population of 162 M depends on these systems. Typical is the maize-wheat system in which maize and wheat are harvested in the same year, though wheat is sown in the preceding year (compare with rice-wheat system, section ##).

5.6.1 Maize-wheat
Prevalence of poverty: moderate
Average yield (t ha\(^{-1}\)): 5 (wheat); 6.2 (maize)
Nitrogen input (kg ha\(^{-1}\)): 130 (wheat), 110 (maize)
Labour input:
Cultivated/total land ratio (%): 31.3
Agric. pop./cultivated land ratio: 5.2
N-balance: ±

Sources:

5.7 Pastoral

These systems are found in the Western and large parts of Central and Northern Mongolia covering 321 Mha of which only 12 Mha is cultivated. However, the typical production systems are pastoral sheep herding systems. The pastoral farming systems provide a livelihood to an agricultural population of about 42 Mha.

5.7.1 Sheep

Prevalence of poverty: extensive
Average yield (t ha⁻¹): 0.08-0.13 t liveweight TLU-1
Nitrogen input (kg ha⁻¹): 0
Labour input:
Cultivated/total land ratio (%): 3.7
Agric. pop./cultivated land ratio: 3.5
N-balance: -

Sources:

5.8 Sparse (forest)

These farming systems are scattered throughout East Asia and the Pacific, cover a large area (172 Mha) but have minor economic importance providing livelihood to an agricultural population of 15 M. Since these systems occur in widely different parts of Asia (in forests and arid areas) the typical production systems are rice in the forest part and wheat in the arid part of these farming systems. About 10 Mha of the total 172 Mha is cultivated.

5.8.1 Wheat

Prevalence of poverty: moderate
Average yield (t ha⁻¹): 0.5-1.0
Nitrogen input (kg ha⁻¹): 0
Labour input:
Cultivated/total land ratio (%): 5.8
Agric. pop./cultivated land ratio: 1.5
N-balance: -

Sources:
FAO, 1996. Crop and food supply in Mongolia. FAO global information and early warning system on food and agriculture.

5.9 Sparse (arid)

These systems cover the largest area in East Asia, 322 Mha of which only 4 Mha is cultivated. The predominant production system is the cattle herding providing livelihood to an agricultural population of 17 M.
5.9.1  Cattle
Prevalence of poverty: extensive
Average yield (t ha⁻¹):
Nitrogen input (kg ha⁻¹):  
Labour input:
Cultivated/total land ratio (%): 1.2
Agric. pop./cultivated land ratio: 4.2
N-balance: -

6. Latin America and Caribbean

6.1 Irrigated
Covering a wide area, 200 Mha of which 7.5 Mha is cultivated, almost all irrigated. The predominant production system is rice providing livelihood to an agricultural population of 11 M.

6.1.1 Rice
Prevalence of poverty: low-moderate
Average yield (t ha⁻¹): 3.7-5.2
Nitrogen input (kg ha⁻¹): 50-100
Labour input: 13-35 ld/ha (mechanized harvesting)
Cultivated/total land ratio (%): 3.7
Agric. pop./cultivated land ratio: 1.5
N-balance: +/-

Sources:
http://www.irri.org/science/ricestat/pdfs/WRS2005-Table03.pdf

6.2 Forest based
This is the largest production system in this region covering 600 Mha in the heart of Latin America of which only about 6 Mha is cultivated. It provides livelihood to an agricultural population of 11 M. The predominant production system is extensive cattle for meat production.

6.2.1 Cattle
Prevalence of poverty: low-moderate
Average yield (t ha⁻¹): <0.3 (t milk/TLU); 0.075-0.1 t liveweight/TLU
Nitrogen input (kg ha⁻¹): 0
Labour input:
Cultivated/total land ratio (%): 1
Agric. pop./cultivated land ratio: 1.8
N-balance: -

6.3 Coastal plantation and mixed
The system covers 186 Mha of which 20 Mha cultivated predominantly with export-oriented large scale plantations with bananas, pineapple and palm heart. The agricultural population is estimated at 20 M.
6.3.1 Banana
Prevalence of poverty: low-extensive, and severe (variable)
Average yield (t ha⁻¹): 60
Nitrogen input (kg ha⁻¹): 400-500
Labour input: 70 ld/ha and 1.4 ld/t for harvesting and processing/packing
Cultivated/total land ratio (%): 10.7
Agric. pop./cultivated land ratio: 1.0
N-balance: +

Sources:

6.4 Intensive mixed
This intensive system covers about 81 Mha of which 13 Mha is cultivated. The agricultural population is estimated at 10 M of which a great part depends on the production of coffee.

6.4.1 Coffee
Prevalence of poverty: low-extensive, and severe (variable)
Average yield (t ha⁻¹): 1.5-4
Nitrogen input (kg ha⁻¹): 100-200
Labour input: 29 ld/ha and 8-11 ld/t for harvesting operation
Cultivated/total land ratio (%): 16.0
Agric. pop./cultivated land ratio: 0.6
N-balance: ±

Sources:
Center for sustainability and the global environment (visited June 29)
https://mywebspace.wisc.edu/clmonfreda/web/cropimages/coffeeyield.gif

6.5 Cereal-livestock (Campos)
This system is estimated at 100 Mha of which 18 Mha is cultivated including 1.8 Mha irrigated land. This system provides a livelihood to an agricultural population of about 7 M. Livestock and rice production dominate in this system.

6.5.1 Rice
Prevalence of poverty: low-moderate
Average yield (t ha⁻¹): 3.5-6.5
Nitrogen input (kg ha⁻¹): 30-40
Labour input: 13-35 ld/ha (mechanized harvesting)
Cultivated/total land ratio (%): 18.0
Agric. pop./cultivated land ratio: 0.4
N-balance: -
6.6 Moist temperate mixed-forest

This system covers only 13 Mha along the coastal zone of Chile and comprises a cultivated area of 1.6 Mha. The agricultural population depending on this systems totals about 1 M. The predominant system is dairy.

6.6.1 Cattle (dairy)

Prevalence of poverty: low
Average yield (t ha⁻¹): < 1.5 t TLU⁻¹ and 0.15-0.2 t liveweight TLU⁻¹
Nitrogen input (kg ha⁻¹):
Labour input:
Cultivated/total land ratio (%): 12.3
Agric. pop./cultivated land ratio: 0.6
N-balance: -

Sources:

6.7 Maize-beans

This system prevails in Central-America covering 65 Mha of which 6 Mha is cultivated on which an agricultural population of about 11 M depends. Historically, this system is based on the production of maize and beans for subsistence.

6.7.1 Maize bean

Prevalence of poverty: extensive-severe
Average yield (t ha⁻¹): 0.5-1.5 (beans); 1-2 (maize)
Nitrogen input (kg ha⁻¹): <25
Labour input: 25-32 ld/ha (maize), 6-36 ld/ha (beans), and for harvesting 9-14 ld/t beans and 2.5-4.5 ld/t maize
Cultivated/total land ratio (%): 9.2
Agric. pop./cultivated land ratio: 1.8
N-balance: -

Sources:

6.8 Intensive highlands

This system covers 43 Mha of which 4.4 Mha is cultivated (including 0.9 Mha irrigated). Two distinct systems can be identified, in the lower altitudes coffee and in the higher altitudes maize predominates. An agricultural population of about 4 M depends on these systems.
6.8.1 Coffee/maize

Prevalence of poverty: low (low altitude)-extensive (high altitude)

Average yield (t ha⁻¹): 1-3 (coffee) 1-2 (maize)

Nitrogen input (kg ha⁻¹):

Labour input: maize: 25-32 ld/ha and for harvesting 2.5-4.5 ld/t; coffee: 29 ld/ha and 8-11 ld/t for harvesting

Cultivated/total land ratio (%): 10.2

Agric. pop./cultivated land ratio: 0.9

N-balance: -

Sources:


6.9 Extensive mixed (Cerrados and Llanos)

This system prevails in vast areas of savannahs in East and central Brazil, Eastern-Columbia, Venezuela and Guyana, totalling 230 Mha of which only 31 Mha is cultivated. The system provides livelihood to an agricultural population of about 10 M. Predominant are livestock systems.

6.9.1 Cattle (meat)

Prevalence of poverty: low-moderate

Average yield (t ha⁻¹): 0.15-0.25

Nitrogen input (kg ha⁻¹):

Labour input:

Cultivated/total land ratio (%): 13.5

Agric. pop./cultivated land ratio: 0.3

N-balance: -

Sources:


6.10 Temperate mixed (Pampas)

This system covers 100 Mha in Central and Eastern Argentina and Uruguay and formerly a livestock area. Increasingly, arable crops are cultivated and now nearly 20 Mha is cultivated providing livelihood to an agricultural population of 7 M.

6.10.1 Wheat

Prevalence of poverty: low

Average yield (t ha⁻¹): 1.5-3

Nitrogen input (kg ha⁻¹): 40

Labour input:

Cultivated/total land ratio (%): 20.0

Agric. pop./cultivated land ratio: 0.3

N-balance: -
6.11  
**Dryland Mixed**

This system covers 130 Mha in Yucatan peninsula of Mexico and along the coast of Northeast Brazil of which 18 Mha is cultivated. The agricultural population is about 10 M of which the majority depends on livestock.

6.11.1  
**Cattle (meat)**

Prevalence of poverty: extensive  
Average yield (t ha⁻¹):  
Nitrogen input (kg ha⁻¹): 0  
Labour input:  
Cultivated/total land ratio (%): 13.8  
Agric. pop./cultivated land ratio: 0.5  
N-balance: -

Sources:

6.12  
**Extensive dryland mixed (Gran Chaco)**

This system is less favourable for agricultural production than the Cerrados and Llanos systems (section 6.9) due to soil and moisture limitations. It comprises 70 Mha of which 8 Mha is cultivated and providing livelihood to an agricultural population of less than 2 M.

6.12.1  
**Cattle**

Prevalence of poverty: moderate  
Average yield (t ha⁻¹):  
Nitrogen input (kg ha⁻¹):  
Labour input:  
Cultivated/total land ratio (%): 11.4  
Agric. pop./cultivated land ratio: 0.2  
N-balance: -

Sources:

6.13  
**High altitude mixed (Central Andes)**

This system covers 120 Mha of which is 3.1 Mha is cultivated mainly at high altitudes. Predominant cropping system is potatoes providing a livelihood to an agricultural population of 7 Mha.

6.13.1  
**Potato**

Prevalence of poverty: extensive-severe  
Average yield (t ha⁻¹): 6.4-12 (Bolivia and Peru)  
Nitrogen input (kg ha⁻¹): 0  
Labour input:  
Cultivated/total land ratio (%): 2.5  
Agric. pop./cultivated land ratio: 2.3  
N-balance: -
Pastoral

The pastoral system covers a very sparsely populated area south of the Pampas covering some 67 Mha, where sheep and cattle systems prevail. The cultivated area is negligible and the agricultural populations is less than 1 M.

6.14.1 Cattle (sheep)

Prevalence of poverty: low-moderate
Average yield (t ha⁻¹):
Nitrogen input (kg ha⁻¹):
Labour input:
Cultivated/total land ratio (%): ??
Agric. pop./cultivated land ratio: ??
N-balance: -

Sources:

6.15 Sparse (forest)

This system is similar to the previous one but located at higher altitudes, which makes agriculture even more marginal. The total area of the system is about 37 Mha of which only about 0.15 Mha is cultivated. Agricultural population is less than 250,000.

6.15.1 Cattle (sheep)

Prevalence of poverty: low
Average yield (t ha⁻¹):
Nitrogen input (kg ha⁻¹):
Labour input:
Cultivated/total land ratio (%): 0.4
Agric. pop./cultivated land ratio: 1.7
N-balance: -

Sources:
7. General data and calculation rules

7.1 Self-sufficiency

Table provides information to convert harvested main produce into energy and proteins.

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<th>N-content in harvested main produce (g kg(^{-1}))</th>
<th>Energy content (kcal kg(^{-1}))</th>
<th>Reference</th>
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<tr>
<td>Yam</td>
<td>770 - 870, 1180</td>
<td>10, 11</td>
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</table>

*) Protein content can be calculated using the general formula: 6.25 * N-content (reference 4)

5) http://www.food-info.net/uk/foodcomp/table.htm.

2.2 Water use and balances of production systems

Current water requirements of rainfed (crop) production systems can be calculated using a reference evapotranspiration (ETP\(_{ref}\)) multiplied with a crop-specific coefficient (k\(_c\)). ETP\(_{ref}\) can be calculated with the Penman-Monteith equation (FAO, 1992) and climate data on minimum and maximum air temperature, sunshine hours, wind speed and relative air humidity. For the crop-specific coefficient k\(_c\) data tables exist with detailed values for different growth stages of crops (FAO, 1992). Water requirement calculations can be done on daily, decade of days, monthly or
growing season basis. The smaller the time step the more data demanding and accurate the estimation procedure becomes. WATCROP (1998) is a simple support tool which performs the underlying calculations on the basis of a database with characteristics of 30 crops and weather data from 3262 climate stations in 144 countries.

On the basis of the difference between the calculated water requirements and prevailing rainfall, a simple water balance at field level can be determined. The difference between water inflows (rainfall and irrigation) and losses (actual evapotranspiration) determines water surplus or deficit situations of production systems: \( k_c \cdot ETP_{ref} \cdot \text{rainfall} \). Also this calculation can be more or less detailed through, for example, the use of smaller time steps, or effective rainfall, i.e. rainfall that enters the soil (so accounting for run-off and other losses), and through expanding the equation, for example, by incorporating changes in water storage in the soil over the considered time period.

2.3 Organic matter of production systems

To estimate the soil organic matter content of different production systems in the world, the farming systems map and FAO soil map should be combined. Major soil types in the FAO soil classification can be associated with soil organic matter content. This overlay will result in patches within zones of each farming systems representing soils with different organic matter contents. Hence, a range of soil organic matter contents may be obtained similarly as the range of inputs and outputs of production systems describe in section 1.
Appendix VI.

Summary of data on the inputs and outputs, species diversity and poverty of the current production systems
<table>
<thead>
<tr>
<th>Farming Systems</th>
<th>Typical production system</th>
<th>Agricultural area (Mha)</th>
<th>Agricultural population (M)</th>
<th>Poverty level</th>
<th>Land area (% of region)</th>
<th>Agric. popn. (% of region)</th>
<th>Cultivated/total land (%)</th>
<th>Man/cultivated land</th>
<th>Average yield (t/ha)</th>
<th>Nitrogen input (kg N/ha)</th>
<th>Labour requirements (ld/ha)</th>
<th>N balance</th>
<th>Input level</th>
<th>Species diversity (%)</th>
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<td>Input level</td>
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<td>Input level</td>
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<td>Farming Systems</td>
<td>Typical production system</td>
<td>Farming systems area (Mha)</td>
<td>Agricultural area (Mha)</td>
<td>Agricultural population (M)</td>
<td>Poverty level</td>
<td>Land area (%) of region</td>
<td>Agric. popn. (%) of region</td>
<td>Cultivated/total land (%)</td>
<td>Man/cultivated land</td>
<td>Average yield (t/ha)</td>
<td>Nitrogen input (kg N/ha)</td>
<td>Labour requirements (ld/ha)</td>
<td>N balance</td>
<td>Input level</td>
</tr>
<tr>
<td>-----------------</td>
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<td>9</td>
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<td>pastoral (cattle)</td>
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<tr>
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<tr>
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<td>12.3</td>
<td>0.6</td>
<td>0.5-1.5 (beans); 1-2 (maize)</td>
<td>18-48</td>
<td>29.5-36.5</td>
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</table>

**Species diversity:**
- Highland: 10.0
- Temperate: 10.0
- Pastoral: 10.0
- Sparse (forest): 15.0
- Sparse (arid): 15.0
- Latin America and Caribbean: 10.012.5
- Forest based: 15.0
<table>
<thead>
<tr>
<th>Farming Systems</th>
<th>Typical production system</th>
<th>Farming systems area (Mha)</th>
<th>Agricultural area (Mha)</th>
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<th>Average yield (t/ha)</th>
<th>Nitrogen input (kg N/ha)</th>
<th>Labour requirements (ld/ha)</th>
<th>N balance</th>
<th>Input level</th>
<th>Species diversity (%)</th>
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<tbody>
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<td>1-3 coffee; 1-2 maize</td>
<td>45-51 (coffee); 29.5-36.5 (maize)</td>
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