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Proceedings of the KIT-Workshop
8th December 2010, Karlsruhe

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Proceedings of the Workshop "Low-Input Intensification of Agriculture – Opportunities and Barriers in Developing Countries" of the Institute for Technology Assessment and Systems Analysis (ITAS) and the Institute of Geography and Geoecology (IfGG) of the Karlsruhe Institute of Technology (KIT) on 8th December 2010 in Karlsruhe

by
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CONTENT

OPPORTUNITIES AND BARRIERS FOR LOW-INPUT INTENSIFICATION OF DEVELOPING COUNTRIES' AGRICULTURE – INTRODUCTION AND OVERVIEW

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The KIT start-up project "Potentials of low-input intensification in developing countries", jointly carried out by the Institute for Technology Assessment and Systems Analysis (ITAS, Campus North) and the Institute for Geography and Geoecology (IfGG, Campus South), is focused on smallholders who represent the vast majority of farmers in developing countries. They play a key role to achieve increasing agricultural production and strong economic growth in agriculture, and therewith to reduce hunger and poverty in developing countries.

BACKGROUND

Many developing countries face agro-ecological disadvantages. Tropical soils are characterised by intense chemical weathering und high vulnerability. From equator towards the tropics, soil constrains are replaced by water constrains. Nonetheless, sustainable agricultural production systems, such as shifting cultivation, had been developed in the past. These production systems are no longer adequate or have disappeared due to changing economic and political conditions from colonisation to globalisation and the increasing population. But overall, the current agricultural production in developing countries does not produce enough food for the population and for a part of the farmers themselves, does not provide sufficient income and economic growth, and does not enable a sustainable use of natural resources.

The project started from the hypothesis that – with the focus on small-scale farmers – agricultural production systems like Conservation Agriculture, System of Rice Intensification, Organic Farming and Agroforestry Systems are candidates for higher food production and sustainable land utilisation in developing countries. These production systems have the potential for a "low-input intensification", in particular meeting the needs and possibilities of small-scale farmers. They can be described as complex agricultural systems of intensification through higher agro-ecological and biological productivity. They do not necessarily require higher external inputs (as mineral fertilizer and pesticides). Instead, they focus on the optimisation of input utilisation. Improved management of soil and water are central elements.

In this context, the workshop on December 8, 2010 at the so-called "Fasanenschlösschen" in Karlsruhe aimed to discuss the potentials of low-input intensification and to identify adequate problem-oriented research approaches. The contributions of the workshop are documented in these proceedings.

In consideration of the complex issue, three perspectives were brought together in the workshop. In the following, a short outline of the contributions in these sections is given.

GLOBAL BASELINES

The geophysical and climatological situation on the one hand is discussed in the contribution of *Katharina Butz (IfGG, KIT)* and the challenges for small-scale farming, the characteristics, distribution and hindrances of low-input agricultural production systems on the other hand in the contribution of *Rolf Meyer (ITAS, KIT)*. The aim of these two contributions is to assess the potentials for low-input intensification in developing countries' agriculture, based on the work in the project. Both contributions come to the conclusion that overall assessments of potentials are only a first step and that locally adapted assessments and solutions are needed in the next step.

CASE STUDIES

The following contributions analyse experiences with low-input intensification for very different settings, regions and research approaches. The contribution of *Shilpi Saxena* discuss the market channels for organic vegetable farmers in Tanzania and the constraints in their marketing chains to explore better marketing strategies for the small-scale farmers on the national market. The first part of the paper gives an overview of organic agriculture in East Africa, while the second part characterizes the supply chain for marketing organic vegetables in Tanzania.

Research results about the influence of soil micro-fauna on soil fertility from a project in Central Amazonia, Brazil are reported by *Dieter Burger and Raphael Knoll (IfGG; KIT).* The soil fertility of the intensifly weathered soils of Amazonia's Terra firme is largely determined by amount and quality of soil organic components. For Central Amazonia's agricultural and forest ecosystems, termites, ants and earthworms, the locally most frequent representatives of the macrofauna, play a great role in decomposition and integration of organic matter in soils. This offers possibilities to essentially increase cation exchange capacity, improve soil structure and systematically fertilise the soil through integration of organic matter.

The current situation of irrigation within the southern date palm oasis of Tunisia and potentials of irrigation efficiency improvement are analysed in the contribution of *Nizan Omrani (Institute of Arid Regions, Tunisia)*. An assessment of the prevailing constraints is conducted, with a focus on the perspectives of irrigation efficiency improvement as the key issue to assure the sustainability of the irrigated agriculture in oasis ecosystems.

Theodor Friedrich and Amir Kassam (FAO) discuss the chances for learning in and between agricultural production system approaches for integrating productivity with ecosystem services for low-input intensification in small-scale farming. They work out three key principles for sustaining soil and ecosystem health as the basis for integrating intensification with ecosystem services: minimizing soil disturbance by mechanical tillage and whenever possible seeding or planting directly into untilled soil; maintaining organic matter cover from cover crops or crop residues over the soil; and species diversification – both annual and perennial – in associations, sequences and/or rotations. The problems which farmers face in a country or region, where sustainable intensification is not practiced, and which make adoption difficult are discussed. These problems are of a diverse nature, such as intellectual, social, biophysical and technical, farm power, financial, infrastructural and policy. Action points that should be considered by policy-makers and institutional leaders to address these problems are outlined.

DEVELOPMENT AND RESEARCH POLICY PERSPECTIVES

In the last part, the contribution of *Stephan Krall (GIZ - Deutsche Gesellschaft für Internationale Zusammenarbeit)* presents research needs from the development assistance perspective. His conclusion is that only research conducted under practical conditions is worthwhile and only this research will provide the necessary results.

The paper of *Marc Dusseldorp (Office for Technology Assessment at the German Bundestag – TAB)* discuss the relevance of participatory research approaches which substantially integrate smallholders into the research process as potential users of the research results, based on the TAB-project “Research contributions to solving the world food problem”. The article discuss the obstacles participatory approaches have been faced with so far regarding research policy and research promotion in Germany as well as the possible steps to be taken with regard to research policy (e.g. changes in research funding and organisation) in order to promote participatory research.

PERSPECTIVES

An important common line in the case studies is the preservation and improvement of the soil fertility as a precondition for achieving significant yield increases. But the implementation of appropriate measures to improve soil fertility is often hampered by economic conditions. For example, agricultural prices and high returns for a specific crop favour monocultures instead of mixed cropping (in the case of date palms in Tunisia) or annual crops instead of Agroforestry Systems (in the case of upland agriculture in Vietnam and Thailand). Access to (and information about) regional, national and/or international markets is another bottleneck for the realisation of increased yields and their economic returns. Research activities often suffer from missing continuity and links to farmers so that research results contribute insufficiently to improved farming practices. Therewith, intensification in smallholder agriculture relies generally on a simultaneous adjustment of economic, social and political surroundings, and vice versa, rural development activities should not neglect agricultural production system improvements.

In the workshop, the term “low-input intensification” was discussed controversially and alternatives such as sustainable intensification or eco-functional intensification were proposed. Agreement was reached that low-input intensification focuses on more independence from classical external inputs such as synthetic fertilizer and pesticides. It is in so far misleading as such external inputs are subsidized by higher demand for information, knowledge, networking, production system adjustments, etc. which are in most case “external” and associated with different kind of costs. This constitutes that low-input intensification normally happens not by itself but requires policy support.

At the end of the workshop, three perspectives for research and action were proposed by workshop organisers:

> Yield potentials of tropical soils: Improved soil fertility is a key issue for significant increases in agricultural productivity. Assessment of the local pedogenic bottlenecks and production potentials is needed as baseline information. The scientific task is to develop a simple method for assessing properties of tropic soils at the local level. Governments of developing countries should implement top-down approaches to facilitate the assessment of soil production potentials on the ground.

> Distribution of agricultural production systems in developing countries: Information about the applied production systems in developing countries is restricted; global figures are available only for Conservation Agriculture and Organic Farming. In many cases, information about the intensity of agricultural land use at the local level is missing. Better understanding and assessment of intensification potentials in developing countries is an important task to enable purposeful projects and programmes.

- Implementation of sustainable intensification principles in local contexts: Agricultural production system principles demand the adaptation to local conditions. Key principles, local configuration of natural resources, economic capabilities of farmers, set of available techniques and approaches for production improvement, opportunities through markets and communities, etc. must be combined case by case. Participatory agricultural research should and can deliver a crucial contribution.

SETTING THE FRAME: CHALLENGES FOR SMALL-SCALE FARMING IN DEVELOPING COUNTRIES

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ABSTRACT

Small-scale farmers are dominating the agriculture of developing countries. After two decades of neglecting agricultural investment, the importance of agriculture for development was reaffirmed in recent years. Beside the task to regain lost time, a number of new challenges such as climate change must be addressed today. Increasing production and strong economic growth in agriculture – with small-scale farmers in the centre of attention – are urgently needed to achieve food security and poverty reduction.

In the context of developing small-scale farming, the most suitable ways of improving agricultural production have to be identified. Candidates for higher food production and sustainable land utilisation in developing countries are agricultural production systems such as Conservation Agriculture, System of Rice Intensification, Organic Farming and Agroforestry systems. They enable intensification by higher agro-ecological and biological productivity, without necessarily increasing external inputs. The preservation and enhancement of the natural production potentials of agriculture (such as soil fertility, water conservation, biodiversity sustainment) are not only a add-on activity, they are essential to stabilize achieved high yield levels in favourable areas, to realise more of existing yield potentials, and to increase the resilience of farming systems.

These production systems have in common to formulate fundamental principles and key elements which have to be translated case-by-case into production technologies and farmer practices adapted to local conditions. Instead of single technologies or fixed technology packages, system-based principles and approaches with local adaptations and integration have the potential to address the specific agro-ecological, social and economic conditions of farmers at their specific locations.

Despite a large number of encouraging examples, low-input intensification will not happen of its own accord in many cases. The successful development and introduction of low-input intensification and its integration into adapted practices in developing countries depend on a number of enabling conditions. Some important framing conditions are discussed, without making any claim to be complete.

The vast majority of farmers in developing countries are small-scale farmers, also called smallholders or family farmers. *Estimated 85% of the farmers in developing countries produce on less than 2 hectares* (World Bank 2007: 90; von Braun, Diaz-Bonilla 2008: 7). In countries as diverse as China, Egypt and Malawi, 95% of the farms are smaller than 2 hectares (Table 1). The dominance of smallholders is found mostly in countries of East, South-East and South Asia, and Sub-Sahara Africa. Some increase of the average farm size can be seen from the equator to the more arid areas in the direction of the tropics. In addition, countries with high percentage of irrigated land show a low average farm size. These relationships reflect land productivity.

Of the three billion rural people in developing countries, over two-thirds reside on small-scale farms. Therewith, *around 500 million small farms* exist in the developing world (Hazell et al. 2010). All in all, agriculture is the source of livelihood for an estimated 86% of the rural population in the developing world. It provides jobs for 1.3 billion smallholders and landless workers (World Bank 2007: 3).

TABLE 1 AVERAGE FARM SIZE IN SELECTED COUNTRIES

Country	Year	Average farm size (hectares per farm)
Asia		
China	1997	0.67
India	2000/2001	1.34
Nepal	2002	0.79
Philippines	2002	2.01
North Africa		
Egypt	1999/2000	0.82
Sub-Sahara Africa		
DR Congo	1990	0.53
Ethopia, Fed. Dem. Rep.	2001/2002	1.03
Malawi	1993	0.75
Senegal	1998/1999	4.30

Source: FAO 2010a, FAO 1990

Small-scale farms play also an essential role in countries with a higher average farm size (Table 2). A fifth or more of all farms in these countries are smallholders, constituting a high number of farm households. Part of developing countries has severe land inequalities between smallholder and large-scale farms, e.g. in Latin America and South Africa. But partly, there are also major disparities in land distribution within the small-scale farm sector itself. In selected Eastern and South Africa countries, households in the highest per capita land quartile control between 5 and 15 times more land than households in the lowest quartile (Jayne et al. 2010).

TABLE 2 PROPORTION OF SMALL-SCALE FARMS IN SELECTED COUNTRIES WITH HIGHER AVERAGE FARM SIZE

Country	Year	Percentage of farms < 2 hectares (%)	Average farm size (hectares per farm)
North Africa			
Tunesia	2004/2005	27.16	10.45
South-Amercia			
Brazil	1996	20.23	72.76
Ecuador	1999/2000	43.43	14.66
Venezuela	1996/1997	22.64	60.02

Source: FAO 2010a

In the last decades, many developing countries saw a *decline in farm size* and in land/labor ratios, i.e. the ratio of cultivated land to agricultural population (Hazell et al. 2010; Jayne et al. 2010).

DIVERSITY OF SMALL-SCALE FARMING

Small-scale farmers can be found under more or less all *agro-ecological and socio-economic conditions*. From the agro-ecological point of view, smallholders are located in irrigated and rain-fed areas, and in high-productive and marginal farming areas. For example in India, the irrigation coverage is higher for small-holdings than for large farms (Table 3). The non-irrigated, rainfed areas not only have lesser productivity than the irrigated lands, they are also the location of a proportionately greater concentration of poor and hungry persons (Singh et al. 2002: 14, 15). In the Indio-Gangetic Plains of India, the North-West is characterised by a largely intensified crop production, with high external inputs, high productivity, and high market integration. In contrast, the eastern plains show poor crop yields, costly and scarce irrigation, high dependence on rain falls, and small and fragmented farm holdings. Together with lack of institutional finance and extension services, poverty and uncertainties of rural livelihoods are much higher (Erenstein, Thorpe 2011). This example shows that the agro-ecological conditions of small-scale farmers in a country can differ significantly, and that agro-ecological and socio-economic circumstances are often intertwined.

TABLE 3 DISTRIBUTION OF HOLDINGS, IRRIGATED AND NON-IRRIGATED GROSS CROPPED AREA BY FARM-SIZE CATEGORIES, ALL INDIA 1991

Farm-size category	Number of holdings (million)	Gross cropped area (million ha)	Irrigated gross cropped area (million ha)	Non-irrigated gross cropped area (million ha)	Ratio irrigated / non-irrigated area
Marginal (< 0.99 ha)	63.6 (59%)	30.7 (17%)	13.0 (20.6%)	16.4 (15.3%)	0.79
Small (1.00 – 1.99 ha)	20.1 (19%)	33.0 (18%)	13.3 (21.0%)	20.1 (18.8%)	0.66
Medium (2.00 – 4.00 ha)	13.8 (13%)	42.6 (24%)	14.8 (23.4%)	25.7 (24.1%)	0.57
Large (> 4.00 ha)	9.2 (9%)	72.9 (41%)	22.1 (35.0%)	44.7 (41.8)	0.49
Total	106.6 (100%)	179.3 (100%)	63.2 (100%)	106.9 (100%)	0.59

Source: Compilation of Singh et al. 2002: 4,5,15

The *market integration of small-scale farmers* is very different (Bennett, Franzel 2009: vii):

> Subsistence: Farmers hardly participate in markets at all;
> Transitional integration: Farmers sell some of their products, generally in informal, local markets;
> Cash-cropping: Farmers sell nearly their entire crop, generally through formal markets.

The surplus production and marketing (of staples) is concentrated on relative few small-scale farmers (Barrett 2008; Jayne et al. 2010). On the other side, a considerable amount of the food supply of farm households comes in developing and emerging countries from their own food production. In India, home-produced foods supplies about half of the farm households' consumption of calories, proteins, and fats, and more than half of the cereals and milk products, aggregated over all farm sizes (1993-94 Survey). However, the sub-marginal households (with less than 0.5 ha) produced proportionately less than the all-farms average (Singh et al. 2002: 27). Therewith, the poorest farmers with sparse land are often net-buyers of food.

The diversity of small-scale farming applies also for the *product categories*:

> Staple foods (e.g. rice, wheat, maize, cassava)
> Non-staple foods (e.g. legumes, fruits, vegetables)
> Traditional export cash crops (e.g. coffee, tea)
> High-value crops and products (e.g. certified organic, horticulture products)

The production programme of small-scale farmers is not static. In many cases, smallholders respond to market forces and opportunities by adapting and adopting new and diversified cropping and farming systems.

AGRICULTURAL DEVELOPMENT IN THE PAST 2.

Major achievements of agricultural development in the last 50 years will be discussed in this chapter, because the challenges ahead are based on developments of the past.

From 1980 to 2004, the *gross domestic product (GDP) of agriculture* expanded globally by an average of 2.0% per year, more than the population growth of 1.6% per year. During this period, developing countries achieved much faster agricultural growth (2.6% per year) than industrial countries (0.9% per year). Therewith, developing countries accounted for 79% of the overall agricultural growth (World Bank 2007: 50).

The increase in productivity has contributed to a *net increase in global food availability*: From 2,360 kcal in the 1960s to 2,800 kcal per person in the 1990s, and this at a time when world population significantly increased (IAASTD 2008d: 5). Therewith, the growing agricultural production has made a major contribution to the reduction and/or prevention of hunger. Additionally, a decoupling between food production increase and cropland expansion has taken place (Lambin et al. 2003).

GREEN REVOLUTION

These achievements in the past were at least partly achieved by so called Green Revolution. The Green Revolution was a *technology package* consisting of improved high-yielding seeds, fertilizers, pesticides and extended irrigation, launched in priority "bread basket" areas with good existing infrastructure and market access. It is important to recognise that the achieved success was based on a *set of initiatives and preconditions* (Hazell 2002, 2009):

> Scale-neutral technology package that could be profitably adopted on farms of all size;

> Public extension systems that prioritized small farms;

> Modern input system with subsidized inputs that serve small-scale farmers at prices they can afford;

> Modern credit systems with fair conditions;

> Enabling economic environment with product markets and price support policies that ensured stable and fair prices for farmers;

> Equitable distribution of land with secure ownership or tenancy rights;

> Continues investment in agriculture to sustain the gains that were achieved.

The technology transfer and local adaptive work in the Green Revolution from 1960s to 1980s was carried out by the public sector and non-profit organisations as leading actors. The objective of developing agricultural research capacity in post-colonial developing countries was to increase food production to avert hunger-led insurrection during the Cold War (Parayil 2003).

The increased food production was associated with raised farmers' income, the stimulation of rural non-farm economy and a long-term food price decline which permitted people to consume more calories and a more diversified diet, and which overall reduced poverty (Hazell 2002). But there were also a number of *shortcomings and critics*:

> High-yielding varieties and the associated technologies were implemented broadly only in Asia and Latin America; Africa was left behind (Hazell 2002).

> Achievements are concentrated on main grains which are major cash crops; production increases of root crops and coarse grains were much smaller (Godfray et al. 2010).

> Success is concentrated on high potential, water secure and/or irrigated areas; the water-insecure, rainfed and marginal and/or remote areas were not reached.

> The expansion and intensification of irrigation has let to increasing water scarcities through overexploitation of groundwater resources.

> The higher food production was associated with a disproportionate increase of fertilizer use, in particular nitrogen (Tilman 1999).

> The intensification let to the degradation of soil (water-logging, salinisation, erosion), and environmental impacts such as increasing climate gas emissions and eutrophication of freshwater and marine ecosystems by high rates of nitrogen and phosphorus release from agricultural fields (Tilman 1999).

> Intensive use of pesticides has created disruptions of natural pest-predator balance and pest resistance problems. Health impacts are associated with improper pesticide use (Matson et al. 1997).

> At least at introduction and early stages, success depends from government interventions to stabilise output prices and to subsidise input supply and credits (Dorward et al. 2004). With the success, the dependency on subsidies continued and became heavy and unsustainable fiscal burdens.

> Social mobilization and peasant movements were a precondition for a successful Green Revolution with smallholder inclusion in Asia and the absence of comparable movements in Africa is among the factors that explain why Africa did not launched a Green Revolution (Birner, Resnick 2010).

> Many studies on the distributional effects of the Green Revolution came to the conclusion that farmer-level (intraregional) income inequality and interregional income differences increased (Freebairn 1995).

> The Green Revolution technologies themselves may be scale-neutral, but other elements within the agricultural production system such as landholding patterns, social relationships and political power sharing are not. Beside productivity-raising technologies, adjustments must be made in the associated structures of the production system if broad spread effects of poverty reduction among producers are to be achieved (Freebairn 1995).

In the last two decades, *agricultural development and productivity growth has changed dramatically*. For the major crops maize, rice, wheat, and soybeans, the annual rates of global yield growth slowed down during the period 1990 to 2007 in comparison to the period1961 to 1990, partly more than halved. In parallel with the development of global crop yields, global land productivity growth has been substantially slower since 1990 than during the previous three decades if China as an exceptional case is left out (Alston et al. 2009). A *number of causes* are named for the reduced agricultural productivity growth:

> Slowdown in the growth rate of public agricultural research and development investment (Alston et al. 2009);

> Shift in the research and development expenditures from the public to the private sector;

> Changing research agenda in industrial countries (from productivity to environmental issues, food safety and quality, etc.) and in consequence lower international spillover of research results (Pardey et al. 2006);

> Increasing differences between capital-intensive technology innovations for farmers in rich countries and innovation demand in developing countries (Pardey et al. 2006);

> Sharp decline of the share of agriculture in official development assistance (from a high of 18% in 1979 to 3.5% in 2004) (World Bank 2007: 41);

> New breakthroughs in plant breeding get more difficult because most promising approaches were covered first and already high-yielding crops can come up to physiological constraints (Lipton 2010; Ruttan 2002: 175);

> Yield gap between maximum potential yields and actual yields due to unexploited intensification potentials in the agricultural production (Neumann et al. 2010);

> New technological trajectory of modern biotechnology shaped by neo-liberal economic globalisation, intellectual property rights (patents), leading role of the private sector and goal of high returns to shareholders of international corporations (Parayil 2003).

In recent years, the *importance of agriculture for development was reaffirmed* (World Bank 2007; IAASTD 2009a; Royal Society 2009; De Schutter 2010; Foresight 2011; Worldwatch Institute 2011). These assessments show a great congruency in the analysis of the current situation of the world food problem and the emerging challenges. After more than two decades of decline in development assistance for agriculture and neglecting agricultural investments, sharply increased public funding is a broadly recognised recommendation.

THE CHALLENGES AHEAD 3.

Since the mid 1990s, the overall number of undernourished has increased once again. With the food and economic crisis from 2007 to 2009, the percentage of hungry people worldwide increased as well. After only three years, the global food crisis with very high food prices is back. In 2009, more than 1 billion people were undernourished, more than 40 years ago (FAO 2010b). The Millennium Development Goal (for 2015) of halving hunger and poverty will not be achieved. The future perspectives are at least uncertain. The challenges ahead are (Meyer et al. 2011):

> *Population increase*: In 2050, food for around 9 billion people has to be produced. The global agricultural production will need to be raised by at least 70 percent to meet the future demands, as projections indicate.

> *Nutrition transition*: Particularly in emerging countries, diets will become more "urban" and similar to the industrialised "western" diet, based on economic development and increasing incomes of people. The higher consumption of meat and vegetable oils causes higher land demand and increasing overnutrition with its health impacts.

> *Growing overall demand for biomass*: Beside food and feed, the demand for fibre and fuel is expected to become more important in the next decades. Established politically defined biofuel targets and concepts of a bio-economy will put additional pressure on the agricultural land base and the agricultural commodity markets.

- *Food prices*: After decades of declining food prices, in the future, food prices will be likely more coupled with the development of the energy prices. At the same time, higher volatility of agricultural prices can hinder growing investment in agriculture, with the possible consequence of insufficient production and productivity increases. The poorest are most strongly effected by increasing food prices.
- *Climate change*: Agriculture is an important contributor to climate gas emissions, and at the same time, climate change will probably reduce agricultural productivity, production stability and incomes, especially in many tropical and subtropical areas that already have high levels of food insecurity. Therefore, mitigation and adaptation have to be achieved at the same time.
- *Natural resource management*: Natural resources as soil, water and biodiversity are essential to agriculture. They are already under severe threat from degradation and will become increasingly threatened and scarce. Conflicts and competition over access to, and the use of these resources are likely to increase in many regions.
- *Pro-poor development with focus on smallholders*: The vast majority of farmers in developing countries are small-scale farmers. Improvements in small-scale farming are essential in meeting development and sustainability goals.

LOW-INPUT AGRICULTURAL PRODUCTION SYSTEMS 4.

In the context of developing small-scale farming, the most suitable ways of improving agricultural production have to be identified. Candidates for higher food production and sustainable land utilisation in developing countries are agricultural production systems such as Conservation Agriculture, System of Rice Intensification, Organic Farming and Agroforestry systems. Additionally, Rainwater Harvesting – in itself not an agricultural production system but a set of techniques designed to collect rainwater for irrigation use – can be an important component in rainfed agricultural production.

Different combinations of these agricultural production systems are possible – for example, the application of Conservation Agriculture principles in the context of Organic Farming or System of Rice Intensification (see Friedrich and Kassam in this volume). At present, additional concepts are in discussion, such as Conservation Agriculture with trees or Evergreen Agriculture (Garrity et al. 2010) and Climate-Smart Agriculture (FAO 2010c).

Agricultural production systems include every step of the cultivation and harvesting of crops, applying a specific approach and set of practices. Therewith, a broad understanding of agricultural production systems is assumed. These agricultural production systems are suitable for different farm types, from smallholders to large farmers, but the reasoning is centred on small-scale farming. The following discussion of the production systems is based on Meyer 2009 and 2010.

Conservation agriculture (CA) (extensive description and discussion in Friedrich et al. 2009, see also Friedrich and Kassam in this volume) is characterised by *three principles* (see FAO 2008: 120):

> Continuous *minimal or no mechanical soil disturbance* (e.g., non-tillage in combination with direct seeding or direct planting);

> *Permanent organic-matter soil cover* (e.g., crop residues, cover crops);

> *Diversified crop rotations* (or plant associations in the case of perennial crops).

Conservation Agriculture aims to prevent soil degradation and to preserve and/or enhance soil fertility by strengthening natural biological processes above and below the ground. The *objectives* to be achieved with CA are in detail (Meyer 2009: 81):

> to provide and maintain an optimum environment in the root-zone of crops;

> to ensure that water enters the soil so that plants suffer less or no water stress and surface runoff is reduced;

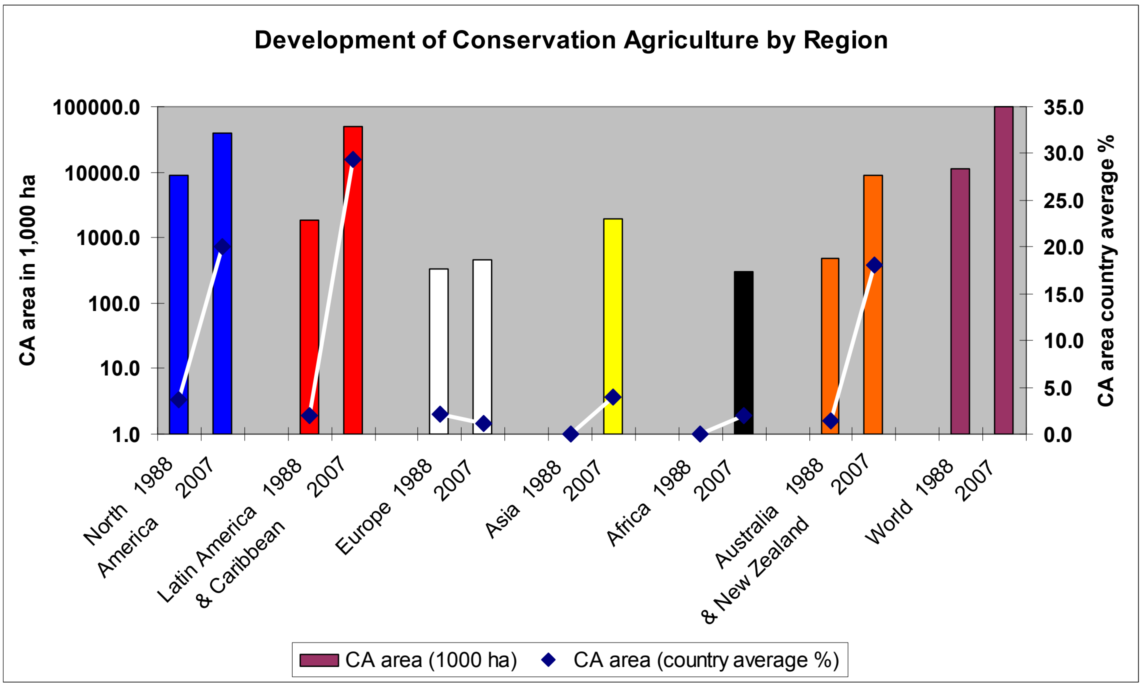
> to favour beneficial biological activity in the soil to maintain and rebuild soil architecture, to compete soil pathogens, to enhance soil organic matter, and to contribute to capture, retention and slow release of plant nutrients;

> to avoid physical and chemical damage to roots that disrupts their effective functioning or limits their nutrient uptake.

Thus CA addresses key problems in tropical and subtropical areas: the danger of erosion due to rainfall is high, soils are usually poor and eroded, and temperatures are high, with the result that decomposition is rapid. As field-based evidence from all continents show (Kassam et al. 2009), CA systems have the potential to raise productivity and income, improve livelihoods and reduce production costs, increase resilience of production, contribute to climate change adaptation and mitigation, enhance water resources and protect ecosystem services and the environment.

CA is used in rainfed and irrigated farming systems and is suitable for different crop types such as grain crops (including rice), roots and tubers, vegetables, perennials and agroforestry systems (Meyer 2009: 16). CA is predominantly used in the cultivation of stable crops and feeds. Worldwide, *nearly 100 million hectares of arable crops are grown without tillage* (Figure 1), with a considerable proportion not following all three CA principles. In the past two decades, no-till has increased most strongly in Latin America, where it is now practised on around 30 per cent of the cropland (Kassam et al. 2009). Asian and African countries have begun to take up CA only in the last 10 to 15 years (Meyer 2009: 84). Although large-scale and/or larger-scale farmers are important actors, CA is also used by small-scale farmers.

FIGURE 1: DEVELOPMENT OF CONSERVATION AGRICULTURE OVER THE LAST 20 YEARS BY WORLD REGIONS



Source: FAO 2008

Important *conditions for a successful introduction of CA* are:

> Availability of necessary equipment for direct seed;

> Knowledge to control weed problems;

> Possibility of a second planting;

> Reduction of temporary high work load;

> Necessity to reduce soil degradation problems;

> No concurrence with other biomass uses in arid and semi-arid regions;

> Openness to change traditional thinking about crop production;

> Farmer organisations with the aim to include small-scale farmers.

SYSTEM OF RICE INTENSIFICATION 4.2

The System of Rice Intensification (SRI) (extensive description and discussion in Uphoff and Kassam 2009) is an innovation in rice production systems and comprises a set of modified practices for managing rice cultivation. These changes to often age-old cultural practices of rice cultivation can be seen as a civil society innovation whose origins lie outside the scientific research system (Uphoff 2006). The *main operational principles of SRI* are as follows (Meyer 2009: 86):

> *Careful transplanting of younger seedlings*: Young seedlings, 8-12 days old, instead of the usual 3-4 weeks old seedlings, are used. Transplanting should be done very carefully but quickly, taking special care to protect the young roots.

> *Wider spacing of plants*: The recommendation is one plant per hill established in a square pattern. The aim of the wider spacing in a square pattern is to give both roots and canopy more room to grow, for taking up nutrients and capturing sunlight.

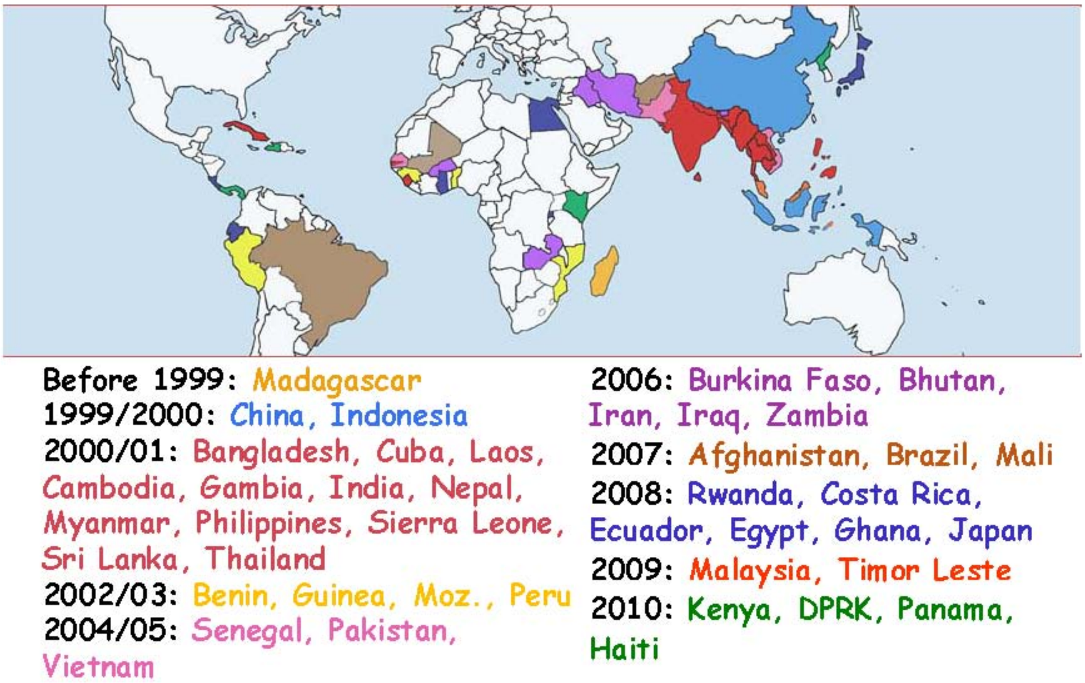
> *Aerobic soil conditions*: The paddy soils should be kept moist but not continuously flooded and saturated to avoid suffocation and degeneration of rice plant roots and to support more abundant and diverse populations of aerobic soil organisms.

> *Enhanced soil organic matter*: As much as possible compost or mulch should be used to enhance the soil organic matter and to "feed" the soil biota which will help to feed and protect the growing plants.

The System of Rice Intensification changes the way in which existing resources are used, and does not require rice farmers to commercially purchase and use any (additional) external inputs. Increases in yield have usually been in the range of 50-100 percent (Uphoff 2011). The improved yields are achieved with less water, less seed and fewer external inputs than in conventional methods of rice cultivation (WWF 2007: 25).

SRI is a relatively young innovation that is still evolving. It has now been demonstrated and become widespread in all world regions except Europe and North America (Figure 2). Its methods have proved to be productive in a wide variety of agroecosystems. In the meantime, the approach has also been applied to other crops. Estimation is that SRI is currently used by one million small farmers producing rice around the world on over one million hectares. The greatest adoption of SRI methods has been in Asia, where 90 per cent of the world's rice is produced (Meyer 2009: 90).

FIGURE 2: INTRODUCTION OF SRI BY YEAR AND COUNTRY



Source: http://sri.ciifad.cornell.edu/images/global/SRISpreadMap102810.pdf

Important *conditions for a successful introduction of SRI* are:

> Openness to change traditional thinking and practice of rice production;

> Availability of organic fertilizer for enhanced soil organic matter;

> Feasibility of changed weed management;

> Incentives for saving of irrigation water;

> Availability of trained workers for the transplanting of young seedlings;

> Participative approaches for extension and advisory services (e.g., farm field schools).

ORGANIC FARMING 4.3

Organic farming (OF) (extensive description and discussion in Hoffmann 2009) relies on ecological processes, biodiversity and cycles adapted to local conditions. Rather than using external inputs, organic farming focuses on input optimisation and deliberately renounces readily soluble mineral fertilizers, synthetic pesticides and performance stimulants (Meyer 2010).

International principles and standards are defined by the International Federation of Organic Agriculture Movements (IFOAM). The *four principles*, including guidelines that go beyond the process of agricultural production itself, are (IFOAM 2008):

> *Principle of health*: Organic Agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible.

> *Principle of ecology*: Organic Agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them.

> *Principle of fairness*: Organic Agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities.

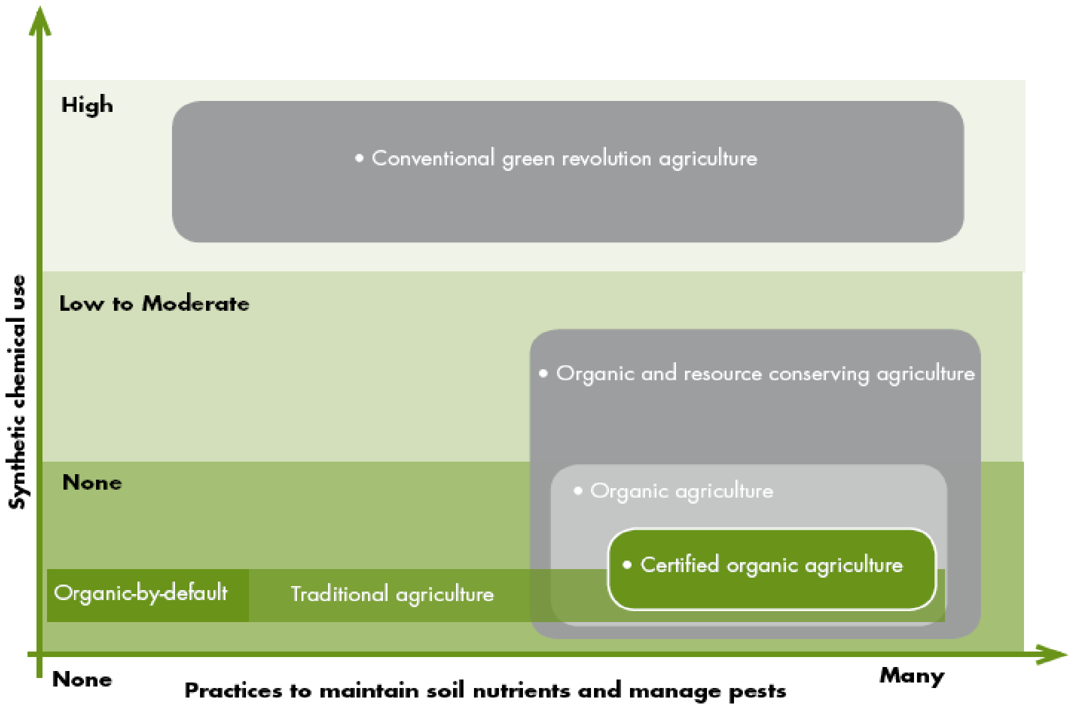
> *Principle of care*: Organic Agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.

In the context of growing international demand for healthy food and its global trading, a highly controlled certification system based on precepts and rules for production has been developed. Additional unique characteristic of Organic Farming is that it represents a legally defined production method for food (Codex Alimentarius Commission 2009; EC 2007). Finally, Organic Farming can also be part of a movement with agro-political and ideological-philosophical influence and/or of a lifestyle.

In developing countries, the shares of grassland (more than half of the organic land in these countries) and those of permanent crops are, compared to Europe and North America, relatively high. This can be attributed to the fact that export plays an important role – either for meat products (mainly from Latin America) or for permanent crops. The most important organic export crops are coffee, olives, cocoa and sugarcane (Meyer 2009: 95).

Organic farming in developing countries is embedded in similar agricultural production systems. Certified organic agriculture produces for national and/or international markets. Beside the certified organic – only these are covered in statistics – exists more organic farming which follows more or less organic production principles without certification (Figure 3). Additionally, a number of common points exist also with other resource conserving production approaches. In the so called "Organic-by-default", farmers also do not use synthetic fertilizers and pesticides, in this case due to poverty and limited access to external inputs. But their practices do not include normally maintenance and enhancement of ecological processes (Bennett, Franzel 2009; UNCTAD 2006: 144).

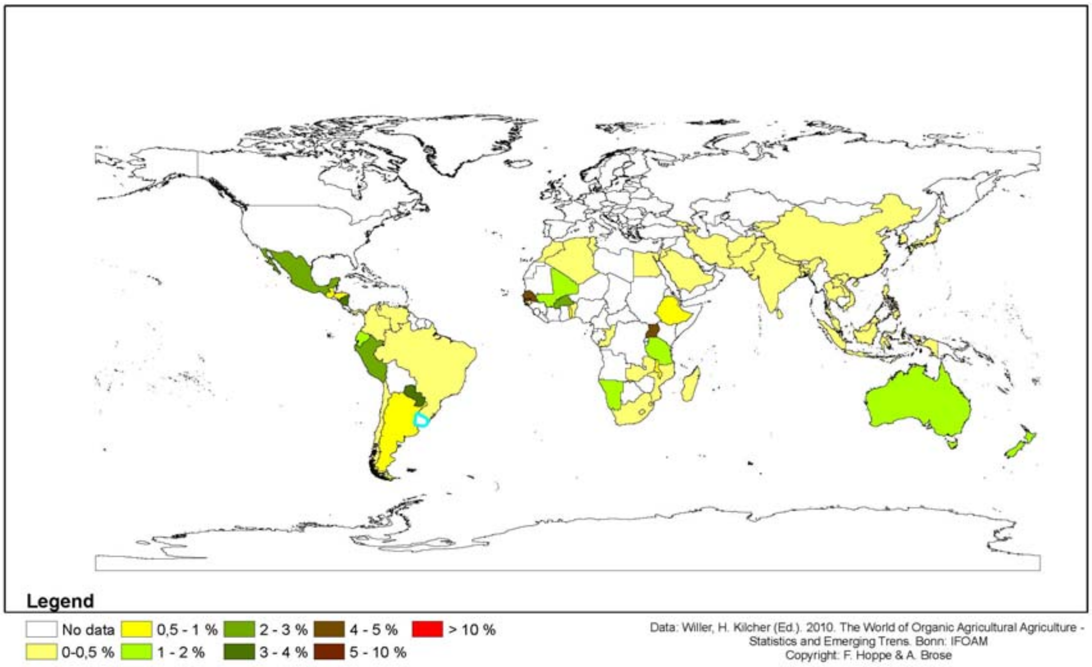
FIGURE 3: VARIOUS AGRICULTURAL PRODUCTION SYSTEMS AND THEIR INTERRELATIONSHIPS IN TERMS OF PRACTICES AND INPUTS



Source: Bennett, Franzel 2009: 4

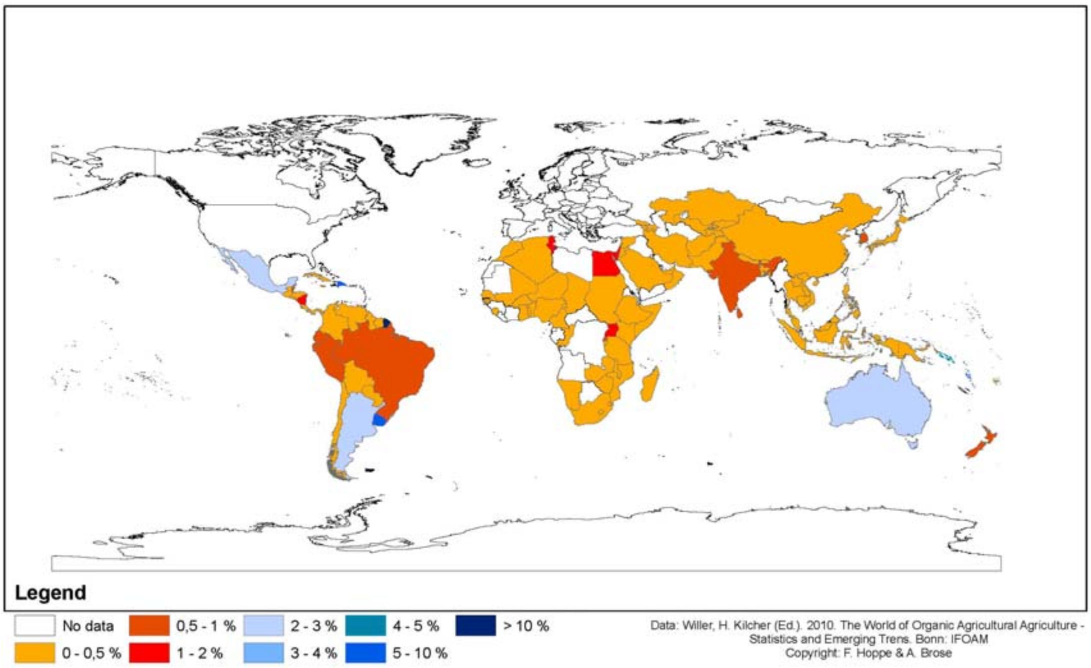
In 2008, 35 million hectares were agricultural land with organic certification, managed by more than 1.4 million farmers worldwide (Willer, Kilcher 2010). Of this total area, around one third is located in developing and emerging countries (8.1 million ha in Latin America, 3.3 million ha in Asia, 0.9 million ha in Africa). The share of Organic Farming area is low in most developing countries (Figure 4). But many organic producers are located in developing and emerging countries. The countries with highest numbers of organic farms are India (340,000 producers), Uganda (180,000) and Mexico (130,000). More than one third of certified organic producers are in Africa (Willer, Kilcher 2010). Nonetheless, the percentage of organic producers is low in most countries (Figure 5).

FIGURE 4: SHARE OF ORGANIC AGRICULTURAL LAND AREA (PERCENTAGE OF TOTAL AGRICULTURAL LAND)



Source: Based on Willer, Kilcher 2010

FIGURE 5: SHARE OF ORGANIC PRODUCERS (PERCENTAGE OF TOTAL NUMBER OF FARMS)



Source: Based on Willer, Kilcher 2010

Important *conditions for a successful introduction of Organic Farming* are:

> Access to markets in developed countries and adequate export organisation;

> Development of local and national market for organic food;

> Infrastructure for market access;

> Solution for certification costs and documentation as an important obstacle for small-scale farmers;

> Availability of extension and advisory services on Organic Farming.

AGROFORESTRY SYSTEMS 4.4

Agroforestry systems (extensive description and discussion in Marohn 2009) are land use systems which combine deliberately interplanted annual crops and trees in different storeys. Agroforestry works on the basis of a *set of reasoning and design principles* rather than fixed planting schemes. The aim is to explore productively a variety of ecological niches while minimising inter- and intraspecies competition. Another key principle is to establish and maintain a tight nutrient cycle, including nitrogen fixation by means of leguminous trees and nutrient pump function by means of deep rooting trees (Meyer 2010). According to their main managed components, Agroforestry systems can be classified into (Marohn 2009):

> *Agrosilvicultural systems*: annual crops and shrubs/trees;

> *Silvopastoral systems*: pasture or cut fodder with animals and trees;

> *Agrosilvopastoral systems*: trees, crops, pasture/cut fodder and animals.

Innumerable systems and designs, adopted to local conditions, are possible, ranging from extensive to intensive systems, from spatially differentiated to sequential systems, and from home gardens to systems with export cash crops.

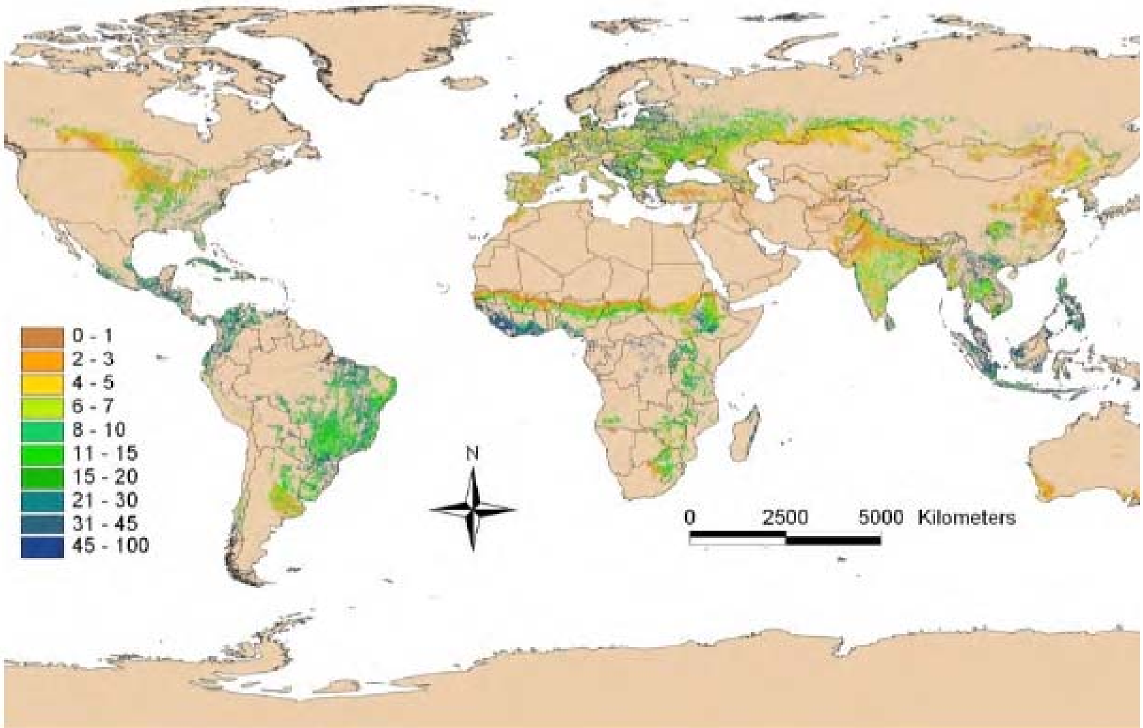
Indigenous and local knowledge is an important source of information when it comes to species selection, tree-site matching, preferred uses and cultural acceptance, and non-governmental organisations (NGOs) play an important role in Agroforestry projects. Various case studies illustrate that, in the long run, Agroforestry systems often prove to be superior to conventional monocropping systems in terms of common economic indicators (e.g., for Bangladesh: Rahman et al. 2007). Agroforests have the ability to mitigate economic and ecological risks, which can be strongly interrelated (Meyer 2010). On a macroeconomic level, Agroforestry products (e.g., coffee, cacoa) account for a significant share (up to 50 per cent) of agricultural export earnings in many developing economies (Meyer 2009: 17).

Statistic data about extent and distribution of Agroforestry system are not available. But the importance of Agroforestry can be measured by two indirect indicators. The first approach describes the *tree cover on agricultural land* (figure 6), based on the following data (Zomer et al. 2009: 4):

> Global land use: Spatial data layers exist which classify any pixel as agricultural or some other land use.
> Global tree cover: Remotely sensed data has been interpreted to give estimates of % tree cover in a pixel.

Result of the analysis is that 17% of the global agricultural land (3.744.544 km^2) involves Agroforestry, based on the assumption that agricultural land with more than 30% tree cover is classified as Agroforestry (Zomer et al. 2009: 14). The data sets and methods used in this analysis have a number of limitations. An important limitation is that information on the tree configuration in the landscape is lacking so that a 50% tree cover in a 1 km x 1 km pixel can vary from 50% treeless crop land and 50% dense forest to 100% trees and crops fully integrated at the finest scale (Zomer et al. 2009: 42).

FIGURE 6: TREE COVER ON AGRICULTURAL LAND



Source: Zomer et al. 2009: 10

The second indicator describes the *regional distribution of major Agroforstery farming systems*, based on the farming system approach (Dixon et al. 2001). Summing-up the land area of these farming systems in Sub-Saharan Africa, South and East Asia (including the Pacific region) and Latin America (including the Caribbean), tree-based agricultural systems in the developing world cover around 425 million hectares (Dixon et al. 2001). The spatial mapping and figures of farming systems is insofar a simplification as they describe the dominant system and don't specify the real extent of Agroforestry systems.

Important *conditions for a successful introduction of Agroforestry systems* are:

> Locally adopted design of the system;

> Knowledge about tree-site matching, upbringing, management, etc. of cultivated trees;

> Compensation for reduced returns in the initial period after establishment;

> Demand peaks of labour affordable;

> Marketing opportunities for multiple products in low quantities.

RAINWATER HARVESTING 4.5

Collecting, storing and concentrating precipitation at different scales, the so called water harvesting, is an ancient technique dating back 4,000–5,000 years. In the last two decades, it is under revival in response to the importance of rain-fed crop production and the escalating water scarcity (Falkenmark et al. 2001, as quoted in IAASTDT 2009b: 134). Eighty percent of the agricultural land worldwide is under rain-fed agriculture, with generally low yield levels (Rockström et al. 2003).

Rainwater harvesting (RWH) (extensive description and discussion in Balke 2009) compromises the collection, filtration and storage of local rainwater and surface runoff and decentralised water distribution systems for domestic consumption, livestock and irrigation. The water can be stored in the soil for the (immediate) water supply of plants, or in cisterns and reservoirs for later use. Various techniques can be applied to reflect local conditions (climate, morphology, soil, etc.) (Meyer 2010).

RWH methods can be applied in any climatic zone with a water deficiency, but existing installations are often not well maintained and need to be improved. The introduction or improvement of RWH systems should be combined with adequate agricultural production methods (e.g., Conservation Agriculture) in order to increase water use efficiency and soil fertility. Examples demonstrate that the crop yield of rainfed cultivation can be doubled and more using RWH techniques (Balke 2009). Compared with other methods of producing usable water (e.g., deep wells), RWH techniques are much cheaper and easier to maintain, making them favourable for resource-poor small-scale farmers (Meyer 2009: 15).

In Burkina Faso, Mali and Niger, formerly degraded and abandoned lands were transformed with the adoption of traditional water-harvesting techniques, for example, tassas in Niger and zaï in Burkina Faso. Farmers are digging planting pits (also known as zaï) across the rock-hard plots. Their innovation was to increase the depth and diameter of the pits and then add organic matter, such as manure, to the bottom of the basins, with the aim to improve soil fertility, water retention and yields. Another innovation based on traditional farming practice was the building of stone contour bunds to harvest rainwater. The total area in Burkina Faso rehabilitated over the past three decades is estimated to be between 200,000 and 300,000 hectares (IAASTDT 2009c: 18; Reij et al. 2009).

In northern Ghana the improved access, adaptation and adoption of soil and water conservation techniques— stone bunds, water harvesting, mulching, composting and planting neem, acacia and mango trees—contributed to a maize yield increase from an average of 0.200 to 1.600 tonnes/ha. Yields of sorghum and millet increased 44 to 120% while farmer income increased 52 to 134% (IAASTDT 2009c: 66).

Rainwater harvesting areas are not well mapped and few statistics are available at the national or regional level. From the AQUASTAT FAO databases, data exist only for Tunisia (898,000 ha), Egypt (133,000 ha), Iran (40,000 ha), and Lebanon (500 ha) (IAASTDT 2009b: 71).

COMMON LINES 4.6

The agricultural production systems outlined above have marked similarities, both in terms of general approach and key objectives (Meyer 2010).

GENERAL APPROACH

All these systems formulate fundamental principles and highlight key elements. These have to be translated on a case by case basis into production technologies and farmer practices adapted to local conditions. A standardised best approach is not possible due to the diversity and variability of agro-ecological and socio-economic conditions associated with farming in general and with less favourable areas and smallholders in particular. The bottom-up approach allows changes to be implemented that reflect local diversity and complexity (Meyer 2010). They avoid reductionist approaches that have a single focus on particular technologies and “interventions” that are seen as silver bullets or panaceas (NRC 2010: 501).

Furthermore, this opens up opportunities to integrate local and indigenous knowledge and traditional production elements in a productive dialogue without simply continuing traditional practices (Meyer 2009: 113). These production systems that are feasible for small-scale farmers may not be high-tech approaches, but are complex systems nonetheless. A high level of knowledge, information and management skills is therefore necessary, requiring learning processes and knowledge sharing (Lee 2005). The introduction of such production systems demands longer-term strategies and more or less far-reaching changes to production practices, whose benefits normally materialise only after some period of time (Meyer 2010).

HIGHER PRODUCTIVITY

Increased yields are frequently reported when traditional or conventional systems with relatively low external inputs – such as are often to be found in small-scale farming – are converted to any of the production systems described above (Pretty 2008). Evidence indicates that productivity can grow over time. This higher productivity can contribute to greater food availability, food security and poverty reduction at different levels: First, more food is available for farm households, especially in subsistence farming. Second, farmers benefit because they can sell surplus food at local markets, thereby increasing their purchasing possibilities. Third, new groups in a community can get involved in agricultural production and marketing, thus generating income for themselves. Finally, surplus from higher on-farm yields can be merchandised to wider communities, national or international markets if market access already exists or can be developed (Meyer 2010).

PRESERVATION AND IMPROVEMENT OF SOIL FERTILITY

Sustaining and improving soil fertility is a common key element. When it comes to protecting the long-term fertility of soils, common objectives are (Meyer 2009: 112):

- to maintain and increase organic matter levels and various grades of humus in the soil,
- to encourage biological soil activities,
- to maintain and rebuild soil architecture and
- to provide crop nutrients by using relatively insoluble nutrient sources which are made available to the plant through soil micro-organisms.

Key methods of achieving these objectives are permanent soil cover and diversified crop rotations. Permanent soil cover can be accomplished by crop residues, cover crops and composts. In the context of crop rotation, important elements are legumes for nitrogen fixation, mixed cropping (especially in Organic Farming) and plant associations in the case of perennial crops (in Agroforestry). In some approaches, careful mechanical tillage which respects soil organisms and soil structure is seen as sufficient to protect the long-term fertility of soils. Minimal or no mechanical soil disturbance – also called non-tillage – is a specific characteristic of Conservation Agriculture. This key element of CA involves directly sowing or broadcasting crop seeds and placing planting material directly in the soil. Non-tillage, and thus the principles of CA, can also be – and in some cases it is – applied in System of Rice Intensification, Agroforestry systems and Organic Farming (see Friedrich and Kassam in this volume). The overall aim of all these systems is to achieve intensification by raising agro-ecological and biological productivity without necessarily increasing external inputs (readily soluble fertilizer, pesticides) (Meyer 2010).

RETENTION AND BETTER USE OF WATER

Rainwater Harvesting for better water collection, storage and distribution needs to be combined with improved water use in agricultural production systems. Better use of so-called green water is closely linked to the preservation and improvement of soil fertility. Good soil condition ensures that

- rainwater enters the soil better, achieving higher infiltration rates,
- water is retained in the soil with the result that plants suffer less water stress,
- residual water passes down to groundwater and stream flow and not over the surface as run-off.

In the System of Rice Intensification, permanent water cover and saturated paddy soils are changed to minimum or alternating water applications and moist paddy soil with aerobic soil conditions. The results are optimised conditions for root growth and soil biota. In consequence, water requirements for irrigation are significantly reduced. Greater water use efficiency is also an important characteristic of Agroforestry systems. Beneficial effects result from an improved physical water retention function (reduction of direct run-off and evaporation thanks to permanent vegetation cover, increased leaf litter, humus and improved soil structure) and a significant reduction in microclimatic extremes (through multi-strata canopies) (Meyer 2010).

PEST MANAGEMENT

The reviewed agricultural production systems include different forms of integrated and/or biological pest management. The aim is to improve the biological regulation of pests and to reduce or eliminate the use of pesticides. Diversified crop rotations and plant associations are key elements to reduce pest pressure (Meyer 2009: 115). In many instances, natural defence systems are exploited. One example is the push-pull system in East Africa maize production, in which different components are designed to push away pests and pull in their natural enemies (Royal Society 2009: 29). Once again, the successful development, adaptation und introduction of integrated pest management is a knowledge- and information-intensive process (Meyer 2010).

WORKLOAD DEMAND AND DISTRIBUTION

A tendency towards a higher workload is associated with Organic Farming and Agroforestry systems, and is required in the initial years for Conservation Agriculture and System of Rice Intensification. A temporary additional workload can also result when building up or restoring Rainwater Harvesting systems. Broader crop rotations, however, mean a better distribution of work and reduce workload peaks (Meyer 2010).

VULNERABILITY OF PRODUCTION

Because they lack resources, reducing production risks and risk aversion in general are of the utmost importance for small-scale farmers. The reviewed systems have great potential to reduce production risks; at the same time, however, they demand a high level of information, adaptation to local conditions and (some) initial investments with delayed returns. This is a major obstacle which has to be overcome if small-scale farmers are to be persuaded of the benefits (Meyer 2010).

OBSTACLES FOR LOW-INPUT INTENSIFICATION IN SMALL-SCALE FARMING 5.

Despite all encouraging experiences, low-input intensification will not happen of its own accord in many cases. The successful development and introduction of low-input intensification and its integration into adapted practices in developing countries depend on a number of enabling conditions. In this last section, some important framing conditions will be discussed, without making any claim to be complete.

SECURE LAND RIGHTS

Land is one of the most important assets for rural people in developing countries. Missing or insecure land tenure is closely linked to poverty, hunger and displacement of small farmers from rural to urban areas (Meyer 2009: 51). In developing countries, roughly 100 million farm families, compromising about 500 million people, lack ownership or owner-like rights to the land they cultivate. Most of these families earn their living as tenant farmers or agricultural labourers. The tenant farmers typically pay high rents and have little security of land possession from season to season (Prosterman, Hanstad 2003: 1).

Low-input intensification approaches such as improving soil fertility or building-up of Agroforestry systems represents a longer-term investment, and such longer term investments demand secure land rights or secure longer-term tenant contracts. Therewith, secure land rights are an important precondition for the successful introduction of low-input intensification.

This is a major problem in Latin America which has the most unequal land distribution system in the world, despite longstanding land reform programmes. Market-based land reforms failed in the past. Beside a large group of landless people, Latin America has a large number of squatters and others with informal holdings, but no legal status. Finally, there are major areas in which indigenous peoples and minority groups claim rights (Meyer 2009: 51).

In Africa, the land rights situation is characterised by legal pluralism with many conflicting and overlapping laws. Only a very low part of land is subject to title, with strong customary and colonial legacy. Common property resources are essential for poorer groups. More than 30% of the land in Africa is jointly held by members of a group or community, making common property rights as important as individual rights. Major disparities exist within the continent: In East & South Africa, large-scale alienation of land by colonial powers, commercial farmers and national parks can be observed; West Africa experiences the continued strength of customary powers, overlaid by sequence of legal, political and institutional changes (Meyer 2009: 52).

But insecure land rights are not always disabling intensification in the complex Sub-Sahara African situation. A case study from southwestern Burkina Faso shows that farmers are intensifying their production systems under uncertain land rights, by manure and fertilizer application, change from fallow to permanent fields, and leaving large number of trees on the field. The tenure status matters little in farmers' decisions to invest in soil fertility. On the contrary, investment in soil quality is used as a strategy to improve tenure security. But it has to be recognised that this development is associated with social costs. The land property rights of poorer farmers are endangered by the intensification, continuous cultivation and tenure right building of wealthier farmers (Gray, Kevane 2001).

OFF-FARM EMPLOYMENT

Smallholders are already quite often engaged with the rural non-farm economy. Non-farm employment partly implies temporary migration to rural towns or urban agglomerations. Subsistence farmers with insufficient production of staple foods need earnings from off-farm employment to supplement their own production with market purchases (Barrett 2008).While non-farm shares of total income among land-poor households are relatively high, their absolute levels of non-farm income are typically not high enough for these households to compensate for the deficient land endowments (Jayne et al. 2010).

Off-farm employment can restrict the available on-farm working force and time. On the other side, learning processes and changes in production systems need at least some additional time. A tendency for higher work demand is associated with Organic Farming and Agroforestry systems, and is required in the initial years for Conservation Agriculture and System of Rice Intensification. A temporary additional work demand can also be the consequence when building-up or restoring of Rainwater Harvesting systems (Meyer 2009: 115). In general, additional on-farm work demand competes with non-farm income opportunities, and their relation depends from the local setting. But off-farm income can also be used to pay wageworker, and therewith, can be a resource for low-input intensification with higher work demand.

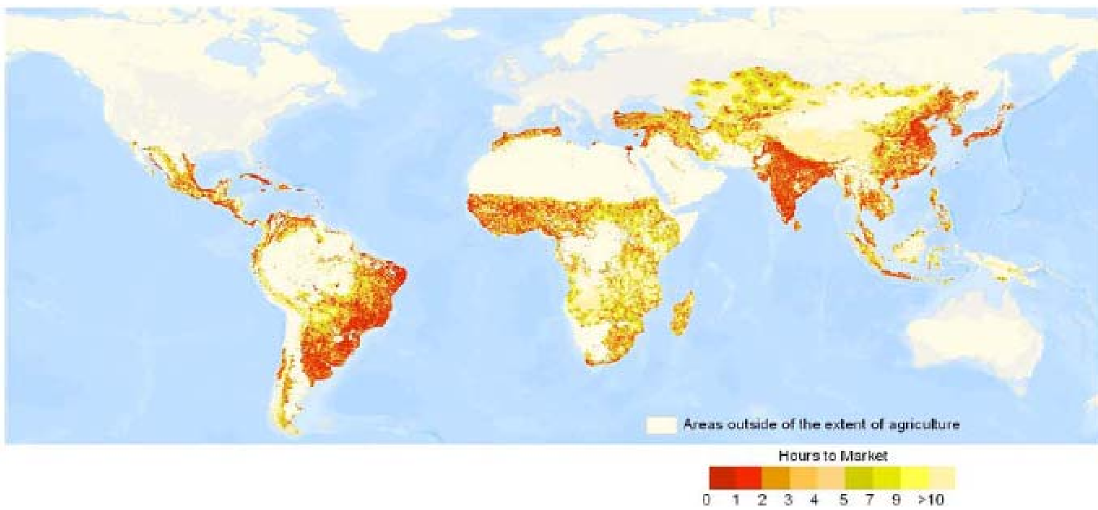
INFRASTRUCTURE

Agricultural development is related to access to markets and services. Rural areas by definition are spatially dispersed, which affect the costs of transport, the quality of public services and the reliance on subsistence production. In developing countries 16% of the rural population or 439 million people live in areas with poor market access, requiring five or more hours to reach a market town of 5,000 or more inhabitants (figure 7) which reflects low and inadequate investments in rural infrastructure (World Bank 2007: 54).

The road system in Africa today is only a fraction of what India had decades ago and leaves about 70% of its farmers poorly connected to markets. Many farmers can neither procure fertilisers and other inputs at affordable prices nor market their own products effectively. Poor telecommunications infrastructure also keeps farmers in isolation. Similarly, poor access to health and education services diminishes agricultural productivity, contributes to the spread of infectious diseases and locks rural people into a poverty trap (InterAcademy Council 2004: 197-199).

In the context of low-input intensification, bad infrastructure has more relevance for the availability of extension services and knowledge exchange than for the access to external inputs such as fertilisers.

FIGURE 7: MARKET ACCESS IN AGRICULTURAL AREAS OF AFRICA, ASIA AND LATIN AMERICA



Source: Sebastian 2007: 9

ACCESS TO MARKETS

Market access is not only important for receiving inputs and information, but also for selling surplus. In subsistence farming, intensification and higher yields beyond the household needs will be realised only if market access exists or can be established. This depends not only from sufficient infrastructure, but also from information, skills and organisation. Facilitating smallholder organisation (cooperatives etc.) is an important step to reduce cost of intermarket commerce and to stimulate smallholder market participation.

A close interdependence exists between production technologies and market participation. The returns to adoption of improved production technologies is fundamentally influenced by the market situation because the gains from cost reducing and production enhancing technologies depend on aggregate supply response and induced price changes: The returns to increased output diminish less quickly in well-integrated markets because excess supply is transmitted to distant locations, in contrast to segmented or poorly integrated markets (Barrett 2008).

Market integration of small-scale farmers is very different from region to region, country to country, and product to product. In staple grain markets, a relatively small group (i.e., less than 10 percent) of relatively well-capitalized farmers located in more favourable agro-ecological zones account for a significant majority of market sales throughout the world (Barrett 2008). In other words, most smallholders are not sellers in staple food grain markets.

The impacts of the changing agrifood system or the so-called “supermarket revolution” (Reardon, Gulati 2008) are ambiguous. On the one hand, this revolution leads to lower food prices for consumers and creates opportunities for farmers and processors to gain access to quality-differentiated food markets and raise incomes. Additionally, sophisticated, efficient supply chain management techniques of modern supermarket chains commonly generate efficiency gains that can be shared among the food chain parties.

On the other hand, modern agrifood chains can create challenges for small retailers, processors and farmers who are not equipped to meet the new competition and requirements from supermarkets. When supermarkets modernise their procurement systems, they require more from suppliers with respect to volume, consistency, quality, costs and commercial practices (Reardon, Gulati 2008).

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GEOPHYSICAL SITUATION AND RESULTING SITE POTENTIALS FOR LOW-INPUT INTENSIFICATION OF AGRICULTURE IN DEVELOPING COUNTRIES

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ABSTRACT

Due to the location of the Tropics, from equator towards the tropic, the climate constraints increase. Together with the consideration of pedogenic properties, it is possible to describe the overall situation for agricultural production. For the implementation and development of concrete local approaches, considering agricultural intensification, the local conditions, additionally the small-scale differences have to be included in the analysis. Consequently, an improvement will only be achieved if it is possible to develop local solutions. The geographical research is still far away from a mature plan, which permits conclusions about the potential in relation to low-input intensification. A first approach is to provide a database for the geophysical facts, which permits predictions of tropical crop yield potentials and assessment of pedogenic bottlenecks. The potential cation exchange capacity is the necessary starting point to calculate the nutrient supply, hence the soil quality. The cation exchange capacity of kaolinite (typical tropical cation) has to be considered due to the difference in the clay fraction of the temperate zone (two- and three-layer minerals). The other parameters reviewing the soil quality have to be determined in situ. The paper presents a manual to evaluate these parameters on the ground and concludes with suggestions for the improvement of agricultural productivity. To achieve a productivity increase, these suggestions have to be used interactively considering local situations.

INTRODUCTION 1.

Due to the location of the Tropics, climatologic constrains on agriculture increase from the Equator towards the Tropics. In combination with information about pedogenic characteristics of soils, the geographic conditions for agriculture can be described. When developing and implementing tangible approaches regarding agricultural intensification, local conditions of the site must be considered, especially regarding its small-scale differences.

Furthermore, comparable assessments of site potentials can only be made if a site description method can be developed which is appropriate to tropic sites both geophysically and in regarding its human specifics. Up to today, we are far apart from having a complex site description technique which allows to draw conclusions on site potentials regarding low-input intensification. However, it is inevitable for geophysical site assessments to create a data base which allows to give applicable statements about pedogenic potentials and pedogenic site bottlenecks. One indicator of major interest for nutrient availability is the potential cation exchange capacity which can be determined from the clay fraction on site.

CLIMATOLOGICAL SITUATION 2.

In accordance with the planetary circulation and the associated precipitation events, increasing constrains on agriculture result from the Equator towards the Tropics. Whereas the Inner (Humid) Topics are referred to as »no constrains« (see map 1), especially water stress is rising towards the Tropics. There, rainfed agriculture is no longer possible and the area has been rated with »severe moisture constrains« (FAO and IIASA 2002; Map 1).

The rate of solar radiation within the Tropics is high enough for agriculture all year. Further, temperature only limits agriculture within the highest mountainous areas. One must take into account that variations in temperature within a day rise towards the Tropics what means that lower temperatures at night may lead to great constrains in agriculture.

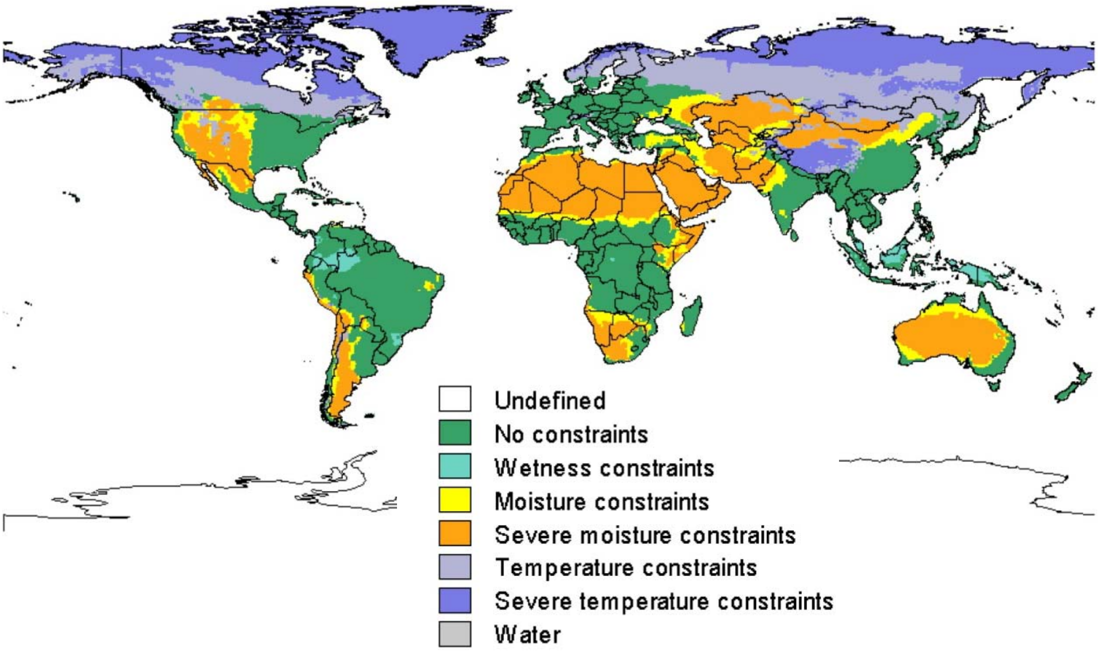
In short: Climatological constrains on agriculture do rise towards the Tropics (see map 1).

Considering the spatial distribution of agricultural land, it is clear that most is located in tropical and marginal tropical regions (see Map 2).

From the soils that are typical for this region, one can deduce the pedogenic potentials which are part of the framework of a low-input intensification. The data basis of that is described more precisely in the authorization paper »Potentiale der low-input Intensivierung in Entwicklungsländern« (Butz 2010).

Pedogenic potentials are deduced from the quality of soils which can be described in more detail after assessing some of its pedogenic processes. In this paper, the most important of those pedogenic processes and their impact on soil quality are explained.

MAP 1 DISTRIBUTION AND TYPE OF CLIMATIC CONSTRAINS ON AGRICULTURE



Source: Based on FAO 2002

PEDOGENIC PROCESSES OF THE TROPICS AND SUBTROPICS 3.

In the Tropics and Subtropics, different soils are formed according to the climatic conditions. Due to the intense chemical weathering, the basic geological ground is of minor relevance, in particular in the wet Tropics.

According to Scheffer and Schachtschabel (1989), there are three zones to be identified in the Tropics and Subtropics which are first Fluvisol-Gleysol-areas in major river systems like the Amazonas, second Ferric/Luvisol-Acrisol-zones in the wet and humid Tropics, and third Vertisol-Nitosol-zones in border areas like the Savannas (ebd.: 45).

In contrast, Weischet (1984) distinguishes especially between the ferralitic bottom fraction of the evergreen rainforest and the fersialitic bottom fraction of the dry savannah. Ongoing, he differs in Vertisoles on calcareous bedrock and Andosoles on volcanic bedrock, especially on ashes (ebd.:92 ff).

Climate is the main driver of soil genesis. As soil moisture is sufficient or even excessive because of annual precipitations of 1,000 mm – 10,000 mm and as the temperature is permanently high, there is both high mineralisation of organic materials and intense chemical weathering of bedrock. Hence, soils become very poor in weatherable minerals and provide hardly any nutrients for plants.

As an extreme result, there are exclusively two-layer clay minerals, specifically Kaolinite and Halloysite, that form in acidic and Si-poor environments only. This happens because of desilication and further because of leaching of alkaline earth cations and alkali cations. In addition, different Al-oxides (e.g. Gibbsite) and Fe-oxides (e.g. Goethite, Hematite) accumulate in soil, which is called ferralisation. Since tropical soils generally have just a very thin humus layer, they are white-grayish or red because of their high Kaolinite or Hematite contents.

Beneath the soil, a voluminous saprolite zone out of partially weathered rock follows on. Within this more than 100 m thick zone of weathered rock, three-layer clay minerals and unweathered minerals are still found.

The previously described soil characteristics limit the potential yields of agriculture strongly. A very acidic environment and the fact that two-layer clay minerals (Kaolinite) dominate, testify to a very low cation exchange capacity. The fast decomposition of the humus layer and an extremely low base saturation are poor conditions for agricultural cultivation.

Soil moisturisation is only possible as Fe-oxide and Al-oxide lead to the cementation of clay minerals to particles of sand size. If that was not the case, rainwater could trickle down to the saprolite zone not or just to a low rate due to the not swellable or just little swellable Kaolinite.

After the protective vegetation cover is removed, tropical soils often are extremely susceptible to erosion. In contact with slope water and fresh air, the terrain edge incrusts. This phenomenon is similar to the formation of Laterite in Plinthosoles which show both the relative enrichment of sesquioxides in the topsoil and, if there is slope water or escaping ground water in sinks, the absolute enrichment of sesquioxides. This enrichment process is also known as plinthisation. It forms a substrate, which used to be named Laterite, but is now referred to as Plinthite. In dry periods and in contact with the atmosphere it hardens and crusts irreversibly.

It is interesting that due to the low pH and high weathering intensity, a high concentration of aluminium and iron is present in soil solution. This is toxic to crops, and the cultivation of less resistant plants such as cotton is not even possible. Tea plants, however, can tolerate relatively high concentrations of dissolved aluminium (<10-20mg / l) (Scheffer, Schachtschabel 1989: 316). In addition, free Fe-ions and Al-ions do strongly adsorb phosphate if the pH is low. Bound on iron or aluminium, the phosphate is not longer available for plants. How legumes can help to solve this issue is to be discussed in detail elsewhere.

Against all expectations, the oldest, most developed soils of the humid Tropics are not very acidic but do have a pH of 5 in some places. This is mainly because after dissolution of all minerals, including the secondary clay minerals, more and more Al and Fe hydroxides form. Thus, an originally very acidic soil can become almost neutral again in the course of time.

In addition to the climatic influences, in particular the age of soils is of great importance. The previously described pedogenic processes run since long times. As a result, few nutrients remain left in the affected soils. Young soils that renew frequently are more suitable for agricultural use. This is the case in regions with rough relief, strong erosion and sedimentation, but also with volcanic activity and flooding events.

Just in younger soils, there are still unweathered minerals that are nutrient sources for plants after they degrade. Further, younger soils are richer in three-layer clay minerals that form in less poor conditions than Kaolinite does. These three-layer clay minerals can even serve as nutrient storage or as silicon and aluminium buffer.

Regarding the developing regions (Butz 2010: 11), typical soil types in agricultural areas can be determined and compared (see Map 2). An output-specific assessment of these soils gives the possibility to make a statement about their agricultural potentials. The classification was made as follows:

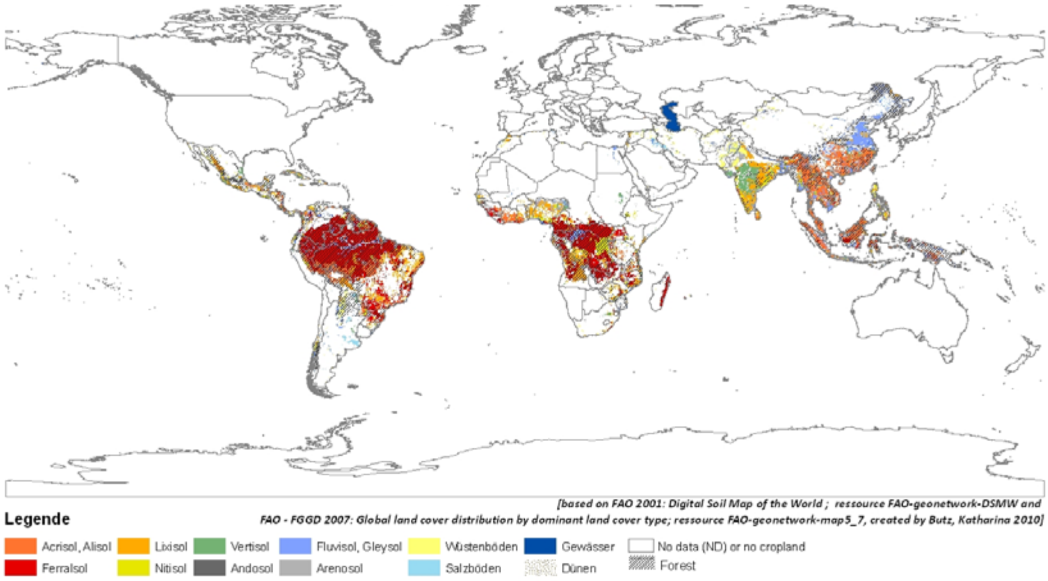
> Among the ferralitic soils are:
  – Plinthosoles
  – Ferralsoles
  – Acrisoles
  – Alosioles
> Among the fersialitic, respectively young soils are:
  – Lixisoles
  – Nitisoles
> The following soils are regarded separately because of their partially recent material supply:
  – Vertisoles
  – Andosoles
  – Fluvisoles

Soil yield potentials can be assigned to the above listed classes based on soil chemical characteristic values:

> Ferralitic soils are characterized by small yield potentials;
> Fersialitic soils by medium yield potentials; and
> young soils (partially with recent material supply) by high yield potentials.

In short: The yield potential of soils, which is derived from soil quality (in particular nutrient supply), is inversely proportional to their age. This is even more the case in the Tropics than in the Mid-Latitudes.

MAP 2 DISTRIBUTION OF SIGNIFICANT SOILS ON AGRICULTURAL AREAS IN DEVELOPING COUNTRIES



Source: Based on FAO 2001, FAO and FGGD 2007

Due to a lack of empirical data for soils of land use areas, generalized soil data was used for this assessment. A regional soil evaluation is essential as general sustainable adaptation of land use systems is not possible on a global scale.

In short: A general and global classification of soil types and yield potentials is not adequate to develop low-input intensification strategies.

As shown in many research papers, there are small-scale differentiations in soil quality within one soil type caused by differences in relief and in former use of the area (e.g. fertilization, wood clearing). Resulting from that, there are also local differences in soil yield potentials and pedogenic bottlenecks. Those are therefore to be assessed locally by making characteristic soil profiles and respectively soil descriptions. A systematic approach to estimate soil yield potentials, based on a few soil characteristics recorded on site, is presented on the following pages.

GUIDELINE TO DETERMINE CROP YIELD POTENTIALS 4.

To determine the yield potential based on soil conditions, some crucial soil characterizing parameters have to be surveyed. These parameters are:

- cation exchange capacity (CEC) and base saturation (BS)
- pH
- humus content

> content of Fe and Al ions

As described in »Guidance for Planning and design processes« (Ministerium für Umwelt Baden-Württemberg 1995: 46), the state of Baden Württemberg assesses the performance of soils derived from clay content, pH and humus content in the upper meter of soil. By these parameters, the content of exchangeable cations can be deduced. Because of their significant impact on nutrient availability, this is one essential factor for determining the yield potential.

When using this method of nutritional assessment, it is to note that the clay minerals that contribute most to the cation exchange capacity in soils of the Tropics are mainly different from the ones in the mid-latitudes. For the State of Baden-Württemberg, there are three layer clay minerals like Illite and Montmorillonite to be found. They both increase the CEC and help in making cations plant available as the minerals adsorb them on their surface.

As aforesaid, in tropic soils Kaolinite forms the biggest clay mineral group. Due to strong chemical weathering in the Tropics, this two-layer clay mineral forms under poor conditions. In Kaolinite, mineral layers are connected via hydrogen bonds. Hence, Kaolinite is poorly or not swellable and, because of non-expandable hydrogen bonds, there are no interlayers for cations to occupy. Next, there is hardly any isomorphous replacement due to low cation concentrations. Thus, Kaolinite is often formed idiomorphic with just a few lattice defects and therefore has low negative charge excess. The variable charge caused by cracks is also low. This is because in the Tropics there are enough H+ ions in soil solution and they compensate the negative charges of the clay minerals, normally by binding at the free oxygen at a crack. This assessment of the clay mineral Kaolinite with respect to the CEC is particularly true for ferralitic soils, but also partly for Lixisols and Nitisols.

For Vertisols, reference values according to table 1 can be used. Because of the high content of Smectites, whose main representative is Montmorillonite, similar CEC based on clay content as in the Mid-Latitudes can be reached. For ferralitic and fersialitic soils, the CEC should be determined empirically depending on Kaolinite or specific regional characteristics.

The cation exchange capacity which deduces from the clay content of soils thus is in the Tropics, especially in the inner Tropics, is usually lower than in the middle latitudes, especially in the inner topics. This peculiarity of tropical soils must be considered when yield potentials are estimated.

TABLE 1 ESTIMATED CATION EXCHANGE CAPACITY (CEC) DEPENDING ON THE CLAY AND HUMUS CONTENT (MMOLC/KG) FOR SOILS OF THE STATE OF BADEN-WÜRTTEMBERG[1]

Humus content	Cation exchange capacity [mmol$_c$ /kg]								
[%] ↓	→ Clay content [%]								
	<3	5	12	20	30	35	40	55	65
<1	60	70	100	120	155	170	190	240	270
2	70	80	100	130	160	180	195	250	280
3	80	90	110	140	170	190	200	260	290
4	90	100	120	150	180	200	220	270	300
6	110	120	140	170	200	220	230	280	320
12	160	170	190	220	250	270	285	340	370
25	250	260	280	310	360	380	400	430	480
35	360	365	390	420	450	465	480	530	570

Source: Ministerium für Umwelt – Baden Württemberg (Hrsg.) (1995): 46 – Anlage 4

DETERMINING THE SOIL COMPONENTS BY THE FINGER TEST

Using the finger test, the soil type and therefore the clay content of a soil can be determined locally. In general, this enables to make conclusions about the field capacity depending on the soil type. The values in table 2, listing water holding capacity in dependence of soil type, also apply for the developing regions. The soil matrix that is also affected by the soil fauna, which further strongly influences water filtration, is not taken into account here. The data in table 2 are from soil core analyses. In this method, soil segments without macropores are taken in most cases. Although it is possible to identify surcharges and reductions for the water-binding characteristics depending on the organic matter content, the intervention of soil organisms remains unconsidered. The field capacity values derived from table 2 hence are no absolute values but can be used for comparison of surveyed water availabilities.

1 These reference values have to be determined again with respect to the tropical clay mineral spectrum if necessary. Its spectrum is significantly different from that ones in the mid-latitudes and hence CECpot, which is dependent on the share of clay minerals, show different absolute values.

TABLE 2

AIR CAPACITY, AVAILABLE FIELD CAPACITY AND HYGROSCOPIC WATER IN % VOL WITH RESPECT TO SOIL TYPE AND DRY BULK DENSITY

Soil type	Air capacity pores > 50 µm (FC < 1,8)			Available field capacity pores 0,2 to 50 µm (pFC 4,2 to 1,8)			Field capacity pores ≤ 50 µm (FC ≥ 1,8)			Hygroscopic water pores ≤ 0,2 µm (FC ≥ 4,2)		
Symbol	ρt1 + 2	ρt3	ρt4 + 5	ρt1 + 2	ρt3	ρt4 + 5	ρt1 + 2	ρt3	Pt 4 + 5	ρt1 + 2	ρt3	ρt4 + 5
Ss	36	32	27	9	7	7	14	11	10	5	4	3
Sl2	23	18	13	20	18	17	28	25	23	8	7	6
Sl3	18	15	10	22	18	17	34	27	25	12	9	8
Sl4	18	12	8	22	18	15	36	30	26	14	12	11
Slu	14	10	7	23	21	19	38	33	30	15	12	11
St2	24	20	15	18	16	13	26	22	18	8	6	5
St3	18	14	9	18	15	12	36	30	26	17	15	14
Su2	24	21	15	20	18	17	26	23	21	6	5	4
17	17	14	10	25	21	20	35	29	26	10	8	6
Su4	14	11	8	27	23	21	39	32	28	12	9	7
Ls2	13	9	6	21	16	14	40	34	31	19	18	17
Ls3	15	9	6	21	16	14	39	33	30	18	17	16
Ls4	15	11	7	20	16	13	39	32	28	19	16	15
Lt2	11	7	5	18	14	1	42	36	32	24	22	21
Lt3	8	5	3	17	12	10	45	39	35	28	27	25
Lts	10	6	5	17	14	11	44	37	31	27	23	20
Lu	12	7	4	21	17	15	41	36	33	20	19	18
Uu	10	7	3	30	26	23	43	38	35	13	12	12
Uls	13	8	5	24	22	21	39	35	33	15	13	12
Us	11	9	4	28	25	22	41	35	32	13	10	10
Ut2	10	6	3	28	26	23	40	37	35	12	11	12
Ut3	11	6	3	26	25	23	39	37	35	16	16	16
Ut4	12	7	3	23	21	19	39	37	15	16	16	16
Tt	4	3	2	15	13	*12*	51	43	35	36	30	23

Tl	5	4	3	15	13	11	48	41	35	33	28	24
Tu2	5	4	3	16	12	10	47	42	36	31	30	26
Tu3	8	6	3	17	13	10	45	38	35	28	25	25
Tu4	10	6	3	19	17	16	41	37	35	22	20	19
Ts2	*5*	*4*	*3*	*16*	*13*	*12*	*47*	*39*	*34*	*31*	*26*	*22*
Ts3	*7*	*6*	*5*	*16*	*13*	*11*	*45*	*37*	*32*	*29*	*24*	*21*
Ts4	*13*	10	6	*17*	14	11	*43*	32	30	*26*	18	19
Sands[1]												
fS, fSms, fSgs	34	31	21	10	9	8	16	14	12	6	5	4
mS, mSfs, mSgs	36	32	26	9	6	5	14	10	8	5	4	3
gS	38	33	29	8	5	4	12	8	6	4	3	2
Total pore volume = Air capacity + field capacity [mass-%] Hygroscopic water = field capacity – available field capacity [mass-%] *Numbers in italics* = interpolated values; 1 = lower FC-limiture sands < 2,5												

Source: Bodenkundliche Kartieranleitung 2005: 342

In what extent possible advantages on infiltration through pseudo sand structures is given has to be discussed elsewhere. However, the high contents of clay and sesquioxide result in a coarser matrix as it would be assumed initially from the grain size of clay. Anyway, table 2 can be used both to roughly estimate water availability and to assess water availability in the soil.

As described in the section above, the potential CEC can be estimated from the clay content and by means of reference values.

Formula 2 (page 17) is used to calculate the real content of alkaline cations from the potential CEC. It is to be noted that the humus content must be considered in the assessment of the potential CEC. Humin acids do significantly increase the negative charge excess in the soil and thus the potential CEC (table 1). This is not only the case for the Mid-Latitudes, but also for the Tropics. To determine the potential CEC, it is necessary to estimate the humus content from the soil color in more detail (see Section: determination of the humus content).

PH DETERMINATION IN SITU

pH is one of the most important and easiest to determine parameters to assess a soil. Not only does it give information about the latest state of a soil, but it also gives indication of former pedogenic processes.

It impacts the (biological) availability of mineral nutrients for plants. Besides phosphorus, sulfur and potassium, nitrogen is of special relevance for the nutrient balance of plants. Plants ingest nitrogen through water-soluble NH^{4+}-ions or more often through nitrate ions (NO^{3-}). Ammonium and nitrate in soils are in balance at pH 7. In acidic soils NH^{4+}-ions dominate, in alkaline soils NO^{3}-ions do so.

If plants can only consume NH^{4+}-ions due to the selective permeability of their root membranes, they are dependent on acidic soils and therefore named acidophil (acid loving). At pH of higher than 6 or lower than 4, nutrients are fixed in soils and hence insufficiently accessible for plants. At low pH, manganese or aluminium compounds dissolve and become available for plants in damaging quantities.

pH can be determined in situ by measuring with the “Hellige pH meter”.

SHARE OF SESQUIOXIDE IN SOILS

Another major factor not to be neglected in the Tropics is the share of iron oxide in soils. To determine its share, a method based on soil colour is useful. Applying this method to determine the share of iron oxide, it’s constrain on yield potential can be investigated in situ. For this purpose, hue, chroma and value are determined by the Munsell color system.

This system is based on Newton’s theory of colours. This implies, that every colour, and in the case of soils accordingly the main groups of iron oxide, can be determined reliably by the three characteristics hue, chroma and value. On site, an assessment of the main iron oxide groups can be made by comparing the soil colour to the Munsell system. As everybody has a personal colour perception, this subjective method has some errors. But after some practice, conclusions can be drawn about soil characteristics (Bodenkundliche Kartieranleitung 2005: 109).

Furthermore, the aluminium content is a major parameter for assessing the yield potential of tropical soils. Especially in soil solution, aluminium is very toxic and reduces the rooting capability of the topsoil layer. To determine aluminium qualitatively and to estimate the aluminium concentration in situ is not very complicated either. To determine aluminium quantitatively requires a laboratory analysis.

Evidence of aluminium by Morin: If aluminium is present, it dissolves when adding hydrochloric acid to a soil sample. Next, the solution is made strongly alkaline by adding potassium hydroxide (KOH). If adding some sample solution with the same volume of Morin to a spot plate and acidifying with concentrated acetic acid (CH_3COOH), it shows green fluorescence on exposure of UV ($\lambda = 366$ nm). The test is validated, if the fluorescence disappears after adding hydrochloric acid. This happens because Al(III) forms a fluorescencing colloidal suspension with Morin in an neutral or acetic medium (Roesky 1998: 76).

For reducing the toxic impact of dissolved aluminium in soil solution, humus content of a soil is of significant importance, similar as it is for the estimation of the CEC. Humic matter can complex with Al ions which are bound in a non-toxic form that way.

Further, aluminium can bind to clay minerals. However, this is not given for aluminium because both of its low negative permanent charge and its strong chemical bonds in the interlayers.

DETERMINATION OF THE HUMUS CONTENT BY A CHANGE IN COLOR AFTER HUMIDIFICATION

The content of organic matter in soil can primarily be estimated on site from the colour of a horizon. However, this estimate is inaccurate and should be validated by laboratory tests. On site, the humus content can be estimated and classified by reference to the values listed in table 3 and 4. By the colour of a horizon or by its value according to the Munsell system, one can find the humus content (in steps) depending on the degree of humidification and the soil type in table 3. Finding the determined number in table 4, one can determine the humus content in percentage of the total soil.

TABLE 3 ESTIMATING HUMUS CONTENT OF MINERAL LAYERS FROM SOIL COLOR AND FINE SOIL TYPE

Color	Lightness = Value-Munsell	Humus content (classes)					
		Humid condition/soil type			Dry condition/soil type		
		Ss G	SI to Ls	L, U, T	Ss, G	SI to Ls	L, U T
Light grey	7	h0	h0	h0	h1	h1	h1
Light grey	6,5	h0	h0	h0	h1	h1	h1 to h2
Grey	6	h0	h0	h0	h1	h1 to h2	h2
Grey	5,5	h0	h0	h1	h2	h2	h3
Grey	5	h1	h1	h1	h2	h3	h3
Dark grey	4,5	h1	h1	h1	h3	h4	h4
Dark grey	4	h1	h1	h1 to h2	h3 to h4	H4 to h5	h4 to h5
Black-grey	3,5	h1 to h2	h2	h2 to h3	h4	h5	h5
Black-grey	3	h2 to h3	h3	h3 to h4	h5	≥ h6	≥ h6
Black	2,5	h3 to h4	≥ h4	≥ h4	≥ h5		
Black	2	≥ h4					

Source: Bodenkundliche Kartieranleitung 2005: 111

TABLE 4 CLASSIFICATION OF SOILS ACCORDING TO THEIR HUMUS CONTENT (ORGANIC MATTER)

Symbol	Mass-%	Description
h0	0	Free of humus
h1	< 1	Very low humus
h2	1–2	Low humus
h3	2–4	Moderate humus
h4	4–8	Strong humus
h5	8–15	Very Strong humus
h6	15–30	Extreme humus, mucky soil (e.g. Aa horizon)
h7	> 30	Organic horizon (H;L;O)

Source: Bodenkundliche Kartieranleitung 2005: 112

To get the yield potential derived from the nutrient availability of a soil, it is not enough to know the potential CEC. It is necessary to calculate the share of exchangeable cations, what is referred to as the "effective CEC". To determine this share, the proportion of bases in the potential CEC is needed.

The amount of bases is strongly correlated with the pH and hence is determined by the pH. With Table 5, one can deduce the base saturation from the pH. From that, one can calculate the amount of exchangeable cations which is named the effective CEC (also CEC_{eff} or S-value). Here, formula 1 is used (see later on this page).

TABLE 5 ESTIMATING THE BASE SATURATION (BS) OF SOILS FROM PH IN THE STATE OF BADEN-WÜRTTEMBERG

pH	≤3,0	3,2	3,4	3,6	3,8	4,0	4,2	4,4	4,6	4,8
BS (% of CEC)	1	7	15	22	28	34	40	46	52	57
pH	5,0	5,2	5,4	5,6	5,8	6,0	6,2	6,4	6,6	≥6,8
BS (% of CEC)	62	67	72	76	81	85	89	93	97	100

Source: Ministerium für Umwelt Baden Württemberg 1995: 46 – Anlage 4

Hence, it is

CEC_{pot} [cmolc/kg] = (S-value + H-value) [$cmol_c$/kg] [Formula 1]

with: S-value: Sum of base cations [primarily Ca^{2+}, Mg^{2+}, K^{+}, NH^{4+}]

H-value: Sume of acidic cations [primarily H^{+}, Al^{3+}, Fe^{3+}]

The share of exchangeable cations:

S-value [$cmol_c$/kg] = (BS[%]/100) · CEC_{pot} [$cmol_c$/kg] [Formula 2]

With reference to the yield potential of tropic soils, one can conclude that higher humus contents in topsoils impact twofold. First, humus increases CEC and base saturation and second, it decreases the toxic impact of aluminium. As evident from table 1, the humus content has significant influence on the potential CEC.

When increasing the humus content by approx 10%, $CEC_{pot.}$ increases by 100 mmolc/kg. With respect to soil improvement methods one can say, that clay minerals make little contribution to the CEC in the Tropics and hence the humus content is of major importance there rather than in the mid-latitudes.

Short conclusion: Similar as it is described in the Guideline to assess the potential of soils in the state of Baden-Württemberg, the most important parameters to determine *the yield potential in detail can be derived on site from pH, finger test and color description of the soil material.*

A classification of the nutrient supply can be made according to Table 6. Soils in class 1 have very low, soils in class 5 very high nutrient supply (Bodenkundliche Kartieranleitung 2005: 33).

TABLE 6 CLASSIFICATION OF NUTRIENT SUPPLY IN SOILS ACCORDING TO THE SHARE OF EXCHANGEABLE CATIONS IN MOLC/M²

Exchangeable cations (mol $_c$ / m²)	< 30	-100	-300	-400	> 400
Classification	1	2	3	4	5

Source: Ministerium für Umwelt Baden-Württemberg 1995: 45

When the soil characteristic values[2] that give information about the yield potential are classified, especially young soils with recent material input show high yield potentials. Plus, a moderate pH, high CEC and moderate to high base saturation support this assumption. Nevertheless, these soils also are limited in their usage because they are in parts difficult to treat (high content of smectite, constrains in rooting).

Ferralitic soils do have low yield potentials for three reasons. First, this is the low pH, second the low CEC and third its extraordinary toxicity. In how far ferralsoles can be classed amongst the group of soils with moderate yield potential cannot be estimated here du to a lack of empirical data. Nevertheless, it is quite possible to designate these soils as to have average yield potential if the toxicity is not too high and the P-fixation can be limited by cultivation techniques. That is because of its moderate pH (4-5), its average workability and its good rooting.

Lixisoles and Nitisoles are stated as to have average yield potential since they both have moderate CEC, in parts high base saturation and pH between 4.5 and 7. Apart from certain vulnerability to erosion, these soils do not have any further constrains regarding workability. Here is some potential for improvement by low-input intensification of agricultural land, in particular by better adaption to the geophysical resources of the region.

In soil description, further factors like hydrological conditions and special climatologic conditions can be incorporated. Further, it is important to consider socio-economic factors in sustainable system approaches. Amongst others, these are market proximity, range of products, mix of subsistence – and market-orientated products as well as farm size and individual goals of farmers.

2 Expected soil characteristic values (specific values for pH, CEC, humus content) from Zech, Hintermaier-Erhard 2002, Beurteilung der Kennwerte in Butz 2010: Anhang 1)

In short: Local experts can help in establishing sustainable system-oriented approaches as they see the whole spectrum of options.

Within the next section, measures are introduced that should be considered when developing sustainable low-input intensification systems. These methods pay special attention to site-specific pedogenic bottlenecks.

CONCRETE LOW-INPUT MEASURES 5.

Pro-poor low-input intensification of agricultural land is always based on adaption to the site and improvement in resources management. Concrete integrative suggestions derive from system-oriented approaches.

Within the various system elements that must be coordinated, there is certain flexibility in their design, for example in crop rotation or mulch composition. That means, for example, the variation of crops within the system has to be ecologically balanced and it has to be assessed as a closed system. When the crop variety that is best for this closed system is determined, other factors have to be considered like subsistence – or market-orientation of local farmers. Ongoing, the possibilities within one system element are explained.

VEGETATION DESIGN

For the purpose of system diversity, a vegetation design is targeted approaching maximum vegetation diversity, as it is done for example in agroforestry systems. Plant cultures near to the ground, shrubs and trees should grow into one another (Rottach 1984: 101). Various elements in vegetation design are to be combined in a way with as little competition as possible, for example regarding nutrients, sunlight and water. They should complement each other in their needs. This way, productivity per unit area can be maximized.

A vegetation system covering several levels should not be cultivated just within agricultural land but also at its edges as it is for the benefit of erosion reduction. For example, hang parallel vegetations stripes of shrubs and trees defend against erosion in that they stop downslope and they gradually lead to terracing of the site. Even on flat land, planting farmland edges with shrubs and trees can be of use as wind protection. This reduces both aeolian-related evaporation and soil erosion. Besides the ecological benefits of vegetation diversity, firewood and timber can be taken from trees.

According to Schweizer (2001), *bactris gasipaes* can be an element in agroforestry systems. First, this palm can raise the share of nitrogen in soil by building mykorrhizas, and second, its litter benefits to the chemical soil properties. The fruit can be used as animal feed and suits for human consumption because of its high starch. From the seeds, the so-called "Macanilla fat" can be made, and the shoot of young, about 2 year old plants is partly used to produce heart of palm. (Loetscher 1985: 79).

IMPROVEMENTS IN WATER MANAGEMENT

In rain fed cultivation, improvements in soil moisture and additional irrigation can result in increasing yields. The focus is not on expansion of the agricultural used area like it was in the past, but on increasing yields per unit area. According to Meyer (2009), strategies of sustainable intensification require integrated management of soil, water and nutrient. For sustainable system development, this could be rainwater harvesting for additional irrigation, organized by run-off management. In addition, the use of organic and mineral fertilizers and the further cultivation of legumes in crop rotation play a significant role.

IMPROVEMENTS IN NUTRIENT BUDGET THROUGH FERTILIZATION

ORGANIC FERTILIZATION

High quality humus management can be developed if all produced organic waste is recycled by composting and mulching. In doing so, the soils humus content and the nutrient cycle are improved. For the soil, the higher humus content and in particular humic acids result in higher sorption capacity. The higher sorption capacity decreases nutrient eluviation and complexes dissolved aluminium ions.

Organic fertilizers also increase the plants defense against pests and diseases (increasing the antiphytopathogene potential) and further contribute significantly to the cation exchange capability of soils (Knoll 2009: 148).

In addition to the external input of nutrients, the potential CEC, or respectively the soils sorption capacity, has to be increased. This can be done either by increasing the pH or by creating free ends at humic acids and cations. At these places, further cations can bind exchangeably.

MULCHING INSTEAD OF BURNING

Regarding its long-term use, the type of organic matter is of importance. After slash-and-burn, nutrients are washed out quickly. Unweathered plant residues have a significantly longer fertilization effect (Knoll 2009: 90ff.).

Using shredded plant material, preferentially legumes, hence is one of the most appropriate ways to mulch. In doing so, nutrients are distributed equally and released gradually. Further, it increases the activity of soil fauna. Fungi, bacteria and other soil organisms keep the decomposition process going. Plant and animal degradation products enrich the soil with humus and provide a favorable crumb structure (BMBF 2001: 21).

In contrast to burning, this results in the best case in a long-term balanced nutrient budget. Here, higher quantities in mulching bring more advantages for soil-chemical parameters than higher quality does (Knoll 2009: 148). Mulching only is an appropriate alternative if local farmers see the benefits and know how to utilize the process and if they can apply the method by the available means. It would be imperative to provide shredders at the local level. Shredding all required plant material to mulch 1-2 acres by hand is not a feasible option for the farmers.

The impact of organic matter on soil fauna: The impact of soil fauna on the chemical and physical soil properties is not to be underestimated. Mulching leads to increasing macrofauna activity. Earthworms mix the soil substrate and organic matter, in a way they plough the ground. Because of the biogenic structures, the infiltration of water is improved. By a system of tunnels and chambers and by the input of organic matter, macrofauna has a vital impact on soil chemical parameters and porosity (Knoll 2009: 146).

After all, the input of organic matter by mulching leads to increased integration of organic matter (Knoll 2009: 146). It is of special importance not only to sustain the activities of a vivid macrofauna but also to increase it. In mulching, this is mainly accomplished by putting out plant residues and integrating them into soil.

FERTILIZATION WITH LIMESTONE, TRAVERTINE OR VOLCANIC ASHES

As exchangeable cations are much lower in parcels solely fertilized with organic matter as in parcels fertilized with rock flour or volcanic ashes, it is recommended to fertilize with a mix of organic matter and volcanic ashes or travertine (Stache 1997: 63). Fertilizing only with organic matter results in lower pH as carboxyl groups dissolve. Hence, dissolved toxic Al^{3+}-ions may form despite the soils ability to complex Al ions (Stache 1997: 63).

Both to sustain high pH and to secure long-term nutrient supply, limestone, travertine or volcanic ashes should be used additionally in fertilization. Volcanic ashes bring the longest-lasting fertilization effect due to the slower weathering of its minerals. Using limestone, the highest pH results can be achieved, but similar to fertilization with organic matter only, this can result in the formation of Al^{3+} and hence in aluminium toxicity. In this regard, travertine works better. Whereas the resulting pH is lower as after using limestone, the share of Ca^{2+} and Mg^{2+} in base saturation is higher (Stache 1997: 58 ff.).

To what extent the combination of undecomposed plant material, kitchen waste or dung and travertine or volcanic ashes suits best for development measures has to be decided locally depending on site conditions. It is not to forget that a mix of mulching and fertilization seems to be the thing to do. In doing so, on the one hand macrofauna activity can be increased and on the other hand, cation exchange capacity can be improved.

COMPLEMENTARY MINERAL FERTILIZER

Complementary mineral fertilizer should only be used to compensate the loss of nutrients from soil eluviation or sold yields and hence to avoid gradual soil degradation. However, N-fertilizer is not to be taken as it decreases nitrogen fixation done by soil microorganisms. Slightly soluble fertilizers are to be applied as they ensure long-term nutrient supply and hence help to reach a maximum in productivity (Rottach 1984: 104).

INTEGRATED KEEPING OF LIVESTOCK

Integrative systems mixing crop and livestock land use show the highest yield potential per area (Rottach 1984: 100). In addition, extensive pastoral economy can be replaced by indoor stock keeping and fodder cropping with Pennisetum and Setaria. One part of the required fodder can come from pruning the vegetation stripes used in erosion management. Here, especially Laucaena, Morus and Cassia are appropriate as fodder (Rottach 1984: 103).

CONCLUSION 6.

Depending on the location, a combination of some of the above described improvement measures will result in increasing yield potential or respectively in different yield orientation and yield assurance. This aims to secure adequate supply and to serve regional markets, and if there is adequate infrastructure, followed by serving national and international markets. This can result in sustainable agricultural development.

Here, applying one or two improvement measures does not increase yields but coordination of different cultivation elements with each other and matching them to the specific site does. Hence it is complex to frame concrete approaches that remain valid. However, the following is substantial for agricultural development aiming both to secure supply and to be sustainable:

- Changes within the system must be geared towards adopting agriculture to the site with the objective to compensate site bottlenecks.
- Within one system, there should be several different products with both subsistence- and market orientation.
- Regarding agricultural systems as closed systems, they can be stabilized by the integration of agroforestry elements that comply with the rules of ecologic growing systems.
- Each System can only generate developments that are accepted both by the specific farmer and that are within the farmers capabilities.

Thus, these principles set the frame for implementing low-input intensification in developing areas. To integrate human-specific potential in the development of measures, other local factors like market proximity, recent range of products, regional networks, and cultural characteristics have to be considered. It is recommended to reassess each single approach locally, to adjust it if needed and to develop it further according to the local circumstances.

Furthermore, the guidelines for the determination of soil yield potentials should be reviewed to ensure reasonable soil descriptions on site. In doing so, one must consider that clay minerals in the Tropics are of a different type than in the mid-latitudes and hence, a comparative study regarding the CEC in the Tropics is required. This issue of basic research must not remain disregarded in describing agricultural yield potentials regarding low-input intensification as this fact impacts significantly on the local intensification options.

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ORGANIC FARMING AND MARKETING CHANNELS IN TANZANIA: CHALLENGES AND CHANCES FOR DEVELOPMENT[3]

Shilpi Saxena

ABSTRACT

There is a growing demand for organic agricultural produce in and from Africa (Parrott and Kalibwani 2005), leading to income generating opportunities for farmers all over Africa. This includes vegetable produce. Despite the rise in demand, the domestic market for organic vegetable produce has not been developed. Small-scale farmers who do practice organic agriculture in Africa find export markets in the US and the EU more attractive than domestic markets (Organic Monitor 2006). However, it is risky for small-scale farmers to rely solely on the export sector. Domestic and regional markets in Africa can be good fallbacks.

No detailed research has been conducted on organic vegetables for the African market. Most research has been geared towards export opportunities for East Africa. Local NGOs that teach small-scale farmers organic agricultural practices do not explain to farmers how to efficiently market their organic produce. There are numerous constraints in the supply chain from the farm gate to the consumer. Therefore, this paper assesses constraints in the supply chain to explore better marketing strategies for small-scale organic vegetable farmers in order to improve their income.

The research project has collected data from a questionnaire survey of more than 200 small-scale organic vegetable farmers, about 70 wholesalers, middlemen, and retailers in the intermediary sector, and more than 200 consumers on aspects of organic vegetable production such as volume, prices, uses, transportation to the market, marketing difficulties, selling points for the main products, main customers, awareness of organic vegetables by market supply chain actors and consumers, and consumers' willingness to pay for organic vegetables. The consumers were chosen by stratified sampling (by income and location), mainly at supermarkets and organic shops, latter additionally in Dar-es-Salaam.

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3 This paper is mainly based on two papers presented at the Tropentag 2007 "Organic vegetables: Domestic and regional marketing constraints and opportunities for small-scale farmers in East Africa" (Saxena 2007) and at the Tropentag 2008 "Increasing income by improving marketing strategies for small-scale organic vegetable farmers in Tanzania" (Saxena 2008).

The *first part* of the paper gives an overview of organic agriculture in East Africa, while the *second part* characterizes the supply chain for marketing organic vegetables in Tanzania.[4]

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BACKGROUND OF ORGANIC AGRICULTURE AND PRODUCTION IN EAST AFRICA 1.

ORGANIC FARMING IN EAST AFRICA 1.1

Certified organic farming is practised throughout Sub-Saharan Africa, but is concentrated in East Africa, particularly Kenya, Uganda and Tanzania (Figure 1). The total certified organic production area in Africa is still very low, comprising just 0.2% of the total agricultural area (Parrott et al. 2006). Most organic products are geared towards the export markets of Europe and the USA, and are affected by volatile market prices and demand. It is important that small-scale organic farmers reduce their risks by building up domestic and regional markets for organic produce in Africa (Organic Monitor 2006).

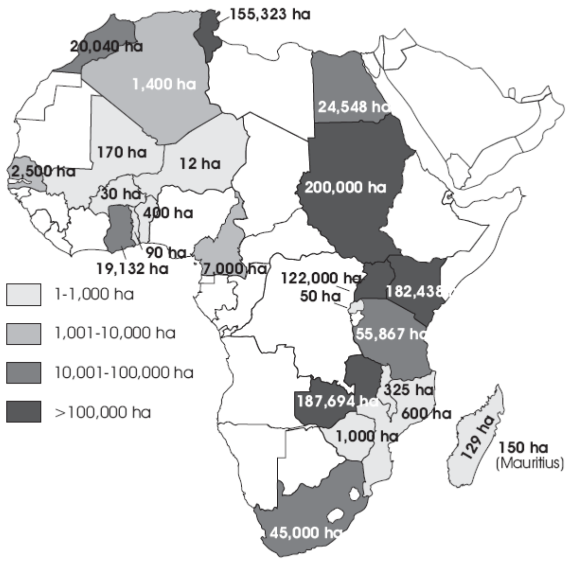
Two types of organic farming can be found in Africa: certified and non-certified, the latter being often perceived as "organic by default" as farmers either have been bypassed by the Green Revolution or simply do not have enough money to pay for agricultural inputs. Farmers who are default organic farmers constitute the majority. In Uganda for example, such traditional, non-certified farming accounts for about 85% of the total farming area, comprising over 2 million hectares (Tumushabe et al. 2006).

Within the certified sector, there are large export-oriented farms converting to organic production in Zambia, Malawi and South Africa, and small-scale farmers who produce their export commodity through organisations, co-operatives or companies such as

4 The research results presented in this paper regarding Tanzania were part of a larger project developed by the author on organic vegetable marketing with surveys conducted in Senegal, Tanzania and South Africa from February till June 2008.

those in Tanzania and Uganda (Hine and Pretty 2006). Uganda's organic exports were valued at about US$ 6.2 million in 2004-05 (Gibbon 2006) and the number of companies exporting organic produce grew from 5 to 15 between 2001 and 2003 (Tumushabe et al. 2006).

FIGURE 1: CERTIFIED ORGANIC AREA IN AFRICA



Source: FiBL Survey 2005 / 2006, in: Parrott et al. 2006

The area under certified organic management compared to the total agricultural area in selected East African countries and in total Sub-Sahara Africa, and their development over different years are shown in table 1.

Most organic market studies have analysed organic produce in general and not the organic vegetable market per se, and so there is little data regarding the production area, volume and markets for organic vegetable production in Sub-Saharan Africa. But the existing information indicates that fresh certified organic vegetables, geared mostly at export markets, are produced in East Africa in Kenya and Uganda in addition to Madagascar, Malawi, South Africa and Zambia (Parrott et al. 2006). Tanzania is also a producer and exporter of fresh vegetables, but it is not quite clear where it is exported to and whether it is certified as organic (Taylor 2006). Other mostly certified and hence export-oriented organic cash crops in East Africa[5] include cotton, coffee, tea, cocoa, vanilla, spices, herbs, fresh and processed fruits, nuts (ITC 2006a, b, c).

5 Countries referred to are Kenya, Tanzania and Uganda.

TABLE 1: OVERVIEW OF THE ORGANIC FARMING AREA FOR ALL CROPS IN EAST AFRICAN COUNTRIES AND TOTAL SUB-SAHARA AFRICA

Country	Year	Area under Organic Management (ha)	Share of Total Agricultural Area (%)
Kenya	2003	494	0.002
	2005	182,438	0.69
	2006	182,586	0.7
Rwanda	2005	50	-
	2006	105	0.0
Tanzania	1998	4,000	0.01
	2003	55,867	0.14
	2006	38,875	0.1
Uganda	2004	122,000	0.99
	2006	182,000	1.5
Sub-Sahara Africa	2005	639,750	<0.2
	2006	701,931	

Source: FiBL Survey 2005 / 2006, in: Parrott et al. 2006; Willer et al. 2007; Hine and Pretty 2006; *abridged*

There is no overall country data on production volumes as most literature provides production information for specific companies or farmers' groups producing vegetables, affiliated with a project (see table 2).

TABLE 2: ORGANIC VEGETABLE PRODUCTION IN EAST AFRICA ACCORDING TO PRODUCER SEGMENT

Country	Producer segment	Crop	Production (t)	Area (ha)	Year	Main Market
Kenya	C[a]: Kisima	Fresh vegetables, dried spices (paprika, birds eye chillies; & dried herbs)	30	42	2005	UK
	C: Sunripe	Beans, peas, sweet corn, chillies, avocadoes (& fruits)	380	190	2005	UK, Europe
	C: Three Palm Garden	Chilli	82	171	2005	USA
	C: Vitacress	Salad, baby vegetables	100	42	2005	UK
Tanzania	W[b]: Mkuranga women vegetable growers	Fresh vegetables	-	3.4	2005	-
	C: Zanz Germ	Ginger, pepper, turmeric, chilli and lemon grass	65	4,400		-
Uganda	C: Bo Weevil - Lango Organic Farming promotion	Chilli	-		2004	EU

[a] C: Company
[b] W: Women's group

Source: Taylor 2006 (Kenya, Tanzania, Uganda), *abridged*

Based on the existing data, there seem to be both domestic and regional markets for organic agricultural produce surfacing in East Africa. Although there are constraints on the development of domestic and regional markets for organic vegetables in East Africa, they do appear to have potential as a part of the high value crops segment in East Africa.

The local markets for organic vegetables are undeveloped as most of the local populations are not prepared to pay price premiums for such products (Taylor 2006). Consumers in African domestic markets often lack awareness of the availability of organic products and don't rate their qualities as important (Mjunguli 2005). Consumers consider African indigenous vegetables as inferior or of low value (although they are actually highly nutritious), which makes it difficult to sell them. According to Taylor (2006: 12), many vegetables whether indigenous or exotic are being perceived as organic by default by the population, therefore, those that are actually certified as such have little extra value in the marketplace.

On the supply side, poor infrastructure, a lack of technical support and especially market information concerning what products are in demand and quality requirements are further constraints to supplying domestic and regional markets with organic vegetables (Taylor 2006). All these factors lead to organic products being only a niche market in Africa.

At the international level, the world market for organic vegetables is very volatile. There is a shift in organic vegetable production from developed to developing countries, as demand exceeds supply in developed countries. High labour requirements are leading to a growing dependency on (small-scale) farmers from developing countries to meet this need, but such farmers also need the security of developed local markets if demand in the richer countries diminishes (Organic Monitor 2006). Table 3 gives an overview of the organic vegetables exported from East Africa.

An additional pressure on small producers in developing countries comes from the structure of marketing systems in developed countries. Big retailers, as well as mergers and acquisitions of large producing companies have led to a domination of the organic sector by a few large players who are able to dictate prices and standards, and restrict market access for small-scale farmers. Strict regulations and certification are having a severe impact on the opportunities for small-scale farmers to sell their organic vegetable produce into these markets (Scialabba 2005).

TABLE 3: EXPORT OF ORGANIC VEGETABLES FROM EAST AFRICA[a]

Exporting Country	Crop	Destination	Quantity / Value	Year
Kenya	Fresh vegetables	ns [b]	510 t	2005 (est.)
	Fresh vegetables, beans	EU, Japan	ns	2003
	French beans, runner beans, mange tout, salads	UK	ns	2005
Tanzania	Fresh vegetables	ns	34 t	2005 (est.)
	Ginger (semi-processed or raw)	Germany, NL, Sweden, Japan, Switzerland, UK, Indonesia, US	ns	2006
Uganda	Fresh & dried vegetables, chilli, ginger	Europe, US	ns	2006
	Dried chilli	ns	US$/t 2,240	2005 ?
	Fresh & dried vegetables	ns	US$ 1 mill.	2004-05
	Organic exports	ns	US$ 4.6 mill.	2002-03
	Organic exports	ns	3,159 t, US$ 7.7 mill.	2003-04

[a] Due to the use of different sources, the data provided are not always complete, e.g. for one country, some sources have indicated destination markets, while others have not specified any

[b] ns: not specified

Source: *own compilation based on* Kenya / Tanzania: ITC 2006a, b; Taylor, 2006; Kenya only: Kimemia and Oyare, 2006; Uganda: Walaga 2005; Gibbon 2006; ITC 2006c

In East Africa, the certification costs for organic vegetables can be very high and often inconsistently applied. In Kenya for example, inspection costs are US$ 325 per year, if a farmer wants to be certified by the UK Soil Association (Wagner 2003). Though the studies did not provide data on production costs, one can say that the "average certification costs at farm level are 3% of business turnover" (The Organic Standard 2001: 7-8). In Uganda, 15 operators "exporting on a certified organic basis" had to pay US$ 132,105 (an average of US$ 8,807 each) whereas another operator paid US$ 4,000 for certification costs (Gibbon 2006). This has to be taken into account in assessing the domestic and regional market opportunities.

The following data give an idea of size and value of the global organic market, along with details of the two largest markets for organic vegetables in Europe, namely Germany and the UK (Kortbech-Olesen 2006):

In 2004, the world market for organic produce of all kinds was valued at US$ 27 billion. Global retail sales between 1997 and 2001 increased from US$10.5 to US$ 19 billion, and by 2003 they had reached an estimated US$ 23-25 billion and in 2005 it was around US$ 30-32 billion. Global sales of fresh organic fruit and vegetables are currently increasing at 8.4% p.a. (Garibay 2007). “The worldwide organic sales top US$ 50 billion a year” (BioFach 2011), while the USA is the largest global market for organic produce: In 2009 organic food sales reached a value of US$ 24.8 billion, with organic fruits and vegetables reaching US$ 9.5 billion (BioFach 2011). The second largest market is Europe with US$ 24 billion, where Germany, France and the UK take the lead (BioFach 2011).

Germany is the world’s second largest market and Europe’s largest importer of organic produce, taking for organic fruits and vegetables (which are mainly fresh) about 30%. Although Germany’s organic share of the total food market is estimated at 2.5-3% (Kortbech-Olesen 2006) the total value is still very significant. The value of organic retail sales in 2004 were US$ 4.4 billion, rising to US$ 5.1 billion in 2006 (Kortbech-Olesen 2006). Germany’s organic market turnover in 2009 had a value of about US$ 7.9 billion (BioFach 2010). A large proportion of organic produce is sold through supermarkets, which in Germany is around 40% (in the US 49%, in Denmark 85%; Scialabba 2005).

The UK is the third largest market for organic produce in the world. Retail sales of organic produce were worth US$ 2.2 billion in 2004 rising to US$ 2.5 billion in 2005 (Kortbech-Olesen 2006). The sales of organic products have largely been driven by big supermarket chains which accounted for 75.3% of total sales in 2004. Independent retailers accounted for 11.9% or retail sales worth US$ 264 million while box schemes and mail orders accounted for 12.9%, worth US$ 286 million (Kortbech-Olesen 2006).

Spending on organic fruits and vegetable accounted for 31% of all spending on organic foods in the UK in 2003 (its production source being domestic), from the EU and developing countries (latter being tropical fruit and off-season vegetables). The next largest categories were dairy products with 23%, bread and bakery products 12% (Kortbech-Olesen 2006). It is interesting to note that “although percentages probably changed somewhat since then, there is no doubt that organic fruit and vegetables remain the most important product category” (Kortbech-Olesen 2006: 11).

In addition to the increasing demand for organic vegetables in markets like Europe, there is also a growing demand in Sub-Saharan Africa. In Tanzania for example, both specialized and non-specialized outlets exist to supply organic vegetables, processed foods and nuts. In Uganda, NOGAMU has established a successful outlet shop (Taylor 2006). The shop grew with monthly sales rising from US$ 93.50 in January 2003 to US$ 1,110 in December 2004 and over US$ 1,650 by December 2005. "By the end of 2005, customer visits averaged 110 per week (up from 50 per week in early 2005), and volumes of home deliveries averaged 850 kg per week up from 150 kg per week earlier in the year" (Taylor 2006: 16). NOGAMU also has three contracts for supplies to schools and restaurants. This example clearly shows that organic produce has been growing in demand.

Such outlets are mostly located in capital cities, where sales are also increasingly conducted through larger supermarket chains (non-specialized outlets), for example Nakumatt Supermarkets in Nairobi, Shoprite in Dar-es-Salaam and Uchumi in Kampala. Organic produce is becoming more popular, and the busiest Uchumi store in Kampala, Uchumi Sarit Hyper, is planning to create an "organic corner" in its supermarket (Nderu 2007).

In part, sales are increasing in both types of outlets due to the health aspects associated with organic produce. According to a survey conducted by EPOPA[6] in Tanzania the clientele mostly comprise European expatriates and some wealthy nationals as well as a small number of tourists and travellers. These buyers are willing to pay reasonable premiums for organic vegetables (Mjunguli 2005). The premium range for fresh organic vegetables in Uganda is between 30–50% and in Kenya 15% (Taylor 2006), while the premiums paid for general organic produce in Tanzania range from 50% to 100% (Mjunguli 2005).

SURVEY RESULTS OF THE SUPPLY CHAIN ANALYSIS FOR ORGANIC VEGETABLES IN TANZANIA 2.

MATERIALS AND METHODS 2.1

In analyzing the supply chains for organic vegetables (OVs), detailed interviews were conducted with a total of 501 respondents in Tanzania using a semi-structured questionnaire (218 small-scale organic vegetable farmers, 71 wholesalers, middlemen, and retailers in the intermediary sector, and 212 consumers). Three types of questionnaires were developed to gather general and specific information from small-scale organic vegetable farmers, the intermediary sector (wholesaler, middlemen, and retailers), and consumers, with the following objectives, though the results below will focus only on some of the aspects:

6 EPOPA: Export Promotion of Organic Products from Africa

> *Objective 1* was
to understand current scope of production and market structure for organic vegetables market in Tanzania by:
- assessing the locations, volume, price of certified and non-certified organic vegetable produce sold
- number of smallholders involved in production
- exploring the potential of sales opportunities (channels) the small-scale farmers use

> *Objective 2* was
to identify constraints in the supply chain for the improvement of market coordination by:
- assessing the constraints of the status quo
- evaluating knowledge on requirements on quality and established standards
- developing potential solutions to improve the current situation

> *Objective 3* was
to assess the demand for organic vegetables by:
- determining the quantities and types of vegetables most widely consumed in urban centres of selected cities Tanzania
- assessing consumers' awareness, attitudes and perception of organic vegetables and its consumption with the following attributes: e.g., organic, pesticide-free, no GMO, environmental-friendly
- evaluating consumers' willingness to pay for fresh, processed, packed and marketed organic vegetables

The research areas in Northern Tanzania were selected based on the location of small-scale organic vegetable farmers (because local NGOs have been working with these farmers on organic agricultural production methods) and their potential supply areas. On this basis, the largest market located closest to the producers was chosen. In the cities, upscale supermarkets, hotels, and restaurants were selected, all with the potential to buy (certified) organic vegetables at a premium price. Consumers were chosen according to income and location, i.e. at supermarkets catering to more-affluent customers. The research areas are Arumeru and Marangu Districts (Figure 2 and table 4); the former is located in the Northern Highlands between 1000 and 1500 m and the latter on the southern slopes of Mt. Kilimanjaro between 1200 and 1800 m.

FIGURE 2: SURVEY AREA, ARUMERU AND MARANGU DISTRICTS

Source: ICRAF 2002-3

The organic farming share of total agricultural area in Tanzania is 0.05% (2006); the organic area in Tanzania is 23,700 ha (2006; Willer et al. 2008).

TABLE 4: CHARACTERIZATION OF RESEARCH DISTRICTS IN NORTHERN TANZANIA

District	Arumeru	Moshi rural (for Marangu)
Location in Tanzania	Northern Highlands	Southern slopes of Mt. Kilimanjaro
Mean annual rainfall (mm)	1,000 (humid)	1,200 - 2,000 mm [a]
Altitude	1,000 – 1,500 m (high)	1,200 – 1,800 m (high)
Soils	volcanic soils; sandy loam with good drainage	volcanic soils; good and very fertile soil
Natural vegetation	brushland and thicket	grasses, heather and various tree species
Location	urban / rural	rural
Population density	55 - 99 p/km^2 (dense)	650 p/km^2 [b]
Land size	3,000 km^2 [c]	1,713 km^2 (Moshi rural incl. Marangu)[a]

a URT 1998: 21;
b ICRAF 2002-3: 4;
c Koenig et al. 2008: 34

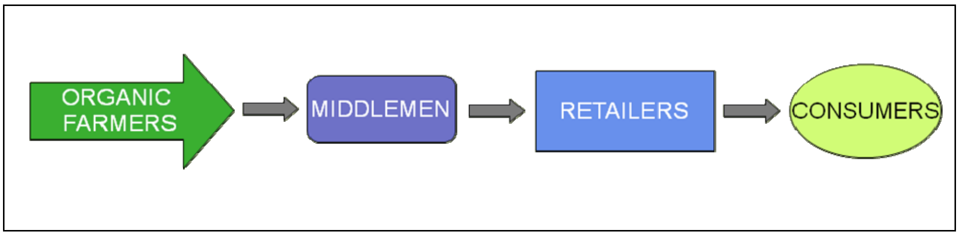
Source: Hathout 1983; Anonymous 1998; Anonymous 2007 in: Keding et al. 2007: 4

2.2 RESULTS AND DISCUSSION

SUPPLY CHAIN CHARACTERIZATION

The typical supply chain for small-scale organic vegetable farmers is either sale at the farm gate to consumers or middlemen, or sale at the market gate to middlemen and retailers (Figure 3). From there on, organic vegetables mostly get sold to consumers. Such markets for the Arumeru District (where surveys were conducted) included Tengeru or Kilombero in Arusha town. In Marangu District, markets are Marangu-Mtoni, Kinyange, or Kisamboki. Often farmers grow organic and conventional vegetables and simply consume the organic ones themselves and sell the conventional ones to the market; they consider organic vegetables as better for them in terms of health, but they can make more money from the conventional ones. In part this is due to the fact that the intermediary supply chain actors do not sell organic vegetables as such (they are mixed with conventional produce) and also do not sell organic vegetables at a higher price. The reason, according to the intermediary actors, is that consumers do not ask for them. Uncertified organic vegetables do not reach the supermarket and only two (0.9%) of the interviewed 218 small-scale farmers were certified organic.

FIGURE 3: SUPPLY CHAIN FOR ORGANIC VEGETABLES IN NORTHERN TANZANIA

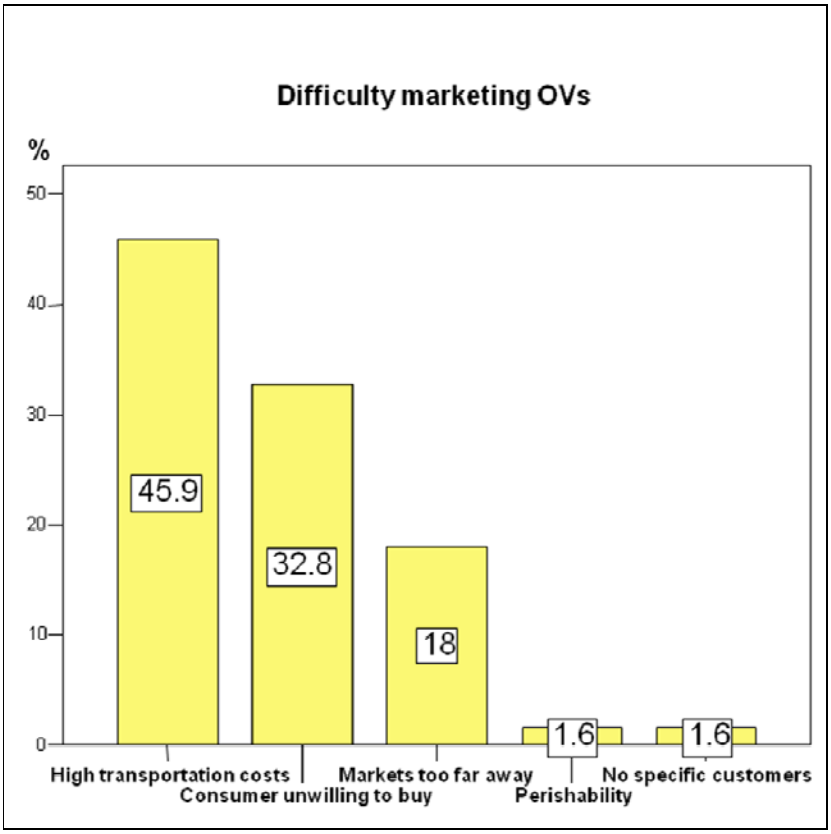


Source: Saxena 2008

MARKETING DIFFICULTIES FACED BY SUPPLY CHAIN ACTORS

Small-scale organic vegetable *farmers* are not well linked to markets due to bottlenecks such as poor transportation (bad roads, markets too far, low prices paid by intermediary sector, no vehicle available or rental too expensive), storage and handling as at the market, organic and conventional vegetables are simply mixed together, and lack of awareness of price premiums they may receive. Of the small-scale organic vegetable farmers, about 46% stated they find high transportation costs a problem, followed by about 33% that say consumers are simply unwilling to buy their organic vegetables (OVs) (Figure 4). Also, 18% state that the markets are located too far from their production areas. Producers are often trained in organic agricultural practices by NGOs, but not in efficient marketing methods. Some local NGOs like Floresta Tanzania, which helped conduct surveys in the Marangu research area, have tried to integrate the marketing aspect, but in that case the producers did not take these on and would rather rely on funding or help from outside.

FIGURE 4: MARKETING DIFFICULTIES FACED BY SMALL-SCALE ORGANIC VEGETABLE FARMERS



Source: Saxena 2008

Concerning the *constraints in the supply chain for buying and selling OVs*, about 40% of the *intermediary* sector thinks there is a lack of awareness and training on organic vegetables, and an insufficient supply (Table 5). As there is no special marketing place for OVs (13.5%), this also adds to the constraints for buying and selling OVs properly. Some stated that they see no difference in organic and conventional vegetables, or see the former as a cheaper production method. As their customers do not ask for OVs, they sell organic produce for the same or lower prices than conventional vegetables.

Furthermore, in the intermediary sector, 29% think that high transportation costs are a *problem for bringing OVs to the market*, 14% believe OVs are simply not known to the consumers, there is a low supply of OVs (8%) as well as the perishability problem (8%), there are no differences in prices (6%) and consumers are unwilling to pay (also 6%). When asked which *marketing difficulty they faced* regarding OVs, 17% stated price, lack of market information (14%), perishability (12%), consumers unwilling to buy (6%), no specific customers (6%), producers too far away, OVs easily attacked by pest and price fluctuation, each with 2%.

In addition, *consumers* are unable to find organic vegetable markets. Interestingly, about 32% of consumers also consider a lack of awareness and training on OVs as a constraint for the development of the organic market in Tanzania (Table 6). Furthermore, about 10% feel there are no strong organizations promoting OVs, and that not enough are produced (about 10%). The low price farmers get for their OVs is another factor that discourages them from attempting organic production (about 6%).

TABLE 5: INTERMEDIARY SECTOR´S POINT OF VIEW ON MARKETING PROBLEMS FOR OVS

Where do you think are constraints in the supply chain for buying and selling OVs?

		Frequency	%	Valid %	Cumulative %
Valid	Lack of awareness & training	21	40.4	43.8	43.8
	Insufficient supply of OVs	8	15.4	16.7	60.4
	No separate OV markets	7	13.5	14.6	75.0
	OV producers not known to buyers	4	7.7	8.3	83.3
	No stable market for OVs	3	5.8	6.3	89.6
	Price fluctuations	2	3.8	4.2	93.8
	Don't know	2	3.8	4.2	97.9
	Lack of committment in producing OVs	1	1.9	2.1	100.0
	Total	48	92.3	100.0	
Missing	System	4	7.7		
Total		52	100.0		

Note: Though the total number of interviewees in the intermediary sector is 71, this response refers to only 52 intermediary actors excluding the 19 specialized and non-specialized outlets as these had different questionnaires.

Source: Saxena 2008

TABLE 6: CONSUMERS´ POINT OF VIEW ON PROBLEMS FOR THE ORGANIC MARKET DEVELOPMENT

What do you consider as main constraints for the development of the organic market in Tanzania?

		Frequency	%	Valid %	Cumulative %
Valid	Lack of awareness & training on OVs	68	32.1	32.1	32.1
	Don't know	51	24.1	24.1	56.1
	No strong organisations to promote OVs	22	10.4	10.4	66.5
	Low production of OVs	21	9.9	9.9	76.4
	Low price of OVs discourage farmers	13	6.1	6.1	82.5
	No specific market for OVs	8	3.8	3.8	86.3
	Poor belief on potential of organic inputs	6	2.8	2.8	89.2
	High production cost	6	2.8	2.8	92.0
	No organic stds & regulation in Tanzania	6	2.8	2.8	94.8
	No OV supply in Tanzania	5	2.4	2.4	97.2
	Economics	4	1.9	1.9	99.1
	Certification not trustable	2	.9	.9	100.0
	Total	212	100.0	100.0	

Source: Saxena 2008

LACK OF STANDARDS KNOWLEDGE BY SUPPLY CHAIN ACTORS

Of the 218 small-scale organic vegetables farmers, 99.1% were not aware of any organic standards and only 0.9% (two farmers) knew of the East African Organic Production Standards (EAOPS). Only two farmers are certified. These and the official East African Organic Mark (Kilimo Hai) were officially launched in June 2007 by the Tanzanian Ministry of Agriculture and include the countries of Tanzania, Kenya, Uganda, Rwanda, and Burundi (Willer et al. 2008). The interviewed farmers had a choice between the following organic standards: IFOAM (Intl.), EU, JAS (Japan), NOP (USA), and EAOPS (East Africa). The lack of uptake clearly shows that after the launch of the logo, no further promotion has been conducted at market and consumer level. The organic label is only a marketing tool and will be issued to those who are certified. Here too, the local NGOs and especially the Tanzanian Organic Agriculture Movement (TOAM, the national movement based on IFOAM, the International Federation of Organic Agriculture Movements) needs to promote the organic label more effectively. Nevertheless, 92% of the farmers consider certification necessary or better for the sale of their organic vegetables. They reached this conclusion mostly after the enumerators explained to them what certification means.

In the intermediary sector, 69% knew what certification means (though the total intermediary sector includes 71 interviews, this response refers to only 52 intermediary actors excluding the 19 specialized and non-specialized outlets as these had different questionnaires). Here too, the majority (about 94%) do not know of any organic standard. With the consumers, about 86% do not know of any standard and about 90% do not know the Kilimo Hai logo even though they were shown the logo during the interview. Only about 6% know that it is the "logo used in East Africa for organic products."

MARKETING STRATEGIES 2.3

Small-scale *farmers* must work together with local NGOs with whom they have started organic agricultural production methods. These NGOs can serve as mediators to help create awareness for organic vegetable farmers at the market and consumer level. Of course, the farmers need to promote themselves as well, especially when selling at farm or market gate to consumers and middlemen. This promotion can include explaining the significant benefits of organic vegetables in terms of soil, health, and environment—and therefore the slightly higher price for uncertified organic vegetables (OVs). For certified OVs, higher prices can be justified due to the certification. Furthermore, farmers need to create a pamphlet explaining who they are and why they are growing OVs; these pamphlets can be handed out when they are selling their OVs. Farmers also need to create their own organic marketplace if possible, and arrange transport possibilities, as many of them simply do not sell at the market because the infrastructure is bad and transportation costs are high. Concerning transportation of organic vegetables from the farm to the market, a shared vehicle can be organized as well as collection points set up, so especially remote areas are not left out of a marketing opportunity. Furthermore, the farmers can participate at the (national) agricultural exhibitions called Nane Nane to promote themselves. Once the quality and quantity get more steady, then contact hotels / restaurants / lodges (latter mostly located out of Arusha town) and set-up a supply chain for this.

The *intermediary* sector suggested themselves that organic vegetables need to be certified, promoted, and sold as OVs at the market stand, at a higher price. Nevertheless, as many middlemen did not know that uncertified and conventional vegetables should not be mixed during transportation, storage and sale, awareness needs to be created here on handling OVs from the point of buying until the point of sale.

Consumers clearly need awareness-raising via the small-scale farmers at sale points. Local NGOs and TOAM can help consumers find out where OVs can be procured; consumers can be invited to visit farmers´ fields and get an idea of organic production for themselves. When consumers are included in the Teikei system, which is a direct producer-consumer relationship based on trust, the sale of OVs will be facilitated. The Teikei system originated in Japan and has been successfully incorporated in the United States as "Community Supported Agriculture" (CSA); the model is also being followed in Thailand and Brazil. This system might be applicable in East Africa over the course of time, when local organic farming and marketing will be better established.

As middle to upper class consumers are willing to pay 10-20% *premium* for (certified) OVs for such criteria as pesticide-free and health, the farmers can calculate their price more efficiently. The term certified is in brackets, because even though the consumers were asked whether they would pay a premium for certified OVs, the successive questions were on "for which criteria" and "how much % above the conventional price", and here it is not sure whether the consumers still had in mind that this refers to certified OVs. As consumers are always in haste (they were interviewed at upper-level supermarkets and organic shops and these were the last few questions), the answer might have been given in general referring to how much they are simply willing to pay more for organic vegetables (certified or not).

WAY FORWARD 2.4

Domestic and regional market development in Sub-Saharan Africa is an important factor for small-scale organic vegetable farmers to gain from this growing sector and be less dependent from the vagaries of the world market. Linking the small-scale farmers to the local market, having transparent and shorter supply chains, as well as being clear on regulations and quality requirements are one side of the issue. The other side is creating more awareness for organic vegetables from the demand side, showing the associated environmental and health benefits of organic vegetables (as such there is a growing demand in SSA), as well as the importance and reason for premium prices. Organic farmers have to get organized and are supported by organizations or projects to successfully access the international market. Furthermore, alternative marketing strategies for the domestic and regional market as practiced in other countries can provide valuable examples of innovative marketing: In Japan the Teikei system connects farmers directly with consumers, as does "Community Supported Agriculture" in the USA. Such movements work when there are direct farm sales to consumers that build trust and remove the need for independent and expensive certification. However, once organic produce enters the anonymity of the domestic market chain consumers will want some certification to guarantee quality standards. For international exports but also regionally, national certification schemes adapted to the African context or the regional setting, which should be less costly, can help create a better market opportunity and be a marketing tool. While organic vegetable production is likely to remain a niche market it is still a valuable market that smallholders cannot ignore.

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INFLUENCE OF SOIL MACROFAUNA ON SOIL MICROMORPHOLOGY AND SOIL CHEMISTRY IN CENTRAL AMAZONIAN AGRICULTURAL AND FOREST ECOSYSTEMS

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ABSTRACT

Ferralsols of the Terra-firme-region near Manaus (Brazil) under primary forest, grassland and agroforestry systems are studied concerning biological structures of ants, termites and earthworms. Tracer experiments showed the control of infiltration of water by biological structures, most important under primary forest in contrast to grassland. Earthworm excrements have an increased content of organic matter and thereby an increased cation exchange capacity. Organic fillings of chambers and some tunnels of termites gave similar values of cation exchange capacity. In contrary tunnels and chambers of ants shows only little organic contents. For the total aspects and results of the study view the dissertation of Raphael Knoll (2010).

INTRODUCTION 1.

The soils of the Terra-firme-region near Manaus in Central Amazonia (Brazil) are heavily and profoundly chemically weathered, rich in clay and show especially in the subsoil a very low cation exchange capacity of the soil's mineral fraction due to the dominance of minerals of the Kaolinite group. Animals living in and on the soil are of great importance for litter decomposition and nutrient supply, as the great thickness of the weathered cover inhibits a subsequent nutrient supply from soil and parent material. Hence soil fertility of the heavily weathered soils of Amazonia's Terra firme is largely determined by amount and quality of soil organic components. For Central Amazonia's agricultural and forest ecosystems termites (Isoptera), ants (Formicidae) and earthworms (Oligochaeta), the locally most frequent representatives of the macrofauna, play a great role in decomposition and integration of organic matter in soils. This offers the possibility to essentially increase cation exchange capacity, improve soil structure and systematically fertilise the soil through integration of organic matter.

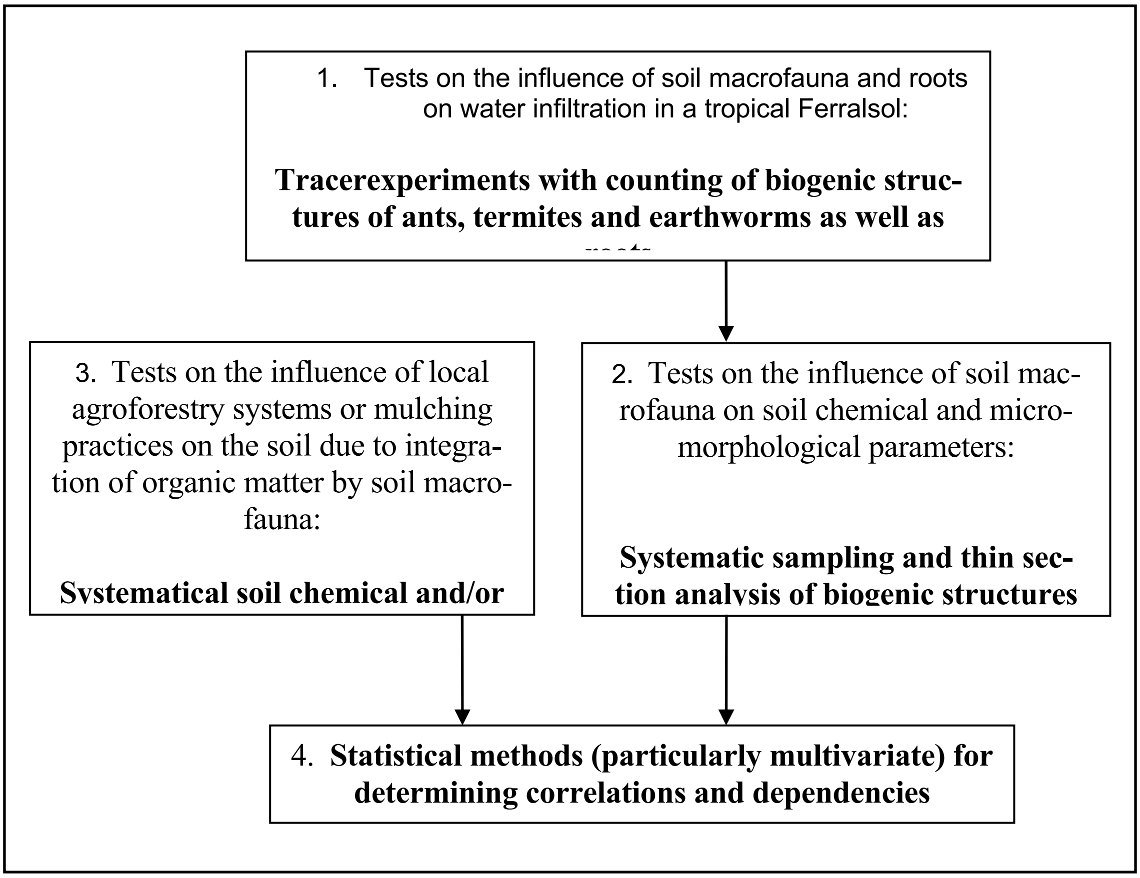
To which extent ants, termites and earthworms influence soil physical (particularly soil porosity) as well as soil chemical (particularly cation exchange capacity) properties and improve local characteristics by construction of tunnels and chambers as well as by the integration of organic matter was exemplarily demonstrated in different cultures of an agroforestry system and on sites of primary forest. Preferential flow paths were indicated with dye tracing experiments to show the distribution of systematically applied fertiliser.

Research was part of a project which was amongst others conducted in cooperation of the Staatliches Museum für Naturkunde Karlsruhe, SMNK, as well as the Centro de Pesquisa Agroflorestal da Amazônia Ocidental da Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)) in Manaus in Central Amazonia. This study was carried out as a part of the SHIFT-Project ENV 52 (BMBF 01LT0014 / CNPq 690018/00-2) "Management of plant residues and its effects on decomposition and soil macrofauna in Central Amazonian agroecosystems" and was financially supported by the German-Brazilian research programme „Studies on Human Impact on Forests and Floodplains in the Tropics" (SHIFT) of the Bundesministerium für Bildung und Forschung, BMBF, Germany, and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, Brazil).

Main goal of the SHIFT-project was to develop sustainable types of land use, which allow a sustainable economic development combined with a decrease of deforestation rates and which thus contribute to the preservation of the tropical rainforests (Höfer et al. 2004). The *Development of stable intercropping systems for smallholder farms on Terra firme in order to improve harvest results of smallholders in Amazonia* was the goal of the ENV 52 project and related projects. Thus a reduction of logging in primary forests for creating new useable area may be achieved (Höfer et al. 2004). A large percentage of anthropogenically used surfaces in the catchment area of the city of Manaus and in other parts of Amazonia lie fallow due to low soil fertility and the consequences of inadequate types of agricultural use. This results in increasing land consumption of previously pristine rainforest area and associated with this a decrease of local biodiversity. Therefore fallow land is required to be used again to protect and preserve undisturbed rainforest (Höfer et al. 2004). Conditions for sustainable agricultural systems are in the short run nutrient recycling and in the long run preservation and improvement of soil fertility, but also its regeneration and thus recultivation of degraded formerly cultivated areas. A key role plays the long-term preservation of soil physical properties and soil organic matter (SOM), whose amount and quality are highly influenced by the activity of soil fauna (Höfer et al. 2004).

The presented research and results are the partly described and summarized findings of the dissertation of Raphael Knoll (2010) and the research's entire content may be found there. Especially research area, applied cropping systems in the agroforestry system, discussion of the current state of research, approach and detailed methodology are elaborately described in the thesis. The different research questions and main focuses are shown in Figure 1. In this article mainly the results on influences of soil macrofauna and roots on infiltration as well as the results on micromorphology and soil chemistry of biogenic structures of the different research focuses are described.

FIG. 1: RESEARCH QUESTION AND METHODOLOGICAL APPROACH OF THE SUBPROJECT



RESULTS 3.

DYE TRACING EXPERIMENTS AND COUNTING OF BIOGENIC STRUCTURES 3.1

The dye tracing experiments with counting of biogenic structures were initiated by Dr. WERNER HANAGARTH and Dipl.-Forstwirt PRZEMYSLAW WALOTEK (graduated forester). Three soil profiles (of overall 89), which differ highly in colouring as well as type and amount of biogenic structures, will be presented exemplarily for all dye tracing experiments. Concerning intensity and depth of infiltration as well as animal occurrence the three profiles represent a gradient from natural primary forest to forest-like, with Pupunha-palms populated agroforestry test areas to an only slightly pristine grassland area. In the primary forest termites (*Isoptera*) dominate the faunistic structures, in the Pupunha-monoculture formations of earthworms (*Oligochaeta*) predominate and those of ants (*Formicidae*) are the most frequent biogenic structures in grassland areas.

PRIMARY FOREST PROFILE 3.1.1

The all over the EMBRAPA terrain found Xanthic Ferralsol is structured into a shallow humic topsoil (of an average of 5 cm and extrema of 2 and 10 cm) and an underlying homogenous yellowish subsoil with microaggregates (pseudo-sand structure). The determined soil type is sandy clay with a downwards increasing content of clay. In the selected profile of primary forest the dye extends to a depth of approximately 60 cm (fig. 2); below only small dyed patches are found. In the topmost 30 cm the dye infiltrated more homogenously than in the area beneath. This is due to the increased occurrence of termites in the upper 30 cm which increase soil porosity and enable the transport of the dye into deeper parts of the soil through their excavating activities and creation of downwards oriented tunnels. Several further termite structures were counted in the dyed area at the depth of 30 to 60 cm. As shown in Figure 2 numerous roots (dead and alive) can be located in the topmost 30 cm along which the infiltration of the dye was eased as well. In comparison with the agroforestry areas and the grassland the infiltration of dye tracer is most intensive in the primary forest, which is due to the high frequency of termite tunnels and roots.

FIG. 2: DYED PROFILE IN PRIMARY FOREST. COUNTING FRAME WITH A SIZE OF 100 X 100 CM. MANY TERMITE-MADE STRUCTURES WERE FOUND IN THIS PROFILE

Photo: P. Walotek

In the primary forest profile the values for cation exchange capacity of the biogenically not or little influenced subsoil lie between 5.1 and 7.2 mmol/100 g, i.e. very low. Exchangeable cations are almost exclusively H^+- and Al^{3+}-ions, which means that base saturation is with 0.6 to 2.4% also very small. In comparison to non-biogenically influenced subsoil termite tunnels found in this profile have about twice as high values for cation exchange capacity (11.0 to 13.3 mmol/100 g) and base saturation (1.3% to 3.0%). Ant and earthworm structures show increased values as well. However values for cation exchange capacity of the termite-made structures are still lower than those of the topsoil.

GRASSLAND PROFILE 3.1.2

The grassland profile in figure 3 shows colouring up to a maximum depth of 30 cm in which however more intense dying is only visible in the topmost 5 cm. Poor infiltration originates from the absence of woody plants with larger, deep reaching roots. Preponderance of ant tunnels with in comparison to other biogenic structures small diameters and hence with little importance for preferential flow is another reason for poor infiltration of the tracer. In the exemplary profile two deep-reaching (approx. 30 cm) desiccation cracks can be identified along which dye seeped in. Those desiccation cracks were exclusively observed in unshadowed grassland with high differences in ground surface temperatures but not in the more shadowed agroforestry areas or the primary forest. In Fig. 3 several ant chambers (by *Mycocepurus sp.*) of a 5 cm diameter are visible which are not dyed. Possibly the ant tunnel dyed up to the depth of 20 cm (in the upper right-hand quadrant) might be the entrance tunnel of the ant chambers and dye did not infiltrate deep enough.

FIG. 3: DYED PROFILE IN GRASSLAND. IN THE SUBSOIL SEVERAL ANT CHAMBERS OF A 5CM DIAMETER ARE VISIBLE

Photo: P. Walotek

The values of cation exchange capacity in the biogenically not or little influenced subsoil of the grassland profile are very low with 7.8 mmol/100 g. Base saturation is with

0.3 % also very small. Ant chambers and tunnels (all in the subsoil) of this profile show similarly low or only slightly increased values for cation exchange capacity (5.8 to 12.5 mmol/100 g) and base saturation (0.5 to 2.3 %). Values for cation exchange capacity of ant-made structures are not as high as those of the topsoil.

PUPUNHA MONOCULTURE PROFILE 3.1.3

The selected profile in a Pupunha monocultur (Fig. 4) was mainly dyed near to the surface in the topmost 10 cm. The hydrophobic nature of earthworm excrements accounts for the patchy pattern with alternation of dyed and undyed areas in the topsoil. Below the topmost 10 cm only small dyed patches are visible even though rooting goes deeper. Beneath 20 cm hardly any biogenic structures of all three animal groups are found. The comparatively low fraction of dyed surface of the profile may be explained by the concentrated dye transport in the earthworm tunnels with large diameters (often wider than 1 cm). In several profiles dye-transporting earthworm tunnels were found in the subsoil.

FIG. 4: DYED PROFILE IN A PUPUNHA MONOCULTURE (*BACTRIS GASIPAES*). TOPSOIL IS ALMOST COMPLETELY COVERED WITH EARTHWORM EXCREMENTS

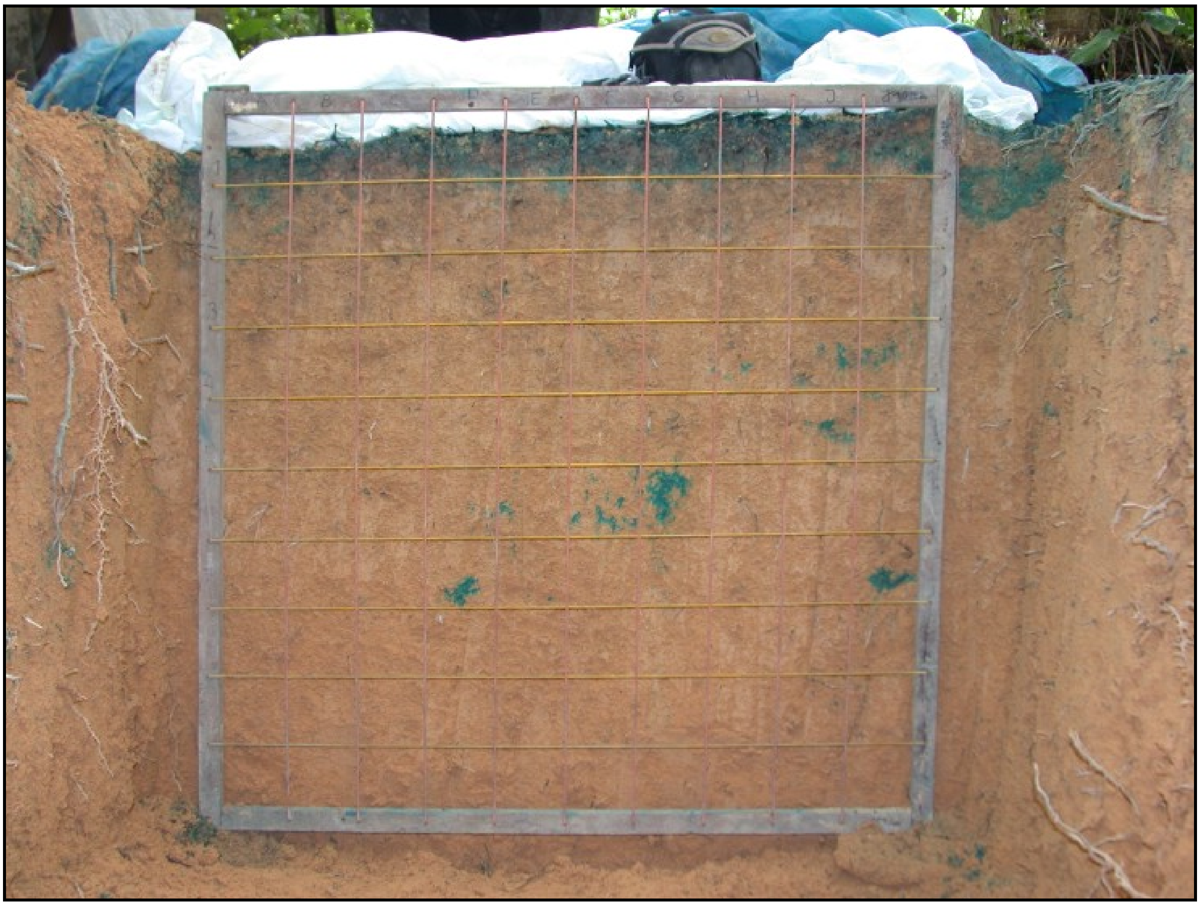


Photo: P. WALOTEK

In the Pupunha profile values for cation exchange capacity in the biogenically not or little influenced subsoil are very low with 7.1 mmol/100 g. Base saturation at 0.8% is also very low. The values of the three earthworm tunnels located in the subsoil, which are not filled with excrements, are only slightly higher than the above mentioned (CEC 8.2 to 11.1 mmol/100 g; base saturation 0.9 to 8.7 %). Earthworm excrements (by *Pontoscolex sp.*) near ground surface show considerably higher values for cation exchange capacity (12.6 to 19.3 mmol/100 g) and base saturation (16.7 to 27.5 %). Those are some of the highest values of all sampled structures in all profiles.

Primary forest and grassland show considerable differences regarding the intensity of infiltration. The (natural) primary forest has on average the biggest fraction of dyed area and (anthropogenically degenerated) grassland the smallest. The best and most homogenous infiltration takes place in the soils of primary forests as it has a good rooting system and numerous termite tunnels. Compacted topsoil probably impedes the infiltration in the degraded grassland area. The portions of dyed area of the six cultures of agroforestry systems are between those of primary forest and grassland. Averaging the portion of dyed area up to a depth of 100 cm for entire profiles the primary forest has on average 15 % dyed area, agroforestry areas with Urucum show 14% and the other agroforestry areas between 11 and 12% dyed area and the dyed surface of the grassland area represents 7%. The found differences between the different agroforestry areas, with the exception of Urucum, are comparatively small.

For average determination for the biogenic structures (roots, ants, termites, earthworms, pores, other structures) 67 of 89 dyed profiles were included, ranging from four profiles in grassland to 18 in primary forest. Hence the following results are based on the counting of biogenic structures in 6,700 quadrants of the counting frame.

The profiles illustrate the eminent role of roots regarding the preferential flow. The channels of coarse roots have a large impact on the infiltration of the dye. In the survey especially dead coarse roots with decomposed wood and only cortex remaining have been identified as preferential flow paths along which water infiltrates fast. Where coarse roots were highly decomposed the tracer infiltrated intensely into adjacent soil matter. Preferential flow is constricted when root channels are blocked by soil sediments washed in by surface runoff.

Considering the three animal groups termites are of outstanding importance for the distribution of precipitation water in soil, because of the large diameters of their tunnels and their frequency (more than half of the counted channels are temite-made). Cultures with high termite occurrences (especially Urucum and primary forest) show the highest fraction of dyed surface in the profiles. Earthworm tunnels also have large diameters and may transport rain water rapidly into greater depth due to their slick wall structure. Channelling of infiltrating water is most distinct in earthworm tunnels. However earthworms are rarely found in some survey areas like e.g. primary forest so that they play only a minor role there. Ant-made tunnels are of little importance for preferential flow as their diameters are too small and the channels are of considerably less frequent occurrences (cumulative only in grassland).

CONNECTION BETWEEN BIOGENIC STRUCTURES AND SOIL CHEMICAL PARAMETERS 3.3

A total of 77 thin sections of biogenic structures was analysed (including the presented structures by *Atta sp*., *Acromyrmex sp.*, *Cornitermes sp.* and *Syntermes molestus*). 39 biogenic structures analysed in the 77 thin sections are ant-made (tunnels and chambers), 28 are termite channels and chambers and 10 thin sections were made from earthworm channels and excrements. The comparatively low number of thin sections of biogenic structures may be explained by the rareness of structures in good condition after excavating the soil profile. Furthermore, extracting the structures undamaged from the soil profile is an intricate task.

ANTS 3.3.1

Especially in grassland areas inhabited and abandoned chambers of *Mycocepurus* were most frequently found. This fungus-growing genus may be identified by fungal cultures on the ceiling of the chambers. Mostly the chambers are about 5 cm in diameter. Some ant chambers show increased growth of roots inside which may be evidence for formerly or currently elevated levels of nutrient content. The ants may use the roots for attaching fungal cultures to them. The qualitative analysis of the thin sections showed, that ants (at least those of the above mentioned genus) do not line their chambers and tunnels with organic matter (fig. 5 and 6, annex). Minimal organic accumulations were sometimes found on the floor of chambers, which most likely originates from unintentionally imported topsoil matter.

Samples of ant chambers (mostly *Mycocepurus sp.*) and tunnels analysed in this study differ only marginally from subsoil with regard to content of organic matter, porosity, cation exchange capacity and base saturation (Tab. 1). Content of C and N of the walls of the ant chambers (similar results in Rabeling 2004, unpublished diploma thesis) are slightly above values for subsoil samples (factors of 1.8 and 1.6, see Tab.1). Qualitative analysis could not generally confirm loosening of soil structure through excavating activities by ants. Values for soil porosity at the walls of biogenic structures as well as for soil matter in the surrounding area are at a mean of about 12 %.

TAB.1: MICROMORPHOLOGICAL AND SOIL CHEMICAL DATA FOR BIOGENIC STRUCTURES OF ANTS, TERMITES AND EARTHWORMS

Mean values (MV) for biogenic structures	*n thin section*	Content of organic matter MV [% of profile surface]	Content of quartz MV [% of profile surface]	Porosity MV [% of profile surface]	Content of matrix MV [% of profile surface]	*n CEC*	CEC nach sum [mmol/100g]	Sum cations [mmol/100g]	Base saturation [%]	*n C/N*	N in % (MV)	C in % (MV)	C/N-ratio
Ant constructions: organic matter	*2*	50.6	0.6	19.1	29.7	-	-	-	-	*2*	0.3	5.7	21.2
Biogenic structures	*24*	0.6	6.2	11.6	81.6	*50*	9.8	0.2	1.9	*54*	0.1	1.8	12.1
Surrounding of biogenic structures	*25*	0.4	5.8	12.3	81.5		*	*	*		*	*	*
Termite construc-tions: Organic matter	*3*	8.6	8.6	26.6	56.2	*10*	14.2	0.3	2.0	*10*	0.2	2.4	12.9
Biogenic structures	*6*	1.4	7.0	10.0	81.6	*33*	12.0	0.5	3.1	*31*	0.2	1.9	11.7
Surrounding of biogenic structures	*8*	0.5	9.4	11.5	78.6		*	*	*		*	*	*
Earthworms: Worm excrements	*8*	4.3	8.7	5.1	81.9	*19*	16.5	0.9	5.8	*17*	0.3	3.3	12.7
Biogenic structures	*2*	0.7	5.0	3.5	90.8	*18*	11.7	0.5	4.1	*16*	0.2	1.8	11.6
Surrounding of biogenic structures	*7*	0.5	8.8	7.6	83.2		*	*	*		*	*	*
Mean values for all **Subsoil** samples	*9*	0.3	3.9	14.5	81.3	*42*	7.8	0.1	1.2	*36*	0.1	1.0	10.9

TERMITES 3.3.2

Qualitative analysis of thin sections from termite constructions showed that only in some cases organic accumulations may be found on the walls of tunnels of termite structures (e.g. *Syntermes*). Even within in one species tunnels may or may not be lined with organic matter. Larger quantities of organic matter (up to a few centimetres in diameter) are located in chambers and tunnels, which are filled with leaf remains or other small pieces of vegetable matter (fig. 7 and 8, annex). Organic material imported by termites (data in Tab.1) showed a higher content of organic matter (8.6 %) and an increased porosity (26.6 %) compared to the surrounding soil material. In comparison to surrounding material content of organic matter in the walls of termite tunnels and chambers is increased by a factor of three (1.4% compared to 0.5%). It is thus four to five times higher than values for subsoil, but is still low viewed in absolute terms. For base saturation (Ca^{2+} dominance) the termite structures show even higher values than the imported organic material (3.1 % compared to 2 %). In comparison to ant-made structures the walls of chambers and tunnels of termite structures show on average more than twice the content of organic matter and slightly increased values for cation exchange capacity and base saturation. The initially assumed loosening of soil structure in areas influenced by termites could not be verified by qualitative analysis of porosity. Even though total porosity of the soil was increased by the construction of channels and chambers, this results only from the structure itself and does not affect the porosity of surrounding soil material. Porosity of the walls of termite structures was even slightly lower than in the surrounding structure (10 % compared to 11.5 %).

EARTHWORMS 3.3.3

In contrast to ant and termite structures earthworm excavations and activities are predominantly limited to the topmost 30 cm and the soil surface, which is supported by the counting of earthworm channels and on-site findings. As a result of lining with secreted mucus the shiny surface of earthworm channels makes them easily identifiable. The lining is only a film-like coating which is hardly visible even in thin sections. The tunnel walls show characteristic, macroscopically well visible, circular marks of the earthworm segments, which are a result of the earthworm's locomotion (fig. 9, annex). Thin sections of earthworm excrements show a well mixed compound of mineral soil matrix, quartz and organic material with plant remains. The portion of organic material in the excrements is particularly high (fig. 10, annex). A defined borderline between excrements and surrounding soil material, which is not influenced by earthworms, is visible. The very compact, clayey consistency of the earthworm excrements with a compared to surrounding soil material considerably reduced porosity is striking. As expected, earthworm excrements have the highest content of organic matter (4.3 %) and a decrease to below 1 % at the walls of the earthworm channels can be stated (fig. 11 and 12, annex). Porosity of imported organic matter (i.e. earthworm excrements) and of the walls of the channels is considerably reduced (5.1 % and 3.5 % compared to 7.6 % in the surroundings). The reduced porosity of the walls of earthworm tunnels is a sign of soil compaction due to earthworm tunneling and accompanying compression of the surrounding material. Cation exchange capacity of earthworm excrements is on average 16.5 mmol/100 g and on a comparable level with imported organic matter by termites. On average base saturation (Ca^{2+}-dominance) of the excrements is 5.8 % and thus approximately five times higher than in subsoil material.

SUMMARY AND DISCUSSION 4.

Dye tracing experiments showed that biogenic structures essentially control the infiltration of water in tropical forest and agricultural ecosystems. The best and most homogenous infiltration takes place in primary forest, whereas degraded grassland areas show the worst performances and agroforestry areas take on intermediate positions. A noticeable relation between percentage of dyed surface and number of animal tunnels exists. Flowing processes especially take place as preferential flow along animal tunnels and root channels. Coarse roots (decomposed) are of special importance for preferential flow. Termite channels are the most frequent of animal tunnels and have great impact on the infiltration of precipitation water. Earthworm tunnels channelize rain water the most effective way and transport water rapidly into the subsoil. By comparison ant-made tunnels are of little importance for preferential flow due to the rarity of their occurrence as well as the comparatively small diameters.

Structures of the leafcutter ants *Atta sp.* and *Acromyrmex sp.* show low values for cation exchange capacity which are similar to those of the adjoining subsoil. The measured values for cation exchange capacity in other ant structures were also only slightly elevated. Organic lining of tunnels and chambers could not be detected in thin sections of ant structures. In termite structures of *Cornitermes sp.* and *Syntermes molestus* the fillings of chambers have increased values for cation exchange capacity. Organic material in nests by *Cornitermes sp.* is entirely confined to the nest chamber close to ground surface, whereas accumulations in numerous chambers in different depths were found in structures by Syntermes molestus. Compared to surrounding soil material structures of other termites also show elevated contents of organic matter and increased porosities. Earthworm excrements have an increased content of organic matter as well as an increased cation exchange capacity, which is on a comparable level to values of termite structures. The considerably reduced porosity of earthworm excrements and of walls of earthworm channels due to compression as a result of earthworm tunneling stands out in comparison to other animal structures.

Statistical evaluation (correlation analysis, cluster analysis and factor analysis) was performed with the objective of revealing connections and dependencies of the different variables. Correlation analysis of the biogenic structures showed a high correlation between cation exchange capacity and C-content, which is a sign for the major participation of organic matter in the exchange of cations.

The agglomerative cluster analysis of the dye tracing experiments reveals a close relation between dyeing, number of roots and number of biogenic pores. Particularly earthworm tunnels are the microfaunistic structures which are important for infiltration of precipitation water, whereas ants and termite tunnels are separated from the dyeing cluster after the first dividing step. K-means cluster analysis verifies the outstanding importance of root channels and earthworm tunnels for preferential flow. Multivariate analysis of the mulching experiments showed that a higher amount of mulching material has a more beneficial effect on soil chemical parameters than better mulch quality. This proves that the approach of the ENV 52 project is correct, even after the currently still short project duration. Application of mulching material leads to an increased macrofaunic activity. Importing of organic material originating from litter and mulch by soil macrofauna leads to an increase of the soil's cation exchange capacity.

In summary, it can be said that ants as well as termites and earthworms with their excavating activities induce an improvement of soil chemical conditions to a varying degree. Therefore promotion of ideal ecological conditions through land cultivation as close to nature as possible is important.

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ANNEX

FIG.5: IMAGE OF THIN SECTION: SOIL FROM A CHAMBER OF *ACROMYRMEX SP*. IMPORTED ORGANIC MATTER CLOSE TO THE BASE OF THE CHAMBER. CROSSED POLARISERS, 25-TIMES (LONG SIDE OF THE IMAGE APPROX. 2 MM)

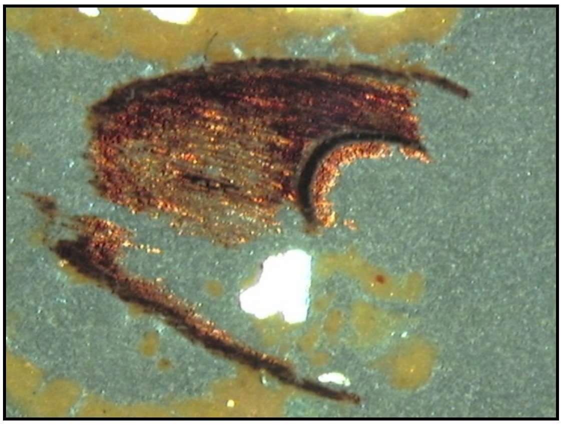


FIG. 6: IMAGE OF THIN SECTION: SIDE WALL OF AN ANT CHAMBER BY *ACROMYRMEX SP*. THIS SPECIES DOES NOT LINE ITS CHAMBERS. CROSSED POLARISERS, 25-TIMES (LONG SIDE OF THE IMAGE APPROX. 2 MM)

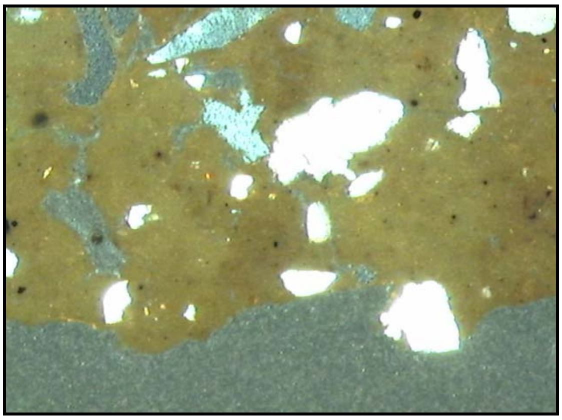


FIG. 7: TERMITE CHAMBER BY *SYNTERMES MOLESTUS*. THE CHAMBER 50 CM BELOW GROUND SURFACE IS FILLED WITH FINE ORGANIC MATTER. THIS TYPE OF CHAMBER SHOWS A LOWER POROSITY THAN THE CHAMBERS WITH LEAF REMAINS.

Photo: P. WALOTEK

FIG. 8: IMAGE OF THIN SECTION: TUNNEL OF *SYNTERMES MOLESTUS*. THE TUNNEL IN A DEPTH OF ABOUT 70 CM IS FILLED WITH DECOMPOSED LEAVES. CROSSED POLARISERS, 25-TIMES (LONG SIDE OF THE IMAGE APPROX. 2MM)

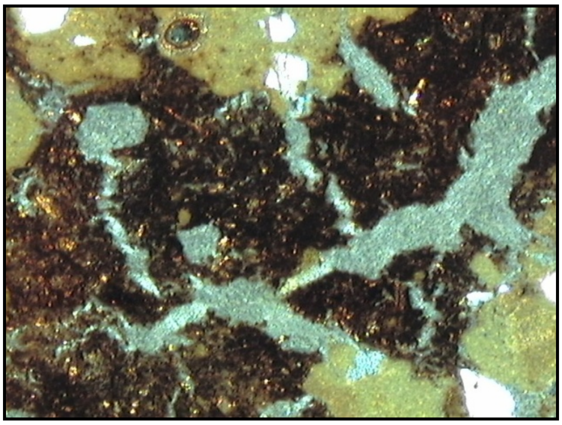


FIG. 9: EARTHWORM TUNNEL WITH MARKS. LOCATED IN A DEPTH OF 20 TO 30 CM, 15 MM IN DIAMETER. THE MARKS OF THE EARTHWORM SEGMENTS ARE VISIBLE ON THE DYED TUNNEL WALL.

Photo: P. WALOTEK

FIG. 10: COMPLETELY EXCREMENT-FILLED EARTHWORM TUNNEL. 12 MM IN DIAMETER. DYE INFILTRATED ALONG THE WALLS OF THE TUNNELS BETWEEN THE WALLS AND THE DENSE EXCREMENTS.

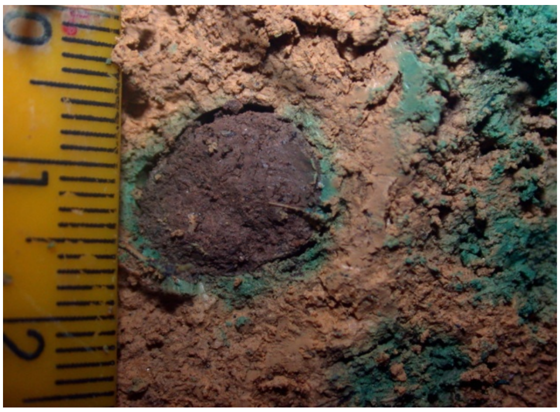
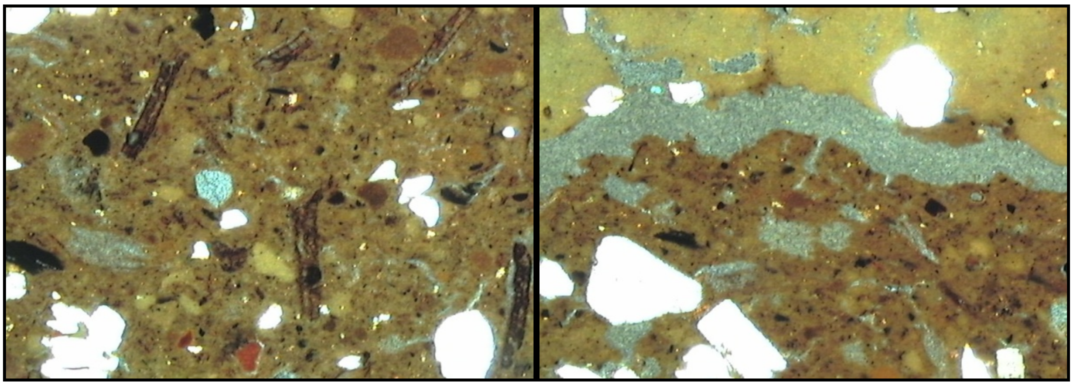


Photo: P. WALOTEK

FIG. 11 AND 12: IMAGES OF THIN SECTIONS: TUNNELS FILLED WITH EARTHWORM EXCREMENTS. POSITIONED IN A DEPTH OF 12 CM, 15 MM IN DIAMETER. THE DENSE EXCREMENTS SHOW AN INTENSIVE MIXING OF ORGANIC (PLANT REMAINS) AND MINERAL MATTER. CROSSED POLARISERS, 25-TIMES (LONG SIDE OF THE IMAGE: APPROX. 2 MM)



IMPROVEMENT OF IRRIGATION EFFICIENCY IN DATE PALM OASES: CONTEXT AND PERSPECTIVES, CASE STUDY KEBILI, SOUTHERN TUNISIA

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ABSTRACT

Nearby 40% of the oases across the world are located in Northern Africa. As one of the Maghreb region countries, Tunisia has more than 40,000 ha of oases located in the main southern country provinces. Irrigation had been always the key issue of the agriculture development in these arid lands. The promotion of the date palm sector contributed strongly to fix the local population and to maintain a stable economical context. The main income of the oases comes from the date palm sector. They still have the highest added value and are mainly destined to the worldwide exportation.

Water is the most important input and determines the parcels productivity within the oases. The main water resources in those areas are deep aquifers, and their reliability is widely compromised under an intensive use context. The water shortage makes the irrigation management more complex, especially for small-scale farmers (less than 0.5 ha). Under such conditions, they are forced to practice a mono cultivation of date palms. Nonetheless, they are hardly able to afford the total costs of their parcels cultivation. Moreover, the traditional irrigation, widely practiced by small-scale farmers, threatens the agricultural sustainability in the major oases.

This paper attempts to highlight the current situation of irrigation within the southern Tunisia oases. An assessment of the prevailing constraints is conducted, with a focus on the perspectives of irrigation efficiency improvement. This is the key issue to assure the sustainability of the irrigated agriculture in oasis ecosystems.

INTRODUCTION 1.

Located between the Mediterranean Sea und the Sahara in Northern Africa, Tunisia is typified by an arid climate over the two thirds of its territory. Due to irregularities in the Mediterranean climate, agriculture has to manage scarce water resources which are unequally distributed in time and space. Nearly 80% of precipitation is concentrated between October and March. The annual evaporation rate ranges from 1,200 mm in the North to 1,800 mm in the south (Aquastat 2005). The country is often subject to drought periods that could be local or generalized. These droughts can occur over one season or more, they can also be prolonged over one or two successive years.

Seventeen percent of the country, located in the 400 to 1,500 mm rainfall zone, receives 41% of the total amount of rain. The area between the 200 and 400 mm isohyets constitutes 22% of the country‘s area and receives 29% of the total rainfall. Finally, the arid region in the south (not including the Sahara), which receives less than 200 mm of rain, constitutes 61% of the country’s area, but receive only 30% of annual rainfall. Under such climate conditions, periods of water shortage occur frequently (Omrani, Ouessar 2008). The irrigated sector is threatened by water scarcity because the water demand continually grows, driven by the population increase and the improvements in the living standards (Horchani 2007).

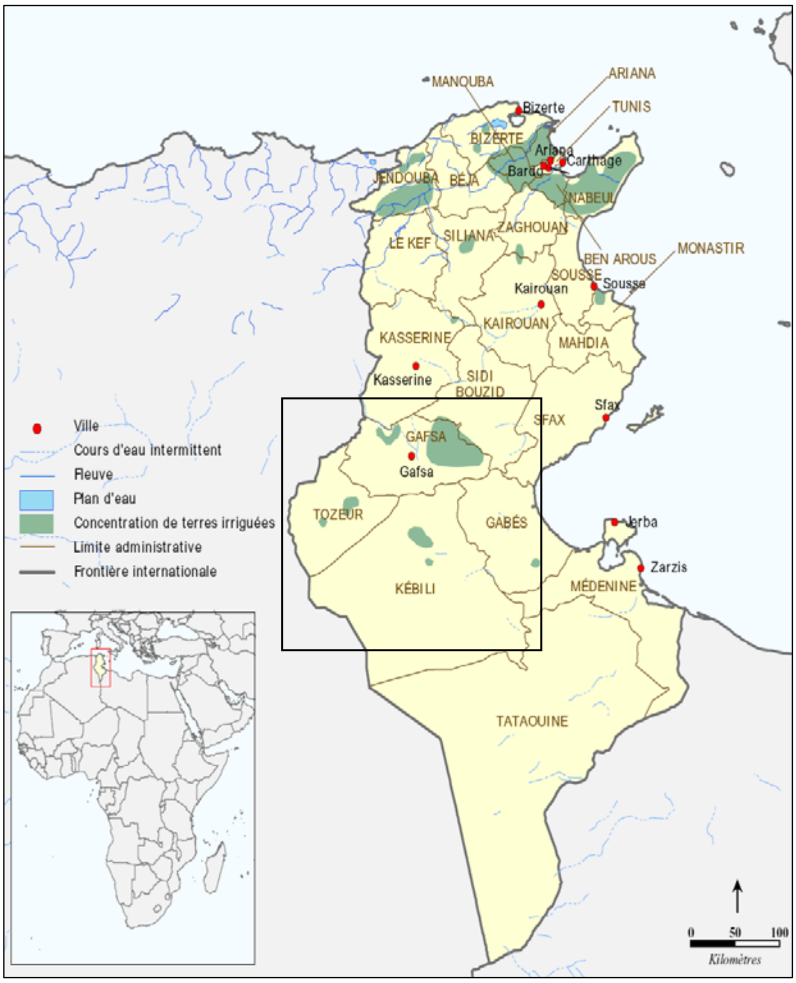
Southern Tunisia remains most exposed to these climate uncertainties that permanently threaten the water resources reliability. In this context, the promotion of the Tunisian oases had been in the recent decades a national challenge that gathered relevant efforts. The development of the irrigation sector in this region stills is the key issue for the safeguard of these particular ecosystems. Within the framework of the national water resources development strategy, these perimeters had been often subject to successive promotion plans that contributed to their expansion.

Since 1972, an accurate assessment of the available underground water resources had been executed. To ensure the water supply of the expanding oases, the national authorities instituted the director plan (1976) that defined the framework of the water resources exploitation. The main components had been: *(i)* the drinking water supply, *(ii)* protecting the old oases that have a irrigation water demand for over 20,000 ha (more than 129 oases) and *(iii)* to satisfy the touristic sector, in the main four important southern provinces: *Gabes*, *Djerba* and *Jarjis* (Seddik 2009).

These interventions aimed to achieve the agriculture development goals following an integrated approach. The first step had been the water resources mobilization. Across the whole southern country, considerable rehabilitation works of the hydraulic infrastructure took place. The deep drillings had been equipped in order to supply wider scale irrigated land and relevant irrigation and drainage networks were built. Furthermore, the implementation of storage reservoirs contributed to optimize the water management, particularly during drought periods.

There are three main important aquifers that are supplying the southern Tunisia oases: (i) *Continental intercalary (CI)*, (ii) *Complex Terminal (CT)* and (iii) the *Jeffara* aquifer (Fig. 1).

FIGURE 1: LOCALIZATION OF THE OASES IN SOUTHERN TUNISIA.



Source: Aquastat 2005

The CI and CT aquifers build the *SASS* (*Aquifer System of the Septentrional Sahara*) and are the key ressource for the irrigation in these regions. This reservoir is extended in Tunisia over 80,000 km^2 and is being exploited from more than 1,200 drillings (OSS 2009). The CT aquifer depth ranges between 30 and 500 m while the CI varies from 60 to 2,800 m. The CI remains the most important water reserve, although it is a non renewable water resource. This aquifer is characterized by relatively hot water (30–75°C) at depths reaching 2,800 m. These Geothermal water resources are located in a reservoir of 600,000 km^2, which covers the regions of *Kebili*, *Tozeur*, *Gabes* and the extreme south, and extends to Algeria and Libya. The CI aquifer is one of the largest confined aquifers in the world, comparable in scale to the great artesian basin of Australia. The principal areas of recharge are in the South Atlas mountains of Algeria and Tunisia and the *Dahar* mountains of Tunisia.

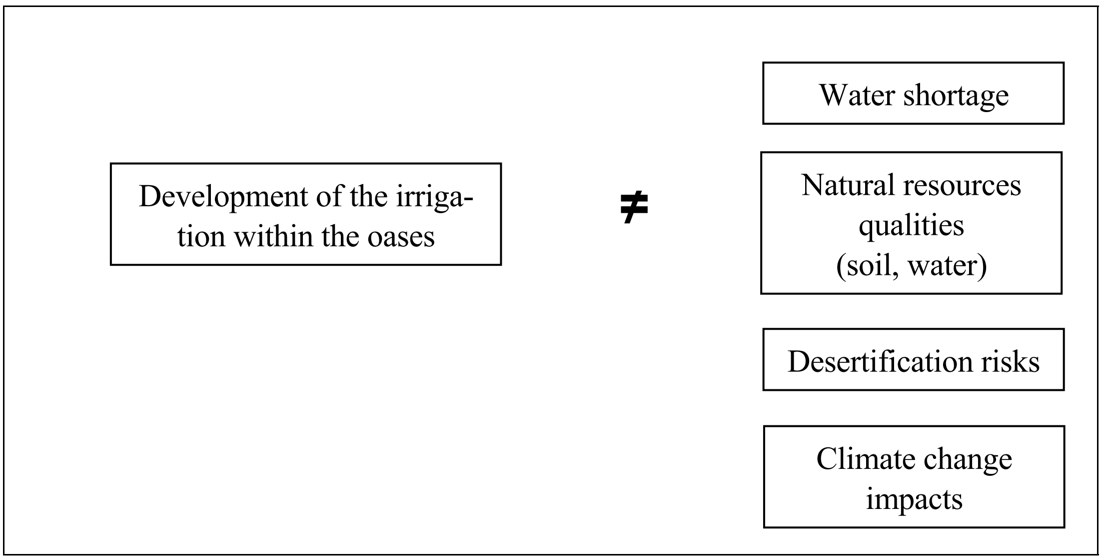
Regarding the imminent risks of desertification, the southern Tunisia oases are called to experience further difficulties in their natural resources management. The underground water resources are still threatened by chronic depletion and the water shortages become acute during the summer period. Moreover, the salinization risks remain important in the low intensification oases. A monitoring system had been established by research and development organizations, with a specific survey of the subsurface drainage networks efficiency in the oases threatened by water logging.

In such context, the development of more efficient irrigation practices would be constitutive to guarantee a sustainable development of the irrigated sector.

THE WATER MANAGEMENT CONSTRAINTS 2.

The agriculture intensification in the southern Tunisia oases remains dependent from the water management. In absence of concrete measures aiming to tackle the different constraints (Fig.2) that could affect the agriculture development in those regions, the sustainability of the irrigation became strongly compromised.

FIGURE 2: THE MAIN CONSTRAINTS TO THE DEVELOPMENT OF THE IRRIGATION IN THE SOUTHERN TUNISIA



The particular context of the oases as intensive perimeters requires a continuous assessment of the natural resources exploitation. A crucial task remains yet the sustainable natural resources management that should be planned and followed until 2050. This task has become more crucial due to the soil fertility degradation in the irrigated lands, as well as to the chronic problems with the irrigation and drainage networks management.

Furthermore, the control of the irrigated area extension becomes a real challenge for the development sector. With the implementation of private parcels at the oases periphery, the water management scheme became strongly affected. These illegal parcels are still being created at the downstream oases, where the shallow water tables are more accessible. In many of these exploitations, the drainage water is also often used for irrigation purposes with inherent salinization and water logging risks (Fig. 3). These private parcels present also very important water consumers: They represent nearby the double of the public irrigated area and contribute strongly to the depletion of the water resources in this region.

FIGURE 3: SALINIZATION SYMPTOMS IN PRIVATE PARCELS IN DOWNSTREAM OASIS IN KEBILI, SOUTHERN TUNISIA

As concrete impacts of these extensions, first prospective studies led by the Observatory of the Sahel and the Sahara (OSS) expect also a considerable decrease in the water table level in the extreme southern region (Mamou 2009). In order to tackle the illegal extension, radical changes in the main stakeholder's behavior dealing with water management in this country part should be considered. The problems should be addressed by strengthening the role of education, knowledge and capacity development in sustainable water management. The importance of the awareness raising for all farmers as well the southern country population would be decisive. Furthermore, the legislative regulation should be stricter in order to eradicate the illegal oases extension. There is an obvious need for a institutional framework redefinition, including the creation of penal and financial incentives.

Another challenge for the irrigated agriculture in general and particularly the oases ecosystems remains the climate change. The impact of climate change is forecasted to be severe on the water resources. The national prospective studies attribute a decrease of nearby 28% in the non renewable underground resources until 2030. The production in drought periods is estimated to decrease by 50% which equals 800,000 ha for the rainfed agriculture. These impacts will be also effect the livestock which will decrease by 80%, either in the center and southern country (OSS 2009).

THE IRRIGATION EFFICIENCY ISSUES 3.

The core problem of the water management in the southern Tunisia remains the low irrigation efficiency within farmer's parcels. After the rehabilitation of the irrigation facilities within the old traditional oases, the state commitment became focused on the enhancement of the irrigation efficiency at parcels scale. The rehabilitation works, which aimed to enhance distribution efficiency within the Southern Tunisia oases, have allowed to save within the rehabilitated oasis 25% to 30% of the water losses. The irrigation interval was shortened by three to two weeks (SAPI 2005).

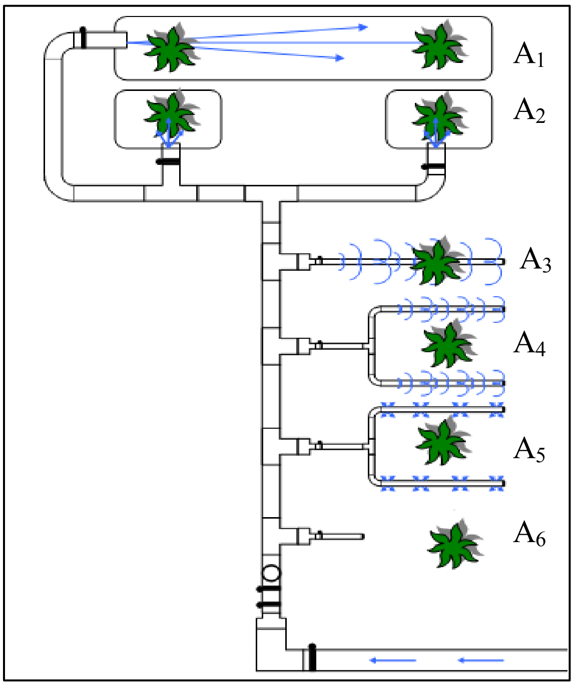
The inventory of seventeen sampled oasis with rehabilitation works on the distribution network revealed a total saved water amount of nearby 7,500,000 m^3. The crop intensity was enhanced from 143 to 164 %, the crop yield was also improved by 35% for palm dates, 36% for olives, the value both of culture was enhanced by 37%. To intensify ratio of water saving equipments within farmer's parcels, several subsidies had been proposed: 40%, 50% and 60% respectively for large, medium and small parcels (Hamdane 2004).

Nevertheless, water consumption in farmer's parcels remains very high and their productivity did not achieve a significant improvement. Traditional irrigation method (Fig. 4) remains the main hindrance to the irrigation efficiency improvement at parcels level. The farmer's commitment to replace the traditional irrigation with newer methods remains sporadic across the *Kebili* region oases. The state of art reveals an obvious need in irrigation modernization.

FIGURE 4: TRADITIONAL IRRIGATION METHOD APPLIED IN OASIS PARCEL IN KEBILI, SOUTHERN TUNISIA

Within that scope, a research program is already on the way to study the technical feasibility of irrigation efficiency improvements within oases farmer's parcels. An experimental installation is built up in pilot parcels of the Institute of the Arid Regions (IRA) in the *Atilet* oasis in *Kebili* (Fig. 5). It aims to assess possible alternatives to the traditional surface irrigation. A survey by watermark devices and water meters allow a comparative evaluation between the surface, sprinkler and micro jet method. The implementation of these techniques to the palm irrigation remains totally new in the southern Tunisia and require rigorous assessment before to be developed for wider use.

FIGURE 5: PILOT INSTALLATION OF IRRIGATION EFFICIENCY IMPROVEMENT IN FARMERS PARCELS



Several research works in these regions showed an alarming situation of the water management. Significant water losses still occur inside farmers parcels. Therewith, the research and development efforts should be stronger relayed to the farmers groups. For the case of the *Souk El Baiez* in *Kebili*, the investigation of the irrigation application efficiency within parcels revealed an over application that could reach 71.9% surplus of the required dose (Omrani and Zayani 2009). This situation is also frequent in the *Jerid* oases where Etten (1996), Van Vuren (1997), Mechergui and Van Vuren (1998) showed a widely applied over irrigation within oases parcels.

The traditional submersion irrigation method has been identified as an important technical constraint. Slimani and Mechergui (1997) focused on the technical parameters of the surface irrigation in *El Kasba* Oasis in *Gafsa* Province's. The farmers don't follow a standard scheme in dividing parcels into basins, their dimensions varies considerably between the oases. These practices affect the irrigation uniformity and cause serious lengthening of the irrigation period especially in the summer period when the infiltration rate enhances.

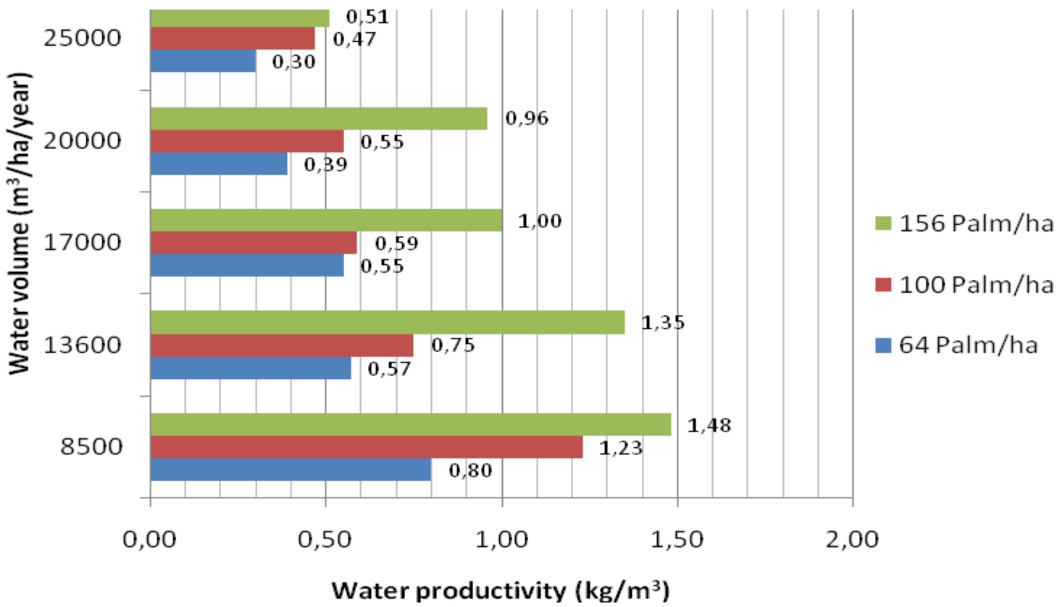
For the case of *Ibn Chabbat* Oasis in *Tozeur*, Goussi (1996) studied the contribution of excess water provided from private illegal wells to the rise of the shallow water table, which led to permanent risks of water logging and soil salinization. Ounis (1999) demonstrated the impact of drainage deficiency on the crop yield and put in evidence the inadequacy of the leaching fraction during irrigation in the *Zarcine* oasis in *Kebili* province. Kacem (1990) demonstrated a significant water flow between farmer's parcels which contributes to water logging in the lower part of the irrigated land.

The impacts of the brackish water management on the soil productivity had been investigated also through the research works of Mtimet and Hachicha (1995), Hachicha et al (1995), Zidi and Hachicha (1997). The gypsum dynamic had been followed across the main important oases (Pouget 1968; Vieillefon 1976; Job 1992; Grira 1993; Job, Hachicha 1990; Hachicha, Job 1994).

In addition to the efficiency issue, water requirement data are not yet exactly defined. The main cultivation system is the date palm tree and the real water amount applied in the *Kebili* oases ranges from 8,000 m^3/ha/year to 40,000 m^3/ha/year. Given the crucial needs for such data, a further research program had been initiated by IRA. It encloses two variants: The palm tree density variants range between D_1= 64 tree/ha, D_2= 100 tree/ha and D_3=156 tree/ha. These are the main density models applied in the southern Tunisia oases, particularly for the recent perimeters, mainly focused on the palm tree production. The second variant of the experiments is the applied irrigation volume. It encloses five volumes: 850 mm, 1,360 mm, 1,700 mm, 2,000 mm and 2,500 mm (1mm=10 m^3/ha/year). There are four repetitions for each variant. The irrigation method is a modern technique (See A_2 in Fig. 5). The irrigation network is equipped by water meters that allow the applied volume control. This comparative study will determine the optimum water amount and density to be applied, and the water productivity in term of Kg/m^3. The yield from each alternative is evaluated in term of quantity (Kg/tree) and the fruits quality (% of good, middle and bad fruit quality).

The preliminary results reveal that the highest water productivity is always obtained with the water amount of 8,500 m^3/ha/year (= 850 mm). It enhances from 0.80 Kg/m^3 for the density D_1 to 1.23 Kg/m^3 for D_2 to 1.48 kg/m^3 for D_3 (Figure 6). Keeping in mind the important gaps between the tested volumes, the water productivity decreases significantly with the enhancement of the irrigation doses. While Simmoneau (1961) claimed that for the most common applied dose of 25,000 m^3/ha/year, the productivity is an average of 0.25 kg/m^3, the first results show for the same dose a productivity of 0.30 kg/m^3 for D_1, 0.40 kg/m^3 for D_2 and 0,51 kg/m^3 for D_3. Nevertheless, beyond the focus on technical problems and the data collection, there is a real gap between the engineering design of the irrigation management in the oases and the farmer's practices that are effectively in charge of the water management (Ghazouani et al. 2009). The extension of the research output should be redefined to improve the water management by the oases population.

FIGURE 6: WATER PRODUCTIVITY IN DEPENDENCY OF IRRIGATION VOLUME AND PALM DENSITY



CONCLUSIONS 4.

The southern Tunisia oases remain very particular ecosystems, known by their biodiversity and the relevant experience of their population in the water management under extreme arid climate. The global changes these perimeters are subjected to threaten their sustainability. The intensive water resources exploitation had led to their chronic depletion, with the progressive disappearance of the artesianism, the pumping had been strongly intensified . The water mobilization cost strongly increased and the small parcels farmers (0.25 ha) became unable to afford such charges as well as the recovery of the global costs.

In this context, the performance of the irrigated perimeters needs to be promoted and require further commitment from all involved stakeholders. The introduction of innovative solutions would be the key element to the safeguard of these perimeters. The tested irrigation systems showed significant applicability for a wider scale implementation, but their introduction is still extremely new. Such a drastic change in the water management behavior would highly contribute to enhance the oases parcels performance as production systems. The introduction of these irrigation practices would contribute to the water resource preservation. The enhancement of the irrigation efficiency within parcels would be most decisive in the summer period when the major irrigation networks total capacity becomes unable to satisfy the oases water requirements. The submersion method still endangers a sustainable water management in the major oases.

The presented experiment results show that new irrigation technologies, as part of an integrated water management, can contribute to a balance between water resources and demand. A close dialogue should now be established between farmers groups and the development stakeholders. Such dialogue should be a decisive tool also to resolve water conflict situation (the problem still more acute between traditional oasis farmers). A deeper understanding and a better assessment of the different aspects (technical, social, land tenure) related to the water management will provide water policy options and facilitate effective decision making in order to meet various societal needs and overcome risks of water resource degradation.

The assessment of more efficient irrigation techniques for the date palm cultivation contributes considerably to define the outline of the water policy in these regions. Enhancing the irrigation efficiency would ensures that the development authorities and the oases farmers can reach their respective objectives.

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COMMUNITIES OF PRACTICE: CHANCES FOR LEARNING IN AND BETWEEN AGRICULTURAL PRODUCTION SYSTEM APPROACHES FOR INTEGRATING PRODUCTIVITY WITH ECOSYSTEM SERVICES FOR LOW-INPUT INTENSIFICATION IN SMALL-SCALE FARMING

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ABSTRACT

There are different paradigms of agriculture that shape prevailing production systems. At one end of the continuum there is the *interventionist approach,* in which most aspects of the production system are controlled by human technological interventions, such as mechanical soil structuring, curative pest and weed control with agrochemicals and controlled plant nutrition with synthetic mineral fertilizers. However, there are now many production systems with a more *ecological approach* generally characterised by minimal disturbance of the ecosystem, and by use of both natural and managed biodiversity in order to provide food, raw materials and other ecosystem services. Ecological approaches to intensification are a proven basis for low-input intensification. Three key principles for sustaining soil and ecosystem health as the basis for integrating intensification with ecosystem services are: minimizing soil disturbance by mechanical tillage and whenever possible seeding or planting directly into untilled soil; and maintaining organic matter cover from cover crops or crop residues over the soil; and species diversification – both annual and perennial - in associations, sequences and/or rotations. Production systems are most sustainable and function best when all three key soil and crop management practices listed above are applied simultaneously in the field as is the case with Conservation Agriculture (CA) which has now spread across all continents and ecologies. Communities of practice exist or come into being to sustain a set of practices which the subscribers consider to be in their interest based on a shared vision and goals. Communities of practices exist to promote production systems such as CA, and CA-based organic farming, CA-based agroforestry, CA-based shifting agriculture, CA-based System of Rice Intensification and CA-based integrated crop-livestock systems. Farmers in a country or region, where sustainable intensification is not practiced, face a number of problems which make adoption difficult. These problems are of a diverse nature, such as intellectual, social, biophysical

and technical, farm power, financial, infrastructural and policy. Action points that should be considered by policy-makers and institutional leaders to address these problems are outlined.

INTRODUCTION 1.

The thrust of these proceedings is on low-input intensification relevant to small-scale farming. This raises the question what is supposed to be meant by low-input intensification? How does scale of operation affect such intensification? Given the specific interpretation of low-input intensification in small-scale farming, the focus of this paper is on agro-ecological approach to sustainable production intensification, and the learning implications of such an approach through various communities of practice (CoP) mechanisms.

If it is to be sustainable, low-input intensification here is taken to be a system that has a low reliance on purchased inputs but a high reliance on natural ecosystem processes to sustain desired output. In small-scale farming, low-input intensification often means that farm power is either manual or animal, although it can also be based on small-scale machinery.

For intensification to be sustainable, independent of input and scale, certain principles must be adhered to in order to integrate productivity with ecosystem services. We believe that there can be no ecological sustainability, and therefore no economic and environmental sustainability, if intensification is not based on ensuring that productivity enhancing interventions do not disrupt ecosystem functions that underpin ecosystem services in agricultural lands. Also, because sustainable production systems are knowledge intensive and location specific, success at the farm level as well as the community level depends on social capital support in which all stakeholders within the innovation systems have a role to play in promoting, learning, testing, uptake and spread of new concepts and principles as well as techniques, inputs and practices that permit low-input intensification at a significant scale. Farmer Field Schools, village organizations, farmers associations, clubs and networks are some examples of such social capital support in the form of communities of practice that generates empowerment and sustainable production intensification in small-scale farming.

WHAT ARE THE PRINCIPLES AND CONCEPTS UNDERPINNING LOW-INPUT SUSTAINABLE INTENSIFICATION OF AGRICULTURAL SYSTEMS? 2.

The principles that underpin sustainable production systems for small or large farmers relate to resource conservation and efficiency of resource use while profitably managing sustainable production intensification and ecosystem services. At the core, sustainable production derives from a number of practical principles that can be applied simultaneously through combined crop-soil-water-nutrient-pest-ecosystem management practices. These practices are locally devised and adapted to capture a range of productivity, socioeconomic and environmental co-benefits of agriculture and ecosystem services at the farm, landscape and provincial or national scale (Pretty 2008; Kassam et al. 2009; Godfray et al. 2010; FAO 2010; Pretty et al. 2011).

There are different paradigms of agriculture that shape prevailing production systems. At one end of the continuum there is the *interventionist approach,* in which most aspects of the production system are controlled by human technological interventions, such as mechanical soil structuring, curative pest and weed control with agrochemicals and controlled plant nutrition with synthetic mineral fertilizers. However, there are now many production systems with a more *ecological approach* generally characterised by minimal disturbance of the ecosystem, and by use of both natural and managed biodiversity in order to provide food, raw materials and other ecosystem services. In order to achieve sustainable intensification, a production system must be able to support and maintain the ecosystem functioning, and services derived from it, while limiting interventions (which may appear necessary for intensifying the production) to levels which do not disrupt these functions. Ecological approaches to intensification are a proven basis for low-input intensification.

One of the main criteria for ecologically sustainable production systems is the maintenance of an environment in the root-zone to optimise soil biota including healthy root function to the maximum possible depth. Roots are thus able to function effectively and without restrictions to capture plant nutrients and water as well as interact with a range of soil microorganisms beneficial for soil health and crop performance (Uphoff et al. 2006; Pretty 2008). In such systems with the above attributes there are many similarities to resilient 'forest floor' conditions (Flaig et al. 1977; Shaxson et al. 2008; FAO, 2008; Kassam et al. 2009). Maintenance or improvement of soil organic matter content and soil structure and associated porosity are critical indicators for sustainable production and other ecosystem services.

A key factor for maintaining soil structure and organic matter is to limit mechanical soil disturbance in the process of crop-management. For this reason no-tillage production methods have in many parts of the world been shown to improve soil conditions, reduce degradation and enhance productivity. However, as a stand-alone practice the elimination of tillage would not necessarily lead to a functioning sustainable production system. This requires a set of complementary principles to enable a functioning soil system. Three key principles for sustaining soil and ecosystem health as the basis for integrating intensification with ecosystem services include particularly (FAO 2010):

- Minimizing soil disturbance by mechanical tillage and whenever possible seeding or planting directly into untilled soil, and completely eliminating tillage once the soil has been brought to good starting condition;
- Maintaining organic matter cover from crops cover crops or crop residues over the soil to protect the soil surface, conserve water and nutrients, promote soil biological activity and contribute to integrated weed and pest management;
- Species diversification – both annual and perennial - in associations, sequences and/or rotations, including trees/shrubs, pastures and crops with legumes for enhanced nitrogen supply, nutrient availability and improved plant hygiene.

The relation between practices (such as mulch cover, no-tillage, legume crops and crop rotation that implement the above principles) and some of the important ecosystem services is shown in Table 1. Even where it is not possible to install all desirable practical aspects in the production system at the same time, progressive improvements towards those goals should be encouraged. However, for any agricultural system to be sustainable in the long term, the rate of soil erosion and degradation (loss of organic matter) must never exceed the rate of soil formation. In the majority of agro-ecosystems this is not possible if the soil is mechanically disturbed (Montgomery 2007). For this reason the avoidance of mechanical soil disturbance can be seen as a starting point for sustainable production. Not tilling the soil is therefore a necessary condition for sustainability, but not a sufficient condition. For a sustainable production system other complementary techniques are required, of which the above key principles constitute the bare minimum.

To achieve and sustain the necessary intensification of these production systems to meet the increasing demand for food and other ecosystem services, productivity needs to be optimized by applying best management practices such as good quality adapted seeds, adequate nutrition and protection from pests and diseases (weeds, insects and pathogens). In addition efficient water management and timely operations are required within suitable cropping systems to achieve desirable and acceptable outcomes.

TABLE 1: EFFECTS OF PRODUCTION SYSTEM COMPONENTS FULLY APPLIED TOGETHER ON SUSTAINABILITY AND ECOSYSTEM SERVICES

SYSTEM COMPONENT ► TO ACHIEVE ▼	MULCH COVER (crop residues, cover-crops, green manures)	NO TILLAGE (minimal or no soil disturbance)	LEGUMES (as crops for fixing nitrogen and supplying plant nutrients)	CROP ROTATION (for several beneficial purposes)
Simulate optimum 'forest-floor' conditions	√	√		
Reduce evaporative loss of moisture from soil surface	√			
Reduce evaporative loss from soil upper soil layers	√	√		
Minimise oxidation of soil organic matter, CO_2 loss		√		
Minimise compactive impacts by intense rainfall, passage of feet, machinery	√	√		
Minimise temperature fluctuations at soil surface	√			
Provide regular supply of organic matter as substrate for soil organisms' activity	√			
Increase, maintain nitrogen levels in root-zone	√	√	√	√
Increase CEC of root-zone	√	√	√	√
Maximise rain infiltration, minimise runoff	√	√		
Minimise soil loss in runoff, wind	√	√		
Permit, maintain natural layering of soil horizons by actions of soil biota	√	√		
Minimise weeds	√	√		√
Increase rate of biomass production	√	√	√	√
Speed soil-porosity's recuperation by soil biota	√	√	√	√
Reduce labour input		√		
Reduce fuel-energy input		√	√	√
Recycle nutrients	√	√	√	√
Reduce pest-pressure of pathogens				√
Re-build damaged soil conditions and dynamics	√	√	√	√
Pollination services	√	√	√	√

Source: Based on Friedrich et al. 2009

There are some farming regions that present special challenges for introducing sustainable agro-ecological production systems, which could be difficulty to retain residues, cold-wet climates, badly drained soils or others, partly based on real problems, partly based on common prejudices. Usually solutions could be found for these problems, provided there is an understanding of the functional principles of sustainable intensification and a community-based support for the solutions (Uphoff et al. 2006; Lindwall and Sonntag 2010; Knuutila et al. 2010). In general these problems have not stopped farmers practicing low tillage operations under those conditions.

Improvement of organic-matter levels and associated biological activity in the soil can have multiple positive effects which may alleviate/eliminate more than one limiting factor at the same time. There have been arguments against no-tillage systems because of the perception that they increase the use of pesticides and herbicides. However, in reality, even in input-intensive systems, when no-tillage is integrated with the other complementary practices of mulch and diversification they can lead to decrease in the use of pesticides and herbicides in absolute amounts, as well as in terms of active ingredient applied per tonne of output, compared with tillage agriculture (Baig and Gamache 2009; Lindwall and Sonntag 2010). In manual smallholder systems, these low-input CA systems can also be practiced without herbicides by applying adequate integrated weed management (Owenya et al. 2011) (see Box 1).

The transformation from common practice to sustainable intensive production systems as described above can occur rapidly where there is a suitable and specific enabling environment, or gradually where farmers may be facing particular agro-ecological, socioeconomic and/or policy constraints, including the unavailability of the necessary equipment. While some economic and environmental benefits will be achieved in the short term, a longer term commitment from all stakeholders is necessary in order to achieve the full benefits from such systems. Total engagement from the outset of farmers and all other key stakeholders in learning, communication and capacity building is critical for the rapid adoption and spread of such systems.

BOX 1: CONSERVATION AGRICULTURE AS EXAMPLE FOR GOOD LAND HUSBANDRY RHOTIA VILLAGE, KARATU DISTRICT, TANZANIA (OWENYA ET AL. 2011)

Conservation Agriculture was introduced in Rhotia village some six years ago and is since that time steadily increasing. The village is located in a hilly, fairly dry area in northern Tanzania. Farmers have stopped ploughing and hoeing and are growing mixed intercrops of direct seeded maize, *Dolichos* lablab and pigeon pea. This system produces good surface mulch, so that weed management can be done by hand without need for herbicides. In some years fields are rotated into wheat. The overall results were positive, maize yields increased despite some dry years during the first 3 years of adoption from an average of 1 t/ha to 6 t/ha. Additional income was derived from selling *Dolichos lablab* and pigeon peas. However, despite this dramatic yield increase, which was achieved without any agrochemicals and mostly livestock manure as fertilizer, the more striking benefits are on the sustainability side. The farmers' perception was:

>CA has helped the community develop in general.

>CA has reduced the cost of farming and increased farm incomes.

>CA has reduced the erosion; gullies have stopped and are starting to be reclaimed.

>CA has diversified production to other crops.

>CA is saving time, which can be spent now on vegetable gardens improving the household nutrition.

>CA is reducing the labour allowing the children to go to school.

>The mulch of cover crops is reducing the workload for weeding and is providing more animal feed despite leaving a good soil cover; the group has *never used herbicides* and is producing their own herbal insecticides and fungicides.

>The most powerful statement regarding sustainability came from the oldest member of the community, a 70 year old farmer: he said that he had seen the land around his village degrading over 40 years. Only when the farmers adopted CA he noticed that the land is coming back to the conditions he remembered from his childhood.

DEVELOPING COMMUNITIES OF PRACTICES FOR SUSTAINABLE INTENSIVE LOW-INPUT PRODUCTION SYSTEMS 3.

Communities of practice exist or come into being to sustain a set of practices which the subscribers consider to be in their interest based on a shared vision and goals. Communities of practices exist to promote production systems such as Conservation Agriculture, Organic Farming, Agroforestry, shifting agriculture, System of Rice Intensification and integrated crop-livestock systems.

A sustainable approach to rainfed and irrigated production cannot be a single technology, but a range of mutually reinforcing practices. For both tillage and no-tillage systems described above, their best performances can only be achieved when the production systems are supported by effective plant nutrition and best agronomic practices. Production systems are most sustainable and function best when all three key soil and crop management practices listed above are applied simultaneously in the field as is the case with *Conservation Agriculture (CA)* as representing a particular set of no-tillage systems (see Box 2) which has now spread across all continents and ecologies. Thus, CA is significantly different from the conventional tillage agriculture (Hobbs 2007; Shaxson et al. 2008; Goddard et al. 2008; Friedrich et al. 2009; Kassam et al. 2009; Kassam et al. 2010).

Much experience now exists to show that when dealing with local application and adaptation of agro-ecological approaches and CA principles, there is an important role for all stakeholders to work together to capture economies of scale but also to share understanding and lessons, to reduce risks, and to seek on-farm, community and landscape solutions to production intensification and rural development opportunities. In sum, this amounts to building social capital in the form of social organizations and institutions for a shared vision of sustainable agriculture production intensification and economic growth. Various communities of practice exist that serve different production system such as CA, System of Rice Intensification (SRI), Organic Farming (OF), Agroforestry (AF), Rotational Farming (shifting agriculture) (RF), and integrated crop-livestock systems (C-LS). What is also emerging is the understanding that CA principles are universally applicable including to other production systems including SRI, OF, AF, RF and C-LS as follows.

BOX 2: CONSERVATION AGRICULTURE

Conservation Agriculture (CA) is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. CA is characterized by three linked principles, namely:

>Continuous minimum mechanical soil disturbance;

>Permanent organic soil cover;

>Diversification of crop species grown in sequences or associations.

CA principles are universally applicable to all agricultural landscapes and land uses with locally adapted practices. CA enhances biodiversity and natural biological processes above and below the ground surface. Soil interventions such as mechanical tillage are reduced to an absolute minimum or avoided, and external inputs such as agrochemicals and plant nutrients of mineral or organic origin are applied optimally and in ways and quantities that do not interfere with, or disrupt, the biological processes.

CA facilitates good agronomy, such as timely operations, and improves overall land husbandry for rainfed and irrigated production. Complemented by other known good practices, including the use of quality seeds, and integrated pest, nutrient, weed and water management, etc., CA is a base for sustainable agricultural production intensification. It opens increased options for integration of production sectors, such as crop-livestock integration and the integration of trees and pastures into agricultural landscapes.

System of Rice Intensification (SRI) has taken root on an international scale in more than 40 countries across all developing regions including China, India, Indonesia, Vietnam, moving beyond its origins in Madagascar (de Laulanié 1993). Trained farmers have shown SRI to offer higher factor productivities and income, and requires less seeds, water, energy, fertilizer and labour compared with conventional irrigated or rainfed flooded rice production systems. As with crops in CA systems, SRI phenotypes are widely reported by farmers to be less susceptible to pest and disease damage. The SRI production concept has been defined on the basis of a set of practices (i.e. seedlings of 10 days for transplanting, or direct seeding; single plant; wide spacing; mainly moist, not saturated and flooded, soil water regimes; regular weeding to also facilitate soil aeration, and liberal use of organic fertilisers) (Uphoff and Kassam 2009; Kassam et al. 2011). An SRI system based on CA principles (CA-SRI) is being practiced on permanent non-tilled raised beds as well as in unpuddled paddies in Asian countries, thus eliminating puddling and the soil disturbing way of weed control.

Organic agriculture (OF)*,* Agroforestry and Shifting Agriculture systems have several features in common with pro-biotic systems, or they can be complemented and improved by underpinning them with pro-biotic principles to harness greater benefits. For example, CA-based organic farming would lead to greater soil health and productivity, increased efficiency of use of organic matter, and reduction in use of energy. Organic CA farming is already practiced in the USA, Brazil and Germany, as well as by subsistence CA farmers in Africa.

Agroforestry (AF) systems involve the cultivation of woody perennials and annual crops together in a sustainable manner, and are increasingly practiced in degraded areas with perennial legumes. CA works well with trees and shrubs and within Agroforestry and related systems. In fact, several tree crop systems in the developing and developed regions already practice some form of CA, but these systems can be further enhanced with improved crop associations including legumes, and integration with livestock. Alley cropping has been one innovation in this area that is beginning to offer productivity, economic and environmental benefits to producers (Sims et al. 2009). Conservation Agriculture with trees (CA with trees, or CA-AF) has now become an important option for many farming situations, particularly in the tropics. It has become the basis for major scaling-up programmes with hundreds of thousands of farmers in Zambia, Malawi, Niger, and Burkina Faso (Garrity et al. 2010). The incorporation of the indigenous acacia species *Faidherbia albida* into maize-based conservation agriculture in Zambia on a large scale is a noteworthy example.

Rotational farming (Shifting agriculture) (RF), also referred to as 'swidden' or 'slash and burn', is based on the clearing of land to prepare a cultivation plot and subsequently returning this to re-growth and eventual natural reforestation, during which damaged soil structure and depleted 'indigenous' plant nutrients are restored. Shifting cultivation has acquired a negative connotation particularly because of the burning of vegetation. However, for sustainable intensification, such systems can be adapted to follow CA principles, changing from slash and burn systems to *slash and mulch* systems with diversified cropping (including legumes and perennial crops) that reduce the need for extra land clearing.

Integrated Crop-Livestock Systems(C-LS) have existed for centuries and are known to have greater resilience and sustainability. Pasture land has important ecological functions. It often contains a high percentage of perennial grasses which have the ability to sequester and safely store high amounts of carbon in the soil at rates which exceed by far those of annual crops. This capacity can be enhanced with appropriate management, for example replacing exported nutrients, maintaining diversity in plant species and allowing for sufficient recovery periods between use by grazing or cutting. In conventional farming systems there is a clear distinction between arable crops and, mostly permanent, pasture land. Under CA based farming, this distinction does not exist anymore, since annual crops may rotate into pasture and vice versa without the destructive intervention of soil tillage, just as additional element of cropping diversity. Integrated

Crop-Livestock Systems including trees and pasture have long been a foundation of agriculture. In recent decades, there have been practical innovations that harness synergies between the production sectors of crops, livestock and agroforestry that ensure economic and ecological sustainability while providing a flow of valued ecosystem services. System integration increases environmental and livelihood resilience through increased biological diversity, effective/efficient nutrient cycling/recycling, improved soil health, enhanced forest preservation and contributes to adaptation and mitigation of climate change. The integration of production sectors can enhance livelihood diversification and efficiency through optimization of production inputs including labour, offer resilience to economic stresses, and reduce risks (Landers 2007; FAO 2010).

Integration can be on-farm as well as on an area-wide basis. Successful crop-livestock integration should be seen through the lens of nutrient use efficiency and nutrient cycling benefits, of ecosystem health advantages and of positive biosecurity outcomes, all of which are strong public goods. Successful integration can also arrest land degradation. In many fragile ecosystems, livestock is the mainstay of livelihoods but at the same time uncontrolled grazing can lead to land degradation. Under such cases the issue of mutually beneficial area integration between the primary and secondary production sectors must be addressed at the community and regional levels. Issues to be addressed include dynamic grazing and functional biomass management, species composition for feed quality and ecosystem services and matching stocking rate to carrying capacity in the context of the prevailing climatic and landscape variability in space and time. In extensive rangeland systems greater precision in matching stocking rate with feed availability and the exposure time to the recovery requirements of vegetation is possible with satellite-guided systems.

SOCIETY-RELATED CONSTRAINTS TO ADOPTION OF SUSTAINABLE LOW-INPUT INTENSIFICATION 4.

Farmers in a country or region, where sustainable intensification is not practiced, face a number of problems which make adoption difficult. These problems are of diverse nature, such as intellectual, social, biophysical and technical, farm power, financial, infrastructural and policy. Most farmers are facing several of these problems, if not all, at the same time to the effect that only very few bold pioneer farmers adopt CA or SRI or CA with trees. Farmers are not in the position to start with a blank sheet and to weigh objectively the merits and disadvantages, for example of CA, against conventional tillage farming. In all cases, CA and SRI are the new unknown concepts, while the default condition for more than 90% of the world's farmers is the conventional tillage-based practice which has 'worked' for them so far. The following sections elaborate upon these constraints using CA as an example but they apply equally to SRI or CA with trees, organic CA, or slash and mulch RF, or C-LS based on CA. They also apply to other complex and management intensive concepts and practices, such as integrated pest management (IPM), which has been successfully introduced by FAO through a network of Farmer Field Schools (FFS) first in Asia, and more recently in Africa (van den Berg and Jiggins 2007).

INTELLECTUAL CONSTRAINTS TO ADOPTION

New technologies that lead to immediate fast adoption often show obvious advantages, resulting in fast acceptance and enthusiasm. In many cases this enthusiasm cools down, once the new technology is known and the downsides become visible. With CA it is just the opposite way: it contradicts so much of the knowledge a farmer has learned and been told that the benefits offered by CA are not obvious in the beginning. However, once the step-wise adoption begins, CA improves their performance over time. The more experience producers have with CA, the more convinced and positive is their opinion about them. The less practical experience people have with CA, the more critical and negative is their attitude towards them. A study carried out with European and American no-till farmers and agricultural experts came to similar conclusions. It was found that the experts, mostly without practical experience in CA, anticipated many problems for its adoption. In their perception actually the problems exceeded the benefits leading to an overall negative attitude. Farmers, however, who were actually practicing CA and had experience with the system, had an overall positive perception with the benefits clearly dominating and the problems being manageable (Tebrügge and Böhrnsen 2000).

CA has actually two intellectual barriers to overcome: the first is that CA concepts and principles are counterintuitive and contradict the common tillage-based farming experience which has worked for generations and which often has created cultural values and rural traditions; the second is the lack of experiential knowledge about CA and the mechanism to acquire it.

Soil tillage, and particularly the plough, has in most countries become part of the culture of crop production. Ploughing, cultivation and tillage are often synonyms for growing a crop. Cropland is called "arable" land which is Latin for "ploughable" land. The plough has been part of the very early developments of agriculture and has the character of a brand symbol for what is 'correct'. It is therefore difficult for people to accept that all of a sudden the plough is dangerous and that a crop can grow without tilling the land. Overcoming this "mental compaction" is often much more difficult than actually physically starting with no-till farming (Landers 2001). Unless a person has seen it happen, it is very difficult to imagine a soil becoming softer and better structured without being tilled. Similar situation applies to irrigated flooded rice production in puddled paddies.

The second intellectual impediment to adoption is simply the lack of sufficient experiential knowledge about it at all and the means of acquiring it. Globally some 8% of the agricultural land is under CA. The adoption is concentrated in some few countries, eventually reaching adoption levels beyond 50%, while in the rest of the world the adoption is at levels below 2%. This explains that most people have never seen a CA system in practice. Since it is also not yet represented in any labels or certification schemes or has any direct relevance to consumers, CA hardly appears in the media. CA is also not included in university curricula even in good agricultural universities. This explains that, despite having an adoption level more than twice that of organic farming, the public knowledge about CA is much lower than about organic farming. Even most agricultural professionals and many farmers have never heard about CA, and if they have, they have only vague ideas. Permanent no-tillage farming and CA are often simply not known and therefore not on the screen as an option for farmers.

For actual adoption of CA the farmer would not only need to know about CA elements in general, she/he would need to know the details on how to implement CA elements under the specific conditions of an individual farm. This knowledge is generally not available as a standard technology package off-the-shelf. Worse, CA is a complex and management intensive farming concept in which crop management has to be planned ahead and is mostly proactive and not reactive, as in the standard tillage-based systems. Problems of soil compaction or uneven surface in tillage-based systems are corrected with tillage, in no-till systems they have to be prevented from occurring from the start. Weed and pest management in conventional tillage systems is often based on chemical or mechanical control as response to the incidence, while in CA the incidence of weeds and other pests is reduced by forward planning of crop rotations. This increased complexity requires a degree of experience and knowledge, which has to be acquired and learned. For early adopters this learning process and experiential knowledge has therefore involved a lot of trial and error until sufficient local experience and knowledge is accumulated to make the adoption easier. However, the solutions to these practical problems are best developed by the farmers themselves and not by scientists. Usually farmer's own adaptive "research and development" process leads to quicker and more applicable results than the so called 'Green Revolution' approach of leaving the development of a standard technology package "ready for adoption" to the scientific community.

To effectively cope with the diverse agro-ecological and socio-economic conditions of farming environments when considering system level alternatives and changes, flexible approaches to on-farm testing and dissemination are required. This is particularly so when knowledge-intensive, integrated practices involving the simultaneous management of several elements are being introduced as is the case with CA, and the elements concerned cannot be reduced to standardized technology package intended for wide applicability (Stoop *et al.* 2009). Thus, a relatively large variation in the implementation and performance of CA practices in farmers' fields is an obvious and logical consequence of this dissemination approach, partly also because the new balances and equilibria as well as full benefits that such practices are expected to offer manifest themselves over time. Therefore, economic assessments and adoption studies based on aggregated results over relatively short periods of time will further contribute to biased and/or pre-mature, generalised conclusions with regards to production potentials, agronomic feasibility and future prospects.

SOCIAL CONSTRAINTS TO ADOPTION

Farming communities in the developing regions are mostly conservative and risk averse. Any farmer doing something fundamentally different from the others will therefore risk being excluded from the community. Only very strong and individually minded characters would take that step, which leads to social isolation and sometimes even to mocking. Even if those individuals have visible success, the aversion created in the community and the peer pressure can result in other farmers not following. The pressure can be so bad that the community gets jealous of the success and instead of also adopting it, it leads to boycott including using 'black magic' and placing bad spells on the fields. For adoption of CA it is therefore not enough to find any progressive farmer who will prove the concept to work, but the farmer must have a socially important role, and be respected and integrated in the community. Ideally the community should be involved from the very beginning to avoid this kind of antagonism.

Other problems can be traditional land tenure systems, where there is no individual ownership of land, which lowers the incentives of farmers to invest in the long term improvement of soil health and productivity. Also communal grazing rights, which often include the right to graze on crop residues or cover crops after the harvest of the main crop, create conflicts which make it difficult for the uptake of CA practices. These problems can be real impediments to the adoption of CA and conflicts arising, for example, from alternative uses of crop residues as mulch or animal feed cannot be solved by orders or directives. Even physical protective structures such as fences might not be the optimal solution, if they work against the traditional social values of the respective cultures. Much more important in the process is that the entire community first understands the issues and the changes and benefits involved in adopting CA and jointly looks for solutions.

CONSTRAINTS OF LACK OF FARM POWER, EQUIPMENT AND MECHANIZATION

One of the most important yet commonly overlooked inputs in agricultural production systems is farm power. Lack of sufficient farm power in many countries is a bottleneck to increasing and intensifying production, especially where it depends on manual or animal traction power.

Farmers working at hand level on average can only feed 3 other persons. With animal traction one farmer can already feed 6 other persons and with a tractor the number further increases to 50 or more persons (Legg et al. 1993). Labour output levels vary widely according to the mechanization level, climatic conditions and mechanization levels, and there is a clear correlation between the production levels and the farm power input (Giles 1975; Wieneke and Friedrich 1989), but they also depend on the kind of farming system used (Zweier 1985; Doets et al. 2000). Suitable mechanization options can lead to improved energy efficiency in crop production, leading to better sustainability, higher productive capacity and lower environmental damage at any level of the socioeconomic development (Baig and Gamache 2006; Lindwall and Sonntag 2010). Particularly for small scale farmers, community-based solutions to the farm power problem are often the only way to overcome the existing shortcomings.

POLICY CONSTRAINTS TO ADOPTION

Adoption of CA can take place spontaneously, but it usually takes a very long time until it reaches significant levels. Adequate policies can shorten the adoption process considerably, mainly by removing the constraints mentioned previously. This can be through information and training campaigns, suitable legislations and regulatory frameworks, research and development, incentive and credit programmes. However, in most cases policy makers are also not aware about CA and many of the actually existing policies work against the adoption of CA. Typical examples are commodity related subsidies, which reduce the incentives of farmers to apply diversified crop rotations, mandatory prescription for soil tillage by law, or the lack of coordination between different sectors in the government. There are cases where countries have legislation in place which supports CA as part of the programme for sustainable agriculture. If those countries, within the same Ministry of Agriculture, have then also a programme to modernize and mechanize agriculture, it usually happens that the first items introduced under such a mechanization programme are tractors with ploughs or disk harrows. This does not only give the wrong signal, but it works directly against the introduction and promotion of CA, while at the same time an opportunity is missed to introduce the tractors with no-till seeders instead of the plough, helping in this way to overcome this technology constraint. Countries, with their own agricultural machinery manufacturing sector, also often apply high import taxes on agricultural machinery to protect their own industry. This industry often has no suitable equipment for CA available in the short term, but due to the high import taxes the importation of equipment from abroad is made impossible to the farmers who wish to adopt CA. In other cases the import tax for raw material might be so high that the local manufacturing of CA equipment becomes unfeasible. In all those cases regulations have to be revised even beyond the influence of the Ministry of Agriculture, which often proves very difficult. Policymakers and legislators must be made aware of CA and its ramifications to avoid such contradictory policies.

Where farmers do not only farm their own land, but rent land from others, there are additional problems with the introduction of CA: the building up of soil organic matter under CA is an investment into soil fertility and carbon stocks, which so far is not recognized by policy makers, but increasingly acknowledged by other farmers. Farmers who still plough know that by ploughing up these lands the mineralization of the organic matter acts as a source of plant nutrients, allowing them to “mine” these lands with reduced fertilizer costs. This allows them to pay higher rent for CA land than the

CA farmer is able to do. To avoid this some policy instruments are required to hold the land owner responsible for maintaining the soil fertility and the carbon stock in the soil, which in absence of agricultural carbon markets is difficult to achieve.

WHAT NEEDS TO BE DONE NOW TO PROMOTE LOW-INPUT INTENSIFICATION? 5.

Amongst the key requirements to accelerate adoption of low-input systems such as CA, SRI/CA-SRI, CA-AF, CA-OF, CA-C-LS in small-scale farming is the establishment of knowledge and learning systems which are community-based. Farm Field Schools, farmers associations and cooperatives and other similar Communities of Practice (CoPs) can empower and produce champions and leaders at the production level as well as in other parts of the innovation system such as in input supply, specially equipment and machinery, and in output delivery and market access.

As described above, sustainable production intensification with low-input small-scale farming systems are systems that offer 'more for less' and therefore are characterised by complexity and need for specific local adaptation and hence cannot be introduced through common top-down linear technology transfer mechanisms. Also, there is a need for the research community to undertake problem-solving research on such systems which must be undertaken on-farm in benchmark sites where discoveries of improved performance from operational research can be disseminated quickly through the various CoP mechanisms.

ACTION POINTS FOR POLICY-MAKERS AND INSTITUTIONAL LEADERS

In light of the above, it is suggest that the following action points should be considered by policy-makers and institutional leaders:

> Establish clear and verifiable guidelines and protocols for low-input agricultural production *systems* which would qualify for sustainable intensification, including as integral elements Conservation Agriculture, SRI and CA-SRI, CA-OF, CA-AF, CA-RF, CA-C-LS as well as for *practices* of Integrated Pest, Nutrient, Weed and Water Management and other good practices from a socio-economic and environmental point of view.

> Institutionalize the new way of farming in public sector education, research and advisory services as officially endorsed policy.

> Establish the conditions for a conducive environment to support this new kind of agriculture, including the provision of suitable technologies and inputs through the commercial supply markets.

> Establish incentive mechanisms such as payments for environmental or community services, based on the adherence to the established protocols for sustainable intensi-

fication and align any eventually existing payments to farmers to such service based approach.

> As adoption levels increase and the sustainable intensification becomes an accessible option to every farmer, introduce penalties for polluting or degrading ways of agriculture as additional incentive for late adopters.

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LOW-INPUT INTENSIFICATION: WHAT KIND OF RESEARCH SUPPORT IS NEEDED? THE DEVELOPMENT ASSISTANCE PERSPECTIVE

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The livelihoods of 2.6 billion people depend on agricultural production systems (UNEP 2011). There are around 525 million small-scale farms worldwide and 404 million of these have less than two hectares (Nagayets 2005). They also cultivate 60% of the land available (McIntyre, B. D. et al. 2009). The world population will continue to grow and is predicted to reach nine billion by 2050. In 1950, there was 5,600 m^2 of arable land for every person in the world; in 2000 this figure was only 2,300 m^2 and when the world population reaches nine billion, this will be 1,500 m^2. However, land – in terms of the area available (quantity) and its productivity (quality) – is not the only resource that is running short and becoming depleted; the same applies to fresh water, for which demand doubled between 1980 and 2000 alone, and other resources such as phosphate. Natural sources of phosphate will be exhausted in the foreseeable future, although exactly when this will occur is still a matter of debate. Some experts believe this could happen within 50 years; other colleagues argue that the recent and future discovery of new deposits means that reserves could last another 200 years.

Climate change is exacerbating this situation. Regardless of whether this is human-made or not (as some sceptics still believe), it is a fact that the climate is changing. The problem is predicting exactly how these changes will present on a small scale. At the moment only very rough charts are available to show how the changing climate is affecting agriculture. Developing countries in particular need to be alert to production decreasing as a result of increasing temperatures and the subsequent reduction in fresh water availability. In addition, spontaneous weather events, such as storms and heavy rain, as well as very early or very late rainfall or extreme fluctuations in rainfall over time, will also cause difficulties for farmers.

The bottom line is that agriculture must now be intensified due to the world's growing population and changes in eating habits (mainly greater consumption of meat). In the medium term, the assumption that there is enough food for all the people and animals in the world and that the problem is actually one of distribution, is not sustainable. More needs to be produced on the land available. Of course, it would also be useful for people to change their eating habits. However, it would be arrogant to advise people in poor countries who achieve some degree of affluence not to eat more meat, even though the increased demand for meat in the future will come from these regions. If changes can be made here, they will only be achieved in the long term. For the present, therefore, the focus should be on the industrialised countries.

There is great potential for increasing small-scale agricultural productivity in developing and emerging countries in particular, because production here relies on very few inputs. In many cases, there are insufficient quantities of seeds, fertiliser, pesticides, equipment, livestock and, to some extent, workers. In addition, the capital needed to finance these inputs is not available. One of the most important inputs is knowledge and access to this knowledge. Today there are many new opportunities that were inconceivable just 10 years ago. These have been made possible thanks, above all, to the mobile telephone, which has found its way into every last corner of the world and which could give farmers access to advice. In many countries, however, the advisory services needed to provide this assistance have been neglected or even closed down in the hope that the private sector can supply this support instead. This has often proved to be the wrong conclusion.

Any inputs into these small-scale systems will normally lead to intensification and an increase in productivity. In this context there is therefore much talk of enormous rates of growth, for example as a result of ecological agricultural practices. If investments are made in a marginal system, then almost every type of intensification will lead to increased productivity. It would therefore be important to compare the various approaches in order to evaluate the different increases in productivity and select the optimum system.

'Low-input intensification' is therefore a relative concept. For a production system already functioning with minimal inputs, providing improved seeds and fertiliser is a fairly significant contribution. And even converting the system to ecological agriculture involves, at the very least, a high knowledge input, because such systems generally require the farmer to have extensive know-how. At any rate, it is always essential to consider each individual system in order to be able to determine what is possible or feasible with the resources available (external) and within the production system (internal). Decisions concerning potential changes or improvements can and should only be taken once this process has been completed and in participation with the producer. One possible system is ecological agriculture; another is conservation agriculture, which usually requires herbicides, but also prevents erosion and improves soil quality. Agroforestry systems are a further alternative, but are far too complicated for many farmers. Another popular system is contract farming, where small-scale farmers are provided with inputs and knowledge, which they use to cultivate a particular product (e. g. cotton). This product is then purchased at a predetermined price. With the right conditions, contract farming can be very profitable for small-scale farmers, as demonstrated in India (Felkl 2010) and in other countries.

Every measure should be assessed with sustainability in mind to ensure that the ecological, economic and social dimensions all meet this objective. Intensification must not take place at the expense of the environment or natural resources and in addition it must be financially profitable without causing social damage, such as child labour (this issue is particularly relevant in developing countries).

Not all of the conditions required by intensification processes can be provided by small-scale farmers. For example, if they are producing increased yields, then not only must there be markets for this produce, but farmers must also be able to access these markets and have reliable information about them. This applies to regional as well as national and international markets.

Everything discussed above raises a number of different questions and issues that need to be researched. In a recent publication, several well-known experts formulated 'The top 100 questions of importance to the future of global agriculture' (Pretty et al. 2010), which is certainly worth reading and for the most part corresponds with this author's own experience. One of the basic requirements is that the rural population helps to establish every research agenda. In the past, the big mistake made by those involved in research was assuming that they knew what was best for the people affected and that the issues that needed to be examined could therefore simply be defined from a distance and this research could then be carried out in institutes. They also overlooked the extent of the innovation that already exists within the target group. Efforts must be made to tap into this innovation more effectively and to integrate it into research agendas. In general, more in-depth knowledge and research is needed in the following areas:

> Institutional conditions
  – markets, access to markets and information about markets
  – training
  – dissemination of knowledge, advisory systems
  – service systems, inputs

> Use of electronic media (information and communications technology, ICT)

> Organisation between farmers
  – cooperatives
  – commons

> Financial services
  – loans
  – insurance
  – environmental services

> More efficient use of water and management of different-sized watersheds (in many cases, water is no longer a technical issue, but a political and governance one)

> Improving soil fertility
  – possibilities derived from humus formation
  – *terra preta* to replace or enhance compost

> Fertilisation and fertiliser issues
  – efficient, sustainable use of mineral fertilisers on different types of soil
  – potential substitutes for mineral fertilisers ('peak phosphorus')

– advantages, disadvantages and potential of organic fertilisation

There are particular issues concerning climate change and its impact on agriculture, especially in developing countries. Research needs to focus on two areas: adapting to climate change and the potential for agriculture to reduce greenhouse gas emissions. Agriculture contributes to around 14% of the harmful greenhouse gas emissions worldwide. In addition to carbon dioxide (CO_2) e. g. from machines powered by fossil fuels, these include nitrous oxide (N_2O) from the incorrect use of mineral fertilisers and methane (NH_4) from animals and wet rice paddies. A further 18% of the emissions come from changes in land use, for example deforestation in tropical forests to clear space for future agricultural use, which has well-documented negative consequences.

The main issues are:

1. Adapting to climate change
    > Which plant varieties and animal breeds are useful and under which conditions (robust rather than high-yield?)

    > Who must adapt to what? A question for climate researchers.

    > Which land use systems are suitable for the change in conditions?

2. Reducing greenhouse gases
    > The potential of different production systems to reduce agricultural emissions
    - conservation agriculture
    - biochar
    - bioenergy in place of fossil fuels
    - changes in land use (in both a positive and negative sense)

    > What compensation mechanisms are there/will there be/could there be that are similar to the Clean Development Mechanism (CDM)?

Another general problem is knowing to what extent a production system is advantageous, because different assessments always provide very different results:

> Can organic farming feed the world (Korte 2010)?

> The risks and opportunities of conservation agriculture (CA) in various contexts
- CA in systems with genetically modified plants
- can CA also be used without herbicides and is it therefore practicable for organic farming?

> Meat vs. plant-based food
- as the world population increases, how much meat consumption is reasonable, or possible?

– the majority of the fertiliser used in organic farming today comes from animals. How can this be reconciled with calls for animal production to be reduced because of the high consumption of fodder and production of methane?
– Cost-benefit comparisons and risk assessments that help to select the best approaches

One of the challenges raised time and time again is the conservation of agrobiodiversity, or at the very least slowing down the rate of decline. The following research is necessary:

> What is the potential of gene banks and how secure or sustainable are they?

> How do we aim to conserve agrobiodiversity (of varieties and species) *in situ*; who pays for this?

  – *De facto* conservation is increasingly no longer the norm (however, a diverse range of pearl millet varieties in Africa and potato varieties in Peru are still grown and used); what will happen if agriculture is intensified?

  – Should rural families actively conserve biodiversity *in situ* and receive payment for doing so? How much would this cost and who would pay?

  – Should national or international research institutions be responsible for *in situ* conservation and where will the money come from to fund this?

  – What are the costs of conserving essential agrobiodiversity and how is 'essential' agrobiodiversity defined?

In conclusion, this topic raises a great many questions; however, costly research is not needed to answer all of these – often compiling and evaluating the data already available will provide solutions. In the majority of cases, the research and studies must have a strong practical relevance and so it is important that they are not just carried out by scientists, degree candidates and PhD students, but also by colleagues working in the field who have direct access to the target groups. As stated above, only research conducted under practical conditions is worthwhile and only this research will provide the necessary results.

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ROLE OF A PARTICIPATORY RESEARCH ORGANIZATION FOR LOW EXTERNAL INPUT INTENSIFICATION IN DEVELOPING COUNTRIES

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ABSTRACT

Smallholder agriculture in developing countries is considered to be one of the essential approaches to find measures to be taken in order to alleviate hunger and poverty. As it is characterized by a low availability of resources and a high heterogeneity of local conditions, approaches of a low external input intensification are considered as a particularly suitable method to increase its productivity. However, precisely these approaches rely on the fact that the way research and development are organized can ensure that the results obtained are adequately adapted to local conditions. Here, participatory research approaches which substantially integrate smallholders into the research process as potential users of the research results offer a possible solution.

This article gives information on results of the project "Possible contributions of research to solve the world food problem" which has been carried out by the Office of Technology Assessment at the German Bundestag (TAB) and which has been focusing – among others – on participatory research. The article outlines requirements for a successful implementation of development-oriented research projects as well as potential solutions from participatory research organization (e.g. using the example of participatory plant breeding). One focus of the article is on obstacles participatory approaches have been faced with so far regarding research policy and research promotion in Germany as well as on possible steps to be taken with regard to research policy in order to promote participatory research.

INTRODUCTION 1.

The alleviation of hunger and poverty is one of the most serious challenges the global community has to face. According to FAO estimates, 925 million people suffered from hunger in 2010, the majority of them living in developing countries and newly industrialized countries (FAO 2010, p. 10). Moreover, several billions of people have to be added who suffer from the so-called "hidden hunger", i.e. an inadequate supply of vital micronutrients such as vitamins or minerals (Stein/Qaim, p. 3). The number of people in developing countries living in absolute poverty is disastrous: According to the recent report of the United Nations regarding the Millennium Development Goals, this number was 1.4 billion people in 2005 which corresponds to a fifth of the entire world population (UN 2010, p. 6).

Smallholder agriculture in developing countries is considered to be one of the major approaches concerning measures to be taken to alleviate hunger and poverty (particularly see IAASTD 2009, also e.g. Deutsche Bank Research 2009). Three quarters of the poor population of developing countries – but only 58% of the total population – are living in rural areas. Here, agriculture serves as a basis for the livelihood of almost nine of ten people. Furthermore, 85% of the farmers in developing countries cultivate a surface of less than two hectares (World Bank 2007, pp. 3, 45, 90). Finally, according to a rough estimate of the UN Millennium Project Task Force on Hunger, 50% of the hungry worldwide are living in smallholder households (UN Millennium Project 2005, p. 5 f.). The yields per unit area that are achieved by smallholder agriculture in developing countries are far below the yields per unit area achieved by intensive agriculture in favourable areas. However, substantial increases are considered to be possible. First of all, productivity increases can improve self-supply with food of people suffering from undernourishment and malnutrition. Furthermore, they can involve improved incomes.

The agriculture in developing countries which is predominantly based on smallholders shows several characteristics that are significant with regard to measures to be taken to increase productivity. Those are in particular the low availability of financial (and other) resources as well as the high heterogeneity of the local (ecological, but also economic, social and cultural) conditions. At the same time, agriculture generally has to face the big challenge to drastically reduce its demand for resources (mainly for soil, water, mineral nutrients, fossil energy sources) and to reduce negative impacts on the environment and health due to current practices (e.g. by using pesticides).

Against this background, low external input intensification approaches are considered to be a particularly suitable method to increase the productivity of smallholder agriculture in a resource-saving manner and thus to contribute substantially to a reduction of hunger and poverty (e.g. Meyer 2010, for details see Meyer 2009).

If the measures taken for a low external input intensification shall have the desired success in practice, however, it is also necessary to consider *how* research is carried out, i.e. to consider research organization. For a long time, development-oriented research has been criticized regarding the fact that it was not adequately oriented towards the needs of its target group. This need for an adequate orientation towards local conditions particularly applies to an increase of agricultural production by means of low external input approaches. This represents a challenge for research that is intended to contribute to an alleviation of hunger and poverty. Here, participatory research approaches which substantially integrate smallholders into the research process as potential users of the research results offer a possible way to find locally adapted solutions. In this respect, participatory agricultural research represents a promising approach. At the same time, however, it is faced with several challenges and obstacles resulting e.g. from the current design of national research policy and research promotion.

Participatory approaches as a promising form of research organization in development-oriented agricultural research were one of the main topics of the project "Possible contributions of research to solve the world food problem", which has been carried out by the Office of Technology Assessment at the German Bundestag (TAB) and which has been completed recently. This project focused on research in Germany and dealt e.g. with the questions of which requirements exist for a successful implementation of development-oriented research projects, where current obstacles can be found and how these obstacles can be overcome. In the following, first of all information will be given on the thematic conception as well as on the methodology of the TAB project (chapter 2). Then, problems of research organization so far with regard to the promotion of smallholders will be outlined (chapter 3) and a participatory organization of agricultural research will be presented as a potential alternative (chapter 4). In chapter 5, participatory plant breeding is used as an example to describe potentials and limits of participatory research. Finally, obstacles with regard to research policy and research promotion will be dealt with and options for action will be put forward for discussion (chapter 6).

THE TAB PROJECT "POSSIBLE CONTRIBUTIONS OF RESEARCH TO SOLVE THE WORLD FOOD PROBLEM" 2.

The question of how research can contribute to solving the problem of world food was the starting point for the TAB project. Within the framework of the project, this issue has been dealt with from a broad perspective. In terms of a heuristic, it has been assumed initially that all factors having a noteworthy influence on the world food situation can offer approaches for measures to be taken in order to alleviate the problem and thus, finally, can also offer corresponding approaches for research. In this way, such fields of research should be focused on which up to now have been neglected in relevant discussions – although they offer noteworthy contributions to solving the problem – and which thus could be part of a comprehensive research strategy. Moreover, the survey focused on the field of research organization. Here, it concentrated on questions like which lessons can be learned from the so-called knowledge and technology transfer problem of development-oriented research with regard to future research design and which obstacles have to be overcome for this purpose.

A methodical focus of the TAB project is the differentiation of three different views or perspectives which are adopted in relevant discussions regarding the world food problem (Dusseldorp/Sauter 2011, p. 39 ff., 48 ff.). From the "*quantity perspective*", the main focus of interest is on the total quantity of food produced and demanded. The quantity perspective is often adopted when the issue of the world population's future food demand – e.g. that of the year 2050 – is broached. In contrast, the *"access perspective"* emphasizes that the decisive factor for evaluating the world food situation is not the calculated, but the actual availability of food for all people. Though there has been a food production surplus compared to the demand for decades now, millions of people do not have any access to food. The access perspective focuses on the mechanisms leading to a certain distribution of the overall available quantity of food among the world population. The *"nutrition perspective"*, however, focuses on the individual nutritional behaviour as well as on its determinants. From this point of view, the world food problem is neither primarily a problem of quantity nor a problem of mere access. In fact, it is mainly considered to be a problem of nutritional behaviour, which is characterized e.g. by insufficient knowledge of a healthy diet and of an appropriate preparation of the available food.

Each of the three perspectives involves a specific understanding of the world food problem. Depending on the perspective, different influencing factors regarding the world food situation are focused on: e.g. influencing factors following the logic of the quantity perspective are those factors concerning the quantity and quality of the agricultural areas (e.g. competing uses, soil degradation) or concerning the demand for food. Significant influencing factors following the logic of the access perspective are poverty as well as the situation regarding land ownership and land rights. As these influencing factors simultaneously represent potential approaches for research in order to solve the world food problem, the different perspectives finally characterize the view on potential contributions of research.

In the first project phase, thirteen short expert analyses were assigned to external experts highlighting potential topics for research and dealing with issues of research organization. On the one hand, the expert analyses have dealt with individual factors of agricultural production (intensification of crop production, underutilized crop varieties, plant breeding for marginal areas), production systems (organic farming) as well as comprehensive factors concerning production (climate change). On the other hand, other expert analyses have dealt with post-harvest methods, the change of dietary habits and with micronutrient deficiencies. In addition, the field of agricultural trade as a major determining factor for the world food situation has been taken into consideration with regard to world trade policy. Finally, three expert analyses have dealt with different aspects of research organization in Germany.

An integral part of the project has been the TAB workshop "Possible contributions of research to solve the world food problem" which took place in June 2010 in the German Bundestag and which was intended to develop three main issues of the project's topic with a circle of experts and the interested public within the framework of a hosted panel discussion. The issues have been determined by TAB based on an evaluation of the short expert analyses as well as of other relevant literature. They have been intended to capture as much as possible of the discussions regarding research in terms of global food supply and to highlight (partly controversial) aspects of the discussion.

The first topic *"In the focus of research: production or consumption?"* assumed that research with regard to global food supply so far has mainly focused on the production side of food supply. Discussion primarily dealt with the question of what contribution can be made for solving the world food problem by research concentrating not on the production, but on the consumption side. The second panel discussion entitled *"Controversial strategies to increase production"*, however, focused on the production side and dealt with the different strategies for alleviating the world food problem by means of production increases which partly have been discussed controversially. While the first two discussions referred to different approaches for research, the third panel discussion *"Research organization: lessons learned from the transfer problem for funding institutions and research policy?"* dealt with aspects of how research is carried out. Here, the focus was on the question of to what extent alternative types of research organization, e.g. participatory research, are appropriate to solve the problems of the way research predominantly is done so far.

Finally, in a general overview of the project's results, possible priorities for future research on global food security as well as options for action regarding research policy have been outlined.

The following statements are based on the expert analyses by Neef (2009), Christinck (2009) and by Christinck & Kaufmann (2009) as well as on the results of the third panel discussion of the public expert workshop. All results of the project (including evaluations of the short expert analyses as well as of the expert workshop) can be found in the project's final report (Dusseldorp & Sauter 2011).

PROBLEMS OF RESEARCH ORGANIZATION SO FAR 3.

For decades now, development-oriented research has been criticized regarding the fact that, in practice, it would fall far short of its own demands and of the objectives of research policy. A major point of criticism is the type of research organization that is predominant so far. The central question in this context is which protagonists shall participate in the research process and how they shall participate.

The development-oriented research dominating so far is closely linked with a certain model of innovation processes. According to this model, these are linear processes in the course of which science develops new technologies which then are passed on by advisory services to the farmers as end users (technology transfer). In the last decades, research and development according to the technology transfer model have involved considerable productivity increases in industrialized countries as well as in favourable areas of the "Green Revolution". However, it has become apparent that this way of intensifying agricultural production involved considerable ecological and social costs. Moreover, it became evident that the corresponding research did not bring the desired success in marginal regions of developing countries, because it is not adequately adapted to the needs of smallholders in developing countries.

It has been concluded that conventional research for fundamental reasons is not suited to increase food production in marginal regions of developing countries. According to the conclusion, this was due to an inadequate understanding of smallholder production methods in so-called low external input systems. These systems are characterized by a low availability of natural and economic resources in conjunction with a high variability regarding the availability of resources (e.g. water) and, as a result, a high production risk. Though, there are several factors why the respective areas become poor areas, for example drought, salinization, low nutrient availability etc. Moreover, cultivation conditions often are very heterogeneous even within the individual smallholder farms.

In such areas, land cultivation is mostly seen as a complex system of using natural resources which is characterized by purchasing only few means of production as well as by using indigenous (locally adapted) plant and animal species, mixed crops, flexible crop rotations etc. The corresponding social forms which are based on task sharing and cooperation are adapted to this form of cultivation as well.

Accordingly, there are several reasons why the technology transfer approach fails: Due to the fact that conditions at research stations of agricultural research do not correspond to the conditions of land cultivation on the local farms with their often unfavorable and heterogeneous conditions of production, e.g. high-yield crop varieties do not entail the desired yield increases. Another fact is that an increase of production cannot be induced simply by increasing the capital investment. Whereas in intensively cultivated favorable areas yield can be influenced quite easily by using production factors, this does not apply to low external input systems. Here, a deeper understanding of the working principles of the concerned farms is necessary in order to succeed. The heterogeneity of the farms requires specific improvement measures, respectively, and these measures have to be adapted to manifold conditions (ecological, cultural, infrastructural) at the same time. In summary, the failure of conventional research approaches can be explained by an inadequate linkage of development-oriented agricultural research with local contexts of knowledge and action which hardly can be corrected subsequently by means of transfer efforts.

PARTICIPATORY AGRICULTURAL RESEARCH AS AN ALTERNATIVE? 4.

Since the beginning of the 1980s, the criticism of conventional agricultural research involved the development of *participatory* research approaches as an alternative model. According to most of the definitions, participatory agricultural research is characterized by an institutionalized interaction of researchers, farmers and other stakeholders, if necessary, with regard to the design, implementation and evaluation of research processes. Partly, participatory approaches are understood as a means to an end, e.g. in order to achieve that a higher rate of technical innovations will be adopted by the target group (functional approaches). Other approaches aim at changing the existing balance of power – e.g. between smallholders and great land owners or between scientists and local stakeholders (empowering approaches).

There are different forms of participation: contractual participation (fields or herds of farmers are used in order to create realistic research conditions), consultative approaches (farmers are involved in consultation about the research process and their positions are taken into consideration, if required) and collegial forms of participation (cooperative relation between scientists, farmers and other stakeholders, if applicable; conjointly supported decisions). Participatory elements can be used in different research phases: for the setting of priorities for research (rare in practice so far), for the implementation (more frequently) and dissemination of project results as well as for the evaluation of agricultural research projects (see Neef, Neubert 2010 for a classification of participatory approaches in agricultural research).

In the course of interaction between researchers and farmers, the linkage of scientific and local knowledge is of central importance in order to get an adequate understanding of the actual situation on the farm and in its surroundings (integration of different knowledge systems). In contrast to the so-called scientific knowledge, local knowledge is context-dependent with adaptation efforts of farmers possibly being very similar in culturally and geographically very different, but ecologically similar regions. In participatory research practice, it has to be taken into consideration that very often not all local social groups dispose of the same local knowledge, i.e. that knowledge might be e.g. gender-specific.

Moreover, the facilitation of learning processes plays a decisive role in participatory approaches. Due to the heterogeneity and dynamics of low external input systems, efforts do not focus on identifying (simple) solutions to existing problems, but on enhancing the farmers' competence in developing adequate solutions.

There are different expectations regarding the participatory design of research projects. First of all, participation of the farmers in the development of innovations shall ensure that those innovations are better suited for the farms. Adoption rates as well as sustainability regarding the use of the research results shall be increased. Moreover, the time between the development and adoption of an innovation shall be reduced considerably. Furthermore, it is assumed that participatory approaches show a better cost-benefit ratio than conventional approaches: Though they caused higher costs in early phases of the project (intensive cooperation with farmers and other stakeholders), these costs would be overcompensated for by a faster adoption and higher acceptance rates of the innovations developed. Finally, participation shall involve strengthened autonomy and self-confidence of the farmers (as a disadvantaged population group) as well as a durable increase of the communication and problem-solving competences of all parties involved in the project. Already the mere realization of participatory projects with their mobilizing methods could increase awareness regarding the fact that situations can be changed and could show where possible changes can be found.

Whereas participatory agricultural research first has been considered as an alternative model for conventional research, the relation of the two approaches meanwhile is considered to be a rather complementary one. Currently, participatory approaches are accepted at least as niche research in most of the international agricultural research centers as well as in many national research systems of the developing and newly industrialized countries. Meanwhile, they are discussed and applied increasingly even in agricultural research of industrialized countries. In research practice, some areas have emerged in which a combination of conventional and participatory research is particularly promising. These include in particular participatory plant breeding, integrated pest management as well as projects regarding the conservation of natural resources (e.g. soil and water). Generally, the application of participatory approaches is mainly suited for research projects with a strong system orientation.

However, publication analyses indicate that there has been a tendency in the last few years for participatory approaches to become less important in international agricultural research. This applies both to the international (CGIAR centers) and national level where the percentage of relevant publications has decreased since the middle of the last decade.

EXAMPLE OF PARTICIPATORY PLANT BREEDING[7] 5.

Without any doubt, plant breeding plays a key role with regard to global food security. In the past, yield increases were the key objective of almost all plant breeding programmes. Increasing the yields of important food plants was considered to be a possibility of overcoming food shortages and of fighting hunger in the world. Up to now, the yield potential has not been exploited for all cultivated plants and possible conditions of production.

7 The statements in this chapter are based on the expert analysis by Christinck (2009).

However, in the past few years there has been an increasing awareness that the availability of food alone is not sufficient for solving the problems of hunger and undernourishment. In fact, food insecurity rather is closely linked with the problem of access to food, with questions regarding an adequate use of food and with the quality of nutrition. These aspects of food security are also influenced considerably by the practice of plant breeding. However, plant breeding so far has focused more on increasing productivity than on the above mentioned aspects of food security.

The future contribution of plant breeding to global food security will depend e.g. on whether benefits can be achieved for population groups which are particularly affected by food insecurity and which often are living and working in marginal areas. The contribution of plant breeding to solving the world food problem will definitely remain a limited one, if breeding programmes are not integrated into more comprehensive strategies of poverty reduction and rural development which are precisely oriented towards the needs and conditions of the people affected by food insecurity. Moreover, it is necessary to combine plant breeding with concepts regarding the conservation and sustainable use of agricultural biodiversity. In particular with regard to conditions of production that are marginal or lacking resources, this is of vital importance in terms of all three aspects of food security mentioned above.

In some semiarid regions that are particularly affected by food insecurity, only low increases of the yield per unit area or even no increases at all regarding important food plants have been observed during the last 20 to 30 years (this applies e.g. to sorghum in West Africa, to barley in North Africa and to beans and maize in East Africa). Surveys regarding so-called high-yield crop varieties have shown for different cultivated plants (e.g. barley and pearl millet) that these crops have not provided higher yields under marginal conditions of production than the local varieties of the farmers (Abay, Bjørnstad 2009; van Oosterom et al. 2003; Yadav, Weltzien 2000), although they outclass those local varieties by far under optimum conditions. These results indicate that the adaptation mechanisms of traditional varieties to specific stress factors of marginal cultivation systems have not been adequately understood yet.

Constraints regarding the use of modern high-yield varieties by farmers who work under marginal conditions are due to the higher prices for seeds which mostly are considerably higher than those of local varieties, but also due to qualitative aspects such as suitability for local cultivation methods, for harvesting and preparation methods, suitability for storage and usability of by-products (e.g. of straw). Thus, crop varieties not only have to be adapted to agro-ecological conditions, but also to socio-economic and cultural conditions which calls for an adequate and precise knowledge of these aspects (Christinck et al. 2005; Soleri, Cleveland 1993). Altogether, it has to be assumed that poorer farmers who produce under marginal conditions do not benefit "automatically" from the products of modern plant breeding, but that plant breeding has to be adapted specifically to the conditions and needs of these user groups.

For decades, plant breeding – together with the expansion of intensive agricultural systems –has contributed to a loss of agricultural biodiversity, e.g. due to a narrow genetic basis of most of the breeding programmes and due to approval procedures and seed legislations which allowed only for a small number of varieties on the market (Meyer et al. 1998). Increasingly decentralized breeding programmes based on local biodiversity and considering innovative models of seed production and distribution could represent an important step towards more diversity and enable breeding improvements for marginal conditions of production at the same time. Due to the commitments made by many states by signing international agreements (e.g. Convention on Biological Diversity [CBD], International Treaty on Plant Genetic Resources for Food and Agriculture [ITPGRFA]), there is a growing interest in a stronger establishment of breeding programmes with a broader genetic basis and a decentralized organization even in industrialized countries.

The future orientation of plant breeding programmes will play a key role worldwide not only with regard to improving food security, but also to conserving agricultural biodiversity. As an answer to these challenges, decentralized and participatory methods of plant breeding have been developed during the last two decades. Higher relevance of the developed varieties for the users, higher acceptance and dissemination of the varieties, shorter times for variety development, improved access to seeds particularly for poor farmers and generally a higher efficiency of the programmes are some of the advantages of such breeding approaches which take into consideration not only local varieties, but also traditional knowledge, social structures and cultural conditions (Weltzien et al. 2000).

Participatory plant breeding (PPB) differs from other methods of plant breeding with regard to the fact that it is a knowledge and system-oriented approach. A central characteristic of this approach is that it assumes detailed knowledge of the conditions of production to be improved as well as of the social, economic and cultural aspects. Moreover, participatory plant breeding relies on the knowledge and skills of the farmers as an essential resource of the innovation process in all phases of a breeding programme.

The basic idea of participatory plant breeding is that farmers and plant breeders have different skills and competences which complement one another and which should be used synergistically (Probst et al. 2007). In participatory plant breeding programmes, farmers, plant breeders and other protagonists thus work closely together in all phases of the breeding programme (development and selection of objectives, selection of breeding material, selection of promising breeding lines, evaluation, seed production and dissemination) so that breeding can be increasingly adapted to the demands of the farmers and their market partners (Cleveland et al. 2000).

Some PPB programmes focus on varieties which can be officially approved, e.g. because this is the only way allowed according to seed legislation in the respective country or in order to make the seeds available for a larger number of farmers. However, this assumes that there are corresponding and functioning institutions and that the varieties developed comply with the criteria for approval. Other projects focus on decentralized types of organization for the production and dissemination of seeds as well as on informal networks of the farmers. This is particularly advantageous, if the projects are strongly oriented towards the objective of conserving agricultural biodiversity, if many different varieties shall be disseminated locally or regionally and/or if seed production deliberately shall be organized by the farmers. Without official approval, seeds of new varieties can be offered faster and mostly for lower prices. This improved access to seeds can be a decisive advantage particularly for poor farmers and mainly in regions where the private sector does not invest in the marketing of new varieties as it is the case in large parts of Africa.

Particularly with regard to the development of seeds for marginal production areas, it is important that yield increases are not achieved at the expense of yield stability and other characteristics that are significant for the farmers. Participatory plant breeding does not primarily aim at the development of only few homogeneous varieties with particularly distinctive individual characteristics. Instead, very often different varieties for different cultivation conditions and purposes are developed simultaneously. This often applies to cultivated plants which have only local or regional significance. This supports or preserves food diversity and the corresponding knowledge and prevents malnutrition. Due to the fact that the time from the development of new varieties to their cultivation could be reduced by several years, the breeding progress reaches the farmers' fields earlier than with conventional breeding programmes.

There are some surveys suggesting that farmers' incomes have been increased and costs have been saved by using participatory breeding (Classen et al. 2008; Mustafa et al. 2006). However, it is hardly possible to explain the positive effects observed unambiguously by improvements regarding the plant varieties bred. Mostly, they are associated with improvements of the overall cultivation system as a consequence of an increased exchange among the farmers and the scientists involved or of specific targeted training programmes such as a "farmer field school" which is installed together with a participatory breeding programme. Basically, effects of the overall process in terms of a so-called "empowerment" of the male and female farmers involved seem to be significant though their benefit cannot be monetarily evaluated. In many rural production systems, women play a decisive role with regard to the conservation, handling and further development of seeds. Participatory plant breeding can contribute to better acknowledge their knowledge and their associated responsibility and to give women access to the corresponding committees and decision-making levels.

OBSTACLES AND POSSIBLE RESEARCH POLICY STEPS 6.

Generally, participatory agricultural research is faced with several structural obstacles impeding expansion. An important cause for this is the policy of research organizations. For some years now, the marginalization of those disciplines in faculties and research institutions of agricultural science has been criticized which are considered to be indispensable for a participatory and recipient-oriented research: subdisciplines of the social sciences, particularly rural sociology, agricultural policy and agricultural economics as well as integrative disciplines in the field of agricultural production such as crop cultivation and animal husbandry. In Germany, the number of respective university professorships has been and still is being reduced gradually and even the situation in institutions of the CGIAR system is characterized by a low allocation of staff having a qualification in social sciences and by downsizing of social sciences. However, the issue is by far not only a weakening of the disciplines mentioned above, but generally the fact that too little significance is given to interdisciplinary as well as participatory capacities and competences in academic education.

There are other central obstacles with regard to institutions of research promotion: One of these obstacles is the strict limitation of research promotion by DFG (German Research Foundation) to basic research. Moreover, applications for funding mostly have to contain a detailed work schedule. Participatory research, however, is based on a relatively open research process which is opposed to the requirement mentioned above. Furthermore, the fact that funding is restricted to relatively short terms (normally three to five years) also represents an obstacle for participatory approaches, because those approaches require more time for the establishment and consolidation of research partnerships with local institutions. Finally, the guidelines of the research organizations often are not flexible enough with regard to the application for funds and their transfer to partner organizations, the contribution of which often will arise only in the course of the project.

Incentive systems within agricultural sciences (including development-oriented agricultural research) represent an obstacle to participatory research approaches. The criterion of practical relevance is hardly given any importance regarding the granting of funds and evaluation. It is easier to obtain funding and prestige with basic research – i.e. research corresponding to the ideal of natural sciences regarding quantification, precision, reproducibility and objectivity – than with participatory research. Participatory research is considered to be hardly publishable (at least in highly renowned journals) and thus obstructive to a career. For the accomplishment of scientific qualification work, there is a risk for young scientists that the quality of the project also depends on the project partners.

Based on the deficit analyses, a number of options for action were identified.

DEVELOPING CAPACITIES IN UNIVERSITIES AND RESEARCH INSTITUTIONS

The deficit analysis outlined above which also corresponds to the diagnosis of the German Council of Science and Humanities (2006) shows the necessity of a consistent reorientation in order to (re-)establish and to develop capacities in terms of social sciences in faculties of agricultural science focusing on developing countries. Interdisciplinary and participatory research should be established as a fundamental methodical approach in academic studies and success in practice should be a relevant criterion for filling job vacancies for young researchers as well as in appointment negotiations. It is necessary to consider the creation of a central body (in terms of a "center of excellence for participatory agricultural research") at an adequate research institution. At the European level, the creation and promotion of a European network called "Participatory Research for Global Food Security" would be an option. Within the 8th Framework Programme for Research of the European Commission as well, the application of participatory methods in projects referring to global food supply should be supported by means of targeted measures.

ADAPTING THE CONDITIONS OF RESEARCH PROMOTION

Particularly research promotion by DFG (German Research Foundation), which is predominantly focusing on basic research, but also other public research programmes offer only little chances of success to applicants representing research projects which are based on a participatory approach. Obstacles result both from the requirements with regard to the academic proof of excellence of the applicant and from the type of funding (mainly of the term of funding and of success evaluation). Presumably, the following changes would considerably improve the opportunities of participatory projects:

Allowing a more open project planning: Mostly, applications for funding have to contain a detailed work schedule. However, such a work schedule normally cannot be submitted at the beginning of participatory projects, because one of the essential characteristics of such projects is that the research process is designed in the course of the project with the participation of non-scientific protagonists who partly cannot be involved until the project is being realized. Research promoting organisations often consider the lack of a detailed work schedule as a lack of precise conception regarding research issues, objectives and methods. Multi-level calls for proposals including funded preliminary phases would be beneficial regarding the design of the project (as e.g. in the "Social-Ecological Research" programme of the German Federal Ministry of Education and Research). It would be possible to allow for systematic consultation (instead of only formalized interim reporting) between funding institutions and researchers aiming at the further development of projects for which there are doubts with regard to their feasibility.

Modifying the proof of excellence and evaluation: Scientific publications preferably in renowned scientific journals play an essential role for research funding both regarding the granting of project funds as well as regarding evaluation of the funded projects and decisions on continued funding. However, the criterion of practical relevance mostly is of almost no significance in this context. The capability and efforts required to manage participatory research processes also are hardly appreciated in evaluations. Though scientific publications also play an important role in transdisciplinary projects including participation, they only play a minor role compared to the purpose of the project (contribution to solving a social problem). For research projects with a participatory approach, the criteria for funding should be modified correspondingly. If required, the efficiency of the funded projects with regard to the promotion objectives, i.e. the tangible success for people affected by hunger and malnutrition, should be proven by means of independent impact studies for which a part of the research budget would have to be reserved.

Increasing the term of funding: Normally, the term of funding is limited to a period of three to five years. However, participatory projects require prolonged terms of funding due to the open research process and particularly in order to consolidate research partnerships with local partners.

Increasing flexibility regarding the allocation of funds: The guidelines of the research organizations often are not flexible enough with regard to the application for funds and their transfer to partner organizations the contribution of which often will arise only in the course of the project. Such an early determination should be avoided.

OPTIONS FOR ACTION WITH REGARD TO PARTICIPATORY PLANT BREEDING

Basically, plant breeding alone can only be one element of many to achieve food security and to fight poverty, in particular for smallholder agriculture. Especially participatory plant breeding has to make sure that its advantages will benefit particularly marginalized groups and not primarily local elites. Among the essential obstacles to a further expansion of participatory plant breeding are those having to do with the currently prevailing concept of science and the increasingly highly specialized orientation of plant breeding research. There are some restrictions in the field of research funding, e.g. because participatory methods need longer terms of funding in order to achieve results. In some case, also seed legislation and intellectual property rights represent obstacles to the (legal) dissemination of participatory plant breeding methods and of the resulting varieties.

Research and teaching in the field of plant breeding should be extended fundamentally by aspects capturing and considering the social, economic and political context in which breeding research is done. In order to be able to better prove the value of participatory plant breeding and thus to achieve a higher acceptance in science and research, it is necessary to promote and fund project-independent impact studies which give more transparency to the effects of different plant breeding approaches and which thus could provide a basis for the development of reasonable promotion strategies. In order to promote implementation and institutionalization, it would be necessary to establish and to strengthen networks of local organizations as well as national and international breeding programmes which can implement participatory plant breeding on a large scale (on both the national and regional level). Moreover, it is necessary to eliminate obstacles in the field of seed legislation and plant variety protection and to integrate plant breeding to a greater extent into a context of conserving, using and advancing agricultural biodiversity.

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Die große Mehrheit der Landwirte in Entwicklungsländer sind Kleinbauern. Steigende landwirtschaftliche Produktion und starkes ökonomisches Wachstum in der Landwirtschaft – mit Kleinbauern im Zentrum der Aufmerksamkeit – werden benötigt, um die Reduktion von Hunger und Armut zu erreichen. Gleichzeitig ist eine nachhaltige Landnutzung dringend notwendig.

Kandidaten für eine höhere Nahrungsmittelproduktion und eine nachhaltigere Flächennutzung in Entwicklungsländern sind Produktionssysteme wie Conservation Agriculture, System of Rice Intensification, Ökologischer Landbau und Agroforstsysteme.

Diese Produktionssysteme haben das Potential zu einer "low-input intensification", was den Bedürfnissen und Möglichkeiten von Kleinbauern besonders entspricht. Sie können als komplexe landwirtschaftliche Systeme zur Intensivierung durch höhere agro-ökologische und biologische Produktivität beschrieben werden. Sie benötigen nicht notwendigerweise steigende externe Inputs (wie Mineraldünger und Pflanzenschutzmittel) und streben stattdessen eine Optimierung der Inputnutzung an.

In diesem Kontext widmet sich der Workshop zwei Fragenkomplexen:

> Zum Einen sollen die Potentiale einer Low-input Intensivierung für Kleinbauern in Entwicklungsländern näher bestimmt und Ansätze zu ihrer Evaluierung diskutiert werden.

> Zum Anderen soll der Frage nachgegangen werden, wie in problemorientierten Forschungsansätzen globale Prinzipien von Produktionssystemen mit konkreten Anwendungen vor Ort verbunden werden können und welche Schlussfolgerungen sich daraus für Forschungsagenden ergeben.

Anreise mit der Bahn:
Vor dem Hauptbahnhof mit den Linien S4/S41 Richtung Heilbronn, der Linie 2 Richtung Wolfartsweiher oder Linie 3 Richtung Heide bis Haltestelle Kronenplatz/KIT Campus Süd, zu Fuß durch Campus über Wolfgang-Gaede-Weg

Anreise mit dem PKW:
A5 Ausfahrt KA-Durlach in Richtung Karlsruhe / KIT Campus Süd (ca. 2,4 km), Einfahrt auf den Campus Süd über beschrankten Zugang (Anmeldung beim Pförtner), auf dem Campusgelände 3. Querstraße rechts (Wolfgang-Gaede-Weg), FBZ am Ende der Straße rechts

Ansprechpartner
PD Dr. Rolf Meyer

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Der Veranstalter bitten um eine Anmeldung der Teilnahme bis zum 19.11.2010.

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Programm

10:00 – 10:15	*Prof. Dr. Dieter Burger* (Institut für Geographie und Geoökologie, KIT, Campus Süd) **Begrüßung und Einführung**
10:15 – 10:45	*PD Dr. Rolf Meyer* (Institut für Technikfolgenabschätzung und Systemanalyse, KIT, Campus Nord) **Setting the Frame: Herausforderungen für Kleinbauern in Entwicklungsländern**
10:45 – 11:15	*Katharina Butz* (Institut für Geographie und Geoökologie, KIT, Campus Süd) **Potentiale für Low-Input Intensivierung in Entwicklungsländern**
11:15 – 11:30	Diskussion
11:30 – 12:00	*Dr. Shilpi Saxena* (Internationales Büro des BMBF, Bonn) **Organic faming and marketing channels in Tanzania: Challenges and chances for development**
12:00 – 12:15	Diskussion
12:15 – 12:30	*Dr. Raphael Knoll, Prof. Dr. Dieter Burger* (Institut für Geographie und Geoökologie, KIT, Campus Süd) **Einfluss der Bodenmakrofauna zentralamazonischer Agrar- und Waldökosysteme auf Bodenmikromorphologie und Bodenchemie: Fallstudie aus Brasilien**
12:30 – 12:45	*Nizar Omrani, M.Sc.* (Institute of Arid Regions of Medenine, Tunesien) **Verbesserung der Bewässerungseffizienz in Dattelpalmoasen am Beispiel Kebili, Südtunesien**
12:45 – 13:00	Diskussion
13:00 – 14:00	Pause
14:00 – 14:30	*Dr. Carsten Marohn* (Institut für Pflanzenproduktion und Agrarökologie in den Tropen und Subtropen, Universität Hohenheim) **Agroforstsysteme: Vom landwirtschaftlichen Produktionssystem-Ansatz zur örtlichen Anwendung**
14:30 – 14:45	Diskussion
14:45 – 15:15	*Dr. Stephan Krall* (GTZ – Deutsche Gesellschaft für Technische Zusammenarbeit, Eschborn) **Aus der Perspektive der Entwicklungszusammenarbeit: Welche Forschungsbeiträge werden benötigt?**
15:15 – 15:45	*Marc Dusseldorp, Dipl.-Geoökol.* (Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag, Berlin) **Beiträge der Forschung zur Lösung des Welternährungsproblems: Ergebnisse aus dem TAB-Projekt**
15:45 – 16:00	Diskussion
16:00 – 16:20	*Prof. Dr. Dieter Burger / PD Dr. Rolf Meyer* (Institut für Geographie und Geoökologie, KIT, Campus Süd / Institut für Technikfolgenabschätzung und Systemanalyse, KIT, Campus Nord) **Perspektiven der Low-Input Intensivierung in der kleinbäuerlichen Landwirtschaft: Wie weiter?**

The KIT project "Potentials of low-input intensification in developing countries", jointly carried out by the Institute for Technology Assessment and Systems Analysis (ITAS, Campus North) and the Institute for Geography and Geoecology (IfGG, Campus South), is focused on smallholders who represent the vast majority of farmers in developing countries. The project started from the hypothesis that – with the focus on small-scale farmers – agricultural production systems like Conservation Agriculture, System of Rice Intensification, Organic Farming and Agroforestry Systems are candidates for higher food production and sustainable land utilisation in developing countries. In this context, the workshop on December 8, 2010 in Karlsruhe aimed to discuss the potentials of low-input intensification and to identify adequate problem-oriented research approaches. The contributions of the workshop are documented in these proceedings.

The geophysical and climatological situation on the one hand is discussed in the contribution of Katharina Butz (IfGG, KIT) and the challenges for small-scale farming, the characteristics, distribution and hindrances of low-input agricultural production systems on the other hand in the contribution of Rolf Meyer (ITAS, KIT), as global baselines.

The following contributions analyse experiences with low-input intensification for very different settings, regions and research approaches. The contribution of Shilpi Saxena discusses the market channels for organic vegetable farmers in Tanzania and the constraints on the national market. Research results about the influence of soil micro-fauna on soil fertility from a project in Central Amazonia, Brazil are reported by Dieter Burger and Raphael Knoll (IfGG; KIT). The current situation of irrigation within the southern date palm oasis of Tunisia and potentials of irrigation efficiency improvement are analysed in the contribution of Nizan Omrani (Institute of Arid Regions, Tunisia). Theodor Friedrich and Amir Kassam (FAO) discuss the chances for learning in and between agricultural production system approaches for integrating productivity with ecosystem services for low-input intensification in small-scale farming.

In the last part, the contribution of Stephan Krall (GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit) presents research needs from the development assistance perspective. The paper of Marc Dusseldorp (Office for Technology Assessment at the German Bundestag) discusses the relevance of participatory research approaches which substantially integrate smallholders into research processes.

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