

Background Paper 6

Water

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The Contribution of Blue Water and Green Water to the Multifunctional Character of Agriculture and Land.

Background Paper 6: Water.

INTRODUCTION

Water is vital to agriculture. It is a central ingredient of the multifunctional character of agriculture and land. This paper explores both the multiple contributions that water makes to agriculture and also, some of the different ways that it supports the multifunctional character of agriculture itself. In particular, the paper examines the extent to which agriculture contributes to food security, improved environmental management and food security. The analysis builds heavily on the so-called MFCAL approach. This approach is built on the recognition of the multiple functions of agriculture beyond food production

The paper examines four questions:

- What amounts of *green* and *blue* water are appropriated in different types of agriculture and by various crops and other vegetation
- What are the tradeoffs between agricultural and other water uses
- What is the significance of urban expansion for water use in agriculture
- What are the pre-conditions for agriculture in various regions of the world in terms of climate and availability of plant nutrients. What particular forms of agriculture is most viable in different regions and water regimes.

THE MFCAL APPROACH

The MFCAL Approach provides the overall referential framework for this paper. The approach recognises that the first and foremost role of agriculture remains the production of food. It stresses however, that agriculture and related land use activity can also deliver a wide range of non-food goods and services, influence the natural resource system, shape social and cultural systems and can contribute significantly to economic growth. The approach also focuses on the trade-offs and synergies that can exist between these different functions.

The first dimension of the multifunctional character of agriculture and related land use concerns food production and the contribution that this makes to food security. Food security has been defined by FAO as a situation in which all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. There are three dimensions implicit in this definition: availability, stability and access. Adequate food availability means that, on average, sufficient food supplies should be available to meet consumption needs. Stability refers to minimising the probability that, in difficult years or seasons, food consumption might fall below consumption requirements. Access to food draws attention to the fact that, even with bountiful supplies, many people still go hungry because they are poor and unable to produce or purchase the food they need. In addition if food needs are met through exploiting non-renewable natural resources or degrading the environment there is no guarantee of food security in the longer-term.

Current concerns for food security stem from both the unacceptability of current levels of food insecure people (at least 800million people) and the recognition that agriculture will have to feed an increasing human population, forecast to reach 8 000 million by 2020, of whom 6 700 million will be in developing countries. In most developing countries, the majority of the poor live in rural areas and depend on agriculture for their livelihoods. Expanding food production to feed this increasing population, while alleviating poverty through gainful employment in agriculture, is a formidable challenge.

In addition to food production and the vital contribution that it makes to food security, the MFCAL Approach recognises three further broad functions 1) environmental 2) economic 3) social.

The Environmental Function. Agriculture and related land use can have beneficial or harmful effects on the environment. The MFCAL approach can help to identify opportunities to optimise the linkages between agriculture and the biological and physical properties of the natural environment. The environmental function of the MFCAL Approach is relevant to a number of critical global environmental problems including biodiversity, climate change, desertification, water quality and availability, and pollution.

The Economic Function. Agriculture remains a principal force in sustaining the operation and growth of the whole economy, even in highly industrialised countries. Valuation of the various economic functions requires assessment of short, medium and long-term benefits. Important determinants of the economic function include the complexity and maturity of market development and the level of institutional development.

The Social Function. Both the maintenance and continuing dynamism of rural communities are basic to sustaining agro-ecology and improving the quality of life (and indeed, to assuring the very survival) of rural residents, particularly of the young. On another level, the capitalisation of local knowledge and the forging of relationships between local and external sources of expertise, information and advice are fundamental to the future of existing rural communities. Social viability includes maintenance of cultural heritage: for we know that in many instances, societies still identify strongly with their historical origins in agrarian communities and rural lifestyles.

WATER AND FOOD REQUIREMENTS

The production of plant biomass in natural and man-made systems requires water. Food, feed and fibre are produced by diverse forms of agriculture through both annual and perennial crops. Crops rely on soil water in the root zone which can extend to approximately one metre deep. In horticultural and agroforestry systems of course, the roots can reach far deeper soil strata. Water extracted by roots leaves the plants through transpiration, which can be seen as a productive branch of water flow. Another part of the extracted water however, is lost through evaporation, which could be described as an unproductive form of water flow. The return flow of water to the atmosphere through evapotranspiration is a major component of the hydrological cycle, which is of crucial importance to agriculture. The cycle itself is also directly affected by agriculture and related land use and other forms of landscape-based human activity.

Agriculture takes place in open landscapes where the forces of Nature are both a blessing and a curse. Owing to the fact that agriculture is based on an open system and can overlay vast areas, it is often difficult to regulate water in relation to crop water requirements. Frequently, there is either too much or too little water, which can both affect yields and can engender a range of further challenges. This contrasts with typical production processes in factory-based industrial systems, in which it is possible to manage inputs such as water with a far higher degree of reliability and certainty. Similarly, much of the water used in urban

contexts can, in principle, be re-used and re-circulated – provided that proper treatment is applied. Only a smaller fraction is actually consumed. There is little doubt then, that water use in biological systems is different from most other types of water use in society.

In addition to problems associated with efficient water management in agriculture, hydrological features play a significant role in relation to the leakage of nutrients and chemical residues. Negative environmental impacts in terms of eutrophication and pollution are primarily felt downstream. Non-desirable impacts for example, which are often associated with efforts to intensify production, have become the focus of growing international and national concern. In many cases, the intensification of agricultural production is essential in order to improve national food security. Likewise, intensification can increase food security and augment income streams at the household level. Similarly, a thriving agriculture improves social conditions in rural areas and can contribute to a regional balance in development. All of these functions are intrinsic to the multifunctional character of agriculture and land that was described in the previous section. Indeed, it is clear that the possibility for the emergence of this type of positive and negative externality is an inherent feature of all forms of production, including agriculture.

Water is an indispensable component in the process of photosynthesis which is necessary for the build-up of plant biomass. It can be used either more or less efficiently in the food production process, but it can not be replaced. Very large amounts of water are required for the successful growth of food, feed and fibre. To produce a kilo of rice in the tropics, for instance, requires between two and three tons of water. In poorly managed systems, the yield per unit of water might be much lower. To produce the amount of food that is required to live “an active and healthy life” for example, requires between two and six cubic meters of water per person per day. Variations stem from differences in the composition of diets (more meat in the diet means that comparatively more water is required) and the climate where the food is produced (hot climates mean that more water is required to produce a given amount of food items). The annual water requirement for food security is estimated at between 1,000 to 2,000 m³/person. Finally, it is necessary to recognise that the amount of water needed to accommodate minimum daily food requirements and to maintain ecosystems is considerably larger than the amounts of water that are needed in order to satisfy other water-consuming societal functions such as industry and typical household requirements.

It is important to recognise the significant variations in water availability in different parts of the world when assessing water requirements for food production. In 26 countries for example, the average annual water availability is below the water scarcity benchmark of 1,000 m³/year/person (Postel 1997). In these countries, with an aggregate population in the early 1990s of over 230 million, the domestic production of adequate amounts of food (i.e. to ensure domestic food self-sufficiency) is increasingly problematic. Current demographic trends mean that the number of people living in countries where water stress or water scarcity prevails may increase by a factor of 10 within the period of one generation (Falkenmark & Rockström 1993). Frequently, population growth is most rapid in areas where the environmental pre-conditions for food self-sufficiency are most constrained. Likewise, the majority of the countries where people suffer from water shortages are also poor. A majority of the world's population - over 3 billion - live in low income countries with an annual per capita income of less than US\$795. Of these, about a third live in countries which already face medium-high to high water stress (UN 1997 a). Low incomes mean, among other things, that the possibility for people to buy adequate amounts of food items, as well as other goods and services, is constrained. Similarly, the lack of purchasing power can often limit the incentives for farmers to increase production.

The combination of poverty and a large and growing population in relation to available water resources constitutes a major challenge to food security. In some countries, the water challenge is compounded by the fact that a very large share of the annually renewable water

resources is already utilised. Exploitation of the blue water resources, (the water that is available in streams, lakes and ground water aquifers) has been instrumental in allowing the substantial food production increases that have taken place in recent decades. Nonetheless, the expansion in irrigation throughout the world has sponsored immense withdrawals of water from various sources. Efforts directed at the further exploitation of blue water resources continue, but the rate of additional extraction has been necessarily reduced. In some countries however, there are simply no more easily accessible sources to exploit. In other countries the financial, environmental and social costs associated with dams and extraction have contributed to an overall reduction in the rate of exploitation. Table 1 shows the levels of water renewals in relation to the per capita availability of renewable freshwater resources in several countries. It shows for example, that several countries in the Middle East have a high population density in relation to available water and that many of them also withdraw a very high percentage of the renewable amounts of water.

Although the significance of blue water for food production and rural and regional development has been growing in recent decades, green water remains the most important water source for most forms of agricultural activity and related land use. Green water is the water in the root zone, which is of key interest from an agricultural point of view. The concept of green water was launched to highlight the significance of soil water and to make a distinction to the water that is available in rivers, lakes and ground water aquifers (Falkenmark, 1995). FAO (1997: 4) has defined green water as "... the water supply for all non-irrigated vegetation, including forests and woodlands, grasslands and rain-fed crops". A somewhat wider interpretation of *green* water may also be used, referring also to the water that is available in the root zone.

Table 1. Examples of various levels of annual renewable amounts of freshwater resources *per capita*, ratio of withdrawal (A: High, B: Medium and C: Low), and GNP.

	Population (1996) (in 1,000's)	GNP <i>per capita</i> (US \$)	Annual Renewable Freshwater (mill. m ³) Within River country	Annual Renewable Freshwater (mill. m ³) From other country	<i>Per capita</i> availability (m ³ /year) (1995)	Withdrawals as percentage of total renewable freshwater (%)
A: High withdrawal Ratio						
Libya	5,593	n.a.	600	0	111	766.0
Qatar	558	18,030	195	0	353	102.0
Israel	5,664	13,920	1,700	500	390	84.0
Malta	369	7,970	30	0	82	n.a.
B: Medium withdrawal Ratio						
Italy	57,227	19,840	159,400	7,600	2,920	33.7
Spain	39,674	13,690	110,300	1,000	2,809	27.6
Germany	81,922	23,560	96,000	75,000	2,095	27.1
C: Low withdrawal ratio						
Finland	5,126	19,300	110,000	3,000	22,126	1.9
Sweden	8,819	24,740	176,000	4,000	20,580	1.6
Brazil	161,087	2,930	6,190,000	1,760,000	42,956	0.6

Sources: Figures from Steering Committee for the Comprehensive Assessment of Freshwater Resources of the World, see United Nations, 1997a; Population figures for 1996 from United Nations, 1997b

A growing population means that more food is required. More food can only be provided if water is available at the right time, in the right place, in the necessary quantity and of the appropriate quality. Clearly, conditions and opportunities vary significantly between different hydroclimatocological regions of the world as well as in relation to different socio-economic environments. It is important to note that there is a clear general correlation between adverse conditions in terms of water shortage, erratic occurrence of rainfall, high potential evapotranspiration, poor nutrient status of the soil and a rapidly increasing population and poverty.

THE IMPACT OF CHANGING CONTEXTS ON THE MFCAL

Any assessment of the multifunctional character of agriculture and land must be grounded in the recognition of the overarching need to produce more agricultural outputs with less inputs. Gurdev Khush, IRRI's principal plant breeder has recently stated, that there is a growing need to modify the plant architecture of rice owing to the fact that population growth continues to outpace food production. The challenge, he argues, is to "boost food production by more than half *with less land, less water, less labour and fewer chemical inputs*" (Interview in Straits Time, March 26, 1999. emphasis added).

Although conditions vary in different parts of the world, the challenge to produce more with the same, or even declining resource inputs remains the same. In Sub-Saharan Africa for example, the annual average increase in yields is below 1.5% whereas population increase is more than double this level, equivalent to approximately 3.1-3.3 between 1990 and 2020 (Rockström 1997). In addition, production increases in this region must come primarily from yield improvements.

Producing more food with less water can only be achieved if the water that is available for agriculture is used more efficiently and more productively. The main way to achieve this must be through minimising unproductive evaporation and optimising productive transpiration. Water harvesting techniques and water conservation will become increasingly important in most rainfed systems in order to make better use of the green water. Irrigated agriculture must cope with increasing demands for blue water from industries and urban areas. Growing competition does not simply imply that efforts must be made to ensure that farming's share of water resources remains unchanged. It also means that in many cases, farmers must also be prepared to contribute more to cover the increasing cost of water development and provision. If representatives of other sectors are willing and able to pay for water and the associated services in terms of conveyance costs, treatment, etc., or if they can promote the notion that blue water sources should not continue to be exploited in the same ways as previously, then farmers should not expect that the same amounts of water will continue to flow to the fields in quantities and at prices that are often highly subsidised. Certainly then, this raises issues relating to the improved assessment of opportunity costs of water for agriculture and likewise, may lead to discussions relating to the value stemming from the multifunctional character of agriculture and land and indeed, the value of the water-related service provided by agriculture.

Growing competition for water and other resources that are essential for agricultural development coupled with growing expectations for increasing production and reducing negative impacts, constitutes, in many cases, an essentially new context for agriculture. Arguments defending the continuation of existing agricultural models in the face of these changing contexts on the grounds that it is a "way of life" may not always be sufficient. These new demands on agriculture will, in many instances, contribute to a more diversified agriculture, thereby emphasising its intrinsically multifunctional character. Similarly, changes in agricultural policies and the increasing influence of consumers may contribute to a considerable re-structuring of the agricultural sector in many countries. In Poland, for instance, it appears that possible entry into the EU has accelerated the transformation of the

agricultural sector. It is possible for example, that the number of small holdings that produce mainly for their own domestic consumption will be significantly reduced within the near future. A similar structural transformation is observable in other Eastern European countries as well as in other parts of the world.

In a rapidly urbanising world, it is particularly relevant to study the links between urban and rural areas. An increasing amount of food for example, is produced for consumers outside agricultural/rural areas. This situation will obviously shape the farming strategies of producers in terms of both crop type and quantity. Likewise, there is clearly no incentive for a farmer to produce food outputs that consumers are either unwilling or unable to purchase. Indeed, in many respects, incentives coming from consumers and national and international policies in agriculture and trade are as important for agricultural and rural development as soil and water.

New patterns of intensified and specialised production are likely to develop in response to changing market incentives and as a consequence of new demands and conditions for agriculture. This can engender competing challenges. The production of sufficient crops to satisfy demand for example, may lead to greater intensification and crop concentration. This may lead to declining agricultural biodiversity. In these instances, it may be necessary to develop arrangements that encourage the co-existence of both intensive mono-cropping systems and land use systems that preserve and/or strengthen local agricultural biodiversity in order to maintain the level of overall biodiversity in the rural landscape (Ausubel 1996).

Agricultural systems in many parts of the world however are neither characterised by the intensive and specialised utilisation of land and water nor by a heavy reliance on technological inputs and market access. Throughout Sub-Saharan Africa for example, farmers often have small and fragmented holdings and prevailing climatic and soil conditions frequently mean that average yields are low and market access is poorly developed. In this type of context, where yields tend to be further reduced through a shortening of fallow periods and the subsequent mining of plants nutrients, the immediate goal of agricultural producers is to harness production in support of household livelihoods. In the short-term, incremental increases in production will probably have to be secured through “site specific farming strategies” (Rockström 1997), where a combination of strategies including water harvesting, plant nutrient management and adaptation to topographical features is the only viable strategy.

Inter-cropping and complex crop rotations, which are principles common to many types of agriculture, are often the only viable options in semi-arid regions in which irrigation is unfeasible. Nitrogen fixing crops grown together with other crops can prove important and similarly, a combination of leguminous crops and cereals may sometimes reduce the risk of pest attacks (although in other instances, legumes can attract harmful insects and nematodes). In the tropics, a mixed system has the advantage of providing vegetation cover over the soil surface for a longer period, which is beneficial for water balance. In some areas however, existing food production systems are becoming less and less viable, creating a seemingly paradoxical situation whereby in a world where food self-sufficiency and food security are so hard to attain, some of the existing agricultural systems are likely to discontinue. Indeed, it is precisely this process that has already occurred in many parts of the world.

EXPLORING THE MULTIPLE FUNCTIONS OF GREEN WATER

Green water and plant nutrients – basis for agricultural production

Plant cover is the basis of all agricultural systems. It is the result of the build up of plant biomass through carbon dioxide (CO₂) assimilation and photosynthesis with the use of water

and plant nutrients. Plant nutrients must be considered together with water as they are dissolved in the soil water and are taken up by plants. A major part of the root system of agricultural crops is concentrated in the topsoil and the upper subsoil (0-100 cm). When herbs and grasses are mixed with trees and shrubs, as in agroforestry and agro-horticulture, the roots can extend to a considerable depth (5-10 m) and the root zone becomes a vague concept. To the extent that the water which is available in the soil is not taken up by the vegetation, it will contribute to the recharge of blue water flows, i.e. the water that is available in streams, lakes and the ground water aquifers.

In arid regions with average annual precipitation levels of 150-300 mm, and with potential evapotranspiration levels in the range of 1500 to 2500 mm, year⁻¹, water deficits mean that food production is not possible during a large part of the year. Under these conditions, the growing period is only about 75-100 days. In semi-arid areas with annual precipitation levels of around 300-600 mm and with potential evapotranspiration levels similar to those found in arid regions, the growing period is about 100-160 days. In arid and semi-arid regions, the combination of water deficits and water evaporating from the soil surface often leads to a concentration of calcium, magnesium, sodium and potassium salts in the soil surface. Under these conditions, plant productivity per year is therefore low and can normally be increased only if water is added through water harvesting or irrigation. Since arid and semi-arid regions are also characterised by significant variations in terms of annual and seasonal rainfall, the occurrence of intermittent droughts can frequently exacerbate the challenges facing agricultural production. Normally, it is only deep rooted perennials such trees and shrubs that can persist through drought periods.

Humid climates do not suffer from the same water shortages as arid and semi-arid areas, except of course, during very dry years. The growing season is instead limited to approximately 100 days by low temperatures and sometimes frost in the normal root zone. Furthermore, water surplus during parts of the year can lead to the leaching of nutrients. The process of podsolisation is typical for cold humid climates. Albeit a somewhat simplistic characterisation, it can be said that humid climates are characterised by plant nutrient dependent agriculture whereas arid and semiarid climates tend to lead to irrigation-dependent forms of agriculture.

In addition to a lack of water, soils in arid areas are often poor in organic matter. A vicious circle can easily develop whereby a harsh climate leads to low plant productivity which in turn leads to low organic matter content. Shorter fallow periods amplify the degradation of soil fertility. Typically, arid areas contain 0.5-1.0 % carbon in the topsoil, whereas humid soils normally have 2-3 %. This represents 5-10 tons of carbon per hectare in arid zones and 50-70 tons per hectare in humid areas. (Persson & Kirchmann 1994; Kätterer & Andrén 1999). A high carbon content indicates a high water-holding capacity and vice versa. Soil nitrogen (N) is closely connected to soil carbon (C), with the C:N-relation 10:1, corresponding to 0.05-0.1 % N in arid soils and 0.2-0.3 % in humid soils. There is a clear gradient of soil carbon content and soil nitrogen from humid to arid climates, which is demonstrated by extensive studies in the United States, from Dakota in the North to Texas in the South (Cole et al. 1989; Paul et al. 1997). Similar gradients can be seen from humid to arid areas in sub-Saharan Africa and also in India and China.

In areas with low total carbon and/or where carbon-clay mineral complexes make nutrients unavailable to plants, a deficiency of nitrogen is common. The addition of nitrogen in easily soluble forms, usually in the form of nitrates, is usually necessary if productivity levels are to be raised. Farmyard manure is normally the main source of this type of nitrogen source but its availability is often limited. Furthermore, nitrogen fertiliser must be applied at a rate sufficient to match the needs of ordinary crops. Clearly, there are substantial differences between developing and developed countries in terms of commercial fertiliser use. In the case of the low crop yields typical of subsistence forms of agriculture, only about 20 kg of N

is obtained from fertilisers. Increased input of fertilisers is only viable however, if there is enough water to support the consequent increases in plant growth. To obtain higher yields, say, five times the subsistence level, an input of 150-200 kg N /ha /year is necessary. This is the case in central Europe but perhaps surprisingly, is also common in some developing countries, including China for example, in areas along the Yangtze river. In Belgium and the Netherlands, the nitrogen input to croplands is about 500 kg /ha/ year, part of which is derived from livestock manure. It is of course recognised that this can lead to the pollution of adjacent waters, especially when crop cultivation is combined with dense, intensive livestock husbandry with pigs, beef cattle and poultry (Clarholm 1997; Matson et al. 1997; Ploeg et al. 1997).

In addition to manure and fertilisers, nitrogen fixing crops are an essential source of nitrogen. The amount of nitrogen that remains in the soil depends to a large extent on how much of the nitrogen fixing crop remains in the field and how much of it is removed with the harvest. Farming systems which include these crops are of great importance for sustainable agriculture in developing countries but likewise, should also be used more frequently in developed countries characterised by more industrialised monocrop production systems. In dry climates, agroforestry and other forms of mixing of nitrogen-fixing trees and shrubs with annual and perennial agricultural crops have a great potential. The viability of such systems is however, invariably dictated by water availability and management capability.

Phosphorus (P) is the second most important plant nutrient, which in several aspects is more complicated and difficult to manage in the long-term than nitrogen. Phosphorus is available in easily mined phosphates, of which there are large reserves in countries such as Morocco, Libya, USA, Russia and China. Estimates suggest that they will endure for at least 400 more years. In the long run, phosphorous must be extracted using other techniques from less concentrated pools in the soil, for example, through the use of plants species with a high efficiency in phosphorous extraction such as tithonia, which is a wild sunflower (Buresh et al. 1997; Rockström 1997). Many soils have low total stores as well as low amounts of plant available phosphorus, like many podsollic soils in humid cold temperate climates and soils in many developing countries within the old continental shields that were never submerged under seas and oceans. Old cropping systems such as bush fallow and meadow-crop field systems have slowly but inevitably contributed to a mining of phosphorus in the order of a few kilograms per hectare a year. Typically, an ordinary crop today contains 0.4 % of P in the dry matter but only 0.2 % in the above mentioned areas with soils deficient in phosphorus. In these instances, the common annual need of fertiliser or phosphorus n manure is 15-25 kg / ha.

Potassium (K) is less problematic as the total resource base is much bigger. In general, clay soils are rich in potassium whereas sandy soils are poor and therefore require additional annual input through, for example, manure or fertiliser. Plant biomass contains 0.8-1.0 % potassium which means an annual extraction with a crop of about 50 kg/ha.

Several micronutrients belong to the same problem group as phosphorus; micronutrient deficiency is a common problem in Africa and Asia, in particular manganese, zinc and copper.

Flows and stocks of green water and blue water

Only a small fraction of the world's freshwater resources is readily available in the form of either green or blue water. Estimates suggest that "soil moisture, ground ice/permafrost and swamp water" constitute about 0.9 % of the overall freshwater resources while freshwater in rivers and lakes is much smaller, in the range of 0.3% (Gleick 1993; Engelman & LeRoy 1993). Groundwater resources are much larger, or about 30% of all freshwater resources. Water locked up in glaciers and permanent snow cover constitutes the largest source of

freshwater. It is worth exploring the extent to which the capacity to utilise the varied components of the freshwater reserve depend on a range of factors and circumstances.

Excluding climatic factors, the level and flow of water in soil - the basis of green water - depends on soil texture and structure. When all soil pores are filled with water, approximately 15% of soil weight is water in the case of sandy soils, but 45 % in clayey soil. Since the hydraulic conductivity is about 10 mm per hour in sand and 2 mm in clay, water moves more rapidly through sandy soil than clay soil. When heavy rains fall in dry climates (50 mm or more per day), a sandy soil can rapidly absorb the major part (c.90%) due to its high hydraulic conductivity. A clay soil with its low hydraulic conductivity may absorb only 10 %, meaning that 90 % is lost through either evaporation and/or surface run-off. For these reasons, deep sandy soils typically contain large amounts of water. Given the comparatively rate and level of movement, this water is sometimes seen as a stock of water, part of which is easily available and of great value during droughts. Despite its low hydraulic conductivity, clay soils have lower amounts of readily available water. From a physiological point of view, clay soils are therefore dryer than sandy soils.

The amount of blue water in aquifers (that is to say, in the saturated layers in the ground) represents a large reserve pool, but for reasons outlined below, in fact constitutes only a comparatively small fraction of the groundwater resources that may be exploited on a continuous basis. In principle, it is the renewable fraction that could be exploited in the long run. Generally speaking, in dry climates, between 10-25% of the precipitation is lost as surface run-off, 30-40% as soil evaporation and 15-30 % as a result of transpiration. Recharge of groundwater aquifers is thus comparatively limited, or in the range from zero to approximately 15 to 20 % of the precipitation in dry climates. There is of course, considerable variation which depends upon a range of contingent factors including topography, precipitation pattern and amounts, soil structure and vegetation. Infiltration is considerably higher in humid climates.

Land-use and green water consumption

Landuse has a significant impact on the water balance. Large scale changes in land-use in terms of vegetation cover and type of vegetation will affect the size and temporal distribution of the various water flow components in a basin. Overwhelming empirical evidence shows that the greater the biomass of the vegetation, the more water will be consumed with a corresponding decrease of streamflow (Bosch & Hewlett 1982; LeMaitre et al. 1996; Enright 1999). This is the generally accepted relationship between landuse and water balance. A reduction of vegetation and biomass in an area does not however, always mean that water availability in downstream portions of a basin will improve. It depends on topography, infiltration and water holding capacity of the soil, among other things. In Cherapunji, in north-east India - one of the wettest places on earth owing to average annual precipitation levels of around 10,000 mm or more - a reduction of vegetation and thus biomass, has contributed to a situation where “a tremendous water scarcity” is witnessed (Kharuna 1998). A combination of undulating topography, a concentration of precipitation in the monsoon period and a denudation of vegetation cover in large parts of the area, has led to a situation whereby the water stemming from heavy rainfall during the monsoon period quickly leaves the area in the form of rapid surface flows.

Change of land use can result from a range of factors such as increasing population pressure or attempts to introduce new crops. In Meghalaya, where Cherapunji is located, the Government of India has tried to implement a new land use policy for more than a decade whereby farmers were advised to shift to commercial fruit cultivation. In many cases however, the new land-use policy either failed or failed to attain its intended goals, owing in part to the fact that insufficient attention was paid to the post-harvest processing and marketing of the fruits, The new policy presented farmers with no viable alternative to

conventional slash and burn agriculture, even though it was associated with lower yields and also contributes to the denudation of the permanent vegetation (ibid.). The situation found in Cherapunji is by no means unique, and mirrors the experiences of many regions throughout the world.

A further interesting example of a separate connection between land-use changes and their impact on hydrological parameters has been reported recently in South Africa. Over a number of years, alien plant species have been introduced and have spread over much of South Africa. Commercial plantation forestry has been one of the major sources of infestation of alien plants. These plants often form tall woodlands, replacing native shrubs or grasslands (Enright 1999). It has been calculated that these alien plants consume about 6.7 % of the estimated mean annual runoff of water over the entire area of South Africa, with considerable regional and seasonal variations. In periods of drought, the alien plants continue to extract the available green water, meaning that the presence of alien plants in South Africa has amplified drought conditions. The direct consequence is a reduction of streamflow, which in turn has given rise to devastating effects on river ecology (fish kill, algal blooms and generally poor water quality through a reduced dilution effect). This also reduces the amount of water that is available for other sectors and functions in downstream areas (a reduction in overall blue water availability). Water shortage in urban areas is an additional and recurrent problem stemming from the invasion of alien plants (ibid.).

These two examples demonstrate the close relationship between land use and hydrological parameters. In the first case, the lack of appropriate vegetation in the landscape contributed to considerable damage and is a direct cause for water shortage in one of the wettest areas in the world. In the other case, a certain type of vegetation is equally harmful and is the cause for heavy green water consumption, reduced blue water flows and higher order effects on the environment and economy. The significance of the problem is illustrated by the decision in South Africa to launch the “*Working for Water*” project. The aim of this project, which will employ thousands of people over a proposed 20 year period, is to eliminate the alien plant species and thereby decrease green water consumption and increase the flow of blue water for the benefit of society. It will involve numerous training programs that will communicate ecological knowledge, and safeguard many thousands of plant and animal species (Enright 1999; Preston 1999).

Green and blue water in rainfed and irrigated agriculture

A close relationship between land use and water resources, as illustrated by the examples from Cherapunji and South Africa, can be expected in connection with other land use systems, for instance, in areas where rainfed agriculture prevails. Throughout the world, the level of rainfed agriculture is far greater than irrigated agriculture in terms of area, the number of people involved and output. Despite robust statistical information, it can be safely argued that at least 60% of world food production comes from rainfed agriculture.

Owing to its scale and area of coverage, non-irrigated agriculture has a significant impact on a number of hydrological parameters. Land-use (as well as *changes* in land uses) influence rainwater partitioning, the amount of water that is evaporated and transpired back to atmosphere, and the size and temporal distribution of water flows that cascade over and below the surface. Whereas some types of land management and vegetation will increase the consumptive use of green water, (i.e. imply a high rate of evaporation), other types of land-use are comparatively less water demanding. It is also worth highlighting that the relationships between land use and green water are understudied and are frequently ignored. Water policy and the administration and regulation of water for example, refer almost exclusively to blue water. One of the reasons is that green water is “invisible” and must therefore be managed indirectly.

THE MULTIPLE FUNCTIONS OF BLUE WATER

Blue water in irrigated agriculture

The attention directed to rain-fed agriculture in agricultural policy is inverse to its size: much more attention is paid to irrigated agriculture. Certainly, the area under irrigation varies significantly between countries and continents, ranging from a very small percentage of total agricultural areas in Sub-Saharan Africa and throughout most of Latin America and much of Europe, to a very high percentage in Egypt and parts of the Middle East. In large parts of Asia, irrigation has been instrumental in the profound transformation of the rural environment that has taken place. Furthermore it has, and continues to be, a major factor behind the significant reduction (and perhaps eradication) of large-scale hunger catastrophes in countries such as India and China.

Stimulated by the seeming signs of success and progress emerging from Asia, the building of irrigation facilities became a “privileged solution” in African development in the 1970s and 1980s (Moris 1987). This notion refers to the high expectations that were attached to irrigation in terms of solving the challenges of increasing food production and reducing rural poverty throughout Africa. Typically however, the early phases of irrigation development were characterised by low levels of attention to performance and efficiency. Massive investments were often made without the necessary identification of goals and success criteria. Similarly, little attention was paid to the meaningful monitoring and evaluation of these projects. Some authors have argued (Kinje, 1999) that with few exception the performance of irrigated agriculture has been meagre throughout Africa. Recently, however, heavy subsidies to the irrigation sector have been reduced and it is possible to detect a more realistic and rational approach to irrigation, whereby interventions and developments are increasingly sensitive to local conditions and seek to reflect variations in social, economic and environmental conditions.

Irrigated agriculture faces increasing competition for water

It is possible to identify a large number of different technical and institutional arrangements under the broad heading of “irrigated agriculture”. The common denominator for areas where irrigation is practised is a lack of green water during the agricultural season/s. In order to compensate for water deficiency, irrigation water is supplied to the fields from various blue water sources such as streams, lakes or the groundwater aquifers. A range of different regulatory devices and technical interventions allow the water to be withdrawn from these sources and be made available directly to agriculture (and other sectors).

Estimates suggest that about 4,000 to 5,000 km³ are annually withdrawn from blue water sources (UN 1997 a). About 70 % of the total is supplied for irrigation purposes, most of which returns to the atmosphere as a result of evapotranspiration. The capacity of society to regulate and withdraw water has increased considerably during this century and particularly during the 1950s and 1960s. On average, the rate of withdrawal of blue water has been about two to two and a half times faster than the rate of population increase during this century. The majority of this increase is associated with the expansion of the irrigated agriculture sector (Falkenmark & Lundqvist 1995). Clearly, a crucial question concerns how much additional blue water can be withdrawn in the future. Analysts estimate that it is theoretically possible to withdraw between 9,000 to 12,000 km³ / year, based on calculations of the stable base flow (UN 1997 a). Postel, Daily & Ehrlich (1996) estimate that humans now appropriate a quarter of all evapotranspiration over land, and more than half of the surface flows. New dams could increase the appropriation of available surface flows by a further ten percent over a thirty-year period (*ibid.*). World population is expected to increase by some 40 percent during the same period.

For several reasons, it is unlikely that a continuous increase in extraction will occur. A reduced rate of extraction will, in most cases, affect irrigated agriculture more than other sectors. It is possible to identify some of the major factors influencing the possible reduction in water provision to irrigated agriculture:

- i) depletion and degradation of blue water sources, leading to multiple consequences;
- ii) soaring costs to develop additional water resources and a low economic return per unit of water and;
- iii) rapidly growing demand from other sectors and interests in society.

1) **depletion of blue water sources.** One of the most serious consequences of the expansion of irrigation is a widespread and sometimes drastic reduction of water in areas downstream of dams and other points of extraction. The Aral Sea provides a very clear example of this problem. A large number of other cases are reported in which a combination of water extraction and changes in land use have contributed to a depletion of water in downstream sections of the river. Recently, scientists have reported a recurrent failure in recent years of the Yellow River to reach the lower sections of its basin and the Yellow Sea for parts of the year (Brown and Halweil, 1998). A number of similar, albeit less dramatic, examples can also be provided, including the Colorado river (Postel et al. 1998) and the Pungue River in Mozambique (personal communication, Jacob Granit).

The expansion of irrigation has also been a significant factor contributing to the lowering of groundwater tables. The overdraw of groundwater has been documented in North Africa, Middle East, and the western parts of North America and the on the Plains in North China. In a detailed study in Tamil Nadu, India, it was shown that out of 384 administrative blocks in the State, 89 were classified as having excess levels of groundwater extraction and another 86 were identified as having groundwater withdrawals that represented a potential danger for safe water supply for household purposes. The remaining 209 were described as having levels of groundwater extraction that did not represent threats to basic water supply for drinking purposes (GoTN 1994). Depending upon geological features, the pumping of water from wells often results in a significant lowering of the water table for the individual farmer and for the local area in general.

In addition to reductions in the quantity of blue water, the degradation of water quality is also growing concern associated with heavy withdrawals. Water extraction is synonymous with the intensive use of land and water resources (including high input use). At the same time, an increase in water extraction leads to the reduced dilution of chemical and other inputs in downstream rivers and lakes. The degradation of water quality is noticeable in both surface and groundwater sources. Twenty-six countries in Europe have high levels of nitrate in ground water and the situation is described as serious in eighteen of these (Stanners & Bourdeau 1995:70). More than 85% of the groundwater located beneath agricultural land in the region exceeds the recommended EU level of nitrate concentration for drinking water ($10 \text{ mg l}^{-1} \text{ NO}_3\text{-N}$). According to a WHO and UNEP study (1991), it is likely that nitrate pollution will become one of the most pressing water quality problems in Europe and North America in the coming decade. If present trends continue, nitrates are likely to be a serious problem for many developing countries as well, including in India and Brazil (*ibid.*). In semi-arid and arid areas, comparatively small levels of extraction may result in comparatively large impacts on blue water quality in downstream parts of a basin simply because the dilution effect could be substantially reduced.

ii) **Soaring costs and poor economic returns.** Exploitation of blue water for irrigation is associated with rapidly escalating costs, in real terms. Every additional unit of water supplied tends inevitably to be more costly since the best sites for dams and storage are already

exploited. The World Bank has estimated that the cost of new supplies of water for urban areas is 2 to 3 times higher in real terms as compared to the cost associated with pre-existing schemes. A corresponding increase in expenditure for irrigation supplies is found in various schemes. For Africa, the average cost per hectare for irrigation schemes is estimated at US\$18 300 which includes the indirect costs associated for example, with the provision of necessary supportive infrastructure and equipment such as roads, houses, electric grids and public service facilities (Kinje 1999). For Asia, the figures are considerably lower although the costs are increasing. It is difficult to undertake meaningful comparisons between costs in different countries partly because costs for supplementary infrastructure arrangements may not be included. Nonetheless, there can be no doubt that in many instances there are considerable financial constraints associated with the expansion of the irrigated sector. This is the case even in countries where expenditure is comparatively low. In India, for instance, the costs for medium and major (M&M) schemes were in the order of US\$2 000 to US\$3 000 per hectare in the beginning of the 1990s. This figure is low when compared to the levels for Africa, shown above. Nonetheless, public investments in M&M schemes increased by two and a half times in real terms during the period from 1970-71 to 1984-85 (Gol 1990; Vaidyanathan 1994). Prospects for irrigated agriculture in India are therefore quite different today as compared to the Green Revolution period.

Dramatically increased development costs associated with the development of new water sources makes it more and more difficult to implement conventional irrigation schemes. In addition to these financial factors, environmental concerns constitute a new constraint on the further exploitation of blue water sources for irrigation development. There is little doubt that non-conventional technologies will have to be further elaborated, such as supplementary irrigation, drip and sprinkler systems for efficient water utilisation.

iii) Rapidly growing demand from other sectors and interests. Growing urbanisation has given rise to challenges to the previously “privileged status” of irrigated agriculture. Urban households and industry are demand increasing levels of water. Although the amounts of water required for these purposes are much lower than those required for agriculture, the increase is nevertheless significant in situations of growing water stress. The magnitude of the demand increase associated with urban growth is well illustrated by urban population projections for the coming decades. Between 1995 to 2025 for example, the increase in the urban population in developing countries is expected to be about 2 000 million (out of a total population increase of about 2 300 million), or about 88% of total growth. It should be born in mind that this projected growth – 2 000 million – is almost equivalent to the entire combined population of India and China in 1996 (approximately 2 200 million). As we enter the 21st century, the rural majority will become a minority and the former urban minority will become a majority. For the world as a whole, it is estimated that half of its population will be living in urban areas by about 2006 (UN 1997 b). Urban migration can be seen as a reflection of both real and perceived higher living standards in urban areas (even though a large part of the migrant population may face considerable hardships in the growing cities and towns). The words of farmers in southern India provide ample testimony to this emergent reality:

Farmers have lost their status in society. The people who live in urban centres as well as the villagers now want their daughters to get married to someone in the city. So, the youths in the farmer's family hate agriculture and try to come out of the villages. In a nut shell, Tirupur [a booming industrial city in Tamil Nadu] has not only swallowed farmers, but also agriculture itself. (Quoted in Blomqvist 1996:66).

Urban expansion will have a multiple impact on agriculture. In addition to the perceived changes in status, it is perhaps more relevant to study the implications for the orientation of agricultural production in general. The increasing concentration of both population and economic growth in urban areas means a corresponding expansion in the market for agricultural products. Urban consumers not only demand increased food production but are also likely to demand new products and they are, of course, anxious about the prices and

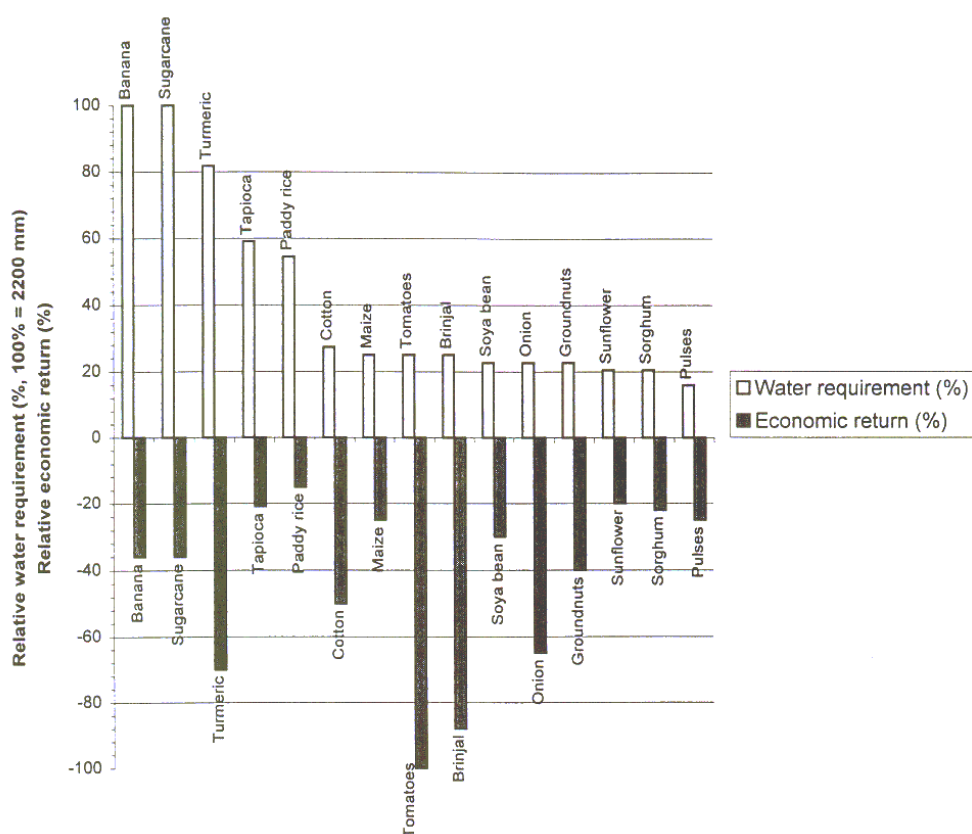
about the quality of the products. Apart from staple food crops, the demand for fruits and vegetables is likely to increase. Markets for non-food items are also growing. Cultivation of flowers, for instance, represents an opportunity for some farmers.

TRADE-OFFS BETWEEN ALTERNATIVE WATER USES

Growing competition for water and increasing demands for new agricultural products mean that it is worth considering the returns associated with water use and related opportunity costs. Three aspects merit attention: 1) different uses of water within the agricultural sector; 2) the trade-offs of water use between sectors, primarily urban and rural sectors; 3: the need to balance concerns for environmental sustainability with the functions and benefits derived from direct water use

Trade-offs within the agricultural sector. It has already been seen above that the amounts of water required to produce different crops vary significantly. Figure 1 shows the crop water requirements for crops commonly grown in Tamil Nadu, India. It is shown that the water requirements of bananas and sugarcane are about 2 200 mm (12 months season). For paddy the requirement is about 1 200 mm whilst it is less than 300 mm for pulses. Figure 1 also indicates the relative economic return for the farmer per unit of water. The estimated net income of the farmers for the various crops was divided by the volume of water that corresponded to the water requirements for the individual crops. A comparison between the two parts of the figure shows that the crop which is most common in the area, paddy, provides the lowest relative economic return per unit of water. Paddy only delivers about 20% of the return per unit of water as compared to tomatoes which fetched the highest price per unit of water. Comparisons are, of course, difficult to make. The price of paddy, for instance, is comparatively fixed and does not fluctuate whereas tomato prices and those of other perishables vary substantially. In addition, the marketing cost of this type of product is generally much higher than those associated with paddy. The key to highlight in this instance is that as long as water services continue to be heavily subsidised, comparison of the crop water requirements and the economic return of different agricultural products is of little interest for the farmer. With growing demand for water from other sectors and with increasing costs to provide water services the pressure on the agricultural sector to use water more efficiently and to use it for those crops and items that are demanded by the consumers or that offer suitable economic returns will increase.

Figure 1. crop water requirements for selected crops in Tamil Nadu, India



Note: Water requirements for various crops are shown in the top part of the figure. 100% corresponds to the crop water requirement of 2,200 mm. In the lower part of the figure, the relative economic return per unit of water for the farmer is shown. The crop which generates the highest return per unit of water, i.e. tomatoes, is put to 100%. Paddy is generating slightly less than 20 % of the value per unit of water as compared to tomatoes.

Source: The figure is based in information collected from Tamil Nadu Agricultural University, Coimbatore, India.

Trade-offs between rural and urban uses. With increasing urbanisation and with the emergence of new relationships between urban and rural areas, the trade-offs between allocating scarce blue water resources to agriculture or to urban sectors assume increasing importance. Industry, tourism and urban activities in general are able to generate much higher economic rates of return per unit of water than those associated with most forms of agriculture, and in many cases the scale of difference is as high as 20 or even more, times higher. In Namibia for example, it has been estimated that the relative return per unit of water in urban sectors was up to 200 times higher than for agriculture (Pallet 1997). Even in cases of a sophisticated agricultural systems with a high water use efficiency, such as is found in parts of Israel, the return to water remains much higher in urban sectors (Shuval 1997). Under these circumstances, the principles of rational policy-making would seem to indicate the need for a reallocation of water away from rural and irrigation sectors to urban sectors. Similarly, under these conditions it is difficult to argue that increasingly scarce water resources should be developed for the benefit of the agricultural sector.

The success and value of switching water use away from agriculture and into the urban and industrial sectors does however, depend on a series of circumstances. For example, in

instances in which domestic industry is unable to compete with imports, there is little economic rationale for effecting the switch away from agriculture (despite the higher efficiency of industrial water use). Similarly, if the opportunities for a successful industry or a potential source of foreign exchange earnings are uncertain, a continued emphasis on the agricultural sector may be more rationale and viable, at least in the short-term. For countries experiencing a growing water scarcity, the trade-offs are often both more demanding and more complex. In the long-term however, it is difficult to identify alternatives for countries with a large population in relation to available water and land resources. If a country cannot satisfy food demand from domestic agricultural production, food supplies must be imported, and imports demand foreign exchange resources which in many cases may require an expanded industrial and/or service sector.

Cities and industries need comparatively little water to produce many times the economic revenues that agriculture is able to generate. On average, agriculture accounts for between 60-70% of total water consumption at the national level, while industry uses some 20-25%, and households some 10-15%. Only a small amount of the water which today is appropriated by agriculture would be enough to support aggregated water demands in cities. In many cases, it is believed that the development of the urban sector typically boosts the national economy and in theory can act as a platform for social progress and development.

Trade-offs between water for the environment and direct water use. A case study from the Cape Town region of South Africa provides an interesting example of how human dependence on direct freshwater availability for households and indirect dependence on ecosystem services in the watershed can be related and valued. The *fynbos* is the predominant vegetation type of the Cape Floristic Region supporting 8,500 plant species, of which 68% are endemic. Alien invasive plants, all shrubs and trees from other fire-prone, Mediterranean-climate ecosystems are the major human-induced threat to *fynbos* biodiversity and ecosystem services. They eliminate native plant diversity and reduce water production from *fynbos* ecosystems by 30-80%. It has been estimated that pristine watersheds will have alien plant cover of between 80-100% after 100 years.

The major services of the *fynbos* ecosystem are wildflower harvesting, biodiversity and storage for various uses including floricultural varieties, rainfall/run off modification providing water for human consumption, hiker and ecotourist visitation, as well as aesthetic cultural and existence values. The value of the services of a pristine *fynbos* system reached more than 82 million US\$ annually and was derived from the development of a dynamic simulation model that integrated ecological and economic data and processes. Clearing alien species amounted to only 0.6-4.8% of the value to society of the ecosystem services supplied by *fynbos* watersheds. Alternative technical solutions to water delivery would cost from 2 to 7 times more than *fynbos* catchment management. The analysis was presented to the South African Minister of Water Affairs and Forestry, who decided to invest 100 million Rand (more than 20 million US\$) annually to clear the *fynbos* of invading alien plants, starting in 1995 as a part of the “*Working for Water*” project discussed above. (Higgins et al. 1997, van Wilgen et al. 1996 quoted in Falkenmark et al. 1999). Improved knowledge of the *fynbos* ecosystem has secured the water supply to the cities downstream while at the same time restored the functions of the watershed ecosystems.

FOOD PRODUCTION, ENVIRONMENTAL AND SOCIAL SUSTAINABILITY IN VARIOUS REGIONS

Pastoralism in arid lands

Poor rangelands in dry areas are often used for grazing domestic livestock but may also for example, provide hunting grounds and possess high value as nature reserves for flora and fauna. Their biodiversity can be high in spite of very low productivity. However, the potential for the multifaceted development of the biomass systems is rather limited. Rangelands are

typically of limited productive value and will remain so, particularly when they are overgrazed. The rangelands cannot be fertilised as the output is minimal under the prevailing dry conditions, nor is there sufficient water for irrigation due to the large areas normally involved. Neither are other improvements very realistic, such as soil surface preparation and the seeding of valuable pasture species. Many attempts have been made but drought and competition with weed species have led to frequent failures. (Pratt et al. 1997).

In areas in which pastoral systems are in crisis, many of the problems can probably only be resolved through the emergence of radical and far-reaching solutions. In the long-term for example, there may be compelling arguments to abandon traditional forms of pastoral activity. Its levels of productivity are too low and there are few ways of forging meaningful increases in these levels as water scarcity is the decisive limiting factor. The abandonment of pastoralism however, leads to the concentration of livestock husbandry in smaller land areas as well as selection of sites with sufficient water resources to produce forage to feed livestock in an economically and ecologically acceptable way. Such changes requires new combinations, new multipurpose activities on the farm and in the village, within the family or as small co-operatives in terms of water use, energy and machinery. Livestock fed in a stationary way for example, increases the potential of domestication, breeding programmes, veterinary and sanitary controls, slaughter, build-up of small scale enterprises for meat, hides and milk. It also increases the possibility of improvements in crop production as a result of more efficient water use. Likewise, it may be that economically more valuable crops such as vegetables, fruits and other horticultural products will have a better chance of profitability. A stationary system will also present new possibilities for family members, especially women and children, to develop new activities and knowledge creating increasing livelihood opportunities.

Rainfed biomass production in semi-arid lands

In instances of higher precipitation, pastoral systems are substituted by rainfed production with different crops, either with or without livestock husbandry. A less developed variant is characteristic of the semi-arid climates of the tropical and sub-tropical regions. Due to the relative scarcity of water, productivity levels tend to be low. The LAI (Leaf Area Index) is 1-3, grain yield of sorghum and millet is 500-1000 kg, of maize 1200 kg. ha/yr and of wheat 1500 kg / ha / yr. This type of rainfed agriculture is typical for many of the dry areas in developing countries where approximately 75 % of the population is tied to this way of life (Hall et al 1979; Arnon 1992; Perason et al 1995). However, there are also large dry areas in developed countries such as the USA and Australia, which likewise, only permit low-productive rainfed forms of agriculture but where a more advanced economy can make irrigated agriculture profitable in addition to rainfed forms.

Agriculture in many dry areas is typically risk-prone and difficult. Crop yields may vary from year to year, crop failures can occur as a result of drought, and household and regional food security is often precarious. Household livelihoods are invariably limited and vulnerable, and producers face difficulties in trying to increase crop yields and output from the livestock for sale on the local and urban market. There is often shortage of manures as most of it is lost in the pastures or is used as fuel, and there are invariably insufficient income streams or access to credit for the purchase of fertilisers. Therefore careful mulching with crop residues and leaves is an important tool for the maintenance of soil fertility. Agroforestry with nitrogen fixing species should be part of such management (Edwards et al. 1990; Buresh et al. 1997).

Potential of old non-conventional water management techniques

Besides the root zone water which normally is available to plants during the growing period of 120-180 days in semi-arid climates, blue water (groundwater and surface water) is used through water harvesting and irrigation. A very long tradition underpins water harvesting,

which involves the small scale collection of water in slopes in the period following rains. This can be done by a runoff-runon method, which means that water from a larger surface runs by gravity downhill to a smaller surface, typically with a ratio of 20:1 between runoff and runon areas. It can also be undertaken through the deployment of small dams. There are cheap and simple techniques, involving stones, boulders, clay and wood constructions but also more expensive and complicated ones like stone or concrete walls with or without iron reinforcements, or terraces with water directed in complicated system of ditches (Arnon 1992; Rockström 1997).

Water harvesting increases root zone water owing to the fact that part of the blue water source is converted into green water. This can allow for plant stands two and even three times more dense (LAI 2-3), higher yields, and the cultivation of more crops including vegetables, fruit trees and crops for sale of a higher economic value than ordinary staple crops. The use of manure and fertiliser can be more efficient. Mulching and more complex spatial and vertical arrangement of trees, shrubs, annual and perennial crops are also made possible. The diversity of livestock, small mammals, poultry, bees and other species can be increased. It appears then, that water harvesting can readily lead to the extension of the multifunctional character of agriculture and land.

The next step on the technical scale is irrigation of larger fields involving different forms of flooding. Arid and semi-arid climates are characterised by short periods of heavy rains, often in the form of violent rain storms, which cause high water levels in water courses and flooding of surrounding land. These floods are rich in silt containing plant nutrients and organic matter for the flooded fields. The Nile provides a clear example of the creative and constructive use of flood water in an advanced and diversified agricultural system for a over five thousand years. This technique involves the mono-directional linear transfer of resources in the form of good quality water and silt from the Ethiopian highlands. It is ecologically sound as the fields are not affected by salination, and soil fertility is maintained. New dams have changed this situation.

Besides the relatively simple flooding techniques, considerably more complicated irrigation techniques were developed very early, such as those found in the Euphrates-Tigris basin area (the *Fertile Crescent*). However, irrigation with diversified systems of canals, ditches and field plots meant a need to washout salts accumulated in the topsoil. Salination caused by poor irrigation techniques in dry areas continues to pose a serious threat and constitute a difficult problem. It demands advanced, high-cost techniques that are often inaccessible to poor countries and producers (Arnon 1992).

Irrigation, if executed effectively, leads to a new and distinct hydrological situation for plant growth in biomass production. Water scarcity need not limit transpiration, CO₂-assimilation nor photosynthesis. A LAI of 6-10 is possible which gives yields in the order of 5-10 tons of dry plant biomass per hectare. The problem is that such a technique can be applied only on very limited areas. There is a tendency to over-utilise the groundwater resource which can lead to sinking groundwater levels. There may also be problems with saline groundwater in areas with soils and geological mother material of marine origin (Greenland et al. 1994; Samad et al. 1994; El Asswad 1995).

Oases provide perhaps one of the clearest examples of concentrated biomass production in arid climates, but only where the hydrological conditions are very favourable with well situated springs with high flow of non-saline water. If the conditions are good a multifunctional production system can be created with date palms, olives, figs, citrus fruits, almonds, apples, water melon, wine and forage for livestock: cattle, pigs, poultry and several other animals. There are good opportunities for the purification and recirculation of water and of materials of value such as manure for mulching and soil conservation. The production outputs are typically high-value. The oasis is multifunctional in character also because of its

character as a station for passing traffic of different kinds, including a growing tourist trade. The oasis is an ecological microcosm and can prove to be a highly sustainable system (Mainguet 1995).

It appears that in many cases, the competition for water will increase. Industrial and domestic sectors will continue to grow, demanding greater quantities of blue water, often at the expense of agriculture. These changes will encourage changes in patterns of irrigation and water use in general. Staple crops such as cereals, pulses and root crops with lower relative economic value for example, will be increasingly replaced by higher economic value agricultural outputs (Postel 1989; Falkenmark & Lundqvist 1998).

Rainfed agriculture in tropical humid zones

The potential for the creation of agricultural systems that are more multifunctional in character is perhaps greater in humid climates including tropical, sub tropical, warm temperate and cold temperate zones. In these areas, water ceases to be a factor limiting biomass production. In these instances, biomass production tends to be limited by the availability of plant nutrients. Conversely, sufficient water coupled with large quantities of nutrients provided through manure and fertilisers can lead to the pollution of surrounding water environments. In these instances, blue water ceases to be clean (and indeed, ceases to be blue), leading to potential technical and sanitary problems in downstream areas.

Tropical humid areas provide clear examples of highly productive agriculture with a great variety of crops, including vegetables and fruits, and with a variation of animals in different forms of livestock husbandry. The rice paddies of East Asia provide a strong example of water-intensive agriculture that is multifunctional in character. Further examples are also provided by the diversified production systems based on sorghum, millet, maize and wheat. This can result in LAI of 6-10 and crop yields of 5-15 ton/ha/yr. Such levels are reached in some of the high potential districts in highland Kenya, in Southern Africa, parts of coastal West Africa, northwestern South America, eastern India, southern China and several other areas in East Asia (Arnon 1992).

However, the major part of totally rain-dependent agriculture tends to be characterised by low productivity with yield levels less than half those of high potential areas. Nonetheless, it constitutes the predominant form of agricultural activity in many humid areas. Under these conditions, rural households tend to enjoy reasonable food security in terms of basic food production but often suffer from undeveloped and distorted agricultural markets. Prices are often determined by non-market factors. This frequently acts as a strong disincentive to investment in factor inputs and other potentially yield-improving initiatives. In many instances, meaningful development will occur in these areas following the development of fair and efficient markets and the emergence of necessary enabling policy environments.

Rainfed agriculture in the temperate humid zones

Conditions in temperate zones and many of the sub-tropical regions are different and in many respects, more favourable. Indeed, the development of agricultural systems that are highly multifunctional in character is in many ways, far more possible. Similarly, there is often considerable variability in the intensity of production throughout these regions. The most intensive areas, such as parts like western Europe (Belgium, the Netherlands, western parts of Germany, Denmark, southern England) belong to the so-called "ten ton club" in which normal wheat yield is 10 tons/ha/yr. These systems typically use 200-300 kg of nitrogen in the form of fertilisers, 150-250 kg of nitrogen in manure (cattle, pigs, poultry) and contribute significantly to a very heavy pollution load on the land, waters and atmosphere. Other plant nutrients are also introduced in high quantities, as well as pesticides to control weeds, insects and microbial diseases. Agriculture is a substantial and important part of

many highly industrialised developed countries. In many cases, agriculture is itself an industry, thereby breaking down the traditional distinction between *agricultural* and *industrial* uses, that exists in many parts of the world and that has been discussed above (Pettersson 1997; Steen 1998).

In addition to the aforementioned environmental problems, there are considerable economic difficulties associated with the agricultural sector in many developed countries. European agriculture is highly subsidised, mainly through the vehicle of the Common Agriculture Policy (CAP). Likewise, there are increasingly differing opinions regarding food quality. Similarly, agriculture in Europe is, like systems elsewhere, rich in biotypes and biota and the aesthetic value of the “agricultural landscape” has become increasingly valued and in many instances, commodified. The social importance of agriculture, rural landscape and land for recreation in many forms is also of high value for urban citizens: in many ways, the town depends on the countryside, not only for material purposes but also in non-material ways.

Many temperate zones however, are not characterised by the highly modernised and industrialised agricultural systems that characterise northern Europe. Instead, crop yields are typically lower and the input of fertilisers and other materials is 75% lower. However, there are often severe environmental problems associated, for example, with the pollution of waters due to dense human (and sometimes, livestock) populations. Eastern Europe, parts of southern Europe, northern China and parts of North America, all provide examples of this type of agriculture. In many of these areas, rural traditions remain strong and the agricultural landscape conserve many features of old, traditional mixed farming systems with crops, livestock, vegetables, horticulture, craftsmanship and small scale enterprises. Links with urban areas are often far weaker in terms of marketing and trade.

Urban agriculture

Urban agriculture is growing throughout the world. Urban agriculture represents a supplement to conventional forms of agriculture. The intensive production of food items has emerged in and around many cities as a response to the daily demands of consumers. In many cases, urban agriculture involves the direct use of urban waste and the re-utilisation of resources after they have been used in urban sectors. Urban agriculture is often driven by the continued growth of large metropolitan areas and represents an opportunity to produce more food in an efficient manner. Intensive vegetable production may for example, use only between 5-20% as much water and only 8-16% of the land as compared to rural, tractor-cultivated crops. In Botswana for instance, a high technology variety of container horticulture is practised. It is highly water- and nutrient-efficient and is able to produce up to 20 tons of maize on a per hectare basis (UNDP 1996). In Israel, the new linkages between urban and agricultural land uses are expressed in a vision which could, in theory, be translated into practice within a relatively short time frame (Shuval 1996; Braverman 1994). According to this vision, the freshwater resources would be allocated entirely to urban sectors. After use and subsequent treatment in urban areas, the waste water would then be made available to agriculture. Under this scenario, industry is able to cover the increasing costs of water supply and also treatment meaning that the water fees charged to farmers could be much lower as compared to a situation where farmers were given freshwater directly from source. This then, offers an intriguing and radically different glimpse of the future. A future that without doubt, will be dramatically different from today.

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