CHAPTER 4

Social and economic aspects of Dryland investment

INVESTMENT CONSTRAINTS

Investment to increase production in drylands has been limited, at least in part due to the popular misconception that drylands are empty, barren places (White *et al.*, 2002). Development and research have focused on high-potential areas with the possible expansion of irrigated areas and intensification of irrigated agriculture. However, increasing numbers of people are living in dryland areas as a result of population growth. Hazell (1998) stated that it is becoming increasingly clear that, on poverty and environmental grounds alone, more attention will have to be given by both national governments and international development agencies to less-favoured lands in setting priorities for policy and public investments. At the same time, evidence of productivity gains, poverty reduction, and environmental benefits are required to encourage the necessary funding in dryland regions.

Pender (1999) reviewed the impact of population growth on the degradation or enhancement of soil resources and stated that the evidence is mixed. He cited Tiffen, Mortimore and Gichuki (1994), who found that in the Machakos District in Kenya between the 1930s and the 1990s the population increased fivefold, per capita income increased, erosion was much better controlled, and trees were more prevalent in the landscape. This study supports the optimistic perspectives advanced by Boserup (1965 and 1981) and Ruthenberg (1980), who postulated that households and communities respond positively to pressures induced by population growth, for example by reducing fallow periods, increasing labour and capital inputs per unit of land, developing and adopting labour-intensive technologies, developing more specific property rights, and market development. Pender (1999) concluded that there are many possible household and collective responses to increasing population pressure. These responses are highly site-specific and interact in complex ways. Therefore, he found it difficult to predict the impacts of increasing rural population pressure on the natural-resource base, agricultural production and poverty. However, the impacts of population growth are more likely to be negative where there is no collective response, and positive where population growth induces infrastructure development, collective action, and institutional or organizational development.

There are many examples, particularly in dryland areas, where soil degradation has resulted from population increases. One notable case is the Loess Plateau in China. This region, covering some 53 million ha, is the largest loess area on earth. The plateau is 1 000–1 400 m above sea level and has a loess thickness of 100 m (Wen Dazhong, 1993). The area is characterized by: sloping lands; sparse vegetation; loose soil; and high-intensity, short-duration rainfall. The annual precipitation is 400-600 mm, most of which falls during the summer months. Using historical information, Wen Dazhong (1993) developed an association between population numbers and soil erosion for the Loess Plateau over the last 3 000 years. For many centuries, the erosion rate was relatively low, and this can be attributed primarily to natural processes. Around 1200, the population began to increase and it has grown very rapidly in the past century. The increased food needs of the growing population were met by expanding the cropland area. Once every piece of flat and fertile land had been used, the inhabitants extended crop cultivation to slopes under natural pasture and forest. Expanding crop production into these areas increased erosion by more than 100 percent, and when soil erosion eventually reduced crop yields on the marginal lands, the people had to destroy more pasture and forests. Forests covered an estimated 40 percent of the Loess Plateau in the period from 221 BC to 581 AD, but only about 6 percent at present. In the worst-affected areas, people collected nearly all the available biomass, including crop residues, leaves and branches of trees, grass roots and manure for household fuel. Removal of this biomass further aggravated soil erosion and reduced the productivity of the land.

Soil conservation in China entered a new era in the 1950s when the Government began to emphasize its importance (Wen Dazhong, 1993). This emphasis is being maintained and erosion has been reduced significantly, even though it remains a major problem. In the Loess Plateau region, about 10 million ha of the eroded area, which account for almost one-quarter of the total erosion in the region, have been controlled since 1950. Terraced fields have been shown to reduce erosion rates by 80 percent, and shrubs and grasses planted on sloping areas can reduce erosion by 70–80 percent. This progress in soil conservation has not only controlled soil erosion, it has also produced economic benefits. For example, crop yields on terraced fields are double those on non-terraced fields, and dam-checked fields have even higher crop yields in some areas. According to an analysis of erosion control practices in small watersheds of this region, the benefit/cost ratio is 2 for erosion control practices, 4 for terraced fields, 1.2 for check-dams, 7 for economic tree plantings, and 10 for shrub plantings (Zhang Jinhui, 1987).

Terraces are effective for conserving soil and water, leading to increased productivity. However, they are costly when large equipment is used and they require large inputs of labour when constructed manually. McLaughlin (1993) reported that terracing of Loess Plateau land in Gansu Province requires 900 labour-days per hectare, not including time for planting crops and for later maintenance. This level of investment is only feasible where land is extremely scarce and the need for food production is paramount. Even so, China terraced more than 2.7 million ha of cropland from about 1950 to 1984, under circumstances that are unlikely to be duplicated elsewhere (Huanghe River Conservancy Commission, 1988). This, coupled with other improved practices, resulted in a 2.8-fold increase in grain production. These extreme measures were required to lessen the widespread hunger in the region, which reached disastrous levels in the late 1950s, when the death rate more than doubled and the birth rate dropped by half (Hellig, 1999). Hunger in the Loess Plateau region was severe with a population of 35.6 million in 1957. By 1981, the population had increased to 72.6 million, doubling in just 24 years (Tian Houmo, 1985).

A significant point illustrated by this example is how rapidly an agro-ecosystem can break down. For centuries, agriculture in the Loess Plateau region was sustainable because of the low population density and the deep loess soils, in spite of significant natural erosion. Then, within a relatively short period, the system began to deteriorate quickly and became clearly unsustainable. However, the example also shows that the downward spiral of degradation can be reversed with institutional intervention, inputs, and infrastructure development.

The International Food Policy Research Institute (IFPRI) reported that land degradation is advancing at an alarming rate in sub-Saharan Africa, particularly as desertification in dryland areas, soil erosion and deforestation in hillside areas, and loss of soil fertility in many cropped areas (IFPRI, 1998). The accelerated soil degradation appears to be related to population increases. While natural forces such as climate change, drought, floods and geological processes contribute to soil degradation, the IFPRI concluded that poverty, rapid population growth and inadequate progress in increasing crop yields were the primary drivers in the land-degradation process. Without substantial investments to improve soil and water management in many areas, conditions will grow worse. The pattern is not homogenous as many issues are site-specific. Investments are required at many levels, including social and institutional investment, applied research, as well as support and incentives to improve soil and water management.

While recognizing that productivity returns had been highest from investments in irrigated and high-potential rainfed lands, Hazell (1998) calls for increased investment in dryland areas. He points out that past decisions had been largely based on the philosophy that adequate poverty reduction and environmental benefits must offset losses in efficiency associated with investing in less-favoured areas. He further states that this view is being challenged by increasing evidence of stagnating productivity growth in many green revolution areas and by emerging evidence that the right kinds of investments can increase productivity to much higher levels than previously thought in some types of less-favoured lands. For example, research in India shows that additional investments in many low-potential rainfed lands can lead to more agricultural growth and a reduction in rural poverty – a “win–win” situation. Hazell concludes that, because of the high levels of investment already made in irrigated and high-potential rainfed areas in India, the marginal returns from some investments (particularly roads, irrigation, education, and agricultural research) are now more attractive in many less-favoured lands. As already discussed, China has been investing on a large scale in the Loess Plateau and other less-favoured lands. Since this effort began in the 1950s, a total of 165 institutes and extension stations for erosion control have been established (Yang Zhenhuai, 1986). In addition, several universities and colleges have established specializations to train soil- and water-conservation professionals. Nevertheless, the development of dryland areas will require investment at many levels before farmers can be successful.

INVESTMENT POTENTIAL

Pingali and Rajaram (1999) stated that there is considerable potential for increasing wheat yields in marginal environments and predicted that future global grain demands could not be met without increasing production in these areas. They emphasized four arguments presented by Byerlee and Morris (1993) to support the allocation of more research resources to marginal environments:

1. Returns to research may now be higher in marginal environments than in more

favourable environments because the incremental productivity of further investment in favourable environments is declining.

2. A large number of people currently depend on marginal environments for their survival, and population pressure is increasing.
3. Because the people who live in marginal environments are often among the poorest groups of the population, increased research investment in the areas is justified on the grounds of equity.
4. Many marginal environments are characterized by a fragile resource base. A special effort is needed to develop appropriate technologies for these areas that will sustain or improve the quality of the resource base in the longer term.

Morris, Belaid and Byerlee (1991) highlighted three related factors that are largely responsible for the relatively slow rate of wheat-yield improvement in marginal environments compared with more favourable areas.

1. The climate in dryland production zones severely constrains the yield potential of cereal crops, so the impact of improved seed and fertilizer technologies is bound to be less dramatic than in the more favourable environments, where these technologies have been highly successful.
2. Investment in agricultural research targeted at rainfed areas has been modest, in part because such research has been perceived as having a lower potential payoff (true only while more responsive alternatives exist).
3. Largely because of the first two, many countries have been slow to implement supportive policies that would promote cereal production in rainfed areas, such as policies to develop market infrastructure.

In contrast, Pingali and Rajaram (1999) point out that wheat research and cultivar development have been fairly successful in these environments despite these factors and contrary to the common perception of the problems of unfavourable environments. Many of the gains in these areas have resulted from the spillover of technologies developed for more favourable environments (Lantican *et al.*, 2003; Dixon *et al.*, 2006). Their findings clearly show that yields have increased in these areas and that the potential for further increases could be significantly greater if research were aimed specifically at marginal areas.

Perhaps the most compelling reason for increasing investment in dryland areas is the fact that the development of additional irrigation is becoming increasingly difficult and, in many semi-arid regions of the world, irrigated agriculture alone will not be able to satisfy the future demand for food. For example, irrigation development in sub-Saharan Africa is very expensive. Investment costs per hectare in World Bank-funded irrigation projects average about US$18 000, more than 13 times the South Asia average (AQUASTAT, 2008). Moreover, external support for investment in agriculture has declined considerably in the last 20 years.

In sub-Saharan Africa, many countries are classified as “economically water scarce”, meaning that they do not currently have adequate infrastructure and capacity (human and financial) to take advantage of the available water resources. Thus, they are not able to cope with the development of irrigation for increased food production and are relying increasingly on the participation of the resource-poor farmers despite their limited access to credit. In other cases, the majority of easily available and inexpensive water resources have been developed.

OPPORTUNITIES AND RISKS OF GROWING FEEDSTOCKS FOR BIOFUELS IN DRYLANDS

Biofuels have been grown and used in drylands for millennia. Twenty-first century interest in biofuels is not in the traditional biofuels (wood fuel and charcoal), but new “generations” of biofuels – principally liquids produced as purportedly environmentally friendly alternatives to petrol and diesel for transport fuels. Ethanol can be produced from sugar cane and cereal crops (currently mainly maize, wheat and sorghum, others are likely to be developed in future), and biodiesel from oil seeds (*inter alia* oil palm, jatropha, soy, sunflower seeds, coconut and rapeseed) – so called “first generation” fuels. Scientists are working to produce “second generation” fuels, which involve more complex chemical and biological processes using maize stalks, wood waste and by-products of other food and fibre processing.

Use of these recently captured sources of carbon for fuels can bring huge benefit, as they should reduce dependence on fossil fuels. However, as most of the 1st generation biofuels use feedstocks which traditionally enter the human food supply, this raises great concern about the impact which a growing demand for biofuels will have on food supplies and security. Further, devoting land to growing crops and feedstock for 2nd generation biofuels may result in the high risk that energy security could lead to water shortages for agriculture, human populations and food insecurity across the world.

The issues are perhaps most acute in drylands, where food supplies are limited. Traditional food and fibre use of land may lose out in this competition because, on the margin, the potential market for energy is huge and could eventually lead to rising food prices. The latter may not dent the welfare of those who can afford to pay higher prices for both food and fuel, including the population groups that benefit from the development of biofuels. However, low income consumers that do not participate in such gains may be adversely affected in their access to food. Several recent economic studies indicate that increased production of biofuels could lead to price increases not only of crops used for biofuels, but also of other crops – as land is shifted towards greater production of crops for biofuels production. The commercialization of cellulosic-based ethanol (2nd generation fuels from wood and agriculture and forestry waste) could alleviate price pressures while also giving farmers new sources of income, as it would open up new land (like low value grazing lands) to crop production and enable greater productivity from existing cropland (e.g. through use of crop residues for biofuels production) (IEA, 2005).

In the short term, care is required in where, when and how much agricultural land is converted to the growing of crops and feedstock for biofuels to avoid exacerbating food shortages (Worldwatch, 2006), where any transfer of food-growing hectares to biofuel may lead to malnutrition and starvation. Countries including India have set up policies prohibiting the use of agricultural areas for biofuel production, instead encouraging the use of unused and marginal areas and by-products (of agriculture, food processing and forestry) instead of cereals (Worldwatch, 2006).

With the development and spread of production of 2nd generation fuels, which utilise “waste” streams, crop stems and stover and woody materials by-products, the pressures will be less intense – although this may result in progressive degradation of soil fertility and physical structure (especially due to diversion of sources of organic matter, traditionally returned to the land).

The development of cropping for biofuels (maize and sorghum for ethanol; jatropha for biodiesel; organic “waste” streams for second generation biofuels) in drylands should bring benefits, reducing dependence on imported fuels and improving local access to energy. These potential benefits must be reviewed against potential negative trade-offs, relating to food supply, security and water supplies and regimes. The implications of this use of water in drylands may have deleterious impacts on downstream water users.

In the longer term, the position is more optimistic. Forecasts of world food supply from 2030 to 2050 by FAO, (2006) predict a slowdown in the growth of world agriculture, as world population numbers stabilise. FAO predicts that this slowdown may be mitigated if the use of crop biomass for biofuels were to be further increased and consolidated. Were these to happen, the implications for agriculture and development could be significant for countries with abundant land and climate resources that are suitable for the feedstock. Several dryland countries in Latin America, South-East Asia and sub-Saharan Africa, including some of the most needy and food-insecure ones, could benefit (FAO, 2006).

Successfully planned development of dryland agriculture to produce feedstocks for biofuels offers the opportunity for states to reduce dependence on imported oil for their own fuel needs – and potentially develop an export market for processed biofuels, generating foreign exchange.

PAYMENTS FOR ENVIRONMENTAL SERVICES

Recent years have seen considerable interest in using Payments for Environmental Services (PES) to finance conservation. PES programs seek to capture part of the benefits derived from environmental services (such as clean water) and channel them to natural resource managers who generate these services, thus increasing their incentive to conserve them. Latin America has been particularly receptive to this approach. PES programs are in operation in Costa Rica, Colombia, Ecuador, Mexico and others are under preparation or study in several countries (Pagiola, 2005). The central principles of the PES approach are that those who provide environmental services should be compensated for doing so and that those who receive the services should pay for their provision, also providing additional income sources for poor land users, helping to improve their livelihoods. Several countries are already experimenting with such systems, many with World Bank assistance.

Some hydrologically sensitive watersheds may have very few downstream water users, and so little potential for being included in a PES program. Further, even if poverty rates in target watersheds are high, it does not follow that payments will be received solely, or even principally, by the poor. Even in watersheds with high poverty rates, some land users are likely to be better off, and there can be substantial variability in the level of poverty among the poor.

The potential impacts of PES programs will only be realized by those who participate in the program. Most such programs are too recent for an assessment of participation decisions. But, insights into the factors that are likely to play an important role can be gleaned from the substantial literature that examines the determinants of participation in reforestation, land conservation, and other rural programs (Pagiola, 2005).

CARBON TRADING

The key element of soil rehabilitation in drylands is the restoration of organic matter which has been widely depleted due to tillage, overgrazing and deforestation (Chapter 3), clearly an example of carbon sequestration. The Clean Development Mechanism of the Kyoto Protocol does not include the possibility of payments for carbon sequestration in soils (the Marrakesh Accords established that afforestation and reforestation would be eligible as project based activities) although techniques such as conservation agriculture increase the soil's ability to sequester carbon (Stern, 2006) However, other markets in carbon are being developed, which could enable developing countries to benefit from carbon trading for soil organic matter. By June 2006, the Chicago Climate Exchange (www.chicagoclimateexchange.com) was supporting 350 000 acres of conservation tillage and grass plantings in four states in the USA – acting as a possible model for expansion to benefit projects in drylands of developing countries. Plan Vivo was created by the Edinburgh Centre for Carbon Management in 1996, as a participatory planning and project monitoring system for promoting sustainable livelihoods in rural communities through the creation of verifiable carbon credits. The Plan Vivo System is being applied in Mexico, Mozambique, Uganda and India to generate verifiable carbon credits for sale on the voluntary market and, potentially, for eligibility under the Clean Development Mechanism (CDM within the Kyoto Protocol). All these projects have carbon credits available for purchase. Through the Plan Vivo System, organisations, companies and individuals can not only help offset some GHG emissions but also can help communities in developing countries invest in their own future, while protecting biodiversity, soil and water quality.

ECONOMICS OF WATER HARVESTING

The success of any agricultural development practice ultimately depends on whether or not it is economically, environmentally and socially sustainable. Critchley and Siegert developed a detailed FAO manual for the design and construction of water-harvesting schemes for plant production (FAO, 1991). The technical aspects of water and soil requirements, rainfall-runoff analysis, water-harvesting techniques and crop husbandry were covered in great detail, and there was some discussion of socio-economic factors.

Oweis, Prinz and Hachum (2001) estimated costs of typical water-harvesting practices for

TABLE 8

Costs of water from water harvesting used for crop production

		Cost per cubic metre of water used for crop production		
Water harvesting development cost [c]	Life of treatment	Annual rainfall [a]		
(US$/ha)	(years)	150 mm	300 mm	450 mm
300 (20%) [b]	2	US$0.58[c]	US$0.29	US$0.19
400 (30%)	3	US$0.36	US$0.18	US$0.12
800 (50%)	4	US$0.34	US$0.17	US$0.11
1 500 (70%)	8	US$0.27	US$0.13	US$0.09
5 000 (90%)	16	US$0.47	US$0.24	US$0.16

[a] 1 mm irrigation supply or rainfall is equivalent to 10 m^3/ha.

[b] Numbers in parentheses are the percentages of rainfall harvested by the land treatment applied to induce runoff.

[c] Development cost per hectare divided by number of cubic metres per hectare delivered annually (cubic metres per hectare of annual rainfall multiplied by proportion harvested), multiplied by the appropriate annuity at a 10-percent discount rate (2 years US$0.5764 per US$1 invested; 3 years US$0.4023; 4 years US$0.3156; 8 years US$0.1875; 16 years US$0.1278).

inducing runoff in countries of the Near East. While these values are not necessarily applicable to other areas, they do provide a basis for making some estimates of benefit/cost ratios for water harvesting compared with irrigation development. On the basis of these estimates, the costs for harvesting 1 m^3 of water were estimated for areas with different annual rainfall (Table 8). They were estimated as annuities, assuming a 10 percent discount rate over the lifetimes of different treatments of the runoff catchment areas. The costs ranged from US$0.09 to US$0.58 per cubic metre of water, depending on rainfall and the cost-effectiveness of treatments.

For comparison, Table 9 lists development costs for delivering 1 m^3 of water by different irrigation systems. Estimated irrigation development costs ranged from US$0.03 to US$0.33 per cubic metre of water. They depend on the cost of developing the infrastructure and on how much the system is used. Where irrigation sources are not limited and climatic conditions allow the growing of two or more crops per year, so that 1 000 mm of

TABLE 9

Development costs of water from irrigation systems used for crop production

		Cost per cubic metre of water used for crop production		
Irrigation development cost [b]	Life of system	Irrigation supply [a]		
(US$/ha)	(years)	500 mm/year	750 mm/year	1 000 mm/year
2 500	25+	US$0.06 [b]	US$0.04	US$0.03
5 000	25+	US$0.11	US$0.07	US$0.06
7 500	25+	US$0.17	US$0.11	US$0.08
10 000	25+	US$0.22	US$0.15	US$0.11
15 000	25+	US$0.33	US$0.22	US$0.17

[a] 1 mm irrigation supply or rainfall is equivalent to 10 m^3/ha.

[b] Development cost per hectare divided by number of cubic metres per hectare delivered annually, multiplied by the 25-year annuity at a 10-percent discount rate (US$0.1102 per US$1 invested). Operation and maintenance costs not included.

TABLE 10

Development and total costs of water used from shallow and moderately deep small tube wells

Unit cost	Lifetime	Lift	Discharge		Investment [b]	Operation [c]	Maintenance [d]	Total cost
(US$)	(years)	(m)	(litres/s)	(m^3/year) [a]	(US$/$m^3$)			
2 500	4	5	2	7 200	0.11	0.03	0.05	0.19
2 500	4	2	5	18 000	0.04	0.01	0.02	0.08
5 000	8	25	2	7 200	0.13	0.10	0.07	0.30
5 000	8	10	5	18 000	0.05	0.04	0.03	0.12

[a] Assuming 1 000 operation hours per year.

[b] Investment cost per tubewell divided by volume (cubic metres per year, multiplied by the appropriate annuity at a 10-percent discount rate (4 years US$0.3156 per US$1 invested; 8 years US$0.1875).

[c] Shallow tubewell 3 kW, US$0.07/kWh; deeper tubewell 15 kW, US$0.05/kWh.

[d] Shallow tubewell 15 percent of unit cost/year, deeper tubewell 10 percent/year.

irrigation water can be used, the cost per cubic metre is relatively low even when the cost of development is high. The development cost per cubic metre increases rapidly when the system provides only 500 mm water or less per year. The development cost per cubic metre water used was estimated as an annuity, assuming a life expectancy of 25 years for the systems and a 10 percent discount rate. These estimates do not include operation and maintenance costs – and are clearly academic where farmers do not have access to credit. Table 10 lists estimated development and total costs per cubic metre of water for shallow and moderately deep small tubewells, on the basis of similar assumptions.

Although irrigation development is usually not an option in areas where water harvesting is practised, it is of interest to compare their development costs. The estimates in Tables 8 and 9 suggest that water harvesting is less cost-effective than irrigation even when the irrigation development cost is US$10 000–15 000/ha. This is particularly true in the lower-rainfall regions. Oweis, Prinz and Hachum (2001) consider that most enhanced water-harvesting catchments are short-lived (Table 6). Thus, although the initial cost is high, the most cost-effective water-harvesting practice in the long term may be to use an impermeable cover such as plastic or asphalt so that a high proportion of the precipitation can be harvested (details in Tables 5 and 6). The estimated development costs are only for harvesting the water and having it run onto adjacent cropped land as a supplement to the rainfall. Where the water is intended for use as supplementary irrigation, a tank or reservoir must be available or installed to store the water until it is needed. In addition, a pump or other means of delivering the water to the crop might be required. This would entail substantial additional costs, and there may also be considerable loss from evaporation or seepage during storage.

Even in drylands, there may be opportunities to develop local, small-scale groundwater resources. Therefore, a comparison of water-harvesting costs with those of small tubewells may be more relevant than with those of irrigation systems. A comparison of Tables 8 and 10 shows that the total costs of water generated through runoff agriculture (without additional water-storage facilities) are of the same order as water costs from shallow or moderately deep tubewells in areas with rainfall of about 450 mm. In lower-rainfall areas, tubewells would be more economic where shallow groundwater of adequate quality were available. Individual catchment areas in many types of runoff farming are smaller than 1 ha, with some much smaller. Consequently the comparison with tubewell-irrigated agriculture, although more direct than with large-scale irrigation, is still across different farming systems.

Perhaps the greatest problem in assessing the benefit/cost ratio of water-harvesting practices is the lack of assurance that water will be available. This is true particularly where perennial crops or trees depend on harvested water. One approach is to include both perennial crops and annual grain crops in the design. When rainfall is adequate, supplemental irrigation water will be available for both. In dry years, water will only be available for the perennial crops, but the design would be conservative enough to almost guarantee sufficient water to maintain the perennial crops even during prolonged droughts.

Supplemental water can be very beneficial when it is available at critical periods (providing application is not immediately followed by heavy rain). Oweis, Prinz and Hachum (2001) showed that 1 m^3 of water applied as supplemental irrigation could produce 2–3 kg of wheat. This compared favourably with the productivity of water from full irrigation, which was in the order of 1 kg/m^3. Even using the high value of 3 kg of wheat per cubic metre, the costs of harvesting water for cereal production often cannot be justified where only price is considered. The perspective may be more favourable with higher-value crops. There are also other benefits, such as maintaining a local supply of food, making use of available family labour in some cases, enhancing the environment, and other social benefits that might make water harvesting more feasible than on the basis of production economics alone.

Economic considerations suggest that water harvesting is most attractive where the harvested water can be used directly by crops on an adjacent area; next where water can be diverted to nearby crops or trees; and least where the harvested water must be stored and used later as irrigation. Although the potential for water harvesting in dryland regions is considerable, there are many problems in addition to constructing the systems that have constrained wide-scale development of water-harvesting systems. Records on water-harvesting areas are often not definitive, with insufficient data for good designs. In some years, there is not enough harvested water to be successful. In other years, waterlogging may be a problem. Erosion on lands receiving harvested water can also be a difficulty, and the maintenance of water-harvesting systems can be labour-intensive and costly. Nevertheless, water-harvesting systems in dryland regions must be given more focus. They may very well be more economically feasible for growing tree crops or other high-value crops than for grain crops. Analysis and design should be based on rainfall-probability distributions rather than average values. Probabilities provide a more realistic evaluation than average values because the rainfall amounts in dryland regions are very erratic.

ECONOMICS OF WATER-CONSERVATION PRACTICES

A realistic goal for producers in dryland regions is to increase growing-season evapotranspiration of grain crops by 25 mm. The effect of this on grain yield can be estimated on the basis of grain-yield and water-supply information. Musick and Porter (1990), Rhoads and Bennett (1991), and Krieg and Lascano (1991) reviewed the water-use efficiencies of wheat, maize and sorghum, respectively, which varied considerably depending on yield levels and climate conditions in the many studies conducted worldwide. However, as a general guide, 1.7 kg of maize grain, 1.5 kg of sorghum or 1.3 kg of wheat can be produced in dryland regions per additional cubic metre of water used by evapotranspiration. These values can be refined where sufficient local data are available. Using these values, some preliminary benefit/cost estimates can be made regarding the amount of investment that can be made based only on production. However, there may be social and environmental benefits that will justify investment costs far beyond those strictly for increased grain production.

Based on the water-use efficiency values above, the average yield of wheat could be increased by 0.32 tonnes/ha by an extra 25 mm seasonal evapotranspiration. FAO (1996a) reported that the 1988–1990 average yield of wheat in developing countries in semi-arid regions was 1.1 tonnes/ha, so this would represent a 30 percent yield increase. Maize yield could be increased by 0.42 tonnes/ha, and sorghum by 0.38 tonnes/ha. The 1988–1990 average yields of maize and sorghum in semi-arid regions of developing countries were 1.13 and 0.65 tonnes/ha, respectively (FAO, 1996a). Therefore, increasing plant water use by only 25 mm could potentially raise the average yields of maize and sorghum by 38 and 58 percent, respectively. These large gains from such a small amount of additional water use are feasible because the threshold amounts of water required for grain production are already met (Figure 5), and the additional water increases grain production directly, providing the water is available at the critical period of the growing season and that sufficient plant nutrients are available to take advantage of the additional water use. In some cases, this will imply the addition of organic matter or mineral fertilizers.

The most effective system for conserving water is no-tillage farming (Rockwood and Lal, 1974; Scoones *et al*., 1996; Tebrügge, 2000; FAO, 2001b; FAO, 2001d). Its effectiveness has been proven in many areas (see Annex 2), but as already discussed, its adoption has been limited because of the cost of new or modified tools, equipment or other inputs, and the high level of management required (Benites & Friedrich, 1998). No-tillage is also disregarded by many producers in developing countries because of conflicting demands on crop residues for animal feed or for household fuel. In situations where no-tillage or another form of conservation agriculture is not feasible, terracing or land levelling may be required to prevent runoff in order to increase the amount of plant-available water. The specific practices will depend on social and economic conditions, soil and terrain variables, and climate.

The benefits from conservation agriculture accrue slowly. Because of this, producers may become disappointed and abandon the systems after only a few years. Several years are required to enhance soil porosity and organic matter content to the point that significant yield increases are apparent (FAO, 2001d; WOCAT, 2007). Although it takes several years to increase the soil organic matter content significantly by conservation agriculture, the increases can be lost in a very short time by just one intensive tillage operation (Fowler and Rockström, 2001; Mrabet, 2002). Therefore, once a producer adopts conservation agriculture, it is important that every effort be made to continue.

Conservation agriculture practices can make better use of the limited amounts of precipitation in dryland areas and increase yields significantly (Mortimore, 1998; FAO, 2001d; Lal, 2002b). This can be an important step towards increasing cereal production and improving the well-being of people living in dryland regions. However, improving the yields in dryland areas by 30–50 percent will have only a relatively small effect on global cereal production. FAO (1996a) reported that only about 10 percent of the wheat, 8 percent of the maize, and 35 percent of the sorghum produced in developing countries were grown in semi-arid regions. Therefore, even though it is highly important to increase investment in dryland regions, agriculture in the more favourable climate regions and irrigated areas must continue to become more efficient if food and fibre supply are to keep pace with population growth.

CURRENT SCENARIO IN DRYLAND REGIONS

In the present circumstances, dryland farming is a risky enterprise. Drought is the principal hazard facing dryland farmers but insects, hail, intense torrential rains and high winds can also damage or destroy crops. Little can be done to prevent most sudden disasters, but there are soil- and crop-management practices that can reduce the impact of all but the most protracted droughts. While low soil-water content commonly restricts crop yields in dryland areas, there are several other soil problems (surface-soil hardening, compaction, water and wind erosion, low soil fertility, shallow soils, restricted soil drainage and salinization) that can also affect dryland production (Singh, 1995).

Improved management of land and water resources can counter desertification (whether due to climate change and / or overgrazing & deforestation) and increase the productivity of low-rainfall areas (Steiner *et al.* 1988). Lal (1987) presented a review of available low-input technologies that can improve the productivity of dryland regions and protect their soil resources from erosion. In order to ensure that the true causes of the problem of drought are identified and that potential solutions are feasible and acceptable to the farmers, a participatory approach must be adopted. Farmers testing possible solutions on their own farms are also encouraged to be more innovative. This is particularly important because farmer innovation is the key to the sustainability of the agricultural development process, especially in the situation all too common in developing countries, with inadequate advisory services.

Achieving long-term sustained growth in the productive capacity of low-rainfall areas requires sound decisions based on accurate assessments of resource problems and potentials, combined with careful analyses of alternative policies, programmes and projects. A study by FAO (1986) outlined specific practices and policies needed to improve African agricultural productivity, focusing on the provision of incentives, inputs, institutions and infrastructure.

General development goals for improving and sustaining the productivity of dryland areas include:
- improvement in the livelihoods of people living in dryland areas;
- a shift from conventional agriculture to a more conservation-effective agriculture (i.e. adoption of agro-ecosystem approaches and conservation agriculture);
- a greater contribution of dryland regions to the growth and development of national economies;
- a sustained productive life of drylands by arresting the processes of land degradation;
- rehabilitation of seriously degraded land;
- adoption and spread of dryland-management systems that are economically and socially viable and environmentally sustainable;
- improved decision-making abilities of local, national and regional (e.g. river basin level) planners.

A more conservation-effective agriculture should be promoted in response to the decline in land productivity under conventional agricultural systems-and to mitigate the effects of climate change. Conventional practices of particular concern include: continuous cultivation using mould-board ploughs or other intensive tillage tools; removal or burning of crop residues; inadequate rotations or monoculture; and overgrazing and deforestation that do not maintain vegetative soil cover or allow appropriate restitution of soil organic matter and plant nutrients.

The strategy for conservation agriculture has four components:
- using no-tillage or minimum-tillage systems;
- maintaining soil cover at all times;
- using suitable crop rotations;
- integrating livestock with cropping systems.

This strategy minimizes soil disturbance, enhances vegetative cover and contributes to the sustained use of agricultural soils. An effective participatory approach to research and extension is needed for the successful adoption of conservation agriculture. The “win-win” impacts of conservation agriculture include:
- labour savings and reduced peak labour demand;
- improved soil organic matter content and biological activity;
- improved soil structure and moisture availability;
- reduced erosion and runoff;
- improved crop yields (totals and reliability);
- crop diversification;
- increased income opportunities.