11

Water*

Asit K. Biswas

The effects of water on biomass production

Production of biomass is directly dependent on the availability of water and prevailing environmental conditions. Chlorophyll in plants uses solar radiation to convert carbon dioxide and water into carbohydrate (ultimately biomass) and oxygen. The chemical reaction can be represented as the following reduction-oxidation equation:

$$nCO_2 + nH_20 \xrightarrow[\text{chlorophyll}]{\text{solar radiation}} (CH_2O)_n + n0_2$$

Solar radiation is thus converted into chemical energy in terms of carbohydrates; part of this is used for plant growth and the balance is stored. Water is thus an essential ingredient of the photosynthesis process.

Different species of plants produce different forms of carbohydrates; which means the time periods over which energy can be stored are also different As a general rule, cellulose and complex starches—$C_6H_{10}O_5$—have longer energy storage periods than sugars—$C_{12}H_{22}O_{11}$.

Photosynthetic efficiencies of plants are quite low. Such efficiencies may not only vary from crop to crop, but are also dependent on climatic conditions. Generally, biomass production tends to be highest in the wet equatorial regions as compared to temperate conditions: for example, for certain plants and under good conditions, photosynthetic efficiencies ca be as high as 2.5 per cent in tropical conditions but only about 1.5 per cent in temperate regions.

There is enough scientific evidence at present to indicate that biomass production suffers if plants are under water stress, since this reduces the photosynthetic process. This relationship is neither one-to-one, nor is it possible at the present state of our knowledge to quantify the linkages accurately because they are dependent on many factors like the type of plants, different growth stages of the same plant, and the duration and severity of the water stress. While even a mild water stress is likely to contribute to reduction in biomass production, the question remains by how much. The problem becomes even more difficult when economic crops like cotton, cereals or tubers are considered, where only a part of the total biomass production is considered to be the yield. As a general rule, it can be said that under such conditions, percentage

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reduction in the yield of the economic parts of the plants is less than in the total biomass production.

There is no question that proper water control has a significant impact on biomass production. The yields of paddy rice, on the basis of available data, under different degrees of water control from different parts of the world are shown in table 11.1 (Biswas and Biswas, 1984). The total biomass production figures under corresponding conditions are likely to be proportionately higher.

Day (1981) reports an experiment where biomass yields for *Hordeum sativum* under irrigated and unirrigated conditions were compared. The unirrigated crop had much less biomass because of the decrease in green leaf area as well as a shorter growing season. This resulted in a 40 per cent reduction in light interception. Furthermore, the estimated effect of stomatal closure in irrigated plants was a rate of photosynthesis that was 7 per cent higher than in unirrigated plants.

Biomass energy, water and environment

Production and use of biomass energy have direct impacts on the quality and quantity of water as well as on other environmental factors. Equally water and environmental issues could influence the production and use of biomass energy.

The pathways linking biomass energy use, water resources and the environment are many, and only two major ones will be discussed here.

Table 11.1 *Yields of paddy rice with different degrees of water control*

Degrees of water control	Material inputs	Location	Average yield (t/ha)
No water control, rainfed uncontrolled flooding	Nil	Laos	1.3
Successive introduction of water control			
Elimination of floods	Nil	Kampuchea	1.5
Elimination of droughts	Fertilizer use, low	Burma, India, Thailand	2.0
Improved water control (irrigation and drainage)	Fertilizer use, low to medium	Pakistan, Vietnam, Sri Lanka, West Malaysia	3.0
Sophisticated management	Fertilizer use high + improved seeds + pest control + mechanization	South Korea, Japan	5.0
Experimental conditions			10.0

The first set of linkages can be construed as a negative environmental cycle, and is shown in figure 11.1. It indicates that increasing population in developing countries is creating greater and greater pressures to develop new agricultural lands and the present rate of use of rangelands. These pressures, together with increasing demands for fuelwood and forest products, mean that forest resources in most developing countries are shrinking. Deforestation is endemic; and the rate of reforestation is not enough to compensate for deforestation, let alone increase the area under forest cover.

A typical example of this problem can be seen by considering the case of Sudan. It is estimated that the clearance of forest land to expand the agricultural area, harvesting of fuelwood and other forest products, and forage requirements for domestic animals, have reduced the country's forested areas by nearly 20 per cent over the past two decades. Some 40 million m^3 of fuelwood are now harvested annually from the savannah areas to provide the basic energy needs of about 75 per cent of Sudan's population. This accounts for nearly 82 per cent of Sudan's total energy consumption (Biswas et al. 1987).

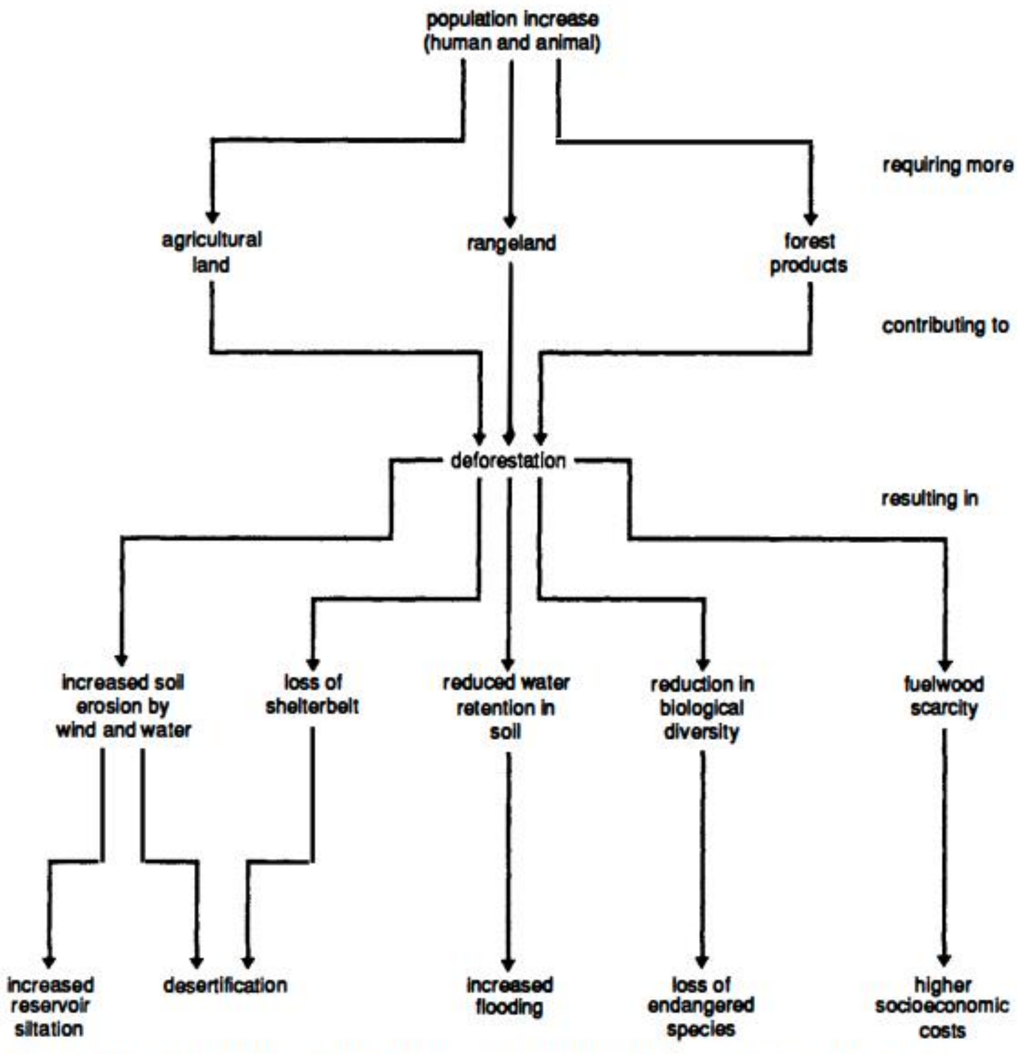

Figure 11.1 Interrelationships between population, fuelwood use, water and environment.

The extent of biomass production and the environmental conditions in the rangelands of Sudan now present the country with even more serious environmental, social and economic problems. This is primarily the result of the imbalance resulting from rapidly increasing livestock forage requirements on the one hand, and the reduced carrying capacity of land used for grazing on the other. Against a background of rising human and livestock populations, and the combined effects of agricultural encroachment and fuelwood harvesting, the Sudanese rangelands are under tremendous environmental pressures. The extent of this increasing pressure can easily be demonstrated. Between 1957 and 1977, the human population increased by a factor of more than 6 times, and the number of cattle by a factor of 21 times, camels 16 times, sheep 12 times and goats 8 times. The recurring drought has further contributed to the deterioration of the environmental and productive conditions. The total seasonal forage production in the Sudan was estimated in 1979 at about 77.7 million tonnes, which could meet the grazing requirements of 22.1 million Animal Units (AU). The livestock population in 1980/81 was estimated at 27.7 million AU, which means that some 5.6 million AU could not be supported on a long-term sustainable basis.

Forests in Sudan are disappearing, especially near centres of population. The natural savannah vegetation surrounding major cities like Khartoum has largely disappeared as a result of constantly increasing demands for fuelwood. Charcoal is currently being transported 500 km or more to urban centres.

If the present deforestation process in Sudan continues uncontrolled, an additional 10 million ha of savannah woodland in the north, representing about two thirds of the remaining resources in the region, will be lost by the year 2000. This would mean the displacement of at least 30 000 nomadic families, accounting for some 6 per cent of the total nomadic population of the country and their livestock. The average haulage distance for fuelwood and charcoal to Khartoum and to urban centres in the Central Province would increase from 500 km to 1000 km, which would further intensify the currently emerging fuelwood supply crisis in the north. The average cost of fuelwood would increase, further degrading the quality of life of the poor. Total elimination of on-farm trees and shelter belts would necessitate the use of agricultural residues as fuel; this would lead to the reduction of organic matter in soil, which is likely to reduce crop and livestock yields by 15 per cent. Wind erosion and desertification would increase, and so would the siltation in the reservoirs. Imports of manufactured industrial wood products would increase to US$50 million annually, and Sudan would be faced with an enormous investment programme in the future. If the estimated 20 million ha of forest that is expected to be lost by the year 2000 is to be replaced, investment of at least US$1500 million would be required which is beyond the financial resources of the government at present.

The disparity between available biomass energy and overall demand is still growing in Africa. The present status of fuelwood availability in Africa and the potential status in the future is shown in figure 11.2. Such continuing unsustainable biomass exploitation in many parts of sub-Saharan Africa has serious environmental repercussions for the deforested zones: effects of fires are increasing, pyrophytic vegetation that establishes itself afterwards is often unsuitable for animal consumption, soils become sterile, crusts form, drainage basins dry up, regeneration of wood species slow or stop altogether, and the process gradually leads to total degradation.

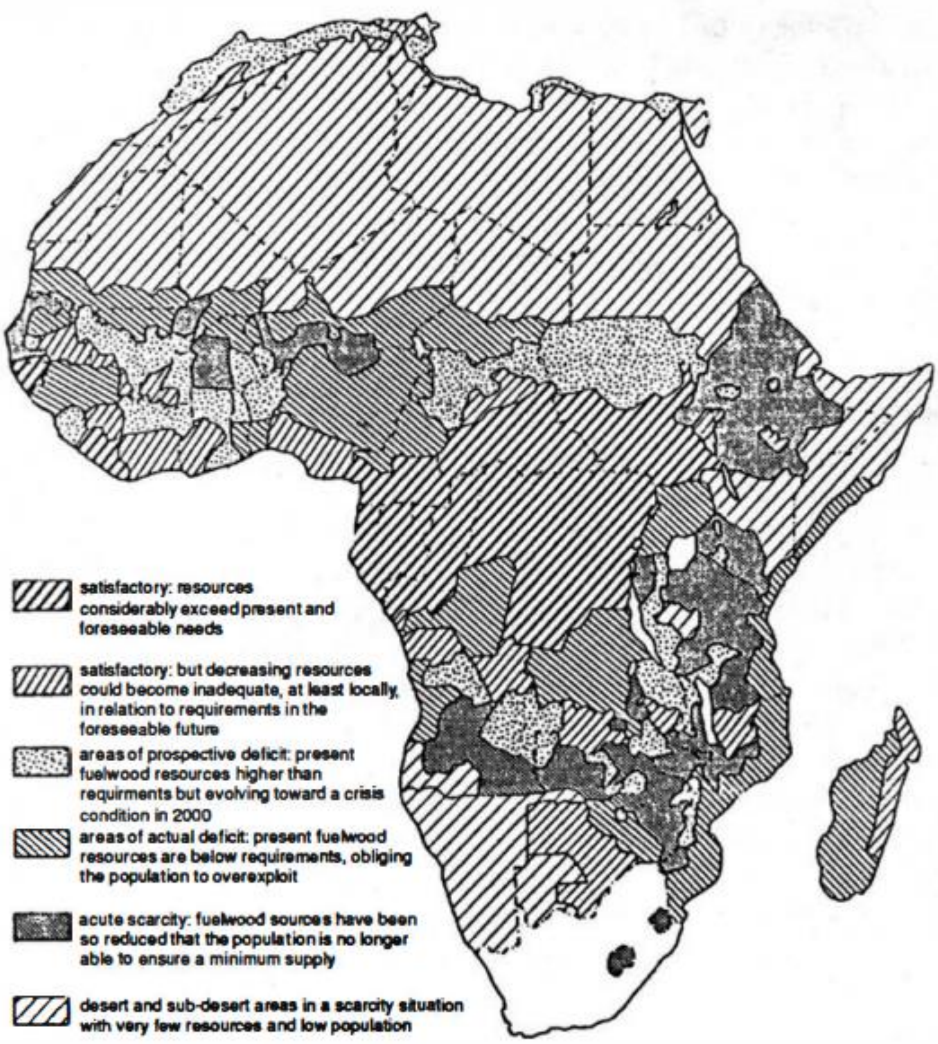

Figure 11.2 Status of fuelwood availability in Africa, present and future.

These types of environmental degradation are not unique to Africa. They can be seen in other parts of the world as well, though the magnitude and intensity of problems will vary from region to region. A similar state of affairs exists in many Asian countries: for example, in Pakistan current estimates indicate that its overall forest resource-base is shrinking. With an annual timber production rate of 1.1 million m^3, and an annual fuel wood consumption rate of 20 million m^3, the present annual growth of wood of 11.3 million m^3 accounts for only about 54 per cent of total annual wood harvest (Biswas 1988). This means the forest resources of Pakistan are being continually mined. Because of such scarcities, fuelwood prices have increased at a much faster rate than the general inflation rate, by about 45 per cent during the decade 1969/70 to 1979/80. If, as expected, the price of fuelwood continues to increase in real terms, as it has in the past decade, it will account for an increasing share of the household expenditure of the rural poor, thus making their life even more difficult. Present agricultural development trends mean that there is a real danger that while Pakistan may become self-sufficient or even an exporter of many food grains in the near future, the rural poor may not have adequate fuelwood to cook their food. Lack of such biomass energy for the rural poor will further contribute to the deterioration of their overall quality of life.

While nearly all of the recent discussions have focused on the negative interrelationships between the use of biomass for energy, water resources and the environment, there is no question that there are positive linkages as well. Unfortunately, not enough field data have been collected on these positive linkages, even though conceptually the latter can be justified; moreover, their presence is indicated in the very few case studies that have so far been undertaken.

During the past two decades, much emphasis has been placed on the development of irrigation projects, mainly in Asia, Latin America and north of the Sahara, to increase agricultural production. Unfortunately, realistic and regular evaluations of the impacts of these irrigation projects are few and far-between. Even in those few cases where irrigated agricultural projects were evaluated, the main emphasis was placed on the efficiency of the irrigation systems and crop yields. Significantly fewer projects have any detailed information on environmental impacts or energy use patterns over a period of years. While during the past two to three years there has been some progress towards including various environmental impacts in evaluating the effects of irrigated agricultural projects, albeit in a somewhat superficial fashion, regrettably there is no sign of the inclusion of energy impacts in such studies. To the best of my knowledge, currently only one study exists which collected any data on the changing pattern of biomass energy use resulting from irrigation development (Biswas 1988).

Table 11.2 ***Percentage energy and protein contents of select agricultural residues***

Crop		Cellulose	Hemicellulose	Lignin	Proteins
Alfalfa	leaves	22.2	11.0	5.2	28.2
	stalks	48.5	6.5	6.6	10.5
Corn	leaves	33.2	31.1	7.4	7.1
	stalks	43.1	10.5	9.6	3.4
Sorghum	leaves	25.6	40.0	7.8	10.4
	stalks	26.1	31.1	8.0	9.3

Irrigated agriculture has always been considered to increase crop production. To the extent energy has been considered, it has been primarily in terms of consumption for direct agriculturally-related activities like draught animal energy, human labour, diesel or electrical energy for irrigation pumps, fertilizers, pesticides,· farm equipment and energy requirements for agro-processing industries and for transportation of crops. Not much thought was given to how such developments could affect the consumption patterns of the various forms of energy in the project areas.

Conceptually, as mentioned earlier, no one will argue with the fact that irrigated agriculture significantly increases the level of biomass production. However, only part of this biomass production, specifically the economic parts of crops, is currently included in the project's calculations. Agricultural and agro-industrial residues, which are by-products of the main crops and provide biomass energy, are not considered. It is important that the contributions of these excess agricultural residues be recognized as a useful source of materials for biomass energy, animal feed and chemicals. Table 11.2 shows potential raw materials in the currently discarded agricultural residues.

Irrigated agriculture also generates additional biomass in a different manner. With rising employment opportunities, incomes in the project areas increase as well. Part of the new income generated is spent on acquiring additional domestic animals, and as animal population increases, so does the dung production and availability. These factors are shown schematically in Figure 11.3.

During the evaluation of the Bhima irrigation project in Maharashtra, India, it was observed that the patterns of biomass fuel utilization within the project area changed very rapidly with the introduction of irrigation. It was noted that the percentage of people purchasing fuelwood, or the total amount of fuelwood purchased per family, or both, in areas where irrigation water is available all year round, are decidedly less when compared to other areas receiving water for one season or no water. Table 11.3 shows an intercomparison of the patterns of biomass energy use in a village before and after irrigation was introduced at the Bhima project.

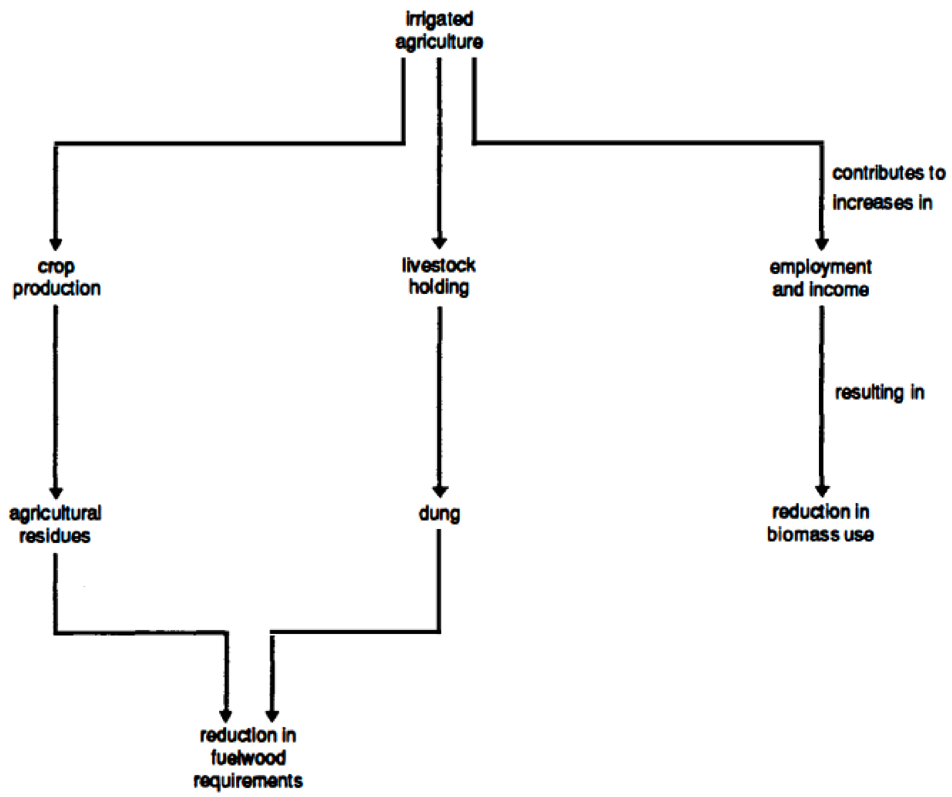

Figure 11.3 Impact of irrigated agriculture on biomass use.

Table 11.3 clearly indicates that the amount of fuelwood used has declined considerably since the introduction of irrigation, although the decline has been offset by an increased usage of cow dung and agricultural residues. This has no doubt contributed to the reduction in pressure on the forest resources of the area, and has tended to alleviate the problem of fuelwood scarcity. In addition, while the total number of hours worked by women has increased due to agriculture-related activities, time spent on fuelwood collection has declined. Equally, quantities of fuelwood purchased have also declined, thus contributing further to the economic well-being of the families.

Table 11.3 ***Changing patterns of biomass fuel use at Bhima as a result of introduction of irrigation***

Type of biomass fuel	Percentage of fuel used	
	Before irrigation (1980/81)	After irrigation (1985/86)
Fuelwood	66.3	53.2
Cow dung	19.2	23.8
Agricultural residues	7.4	13.1
Others	7.1	9.9

Source: Biswas 1988.

Even though the fuelwood problem is serious in many parts of the world, what is generally not realized is that the magnitude and intensity of the problem would unquestionably have been much worse had it not been for the increases in the availability of agricultural biomass residues through irrigation. For example, in Pakistan one of the most common biomass fuels used is cotton sticks from the irrigated areas. In 1981/82, 2276 million ha of land was under cotton cultivation and produced some 3.02 million tonnes of cotton sticks (Biswas 1987). If it is assumed that 90 per cent of the cotton sticks are used as domestic fuel, an estimate that appears to be realistic, the total amount is equivalent to about 2.2 million m^3 of fuelwood per year. If all types of agricultural residues and cow dung are considered, their total annual use in 1981/82 was equivalent to about 12 million m^3. Together they accounted for about 37 per cent of the total energy requirements for the domestic sector of the Pakistan economy, the balance being accounted for by fuelwood (50 per cent) and fossil fuels (13 per cent).

Finally, it should be noted that proper water control is not only important to produce biomass through irrigated or rainfed agriculture but is also essential for reforestation of marginal lands. A low and erratic rainfall and an inhospitable climate will neither produce adequate biomass nor promote reforestation.

Importance of efficient water use for biomass production

For assured biomass production, water control is an essential requirement, since either too much or too little water is generally undesirable for biomass growth. For the same land area, biomass production can be significantly increased by increasing cropping intensity after introducing perennial irrigation as well as by changing cropping patterns.

After the biomass is produced, water is again necessary for processing it into energy, especially for biogas production and in alcohol distilleries. All these processes produce waste water as an end product, which may need various degrees of treatment, ranging from none to quite extensive. Whatever way the final effluent may be produced, it is generally quite rich in nitrogen, phosphorous or potassium. If sufficient qualities of these nutrients are discharged into closed water bodies such as lakes or slow-flowing rivers, eutrophication may result. However, if the properly treated effluents from biogas plants or distilleries are reused for irrigation, the nutrients present in them act as fertilizers to enhance biomass growth. The result could be regarded as a positive cycle of biomass production, with processing for energy generation and linkages with water. This is shown schematically in figure 11.4.

Efficient water use for biomass production is especially important for arid and semi-arid countries for two reasons. First, in both types of region, often the main constraint for increasing biomass production is that water available is limited and its supply is unreliable, unless proper control systems exist. Most of the readily available water sources in such countries as Egypt, Jordan, China and India are already being utilized. The potential for developing new sources of water economically in such water-short countries to increase biomass production is now very limited. Accordingly, it is important that policies are formulated to promote the more efficient use of existing water supplies so that they can be used or reused for agricultural production. This is especially important in most major developing countries, where agricultural water use often accounts for more than 90 per cent of total water use, and is generally inefficient. A 20 per cent increase in the present agricultural water use efficiency, which can be achieved with improved management techniques but with existing knowledge and technology, can save a substantial amount of water that can then be used for additional biomass production. Existing socio-cultural practices and institutional constraints mean that significant increases in water use efficiency will not come overnight; there is, however, no question that this has to be the future direction.

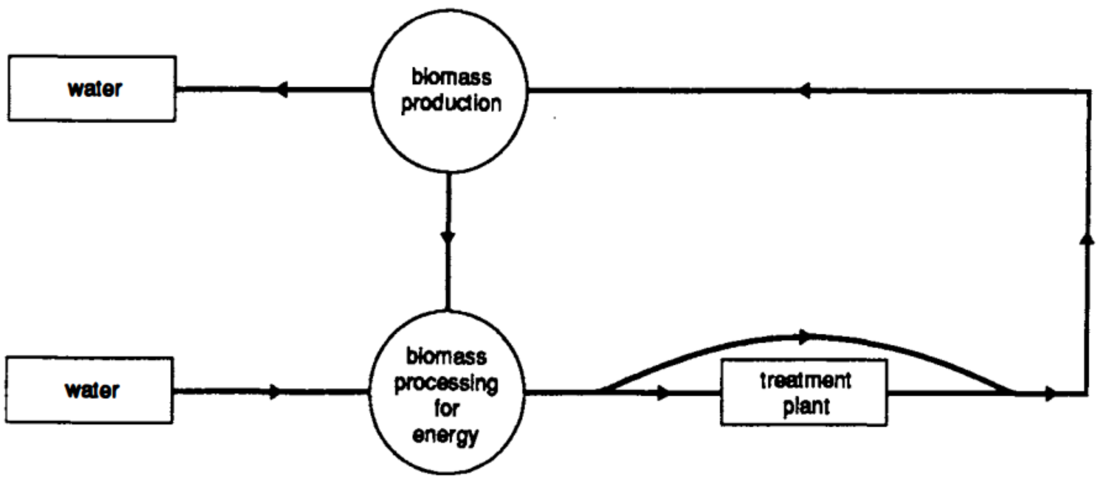

Figure 11.4 Positive biomass production cycle.

Second, and ironically, poor water use patterns in irrigated areas are now contributing to a decrease in total biomass production in the long term. In all developing countries, where significant amounts of land area are under irrigation excessive water use by farmers, poor overall design and construction of the system components, and inadequate operation and maintenance procedures have meant that groundwater tables are rising in many project areas. This is contributing not only to waterlogging but also to a steady increase in soil salinity, both of which are responsible for reductions in biomass production. There are now many cases all over the world where biomass production has stopped completely as a result of very high groundwater tables and increased soil salinity. Efficient water use is therefore not only important to provide a new source of water that can then be used to increase biomass production but also to ensure that these production levels are sustainable on a long-term basis.

A direct benefit of increased biomass production through efficient water use will be the simultaneous increases in the availability of both agricultural residues that can then be used as an alternative source of energy, and raw materials such as corn, sugarcane or sugar-beet for alcohol production. A secondary benefit, which is equally important from an energy viewpoint, is that enhanced agricultural activity contributes to the improvement in the economic well-being of the area. This enables people to purchase cattle, both as draught animals and as a source of milk that can be consumed or marketed. Increases in the number of cattle in tum ensure a concomitant increase in dung production, which then becomes an important source of biomass energy. So far, these secondary benefits and links have generally not been appreciated by project planners. The case of the Bhima Project in India, where such links were clearly observed, is referred to elsewhere in this chapter.

Cropping patterns may also have important implications in terms of water use. For example, the average annual water requirements of main food crops vary from 3000 m^3/ha for the countries of humid Central Africa to 16 000 m^3/ha for countries in North Africa. However, if requirements energy crops are considered, the main controversy in terms of water has so far primarily concerned eucalyptus. Opposition to eucalyptus as an energy crop has come mainly from India, where a vociferous group of people has claimed that water requirements for eucalyptus trees are abnormally high, and that accordingly eucalyptus plantations reduce groundwater tables and thereby make production of other crops difficult. There are currently not enough results from controlled experiments to draw definite conclusions about the truth of this claim.

One of the very few experimental results that is at present available comes from the study conducted during the first rotation of *Eucalyptus globulus* in the Nilgiri hills, India, by the Central Soil and Water Conservation Research and Training Institute (1987) of the Indian Ministry of Agriculture. This indicated a reduction of about 16 per cent in the expected water yield from eucalyptus plantations during the first ten-year rotation period from 1972 to 1981, when compared with open grasslands used as the control. The reduction in water yield can be minimized by adopting suitable silvicultural practices such as wider plant spacing and reduction of the rotation periods. If the eucalyptus is to be raised over a significant area, water losses can be further minimized by staggering the maturity periods of the plantations. This will reduce simultaneous peak water consumption, which appears to occur during the second half of the ten-year rotation, probably due to the lack of enough canopy in the initial stages.

Other experiments that are currently under way in India appear to indicate that loss due to evapotranspiration from eucalyptus plantations is very much a function of water availability: the higher the water availability, the greater are the evapotranspiration losses. This means that the possibility of the effective development of eucalyptus plantations in areas requiring some drainage may have considerable potential, in terms of both water management and biomass production.

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