MANAGEMENT OF AGRICULTURAL LAND: CLIMATIC AND WATER ASPECTS

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Keywords: Climatic hazards, drainage, drip irrigation, groundwater, irrigation, moisture deficit, mole drains, pipe drains, runoff, sprinkler, subsurface irrigation, surface flow, water harvesting

Contents

Summary

This chapter deals with the management of agricultural land, in particular with respect to climatic and water aspects. Climate affects crop production directly through temperature and rainfall, and additionally through air humidity and radiation. Rainfall and moisture have also an indirect effect on field operations. Adverse climatic hazards, like extreme temperatures, can be overcome by adapting the crop calendar (annual crops) or through some sophisticated techniques (perennial crops).

Agricultural production and activities have a problem when either too much or too little water is available in the root zone. A shortage of water can be compensated by irrigation. There are three major irrigation systems, involving pressurized water distribution (sprinkler, drip or trickle irrigation), surface irrigation and gravity flow (basin and furrow irrigation), and controlled drainage flow or subsurface irrigation. Excess water has to be drained off, either by surface drains (or open ditches) or by subsurface mole or pipe drains. Tillage operations are affected by the moisture status of the root zone.

The theoretical considerations discussed in the first part of the chapter are illustrated with a case study of an irrigation project in the Senegal River basin.

1. Introduction

Agricultural land is by definition land that is, or can be used for agriculture and crop farming. Agriculture focuses mainly on the cultivation of soils for annual or perennial crop production, vegetables and fruits. It involves the preparation and proper care of the soil, sowing and planting, seed and crop variety selection, protection against pests and diseases, and harvesting. In a broader sense, agriculture includes also gardening or horticulture, and the raising of livestock. Agricultural land management involves all these aspects and is therefore multifaceted.

Land has properties - good or bad, temporary or permanent - that make it suitable or unsuitable for agriculture. Some of these properties can be corrected or adjusted, others do not. Clearly, agricultural land management has to focus (1) on the conservation of those land properties that contribute positively to production and soil health (by maintaining them in an optimal state and by avoiding their degradation), and (2) on the reclamation of those properties that hamper optimal production. Land management in general, and agricultural land management in particular, is therefore primarily determined by (a) a combination of technical criteria, (b) farmer's know-how to deal with natural resources and constraints, and (c) economic considerations of profitability.

2. Types of Agricultural Land Management

Agricultural land management deals with the production of annual or perennial crops, fruits and tree crops, and grassland. All of these have their own requirements in terms of climatic growth conditions, root development, water and nutrient uptake, photosynthetic activity and biomass production and, additionally, field preparation and harvesting conditions. Moreover, as land use has to be operated in a spirit of sustainability and conservation of the natural environment, all management operations have to be achieved in view of a proper care and maintenance of soil health. Hence, five major types of agricultural land management can be differentiated:

- management aspects related to climatic conditions or constraints;
- management activities related to crop moisture supply;
- management activities related to fertilization and nutrient supply;
- management activities related to workability, field preparation and harvesting; and
- management aspects related to soil care and sustainability.

In this chapter the main focus will be on the agricultural land management of climatic and water aspects, with some additional considerations to soil workability and land preparation. The other issues will be discussed in a companion chapter dealing with chemical and fertility aspects of agricultural land management (see: *Management of Agricultural Land: Chemical and Fertility Aspects*).

3. Agricultural Land Management related to Climatic Hazards

Climate affects crop production primarily through temperature and rainfall, and additionally through air humidity and wind. Rainfall and moisture influence also indirectly agricultural field operations. Optimizing climatic growth and production conditions involves that the positive climatic conditions are exploited to a maximum while the adverse effects of the harmful factors are reduced or waved away.

3.1. Managing Temperature Constraints

The importance of temperature as a growth factor depends on the type and sensitivity of the crop. Some crops like rubber or cocoa need high energy inputs and suffer already when minimum temperatures drop below 15° C. Others, e.g. most vegetables, grow best in cooler climates. A third group, like maize, has developed a great adaptability and can now be cultivated over a wide range of world climates.

Managing temperature hazards can be achieved in two ways: for annual crops the growth calendar can be adapted in order to avoid adverse seasonal conditions; for perennial crops this is more difficult and, unless sophisticated methods are used, the areal extension of the crop will be restrained by the occurrence of the most critical climatic parameter.

3.1.1. Average Temperature

Though average temperatures have little meaning for crop growth *in se,* mean monthly temperature determines the distribution of crops in the world or, for a given crop, defines the high-productive from the less suitable production areas. Oil palm, coffee or cocoa are typical crops of the humid tropics which require high temperatures (and rainfall). Therefore, they cannot be grown successfully outside the inter-tropical belt. Even in areas where average day temperature is 22-25° C, but night temperatures drop below 16-18° C oil palm suffers from diseases and lower production. The successful cultivation of maize and other grain crops is mainly determined by the length of the growing period (Fig. 1).

A similar situation occurs for coconut palm which requires high average temperatures (above 22° C) but does not support daily variations of more than 5° C; for this reason coconuts are only encountered in tropical lowlands, in particular along coastlines. Under these conditions large-scale plantation agriculture for this type of crops is restricted to the suitable climates, and the most adequate management policy is to limit their extension to those areas.

3.1.2. Low Temperature

Low temperatures are critical for many crops, and quite a number of higher plants go into a dormancy period when air temperatures drop below 5° C. The critical temperature below which the crop is damaged depends on the growth stage, degree of cold hardening and even mineral nutrition. Ice formation in the intercellular spaces is generally lethal to plant tissues, and is the normal cause of frost damage in plants. Some plants have nevertheless the ability to move into a super cool stage, and this phenomenon explains why some crops, like banana for instance, can support light frosts up to -3° C without major production loss.

Annual crops can relatively easily overcome low temperatures over a short period in the year. Rice production in the Senegal River floodplain for example suffers from the low night temperatures in December-February and requires therefore that the crop calendar is adapted (see Section 5: Case study). A similar situation occurs in tropical highlands (as for instance in Rwanda) where in valleys above 1500 m altitude the night temperatures in May-June drop as low as 5-7° C. Under those conditions the rice panicles are incompletely filled, and harvests are substantially lower. By adapting the crop calendar rice production is nevertheless very successful in these regions, whereby yields up to 2.5-3 tons/ha can be obtained under farmers' conditions.

Some crops on the other hand need explicitly low temperatures to stimulate growth. This is the case for winter wheat which requires a cool vernalization period to stimulate germination and early vegetative development. It explains also why wheat cannot be grown in the tropics unless in high-altitude or desert areas with cool nights.

The problem is more difficult for perennials, though even then an adapted management can technically overcome short-term low temperatures. Because of the extra costs involved these techniques are only implemented for high-value crops. Moreover, protection against frost (or otherwise low temperatures) is normally only profitable when frost in the growing season is not frequent, as is the case for example, of winter frosts in Mediterranean climates or spring and autumn frosts in more temperate regions. In some vineyards in Germany, Luxemburg, and the Vosges and Savoie regions in France light frost damage in spring is overcome by installing a temporary sprinkler irrigation system, or a smoke curtain in the fields. Likewise ground sprinkling is employed in deciduous fruit and nut orchards in northern California.

3.1.3. High Temperature

Excessive maximum temperatures are rarely reported in crop production. Often, these are associated with other factors such as radiation and crop-evaporative demands.

Maize, some types of beans and tomatoes are typical examples of crops that are sensitive to temperatures above 35° C; sorghum on the other hand is well adapted to those conditions and stands temperatures above 40° C without apparent harm. The problem of maize is that it suffers from excessive evapo-transpiration, while in the case of tomatoes the flowers are dropped and fruits malformed. The sensitivity of beans is, nevertheless, only limited to a specific period in the growth cycle. The most direct management solution in these cases is either to adapt the crop calendar (annual crops), to introduce a cover crop which creates more shadow and a cooler microclimate, or to change to alternative and better adapted crops.

3.2. Managing Rainfall Constraints

Rainfall is, together with temperature, the major climatic component in crop production, and the primary source for plant moisture supply. Problems related to an inadequate rainfall refer either to a shortage or to an excess of rain. Rainfall characteristics in combination with temperature criteria determine the distribution of the major crops over the world (Fig. 1).

The rainfall regime in terms of precipitation amount and distribution over the year affects in the first place the length of the growing period - that is the period in the year that crop growth is not hampered by moisture (and temperature) limitations - and, in this respect, it has a direct impact on the nature of the crops grown and on the quantity and quality of the yield. This growing period can directly be derived from a water balance model involving rainfall (moisture input), crop-evaporative demands (moisture output) and soil water holding capacity (water storage) as described in more detail in *The FAO Guidelines for Land Evaluation.*

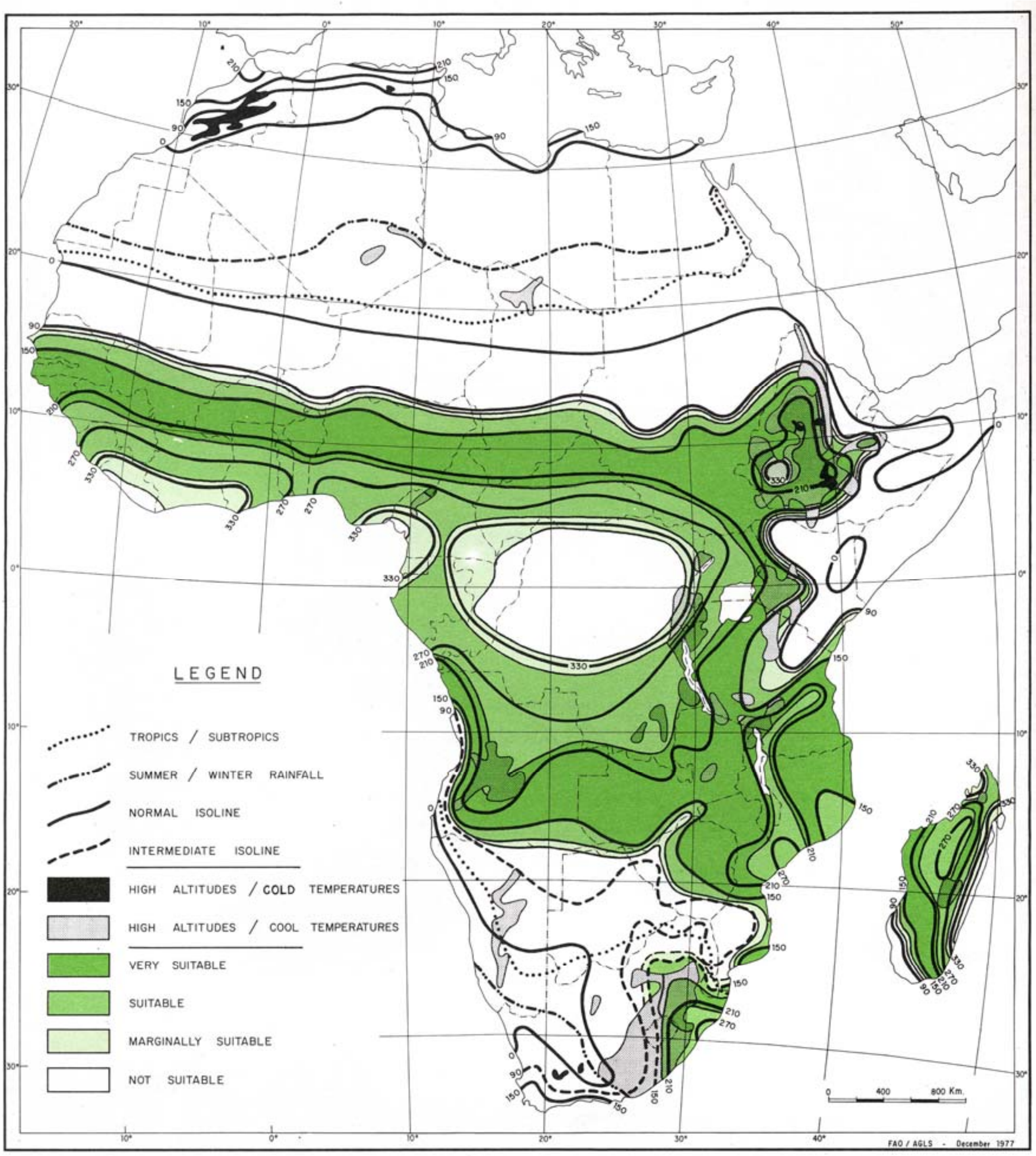

Figure 1: Aerial extension of major production zones for maize in Africa south of the Sahara (FAO, 1978)

The nature of the growing period indicates to what degree rainfall is satisfactory for physiological plant growth. Three situations can hereby be differentiated:

- rainfall amount and distribution are equal or overpass the time of the growing period: the crop can satisfactorily be cultivated;
- rainfall amount and distribution are smaller than the time needed for normal plant growth : either an additional irrigation is required to extend the growth cycle, or crop yields are lower, or the crop can no more be satisfactorily grown and has to be replaced by a crop with less exacting water requirements;
- rainfall distribution is irregular, showing intermediate dry spells: different

management options remain open depending on: the length of the dry spells, the importance of the water deficit, and the nature of water source available.

Though in general it is the overall moisture supply that governs crop development, many crops are particularly sensitive during some critical periods in their growth cycle. Table 1 shows that flowering and, to a lesser extent heading, is often the most sensitive period.

Crop	**Most critical periods for water deficit**
Barley	Shooting and earing
Cabbage	Head formation
Cauliflower/ Broccoli	All stages (curd production)
Cotton	Flowering and boll development
Maize (corn)	Flowering and early grain formation
Oats	Heading and flowering
Onions	Flowering (seed production)
Peanuts	Flowering and seed development
Peas	Flowering and pod filling
Potato	Tuber initiation through maturity
Rice	Heading and flowering
Rye	Flowering and early grain formation
Sorghum	Booting (end of shooting stage prior to emerge of head) and heading
Soybeans/Other beans	Flowering and pod set
Sunflower	Heading and grain filling
Wheat	Shooting and earing

Table 1: Critical growth periods for water deficits in selected crops (from Salter and Goode, 1967, in: T.A. Howell, 1990)

3.2.1. Rainfall Shortage

The most sophisticated, though not always feasible way to compensate for a shortage of rain, is **cloud seeding**. This modern technique has been applied with variable success in the US and in the former USSR, especially in mountainous areas. The alternative and more plausible management option is to look for water from another source. Three alternatives can hereby be taken into consideration:

- use of groundwater either through natural capillary rise or pumped from shallow wells;
- water harvesting, i.e. the collection of runoff water;
- large-scale irrigation.

Use of the groundwater table - In areas where there is a water table at shallow depth, two relatively cheap options are open. The first is to bring an additional amount of water in the root zone by direct capillary rise from the groundwater table. This capillary action depends on a wide range of factors including the depth of the water table, soil texture, ambient air temperature, and humidity. In general, the amount of capillary moisture that can be supplied to the root zone is in the order of 1-2 mm/day provided that the water table is between 0.60 and 1.20 m depth. Capillary rise can normally be assumed to be zero when the water table is more than about 1 m below the bottom of the root zone.

Additional supply of capillary water is only useful and feasible under conditions where the soil moisture stress is small and temporary. This system is successfully applied in oil palm plantations in Guinea, where it allows for very high production levels (more than 20 tons fresh fruit bunches per ha) despite a 200 mm rainfall deficit in the region.

Photo 1: Collection of runoff water to allow for the creation of a small shaded resting place along a road crossing the Negev desert

The second option is to pump water from shallow wells. Many inland villages in West Africa rely for their drinking water supply on hand-dug wells in the laterite crust, going as deep as 20 m below the surface. As the compact gravel layers and thick laterite crust in this area is often a good conduct of infiltrated rain water, it provides a relatively safe drinking water for most of the season. In Iran hand-made wells up to 20 m deep - known as *quanats* - follow the underground aquifer and form geometric lines in the landscape. The quanat system tapping water from the surrounding mountains and leading it by gravity to irrigated small village plots, is still used in Iran in much the same way as it was 2,500 years ago. Likewise is in the Ganges valley of Bihar, India, rice irrigation in the dry season largely achieved by means of water pumped from shallow wells, hardly 5 to 10 m deep.

Water harvesting from runoff - In areas where precipitation is irregular and there is no shallow groundwater table, part of the seasonal rainfall can be “harvested” downhill through the construction of a small earthen dam at the outlet of small collection areas. Water is then "harvested" by collecting surface runoff and, hence, allows for the growth of species which otherwise would never be possible (Photo 1). This can be considered as a rudimentary form of irrigation, with the difference that the farmer or agro-pastoralist has no control over timing, because runoff can only be harvested when it rains.

Water harvesting is almost as old as humanity. Evenari and co-workers (1971) have described water harvesting techniques in the Negev Desert dating back to pre-Nabatean times, and involving the clearing of hillsides from vegetation to increase runoff, which was subsequently directed to field plots in the plains. Likewise has water harvesting been practiced by native Indians in Arizona and New Mexico more than 1000 years ago. In Sub-Saharan Africa however there is no tradition in water harvesting, and projects set up to harvest local runoff and improve crop production were never a success.

Finkel (1986) and Chritchley and Siegert (1991) have described in detail a variety of water harvesting systems including (Figures 2 and 3):

- *Triangular, diamond or V-shaped micro-catchments* (also known as *negarim*, from the Hebrew word *neger* which means runoff), being small basins surrounded by earth bunds, and with an infiltration pit in their lowest corner. Runoff is collected from within the basin and stored in the infiltration pit wherein a small tree is planted. The size of the catchments is in the order of 10 to 100 m². They are currently found in Israel, India and Tunisia.
- *Semi-circular and trapezoidal micro-catchments* constitute an alternative form to the type described above. They are equally earth embankments in various shapes with the tips of the bunds on the contour line. The semi-circular hoops have a radius from 4 to 12 or maximum 20 m and are mainly used for the improving grazing areas or for fodder production. *Trapezoidal bunds* are similar in the principle but allow to enclose larger areas and to impound larger amounts of water. They consist of trapezoidal-shaped bunds with the tips lying on the contour line. The bund may enclose an area of 0.25 to 2 ha, and the size depends upon the catchments/cultivated area ratio which also defines the distance between the bunds. They are used for planting either field crops or trees.
- *Contour bunding for trees* constitute a simplified form of micro-catchments. As the name indicates, the bunds follow the contour at close spacing and, by provision of small earth ties, the system is divided into individual micro-catchments of approximately 25 m² per tree. This system is more economical than the *negarim*, particularly for large-scale implementation on even land since less earth has to be removed. A second advantage of the contour bunds is their suitability to the cultivation of crops or fodder between the bunds.

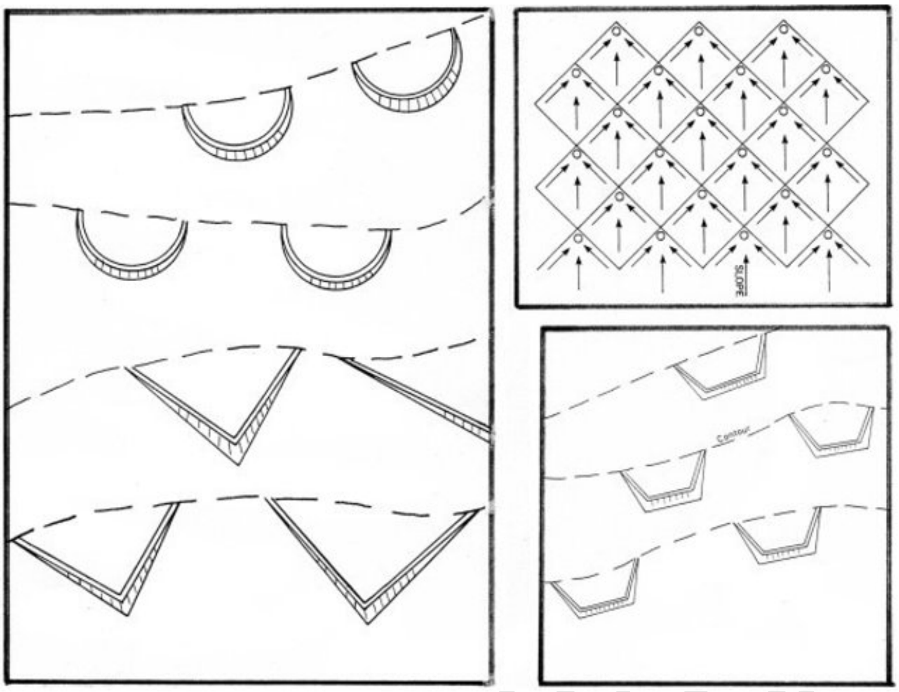

Figure 2: Outline of different types of micro-catchments: semi-circular, triangular (left) trapezoidal (right under) and diamond-shaped (right upper) micro-catchments; (Finkel, 1986; Critchley and Siegert, 1991)

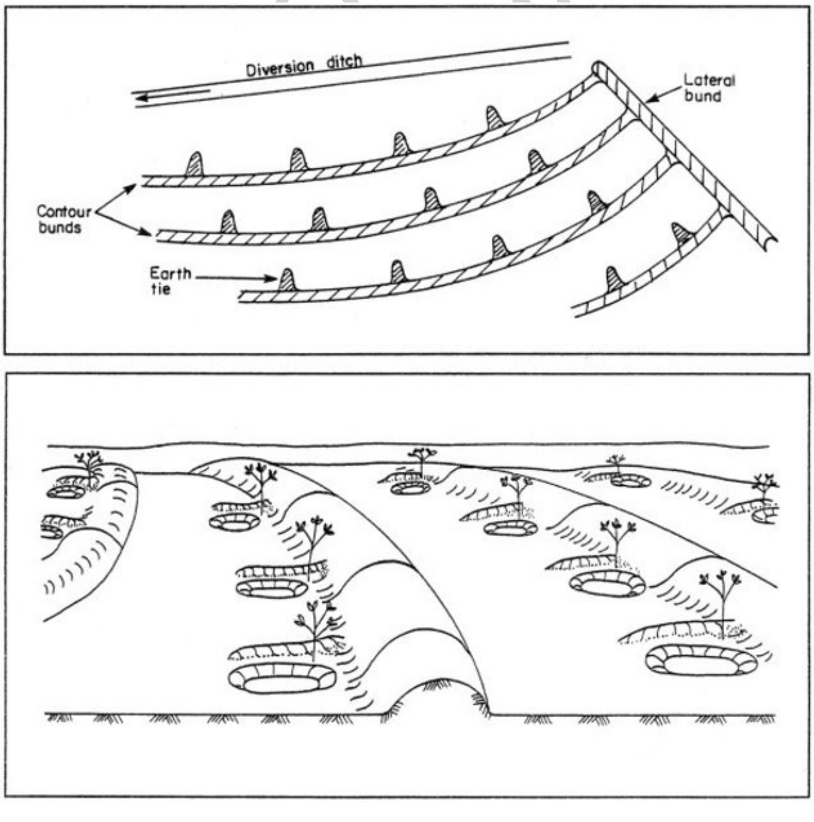

Figure 3: Contour bunds. Above: view from the top; Below: side view (Critchley and Siegert, 1991)

- *Micro-watershed management*. This system is based on the collection of runoff water behind an earthen dam at the outlet of a small valley. Though watersheds may vary in size from more than 10,000 ha to less than 100 ha, the system is best known for its successful application by the World Bank in micro-catchments in southern India. In small valleys of 70 to 200 ha the runoff is controlled and the water is collected at a dam constructed and maintained by local manpower. The system is also frequently used in small NGO-sponsored rural development projects.

The stored water at the outlet at the end of the rainy season is often not enough to irrigate large fields, but allows to overcome temporary dry spells in the growth cycle, and eventually to extend the growing period by one or two weeks.

Large-scale irrigation - Large-scale irrigation projects are an ultimate solution which can only be considered if a major water source is available, either from a dam or from deep (semi) artesian wells. These projects involve a major financial basis which is beyond the potential of local communities, and require a complete irrigation system and complex field lay-out. The technical aspects of irrigation are discussed in more detail in sections 4.1 and 6 below.

3.2.2. Excess Rainfall

Water logging and flooding occur when too much rain concentrates in a too short period. Excess rainfall is often a seasonal phenomenon, for example along the West African Coast where precipitation in the Conakry area may attend more than 1000 mm/month in July and August while the region remains almost dry between October and May. Overall, intensive rainfall creates erosion on sloping areas, flooding of lowlands, and water logging in the valleys and lower parts of the landscape. Except wetland rice very few crops can stand such poor drainage conditions.

High-intensity rainfall and kinetic raindrop energy have a direct impact on the growth and production of plants with sensitive flowers or leaf branches. High rainfall is also a problem for tapping the latex in rubber plantations. Therefore, areas with monthly rainfall over 500 mm are generally not recommended for rubber because too many tapping days are lost.

One of the major side effects of excessive rainfall is the development of a **groundwater table.** This situation occurs when excess rainfall infiltrates the soil and reaches an impermeable layer. Under natural conditions the water table fluctuates over the year as a function of the height of the precipitation and plant water consumptive use. High water levels exert an influence on production, depending on the crop development phase. Some plants (like rubber) do not tolerate water logging at all, while others (oil palm or sorghum for instance) can stand it for a short period (2-3 weeks at maximum). Annual crops are most sensitive during germination and in the reproductive phase. In the dormant phase, many plants (e.g. deciduous trees or meadow grasses) are usually not adversely affected by high water tables.

Managing the depth of the water table is a primary agricultural activity because it maintains a good equilibrium between aeration and soil moisture supply in the root zone independent from the rainfall regime and, hence, determines the availability of moisture, oxygen and soluble nutrients to the crop. Table 2 gives an overview of the optimal groundwater depth for a number of selected crops. It illustrates that for alfalfa for example the best conditions are met with a water table at 40-50 cm or deeper, but that yields are rapidly declining when the water table is shallower. The optimal situation for maize (corn) is attended when the groundwater is at 75 cm or more. Peas, potatoes and sugar beets are relatively sensitive to high ground water levels.

Crop	**Water table depth**								
	15-20	**30**	**40-50**	**60**	**75**	**80-90**	**100**	**120**	**150**
Alfalfa	37	63	100	100				92	
Barley			58	80	89	95			100
Beans			79	84	100	100		94	100
Cabbage	6	85	84	89	89	100		94	100
Corn		41	82	85	100	100	100		
Fescue grass	100	100	87						
Grain sorghum	73	86	93	100	93	100			
Lettuce			97	100		99			
Millet	41	69	80	87	98	100	93		
Pea			50	90		100		100	100
Potato	14	65	96	100		95	92		96
Soybean			87	100		100	85		
Sugar beet	9	28	47	92		100	99	100	100
Wheat				91		100			100

Table 2: Relative yield (%) of a number of selected crops at varying groundwater depths (Evans and Fausey, 1999)

In The Netherlands, where extensive areas are located below sea-level and soil drainage is necessary, the water table is used as a supplementary source for crop moisture supply through capillary water uptake. The highest grassland yields are obtained when the groundwater was kept at 60-80 cm depth for fine-textured soils, and at 40-60 cm depth for sandy soils. Leguminous crops like clovers and pulses prefer water levels at about 50 cm. Shallow-rooting vegetables behave best with water tables at 30-50 cm. when crops benefit from capillary moisture while not being affected by a poor drainage.

Technical aspects of soil drainage are discussed in more detail in section 4.2 below.

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Biographical Sketch

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He has been active for more than thirty-five years, both in the academic world, as a professor/ research director in soil science, land evaluation, and land use planning, and as a technical and scientific advisor for rural development projects, especially in developing countries. His research has mainly focused on the field characterization of soils and soil potentials and on the integration of socio-economic and environmental aspects in rural land use planning. He was a technical and scientific advisor in more than 100 development projects for international (UNDP, FAO, World Bank, African and Asian Development Banks, etc.) and national agencies, as well as for development companies and NGOs active in inter-tropical regions.