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2.3 Water demand in agriculture

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SUMMARY: *World-wide, agriculture is the economic sector which has the highest demand for water, which is about 70% of total water withdrawals. This amount varies from region to region. An especially high demand exists in the arid and semi-arid climates where irrigated agriculture dominates. In these regions the water requirement for irrigation rises up to 85% and more. Today 40% of all foods world-wide are already produced by irrigated agriculture. Growing population and climate change will increase the need for water. For this reason efficient irrigation systems, regional adapted agricultural practices as well as water conserving cultivation methods will be necessary to produce sufficient food also in future.*

Water is a valuable good that becomes increasingly scarce because of the continually growing world population, the increasing demand for food, and individual needs. The daily water demand in private households ranges between 10 l (countries with water deficiencies) and up to 400 l (developed countries, USA ca. 380 l, Germany ca. 130 l) *per capita*. According to the animal breed and the climate conditions, daily water requirement of animals range between 20–50 l water. For the production of 1 kg bread about 1,000 l water is necessary (precipitation or irrigation water), which requires approx. 2 kg wheat (above ground biomass, see *Table 2.3-2*). Thus, about 260,000 l water per year is necessary to nourish one person with vegetarian food (2,500 kcal per day). In order to produce 1 kg of meat more than fivefold of this water amount is needed, because livestock transforms only 10% of its vegetable food into meat.

Water demand in agriculture

For plant production the availability of water is of great economic interest. On the global scale agriculture account for 70% of the world's total freshwater withdrawals (UNEP 2002). Compared to this, the industrial (20% of global freshwater withdrawals) and the domestic water uses (10% of global freshwater withdrawals) are relatively low.

Almost 40% of the world food production comes from irrigated agriculture, i.e. about 20% of the global cropping area is irrigated. However, there are distinct regional differences which depend on the climate conditions and the industrialisation level of the country.

In the arid and semi-arid regions of the earth, commercial agriculture is only effective with irrigation systems. Accordingly, irrigated agriculture dominates these regions. The irrigation water is taken from reservoirs, wells (groundwater) and from rivers and lakes. Desalination of sea water is also possible, but is very energy-consuming and thus only practicable in few wealthy countries, like the Arabian Emirates. In tropical and subtropical climates with pronounced rainy seasons and dry periods in alternation, the agricultural calendar has to be adapted to these natural conditions. With increasing distance from the equator, the rainy season in the tropics becomes shorter and the annual amount of rainfall decreases. For some crops rain-fed farming is still possible, however in the dry season irrigation is an important measure for crop production. Therefore, in some Asian and African countries water use of agriculture is more than 80% of total water withdrawals. In contrast, the industrial water withdrawals are comparatively low here (about 10%).

In mid latitudes precipitation is usually well distributed throughout the year so that irrigation mainly leads to an average increase of crop yields or to a reduction of the annual yield variability. This is of relatively high interest in regions with light (sandy) soils and frequent drought periods in late spring or summer. Here, irrigated crops are mostly potatoes, quality wheat, brewer's barley, sugar beets, maize, as well as vegetable (asparagus, cucumber, etc.). A positive side effect of irrigation is the improved yield quality. For instance it can increase the starch content in food potatoes or reduce the protein content in brewer's barley. Irrigation mainly improves yield stability in agricultural enterprises. In Europe, agriculture uses about 35% of total water withdrawals for irrigation.

Table 2.3-1: Irrigated land areas in Germany 2002 (BUNDESFACHVERBAND FELDBEREGNUNG).

Land	*Irrigated area 2002 in ha*
Bavaria	*35,000*
Baden-Wuerttemberg	*20,000*
Berlin	*200*
Brandenburg	*25,500*
Hessen	*45,000*
Mecklenburg-Vorpommern	*15,000*
Niedersachsen	*235,000*
Nordrhein-Westfalen	*35,000*
Rhineland-Palatinate	*35,000*
Saarland	*150*
Sachsen	*15,000*
Sachsen-Anhalt	*25,500*
Schleswig-Holstein	*5,500*
Thueringen	*15,000*
Germany	***507,000***

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Table 2.3-1 gives a survey of the irrigated land in Germany in 2002. In this country, only 3 % of the whole cropland area (17 Mio. ha) is irrigated. This is only 4 % of the total water withdrawals which is used by agriculture. In contrast, the industrial sector in Germany uses 23%, the power stations 64%, and the private households 9% of the total water withdrawals (see *Chart 2*).

The average costs for irrigation in Germany are about 250–300 Euros per hectare. In extremely dry and warm years, as in 2003, irrigation-costs can rise up to 500 Euros and more per hectare. During this year some regions experienced a water deficit of more than 450 mm, so that continuous irrigation was necessary between April and September.

The availability of water for growth and plant development not only depends on the annual amount and distribution of precipitation, but also on the physical soil properties to store water, the climatic conditions which influence the evapotranspiration of crop stand, and finally on the water demand of the crop itself.

There is a strong relationship between biomass production and water consumption of plants. In the case of water shortage transpiration of plants is limited and thus the biomass production is reduced. This results in crop losses. The relationship between water consumption and biomass production can be described by the transpiration coefficient (Litre H_2O/kg dry matter) or the water use efficiency (kg dry matter /Litre H_2O).

Between individual crops large differences in water consumption exist (*Table 2.3-2*), because of the varying growing periods and the specific water demand of the crops themselves. For example, winter cereals which have some developmental stages in periods with lower temperatures (autumn, spring), generally have lower water consumption than the corresponding spring cereals. Leaf crops such as potatoes and sugar beets have usually a higher water demand, because of the significant longer growing time. Forage plants such as red clover, alfalfa with a long growing time and grassland have the highest water consumption.

For this reason an important control measure in horticulture and crop growing is the soil moisture which can be described by the water balance equation:

Table 2.3-2: Transpiration coefficients for different crops (GEISLER 1988).

Transpiration coefficient (Litre H_20/kg dry matter)	***Crop***
200 – 300	millet
300 – 400	maize, sugar beets
400 – 500	barley, rye, durum wheat
500 – 600	potato, sunflowers, soft wheat, cabbage, buckwheat
600 – 700	rape, peas, beans, oats, cucumber, red clover
> 700	alfalfa, soy, flax, pumpkin, swede

$$DS = P - I - E - T - R_O - V_P \text{ [mm]}$$

Changes in the soil water content (DS) mainly depend on precipitation (P). They are also influenced by interception losses (I), the evaporation of soil (E), the transpiration of plants (T), the surface runoff (R_O), and the percolation of water out of the rooting zone (V_P). In Germany, relatively large differences in the spatial distribution of rainfall exist. For example, in major parts of north-east Germany, mean annual precipitation is below 600 mm.

Optimal values of soil moisture range between 60 and 80 Vol.% of available field capacity (aFC). Moisture values below 30–40 Vol.% aFC lead to distinct growth depressions and crop failures. This was observed at several sites in Germany during 2003 (*Fig. 2.3-1*). On the other hand, long periods with soil moisture values above 80% aFC can also have negative effects, because of insufficient air in the soil. Steering of soil moisture by irrigation should always consider the plant specific optimal range. For this also the developmental stage of the plant should also be considered, because of the changing water requirements during the different growing periods of plants. Water stress for spring cereals in May and June, for potatoes between June and August, and for sugar beet from July to September can lead to distinct crop failures (CHMIELEWSKI & KÖHN 1999). At soil water conditions between 40–50 Vol.% aFC, 1 mm additional irrigation water can lead to an extra yield of 0.14 dt/ha; for beets and potatoes of 1.2 dt/ha in north-western Germany (RENGER & STREBEL 1982). In Brandenburg optimal irrigation led to an extra yield of potatoes of 1.6 dt/(mm×ha) on the long-term average (1996–2002, DITTMANN 2003).

Irritation techniques

Water for irrigation can be used from lakes, rivers, as well as from stored precipitation water and groundwater resources.

Use of surface water

In arid and semi-arid regions, at all times irrigation is the basic for crop and stock farming. For this all technical measures are helpful which supply sufficient water for crop production in dry periods. In regions with short seasonal rainfall the floodwater can be stored in basins along so-called arroyos, in which the water remains for several weeks, so that the soil is well soaked. After the floodwater is percolated sowing can start. This is a very ancient type of flood irrigation and was practised already 1,000 years B.C. in southern Israel (Negev desert). For this kind of irrigation, the danger of soil salinisation is low. Besides, the flooding leads to an enrichment of fertile mud which increases the yield capacity of the soil.

The use of cisterns or reservoirs is another way to store precipitation water. With this type of irrigation water can be stored for several weeks or months. Natural sources for irrigation are lakes, ponds, and rivers; as long as they do not dried up. It is much more extensive to change the course of rivers or to build dams for irrigation purposes. The latter requires the construction of pipelines and the transport of irrigation water to the agricultural regions.

Groundwater use

In regions with sufficient winter precipitation the groundwater is usually renewed in spring, so that during summer the groundwater can be used for irrigation. Problems mainly occur in some arid and semi-arid regions, were the rainy season is highly variable and the annual amount of rainfall is relatively low. It frequently occurs in these regions that more water is taken from wells than is renewed during the rainy season.

Groundwater for irrigation is usually taken from wells (draw wells or drilled wells). It is transported to the surface by scoops or electronic pumps. Then the water has to be distributed by widely ramified canals into the irrigation areas. This techniques leads to remarkable water losses by transpiration or leaching, if the irrigation canals are not lined with clay, stonework, concrete and foils, or if they are not consist of pipes or rainproof flutings.

Well known kinds of field irrigation are flood irrigation, furrow irrigation, sprinkler irrigation, and droplet (drip) irrigation. The kind of irrigation partially depends on the surface (slope of the field), the soil properties, and the crop. Sprinkler, ground, and droplet irrigation are much more efficient and water saving than flood irrigation and furrow irrigation.

Inappropriate irrigation methods in dry climates frequently lead to a overstraining or salinisation of the usually fertile soils in these regions. The uncontrolled extraction of groundwater can lead to ebbing wells. In this case, a declining ground-water table not only affects the regional agriculture but also the natural vegetation. As a result the last trees and bushes die and desertification proceeds. Over and above this, salinisation is an acute problem in arid regions. The principle ”no irrigation without sufficient drainage” is often disregarded. All soils contain salt. Salinisation can be caused by excess water from irrigation which raises the water table, and brings salt to the surface. When the concentration of salts in soil reaches 0.5–1.0%, land becomes toxic to plants. Even before that water reaches the surface, it starts affecting crop yields. The results are remarkable crop yield losses. Irrigation-salinisation can be reduced by using less water on crops, by sufficient drainage, or by growing crops which require less irrigation.

Droplet irrigation is one of the most effective and economic irrigation methods and has advantages even in arid regions. With this type of irrigation salinisation of soils hardly occurs. Since the leaves are not wetted, the risk of fungal infection is reduced by this irrigation method. The main problem is that for these irrigation systems the investment costs are relatively high. For this reason these techniques today are mainly used in developed countries. But in the future these water conserving irrigation systems should be applied in more and more countries world-wide.

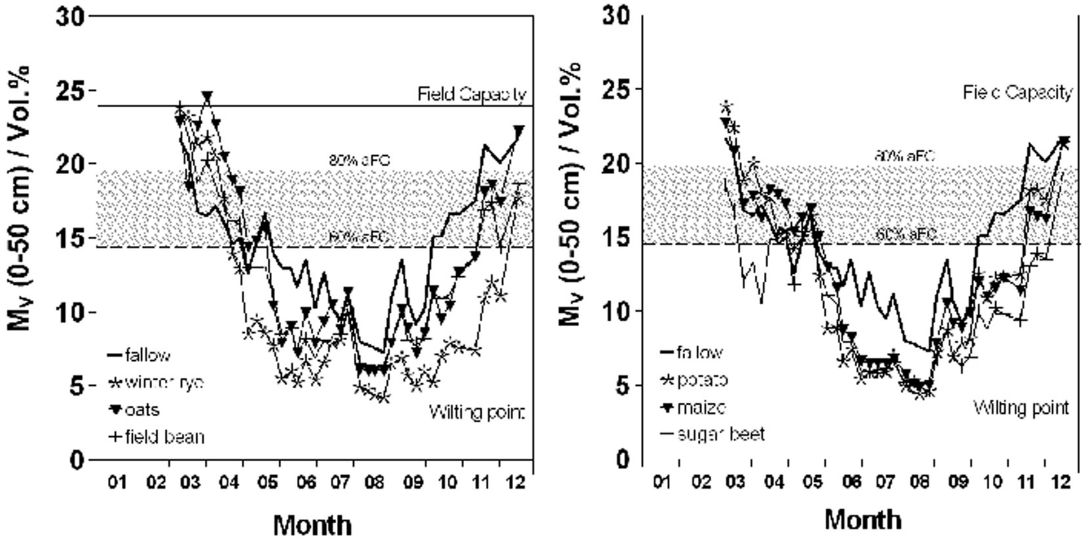

Fig. 2.3-1: Development of soil moisture for different crops and fallow during the year 2003 (Data: Agrometeorological field experiment, Berlin-Dahlem, Germany), M_V: Soil moisture in Vol.%, aFC: available field capacity.

Climate change and water demand

Effects of climate change on agriculture depend on several factors. Positive effects, for example the CO_2-fertilisation, will be only beneficial for crop production if the further climate change (e.g. increase of temperature, availability of soil water) do not lead to additional stress for the plants. In this case, positive effects of a higher atmospheric CO_2-content will be compensated or overcompensated.

Global warming will intensify the water cycle and will probably lead to more precipitation on global average (IPCC 2001a). An intensification of the hydrological cycle also means increased evaporation rates. Therefore, the surplus of rainfall will probably be compensated. If the intensity of rainfall events rises the rates of surface runoff will increase likewise. Higher evaporation and increased runoff will finally not increase the soil moisture which is the most important measure for growth and yield formation of field crops. Over and above this the seasonal rainfall distribution is very important for crop production.

Climate change will probably lead to a shift of growing zones and to an extension of arid and drought-prone areas, as e.g. the Sahel zone. Already today, declining precipitation and increasing temperatures can be observed (*Fig. 2.3-2*). In regions with monsoonal precipitation, the timing, duration, and intensity of the rainy season may also shift.

Climate change scenario results point to an increased population which will be threatened by water scarcity. The arid and semi-arid regions on the Earth where the water is already today strongly limited are particularly vulnerable. Model projections show that it is very likely that in 2050 an additional number of ca. 1,000–2,000 Mio. people will suffer from water scarcity (IPCC 2001b). A rise in mean global air temperature of more than 2 °C could be critical. In this case the developing countries in Asia will be strongly affected due to climate change, so that the amount of people which suffer from water scarcity could increase rapidly (Parry et al. 2001).

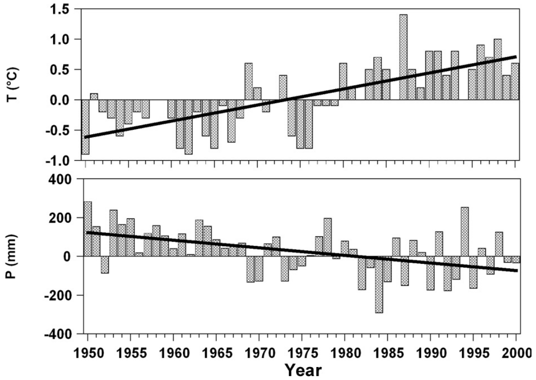

Fig. 2.3-2: Mean annual air temperature (T) and precipitation (P) at San (Mali), 1950–2000. The graph presents anomalies of the period 1961–1990 with linear trends for T: +0.26 K/decade, ($p<0.01$), and P: -39 mm/decade ($p<0.01$).

Conclusions

Beside climate change, the population growth is an additional factor which increases water demand. To feed the increasing population the crop yields have to rise (ca. 70%), arable land must be extended (ca. 20%), and the annual number of harvests has to increase (ca. 10%, FAO 2001). One way to reach these aims is the extension of irrigated agriculture. As water in the future becomes increasingly limited, agriculture has to find additional solutions to use and conserve the available soil water efficiently.

At any rate, crop rotation should be adequate to the regional climatic conditions. Especially the water requirements of individual crops should be considered. Water consumption can also be controlled by sowing rate and thus by crop density. In order to improve the growing conditions for possible follower crops, growing of intermediate crops is not recommended at dry sites.

Direct drilling or conservation tillage methods (shallow ploughing) which hardly destroy the soil surface are additional methods to save soil water, mainly on light soils (Ellmer et al. 2001). In the case of shallow ploughing more soil water remains in the topsoil so that irrigation can be partially reduced.

Rainfed farming (dry land farming) is an alternative to irrigated agriculture in semi-arid regions. It uses all measures which optimise the water use. These methods include practices such as mulching, loosing the topsoil, sowing of mixed cultures, etc. As already mentioned above, cropping of drought resistant crops (millet, sorghum) can also save water resources.

Compared to conventional methods of sprinkler irrigation, droplet irrigation - which is increasingly used in fruit and vegetable growing - also helps to save water. On the one hand, water is directly applied to the plants so that evaporation losses are reduced. On the other hand, irrigation water can be saved if the amount of water is strongly orientated on the demand of plants, considering the available soil water and the developmental stage of the plant. In developing countries comprehensive investments and advanced training is necessary to use this kind of irrigation. The water demand in agriculture can be further optimised by efficient technologies of irrigation, as well as by site adapted and water saving management. Hereby, agriculture can help to save water on the global scale♦