Effects of climate change on crop production in the Rhine basin

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ABSTRACT

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Effects of climate change induced by greenhouse gases on crop production and water use in the basin of the river Rhine and on land use and cropping calendar have been studied. Yield levels have been calculated with the crop growth simulation model WOFOST for winter wheat, grass and silage maize, both for current and future climate conditions. Climate change due to doubled atmospheric CO_2 concentration was found to have a positive impact on crop yields, which may increase by 30 to 50 percent, and a negative one on crop. Sensitivity of crop yields to changes in weather variables was determined.

Keywords: crop production, crop growth simulation model, climate change, greenhouse effect, Rhine basin

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PREFACE

In this report prepared by the DLO-The Winand Staring Centre in Wageningen at the request of Rijkswaterstaat RIZA (Institute for inland water management and waste water treatment) in Lelystad, results are presented from an analysis of the effects of climate change on land use, crop production and water use in the Rhine basin. An extensive study on the effects of climate change on the discharge of the Rhine was initiated by the international Committee for the Hydrology of the Rhine basin (CHR). The Dutch contribution to this CHR study also forms part of the Dutch national research program on Global air pollution and Climate change (NOP). Within this framework Rijkswaterstaat RIZA initiated a project "Development of scenarios for changing land use in the Rhine basin due to climate change" of which this study can be considered as the preliminary phase.

For the present study, the effects on land use are mainly derived from literature. The other effects are quantified by way of a crop growth simulation model. This model is an elaboration of a model developed by the Centre for World Food Studies for calculating agricultural production potentials on the basis of physiological, physical and agronomic information. It can be used to simulate crop growth and components of the soil water balance for specified soil and climate conditions. This is done both for current climate conditions in the Rhine basin and for possible future climate conditions. In this way the effects of climate change on crop production and water use in the Rhine basin are derived.

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SUMMARY

Possible changes in climate conditions due to increasing concentrations of greenhouse gases in the atmosphere will result in changes in use of agricultural land, crop production and water use. In this way and also directly through changes in precipitation and potential evapo-transpiration, climate change may affect the hydrological cycle in the Rhine basin and may cause changes in the discharge pattern of the river Rhine.

For better understanding of the effects of climate change on the discharge of the Rhine, the international Committee for the Hydrology of the Rhine basin initiated a project on this topic. The main part of this project is the development of a hydrological model for the Rhine basin. This model will be used to estimate the effects of various scenarios for climate change and future land use on the annual pattern of Rhine discharge. Rijkswaterstaat RIZA has taken responsibility, among other topics, for the development of scenarios for changing land use in the Rhine basin due to climate change and has boarded out the preliminary phase of this project with the DLO-The Winand Staring Centre. In this and subsequent phases of this project the effects of climate change on land use, crop production and water use are analyzed and the results may be used for the development of land use scenarios and the hydrological model for the Rhine basin.

For the Rhine basin information on the present land use and on the possible land use in future on the basis of a climate scenario has been collected from literature. As land use does not depend only on climate but also on many other factors, it is hard to establish to what extent differences in land use are due to differences in climate alone. Probably the following changes in land use due to climate change are to be expected for the Rhine basin:
- increase in area of permanent crops, particularly in use for vineyards;
- decrease in area of permanent grassland;
- decrease in areas cultivated with root crops, oats, rye, rape and turnip rape;
- increase in areas cultivated with grain maize, sunflower and soyabean.

In addition, the start of crop growth is derived to be about three weeks earlier, if future temperatures in spring increase by 3 °C.

Effects of climate change on crop production and water use have been calculated with a crop growth simulation model. First, calculations have been carried out for historical weather data. In a next step, the model has been adapted to situations with increased atmospheric CO_2 concentrations on the basis of information from literature and the calculations have been repeated for "future" weather data. These data have been derived from historical weather data on the basis of a climate scenario and a sensitivity analysis (i.e. separate change of weather parameters to various extents).

Climate change due to doubled atmospheric CO_2 concentration as defined in the climate scenario, was found to influence crop production in the Rhine basin mainly in a positive way. Average grain production of winterwheat in the Rhine basin increased by 2900 kg/ha dry matter (+ 35%) and average production of permanent grassland by 8600 kg/ha dry matter (+53%). Only for silage maize a decrease in total production was calculated.

Because at rising temperatures maize varieties with a relatively longer growth period and a higher production will be grown, this decrease will not occur in reality.

This climate change also influences the evapo-transpiration, which during the growth periods of winterwheat, silage maize and permanent grassland in the Rhine basin was calculated to change by -6 cm, -7 cm and +1 cm, respectively. The decrease in evapo-transpiration for winterwheat and silage maize was caused mainly by the decrease in transpiration at doubled atmospheric CO_2 concentration and by the shortened period of crop growth. For permanent grassland the decrease in transpiration at doubled CO_2 concentration was about compensated by the longer period of grass growth at the higher temperatures in future.

From a sensitivity analysis it was derived that grain production of winterwheat mainly increases due to increasing atmospheric CO_2 concentration and decreases due to increasing temperature and windspeed, that total production of silage maize mainly increases due to increasing atmospheric CO_2 concentration and solar radiation and decreases due to increasing temperature and windspeed, and that production of permanent grassland mainly increases due to increasing atmospheric CO_2 concentration, temperature, rainfall and vapour pressure and decreases due to increasing windspeed.

From the sensitivity analysis it was also derived that evapo-transpiration during the growth period of winterwheat mainly increases at increasing solar radiation and windspeed and decreases at increasing atmospheric CO_2 concentration, temperature and vapour pressure, that evapo-transpiration during the growth period of silage maize mainly increases at increasing solar radiation and windspeed and decreases at increasing atmospheric CO_2 concentration and vapour pressure, and that evapo-transpiration of permanent grassland mainly increases at increasing temperature and windspeed and decreases at increasing vapour pressure.

In this study the effects of climate change on crop production and water use have been calculated with a crop growth simulation model. The calculations have been carried out for a limited number of crops and meteorological stations and for artificially derived soil characteristics. For a more thorough analysis of the effects of climate change on crop production and water use in the Rhine basin, the same simulation model may be used in combination with a geographical information system, containing information on the regional distribution of soil types, land use and climate. For such an analysis information on the characteristics and the regional distribution of the main soil and climate types and crop species should be collected. That could be one of the possible subjects for a subsequent phase of this project.

1 INTRODUCTION

The considerable changes in the climate on this planet that might occur within a limited period of time due to rising concentrations of so-called "greenhouse" gases in the atmosphere, has called worldwide attention. Greenhouse gases are able to absorb the longwave radiation emitted by the earth and thereby influence strongly the temperature regime on the earth. Without the presence of greenhouse gases in the atmosphere, the average temperature on earth would be -18 °C instead of 15 °C. Increasing concentrations of greenhouse gases in the atmosphere, particularly carbon dioxyde (CO_2) due to combustion of fossil fuels, may reduce the heat emission of the earth, by which possibly the average temperature at the earth's surface will rise. This rise in temperature might result in considerable climate changes, in a rapid transfer of climate and vegetation zones and in a rise of the sea-level.

1.1 Effects of climate change on the discharge of the river Rhine

The changes in climate conditions that are to be expected for the Rhine basin due to increasing concentrations of greenhouse gases, are mainly an increase in air temperature, an increasing amount of precipitation in winter and a constant or decreasing amount of precipitation in summer. As higher temperatures may result in less snowfall and an earlier snow melting, it is to be expected that in winter and early spring river discharge will become larger and that high water will occur more frequently and will attain higher levels and that in the summer the discharge will become smaller (CHR, 1989).

Changes in climate conditions may also result in changes in the level of crop production and in the use of agricultural land in the Rhine basin. For example, rising temperatures may result in a higher production, in cultivation of other crops, in advanced periods of crop growth, etc. and thus may affect the degree of soil coverage and hence the amounts of rainfall discharged by surface runoff, may affect the water use by evapotranspiration and hence the amount of water leached to deeper soil layers, etc. In this way climate change will cause changes in the discharge pattern of the river Rhine, too.

1.2 Purposes and backgrounds

Climate change might affect the annual course of discharge of the Rhine and hence might cause problems with respect to supply of drinking water, shipping, etc. in future. A better understanding of the effects of climate change on the hydrological processes is needed to take purposeful actions for minimizing such negative effects. Hence, the international Committee for the Hydrology of the Rhine basin (CHR) initiated in 1989 a project "Effects of climate change on the discharge of the Rhine". The main part of this project is the development of a hydrological model for the Rhine basin. This model will be used to estimate the effects of various scenarios for climate change and future land use on the hydrological characteristics of the Rhine, such as annual patterns of discharge and water level (CHR, 1989).

Rijkswaterstaat RIZA has taken responsibility for the development of the lowland part of the hydrological model and besides, of scenarios for changing land use in the Rhine basin due to climate change. These projects form part of the Dutch national research program on Global air pollution and Climate change (NOP). This study can be considered as the preliminary phase of the development of scenarios for changing land use in the Rhine basin. Land use may have a considerable influence on the hydrological cycle. If due to climate change the cultivated crop species, the period of crop growth, the soil coverage by the canopy, etc. are changed, this may result in changes in surface runoff, evapo-transpiration, leaching, etc. Information on such changes in land use due to climate change can subsequently be entered into the hydrological model for the Rhine basin.

In this study the effects of climate change on crop production and land use in the Rhine basin are analyzed. In short, the following activities are carried out:
- information is collected on the actual land use in the Rhine basin and on the possible change in land use due to climate change;
- crop productions are calculated with a simulation model for historical weather data;
- the crop growth simulation model is adapted to situations with increased atmospheric CO_2 concentration on the basis of information from literature;
- crop productions are calculated with the adapted model for "future" climate conditions;
- effects of climate change on crop production, components of the soil water balance and land use are analyzed.

The calculations are carried out for a limited number of crops and for artificially derived soil characteristics. This gives a first impression of the possible effects of climate change on future land use, production, evapo-transpiration, leaching from the root zone, etc. in the Rhine basin.

2 LAND USE

The use of land for agriculture depends on environmental, on socio-economic and other factors. Environmental factors that set limitations to land use, are mainly the climate, soil, topography and hydrology. For example, low temperatures may prevent maturing of a crop, like grain maize, frost in late spring may damage orchards, drought periods in summer may reduce yields considerably, particularly on shallow or gravelly soils with small amounts of available water. Soils may set limitations to agriculture, for example being too heavy for cultivation of root crops or too gravelly. Landscapes with steep slopes cannot be used for arable cropping, as without permanent coverage erosion finds place at a too high rate. High groundwater levels and unsufficient natural or artificial drainage generally prevents use of land for arable cropping.

Other factors that determine land use, are the size of the consumer market, market regulations of the European Communities and hence, the prices for the various agricultural products, the historical development of agriculture per region, the distance to consumer market and processing industries, the infra- and marketing structure, transport facilities and transport costs, the fodder demand of the animal husbandry sector, and the introduction of new crop species that produce raw material for non-food use (energy, paper, oil, plastic, medicines, etc.).

The examples mentioned above indicate that a possible change in climate can only be just one of the many factors that altogether determine the changes in land use. Also at present climate conditions, land use can already change quite rapidly as shown in Table 1. The areas of permanent grassland and cereals in the Netherlands appear to decrease quite rapidly. Simultaneously, the area of arable land cultivated with silage maize increases strongly over the last 20 years.

Table 1 Change in use of agricultural and arable land (10 000 ha) in the Netherlands (CBS, 1986)

	1930	1950	1970	1987
Agricultural land	**225**	**234**	**213**	**201**
Permanent grassland	**132**	**132**	**133**	**113**
Horticulture	**8**	**9**	**11**	**12**
Arable land	**85**	**93**	**69**	**77**
Cereals	**43**	**48**	**36**	**18**
Root crops	**26**	**30**	**27**	**30**
Silage maize	**0**	**0**	**0**	**20**
Other crops[1]	**16**	**16**	**6**	**9**

[1] Pulses, rape seed, lucerne, etc.

Total area of agricultural land is equal to the sum of the areas used for permanent grassland, for permanent crops (orchards, vineyards) and for arable cropping. The main crop groups grown on arable land are cereals, root crops and green fodder crops.

2.1 Actual land use in the Rhine basin

For the regions that drain to the river Rhine, data on land use are derived from statistics (Eurostat, 1987, 1988). For each region it is also estimated which fraction of the area drains to the Rhine (Table 18). Multiplication of the areas in use for specified types of agriculture per region by the draining fraction of the area results in data on the land use in regions that drain to the Rhine in the Netherlands and Germany (Figure 1) and in France and Luxemburg (Figure 2). Only for Switzerland no data on land use are given, as they were not available.

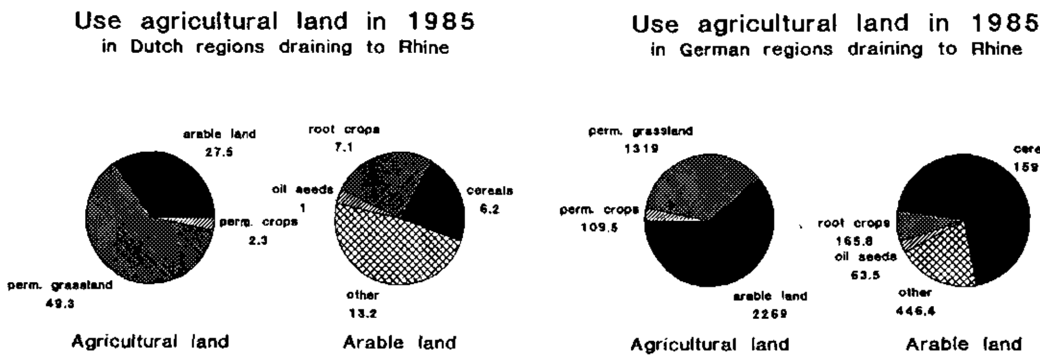

Fig. 1 Land use (1000 ha) in 1985 for agriculture and arable farming in the Dutch and German regions that drain to the river Rhine. Data were derived from Tables 18 and 19 (Source: Eurostat, 1987) and were corrected for the area fraction that drains to the Rhine (Table 18)

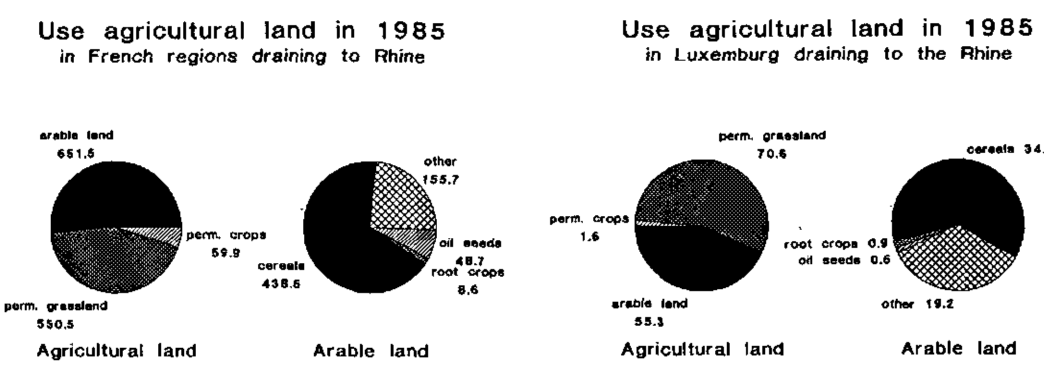

Fig. 2 Land use (1000 ha) in 1985 for agriculture and arable farming in the French regions and in the Grand Duchy of Luxemburg that drain to the river Rhine. Data were derived from Tables 18 and 19 (Source: Eurostat, 1987) and were corrected for the area fraction that drains to the Rhine (Table 18)

In 1985 the relative use of agricultural land in the regions draining to the Rhine was as follows (see Figures 1 and 2) in

Netherlands:	**arable crops**	**35%;**	**permanent crops**	**3%;**	**permanent grassland**	**62%**
Germany:	**„ „**	**61%;**	**„ „**	**3%;**	**„ „**	**36%**
France:	**„ „**	**52%;**	**„ „**	**5%;**	**„ „**	**43%**
Luxemburg:	**„ „**	**43%;**	**„ „**	**1%;**	**„ „**	**56%**

The area of agricultural land in German regions that drain to the Rhine (3698 000 ha) is much larger than that in regions in the Netherlands, France and Luxemburg together (1470 000 ha). As a consequence, the overall use of agricultural land in the Rhine basin corresponds to the land use in the German regions and to less extent to that in the French regions: arable cropping 58%; permanent crops 4%; permanent grassland 38%.

In 1985 the relative use of arable land in the regions draining to the Rhine was as follows (see Figures 1 and 2) in

Netherlands:	**cereals**	**22%;**	**root crops**		**26%;**	**oil seeds**		**4%;**	**other crops**		**48%**
Germany:	**"**	**70%;**	**"**	**"**	**7%;**	**"**	**"**	**3%;**	**"**	**"**	**20%**
France	**"**	**67%;**	**"**	**"**	**1%;**	**"**	**"**	**8%;**	**"**	**"**	**24%**
Luxemburg	**"**	**62%;**	**"**	**"**	**2%;**	**"**	**"**	**1%;**	**"**	**"**	**35%**

The overall use of arable land in the Rhine basin, largely corresponding to the land use in German regions, is: cereals 69%; root crops 6%; oilseed crops 4%; other crops 21%. More information on the areas per region in use for different types of agriculture and for different crops, can be found in Tables 18 and 19.

2.2 Actual land use in five European countries

For the countries of the European communities more elaborate information on the cultivated areas per crop species is given (Eurostat, 1988) but only per country as a whole. Land use per country may be different from that in the regions per country that drain to the Rhine, as these regions include only the eastern part of the Netherlands, the central-western and south-western parts of Germany and the north-eastern part of France. Yet it gives some indications on actual land use and also on the possible effects of a rise in average temperature on land use.

In 1986 the relative use of agricultural land per country as a whole was as follows (see Figures 3, 4 and 5) in

Netherlands:	**arable crops**		**43%;**	**permanent crops**		**2%;**	**permanent grassland**		**55%**
Germany:	**"**	**"**	**60%;**	**"**	**"**	**2%;**	**"**	**"**	**38%**
France:	**"**	**"**	**57%;**	**"**	**"**	**4%;**	**"**	**"**	**39%**
Italy:	**"**	**"**	**52%;**	**"**	**"**	**19%;**	**"**	**"**	**29%**
Greece:	**"**	**"**	**51%;**	**"**	**"**	**18%;**	**"**	**"**	**31%**

Comparing the use of agricultural land in France and Germany, and also that for the regions draining to the Rhine as given in Section 2.1, with that in Italy (average temperature in Central Italy 4 à 5 °C higher than that in the Rhine basin) and that in Greece (average temperature 7 à 8 °C higher than that in the Rhine basin, relatively low rainfall) the following effects of temperature increase may be derived:
- for permanent crops an increase of about 15% of the agricultural area;
- for arable land a decrease of about 7% of the agricultural area;
- for permanent grassland a decrease of about 8% of the agricultural area.

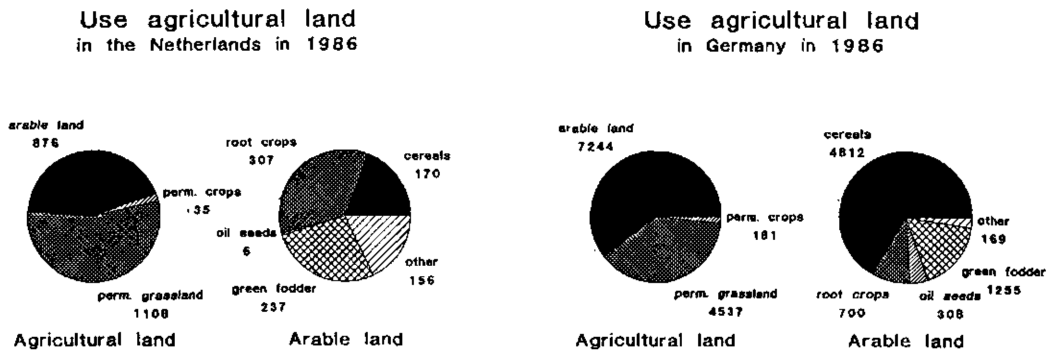

Fig. 3 Total land use (1000 ha) in the Netherlands and Germany for agriculture and arable farming in 1986. Data were derived from Table 24 (Source: Eurostat, 1988)

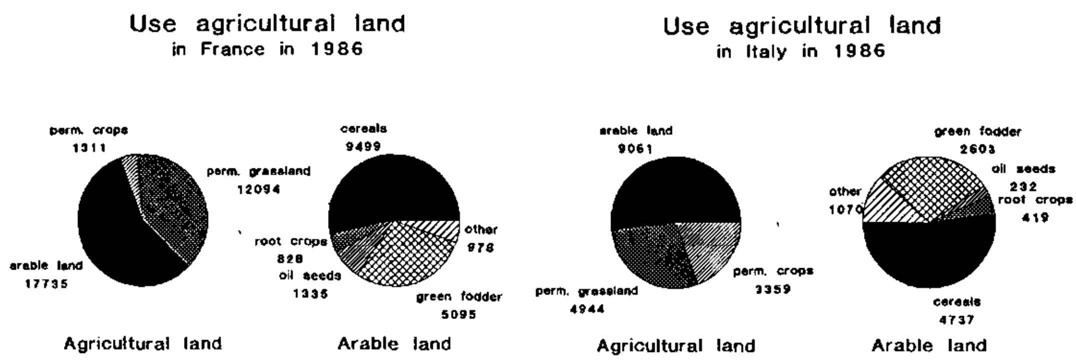

Fig. 4 Total land use (1000 ha) in France and Italy for agriculture and arable farming in 1986. Data were derived from Table 24 (Source: Eurostat, 1988)

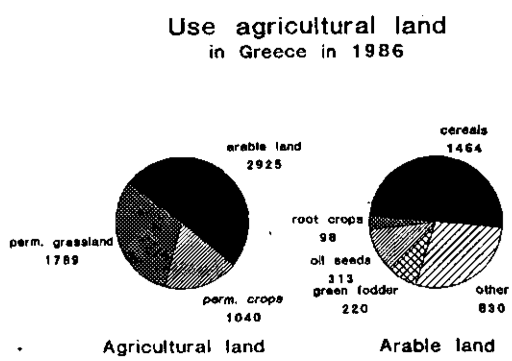

Fig. 5 Total land use (1000 ha) in Greece for agriculture and arable farming in 1986. Data were derived from Table 24 (Source: Eurostat, 1988)

In 1986 the relative use of arable land was as follows (see Figures 3, 4 and 5) in

Netherlands:	**cereals**	**19%;**	**root crops**	**35%;**	**oil seeds**	**1%;**	**green fodder**	**27%;**	**other crops**	**18%**
Germany:	„	**67%;**	„ „	**10%;**	„ „	**4%;**	„ „	**17%;**	„ „	**2%**
France:	„	**54%;**	„ „	**5%;**	„ „	**7%;**	„ „	**29%;**	„ „	**5%**
Italy:	„	**52%;**	„ „	**5%;**	„ „	**2%;**	„ „	**29%;**	„ „	**12%**
Greece:	„	**50%;**	„ „	**3%;**	„ „	**11%;**	„ „	**8%;**	„ „	**28%**

Comparing these data, arable cropping in the Netherlands is rather different from that in France and Germany. Cereals are cultivated only on a very limited part of the area. Oppositely, root crops such as potatoes and sugarbeets are cultivated on a relatively large area, just as green fodder crops, mainly silage maize, that are used for cattle feeding and other crops, mainly horticultural ones. Arable cropping in France and Germany does not differ much, except for the larger area fraction used for cereal cultivation in Germany and a larger one used for green fodder crops in France, respectively. Arable cropping in Italy is about identical to that in France. Only in Greece the use of arable land is different. Particularly, the area used for cultivation of green fodder crops is relatively small. As this also applies to the relative area of permanent grassland, this indicates that the animal husbandry sector in Greece is not yet as important as in the other European countries. The large area fraction used for other crops in Greece can only for one third be explained with data from statistics (Eurostat, 1988), being the areas used for cultivation of pulses and tobacco and for horticulture.

More detailed information on cultivated crops can be derived from Table 24. For example, the relative areas used for cereals do not differ much between the European countries, except for the Netherlands. In Germany besides wheat, also barley, oats and rye are cultivated on relatively large areas. But in France, Italy and Greece in addition to wheat, mainly barley and grain maize are of importance. The areas used for root crops such as potatoes, sugar and fodder beets, are relatively smaller in France, Italy and Greece, compared to Germany. Oilseed crops are cultivated to relatively different extents in the five countries and the cultivated crop species also differ considerably. In the Netherlands and Germany, for example, rapeseed is cultivated, in France also sunflower is of importance, and in Italy and Greece sunflower and other crops such as soyabean, sesame, cotton, etc. are cultivated for oilseed production. For green fodder production on arable land in the Netherlands and Germany mainly silage maize is cultivated. On about one third of the arable land area in use for green fodder production in France, silage maize is cultivated and on the rest lucerne and temporary grases are grown. In Italy and Greece cultivation of silage maize is of minor importance.

2.3 Actual and potential yields in the Rhine basin

For the regions that drain to the river Rhine, yields for the main crops are collected from statistics (Table 20). In these regions in Germany and France yields are:
wheat 5500 à 6000 kg/ha; barley 4500 à 5000 kg/ha; grain maize 5500 à 7500 kg/ha; potatoes 26 000 à 38 000 kg/ha; sugarbeets 34 000 à 60 000 kg/ha. Yields in Luxemburg are generally on the lower side and yields in the Netherlands on the higher side. Expressed in dry matter (see Table 20) these yields are: wheat 4900 kg/ha; barley 4000 kg/ha; grain maize 5500 kg/ha; potatoes 7000 kg/ha; sugarbeets 11 000 kg/ha.

For winterwheat average grain yields are calculated with a crop growth simulation model for historical weather data from locations in the Rhine basin. The calculated grain yields on sandy loam soil are about 8000 kg/ha dry matter (Table 28). It should be taken into account that yields for winterwheat are about 5% higher than those for wheat, being a mixture of yields for winter- and spring wheat. If unavoidable losses are estimated at 10%, the maximum wheat grain yield in the Rhine basin becomes (0.95 * 0.90 * 8000=) 6800 kg/ha dry matter.

For silage maize average yields are calculated for historical weather data from locations in the Rhine basin too. The calculated total dry matter yields on sandy loam soils are about 18 000 kg/ha dry matter (Table 29), of which for grain maize about half the total yield is harvested (= 9000 kg/ha). Considering unavoidable losses, the maximum maize grain yield in the Rhine basin becomes (0.90 * 9000=) 8100 kg/ha dry matter.

For potatoes and sugarbeets yields are not calculated for historical weather data but can be estimated as follows. The total dry matter production of winterwheat as calculated for sandy loam soils (Table 28), is about 17 000 kg/ha. Considering unavoidable losses and a harvested fraction of 80% for potatoes and beets, the maximum potato and sugarbeet yields in the Rhine basin become about (0.90 * 0.80 * 17 000=) 12 200 kg/ha dry matter. Particularly for sugarbeet, this estimate is rather low, as in reality the growth period of sugarbeet is longer than that of wheat and thus the total dry matter production is higher than 17 000 kg/ha.

Yield data for the Netherlands (Table 20) show that present yield levels are relatively high and approach the maximum yield levels. In other regions, however, there is still ample scope for increase in production at current weather conditions.

2.4 Current trends in land use and yield

From statistics some data are collected on the harvested areas and crop yields in 1983 and 1986 in Germany and France as a whole (Table 21). This may give indications on the present changes in yields and land use. However, it is impossible to make a distinction between changes that form part of a continuous trend and changes that can be considered as an annual variation. The main changes in land use observed during this period are:
- decrease in area of permanent grassland;
- increase in area of arable land;
- decrease in area of permanent crops in France;
- decrease in area of rye, oats and barley;
- increase in area of grain maize;
- increase in area of dried pulses;
- decrease in area of fodder beet and of sugarbeet and other root crops in France alone;
- decrease in area of rapeseed in France and increase in area of rapeseed in Germany;
- increase in area of sunflower in France;
- increase in area of green fodder crops on arable land in Germany and a decrease in France;
- increase in area of silage maize.

Yields in 1986 are for about all crop species higher than those in 1983. This may be partly the result of more favourable weather conditions in 1986 (amount of sunshine and rainfall, etc.) but may also partly be the result of gradually improving crop varieties, crop and land management and nutrient supply with time. Only if a yield serie over a longer period of time is available, it is possible to subdistinguish between both effects on crop yield.

2.5 Actual land use in South France and North Italy

Doubling the atmospheric CO_2 concentration is expected to result in changes in climate conditions. For example, in the Bultot scenario (Section 6.1) the temperatures rises with 3 °C, the precipitation increases but not much more than the evapo-transpiration, and the relative air humidity and other weather parameters are not changed. Such weather conditions can be found at present in South France and in North Italy. For example, the average temperatures in Bordeaux, France and in Milan and Turin, Italy are 12.3, 13.1 and 13.0 °C and the annual amounts of rainfall are 900, 963 and 845 mm, respectively. The average temperatures in De Bilt, Netherlands and Karlsruhe, Germany are 9.3 and 10.1 °C and the annual amounts of rainfall 765 and 761 mm, respectively (Müller, 1987).

In 1985 the relative use of agricultural land was as follows (see Figure 6) in

South France:	**arable crops 53%;**	**permanent crops 9%;**	**permanent grassland 38%**
North Italy:	**„ „ 62%;**	**„ „ 8%;**	**„ „ 30%**

Compared to the overall land use in the Rhine basin (Section 2.1), the relative areas used for permanent crops in these regions are larger (8% compared to 4% in the Rhine basin) and the relative area in use for permanent grassland is smaller, particularly in North Italy (compared to 38% in the Rhine basin). Besides, the fraction of the areas in use for permanent crops that is used as vineyards, increases from about half the area in the Rhine basin (Table 18) to three fourth of the area in South France and North Italy (Table 22).

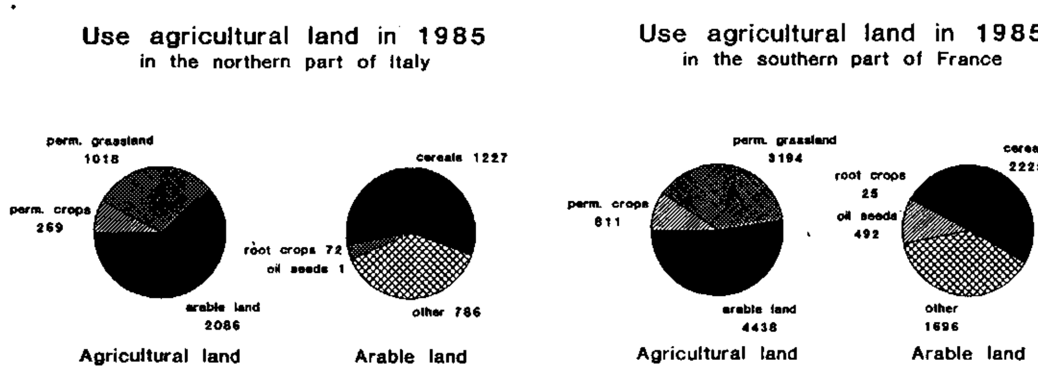

Fig. 6 Land use (1000 ha) in 1985 for agriculture and arable farming in various regions of South France and North Italy. Data were derived from Tables 22 and 23 (Source: Eurostat, 1987)

In 1985 the relative use of arable land was as follows (see Figure 6) in
South France: cereals 50%; root crops 1%; oil seeds 11%; other crops 38%
North Italy: „ 59%; „ „ 3%; „ „ 0%; „ „ 38%

Comparing these data with those for the Rhine basin (Section 2.1), the relative areas used in these regions for cereals are smaller (compared to 69% in the Rhine basin), for root crops are smaller too (compared to 6% in the Rhine basin) and for other crops are larger (compared to 21% in the Rhine basin). From data in Tables 22 and 24 it can be derived that the areas cultivated in South France and North Italy with other crops, are mainly used for green fodder production, i.e. about 30% of the arable land area. From statistics (Eurostat, 1988) and from Table 23 it can be derived that cereals cultivated in South France and North Italy are mainly wheat, barley and grain maize and that the main oil seed crop cultivated in South France is sunflower and in Italy soyabean.

3 METHODOLOGY

3.1 General

In the last two decades methods have been developed for estimating the yield levels of crops growing under well-specified conditions. These methods are based on application of crop growth simulation models, combining knowledge about crop characteristics and their interactions with the environment. Their basic structure is schematically presented in Figure 7.

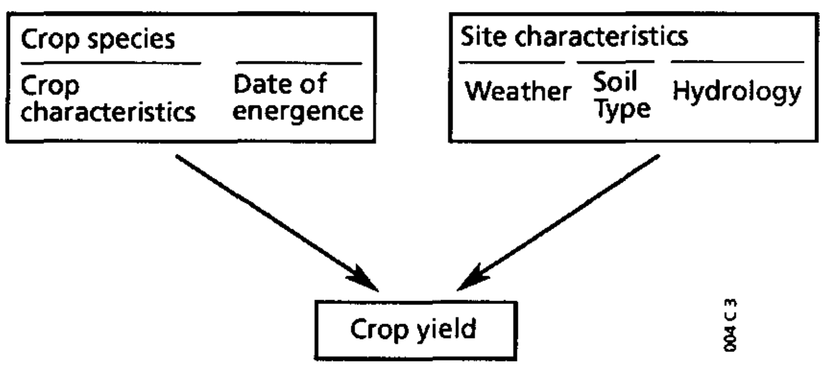

Fig. 7 Basic structure of methodology

For any selected emergence date the relevant phenological and physiological crop characteristics, weather data (amount and distribution of rainfall, temperature, solar radiation,etc.) and soil and topographic characteristics (water-holding capacity of the soil, infiltration capacity, etc.) are combined to calculate the total and the marketable (grain, tubers, etc.) crop production for specified situations. For actually attaining these productions, inputs are required such as human labour, fertilizers, pesticides, technical inputs, etc. The required input levels are dictated by the productions aimed at and the specified production situation.

In such approach three levels of crop production can be distinguished:
1. Potential: yield level is determined by crop characteristics, temperature and solar radiation. Water and nutrient availability are assumed to be optimal, and effects of weeds, pests and diseases negligible. Realization of that situation requires adequate supply of water and nutrients, and optimum crop management;
2. Water-limited: yield level is determined by crop characteristics, temperature, solar radiation and water availability, dictated by rainfall pattern and soil physical properties. Realization of that situation requires adequate supply of plant nutrients and optimum crop management;
3. Actual: yield level is determined by crop characteristics, temperature, solar radiation, water availability, as dictated by rainfall pattern and soil physical properties, by the nutrient supply from soil and applied fertilizer and by the quality of crop and land management (control of pests, diseases and weeds, tillage, etc.).

An example of the approach is given in Table 2, based on data from this study. For winterwheat in De Bilt, the Netherlands, growing under "average" conditions with respect to climatic conditions, soil texture, etc., grain productions as calculated for the potential and the water-limited production situations and the actual average grain production in the Netherlands are given as well as the production limiting factors and the required inputs. These data indicate that under the conditions in the Netherlands water availability is practically no constraint for crop production and that only limited production increases can be obtained from optimized crop and land management and nutrient application.

Table 2 Sequence of production levels with decreasing amounts of external inputs and corresponding increase in number of production-limiting factors. Grain yields of winterwheat as calculated for potential and water-limited production situations on loamy soil in De Bilt, the Netherlands and the actual average grain yield in the Netherlands in 1986[1,2]

Level of production	Production-limiting factors	Required inputs in agriculture	Wheat grain yield (kg/ha)
Potential production	solar radiation, crop characteristics, temperature	irrigation,drainage, optimal fertilizer appl., optimal crop and land management	10800
Water-limited production	idem + soil water	optimal fertilizer appl., optimal crop and land management	10600
Actual production	idem + soil water + nutrients + yield losses	suboptimal fertilizer appl., suboptimal crop and land management	8100

1 Dry matter fraction in grains is 0.85 kg/kg.
2 Actual yield data for winterwheat in the Netherlands from PAGV (1987).

3.2 Simulation model for calculation of potential and water-limited crop production

The Centre for World Food Studies developed a dynamic crop growth simulation model, WOFOST, to calculate agricultural production potentials on the basis of physiological, physical and agronomic information. The principles underlying the model are treated in detail by Van Keulen & Wolf (1986), and the implementation and structure are described by Van Diepen et al. (1988) and Van Diepen et al. (1989). For this study the 5th version of the WOFOST model has been used.

3.2.1 Model principles and structure

In the model, the growth of a crop is simulated from emergence to maturity on the basis of physiological processes as determined by the crop's response to environmental conditions. The simulation is carried out in time steps of one day. The major processes considered are CO_2 assimilation, respiration, partitioning of assimilates to various plant organs, transpiration and phenological development. In calculating potential production, solar radiation and temperature are the only environmental conditions considered. In calculating water-limited production, water availability is introduced as a possible growth-limiting factor.

The basis for the calculation of dry matter production is the rate of gross CO_2 assimilation of the green canopy, determined by prevailing radiation level, the intercepting leaf surface of the crops and the assimilation characteristics of individual leaves. Part of the assimilates formed is used by the crop for respiratory processes to provide energy for maintenance, which is a function of crop dry weight and chemical composition, modified by ambient temperature. The remainder is used for increase in structural dry matter, which is partitioned over the plant organs, roots, leaves, stems and storage organs (Figure 8), as a function of phenological development stage. The fraction partitioned to the leaves determines leaf area development and hence the dynamics of radiation interception. This procedure results in potential yield, assuming that water and nutrient supply are optimal throughout the crop's life cycle, and that weeds, pests and diseases are completely controlled.

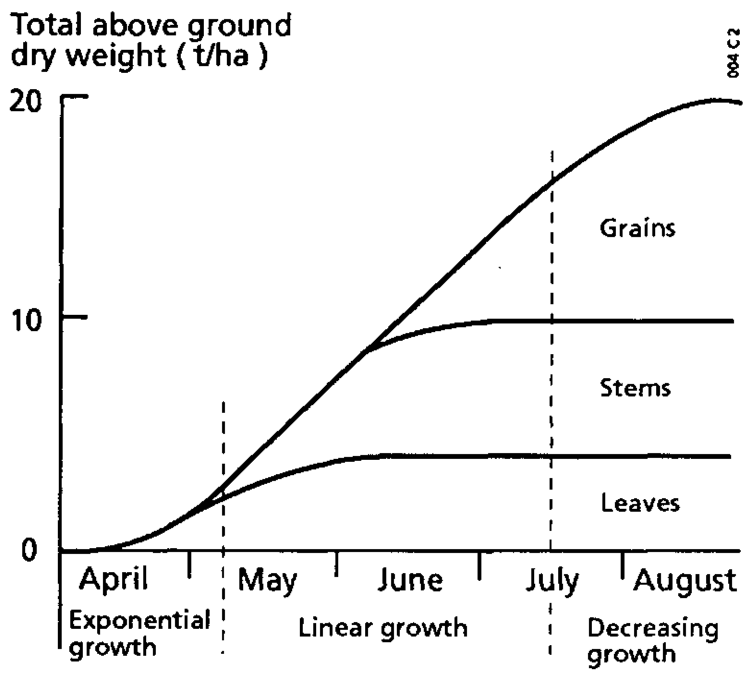

Fig. 8 Simulated course of dry weights of the various plant parts for summer wheat growing in the Netherlands

Transpiration refers to the loss of water from the crop to the atmosphere. The transpiration losses are replenished by water uptake from the soil. Within the optimum soil moisture range for plant growth the losses are fully compensated, and transpiration and hence assimilation proceed at their potential rates. In the model the potential rate of transpiration is calculated with the Penman formula (Frère & Popov, 1979). Outside the optimum range the soil can be either too dry or too wet. Both conditions lead to reduced water uptake by the roots, desiccation of plant tissue, closure of the stomata and hence reduced growth: in a dry soil due to water shortage, in a wet soil due to oxygen shortage (Figure 9).

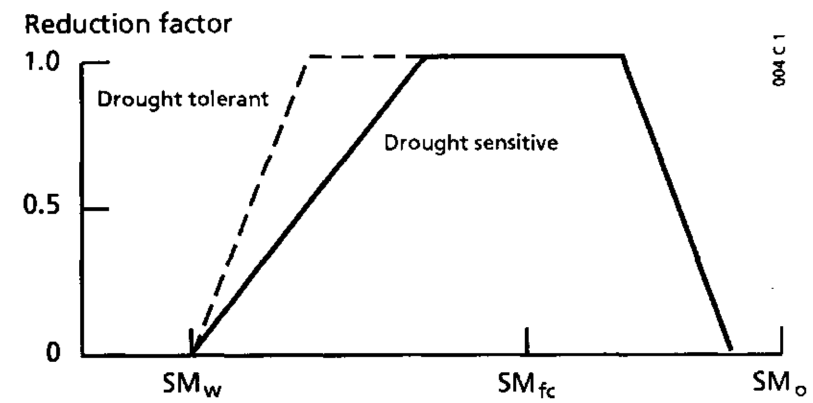

Fig. 9 Schematic representation of the reduction in transpiration and assimilation rates of drought-tolerant and drought-sensitive crops as a function of soil moisture content. SM_w, SM_{fc} and SM_0 are the soil moisture contents at wilting point, field capacity and saturation, respectively

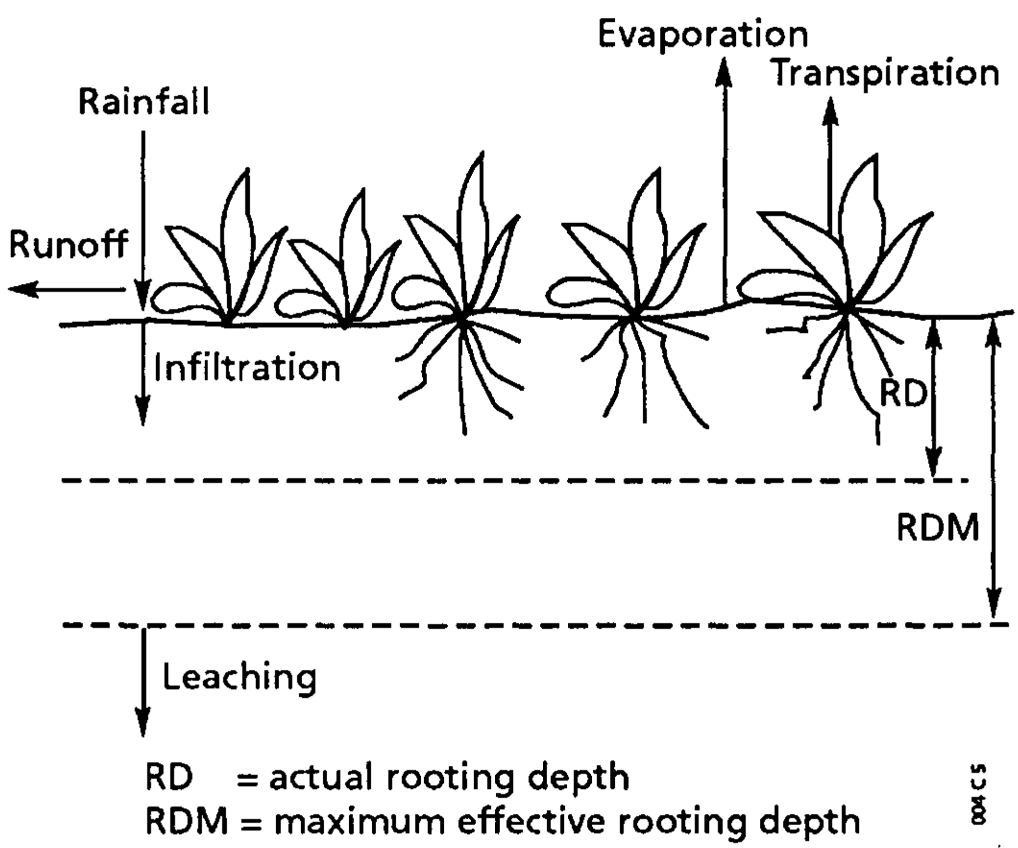

Fig. 10 Schematic representation of the terms of the water balance

Soil moisture content in the root zone (SM) follows from quantification of the water balance (Figure 10) including rainfall (R), surface runoff (SR), soil surface evaporation (E), crop transpiration (T) and leaching from the root zone (L). In this study surface runoff is assumed to be negligible (see Section 4.3).

3.2.2 Data requirements

Crop data
For application of the model, data that specify growth and phenological development for each crop are required. Such information on crops includes data on initial crop weight, properties that determine assimilation and respiration processes and response to moisture stress, partitioning of assimilates to plant organs, life span of leaves, death rates of plant organs, and a crop calendar defining dates of emergence, anthesis and maturity. The production potential is strongly dependent on growth duration, which for a given crop cultivar mainly depends on temperature, for photo-sensitive cultivars modified by effects of daylength (Van Keulen & Wolf, 1986).

Weather data
For the calculation of CO_2 assimilation rates, daily minimum and maximum air temperatures and solar radiation are required (Goudriaan & Van Laar, 1978). For the calculation of components of the water balance data on daily rainfall, windspeed and vapour pressure are also required. For example, for calculation of the potential rates of evaporation and transpiration with the Penman formula, data on radiation, average daily air temperature, vapour pressure and windspeed are used (Frère & Popov, 1979).

Soil physical data
For calculating the soil water balance, the soil's infiltration, retention and transport properties must be known. Soils are physically defined by:
- soil moisture characteristics, notably soil porosity and volumetric moisture contents at field capacity and wilting point, respectively;
- effective soil depth;
- maximum infiltration rate or other characteristics from which surface runoff can be derived;
- hydraulic conductivity of the subsoil.

3.2.3 Adaptation of model to future climate conditions

The simulation model is used for calculating productions in current and in future climate conditions, and for calculating the sensitivity to changes in weather parameters. The same daily weather data that are read from climate files to calculate current productions, are also used for calculating the future productions. In that case, however, the daily weather data after being read from file, are changed according to the Bultot scenario (see Section 6) :
- average daily air temperatures increased by 3 °C;
- relative vapour pressure kept constant, i.e. the actual vapour pressure is corrected for

changed temperature by multiplication with the ratio between saturated vapour pressure at daily air temperature + 3 °C and saturated vapour pressure at daily temperature;
- daily rainfall data multiplied by 1.10 à 1.16 in winter and by 0.97 in summer;
- rate of assimilation process adapted to doubled atmospheric CO_2 concentration as described below.

For calculating the sensitivity to changes in weather parameters the same daily weather data that are read from climate files for calculating current productions, are used too. However, the data for each weather parameter after being read from file, have been changed separately to various extents:
- rate of assimilation process adapted to doubling and tripling the atmospheric CO_2 concentration;
- daily air temperature data varied between 1 °C below and 5 °C above the actual daily air temperature data;
- rainfall data varied between 0.7 times and 1.3 times the actual rainfall data;
- radiation data varied between 0.9 times and 1.3 times the amounts of radiation actually received;
- windspeed data varied between 0.5 times and 2.0 times the actual mean daily windspeed data;
- vapour pressure data varied between 0.9 times and 1.1 times the actual vapour pressure data.

The effect of increased atmospheric CO_2 concentration on the CO_2 assimilation of the green canopy was described as follows. For plants as wheat and grass that belong to the C3 plant type, atmospheric CO_2 concentration is generally suboptimal, and in that case the CO_2 assimilation - light response curve (Figure 11) is changed by increasing CO_2 concentration in two ways. Up to a concentration of about three times the actual CO_2 concentration, the maximum assimilation rate of light-saturated individual leaves increases about proportionally to the atmospheric CO_2 concentration and becomes twice the present rate at a doubled atmospheric CO_2 concentration. Second, the initial light use efficiency, i.e. the initial angle of the CO_2 assimilation - light response curve, increases by about 25% through doubled atmospheric CO_2 concentration (Goudriaan et al., 1984; Goudriaan et al., 1985; Goudriaan, 1990; Goudriaan & Unsworth, 1990). For C4 plants such as maize and other tall tropicall grasses, such as millet, sorghum and sugarcane, the photosynthetic response to CO_2 is very steep until an atmospheric CO_2 concentration of one third of the present one. At the atmospheric CO_2 concentration at present (about 350 μmol/mol) the CO_2 assimilation - light response curve practically does not change through increasing CO_2 concentration, even under high light intensities (Goudriaan & Unsworth, 1990).

The effect of CO_2 concentration on leaf area development is rather difficult to quantify, as indicated in comparable studies on effects of climate change on crop production (Van Diepen et al., 1987; Jansen, 1990). It has been observed that increased assimilate availability at increasing atmospheric CO_2 concentration results partly in thicker leaves, rather than in increased leaf area growth (Goudriaan & De Ruiter, 1983; Goudriaan & Bijlsma, 1987). In agreement with these observations the specific leaf areas (m^2 leaf area per kg leaf weight) of wheat and grass under doubled atmospheric CO_2 concentrations have been set to 80% of those under present conditions.

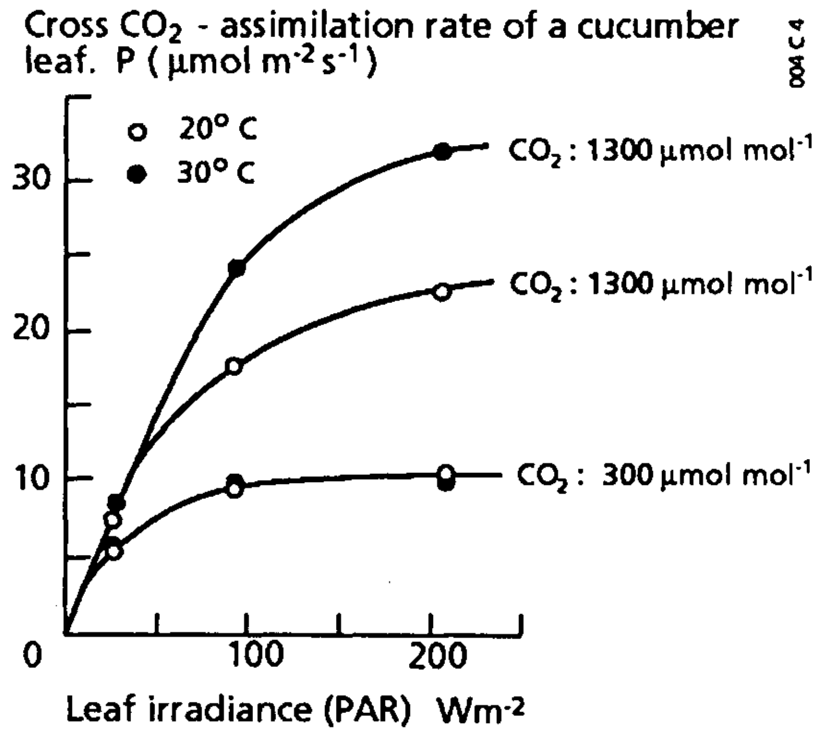

***Fig. 11** CO_2 assimilation - light response curves of single leaves of cucumber at different atmospheric CO_2 concentrations (Source: Goudriaan & Unsworth, 1990)*

Large increases in CO_2 assimilation might result in a situation that formation of plant organs becomes more limiting for crop growth than the CO_2 assimilation process. In this study, however, it is assumed that also at very high CO_2 concentrations resulting in high assimilation rates, the rate of organ formation is never the limiting factor for crop growth.

As described in Section 3.2.1, the simulation model calculates the potential rates of evaporation and transpiration by way of the Penman formula. In a situation of soil water shortage and hence reduced water uptake by the roots, the actual transpiration rate becomes lower than its potential value, as indicated schematically in Figure 9. This reduction in transpiration is regulated by partial closure of the stomatal pores in the leaves, which results in decreasing stomatal conductance. The stomata permit at the same time uptake of CO_2 from the ambient air and escape of water vapour, leading to transpiration. When ambient CO_2 is raised, CO_2 assimilation may increase and/or transpiration losses may be reduced, depending on how the stomata react. In both ways the water use efficiency of plants may be stimulated considerably. Typically in C3 plants transpiration is reduced to a limited extent and the CO_2 assimilation is stimulated considerably and in C4 plants that have a much higher affinity for CO_2, the transpiration is reduced considerably and the CO_2 assimilation does not change. (Goudriaan & Unsworth, 1990). These changes in the transpiration rate due to changing stomatal conductance and closure at increasing atmospheric CO_2 concentrations cannot be handled with the simple method described above.

A stratified micrometeorological model (Goudriaan, 1977; Chen, 1984) that includes detailed profiles of radiation and aerial conditions in the canopy and uses the Penman - Monteith equation for calculating the energy balances of canopy and soil surface, is applied for simulating the effects of doubled atmospheric CO_2 concentration on the transpiration rate (Goudriaan & Unsworth, 1990). For C4 plant species the CO_2 assimilation rate was not affected but the stomatal resistance almost doubled, proportional to the increased CO_2 concentration. The transpiration rate, however, was not about halved because of a negative feedback in two ways. First, the reduced transpiration rate causes an increase in leaf temperature. Second, the reduced transpiration rate affects air conditions inside the canopy. Both effects result in a transpiration rate at doubled atmospheric CO_2 concentration of 74% of the original value for C4 crops. For C3 plant species the CO_2 assimilation rate is mainly affected by the doubled atmospheric CO_2 concentration and in that case model simulations result in a transpiration rate of 90% of that at the actual CO_2 concentration. These fractions of the transpiration rate derived for a situation of doubled atmospheric CO_2 concentration, are used in the present study as overall reduction factors for calculating the transpiration rates at changing CO_2 concentrations.

The complete set of crop parameters that have been used for adaptation of the model to future weather conditions and have been treated above, is given in Section 4.4.

4 DATA BASE

Effects of climate change on crop production have been analyzed for three crops, winterwheat, silage maize and permanent grassland, growing on four soil types with different amounts of available water at six locations in the Rhine basin.

4.1 Crops

4.1.1 Winterwheat

The standard crop data set has been used largely. Sowing of winterwheat in the Netherlands takes place in October, November or December (Alblas et al., 1987), so crop emergence generally occurs in autumn. As the period of standstill in the winter cannot be handled by the model, the simulation is started on January 1 at an estimated amount of above-ground plant material at that date. The rate of phenological development that determines the dates of anthesis and maturity, the level of production and the partitioning of assimilates to the plant organs that determines the grain/straw ratio, are based on data from field experiments in the Netherlands (Alblas et al., 1987; Darwinkel, 1985; Darwinkel, 1988; Van Keulen et al., 1988; PAGV, 1987). For locations in Germany and France the same crop data as derived for wheat varieties in the Netherlands, are used in the calculations.

4.1.2 Silage Maize

The standard crop data set has been used largely. Sowing of silage maize in the Netherlands is advised to be done in the end of April, as delay results in a lower production (Alblas et al., 1987). This results in emergence on about May 15. Hence, the simulations for the Netherlands are started on that date. For locations in France and Germany the temperature in spring is about 1 °C higher than that in the Netherlands. As in the Rhine basin temperature in spring increases by about 4 °C per month, the simulated growth of maize on locations in France and Germany is started one week earlier, i.e. on May 8. The rate of phenological development, the level of production and the partitioning of assimilates to plants organs are based on data from field experiments in the Netherlands (Alblas et al., 1987; PAGV, 1985; De Jong, 1985; Sibma, 1987). For locations in Germany and France the same crop data as derived for maize varieties in the Netherlands, are used in the calculations.

4.1.3 Permanent grassland

For the growth simulation of permanent grassland that is mown regularly, some changes to the model and additional data that reflect the management of grassland were required. In spring simulated growth starts at an initial leaf area index. At the moment that at least 3500 kg/ha dry matter can be harvested, in addition to the weight corresponding with the initial leaf area index, this amount is removed and grass growth starts again. After the harvest, regrowth is retarded for a number of days that increase with the amount of grass removed and the duration of the harvest period, and is set to 6, 5, etc. days for at least 3500, 3000, etc. kg/ha dry matter removed (PR, 1988). From midsummer the rate of grass growth decreases gradually and for that reason it is assumed that from end of July grass is cut already at the moment that at least 3000 kg/ha dry matter can be harvested. At the end of November, the residual amount of grass is harvested. The growth simulations for grass are performed over one complete year, i.e. 365 days, for all locations. The level of production, the partitioning of assimilates to the plant organs and the regrowth retardation are based on data from field experiments in the Netherlands (PR, 1988; Wieling & De Wit, 1987; Lantinga, 1985; Noy, 1989; Van Dijk, 1989). For locations in Germany and France the same plant data as derived for permanent mown grassland in the Netherlands, are used in the calculations.

4.2 Climate

The weather data used for the calculations were daily values from six meteorological stations. They cover the degree of variation in climate in the Rhine basin. As shown in Table 3, lowest annual temperatures are found in the Netherlands (De Bilt, Twente) and highest in South Germany (Karlsruhe, Freiburg).

Table 3 Information on location and climate for six meteorological stations in the Rhine basin

Location, Country	Longitude (°N)	Latitude (°E)	Elevation above sea level (m)	Average annual temperature[1] (°C)	Average annual rainfall[1] (mm)	Average relative humidity[1] (%)	Annual sunshine duration[1] (h)
De Bilt, Neth.	52°06'	5°11'	2	9.3	765	77	1572
Twente, Neth.[2]	52°16'	6°54'	14	9.5	755	76	1337
Strasbourg, France	48°33'	7°38'	153	9.7	607	78	1685
Frankfurt, Germany	50°03'	8°36'	111	9.4	663	77	1640
Freiburg, Germany	48°00'	7°51'	269	10.3	903	74	1808
Karlsruhe, Germany	49°02'	8°22'	112	10.1	761	77	1771

[1] Average climate data from Müller (1987).
[2] Climate data for Twente were not given by Müller (1987) and have been replaced by those for nearest meteorological station in Winterswijk (51°58' N, 6°43' E).

The courses of temperature over the year (Figure 12) show that on locations in Germany and France temperatures in winter are 1 °C below, in spring are 1 °C above, in summer are 2 °C above and in autumn are 0 °C above temperatures on locations in the Netherlands. This decreased temperature variation over the year in the Netherlands is due to the sea influence. Sunshine duration (Table 3) and thus the solar radiation increases in southern direction but also in the direction of the sea coast (De Bilt compared to Twente). Table 3 also shows the difference in annual rainfall between locations, from relatively dry ones as Strasbourg and Frankfurt to relatively wet ones as Freiburg.

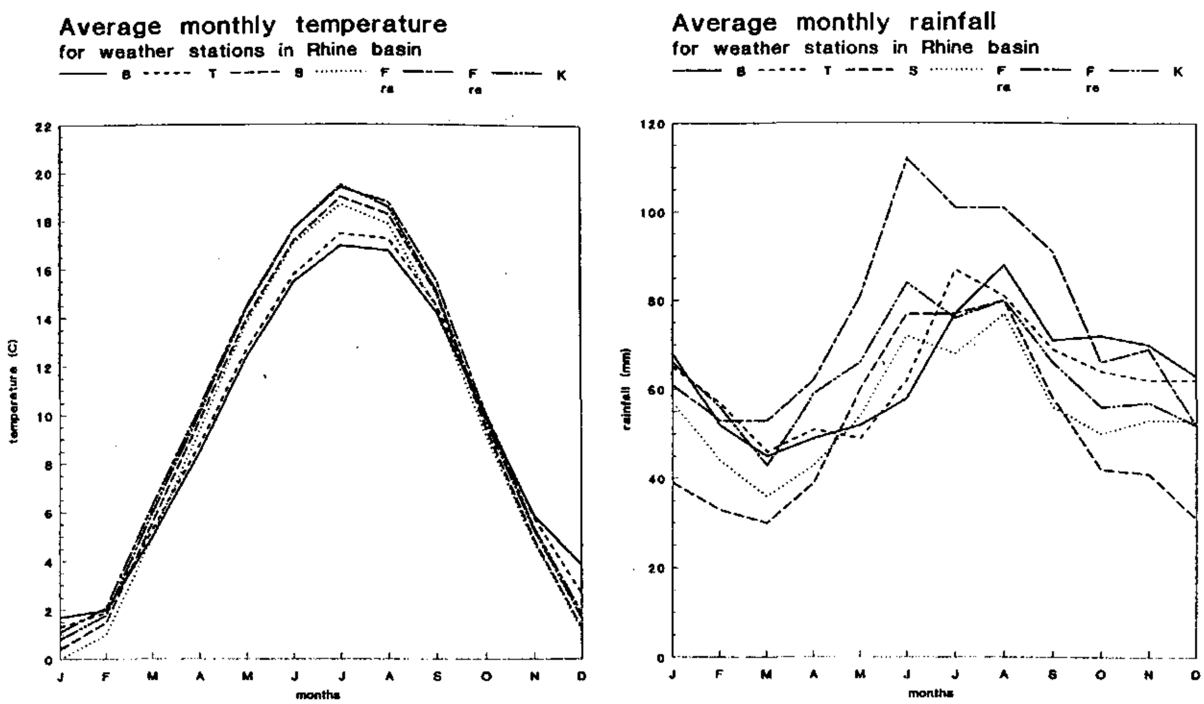

***Fig. 12** Course of average monthly temperature and rainfall over the year in De Bilt (B) and Twente (T), the Netherlands, Strasbourg (S), France, and Frankfurt (FRA), Freiburg FRE) and Karlsruhe (K), Germany (Source: Müller, 1987). In this handbook climate data for Twente were not given and have been replaced by those for nearest meteorological station in Winterswijk*

As shown in Figure 13, one out of 10 years the annual amount of rainfall in De Bilt (B), Twente (T), Strasbourg (S), Frankfurt (FRA), Freiburg (FRE) and Karlsruhe (K) is less than:

B	T	S	FRA	FRE	K
56 cm	56 cm	47 cm	47 cm	72 cm	65 cm

The average potential evapo-transpiration of grassland over one year on the same locations (see Table 30) is:

B	T	S	FRA	FRE	K
44.7 cm	43.6 cm	51.0 cm	46.8 cm	55.2 cm	49.2 cm

From comparison of these rainfall data with the average potential evapo-transpiration of grassland, it can be derived that the risk for watershortage in low-rainfall years is considerable in Strasbourg and Frankfurt.

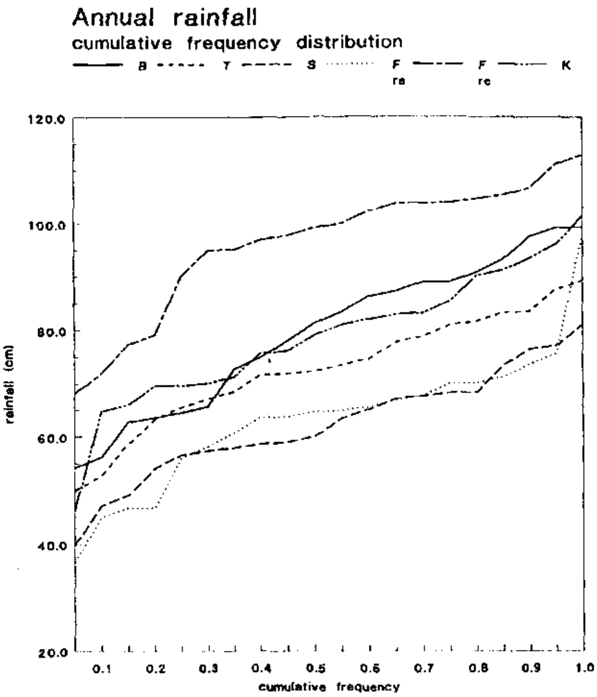

Fig. 13 Cumulative frequency distribution of annual rainfall (cm) over a period of twenty years (1969-1988) in De Bilt (B) and Twente (T), the Netherlands, Strasbourg (S), France, Frankfurt (FRA), Freiburg (FRE) and Karlsruhe (K), Germany (see Table 27)

The course of rainfall over the year (Figure 12) shows again that in Freiburg, particularly in spring and summer, rainfall is much higher than on the other locations. De Bilt, Twente and Karlsruhe represent about the average rainfall situation in the Rhine basin. These locations differ only by the fact that in spring more rain falls in Karlsruhe and in autumn more in De Bilt and Twente. Lowest amounts of rain fall in Strasbourg and Frankfurt. In autumn and winter the amounts of rainfall in Strasbourg are lower and in spring and summer, the period of crop growth, the amounts are higher than those in Frankfurt. Hence, the risk for water shortage is larger in Frankfurt than in Strasbourg.

In mountainous areas the temperature can be much lower and the amounts of rainfall much higher than these on the specified locations. As such areas are not used for agriculture in the Rhine basin, weather data from meteorological stations representative for mountainous areas are not used in this study.

For the six locations historical weather data over a period of 20 years, from 1969 upto and including 1988, have been used. It should be kept in mind that these weather data are more recent than those of Müller (1987), used for Table 3 and Figure 12. The daily weather data used are: maximum and minimum air temperature, solar radiation, vapour pressure, average windspeed and rainfall. As only for De Bilt and Strasbourg measured radiation data are available, solar radiation for the other stations has been calculated from measured data on sunshine duration. Only for Twente the daily weather data set was not complete and had to be repaired. The missing values were replaced by values from a reference data set. This data set contains average weather data on a daily basis, which have been derived from the total historical set of weather data.

4.3 Soils

Four soil types were specified for the calculations. They cover the degree of variation in soil water-holding capacity that can be expected in the Rhine basin, but they are theoretical concepts representing a sandy soil, a sandy loam soil, a loamy soil and an optimal soil. For each soil type the following assumptions apply:

- no groundwater and hence no flow of water by capillary rise to the root zone;
- water balance calculated for effective rooting depth of 100 cm for cultivation of winterwheat and silage maize and for permanent grassland on optimal soils and calculated for depth of 50 cm for permanent grassland on the other soils;
- infiltration rate is so large that no surface runoff may occur;
- no risk for oxygen shortage in wet soils.

The sandy soil has an available volumetric moisture content of 0.07 cm^3/cm^3 (between moisture contents at field capacity and at wilting point, respectively). Hence, the maximum amount of available soil water is 7 cm for cultivation of winterwheat and silage maize and 3.5 cm for permanent grassland.

The sandy loam soil has an available volumetric moisture content of 0.14 cm^3/cm^3. Hence, the maximum amount of available soil water is 14 cm for cultivation of winterwheat and silage maize and 7 cm for permanent grassland.

The loamy soil has an available volumetric moisture content of 0.21 cm^3/cm^3. Hence, the maximum amount of available soil water is 21 cm for cultivation of winterwheat and silage maize and 10.5 cm for permanent grassland.

The optimal soil has an available volumetric moisture content of 0.50 cm^3/cm^3. Hence, the maximum amount of available soil water is 50 cm for cultivation of winterwheat and silage maize and also for permanent grassland. The optimal soil is fictive but allows calculation of the potential production (i.e. production in situation without water shortage and crop stress) under any climatic condition.

Water-holding capacity of soils that are used for agriculture in the Rhine basin, can be expected to be in between those of sandy loam and loamy soils, respectively. The sandy soil represents with respect to water-holding capacity shallow, gravelly or stony soils that generally are found on eroded slopes, which mostly are not used for agriculture.

4.4 Adaptation of crop parameters to future climate conditions

The simulation model is used for calculating productions in future climate conditions and for calculating the sensitivity to changes in climate conditions. In section 3.2.3 it was described how in the model the historical set of weather data was changed to create "future" weather data (scenario analysis) and how in the model values for weather parameters were varied separately to analyse their sensitivity to changes. In Section 3.2.3 also the effects of increasing atmospheric CO_2 concentration on plant behaviour were treated:

- change in CO_2 assimilation - light response curve for C3 crops;
- increasing thickness of leaves;
- decrease in transpiration rate for C4 crops and to less extent for C3 crops.

The resulting changes in crop parameters of the model that reflect these changes in plant behaviour at increasing atmospheric CO_2 concentrations, are summarized in Table 4.

The CO_2 assimilation - light response curve of single leaves is changed by increasing atmospheric CO_2 concentration in two ways. The maximum leaf assimilation rate (AMAX), i.e. the maximum of the curve, and also the initial angle (EFF) of this curve increase at increasing CO_2 concentration. At the same time, specific leaf area (SLA), i.e. m^2 leaf area per kg leaf weight, decreases and the transpiration is reduced by way of an overall reduction factor (RTRA) (see Section 3.2.3.).

***Table 4** Changes in specific leaf area (SLA), in initial light-use efficiency of CO_2 assimilation of single leaves (EFF), in maximum leaf CO_2 assimilation rate (AMAX) and in the reduction factor for potential transpiration (RTRA) for adaptation of the model to doubled and tripled atmospheric CO_2 concentrations*

Atmospheric CO_2 concentrations	SLA (m^2/kg)	EFF $\left(\frac{kg/ha/h}{J/m^2/s}\right)$	AMAX (kg/ha/h)	RTRA
Winterwheat				
1*CO_2	**18.0**	**0.45**	**40**	**1.00**
2*CO_2	**14.4**	**0.55**	**80**	**0.90**
3*CO_2	**12.0**	**0.59**	**120**	**0.85**
Silage maize				
1*CO_2	**26.0**	**0.45**	**70**	**1.00**
2*CO_2	**26.0**	**0.45**	**70**	**0.74**
3*CO_2	**26.0**	**0.45**	**70**	**0.64**
Grass				
1*CO_2	**25.0**	**0.45**	**40**	**1.00**
2*CO_2	**20.0**	**0.55**	**80**	**0.90**
3*CO_2	**16.7**	**0.59**	**120**	**0.85**

5 RESULTS FOR CURRENT CLIMATE

For the six locations, De Bilt, Twente, Strasbourg, Frankfurt, Freiburg and Karlsruhe daily weather data are available for a period of 20 years (1969-1988). For this period of time crop production and the components of the water balance have been calculated. Only the results for crop growth on loamy soils are specified per year and are presented in a cumulative frequency distribution.

5.1 Winterwheat

Crop growth and the components of the water balance are simulated from January 1 till the date of maturing. Actually sowing of winterwheat occurs in October or November. After about two weeks crop emergence finds place, so that at January 1 a limited amount of crop material is already formed. An estimate for this amount is used as start weight in the crop growth simulation. The initial amount of available soil water at January 1 is set at the maximum per soil type.

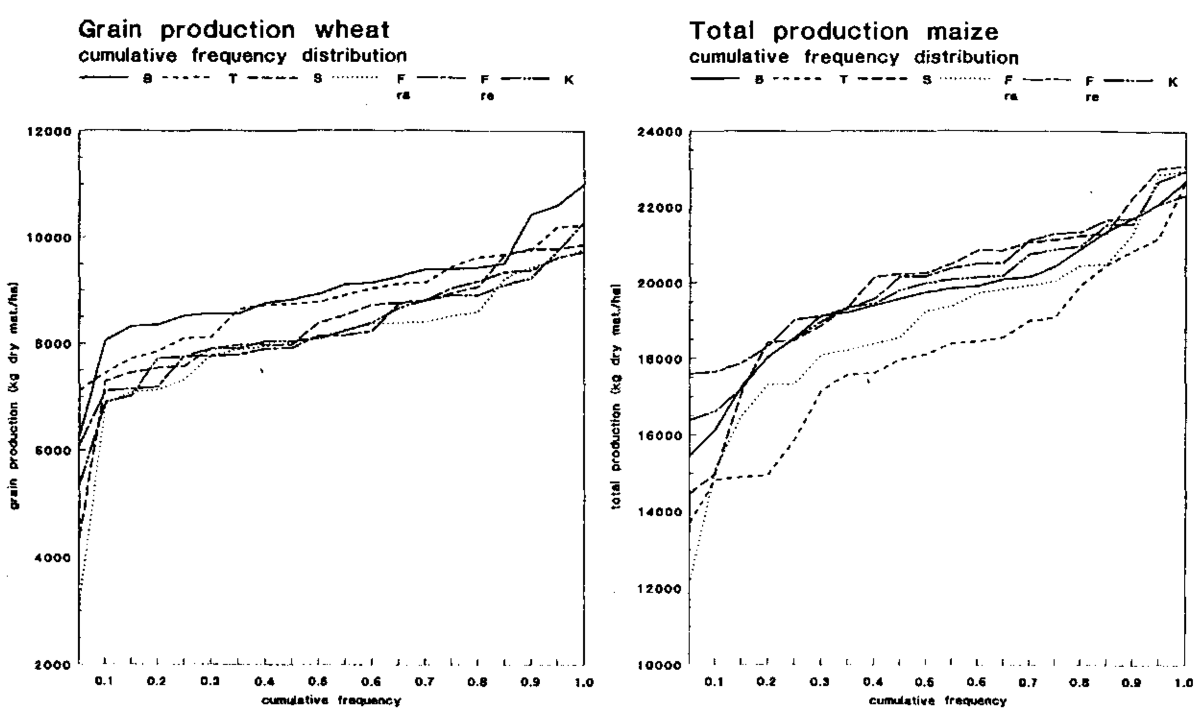

***Fig. 14** Cumulative frequency distributions of the grain production of winterwheat and the total production of silage maize (kg/ha dry matter) cultivated in current climate conditions on loamy soils. Productions have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt (B) and Twente (T), the Netherlands, Strasbourg(S), France, Frankfurt (FRA), Freiburg (FRE) and Karlsruhe (K), Germany (see Tables 25 and 26)*

5.1.1 Cumulative frequency distribution

Over the period of 20 years an average water-limited grain production on loamy soils in De Bilt and Twente is calculated of about 9000 kg/ha dry matter (Figure 14). The standard deviation is derived to be about 1000 kg/ha (Table 25), so the annual production varies mainly between 8000 and 10 000 kg/ha. The average water-limited grain production in Strasbourg, Frankfurt, Freiburg and Karlsruhe is about 8200 kg/ha dry matter, and also the total dry matter production is lower (Table 5). This difference in production results from the shorter growth periods on these locations. In spring crop growth starts about one week earlier than on locations in the Netherlands, but crop maturing occurs about 2.5 week earlier.

***Table 5** Average values for water-limited productions and components of the water balance (cm) during the growth period of winterwheat sown half November in De Bilt and Twente, the Netherlands, in Strasbourg, France, and in Frankfurt, Freiburg and Karlsruhe, Germany on loamy soils; average values have been established for historical weather data over a period of 20 years (1969-1988) (see Table 25)*

Location	Duration growth period (d)	Dry matter production (kg/ha)		Rainfall	Transpiration	Evaporation	Leaching	Change Soil water
		Total	Grain					
De Bilt	228	19197	9022	46.8	25.9	9.0	20.3	-8.3
Twente	233	18639	8819	45.7	25.2	9.1	19.4	-8.0
Strasbourg	214	17296	8320	37.4	25.2	9.0	11.3	-8.1
Frankfurt	218	17190	7990	38.6	24.6	8.3	15.3	-9.6
Freiburg	207	17240	8252	56.9	25.5	9.9	24.9	-3.4
Karlsruhe	210	17239	8250	47.6	23.9	8.8	21.0	-6.2

5.1.2 Production

The potential grain production, i.e. the production on the optimal soil with an artificially high amount of available water that prevents water shortage under practically all conditions, is also highest in De Bilt and Twente and lower on the other locations (Figure 15). This results from the shorter growth period as described in Section 5.1.1.

On the loamy soils the average water-limited grain production is about as high as the average potential production and is again higher for the Dutch locations than for the other ones. On the sandy loam soils the reduction in average water-limited grain production due to water shortage compared to the potential production is still very limited (1 to 3%) in Freiburg and Karlsruhe and limited (5 to 10%) on the other locations. Only on the sandy soils the grain production is reduced strongly, by 20 to 30% on most locations. In Freiburg the amount of rainfall during the growth period is relatively higher and consequently, the reduction in grain yield is only 8%. In Frankfurt the amount of rainfall is low and besides the distribution of rainfall over the growing season is rather unfavourable, which results in more leaching from the root zone and in more depletion of available soil water (Table 28) and consequently in more severe yield reduction (34%).

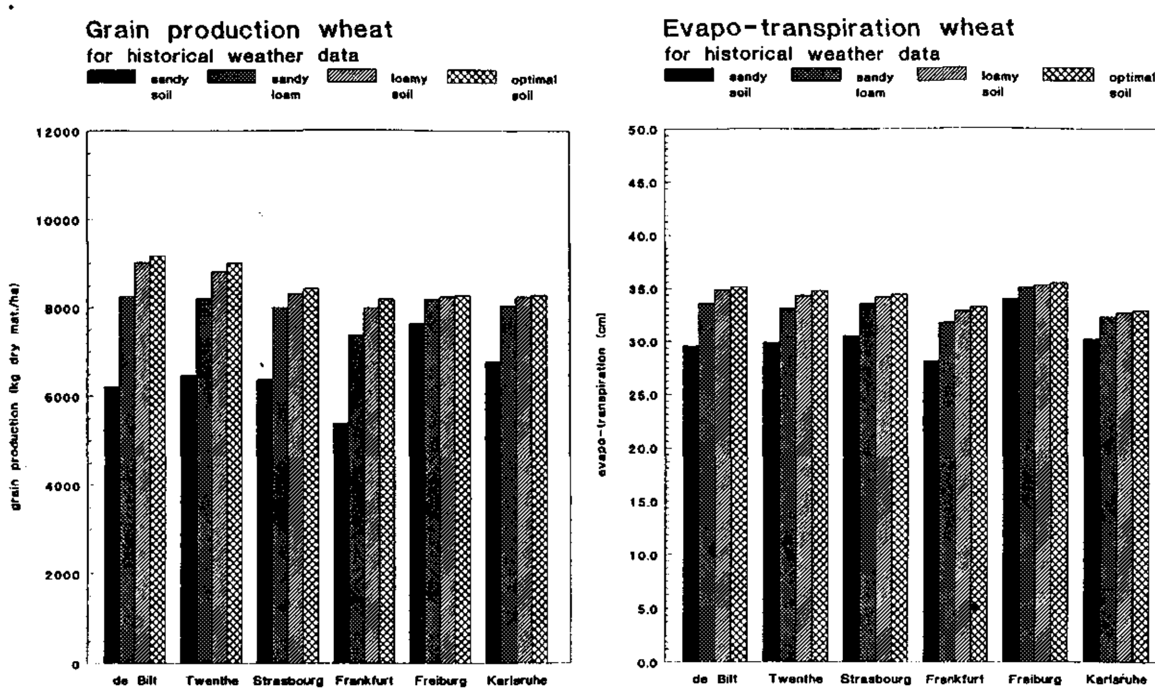

Fig. 15 Average grain production (kg/ha dry matter) and evapo-transpiration (cm) during the growth period of winterwheat cultivated in current climate conditions on four different soil types. Average values have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt and Twente, the Netherlands, Strasbourg, France, Frankfurt, Freiburg and Karlsruhe, Germany (see Table 28)

The standard deviation for the calculated productions increases from about 800 kg/ha dry matter for the potential production to about 1650 (Freiburg, high rainfall) à 2650 kg/ha dry matter (Frankfurt, low rainfall) for the water-limited productions on sandy soils (Table 28). Thus yield variation increases with increasing risk for water shortage. As the water-holding capacity of most soils used for agriculture in the Rhine basin is not less than that of the sandy loam soils, reduction in grain production due to water shortage will occur only to a limited extent (not more than 10% yield reduction).

5.1.3 Water balance

The highest cumulative water losses by evaporation and transpiration are calculated for Freiburg (Figure 15). On this location the average temperature over the growth period is highest and also the amount of solar radiation received (Table 3). In Strasbourg, Frankfurt and Karlsruhe the average temperature is also somewhat higher than in De Bilt and Twente, but on these locations the shorter growth period (see Table 5) causes equal or lower amounts of evapo-transpiration. Evapo-transpiration on loamy soils is about as high as that on optimal soils. On sandy loam soils evapo-transpiration is reduced by 2 to 5% on most locations, and even less in Freiburg (high rainfall). Only on the sandy soils the evapo-transpiration is clearly reduced due to a limited supply of water from rainfall and soil, i.e. 10 to 15% on most locations. However, on a high-rainfall location such as Freiburg, the reduction amounts only 4%. On the other soils the water supply from rainfall and soil will on all locations practically not be limiting for the evapo-transpiration (see Table 28) and thus also for the grain production. For more elaborate information on the variation from one year to the other in crop production and in components of the water balance it is referred to Tables 25 and 28.

5.2 Silage maize

Crop growth and the components of the water balance are simulated from the date of emergence, i.e. May 8 for locations in France and Germany, and May 15 for locations in the Netherlands, till the date of maturing or the date of harvest, set at October 2 when the crop is not yet mature at that date. The initial amount of available soil water at crop emergence is set for all locations at the maximum amount per soil type minus 3 cm water, taking into account limited evaporation losses from bare soil before the date of emergence.

5.2.1 Cumulative frequency distribution

Over the period of 20 years an average water-limited total production on loamy soils of 18 000 to 20 000 kg/ha dry matter is calculated (Figure 14). Highest productions are found on locations with the highest temperatures, i.e. Freiburg, Karlsruhe and Strasbourg and lowest productions in Twente and Frankfurt, but the difference in production is limited. The standard deviation is calculated to be between 2000 and 2500 kg/ha (Table 26), so annual production varies mainly from 16 000 to 21 000 kg/ha. Only in Freiburg the high-rainfall regime (Table 6) results in less variation in production.

***Table 6** Average values for water-limited productions and components of the water balance (cm) during the growth period of silage maize sown end of April in De Bilt and Twente, the Netherlands, and half April in Strasbourg, France, and in Frankfurt, Freiburg and Karlsruhe, Germany on loamy soils; average values have been established for historical weather data over a period of 20 years (1969-1988) (see Table 26)*

Location	Duration growth period (d)	Dry matter production (kg/ha)		Rainfall	Transpiration	Evaporation	Leaching	Change Soil water
		Total	Grain					
De Bilt	138	19583	10029	29.9	23.8	6.4	3.4	-3.7
Twente	139	18063	9029	28.4	22.4	7.3	3.2	-4.5
Strasbourg	122	19882	10676	28.0	26.3	6.4	2.6	-7.3
Frankfurt	126	18891	10153	25.4	24.8	6.4	2.9	-8.6
Freiburg	114	20084	10900	38.8	27.4	6.6	7.9	-3.0
Karlsruhe	116	19805	10514	29.8	25.7	5.9	4.3	-6.3

As shown in Table 6, the growth period of silage maize is longer for the Netherlands than for the other locations (if maize variety is identical), due to lower average temperatures. Silage maize grows very slowly as long as temperatures in spring are rather low. For that reason the lower temperature and corresponding longer growth period in the Netherlands does not generally result in a higher production, as found in Section 5.1.1 for winterwheat.

5.2.2 Production

The potential production, i.e. the production on the optimal soil, is highest in Strasbourg and lowest in Twente, but the differences between the six locations are limited (Figure 16). These differences can be explained from different amounts of solar radiation received.

On the loamy soils the average water-limited total production is about as high as the average potential production. On the sandy loam soils the decrease in average water-limited production compared to potential production is about 10%. Exceptions are Freiburg (high rainfall) with a decrease of only 2% and Frankfurt (low rainfall, see Table 6) with a decrease of 14%. On the sandy soils the total production is reduced by almost 30%, with again in Frankfurt a larger yield reduction and in Freiburg a smaller one.

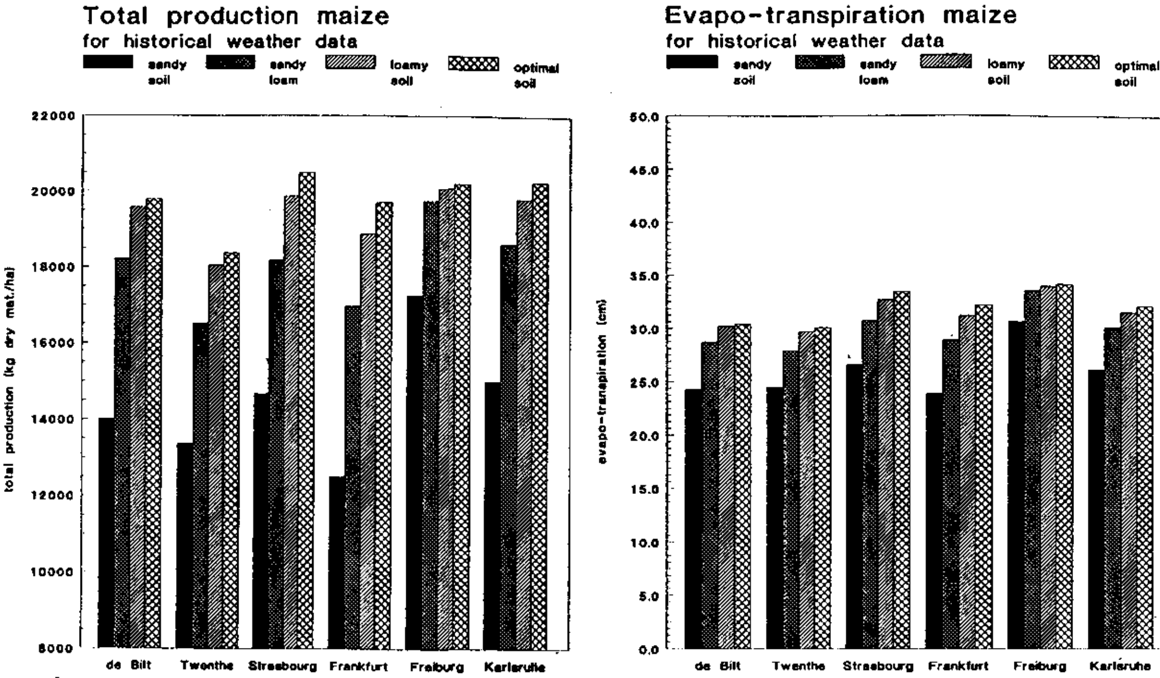

***Fig. 16** Average total production (kg/ha dry matter) and evapo-transpiration (cm) during the growth period of silage maize cultivated in current climate conditions on four different soil types. Average values have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt and Twente, the Netherlands, Strasbourg, France, Frankfurt, Freiburg and Karlsruhe, Germany (see Table 29)*

The standard deviation for the calculated productions is calculated to be about 1500 to 2000 kg/ha for potential production on most locations (Table 29). Only in Twente the standard deviation is 2500 kg/ha which is probably due to the larger risk for yield reduction in relatively cold summers. The standard deviation increases with an increasing risk for water shortage, i.e. from water-limited production on loamy soils to that on loamy sand and sandy soils, and is highest on sandy soils, i.e. 3200 kg/ha in Freiburg (high rainfall), 4500 kg/ha in Frankfurt (low rainfall), and about 4000 kg/ha on the other locations. As the water-holding capacity of most soils in the Rhine basin is not less than that of sandy loam soils, reduction in total production due to water shortage will occur to a limited extent, i.e. not more than 10% on most locations and about 15% on relatively dry locations such as Frankfurt.

5.2.3 Water balance

The highest cumulative evapo-transpiration is calculated for Freiburg and Strasbourg and the lowest for De Bilt and Twente (Figure 16). This difference in evapo-transpiration is mainly related to differences in the amounts of solar radiation received, but the difference in evapo-transpiration is small. Differences in average daily rate of evapo-transpiration between locations are larger, because the growth periods of maize over which evapo-transpirations are calculated, are longer in De Bilt and Twente than in the other locations (Table 6). Evapo-transpiration on loamy soils is about as high as on optimal soils. On sandy loam soils evapo-transpiration is reduced by about 7% on most locations, to a negligible extent (2%) in Freiburg (high rainfall) and more strongly (10%) in low-rainfall locations such as Frankfurt. Only on the sandy soils the evapo-transpiration is reduced by about 20% on most locations, due to a limiting supply of water from rainfall and soil, and again a larger relative decrease is found for Frankfurt and a smaller one for Freiburg. On soils with a relatively high water-holding capacity (loamy soils) or on locations with high rainfall (Freiburg) and soils with a moderate water-holding capacity (sandy loam) reduction in evapo-transpiration and thus in total production are negligible and in other situations these reductions will increase with decreasing rainfall and soil water-holding capacity. For more elaborate information on the variation from one year to the other in crop production and in components of the water balance it is referred to Tables 26 and 29.

5.3 Permanent grassland

Growth of regularly mown grassland and the components of the water balance are simulated over one year, i.e. from January 1 till January 1. In the period from spring upto August 1 grass is assumed to be cut at the moment that at least 3500 kg/ha dry matter can be harvested. In the subsequent months the rate of grass growth decreases and hence, it is assumed that grass is cut at the moment that at least 3000 kg/ha dry matter can be harvested. November 26, the residual amount of harvestable grass is cut. The initial amount of soil water at January 1 is set at the maximum amount per soil type.

5.3.1 Cumulative frequency distribution

Over the period of 20 years an average water-limited production on loamy soils is calculated of 15 000 to 19 000 kg/ha dry matter (Figure 17). Highest production is found on locations with highest temperatures, i.e. Freiburg and Karlsruhe, and the lowest production on locations with lowest temperatures, i.e. Frankfurt, Twente and De Bilt. The standard deviation is calculated to be 2000 to 3000 kg/ha (Table 27), so the annual production varies mainly from 12 000 à 15 000 kg/ha to 17 000 à 19 000 kg/ha. Only in Freiburg the high-rainfall regime (Table 7) results in less variation in production.

For all locations the components of the water balance are calculated for a complete year and hence, comparison of components of the water balance can be done better for grass than for winterwheat or silage maize with their growth periods varying per location. On locations with relatively higher temperatures (Freiburg, Karlsruhe and Strasbourg) grass growth starts earlier in spring and the total period of growth is longer. This results not only in a higher production but also in a higher evapo-transpiration than on the other locations (Figure 17; Table 7). The annual variation in evapo-transpiration on loamy soils is derived to be lowest in Freiburg (high rainfall) and highest in Strasbourg and Frankfurt (low rainfall) (Figure 17; Table 27).

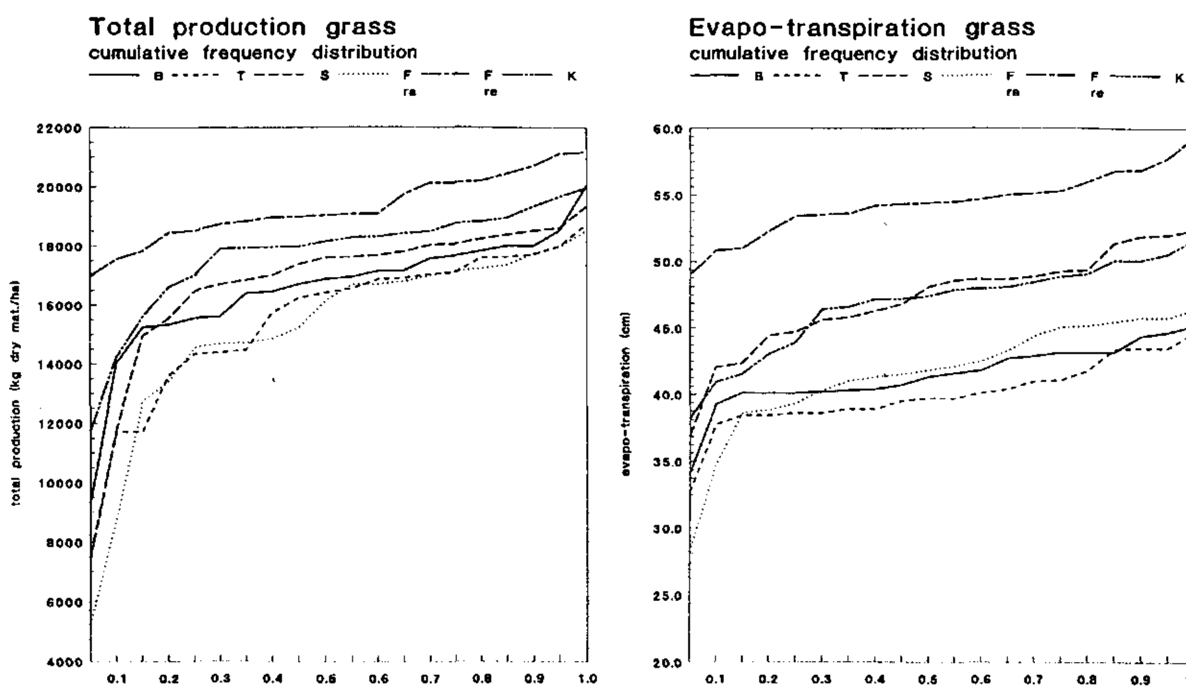

Fig. 17 Cumulative frequency distributions of the total production (kg/ha dry matter) and the evapo-transpiration (cm) per year of mown permanent grassland growing in current climate conditions on loamy soils. Production and evapotranspiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt (B) and Twente (T), the Netherlands, Strasbourg(S), France, Frankfurt (FRA), Freiburg (FRE) and Karlsruhe (K), Germany (see Table 27)

Table 7 Average values for water-limited productions and components of the water balance (cm) per year for mown permanent grassland in De Bilt and Twente, the Netherlands, in Strasbourg, France, and in Frankfurt, Freiburg and Karlsruhe, Germany on loamy soils; average values have been established for historical weather data over a period of 20 years (1969-1988) (see Table 27)

Location	Duration growth period (d)	Dry matter production (kg/ha)	Rainfall	Transpiration	Evaporation	Leaching	Change Soil water
De Bilt	365	16526	79.4	29.6	11.9	37.8	+0.2
Twente	365	15514	72.6	28.0	12.0	32.5	+0.2
Strasbourg	365	16712	62.4	33.9	13.3	15.9	-0.8
Frankfurt	365	15178	63.3	29.8	11.7	21.9	-0.2
Freiburg	365	19287	96.3	39.8	14.6	41.9	+0.0
Karlsruhe	365	17713	78.8	33.9	12.9	31.8	+0.2

5.3.2 Production

The potential production, i.e. the production on the optimal soil, is highest in Freiburg and lowest in Twente and Frankfurt, but the differences between the six locations are limited (Fig. 18). On locations with a higher average temperature the period that grass growth may occur, is longer and hence, the grass production is higher. On locations with a high degree of cloudiness the amount of radiation received (Table 3) and thus grass production is less.

On the loamy soils the average water-limited grass production is reduced by about 10% on most locations compared to the potential production. Exceptions are Freiburg (high rainfall; see Table 7) with almost no decrease in production due to water shortage and Frankfurt (low rainfall) with a relatively larger decrease in production. On the sandy loam and the sandy soils the average water-limited grass production is reduced by about 16% and 30%, respectively on most locations compared to the potential production, and again a larger decrease in production is found in Frankfurt and a smaller one in Freiburg. As the water-holding capacity of most soils in use for agriculture in the Rhine basin is not less than that of sandy loam soils, the relative decrease in grass production will not be more than 16% on most locations and about 24% on relatively dry locations such as Frankfurt.

The standard deviation for the calculated productions is calculated to be about 700 kg/ha for potential production on all locations (Table 30), so the variation in grass production with optimal water supply is very limited. The standard variation increases with increasing risk for water shortage, and amounts 2000 à 3000 kg/ha for the water-limited productions on the loamy and the sandy loam soils, with less variation in Freiburg and more variation in Frankfurt, and amounts 3000 à 3600 kg/ha on sandy soils, with again less variation in Freiburg.

5.3.3 Water balance

The highest cumulative evapo-transpiration on optimal soils is calculated for Freiburg, i.e. 55 cm per year, and the lowest for De Bilt and Twente, i.e. 44 cm per year (Figure 18). This difference in evapo-transpiration is mainly related to differences in average temperature and in amount of solar radiation received. On loamy soils evapo-transpiration is reduced by about 7% compared to that on optimal soils. Only in Freiburg (high rainfall) the decrease in evapo-transpiration is negligible and in Frankfurt (low rainfall) the decrease amounts 11%. On sandy loam and sandy soils evapo-transpiration is reduced further by about 12 and 20%, respectively and again in Freiburg the decrease in evapo-transpiration is much less. From the complete water balance as presented in Table 30, it can be derived that on all locations a decreasing water-holding capacity of the soil, i.e. less capacity to bridge drought periods, results in less transpiration and thus in less production, in more evaporation due to less soil covering by the canopy, and in more leaching from the root zone. Only on soils with a relatively high water-holding capacity (loamy soil) on locations with high rainfall (Freiburg) reduction in evapo-transpiration and thus in grass production are negligible. Hence, practically on all locations additional water supply during drought periods results in a higher grass production. For more elaborate information on the variation from one year to the other in grass production and in components of the water balance it is referred to Tables 27 and 30.

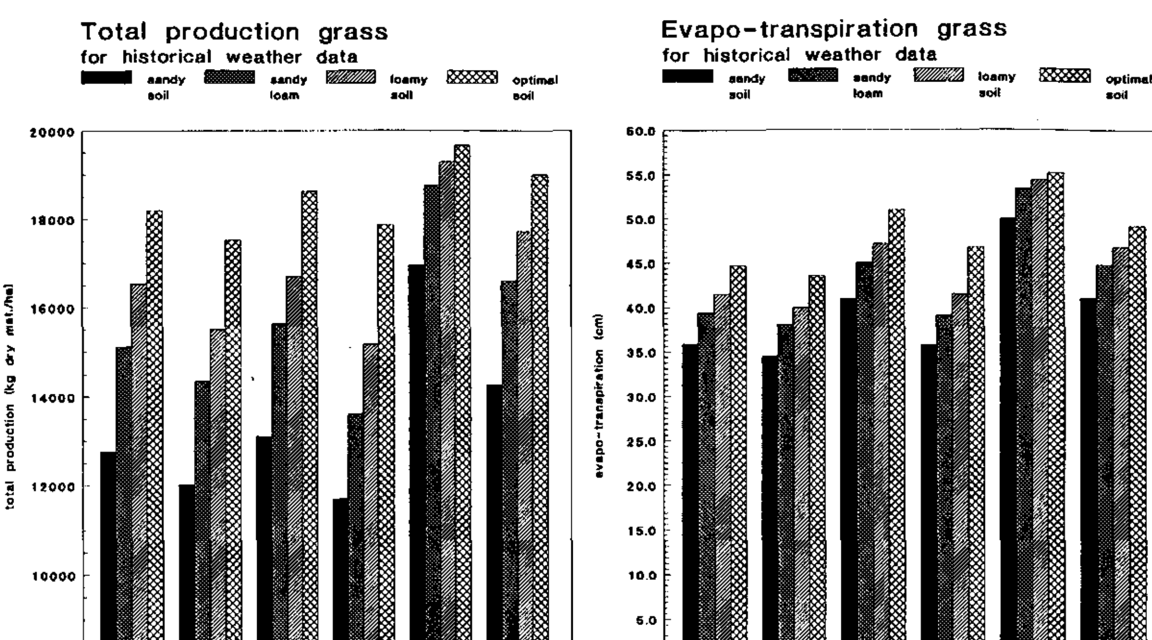

***Fig. 18** Average total production (kg/ha dry matter) and evapo-transpiration (cm) per year of mown permanent grassland growing in current climate conditions on four different soil types. Average values have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt and Twente, the Netherlands, Strasbourg, France, Frankfurt, Freiburg and Karlsruhe, Germany (see Table 30)*

6 RESULTS FOR CHANGED CLIMATE ACCORDING TO BULTOT SCENARIO

Reliable information on climate conditions after doubling the actual atmospheric CO_2 concentration is not available. Best information on the response of the atmosphere to increasing concentrations of greenhouse gasses is provided by general circulation models. These models are detailed, three-dimensional numerical simulation models that describe atmospheric motions, heat exchanges and land - ocean - ice interactions. However, the spatial resolution of the output of general circulation models is too coarse to be of interest for hydrologic studies of river basins. For example, even if such a model is run on one of the fastest computers, the grid area is still about 400 km * 600 km, i.e. the total Rhine basin, and this is unlikely to improve dramatically for many years (Gleick, 1989).

In a study on the impact of climate change at doubling the actual atmospheric CO_2 concentration on the water resources that drain into the Laurentian Great Lakes (Croley, 1990), output from three general circulation models was used. This output indicates the expected changes in climate and is used to make similar changes in historical weather data. The resulting "future" weather data are used in the hydrological model for the Laurentian Great Lakes. The variation in output from the three general circulation models is found to be large, as shown by the expected increase in temperature, varying between 3.7 and 6.2 °C. The three estimates on the expected changes in rainfall were even strongly conflicting. So the output of general circulation models should be received with caution.

Scenarios on climate change are developed for use in hydrological studies. In such scenarios weather parameters are changed to various extents to test their effects on future water resources. But the internal consistency in the changed weather parameters is often a weak point (Gleick, 1989).

Bultot scenario
For river basins in Belgium a scenario of the climate change induced by doubling the actual atmospheric CO_2 concentration, has been reported by Bultot et al., 1988. This scenario applies to an area close to the Rhine basin, is compiled in a consistent way and hence is used for calculating "future" climate conditions in the Rhine basin.
Future climate conditions are calculated from historical weather data (period 1969-1988) by changing the weather data for each location according to the Bultot scenario. The following changes are applied:
- change in air temperature + 3 °C;
- change in precipitation in November, December and January + 10%;
- ,, ,, ,, ,, February, March and April + 16%;
- ,, ,, ,, ,, May, June, July and August - 3%;
- ,, ,, ,, ,, September + 0%;
- ,, ,, ,, ,, October + 7%;
- no change in relative air humidity, hence vapour pressure corrected for increased temperature;
- no change in windspeed (no information in Bultot scenario);
- no change in solar radiation because relative humidity does not change and thereby

cloudiness remains about constant (in Bultot scenario 1.5% increase in cloudiness and hence 2.0% decrease in solar radiation);
- doubled atmospheric CO_2 concentration.

6.1 Winterwheat

Crop growth and components of the water balance are simulated from January 1 till the date of maturing. Crop emergence generally finds place in autumn, so at January 1 a limited amount of crop material is already formed. An estimate for this amount is used as start weight in the crop growth simulation. The initial amount of available soil water at January 1 is set at the maximum amount per soil type.

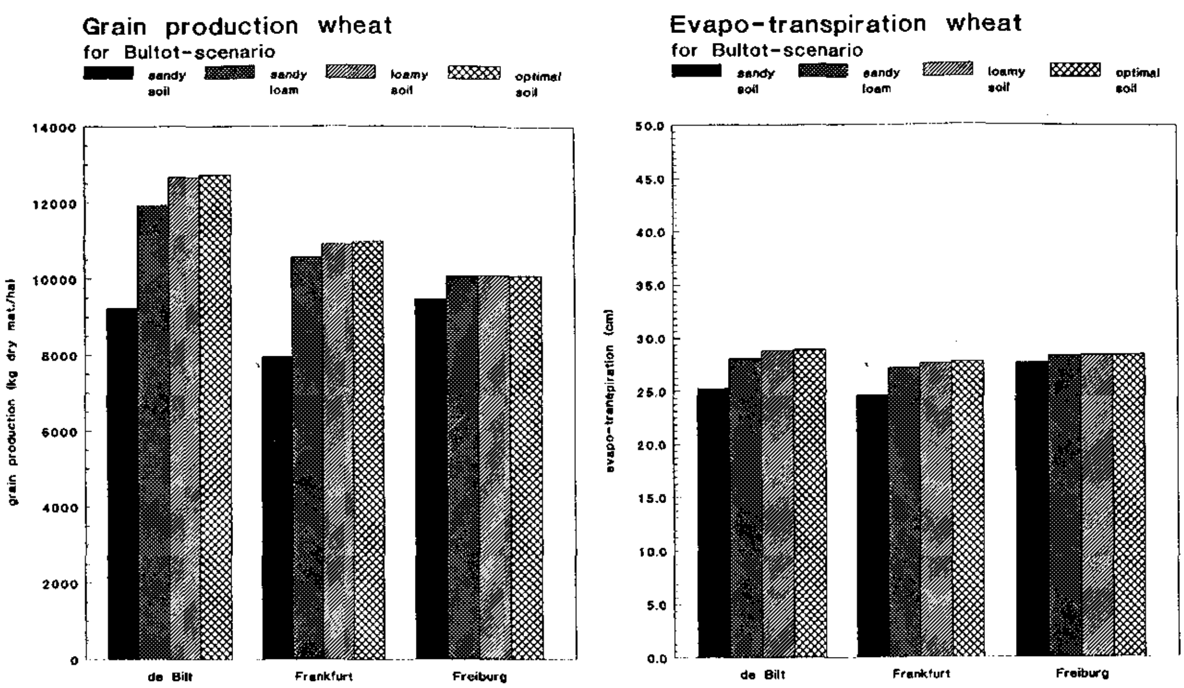

***Fig. 19** Average grain production (kg/ha dry matter) and evapo-transpiration (cm) during the growth period of winterwheat cultivated in future climate conditions on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and Frankfurt and Freiburg, Germany that were changed on the basis of the Bultot scenario (see Table 31)*

6.1.1 Production

Potential grain productions of winterwheat (on optimal soils) calculated for current climate conditions are about 9200 kg/ha dry matter in De Bilt and about 8200 and 8300 kg/ha dry matter in Frankfurt and Freiburg, respectively (Figure 15). For future climate conditions, i.e. the historical weather data that are changed on the basis of the Bultot scenario, the potential grain productions have been calculated again. They were found to increase to 12 700, 11 000 and 10 100 kg/ha dry matter in De Bilt, Frankfurt and Freiburg, respectively (Figure 19). This increase in potential production and the increases in water-limited production on sandy, sandy loam and loamy soils appear to be about identical (Table 8). The production increases at future climate conditions are mainly caused by the doubled CO_2 concentration that allows a larger assimilate production of the leaves (see Section 3.2.3).

The growth period of winterwheat decreases if the average temperature rises. At locations with a relatively high temperature (Freiburg), this results in growth periods that are so short that production increases due to climate change are limited much more strongly than those on locations with relatively lower temperatures (De Bilt) (see Table 8).

Table 8 Changes in average grain production of winterwheat (kg/ha dry matter) due to climate change[1]

Soil	**Location**		
	De Bilt	**Frankfurt**	**Freiburg**
sandy	**+3026**	**+2572**	**+1828**
sandy loam	**+3673**	**+3203**	**+1875**
loamy	**+3658**	**+2927**	**+1838**
optimal	**+3571**	**+2802**	**+1801**

[1] **Change in production results from average grain production calculated for historical weather data that were changed on the basis of the Bultot scenario (Figure 19) minus average grain production for the same location but calculated for unchanged historical weather data (Figure 15)**

6.1.2 Water balance

Cumulative water losses by evapo-transpiration during the growth period, calculated for potential production of winterwheat at current climate conditions, are 35.1, 33.3 and 35.6 cm in De Bilt, Frankfurt and Freiburg, respectively (Figure 15). At future climate conditions these water losses are found to decrease to 28.9, 27.8 and 28.4 cm, respectively (Figure 19).

For water-limited production on the different soil types a comparable decrease in evapo-transpiration is found (Table 9). Only for the sandy soils where at current climate conditions evapo-transpiration is limited by water availability (Figure 15), a lower decrease in evapo-transpiration due to climate change was calculated. The decrease in evapo-transpiration due to climate change can be explained as follows:
- a higher crop production results in more soil coverage and thus in less evaporation;
- a doubled CO_2 concentration results in less transpiration due to increased stomatal resistance (see Section 3.2.3), but this effect is largely compensated by the larger crop production;
- higher air temperature results in a growth period calculated from January 1 till maturing that decreases from 228 to 195 days for De Bilt, from 218 to 191 days for

Frankfurt and from 207 to 181 days for Freiburg (assuming an identical wheat variety in all situations).

Table 9 Changes in average evapo-transpiration (cm) due to climate change for soils cultivated with winterwheat[1]

Soil	Location		
	De Bilt	Frankfurt	Freiburg
sandy	-4.3	-3.6	-6.4
sandy loam	-5.5	-4.6	-6.9
loamy	-6.1	-5.3	-7.0
optimal	-6.2	-5.5	-7.2

[1] Change in evapo-transpiration results from the average evapo-transpiration during the growth period calculated for historical weather data that were changed on the basis of the Bultot scenario (Figure 19) minus the average evapo-transpiration for the same location but calculated for unchanged historical weather data (Figure 15)

If the water balances at current and future climate conditions are compared (Tables 28 and 31), the climate change is found to result in a decrease in evapo-transpiration and consequently in less depletion of available soil water during the growing season. But comparison of water balances over different periods of time can only be of limited value. Therefore, it is referred to the comparison for permanent grassland that compares identical periods (Sections 6.3).

6.2 Silage maize

Crop growth and components of the water balance are simulated from the date of crop emergence, i.e. April 25 for De Bilt, the Netherlands and April 18 for locations in Germany, till the date of crop maturing or the date of harvest. If the maize crop is not yet mature at October 2, it is assumed to be harvested on that date anyway. The date of emergence at future climate conditions has been fixed three weeks earlier than that at current weather conditions (see Section 4.1.2). This is caused by the rise in average temperature of 3 °C. The initial amount of available soil water at crop emergence is set at the maximum amount per soil type minus 3 cm water.

6.2.1 Production

Potential total productions of silage maize (on optimal soils) calculated for current climate conditions, are 19 800, 19 700 and 20 200 kg/ha dry matter in De Bilt, Frankfurt and Freiburg, respectively (Figure 16). For future climate conditions according to the Bultot scenario, the potential total productions have been calculated too and were found to decrease to 19 100, 16 500 and 16 300 kg/ha dry matter in De Bilt, Frankfurt and Freiburg, respectively (Figure 20). Particularly on soils with a small water-holding capacity, water-limited productions were found to increase at future climate conditions or to decrease to much less extent (Table 10). As described in Section 3.2.3, the assimilation rate of silage maize does not change at doubled atmospheric CO_2 concentration but the transpiration rate is reduced considerably. In situations where available water is limiting for production, i.e. on sandy soils and on locations with relatively less precipitation (De Bilt and Frankfurt), the larger water use efficiency at doubled atmospheric CO_2 concentration results in a higher production. Oppositely, if water availability is not limiting for production (i.e. potential production), productions are found to decrease in future by the increased temperature, resulting in a shorter growth period. Particularly on locations with a relatively high temperature (Freiburg), the effect of temperature rise on production is strong (Table 10).

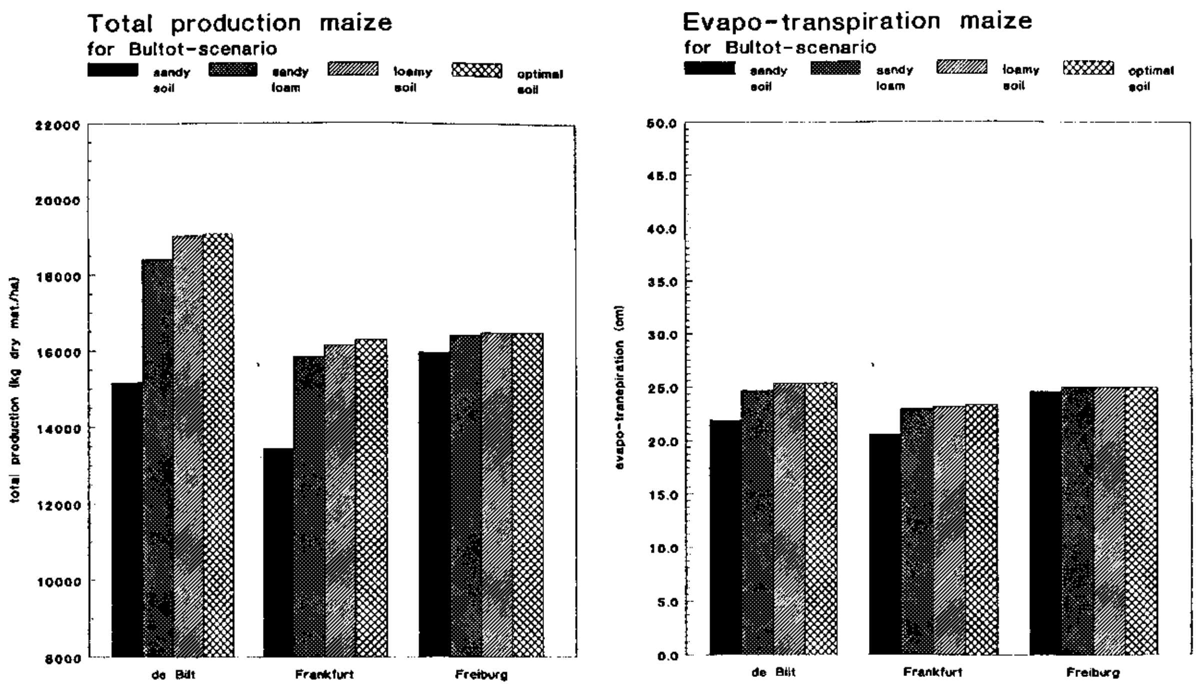

Fig. 20 Average total production (kg/ha dry matter) and evapo-transpiration (cm) during the growth period of silage maize cultivated in future climate conditions on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and Frankfurt and Freiburg, Germany that were changed on the basis of the Bultot scenario (see Table 32)

Table 10 Changes in average total production of silage maize (kg/ha dry matter) due to climate change[1]

Soil	Location		
	De Bilt	Frankfurt	Freiburg
sandy	+1161	+921	-1281
sandy loam	+190	-1128	-3340
loamy	-555	-2729	-3589
optimal	-716	-3422	-3699

[1] Change in production results from average total production calculated for historical weather data that were changed on the basis of the Bultot scenario (Figure 20) minus average total production for the same location but calculated for unchanged historical weather data (Figure 16)

6.2.2 Water balance

Cumulative water losses by evapo-transpiration during the growth period, calculated for potential production of silage maize at current climate conditions, are 30.4, 32.2 and 34.2 cm in De Bilt, Frankfurt and Freiburg, respectively (Figure 16). At future climate conditions these water losses are found to decrease to 25.4, 23.4 and 25.0 cm, respectively (Figure 20). For the water-limited production on the loamy soil a comparable decrease in evapo-transpiration is found (Table 11). For the sandy soil and to less extent also for the sandy loam soil, where at current climate conditions evapo-transpiration is limited by water availability (Figure 16) lower decreases in evapo-transpiration due to climate change were calculated. The decrease in evapo-transpiration due to climate change can be explained as follows:

- a doubled atmospheric CO_2 concentration results in considerably less transpiration due to increased stomatal resistance (see Section 3.2.3);
- higher air temperature results in a growth period between crop emergence and maturing that decreases from 138 to 118 days for De Bilt, from 126 to 110 days for Frankfurt and from 114 to 104 days for Freiburg (assuming identical silage maize variety in all situations).

***Table 11** Changes in average evapo-transpiration (cm) due to climate change for soils cultivated with silage maize*[1]

Soil	**Location**		
	De Bilt	**Frankfurt**	**Freiburg**
sandy	**-2.4**	**-3.3**	**-6.1**
sandy loam	**-4.0**	**-5.9**	**-8.6**
loamy	**-4.8**	**-8.0**	**-9.0**
optimal	**-5.0**	**-8.8**	**-9.2**

[1] **Change in evapo-transpiration results from the average evapo-transpiration during the growth period calculated for historical weather data that were changed on the basis of the Bultot scenario (Figure 20) minus the average evapo-transpiration for the same location but calculated for unchanged historical weather data (Figure 16).**

If the water balances at current and future climate conditions are compared (Tables 29 and 32), the climate change is found to result in a large decrease in transpiration. In De Bilt the amount of rainfall during the shorter growth period in future is reduced to such extent that climate change still results in less leaching from the root zone and in more depletion of available soil water during the growth period. In Frankfurt and Freiburg the amount of rainfall during the shorter growth period in future is reduced to a limited extent and consequently, climate change results in less depletion of available soil water and in more leaching in Freiburg (relatively high rainfall). But comparison between water balances over different periods of time can only be of limited value. Therefore, it is referred to the comparison for permanent grassland that compares identical periods (Section 6.3).

6.3 Permanent grassland

Growth of regularly mown grassland and components of the water balance are simulated over one year, i.e. 365 days. The initial amount of available soil water at January 1 is set at the maximum amount per soil type.

6.3.1 Production

Potential productions of mown permanent grassland (on optimal soils) calculated for current climate conditions, are 18 200, 17 500, 18 600, 17 900, 19 700 and 19 000 kg/ha dry matter in De Bilt, Twente, Strasbourg, Frankfurt, Freiburg and Karlsruhe, respectively (Figure 18). Highest productions are found on locations where the temperature is relatively high, i.e. the period of grass growth is relatively long, and where the amount of solar radiation is relatively high (Freiburg and Karlsruhe, see Table 3). For future climate conditions according to the Bultot scenario, the potential productions have been calculated too and were found to increase to 27 800, 26 800, 27 800, 26 900, 28 600 and 28 100 kg/ha dry matter in De Bilt, Twente, Strasbourg, Frankfurt, Freiburg and Karlsruhe, respectively (Figure 21).

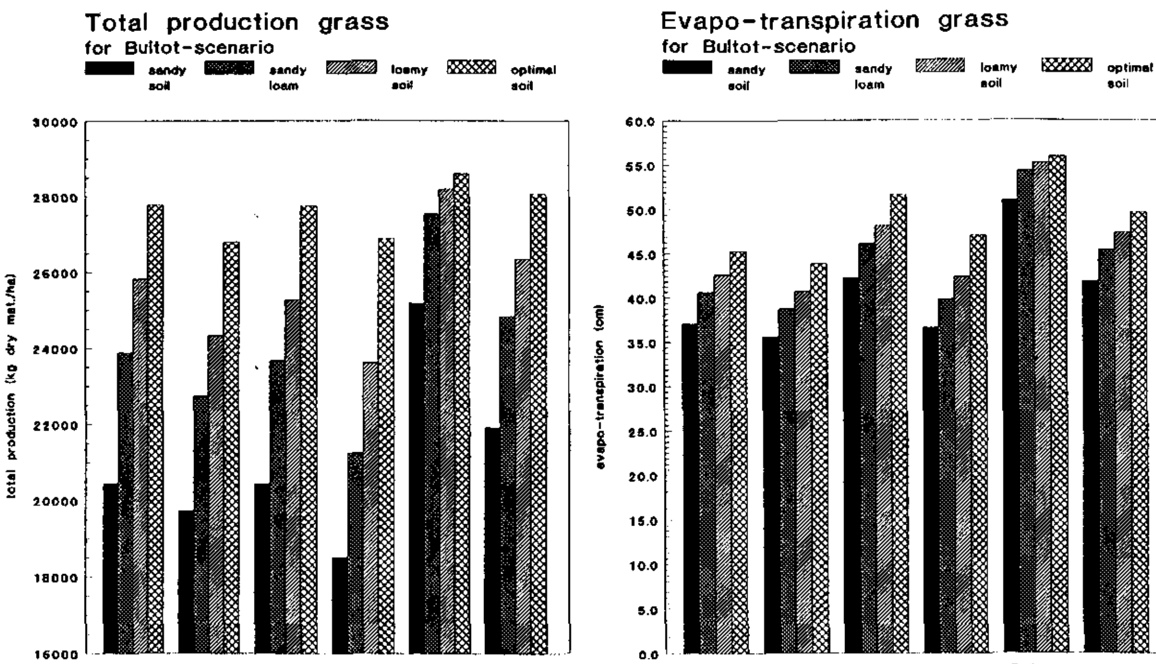

Fig. 21 Average total production (kg/ha dry matter) and evapo-transpiration (cm) per year of mown permanent grassland growing in future climate conditions on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt and Twente, the Netherlands, Strasbourg, France, and Frankfurt, Freiburg and Karlsruhe, Germany that were changed on the basis of the Bultot scenario (see Table 33)

For future climate conditions water-limited productions were found to increase too (Table 12). On soils with relatively high amounts of available soil water, water availability is less limiting for increases in production and hence, highest increases in production due to changed climate are found on loamy soils. The production increases at future climate conditions are mainly caused by the doubled atmospheric CO_2 concentration that allows a larger assimilate production of the leaves (see Section 3.2.3). The rise in temperature extends the period that grass growth may occur and in this way grass production increases to a more limited extent too.

Table 12 Changes in average production of regularly mown grassland (kg/ha dry matter) due to climate change[1]

Soil	Location					
	De Bilt	Twente	Strasbourg	Frankfurt	Freiburg	Karlsruhe
sandy	+7685	+7710	+7333	+6823	+8224	+7668
sandy loam	+8768	+8398	+8059	+7646	+8792	+8231
loamy	+9303	+8829	+8570	+8451	+8900	+8644
optimal	+9593	+9269	+9138	+9025	+8931	+9059

[1] Change in production results from average grass production calculated for historical weather data that were changed on the basis of the Bultot scenario (Figure 21) minus average grass production for the same location but calculated for unchanged historical weather data (Figure 18).

6.3.2 Water balance

Cumulative water losses by evapo-transpiration over the year, calculated for potential production of grassland at current climate conditions, are 44.7, 43.6, 51.0, 46.8, 55.2 and 49.2 cm in De Bilt, Twente, Strasbourg, Frankfurt, Freiburg and Karlsruhe, respectively (Figure 18). At future climate conditions evapo-transpiration is found to increase slightly to 45.3, 43.8, 51.6, 47.0, 55.9 and 49.6 cm, respectively (Figure 21).

For water-limited production on the different soil types the increase in evapo-transpiration by climate change is found to be slightly larger (Table 13). Particularly on soils where at current climate conditions evapo-transpiration is limited more strongly by water availability (sandy and sandy loam soils, see Figure 18), a larger increase in evapo-transpiration due to climate change was calculated. The small increase in evapo-transpiration due to climate change can be explained as follows:
- evaporation increases at higher temperatures (larger vapour pressure deficit) but this effect is partly compensated by the longer period of grass growth resulting in more soil coverage;
- a doubled CO_2 concentration results in less transpiration due to increased stomatal resistance (see Section 3.2.3), but this effect is largely compensated by a longer period of grass growth at the higher temperatures in future.

Table 13 Changes in average evapo-transpiration (cm) due to climate change for regularly mown permanent grassland[1]

Soil	Location					
	De Bilt	Twente	Strasbourg	Frankfurt	Freiburg	Karlsruhe
sandy	+1.2	+1.1	+1.2	+0.8	+1.0	+0.9
sandy loam	+1.2	+0.7	+1.0	+0.7	+0.9	+0.6
loamy	+1.1	+0.7	+0.9	+0.9	+0.8	+0.5
optimal	+0.6	+0.2	+0.6	+0.2	+0.7	+0.4

1 Change in evapo-transpiration results from the average evapo-transpiration per year calculated for historical weather data that were changed on the basis of the Bultot scenario (Figure 21) minus the average evapo-transpiration for the same location but calculated for unchanged historical weather data (Figure 18).

If the water balances at current and future climate conditions are compared (Tables 30 and 33), climate change is found to result in a small increase in evapo-transpiration and in a relatively larger increase in annual amount of rainfall. As over a period of one year the change in available soil water is about zero, leaching from the root zone is calculated to increase by about 10% due to climate change.

6.4 Permanent grassland under modified Bultot scenario

The changes in weather data on the basis of the Bultot scenario consist of a rise in temperature (+ 3 °C), a changed rainfall distribution (more rainfall in winter and slightly less in summer) and a doubled atmospheric CO_2 concentration. As these changes affect production and evapo-transpiration in different ways, the sensitivity of results of the Bultot scenario to changes in temperature and rainfall distribution has been determined. This has been done by calculating the average production and the average components of the water balance for mown permanent grassland in De Bilt, the Netherlands. These average values have been established for historical weather data over a period of 20 years (1969-1988) that were changed as follows:

- doubled atmospheric CO_2 concentration;
- no change in relative air humidity (vapour pressure corrected for higher temperature);
- actual daily average temperature increased by 1, 3 and 5 °C;
- unchanged historical rainfall data or historical rainfall data changed on the basis of the Bultot scenario or historical rainfall data changed two times as strongly as according to the Bultot scenario.

6.4.1 Production

In Figure 22 the sensitivity of grass production to changes in temperature and rainfall distribution is shown. The grass production calculated on the basis of the Bultot scenario is indicated by B (Bultot), T (Temperature) + 3 in this figure. Potential production of mown permanent grassland (on optimal soils) calculated for current climate conditions in De Bilt, the Netherlands (Figure 18), increases from 18 200 kg to 26 100, 27 800 and 28 300 kg/ha dry matter, if atmospheric CO_2 concentration is doubled and average temperature increases by 1, 3 and 5 °C, respectively (Figure 22). Rainfall distribution has of course no influence on the level of potential production. Higher temperature extends the period of grass growth and hence the potential production but the doubled atmospheric CO_2 concentration that allows a larger assimilate production of the leaves (see Section 3.2.3), causes clearly a much larger increase in production.

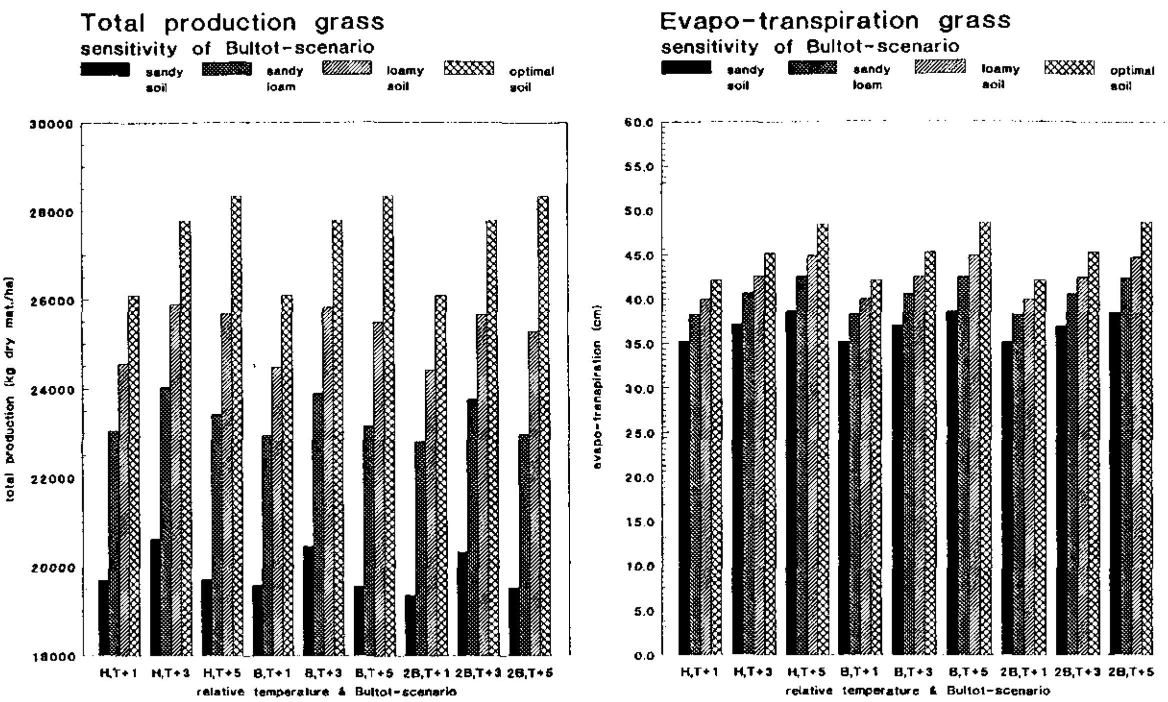

***Figure 22** Sensitivity to changes in temperature and rainfall distribution of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) per year of mown permanent grassland growing in future climate conditions on four different soil types. Production and evapo-transpiration have been established for historical weather data (H) over a period of twenty years (1969-1988) from De Bilt, the Netherlands, with doubled CO_2 concentration and a daily average temperature increased by 1, 3 and 5 °C, for historical weather data of which also the rainfall data were changed on the basis of the Bultot scenario (B) and for historical weather data of which the rainfall data were changed two times as strongly as according to the Bultot scenario (2B) (see Table 34)*

In Table 14 the water-limited productions are found to increase considerably too. This increase is also caused mainly by the doubled atmospheric CO_2 concentration. Rising temperature increases production first by extending the period of grass growth but if temperature rises further (T + 5 °C), the increased rate of evapo-transpiration causes larger periods of water shortage and hence the level of water-limited production decreases again. On soils with a large (small) amount of available water, i.e. loamy (sandy) soils, where periods of water shortage occur over limited (long) periods of time, the largest (smallest) increases in production are found. If the amount of rainfall increases and at the same time rainfall becomes more unevenly distributed over the year, in the order of historical data, data changed according to Bultot scenario and data changed two times as strongly as according to Bultot scenario, the increase in water-limited production is slightly less for the more uneven rainfall distribution.

*Table 14 Change in average production[1] of regularly mown grassland (kg/ha dry matter) in De Bilt, the Netherlands due to doubled atmospheric CO_2 concentration in combination with various changes in temperature and rainfall[2]: daily average temperature increased by 1, 3 and 5 °C (T +1, T + 3, T + 5) and unchanged historical rainfall data over a period of 20 years (1969-1988) for De Bilt (HIST) or historical rainfall data changed on the basis of the Bultot scenario (BULT) or historical rainfall data changed two times as strongly as according to the Bultot scenario (2*BULT)*

Rainfall distribution, temperature	Soil			
	sandy	sandy loam	loamy	optimal
HIST, T + 1	6915	7932	8038	7910
HIST, T + 3	7842	8913	9370	9593
HIST, T + 5	6933	8306	9160	10148
BULT, T + 1	6807	7847	7961	7910
BULT, T + 3	7685	8768	9303	9593
BULT, T + 5	6784	8035	8980	10148
2*BULT, T + 1	6591	7689	7896	7910
2*BULT, T + 3	7552	8635	9152	9593
2*BULT, T + 5	6749	7857	8771	10147

1 Change in production results from average grass production calculated for the changed weather data (Figure 22) minus average grass production calculated for unchanged historical weather data (Figure 18).
2 The combination BULT, T + 3 represents the Bultot scenario.

6.4.2 Water balance

The average amount of water losses by evapo-transpiration over the year, calculated for potential production of grassland at current climate conditions in De Bilt, the Netherlands, is 44.7 cm (Figure 18). At future climate conditions according to the Bultot scenario evapo-transpiration is found to increase by 0.6 cm (Table 15: BULT, T + 3). With increasing temperature the evapo-transpiration increases as result of the increasing vapour pressure deficit and the increasing length of the growth period. If the daily average temperature has been changed only by 1 °C, evapo-transpiration is found to be less than that at current climate conditions, which means that the effect of doubled atmospheric CO_2 concentration on the transpiration (increased stomatal resistance) is larger than the temperature effect. Rainfall distribution has of course no effect on the evapo-transpiration of the potential production situation.

*Table 15 Change in average evapo-transpiration[1] (cm) of regularly mown grassland in De Bilt, the Netherlands due to doubled CO_2 concentration in combination with various changes in temperature and rainfall[2]: daily average temperature increased by 1, 3 and 5 °C (T +1, T + 3, T + 5) and unchanged historical rainfall data over a period of 20 years (1969-1988) for De Bilt (HIST) or historical rainfall data changed on the basis of the Bultot scenario (BULT) or historical rainfall data changed two times as strongly as according to the Bultot scenario (2*BULT)*

Rainfall distribution, temperature	Soil			
	sandy	sandy loam	loamy	optimal
HIST, T + 1	-0.7	-1.1	-1.5	-2.6
HIST, T + 3	+1.3	+1.3	+1.1	+0.5
HIST, T + 5	+2.8	+3.2	+3.4	+3.8
BULT, T + 1	-0.7	-1.1	-1.5	-2.6
BULT, T + 3	+1.2	+1.2	+1.1	+0.6
BULT, T + 5	+2.7	+3.1	+3.4	+3.9
2*BULT, T + 1	-0.8	-1.1	-1.5	-2.5
2*BULT, T + 3	+1.1	+1.2	+1.0	+0.6
2*BULT, T + 5	+2.6	+3.0	+3.2	+4.0

1 Change in evapo-transpiration results from average evapo-transpiration calculated for the changed weather data (Figure 22) minus average evapo-transpiration calculated for unchanged historical weather data (Figure 18).

2 The combination BULT, T + 3 represents the Bultot scenario.

For the water-limited productions the highest amount of evapo-transpiration is also found at the highest average temperature (Figure 22). The effect of rainfall distribution on evapo-transpiration is very small. If the rainfall distribution is more even, the evapo-transpiration is a little higher (Table 15). At doubled CO_2 concentration, transpiration is reduced due to increased stomatal resistance but this effect is compensated by the effect of rising average temperature on vapour pressure deficit and length of the growing period (Table 15). If water availability is not or almost not limiting for evapo-transpiration (loamy and optimal soils), the effect of temperature on the evapo-transpiration appears to be larger than that on sandy and sandy loam soils.

If the water balances are compared (Table 34), increase in average temperature results in an increase in evapo-transpiration. Hence, leaching from the root zone is calculated to decrease by about 10%. If the historical rainfall data are changed according to the Bultot scenario or are changed two times as strongly as according to Bultot scenario (amount of rainfall increases and rainfall distribution becomes more uneven), leaching is calculated to increase by about 10% and 20%, respectively.

7 SENSITIVITY TO CHANGES IN CLIMATE PARAMETERS

The weather parameters that determine crop production directly, are atmospheric CO_2 concentration, solar radiation and temperature, and those that determine the water balance, are rainfall, windspeed, vapour pressure and again solar radiation and temperature. These parameters have been changed separately to various extents. In this way the sensitivity of crop production and components of the water balance to changing values for each parameter can be derived.

Weather data used for these calculations were the historical weather data over a period of 20 years (1969-1988) from De Bilt, the Netherlands. In each sensitivity analysis historical data for one parameter were changed in the model in the way described in Sections 7.1-7.6.

7.1 Atmospheric CO_2 concentration

The CO_2 concentration has been assumed to vary between the present concentration (350 µmol/mol) and three times the present concentration. Effects of such increases in atmospheric CO_2 concentration on plant behaviour were treated in Section 3.2.3. They consist mainly of:
- a change in CO_2 assimilation - light response curve for C3 crops;
- an increasing thickness of leaves;
- a decrease in transpiration rate for C4 crops (maize) and to less extent for C3 crops (wheat, grass).

7.1.1 Winterwheat

Potential grain production increases from 9200 kg/ha dry matter at present atmospheric CO_2 concentration to 13 700 and 15 600 kg/ha dry matter at doubled and tripled CO_2 concentrations (Figure 23). Water-limited grain productions on sandy loam and loamy soils are almost identical to the potential production, both at the present and at doubled and tripled CO_2 concentrations. Only on sandy soils grain production is reduced considerably due to prolonged periods with drought stress, to the same extent at the present and at doubled and tripled CO_2 concentrations.

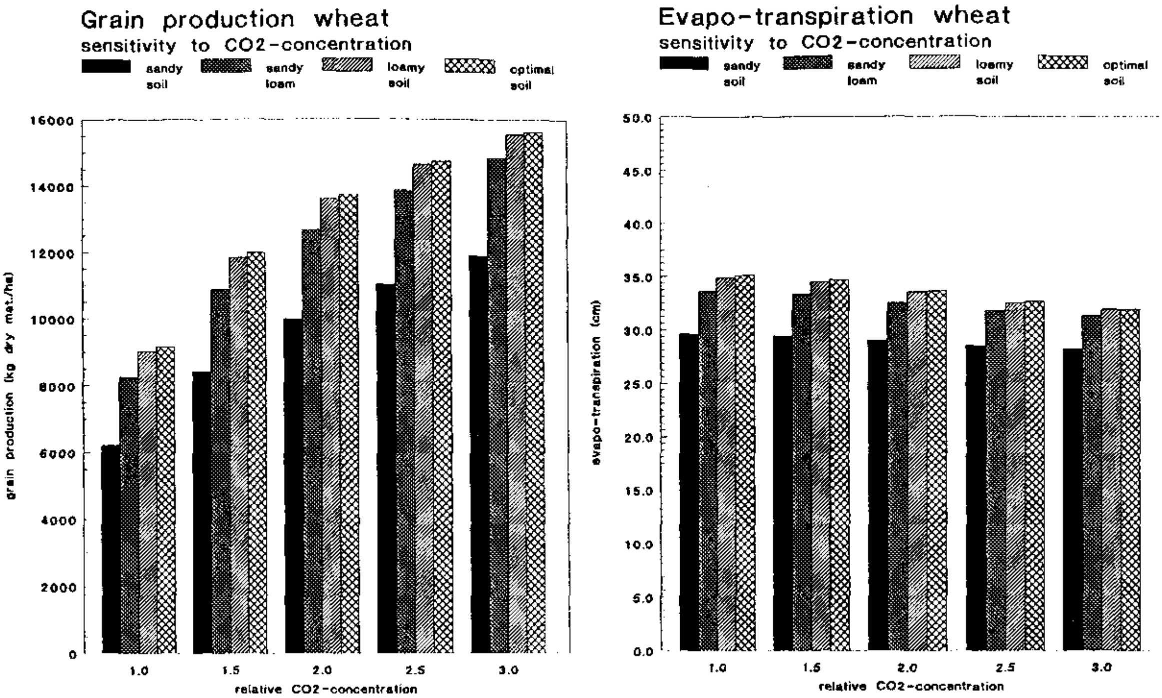

***Fig. 23** Sensitivity to changes in atmospheric CO_2 concentration of the average grain production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of winterwheat cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in CO_2 concentration from the actual to three times the actual concentration (see Table 35)*

Cumulative evapo-transpiration during the growth period (from January 1 till moment of crop maturing) decreases at increasing CO_2 concentrations, both at potential and at water-limited production situations (Figure 23). This decrease can be explained as follows:

- a higher CO_2 concentration results in less transpiration due to increased stomatal resistance;
- a higher crop production at increased CO_2 concentration results in more soil coverage and thus in less evaporation.

Only on the sandy soil, transpiration is strongly limited due to drought stress and consequently, higher CO_2 concentrations result only in a limited decrease in transpiration and this effect is just compensated by the increase in transpiration as result of the higher crop production.

If the water balances at increasing CO_2 concentrations are compared (Table 35), increase in CO_2 concentration is found to result in a decrease in evapo-transpiration and consequently, in more leaching from the root zone and in less depletion of available soil water during the growth period.

7.1.2 Silage maize

Potential total production is 20 200 kg/ha dry matter at present atmospheric CO_2 concentration and does not change at doubled and tripled CO_2 concentrations (Figure 24). Water-limited total production on loamy soil is about identical, as on that soil type water availability is not limiting for crop production. On sandy loam and sandy soils production is limited slightly and considerably, respectively due to periods with drought stress at present atmospheric CO_2 concentration. As at higher CO_2 concentrations the transpiration rate of maize is reduced strongly, the degree of drought stress becomes more limited and yields, particularly on sandy soils, will increase considerably.

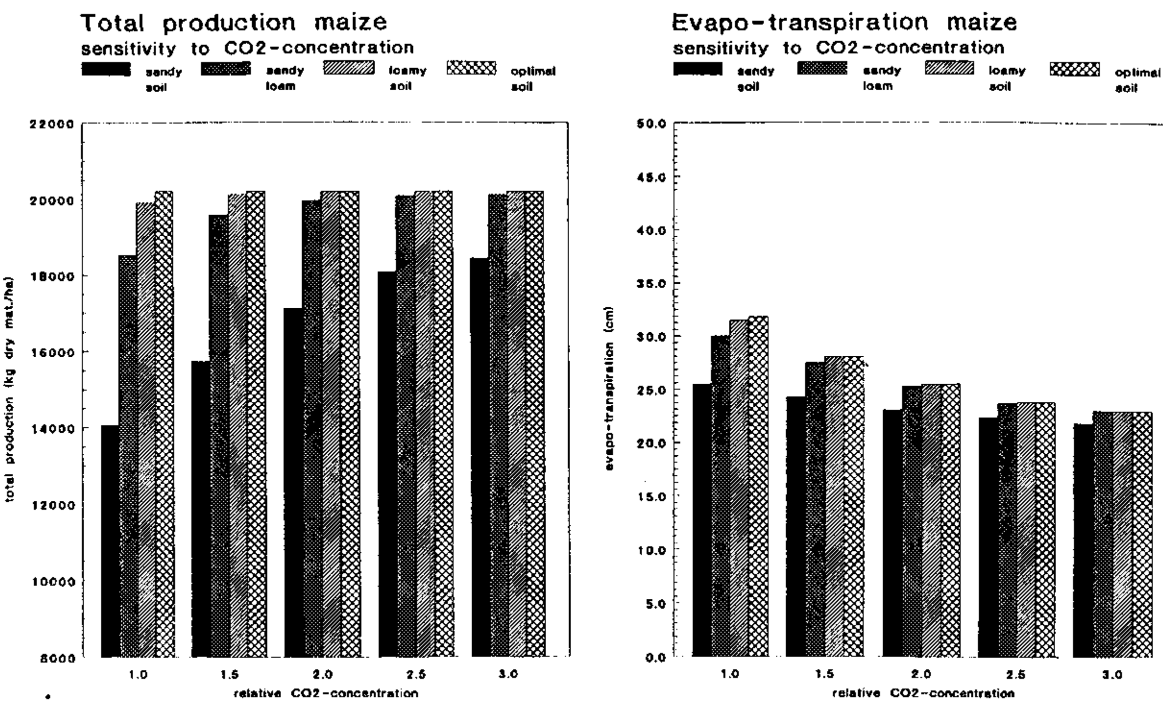

***Fig. 24** Sensitivity to changes in atmospheric CO_2 concentration of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of silage maize cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in CO_2 concentration from the actual to three times the actual concentration (see Table 35)*

Cumulative evapo-transpiration during the growth period (from crop emergence at May 5 till moment of crop maturing or date of harvest (set at October 2 when crop is not yet mature at that date)) decreases strongly at increasing CO_2 concentrations (Figure 24). This decrease can be explained from the decrease in crop transpiration rate due to increased stomatal resistance at higher CO_2 concentrations. On sandy soils, transpiration at present is strongly limited due to drought stress and consequently, higher CO_2 concentrations result in a more limited decrease in transpiration.

If the water balances at increasing CO_2 concentrations are compared (Table 35), increase in CO_2 concentration is found to result in a decrease in evapo-transpiration and consequently, in more leaching from the root zone and in less depletion of available soil water during the growing season.

7.1.3 Permanent grassland

Potential production of grassland is 18 200 kg/ha dry matter at present atmospheric CO_2 concentration and increases to 24 800 and 27 000 kg/ha dry matter at doubled and tripled CO_2 concentrations (Figure 25). Water-limited production on the different soil types increases with increasing CO_2 concentrations to the same extent as the potential production. Hence, the yield reduction due to drought stress, increasing from production on loamy soils to that on sandy loam and sandy soils, does not change with increasing CO_2 concentrations.

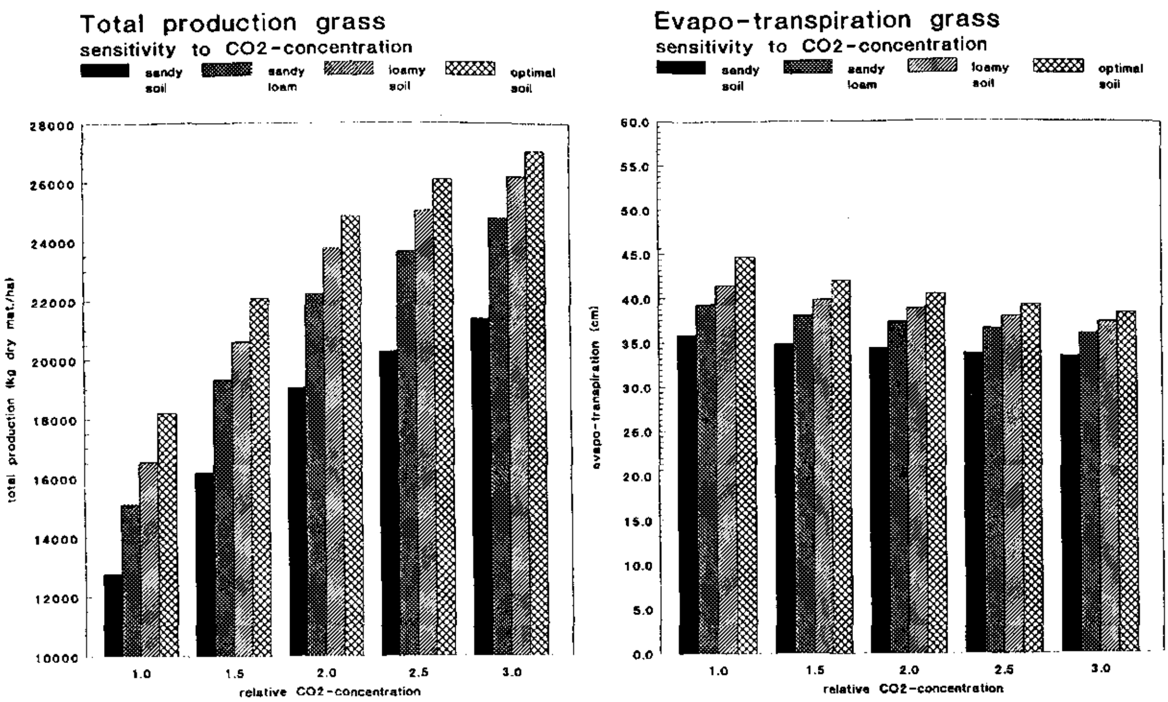

***Fig. 25** Sensitivity to changes in atmospheric CO_2 concentration of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) per year of mown permanent grassland growing on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in CO_2 concentration from the actual to three times the actual concentration (see Table 35)*

Cumulative evapo-transpiration during one year (i.e. 365 days) decreases at increasing CO_2 concentrations, considerably at the potential production situation and slightly at water-limited production on sandy loam and sandy soils (Figure 25). This decrease can be explained from the decrease in crop transpiration rate due to increased stomatal resistance at higher CO_2 concentrations. On sandy loam and particularly on sandy soil where at present transpiration is strongly limited due to drought stress, higher CO_2 concentrations result in a more limited decrease in transpiration.

If the water balances at increasing CO_2 concentrations are compared (Table 35), increase in CO_2 concentration is found to result in a decrease in evapo-transpiration and consequently in more leaching from the root zone.

7.2 Temperature

The temperature has been varied between 1 °C below and 5 °C above the actual daily air temperatures in De Bilt, the Netherlands. To prevent an unintended effect on the evaporative demand of the air, the actual relative air humidity is kept constant by correcting the vapour pressure for the change in temperature. Increases in temperature influence crop production and the water balance in the following ways:

- the growing season of crops is abbreviated;
- the evaporative demand of the air increases slightly.

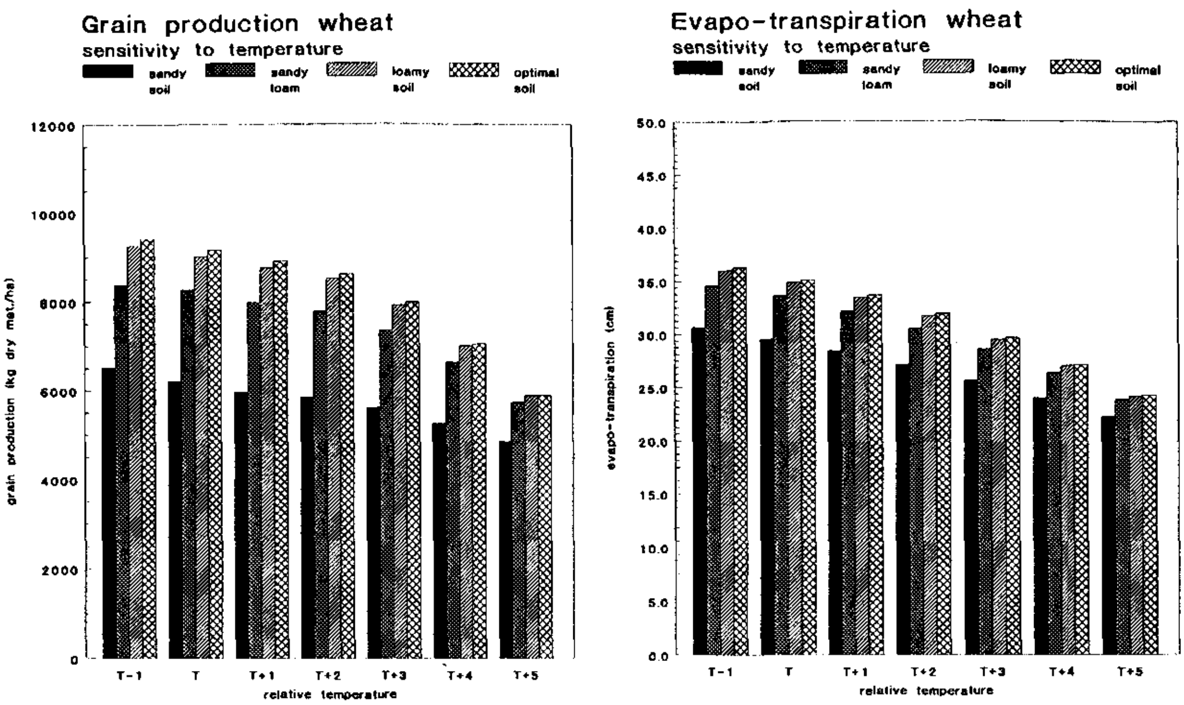

Fig. 26 Sensitivity to changes in average daily air temperature of the average grain production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of winterwheat cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in average daily temperature from 1 °C below to 5 °C above the actual temperature (see Table 36)

7.2.1 Winterwheat

Potential grain production decreases from 9400 kg/ha dry matter at 1 °C below actual temperatures in De Bilt (T - 1) to 9200 kg/ha at actual temperatures (T) and to 8000 and 5900 kg/ha dry matter at 3 °C and 5 °C above actual temperatures (T + 3, T + 5), respectively (Figure 26). Simultaneously, the duration of the growth period considered (from January 1 till moment of crop maturing) decreases from 241 days at (T -1) to 228 days at (T), to 195 days at (T+ 3) and to 177 days at (T + 5). This decrease in growth duration causes the large decrease in grain production at higher temperatures. It should be kept in mind that in all situations the calculations are done for the same wheat variety.

At actual temperatures (T) water-limited grain productions on sandy loam and on sandy soils are reduced slightly and strongly, respectively due to periods with drought stress. At higher temperatures the growth duration decreases to such extent that on these soils the reductions in grain production due to drought stress become less (Figure 26).

Cumulative evapo-transpiration during the growth period decreases at increasing temperatures, both at potential and at water-limited production situations (Figure 26). This decrease is caused by the large decrease in duration of the growth period as described above, which results in a strong reduction of crop transpiration and a limited reduction of soil evaporation.

If the water balances at increasing temperatures are compared (Table 36), increase in temperature is found to result in a shorter growth period and thus in less evapo-transpiration but also in lower amounts of rainfall. It is calculated that this results in less leaching from the root zone but also in less depletion of available soil water at increasing temperatures. But such comparison between water balances over different periods of time can only be of limited value. Therefore, it is referred to the comparison for permanent grassland, which compares identical periods (Section 7.2.3).

7.2.2 Silage maize

Potential total production increases from 18 200 kg/ha dry matter at 1 °C below actual temperatures (T - 1) in De Bilt to 20 200 and 20 800 kg/ha at actual and 1 °C above actual temperatures (T, T + 1), respectively and decreases again to 19 300 and 16 900 kg/ha dry matter at 3 and 5 °C above actual temperatures (T + 3, T + 5), respectively (Figure 27). Simultaneously, the duration of the growth period (from crop emergence at May 5 till moment of crop maturing or date of harvest (set at October 2 when crop is not yet mature at that date)) decreases from 150 days at (T - 1) to 145 days at (T), 134 days at (T + 1) and 112 and 98 days at (T + 3) and (T + 5), respectively. At relatively low temperatures the assimilation process in maize is reduced and hence, crop production at (T) and (T - 1) is a little lower. At relatively high temperatures the growth duration becomes so short that crop production is reduced too. It should be kept in mind that in all situations the calculations are done for the same maize variety for one date of emergence (May 5). In reality a rise in temperature of 1 °C results generally in a date of sowing and hence of emergence advanced by one week. Such a shift in emergence date would reduce the effect of higher temperatures on crop production considerably, but that is not done to allow comparison between the different sensitivity analyses.

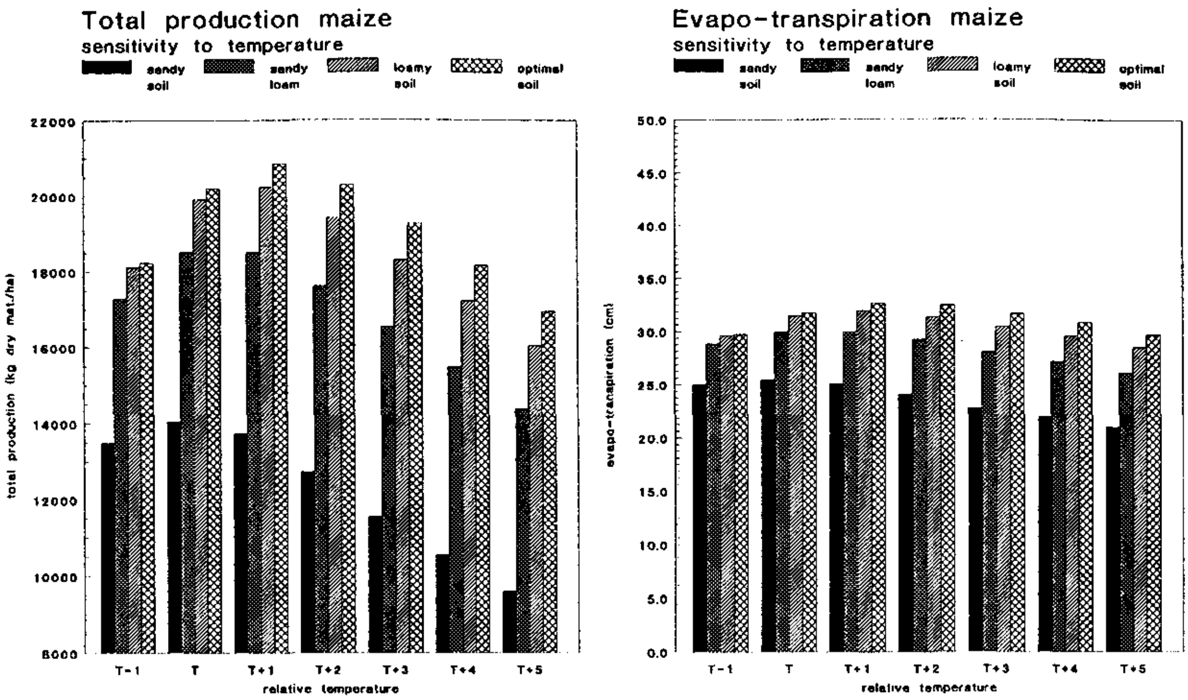

***Fig. 27** Sensitivity to changes in average daily air temperature of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of silage maize cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in average daily temperature from 1 °C below to 5 °C above the actual temperature (see Table 36)*

At actual temperatures (T) water-limited total productions on sandy loam and on sandy soils are reduced slightly and strongly, respectively due to periods with drought stress. At higher temperatures the duration of the growth period decreases and simultaneously, the amount of rainfall in this period decreases considerably too. This results in a longer period with drought stress and in a larger reduction of the water-limited productions on these soils compared to potential production (Figure 27).

Cumulative evapo-transpiration during the growth period increases at increasing temperatures due to the larger evaporative demand of the air and the larger amount of plant material on the field, resulting in a higher transpiration rate. If temperatures rise further, the growth period becomes so short that evapo-transpiration is reduced again (Figure 27). On sandy soils the water availability is strongly limiting for evapo-transpiration and crop production. At increasing temperatures the duration of the growth period becomes shorter and the amount of rainfall during this period becomes lower. Hence, the amount of available water (from soil and rainfall) becomes less and evapo-transpiration is reduced even more strongly than at actual temperatures.

If the water balances at increasing temperatures are compared (Table 36), increase in temperature is found to result in a shorter growth period and thus in lower amounts of rainfall. It is calculated that this results in less leaching from the root zone and in more depletion of available soil water at increasing temperatures. But such comparisons between water balances over different periods of time can only be of limited value. Therefore, it is referred to the comparison for permanent grassland (Section 7.2.3).

7.2.3 Permanent grassland

Potential production of grassland increases from 17 300 kg/ha dry matter at 1 °C below actual temperatures in De Bilt (T - 1) to 18 200 kg/ha at actual temperatures (T) and to 20 200 and 20 300 kg/ha dry matter at 3 and 5 °C above actual temperatures (T + 3, T + 5), respectively (Figure 28). The duration of the growth period considered is 365 days for all situation but at increasing temperatures the period that grass may really grow, increases. In this way higher temperatures will result in a higher production upto that temperature (T + 4) where yeararound grass growth becomes possible.

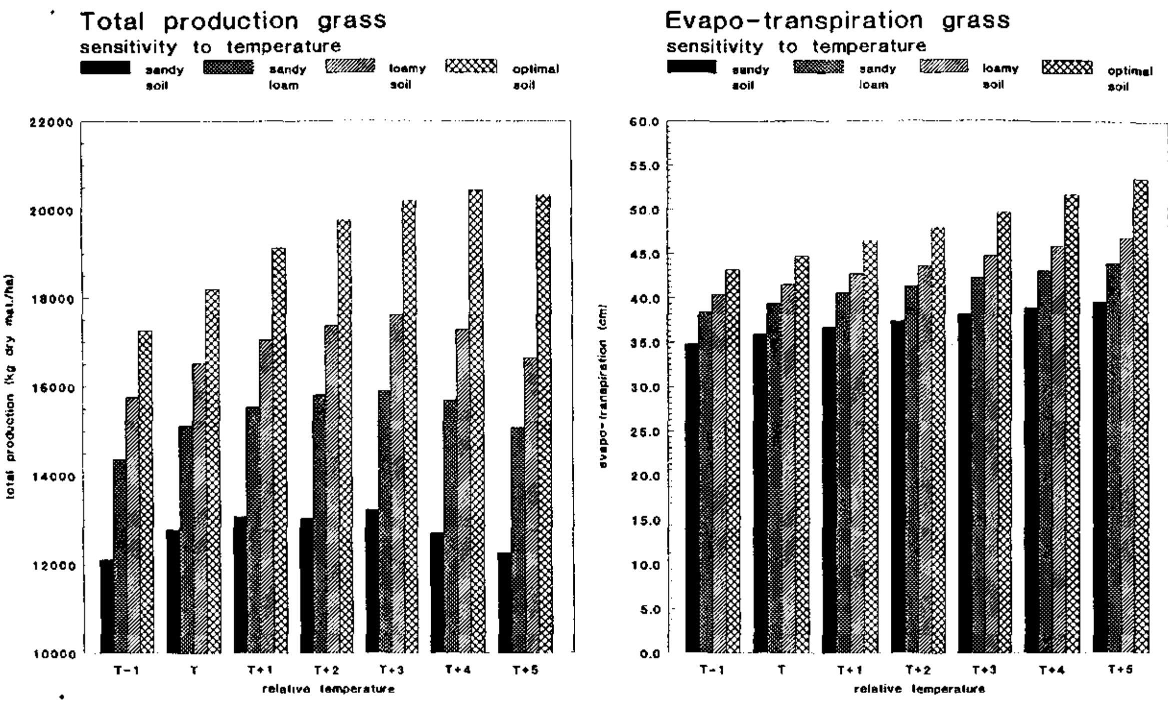

***Fig. 28** Sensitivity to changes in average daily air temperature of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) per year of mown permanent grassland growing on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in average daily temperature from 1 °C below to 5 °C above the actual temperature (see Table 36)*

At actual temperatures (T) water-limited production of grassland is limited strongly by the available amount of soil water. Hence, production on sandy loam and sandy soils is reduced strongly due to periods of drought stress (Figure 28). At increasing temperatures the productions may increase due to extension of the period that grass may really grow, but on sandy and sandy loam soils this effect is largely nullified by the increasing evaporative demand of the air and hence, increased periods of drought stress.

Cumulative evapo-transpiration over the year increases with increasing temperature (Figure 28). This increase is highest for the potential production situation and is lowest for water-limited production on sandy soils, where the available amount of soil water is lowest and is most limiting for evapo-transpiration. The increase in evapo-transpiration can be explained as follows:

- the period that grass may really grow, is extended if temperature rises;
- increasing evaporative demand of the air that results in a larger crop transpiration and in a larger evaporation from the soil surface.

If the waterbalances at increasing temperatures are compared (Table 36), increase in temperature is found to result in more evapo-transpiration and hence, in less leaching from the root zone.

7.3 Rainfall

The rainfall data used have been varied between 0.70 times and 1.30 times the actual daily rainfall data from De Bilt, the Netherlands. Changes in rainfall result in changed amounts of available soil water and thereby affect crop production and evapo-transpiration.

7.3.1 Winterwheat

Potential grain production in De Bilt is 9200 kg/ha dry matter. It is not limited by available soil water and thus is not affected by changes in rainfall. For the actual rainfall data water-limited grain productions were found to be reduced considerably on soils with a limited amount of available soil water. For example, productions on the sandy loam and the sandy soils were calculated to be reduced to 8300 and 6200 kg/ha dry matter, respectively (Figure 29). If the amounts of rainfall are set to 70% of the actual rainfall data, grain yields on sandy loam and sandy soils are reduced further to 7400 and 4600 kg/ha dry matter respectively. If on the other hand, the amounts of rainfall are set to 130% of the actual rainfall data, grain yields on sandy loam and sandy soils become higher, i.e. 8600 and 7000 kg/ha dry matter, respectively.

For cumulative evapo-transpiration the lowest value is found if both the amount of rainfall and the amount of available soil water are small. Hence, on sandy soils the largest increase in evapo-transpiration due to increasing amounts of rainfall is found (Figure 29).

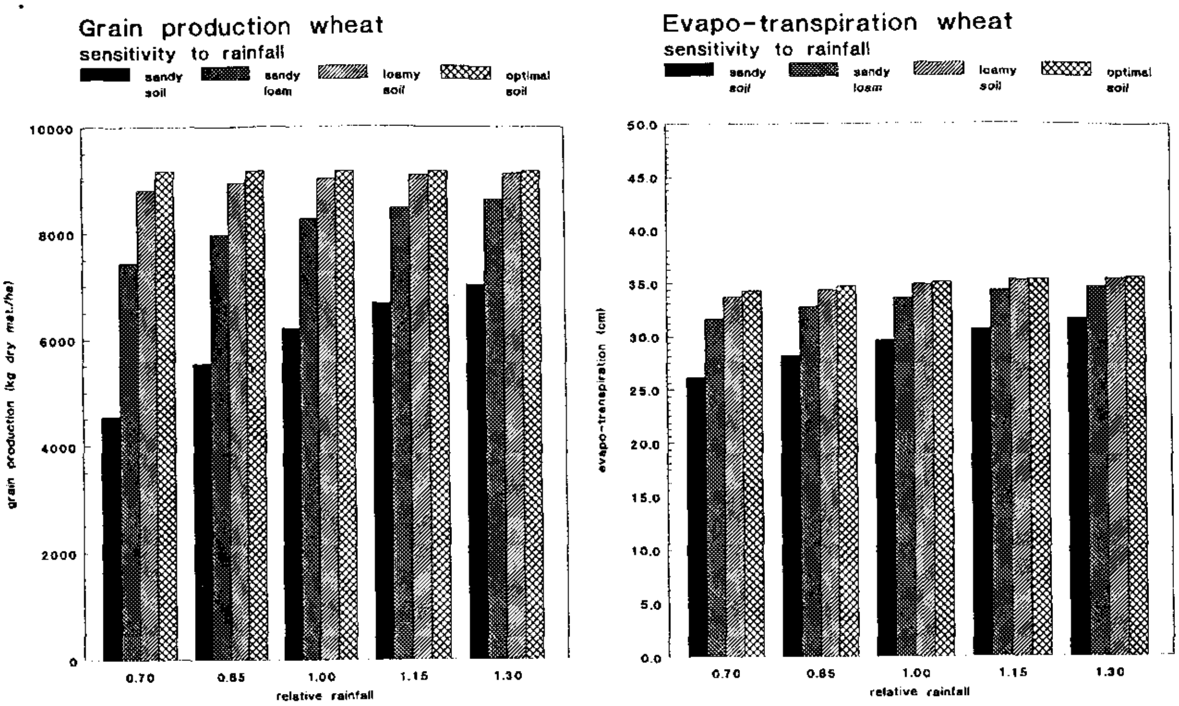

***Fig. 29** Sensitivity to changes in amount of rainfall of the average grain production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of winterwheat cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for daily rainfall data changing from 0.7 to 1.3 times the actual rainfall data (see Table 37)*

If the water balances at increasing amounts of rainfall are compared (Table 37), increase in rainfall is found to result mainly in more leaching from the root zone and also in more evapo-transpiration and in less depletion of available soil water.

7.3.2 Silage maize

Potential total production in De Bilt is 20 200 kg/ha dry matter. It is not limited by available soil water and thus is not affected by change in rainfall. For the actual rainfall data the water-limited productions were found to be reduced considerably on soils with a limited amount of available soil water. For example, the productions on sandy loam and sandy soils were calculated to be reduced to 18 500 and 14 100 kg/ha dry matter, respectively (Figure 30). If the amounts of rainfall are set to 70% of the actual rainfall data, total productions on sandy loam and sandy soils are reduced further to 16 800 and 10 900 kg/ha dry matter, respectively. If on the other hand, the amounts of rainfall are set to 130% of the actual rainfall data, total productions on sandy loam and sandy soils become higher, i.e. 19 400 and 15 700 kg/ha dry matter, respectively.

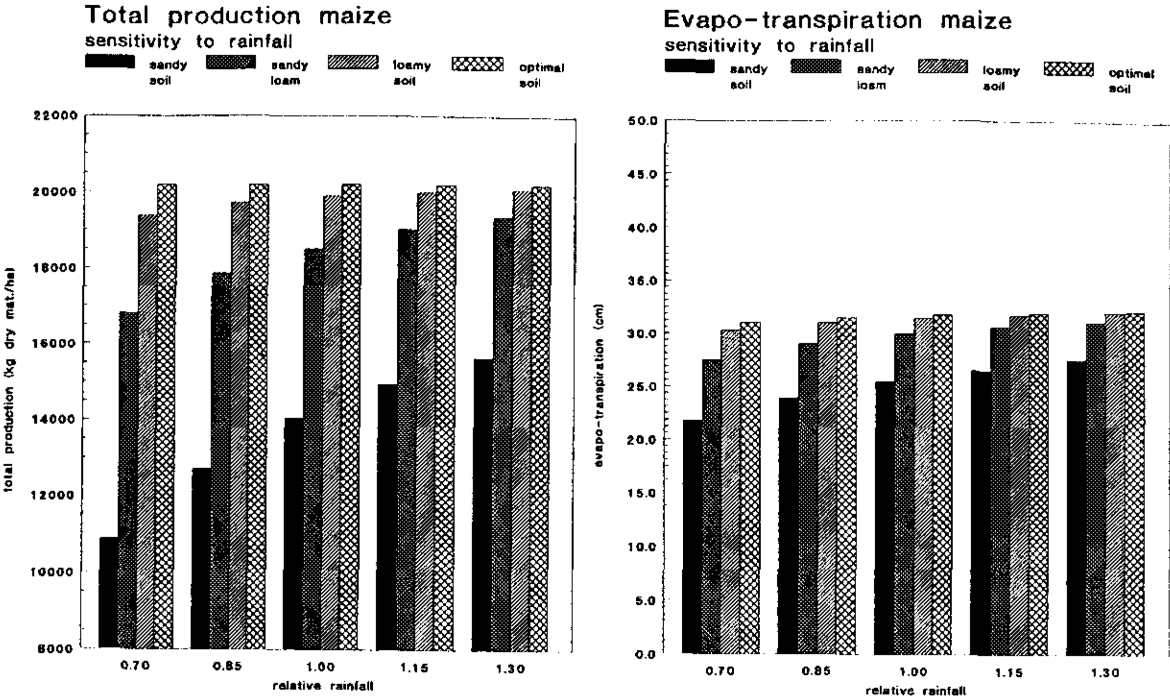

***Fig. 30** Sensitivity to changes in amount of rainfall of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of silage maize cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for daily rainfall data changing from 0.7 to 1.3 times the actual rainfall data (see Table 37)*

For cumulative evapo-transpiration the lowest value is found if both the amount of rainfall and the amount of available soil water are small. Hence, on sandy soils the largest increase in evapo-transpiration due to increasing amounts of rainfall is found. (Figure 30).

If the water balances at increasing amounts of rainfall are compared (Table 37), increase in rainfall is found to result in more evapo-transpiration, in more leaching from the root zone and in less depletion of available soil water.

7.3.3 Permanent grassland

Potential production of grassland in De Bilt is 18 200 kg/ha dry matter. It is not limited by available soil water and thus is not affected by change in rainfall. For the actual rainfall data the water-limited productions are calculated to be 16 500, 15 100 and 12 800 kg/ha dry matter on loamy, sandy loam and sandy soils, respectively (Figure 31).

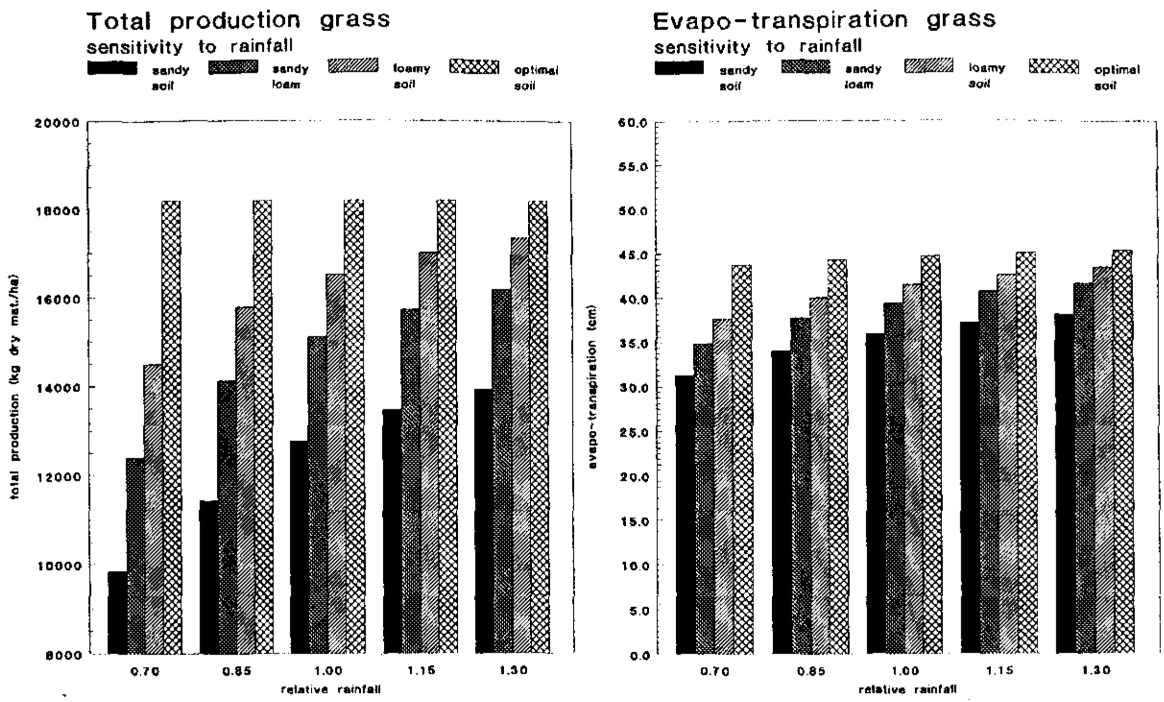

***Fig. 31** Sensitivity to changes in amount of rainfall of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) per year of mown permanent grassland growing on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for daily rainfall data changing from 0.7 to 1.3 times the actual rainfall data (see Table 37)*

If the amounts of rainfall are set to 70% of the actual rainfall data, productions on these soils are reduced further to 14 500, 12 400 and 9900 kg/ha dry matter, respectively. If on the other hand, the amounts of rainfall are set to 130% of the actual rainfall data, productions on loamy, sandy loam and sandy soils become higher, i.e. 17 400, 16 200 and 13 900 kg/ha dry matter, respectively.

For cumulative evapo-transpiration the lowest value is found if both the amount of rainfall and the amount of available soil water are small (i.e. sandy soils). Increasing amounts of rainfall result in about identical increases in evapo-transpiration on sandy, sandy loam and loamy soils (Figure 31).

If the waterbalances at increasing amounts of rainfall are compared (Table 37), increase in rainfall is found to result mainly in more leaching from the root zone and further in more evapo-transpiration.

7.4 Radiation

The amount of radiation has been varied between 0.9 times and 1.3 times the amount of solar radiation actually received in De Bilt, the Netherlands. Increases in solar radiation influence crop production and the water balance in the following ways:

- the rate of CO_2 assimilation process and thus crop production increase;
- the rate of evaporation from the soil surface increases;
- the rate of crop transpiration increases.

7.4.1 Winterwheat

Potential grain production increases from 8300 kg/ha dry matter at 0.9 times the amount of radiation actually received in De Bilt (0.9*RAD), to 9200 kg/ha at the actual amount of radiation (1.0*RAD) and to 11 100 kg/ha dry matter at 1.3 times the amount of radiation actually received (1.3*RAD) (Figure 32).

Water-limited grain productions increase too at increasing amounts of radiation received. Simultaneously, an increase in amount of radiation results in more evapo-transpiration and in longer periods with drought stress, particularly on soils with a small amount of available water. As a consequence, the grain production on sandy soils increases at most upto 6300 kg/ha dry matter and decreases again at radiation levels of 1.2*RAD and more. On sandy loam and loamy soils the grain productions increase at most upto 8500 and 10 100 kg/ha dry matter, respectively and decrease again at radiation levels of 1.3*RAD and more.

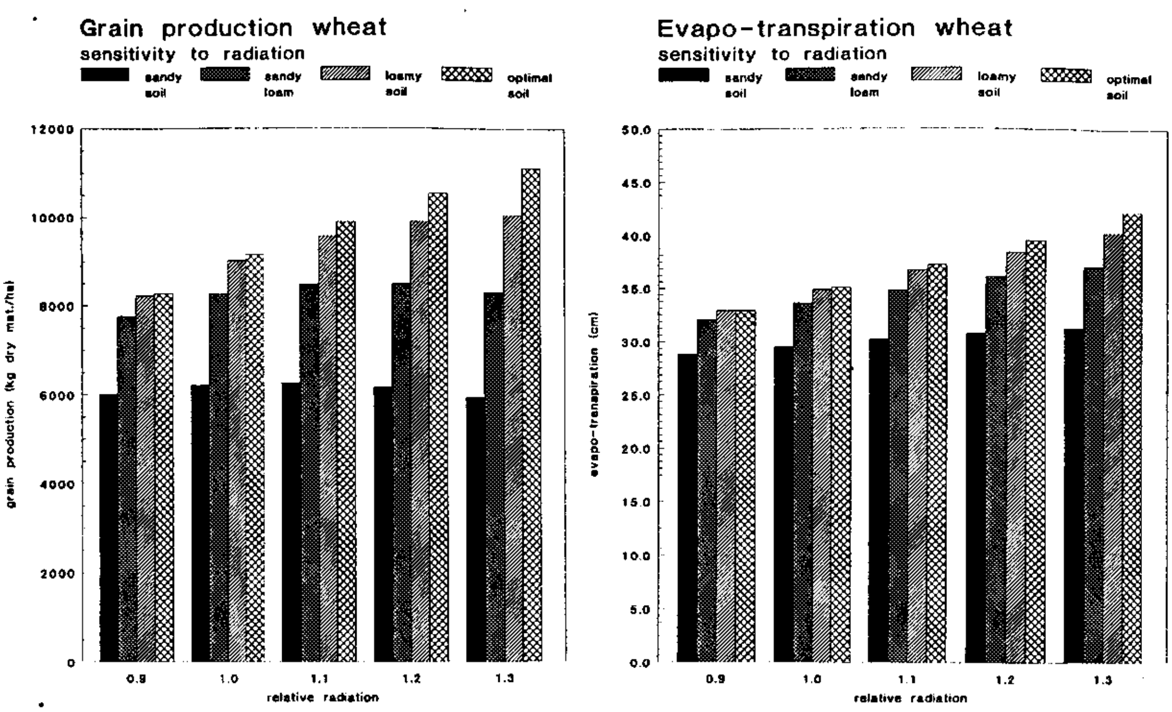

Fig. 32 ***Sensitivity to changes in radiation of the average grain production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of winterwheat cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for an amount of radiation changing from 0.9 to 1.3 times the amount of radiation actually received (see Table 38)***

At increasing amounts of radiation received the crop transpiration increases strongly. Evaporation from the soil surface remains about constant, because the effect of increasing amounts of radiation received is nullified by the increasing soil coverage due to increased crop production. Largest increases in evapo-transpiration due to increasing amounts of radiation received are found on soils with a large amount of available water (Figure 32). On such soils, available water does not limit increases in evapo-transpiration.

If the water balances at increasing amounts of radiation are compared (Table 38), increase in radiation is found to result in more evapo-transpiration and hence in less leaching from the root zone and in more depletion of available soil water.

7.4.2 Silage maize

Potential total production increases from 18 300 kg/ha dry matter at 0.9 times the amount of radiation actually received in De Bilt (0.9*RAD) to 20 200 kg/ha at the actual amount of radiation (1.0*RAD) and to 24 700 kg/ha dry matter at 1.3 times the amount of radiation actually received (1.3*RAD) (Figure 33).

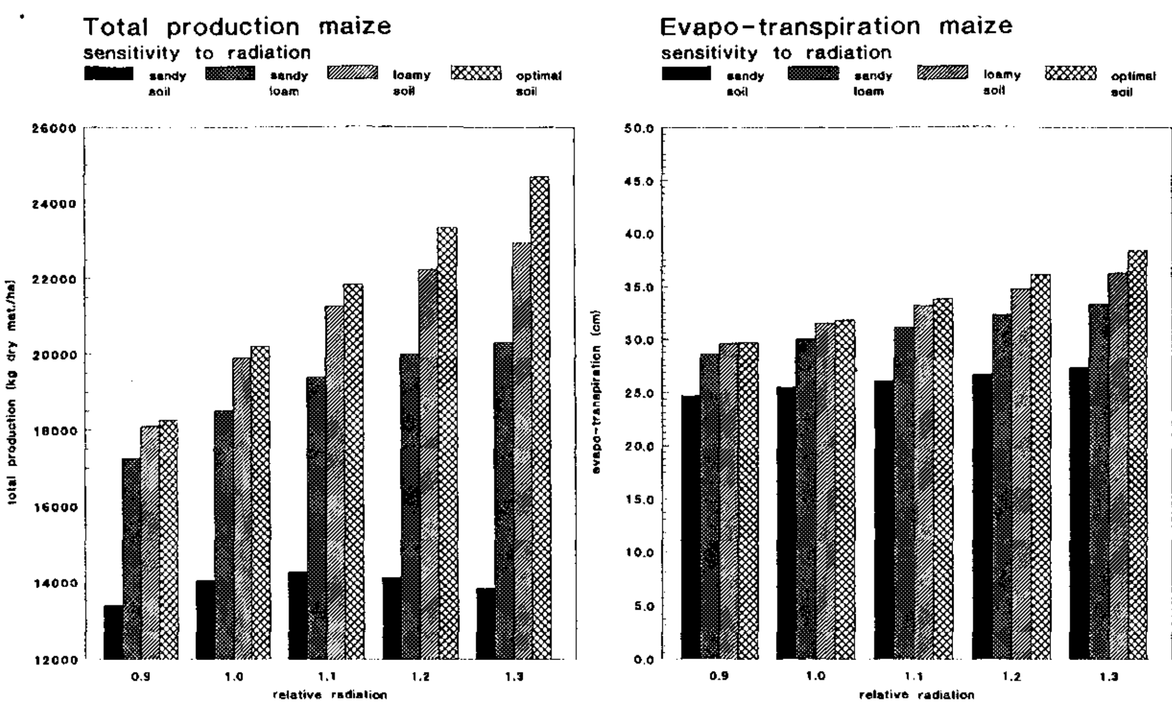

Fig. 33 Sensitivity to changes in radiation of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of silage maize cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for an amount of radiation changing from 0.9 to 1.3 times the amount of radiation actually received (see Table 38)

Water-limited total productions increase too at increasing amounts of radiation received. Simultaneously, an increase in amount of radiation results in more evapo-transpiration and in longer periods with drought stress, particularly on soils with small amounts of available water. As a consequence, the total production on sandy soils increases at most upto 14 300 kg/ha dry matter and decreases again at radiation levels of 1.2*RAD and more. On sandy loam and loamy soils maximum productions of 20 300 and 22 900 kg/ha dry matter, respectively are found at the highest radiation level (1.3*RAD), but the increase in production with increasing amounts of radiation becomes smaller at the highest radiation levels where available water becomes more limiting, particularly on sandy loam soils.

At increasing amounts of radiation received the crop transpiration increases strongly. Evaporation from the soil surface remains about constant, because the effect of increasing amounts of radiation is nullified by the increasing soil coverage due to increased crop production. Only on sandy soils, evaporation is found to increase with increasing amount of radiation. On this soil, increase in production and thus in soil coverage is severely limited by drought stress. Largest increases in evapo-transpiration due to increasing amounts of radiation received are found on soils with a large amount of available water (Figure 33). On such soils available water does not limit increases in evapo-transpiration.

If the water balances at increasing amounts of radiation are compared (Table 38), increase in radiation is found to result in more evapo-transpiration and hence in less leaching from the root zone and in more depletion of available soil water.

7.4.3 Permanent grassland

Potential production of grassland increases from 17 300 kg/ha dry matter at 0.9 times the amount of radiation actually received in De Bilt (0.9*RAD), to 18 200 kg/ha at the actual amount of radiation received (1.0*RAD) and to 20 300 kg/ha dry matter at 1.3 times the amount of radiation actually received (1.3*RAD) (Figure 34).

Water-limited productions increase too at increasing amounts of radiation received. Simultaneously, an increase in amount of radiation results in more evapo-transpiration and in longer periods with drought stress, particularly on soils with small amounts of available water. As a consequence, the maximum production on sandy soils is 12 900 kg/ha dry matter at a radiation level of 1.1*RAD and production decreases again at higher radiation levels. On sandy loam and loamy soils maximum productions of 15 300 and 16 900 kg/ha dry matter are found at radiation levels of 1.1*RAD and 1.2*RAD, respectively.

At increasing amounts of radiation received both evaporation and crop transpiration increase on soils with a large amount of available water. On soils with a small amount of available water, however, the increasing evaporative demand at higher radiation levels causes longer periods with drought stress. This results in an increase in evaporation that goes at the expense of transpiration and grass production. Largest increases in evapo-transpiration due to increasing amounts of radiation received are found on soils with a large amount of available water (Figure 34). On such soils available water does not limit increases in evapo-transpiration.

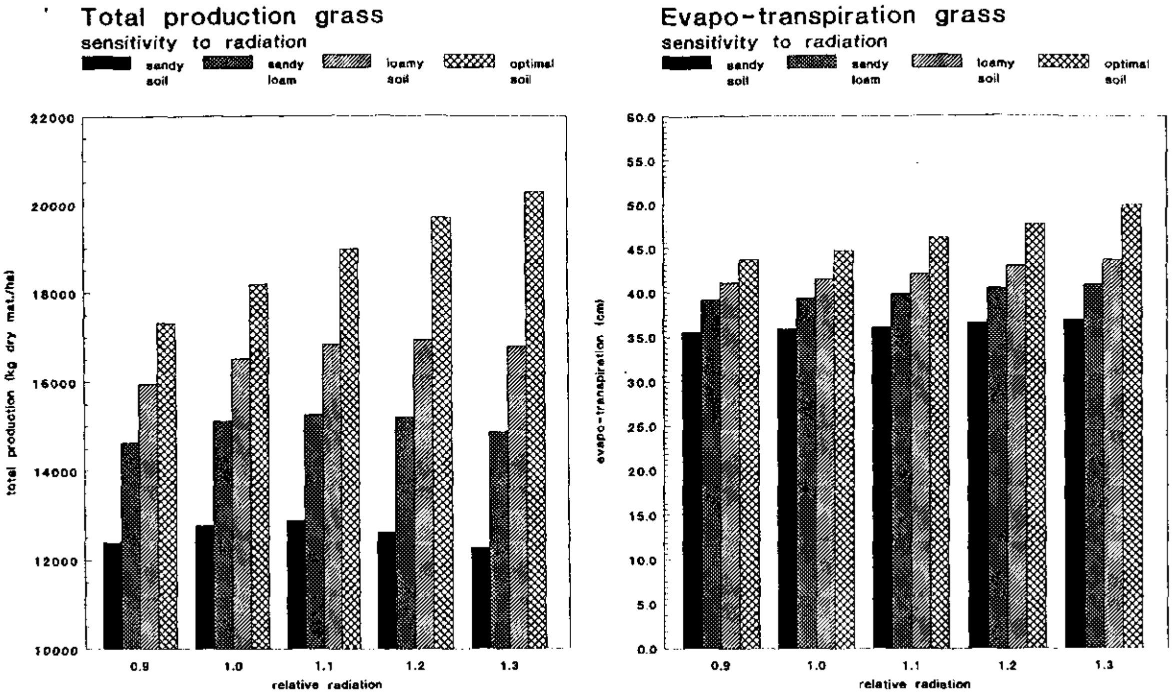

Fig. 34 ***Sensitivity to changes in radiation of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) per year of mown permanent grassland growing on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for an amount of radiation changing from 0.9 to 1.3 times the amount of radiation actually received (see Table 38)***

If the water balances at increasing amounts of radiation are compared (Table 38), increase in radiation is found to result in more evapo-transpiration and hence in less leaching from the root zone.

7.5 Windspeed

The windspeed has been varied between 0.5 times and 2.0 times the actual values for the mean daily windspeed in De Bilt, the Netherlands. Increasing windspeed results in higher rates of evaporation and transpiration.

7.5.1 Winterwheat

Potential grain production is 9200 kg/ha dry matter and does not change due to changes in windspeed. If the windspeed is set at 0.5 times the actual windspeed in De Bilt, water-limited grain productions are about identical to the potential production (Figure 35).

Only in sandy soils the amount of available water is so small that production is reduced to 7100 kg/ha dry matter by drought stress. At the actual windspeed both evaporation from the soil surface and crop transpiration are larger and hence, production on sandy soils is reduced more strongly (6200 kg/ha) and on sandy loam soils is reduced too (8300 kg/ha). If the windspeed is set at 2.0 times the actual windspeed, water losses by evaporation and transpiration become even higher. This results in a larger reduction in grain production to 4700, 6800 and 8200 kg/ha dry matter on the sandy, sandy loam and loamy soils, respectively.

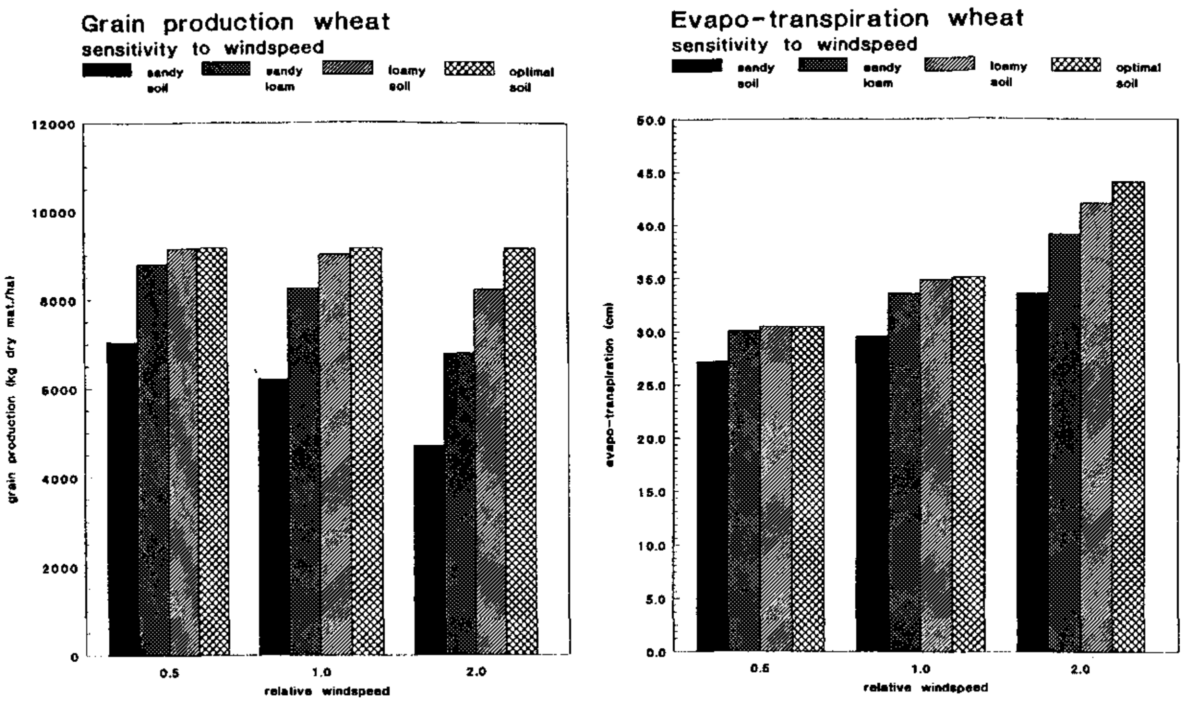

Fig. 35 ***Sensitivity to changes in windspeed of the average grain production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of winterwheat cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in windspeed from 0.5 to 2 times the actual values for the mean daily windspeed (see Table 39)***

At increasing windspeed both evaporation from the soil surface and crop transpiration increase strongly. On soils with a small amount of available water (sandy and sandy loam soils) the increased evaporative demand causes longer periods with drought stress. This results in an increase in evaporation that goes at the expense of transpiration and grain production. Largest increases in evapo-transpiration due to increased windspeed are found on soils with a large amount of available water (Figure 35). On such soils, available water does not limit increases in evapo-transpiration.

If the water balances at increasing windspeed are compared (Table 39), increase in windspeed is found to result in more evapo-transpiration and hence, in less leaching from the root zone and in more depletion of available soil water.

7.5.2 Silage maize

Potential total production is 20 200 kg/ha dry matter and does not change due to changes in windspeed. If the windspeed is set at 0.5 times the actual windspeed in De Bilt, water-limited grain productions are about identical to the potential production (Figure 36). Only in sandy soils the amount of available water is so small that production is reduced to 15 900 kg/ha dry matter by drought stress. At the actual windspeed both evaporation from the soil surface and crop transpiration are larger and hence, production on sandy soils is reduced more severely (14 100 kg/ha) and on sandy loam soils is reduced too (18 500 kg/ha). If the windspeed is set at 2.0 times the actual windspeed, water losses by evaporation and transpiration become even higher. This results in a larger reduction in total production to 10 500, 16 300 and 18 600 kg/ha dry matter on the sandy, sandy loam and loamy soils, respectively.

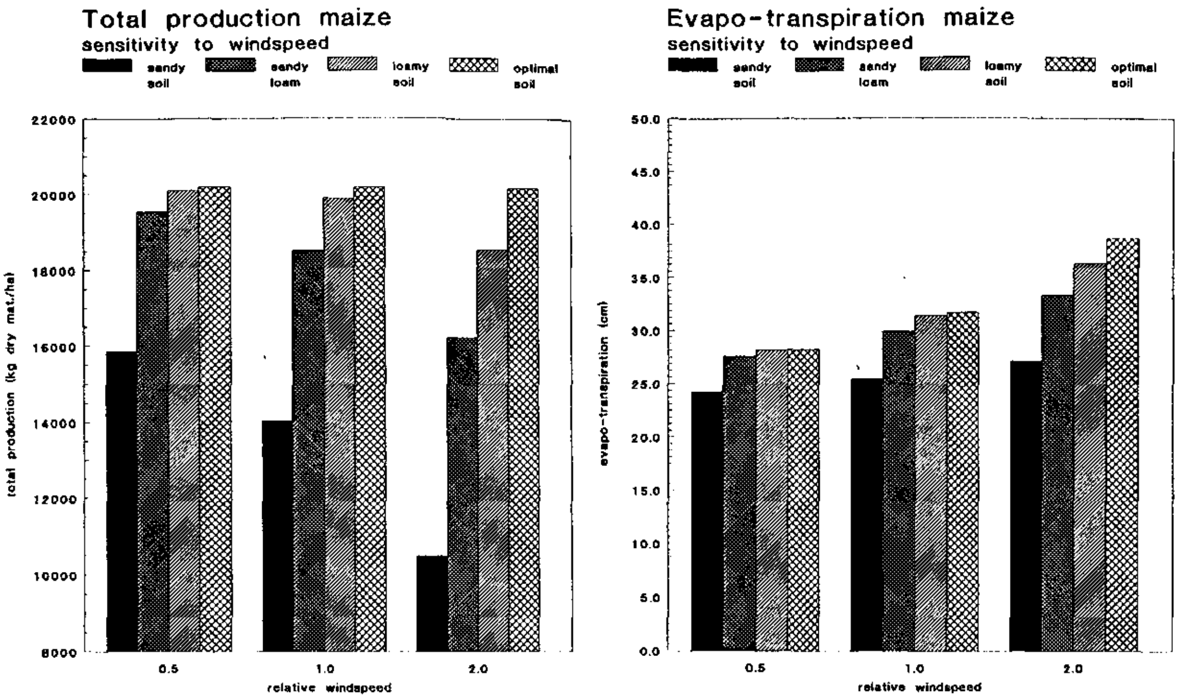

Fig. 36 ***Sensitivity to changes in windspeed of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of silage maize cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in windspeed from 0.5 to 2 times the actual values for the mean daily windspeed (see Table 39)***

At increasing windspeed both evaporation from the soil surface and crop transpiration increase strongly. On soils with a small amount of available water (sandy and sandy loam soils) the increased evaporative demand causes longer periods with drought stress. This results in an increase in evaporation that goes at the expense of transpiration and total production. Largest increases in evapo-transpiration due to increased windspeed are found on soils with a large amount of available water (Figure 36). On such soils, available water does not limit increases in evapo-transpiration.

If the water balances at increasing windspeed are compared (Table 39), increase in windspeed is found to result in more evapo-transpiration and hence, in less leaching from the root zone and in more depletion of available soil water.

7.5.3 Permanent grassland

Potential production of grassland is 18 200 kg/ha dry matter and does not change due to changes in windspeed. If the windspeed is set at 0.5 times the actual windspeed in De Bilt, water-limited production on the loamy soil is about identical to the potential production (Figure 37). In sandy and sandy loam soils the amount of available water is so small that productions are reduced to 13 900 and 16 200 kg/ha dry matter, respectively by drought stress. At the actual windspeed both evaporation from the soil surface and crop transpiration are larger and hence, productions on sandy, sandy loam and loamy soils are reduced more severely to 12 800, 15 100 and 16 500 kg/ha dry matter respectively. If the windspeed is set at 2.0 times the actual windspeed, water losses by evaporation and transpiration become even higher. This results in a larger reduction in grass production to 9800, 12 600 and 14 200 kg/ha dry matter on the sandy, sandy loam and loamy soils, respectively.

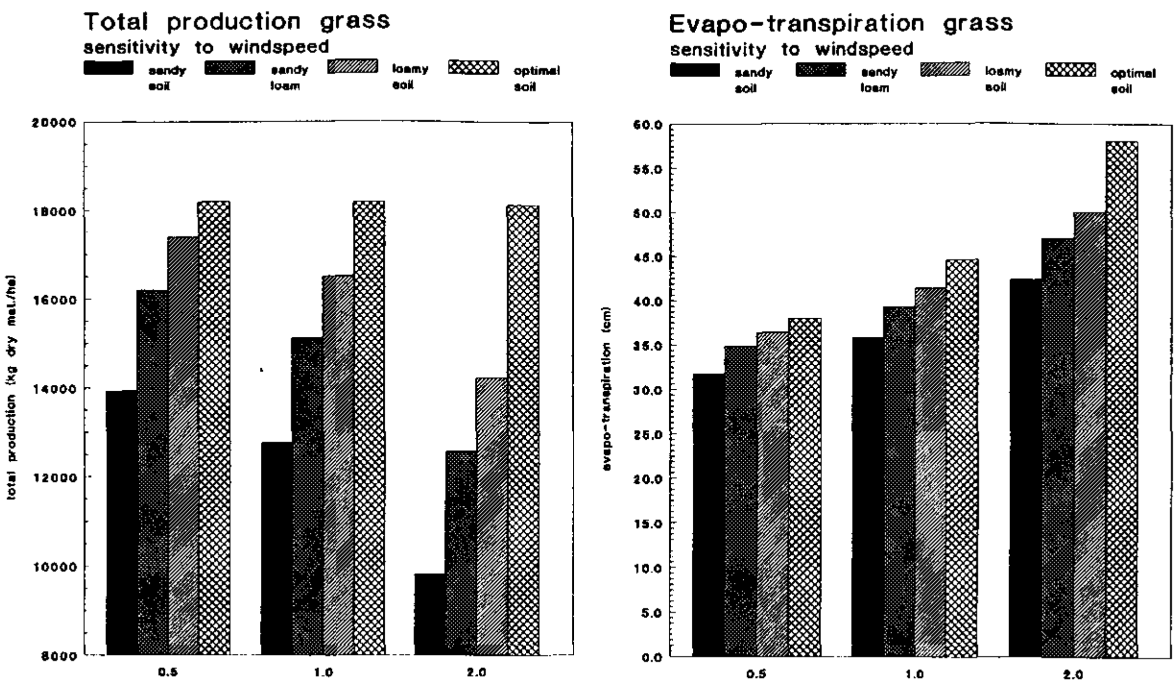

Fig. 37 Sensitivity to changes in windspeed of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) per year of mown permanent grassland growing on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in windspeed from 0.5 to 2 times the actual values for the mean daily windspeed (see Table 39)

At increasing windspeed both evaporation from the soil surface and crop transpiration increase strongly. On soils with a small amount of available water (sandy and sandy loam soils) the increased evaporative demand causes longer periods with drought stress. This results in an increase in evaporation that goes at the expense of transpiration and grass production. Largest increases in evapo-transpiration due to increased windspeed are found on soils with a large amount of available water (Figure 37). On such soils, available water does not limit increases in evapo-transpiration.

If the water balances at increasing windspeed are compared (Table 39), increase in windspeed is found to result in more evapo-transpiration and hence in less leaching from the root zone.

7.6 Vapour pressure

The vapour pressure has been varied between 0.9 times and 1.1 times the actual vapour pressure in De Bilt, the Netherlands. An increase in vapour pressure which corresponds with an increase in relative air humidity as long as the daily average air temperature is not changed, results in a decrease in evaporative demand of the air and thus in less evaporation and transpiration.

7.6.1 Winterwheat

Potential grain production is 9200 kg/ha dry matter and does not change due to changes in vapour pressure. If the vapour pressure is set at 1.1 times the actual vapour pressure in De Bilt, water-limited grain production on loamy soil is about identical to the potential production (Figure 38). In sandy and sandy loam soils, the amounts of available water are small and hence, productions on these soils are reduced by drought stress to 6800 and 8600 kg/ha dry matter, respectively. At the actual vapour pressure both evaporation from the soil surface and crop transpiration are larger and hence, productions on sandy and sandy loam soils are reduced more strongly to 6200 and 8300 kg/ha dry matter, respectively. If the vapour pressure is set at 0.9 times the actual vapour pressure, water losses by evaporation and transpiration become even higher. This results in a larger reduction in grain production to 5600, 7800 and 8900 kg/ha dry matter on the sandy, sandy loam and loamy soils, respectively.

At decreasing vapour pressure both evaporation from the soil surface and crop transpiration increase. Largest increases in evapo-transpiration are found on soils with a large amount of available water (Figure 38), as on such soils available water is not limiting for evapo-transpiration. On soils with a small amount of available water (sandy and sandy loam soils) the increase in evaporation goes at the expense of transpiration and grain production.

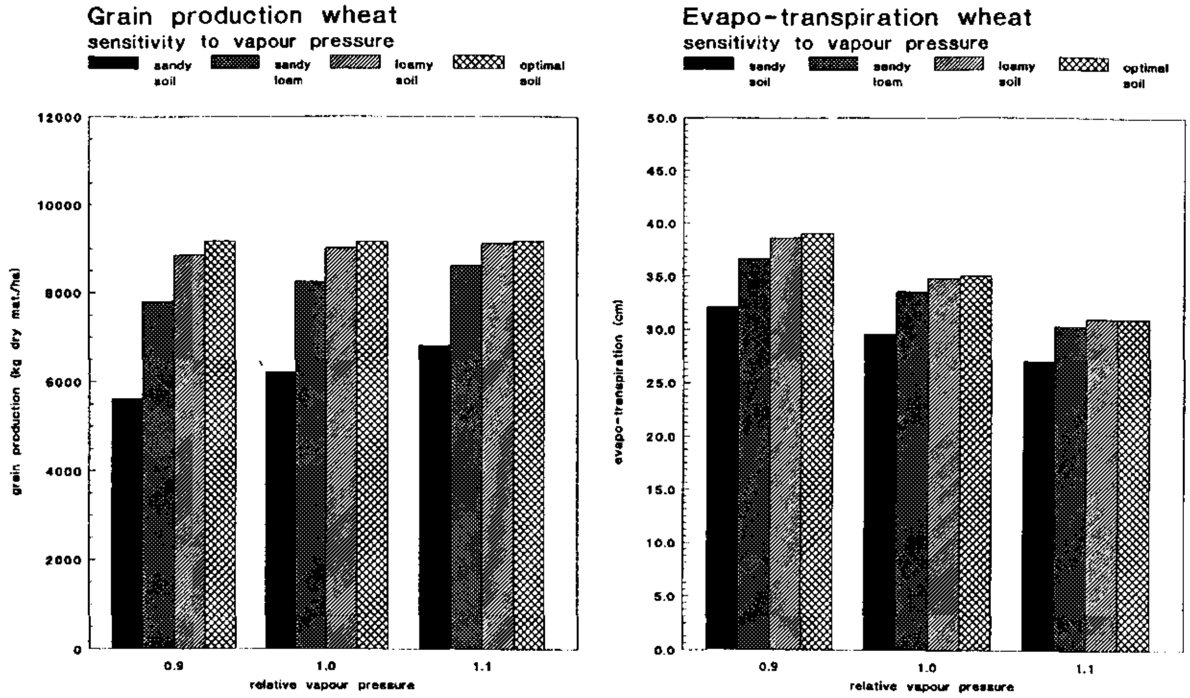

Fig. 38 ***Sensitivity to changes in vapour pressure of the average grain production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of winterwheat cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in vapour pressure from 0.9 to 1.1 times the actual vapour pressure (see Table 40)***

If the water balances at decreasing vapour pressure are compared (Table 40), decrease in vapour pressure is found to result in more evapo-transpiration and hence, in less leaching from the root zone and more depletion of available soil water.

7.6.2 Silage maize

Potential total production is 20 200 kg/ha dry matter and does not change due to changes in vapour pressure. If the vapour pressure is set at 1.1 times the actual vapour pressure in De Bilt, water-limited total production on the loamy soil is about identical to the potential production (Figure 39). In sandy and sandy loam soils, the amounts of available water are small and hence, productions on these soils are reduced by drought stress to 15 300 and 19 200 kg/ha dry matter, respectively. At the actual vapour pressure both evaporation from the soil surface and crop transpiration are larger and hence, productions on sandy and sandy loam soils are reduced more strongly to 14 100 and 18 500 kg/ha dry matter, respectively. If the vapour pressure is set at 0.9 times the actual vapour pressure, water losses by evaporation and transpiration become even higher. This results in a larger reduction in total production to 12 800, 17 800 and 19 600 kg/ha dry matter on the sandy, sandy loam and loamy soils, respectively.

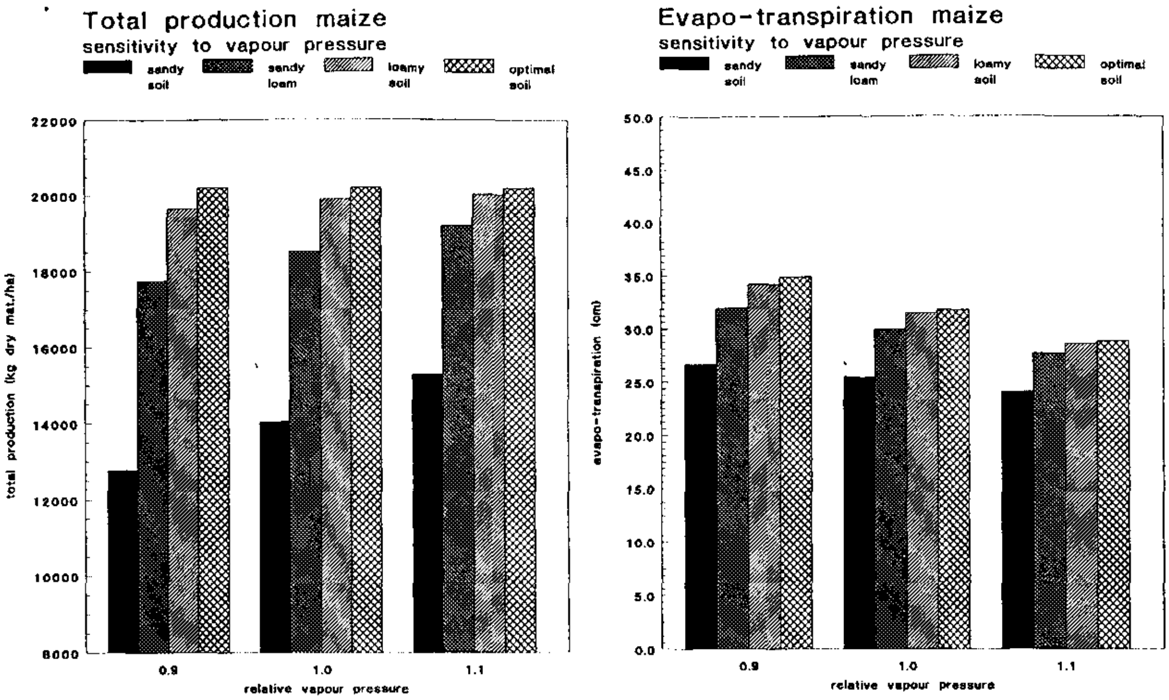

Fig. 39 ***Sensitivity to changes in vapour pressure of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) during the growth period of silage maize cultivated on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in vapour pressure from 0.9 to 1.1 times the actual vapour pressure (see Table 40)***

At decreasing vapour pressure both evaporation from the soil surface and crop transpiration increase. Largest increases in evapo-transpiration are found on soils with a large amount of available water (Figure 39), as on such soils available water is not limiting for evapo-transpiration. On soils with a small amount of available water (sandy and sandy loam soils) the increase in evaporation goes at the expense of transpiration and crop production.

If the water balances at decreasing vapour pressure are compared (Table 40), decrease in vapour pressure is found to result in more evapo-transpiration and hence, in less leaching from the root zone and in more depletion of available soil water.

7.6.3 Permanent grassland

Potential production of grassland is 18 200 kg/ha dry matter and does not change due to changes in vapour pressure. If the vapour pressure is set at 1.1 times the actual vapour pressure in De Bilt, water-limited productions on sandy, sandy loam and loamy soils are reduced by drought stress to 13 600, 15 900 and 17 100 kg/ha dry matter, respectively (Figure 40). At the actual vapour pressure both evaporation from the soil surface and crop transpiration are larger and hence, the productions on these soils are reduced more strongly to 12 800, 15 100 and 16 500 kg/ha dry matter, respectively. If the vapour pressure is set at 0.9 times the actual vapour pressure, water losses by evaporation and transpiration become even higher. This results in a larger reduction in grass production to 11 500, 14 200 and 15 800 kg/ha dry matter on the sandy, sandy loam and loamy soils, respectively.

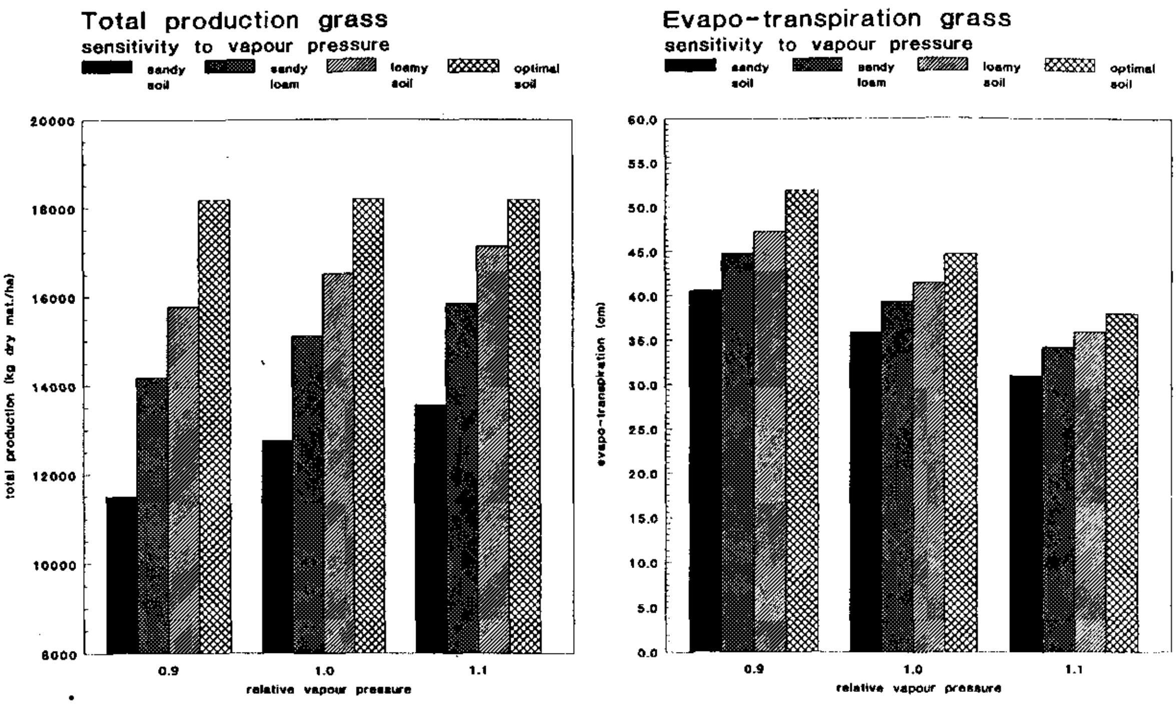

Fig. 40 ***Sensitivity to changes in vapour pressure of the average total production (kg/ha dry matter) and the evapo-transpiration (cm) per year of mown permanent grassland growing on four different soil types. Production and evapo-transpiration have been established for historical weather data over a period of twenty years (1969-1988) from De Bilt, the Netherlands and for a change in vapour pressure from 0.9 to 1.1 times the actual vapour pressure (see Table 40)***

At decreasing vapour pressure both evaporation from the soil surface and crop transpiration increase. Largest increases in evapo-transpiration are found on soils with a large amount of available water (Figure 40), as on such soils available water is not limiting for evapo-transpiration.

If the water balances at decreasing vapour pressure are compared (Table 40), decrease in vapour pressure is found to result in more evapo-transpiration and hence in less leaching from the root zone.

8 SUMMARY OF THE EFFECTS OF CLIMATE CHANGE

As shown in the previous sections, the effects of climate change on crop production and on the soil water balance in the Rhine basin can be estimated from the moment that weather data for the future are available. Unfortunately, reliable information on climate conditions after for example doubling of the atmospheric CO_2 concentration, is not yet available at a sufficiently fine spatial resolution, as has been discussed at the beginning of Section 6.

Hence, a scenario on climate change for a region close to the Rhine that is compiled in a consistent way (Bultot et al., 1988), has been used for the calculation of "future" climate conditions. On the basis of this scenario historical weather data for a period of 20 years (1969-1988) have been changed in the way described in Section 6 to obtain future weather data. These data are used to calculate future crop productions. The changes in temperature and rainfall according to this scenario are rather limited.

Probably much larger changes in climate will occur in situations that for example rising temperatures cause changed courses of the gulfstreams. This might result in larger changes in temperature and precipitation and in a larger differentiation in temperature and rainfall between summer and winter. An indication of the effects of such more drastical changes in climate can be derived from the sensitivity analyses for weather parameters that are changed separately to various extents (Section 7).

8.1 Effects on land use

As discussed at the beginning of Section 2, the use of land for agriculture depends on both environmental and on socio-economic and other factors. In addition to climate, other environmental factors that may set limitations to land use, are the soil, the topography and the hydrology. This means that possible change in climate can only be just one of the factors that altogether determine changes in land use.

A main problem in analyzing the effects of climate change on land use is the fact that information on future climate conditions contains a considerable degree of uncertainty. In this study the changes in climate conditions that may occur at doubling atmospheric CO_2 concentration, are derived from the Bultot scenario (see Section 6). These changes are mainly a rise in temperature of 3 ^{o}C, a limited increase in precipitation which is a little more unevenly distributed over the year and is not much larger than the increase in evapo-transpiration (due to rise in temperature), and a relative air humidity that is kept constant at the higher temperature.

The resulting future climate conditions for the Rhine basin can be found at present in South France and North Italy. In all these european regions agriculture functions within the same system of market regulations of the European Communities. Hence, socio-economic conditions do not differ too much and comparison of the land use in South

France and North Italy with that in the Rhine basin (Section 2.5) and comparison of the land use in France and Italy with that in Germany (Section 2.2) may give good indications of the possible changes in land use that are to be expected from climate change.

The following changes in land use in the Rhine basin as based on the comparisons, may be expected:
- increase in area of permanent crops;
- decrease in area of permanent grassland and possibly also of arable land;
- increasing part of the area with permanent crops used as vineyards;
- smaller areas cultivated with oats and rye and larger areas with grain maize;
- smaller areas cultivated with root crops;
- smaller areas cultivated with rapeseed and turnip rapeseed and larger areas with sunflower and soyabean.

8.2 Effects on crop production

For the field crops, winterwheat and silage maize, and for permanent grassland the effects of climate change on production have been calculated. The calculations have been carried out for four soil types (i.e. sandy, sandy loam, loamy and optimal soils) that differ in their maximum amount of available water. The sandy soils are the marginal, gravelly and/or stony, eroded etc. soils that generally are not used for agriculture. The potential production level that has been calculated for the optimal soils, can only be attained if crop stress due to water excess and/or drought can be prevented completely by artificial draining and irrigation. Hence for the Rhine basin the results for the sandy loam and the loamy soils may be considered as representative.

Crop productions have been calculated for historical weather data over a period of 20 years (1969-1988) from six meteorological stations in the Rhine basin. On the basis of the Bultot scenario (see Section 6) these historical weather data have been changed to obtain future weather data. For these future weather data crop production has been calculated again to derive effects of climate change on crop production.

The following average changes in production (absolute change and relative change compared to production at present climate conditions) due to climate change in the Rhine basin have been calculated (i.e. average of results for sandy loam and loamy soils and for all meteorological stations in the Rhine basin, for which calculations have been carried out; see Sections 6.1, 6.2 and 6.3):

winterwheat	**+2860 kg/ha grain dry matter**	**(+35%);**
silage maize	**-1860 kg/ha total dry matter**	**(-10%);**
permanent grassland	**+8550 kg/ha dry matter**	**(+53%).**

The productions are influenced by climate change in the following ways. Doubled atmospheric CO_2 concentration results in a larger assimilate production of the leaves of winterwheat and grass. But the assimilate production of maize leaves remains unchanged (Section 3.2.3). The rise in temperature causes a shorter growth period for winterwheat and silage maize. This undoes partly the yield increase of winterwheat by doubled atmospheric CO_2 concentration and results in a yield decrease for silage maize.

On locations where temperatures at present are relatively higher, this effect is found to be relatively stronger than on locations with relatively lower temperatures (Section 6.1.1). In reality, yields for silage maize probably will not decrease, as for maize cultivation varieties with a longer growth duration can be chosen. Highest increases in production due to climate change are found for grassland. This is due to both the doubled atmospheric CO_2 concentration and the extension of the period that growth of grass may occur. This extension of the growth period is caused by the rise in temperature.

A sensitivity analysis of the change in grass production due to climate change according to the Bultot scenario has been carried out (Section 6.4). For this analysis the change in production has been established for historical rainfall data for De Bilt, for rainfall data that were changed on the basis of the Bultot scenario and for rainfall data that were changed two times as strongly as on the basis of the Bultot scenario. In addition, it is assumed that atmospheric CO_2 concentration was doubled in all cases and that the average daily air temperature increased by 1, 3 (= Bultot scenario) and 5 °C. The increase in grass production is found to be about completely caused by the increase in atmospheric CO_2 concentration. A temperature increase of 1 °C results in a lower production (compared to production at temperature increase of 3 °C) due to the shorter growth period and a temperature increase of 5 °C results also in a lower production because of prolonged periods with drought stress. If rainfall distribution over the year becomes more uneven, production is reduced too. But all these effects on production are very small compared to the effect of doubling the CO_2 concentration.

Weather parameters that determine crop production, are also changed separately to various extents. In this way the sensitivity of crop production to changing values for each parameter can be derived. For winterwheat the grain production in De Bilt on sandy loam and loamy soils is found to increase strongly at increasing atmospheric CO_2 concentration, to decrease moderately at increasing temperature, to increase slightly at increasing rainfall, to increase slightly at increasing solar radiation, to decrease moderately at increasing windspeed and to increase slightly at increasing vapour pressure.

For silage maize the total production in De Bilt on sandy loam and loamy soils is found to increase moderately at increasing atmospheric CO_2 concentration, to decrease moderately at increasing temperature, to increase slightly at increasing rainfall, to increase moderately at increasing solar radiation, to decrease moderately at increasing windspeed and to increase slightly at increasing vapour pressure.

For permanent grassland the production in De Bilt on sandy loam and loamy soils is found to increase strongly at increasing atmospheric CO_2 concentration, to increase moderately at increasing temperature, to increase moderately at increasing rainfall, to remain constant at increasing radiation, to decrease strongly at increasing windspeed and to increase moderately at increasing vapour pressure. In Table 16 the sensitivity of crop production to changing values for the different weather parameters is summarized for winterwheat, silage maize and permanent grassland, respectively.

Table 16 Sensitivity of crop production in De Bilt, the Netherlands on sandy loam and loamy soils to increasing values for atmospheric CO_2 concentration (C), temperature (T), rainfall (R), solar radiation (S), windspeed (W) and vapour pressure (V)[1]

Crop	C	T	R	S	W	V
Winterwheat	+++	--	+	+	--	+
Silage maize	++	--	+	++	--	+
Permanent grassl.	+++	++	++	o	---	++

[1] **o, +, ++, +++ : no, slight, moderate, strong increase;**
-, --, --- : slight, moderate, strong decrease;
Production refers for winterwheat to grain production, for silage maize to total crop production and for grassland to grass production.

Climate change and particularly doubling the atmospheric CO_2 concentration is found to result in large production increases for winterwheat and permanent grassland, as treated at the beginning of this section. However, it should be kept in mind that such production increases can only be attained if nutrient supply does not limit production. For example, the dry matter production of wheat and grass in pot experiments was found to increase to 140 à 145%, if the atmospheric CO_2 concentration was doubled and nutrient supply was sufficient (Goudriaan & De Ruiter, 1983). If nitrogen supply was deficient, the dry matter production increased to 120 à 125% and if phosphorus supply was deficient, the dry matter production remained 100% (i.e. no increase in production due to doubled atmospheric CO_2 concentration). As discussed by Van Kraalingen (1990), increases in dry matter production by doubled atmospheric CO_2 concentration might in situations with deficient supply of nitrogen and/or phosphorus result in larger amounts of vegetative plant material but in lower grain yields. Hence, the increases in grain and grass production at doubled CO_2 concentration will only be realized, if simultaneously the amounts of applied fertilizer nutrients are adapted to the higher productions.

8.3 Effects on evapo-transpiration and leaching

For the field crops winterwheat and silage maize and for permanent grassland the effects of climate change on the components of the water balance have been calculated. These calculations have been carried out for four soil types, differing in their maximum amount of available water, of which as discussed in Section 8.2, the sandy loam and the loamy soils may be considered as representative for agricultural land in the Rhine basin.

The way in which the effect of climate change on crop production and on components of the water balance has been handled, is described in Section 8.2. The following average changes in evapo-transpiration and in leaching from the root zone due to climate change in the Rhine basin have been calculated (i.e. average of results for sandy loam and loamy soils and for all meteorological stations in the Rhine basin for which calculations have been carried out; see Sections 6.1, 6.2 and 6.3) for

winterwheat:	**evapo-transpiration**	**-5.9 cm;**	**leaching**	**+0.4 cm;**	**change**	**growth**	**duration**	**-29d.;**
silage maize:	**„**	**-6.7 cm;**	**„**	**+0.8 cm;**	**„**	**„**	**„**	**-15d.;**
permanent grassl.:	**„**	**+0.8 cm;**	**„**	**+3.0 cm;**	**„**	**„**	**„**	**0d.**

The components of the water balance are influenced by climate change as follows. Doubled atmospheric CO_2 concentration results in a lower transpiration rate of grass due to increased stomatal resistance (Section 3.2.3), but this effect is largely compensated by a longer period of grass growth at the higher temperatures in future. Evaporation increases at higher temperatures but this is partly compensated by the higher degree of soil coverage by the canopy. Together this results in a slight increase in evapo-transpiration. As the amount of rainfall in future increases more strongly and the change in available soil water over one year is about zero, leaching from the root zone is found to increase due to climate change.

The decrease in evapo-transpiration for winterwheat and silage maize can be explained via the lower transpiration rate at doubled atmospheric CO_2 concentration (Section 3.2.3) and the shortened period of growth at higher temperatures, and for winterwheat alone, also via the decrease in evaporation due to increased soil coverage by the canopy. This decrease in evapo-transpiration is found to result mainly in less depletion of available soil water in the root zone and practically not in more leaching. But these comparisons of water balances over different periods of time can only be of limited value.

A sensitivity analysis of the change in grass production due to climate change according to the Bultot scenario has been carried out (Section 6.4). This analysis that has been described already in Section 8.2, yields the following. Doubling of the atmospheric CO_2 concentration results in a decrease in evapo-transpiration due to increased stomatal resistance. If also the temperature rises by 1 ^oC, evapo-transpiration is still less than the present evapo-transpiration. If temperature rises further by 3 and 5 ^oC, evapo-transpiration on sandy loam and loamy soils becomes 1.2 and 3.3 cm, respectively larger than the present evapo-transpiration. This increase in evapo-transpiration is caused by the increasing vapour pressure deficit and the extension of the growth period at higher temperatures. The rainfall distribution is found to have practically no effect on the evapo-transpiration. Leaching from the root zone is found to increase if evapo-transpiration decreases, i.e. at increasing atmospheric CO_2 concentrations and decreasing temperatures, and if the amount of rainfall increases.

Weather parameters that determine crop production, are also changed separately to various extents. In this way the sensitivity of crop production and components of the water balance to changing values for each parameter can be derived. For the cultivation of winterwheat in De Bilt on sandy loam and loamy soils, evapo-transpiration is found to decrease moderately at increasing atmospheric CO_2 concentration, to decrease strongly at increasing temperature, to increase slightly at increasing rainfall, to increase moderately at increasing solar radiation, to increase strongly at increasing windspeed and to decrease moderately at increasing vapour pressure.

For the cultivation of silage maize in De Bilt on sandy loam and loamy soils, evapo-transpiration is found to decrease strongly at increasing atmospheric CO_2 concentration, to remain about constant at increasing temperature, to increase slightly at increasing rainfall, to increase moderately at increasing solar radiation, to increase moderately at increasing windspeed and to decrease moderately at increasing vapour pressure.

For permanent grassland in De Bilt on sandy loam and loamy soils, evapo-transpiration is found to decrease slightly at increasing atmospheric CO_2 concentration, to increase moderately at increasing temperature, to increase slightly at increasing rainfall, to increase slightly at increasing solar radiation, to increase strongly at increasing windspeed and to decrease strongly at increasing vapour pressure. In Table 17 the sensitivity of evapo-transpiration to changing values for the different weather parameters is summarized for cultivation of winterwheat and silage maize and for permanent grassland.

Table 17 Sensitivity of cumulative evapo-transpiration in De Bilt, the Netherlands on sandy loam and loamy soils to increasing values for atmospheric CO_2 concentration (C), temperature (T), rainfall (R), solar radiation (S), windspeed (W) and vapour pressure (V)[1]

Crop	C	T	R	S	W	V
Winterwheat	--	---	+	++	+++	--
Silage maize	---	o	+	++	++	--
Permanent grassl.	-	++	+	+	+++	---

[1] o, +, ++, +++ : no, slight, moderate, strong increase;
-, --, --- : slight, moderate, strong decrease;
For winterwheat and silage maize cumulative values for evapo-transpiration during the growth period (dependent on temperature) are compared and for permanent grassland cumulative values during one year.

The water balance for permanent grassland is calculated for a period of one year. The change in available soil water over this period is about zero. As a consequence, an increase/decrease in evapo-transpiration due to for example changes in solar radiation results in a decrease/increase of leaching from the root zone, if the amount of rainfall is not changed. Hence, leaching from permanent grassland in De Bilt on sandy loam and loamy soils is calculated to increase slightly at increasing atmospheric CO_2 concentration, to decrease moderately at increasing temperature, to increase strongly at increasing rainfall, to decrease slightly at increasing solar radiation, to decrease strongly at increasing windspeed and to increase strongly at increasing vapour pressure.

9 CONCLUSIONS

Increasing atmospheric CO_2 concentrations will probably cause changes in climate conditions. For the Rhine basin this may result in changes in land use, in crop production and in the soil water balance.

Land use does not depend only on weather conditions but also on many other factors, both environmental and socio-economic. Altogether, these factors will determine future changes in land use. Future climate conditions in the Rhine basin, according to the applied Bultot scenario for climate change at doubled atmospheric CO_2 concentration, can be found at present in South France and North Italy. Besides, the socio-economic conditions in the Rhine basin and in South France and North Italy do not differ much. Consequently, the effects of climate change on future land use in the Rhine basin may be derived from the comparison of actual land use in the Rhine basin and in South France and North Italy, respectively.

On the basis of this comparison mainly the following changes in land use in the Rhine basin may be expected:
- increase in area of permanent crops, particularly in use for vineyards;
- decrease in area of permanent grassland;
- decrease in areas cultivated with root crops, oats and rye, rapeseed and turnip rapeseed;
- increase in areas cultivated with grain maize, sunflower and soyabean.

In addition, crop growth will start about three weeks earlier, if future temperatures in spring increase by 3 ^oC.

Climate change due to doubled atmospheric CO_2 concentration according to the Bultot scenario influences crop production in the Rhine basin mainly in a positive way. Average grain production of winterwheat in the Rhine basin was calculated to increase by 2900 kg/ha dry matter and the average production of permanent grassland by 8600 kg/ha dry matter. However, these increases in production due to climate change will only be realized completely, if applications of fertilizer nutrients are adapted to the higher productions. Only for silage maize a decrease in total production was calculated, mainly due to a decreasing length of the growth period at higher temperatures. This decrease in production will not occur in reality, because at rising temperatures maize varieties with a relatively longer growth period and a higher production will be grown.

The climate change also influences the components of the water balance. Average evapo-transpiration during the growth periods of winterwheat, silage maize and permanent grassland in the Rhine basin, was calculated to change by -6 cm, -7 cm and +1 cm, respectively. The decrease in evapo-transpiration for winterwheat and silage maize is caused mainly by the lower transpiration rate at doubled atmospheric CO_2 concentration and by the shortened period of crop growth. For permanent grassland the lower transpiration rate at doubled atmospheric CO_2 concentration is about compensated by the longer period of grass growth at the higher temperatures in future.

From a sensitivity analysis it was derived that grain production of wheat mainly increases due to increasing atmospheric CO_2 concentration and decreases due to increasing temperature and windspeed, that total production of silage maize mainly increases due to increasing atmospheric CO_2 concentration and solar radiation and decreases due to increasing temperature and windspeed, and that production of permanent grassland mainly increases due to increasing atmospheric CO_2 concentration, temperature, rainfall and vapour pressure and decreases due to increasing windspeed.

From the sensitivity analysis it was also derived that evapo-transpiration during the growth period of winterwheat mainly increases at increasing solar radiation and windspeed and decreases at increasing atmospheric CO_2 concentration, temperature and vapour pressure, that evapo-transpiration during the growth period of silage maize mainly increases at increasing solar radiation and windspeed and decreases at increasing atmospheric CO_2 concentration and vapour pressure, and that evapo-transpiration of permanent grassland mainly increases at increasing temperature and windspeed and decreases at increasing vapour pressure. Leaching from the root zone of permanent grassland was calculated to increase at increasing rainfall and vapour pressure and to decrease at increasing temperature and windspeed.

10 SUBSEQUENT PHASES OF THE PROJECT

In this study it has been shown that for each cropping system in the Rhine basin crop production and the components of the water balance can be calculated. This may be done for each combination of crop species, soil type and climate in the Rhine basin, and both for present climate conditions and for "future" conditions derived on the basis of a climate scenario. In subsequent phases of the project, the following activities may be carried out:

- analysis of the crop production on a regional scale by use of a geographical information system. This system contains information on the regional distribution of soil types, land use and climate and allows calculation of crop production for each soil - crop - climate combination as specified per location;
- analysis of the components of the water balance (evapo-transpiration, leaching, etc.) on a regional scale by use of a geographical information system, which allows calculation of evapo-transpiration, etc. for each soil - crop - climate combination as specified per location;
- analysis of the effects of climate change on land use, crop production and the components of the water balance (evapo-transpiration, leaching, etc.), if a specific climate scenario for the Rhine basin has come available. As discussed in this study, consequences of climate change for future land use can only be estimated, because many other factors influence land use too;
- for the main crops and local crop varieties that are cultivated in the Rhine basin and for newly introduced crop species and varieties after climate change, the plant data that specify for each plant species the growth and physiological development, can be collected. This information, together with information on climate and soil characteristics, may be used to calculate with the WOFOST model crop production, soil coverage and the components of the water balance for specified locations;
- development of scenarios for changing land use in the Rhine basin due to climate change. This requires a mixed approach that includes both a study on the effects of climate change and other environmental factors on crop growth and land use as presented in this report, and a study on the socio-economic factors that might cause changes in land use in future;
- approximation of the production and the components of the water balance for areas in use for permanent crops (vineyards, orchards, etc.);
- approximation of the components of the water balance for forests, nature reserves, mountainous areas, etc. Particularly in mountainous areas the amount of rainfall is about double the amount in the lowlands and the evapo-transpiration is about halved. This results in four times larger amounts of leaching water.

At last, it should be mentioned that as discussed in this study, scenarios on climate change have a considerable degree of uncertainty. This limits the reliability of results on future crop production, water use, leaching and land use that are calculated on the basis of these scenarios.

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ANNEX 1 TOTAL LAND USE, USE OF ARABLE LAND AND CROP YIELDS IN COUNTRIES OF THE EUROPEAN COMMUNITIES (TABLES 18-24)

Table 18 Land use (1000 ha) in 1985 for the regions that drain to the river Rhine (Source: Eurostat, 1987)

Country, Country part (Nuts I), Region (Nuts II)	Total area	Fraction draining to Rhine (roughly estimated)	Wooded area	Agricultural area					
				Total	Permanent grassland	Permanent crops	(fr. vineyards)	Arable crops	(fr. greenfodder crops)
Germany									
Nordrhein-Westfalen	3406.6	0.47	838.1	1619.3	510.3	9.4	(0.0)	1094.4	(0.16)
- Düsseldorf	528.8	0.5							
- Köln	736.8	0.75							
- Münster	689.7	0.0							
- Detmold	651.5	0.0							
- Arnsberg	799.8	1.0							
Hessen	2111.4	0.61	835.8	778.6	258.8	5.9	(0.56)	512.8	(0.11)
- Darmstadt	744.6	1.0							
- Gießen	538.0	1.0							
- Kassel	828.8	0.0							
Rheinland-Pfalz	1984.7	1.0	781.5	729.4	224.0	75.3	(0.89)	428.8	(0.08)
- Koblenz	809.2	1.0							
- Trier	492.5	1.0							
- Rheinhessen-Pfalz	683.0	1.0							
Baden-Württemberg	3575.2	0.49	1305.5	1515.3	626.3	44.7	(0.56)	839.7	(0.19)
- Stuttgart	1055.7	1.0							
- Karlsruhe	692.0	1.0							
- Freiburg	935.8	0.0							
- Tübingen	891.7	0.0							
Bayern	7055.1	0.27	2378.2	3455.7	1343.3	13.6	(0.39)	2085.0	(0.24)
- Oberbayern	1752.8	0.0							
- Niederbayern	1033.0	0.0							
- Oberpfalz	969.1	0.0							
- Oberfranken	723.1	0.5							
- Mittelfranken	724.5	1.0							
- Unterfranken	853.1	1.0							
- Schwaben	999.4	0.0							
Saarland	257.0	1.0	85.1	67.6	28.0	0.6	(0.17)	38.7	(0.14)
France									
Est	4803.0	0.54	1863.7	2302.0	1236.4	125.7	(0.14)	1043.0	(0.22)
- Lorraine	2354.7	0.75	859.1	1187.0	605.7	60.8	(0.01)	578.0	(0.21)
- Alsace	828.0	1.0	305.6	331.0	96.2	4.3	(1.0)	218.0	(0.15)
- Franche-Comté	1620.2	0.0	698.9	784.0	534.5	53.7	(0.04)	247.0	(0.32)
Luxemburg (Grand Duchy)									
	258.6	1.0	82.1	127.6	70.6	1.6	(0.81)	55.3	(0.33)
Netherlands									
Oost Nederland	1124.7	0.15	131.8	561.7	362.1	10.6	(0.0)	189.0	(0.35)
- Overijsel	433.3	0.0	34.5	245.7	165.0	1.6	(0.0)	79.1	(0.39)
- Gelderland	691.4	0.25	97.3	316.0	197.0	9.1	(0.0)	109.9	(0.32)

Table 19 Areas of arable land (1000 ha) used in 1985 for the main crops in regions that drain to the river Rhine (Source: Eurostat, 1987)

Country + Region	All cereals	Wheat	Barley	Grain maize	Potatoes	Sugar-beet	Sunflower	Rape
Germany								
Nordrhein-Westfalen	771.5	235.4	327.4	57.5	18.3	81.6	0.0	19.6
Hessen	388.7	141.7	141.6	4.9	9.7	21.7	0.0	18.6
Rheinland-Pfalz	333.8	106.9	138.4	2.9	12.5	23.1	0.0	10.0
Baden-Würtemberg	571.0	218.6	200.8	29.1	15.5	23.4	0.0	34.1
Bayern	1292.6	487.6	530.8	44.2	80.9	83.8	0.0	56.8
Saarland	30.8	6.1	10.7	0.2	0.5	0.0	0.0	0.9
France								
Est	673.2	260.5	285.9	79.2	5.1	6.3	1.1	75.3
- Lorraine	376.8	150.4	193.9	10.3	1.7	0.4	0.1	52.5
- Alsace	155.9	65.8	27.9	57.5	2.3	4.7	1.0	8.2
- Franche-Comté	140.4	44.3	64.0	11.4	1.1	1.2	0.1	14.7
Luxembourg (Grand Duchy)								
	34.7	6.6	17.0	0.0	0.9	0.0	0.0	0.5
Netherlands								
Oost Nederland	32.0	23.1	6.6	0.1	30.8	24.4	0.0	4.1
- Overijsel	7.2	5.9	0.6	0.0	16.8	9.9	0.0	0.0
- Gelderland	24.8	17.2	6.0	0.0	14.0	14.5	0.0	4.0

Table 20 Yields (100 kg/ha) in 1985 for the main crops in regions that drain to the river Rhine (Source: Eurostat, 1987)[1]

Country + Region	All cereals	Wheat	Barley	Grain maize	Potatoes	Sugar-beets	Sunflower	Rape
Germany								
Nordrhein-Westfalen	55	62	52	65	386	502	-	28
Hessen	53	60	50	70	314	489	-	27
Rheinland-Pfalz	48	55	46	61	304	509	-	24
Baden-Würtemberg	52	56	47	71	313	522	-	28
Bayern	54	61	50	68	338	578	-	29
Saarland	45	53	44	47	296	327	-	24
France								
Est	54	56	47	78	296	594	30	30
- Lorraine	50	53	48	58	251	435	23	29
- Alsace	67	61	49	84	335	610	31	32
- Franche-Comté	50	57	45	70	282	591	20	31
Luxemburg (Grand Duchy)								
	38	43	36	-	320	444	-	19
Netherlands								
OostNederland	60	67	43	-	472	541	-	31
- Overijsel	63	67	46	-	427	504	-	30
- Gelderland	60	67	43	-	527	565	-	31

[1] Dry matter fractions in grains, in seeds from sunflower and rape, in potatoes and in sugar-beets are 0.85, 0.85, 0.22 and 0.23 kg/kg, respectively.

Table 21 Areas harvested (1000 ha) and crop yields (100 kg/ha) in Germany (D) and France (F) (Source: Eurostat, 1988)

		Country Area		Crop yield[1]	
		1983	1986	1983	1986
Total agricultural area	D	12079	12000		
,,	F	31557	31389		
Total arable land	D	7226	7244		
,,	F	17410	17735		
Permanent grassland	D	4630	4537		
,,	F	12535	12094		
Permanent crops	D	181	181		
,,	F	1358	1311		
Cereals (excl. rice)	D	5044	4812		
,,	F	9382	9487		
Wheat and spelt	D	1655	1648	54.4	63.4
,,	F	4825	4865	51.8	55.5
Rye	D	445	414	36.0	42.7
,,	F	101	80	28.9	28.2
Oats and mixed grain	D	729	605	34.4	45.0 (oats)
,,	F	546	407	32.6	34.2 (")
Barley	D	2035	1947	44.0	48.2
,,	F	2143	2097	40.9	48.3
Grain maize	D	169	187	55.3	69.6
,,	F	1685	1884	62.5	61.8
Dried pulses	D	13	69		
,,	F	204	354		
Potatoes	D	224	210	253.0	352.4
,,	F	204	201	261.0	299.1
Sugar beet	D	393	390	414.7	518.8
,,	F	490	449	537.0	553.9
Fodder beet	D	120	94		
,,	F	136	105		
Other root crops	D	6	6		
,,	F	132	74		
Rape and turnip rape	D	232	308	25.9	31.5
,,	F	470	386	20.6	27.1
Sunflower		D	0	0	
,,	F	431	901		
Green fodder total	D	5734	5791		
,,	F	17748	17189		
Permanent grassland	D	4630	4537	74.2	78.1
,,	F	12535	12094	49.2	48.7
Green fodder from arable land	D	1104	1255		
,,	F	5214	5095		
Silage maize	D	807	947	414.0	479.7
,,	F	1409	1619	399.7	377.2

[1] Dry matter fractions in grains, in seeds from sunflower and rape, in potatoes, in beets and in silage maize are 0.85, 0.85, 0.22, 0.23 and 0.27 kg/kg, respectively.

Table 22 Land use (1000 ha) in 1985 in South France and North Italy (Source: Eurostat, 1987)

Country, Country part (Nuts I), Region (Nuts II)	Total area	Wooded area	Agricultural area					
			Total	Permanent grassland		Permanent crops (fr. vine-yards)		Arable crops (fr. green fodder crops)
<u>France</u>								
Ouest								
- Poitou-Charentes	2581.0	434.9	1860.0	412.3	102.7	(1.00)	1342.0	(0.33)
Sud-Ouest								
- Aquitaine	4130.8	1832.3	1697.0	605.3	140.0	(1.00)	926.0	(0.25)
- Midi-Pyrénées	4534.8	1163.4	2734.0	1031.3	111.7	(0.55)	1616.0	(0.30)
- Limousin	1694.2	552.1	936.0	638.9	64.4	(0.02)	291.0	(0.57)
Méditerranée								
- Languedoc-Rousillon	2737.6	794.6	1204.0	506.0	392.4	(0.99)	263.0	(0.22)
<u>Italy</u>								
Nord-Ovest								
- Piemonte	2539.9	598.5	1337.7	494.0	104.2	(0.70)	681.8	
Lombardia	2385.7	479.1	1215.9	335.4	37.3	(0.83)	801.9	
Nord-Est								
- Veneto	1836.4	263.1	1002.7	189.0	127.0	(0.73)	602.0	

Table 23 Areas of arable land (1000 ha) used in 1985 for the main crops in South France and North Italy (Source: Eurostat, 1987)

	All cereals	Wheat	Barley	Grain maize	Potatoes	Sugar-beet	Sunflower	Rape
<u>France</u>								
Ouest								
- Poitou-Charentes	622.6	331.9	140.5	111.5	2.4	0.0	167.6	38.4
Sud-Ouest								
- Aquitaine	571.4	91.2	53.8	404.7	5.4	-	42.1	5.3
- Midi-Pyrénées	824.5	317.3	148.8	269.8	7.3	-	160.0	44.2
- Limousin	100.4	29.8	26.9	7.7	4.4	-	0.2	1.1
Méditerranée								
- Languedoc-Rousillon	106.2	57.9	19.5	8.6	5.5	-	28.1	5.1
<u>Italy</u>								
Nord-Ovest								
- Piemonte	431.4	141.0	32.1	145.1	8.3	4.5	-	
- Lombardia	424.5	81.9	92.3	178.3	4.2	15.0	0.2	
- Nord-Est								
- Veneto	371.1	80.3	25.3	264.5	6.4	33.6	0.2	-

Table 24 Areas of agricultural land and arable land used in 1986 in the Netherlands (NL), Germany (D), France (F), Italy (I) and Greece (GR) (Source: Eurostat, 1988)

	Country	Area (1000 ha)	Relative area (%)
Total agricultural area	NL	2024	100
"	D	12000	100
"	F	31389	100
"	I	17445	100
"	GR	5741	100
Total arable land	NL	876	43.3
"	D	7244	60.4
"	F	17735	56.5
"	I	9061	51.9
"	GR	2925	50.9
Permanent grassland	NL	1108	54.7
"	D	4537	37.8
"	F	12094	38.5
"	I	4944	28.3
"	GR	1789	31.2
Permanent crops	NL	35	1.7
"	D	181	1.5
"	F	1311	4.2
"	I	3359	19.3
"	GR	1040	18.1
Cereals (incl. rice)	NL	170	8.4
"	D	4812	40.1
"	F	9499	30.3
"	I	4737	27.2
"	GR	1464	25.5
Wheat and spelt	NL	116	5.7
"	D	1648	13.7
"	F	4865	15.5
"	I	3072	17.6
"	GR	904	15.7
Rye	NL	4	
"	D	414	3.5
"	F	80	0.3
"	I	8	
"	GR	13	
Oats and mixed grain	NL	7	
"	D	605	5.0
"	F	407	1.3
"	I	177	1.0
"	GR	43	0.7
Barley	NL	42	2.1
"	D	1947	16.2
"	F	2097	6.7
"	I	440	2.5
"	GR	266	4.6
Grain maize	NL	0	
"	D	187	1.6
"	F	1884	6.0
"	I	833	4.8
"	GR	218	3.8
Dried pulses	NL	32	1.6
"	D	69	0.6
"	F	354	1.1

Table 24 (continued)

	Country	Area (1000 ha)	Relative area ((%)
Dried pulses	I	174	1.0
"	GR	43	0.7
Potatoes	NL	167	8.3
	D	210	1.8
"	F	201	0.6
"	I	120	0.7
"	GR	56	1.0
Sugar beet	NL	138	6.8
"	D	390	3.3
"	F	449	1.4
"	I	273	1.6
"	GR	42	0.7
Fodder beet	NL	2	
"	D	94	0.8
"	F	105	0.3
"	I	12	
"	GR	0	
Other root crops	NL	0	
"	D	6	
"	F	74	
"	I	14	
"	GR	0	
Rape and turnip rape	NL	6	
"	D	308	2.6
"	F	386	1.2
"	I	14	
"	GR	-	
Sunflower	NL	-	
"	D	-	
"	F	901	2.9
"	I	90	0.5
"	GR	79	1.4
Green fodder total	NL	1345	66.5
"	D	5791	48.3
"	F	17189	54.8
"	I	7547	43.3
"	GR	2009	35.0
Permanent grassland	NL	1108	54.7
"	D	4537	37.8
"	F	12094	38.5
"	I	4944	28.3
"	GR	1789	31.2
Green fodder from arable land	NL	237	11.7
"	D	1255	10.5
"	F	5095	16.2
"	I	2603	14.9
"	GR	220	3.8
Silage maize	NL	196	9.7
"	D	947	7.9
"	F	1619	5.2
"	I	300	1.7
"	GR	4	0.1

ANNEX 2 CALCULATED PRODUCTIONS OF WINTERWHEAT, SILAGE MAIZE AND PERMANENT GRASSLAND AND WATER BALANCES DURING THE GROWING SEASONS (TABLES 25-40)

Table 25 Water-limited production and water use of winterwheat sown half November in De Bilt (B) and Twente (T), the Netherlands, in Strasbourg (S), France and in Karlsruhe (K), Freiburg (Fre) and Frankfurt (Fra), Germany on loamy[1] soils and leaching during the growing season over twenty years (1969-1988)

Year, location	Duration growing season[2] (d)	Dry matter production Total (kg/ha)	grain	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[3] (cm)
1969,B	226	19568	8520	41.4	28.6	9.2	18.2	-14.5
1969,T	229	17683	7115	41.1	30.5	9.5	17.6	-16.5
1969,S	216	17733	8386	41.7	25.2	9.1	15.9	-8.5
1969,K	212	19574	8917	53.8	26.2	8.4	24.6	-5.4
1969,Fre	209	19616	9623	62.9	28.4	9.1	25.6	-0.3
1969,Fra	219	18168	8116	38.9	25.8	8.8	15.4	-11.1
1970,B	235	20330	9405	55.6	29.2	10.2	24.5	-8.2
1970,T	237	18208	8099	52.4	31.6	9.8	24.2	-13.3
1970,S	220	18222	8729	45.2	24.7	10.8	18.6	-9.0
1970,K	216	17280	8048	64.0	23.8	11.3	37.5	-8.6
1970,Fre	215	17134	7917	73.5	25.5	12.6	38.5	-3.1
1970,Fra	227	18166	8368	46.5	25.2	9.7	19.5	-7.9
1971,B	226	19738	10611	39.0	26.0	8.0	13.4	-8.4
1971,T	229	18823	10237	34.2	23.1	8.1	11.3	-8.4
1971,S	211	18711	9673	22.1	27.0	6.1	3.3	-14.3
1971,K	208	17658	9233	26.5	23.5	6.5	5.5	-9.1
1971,Fre	206	17971	9352	41.4	26.3	8.6	10.0	-3.4
1971,Fra	215	18323	9773	28.5	25.2	5.8	5.7	-8.2
1972,B	230	19832	8932	46.2	25.0	9.5	11.9	-0.2
1972,T	236	17361	8109	55.4	20.3	10.2	25.0	-0.1
1972,S	218	17949	8808	32.3	23.9	7.5	6.0	-5.1
1972,K	212	15853	7892	37.2	21.0	8.6	12.5	-4.9
1972,Fre	208	18978	9042	49.0	27.5	7.4	14.3	-0.2
1972,Fra	220	17170	7763	34.8	23.4	6.7	9.7	-5.1
1973,B	229	18460	8826	42.6	25.1	11.3	18.4	-12.2
1973,T	232	15647	7851	40.5	21.3	13.4	18.6	-12.8
1973,S	215	17141	7982	31.4	25.6	9.1	6.4	-9.7
1973,K	214	16869	7717	44.7	24.5	9.7	14.4	-3.8
1973,Fre	212	17090	7895	57.8	26.2	10.8	22.7	-2.0
1973,Fra	220	15503	7090	25.5	23.3	8.9	5.7	-12.3
1974,B	223	22376	11007	43.8	27.0	6.9	12.4	-2.5
1974,T	228	19669	9445	42.4	25.5	8.4	11.7	-3.2
1974,S	204	18774	9784	28.0	25.8	7.4	5.5	-10.7
1974,K	205	17278	9109	40.1	21.7	8.6	13.7	-3.9
1974,Fre	201	17550	9375	50.0	23.4	9.1	17.3	+0.2
1974,Fra	214	19283	9610	32.4	24.4	7.1	10.9	-10.0
1975,B	220	16812	8350	38.5	23.3	10.0	18.5	-13.4
1975,T	223	18220	8745	39.7	24.6	8.9	20.2	-14.0
1975,S	211	15569	7569	30.3	21.1	8.1	5.6	-4.6
1975,K	206	14389	6898	50.5	19.0	9.8	23.4	-1.7
1975,Fre	205	14225	7147	53.8	19.7	10.6	24.7	-1.3
1975,Fra	214	16100	7316	40.9	22.5	8.9	16.2	-6.6

Table 25 (*continued*)

Year, location	Duration growing season[2] (d)	Dry matter production Total (kg/ha)	grain	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[3] (cm)
1976,B	218	14858	6259	29.8	24.4	8.2	13.3	-16.0
1976,T	226	17099	7434	30.2	27.4	6.6	13.3	-17.2
1976,S	206	13493	4357	21.6	24.9	7.2	5.7	-16.2
1976,K	200	14251	5327	26.4	23.7	7.3	12.4	-17.0
1976,Fre	198	16617	6088	31.0	29.5	7.0	9.7	-15.2
1976,Fra	209	11238	3112	19.7	21.3	7.0	7.3	-15.9
1977,B	225	18108	8554	45.8	24.7	9.7	22.4	-11.1
1977,T	233	19600	9033	46.6	25.5	9.9	15.2	-4.0
1977,S	208	14997	7283	39.3	23.7	10.1	9.6	-4.1
1977,K	203	16185	7905	40.0	23.2	8.1	18.0	-9.3
1977,Fre	199	16045	8153	55.1	23.0	10.5	22.5	-0.9
1977,Fra	215	15514	7128	37.8	22.5	9.1	18.9	-12.8
1978,B	231	20448	10433	38.7	26.5	8.8	14.1	-10.7
1978,T	237	19210	9758	41.8	23.7	8.7	13.2	-3.8
1978,S	217	19363	9796	47.5	26.9	10.4	16.5	-6.3
1978,K	214	19775	10290	67.4	25.7	8.2	34.4	-0.9
1978,Fre	212	19520	9737	70.5	26.8	9.2	33.5	+0.9
1978,Fra	220	17856	9430	43.2	23.6	8.4	21.8	-10.5
1979,B	243	19782	8759	59.6	25.9	11.3	30.3	-8.0
1979,T	249	19155	8723	49.2	24.3	10.1	19.2	-4.3
1979,S	217	18241	9070	37.2	27.7	10.3	12.7	-13.5
1979,K	213	19060	8917	39.6	27.2	7.6	20.3	-15.6
1979,Fre	211	19029	9178	61.3	28.7	9.7	32.2	-9.4
1979,Fra	223	17818	8386	43.0	27.2	9.3	16.9	-10.4
1980,B	229	21013	9262	53.8	28.9	6.9	20.7	-2.6
1980,T	239	20481	8917	49.4	26.9	7.4	20.0	-4.8
1980,S	221	18334	7971	36.2	27.4	8.1	7.9	-7.2
1980,K	217	19237	8237	53.5	26.5	7.7	21.2	-1.8
1980,Fre	216	17539	7787	64.9	25.6	9.3	31.3	-1.3
1980,Fra	224	19084	8519	51.4	27.1	7.7	19.1	-2.5
1981,B	223	19135	9514	57.4	23.6	7.5	27.5	-1.2
1981,T	222	18049	9126	52.2	23.5	7.3	23.1	-1.8
1981,S	209	15263	7540	35.1	22.0	8.6	4.8	-0.4
1981,K	208	16208	8034	49.7	22.7	9.1	20.3	-2.4
1981,Fre	204	15906	7753	53.5	23.7	10.4	19.1	+0.2
1981,Fra	215	17066	8250	51.3	24.1	8.3	21.2	-2.3
1982,B	219	19006	9391	30.3	27.3	7.4	10.1	-14.5
1982,T	225	16777	8643	32.4	22.9	8.3	12.6	-11.3
1982,S	210	18300	8532	41.9	28.9	7.9	8.8	-3.7
1982,K	206	17831	8393	48.7	27.0	7.5	14.2	-0.1
1982,Fre	201	18638	8137	47.6	31.0	7.8	16.0	-7.3
1982,Fra	214	16176	6862	29.9	25.2	7.7	14.1	-17.1
1983,B	217	17955	8558	53.2	24.1	9.6	32.7	-13.2
1983,T	222	17966	8777	50.8	26.4	10.2	30.4	-16.1
1983,S	205	16173	7980	51.7	22.7	10.2	29.9	-11.0
1983,K	201	16305	8089	49.3	21.7	8.7	30.4	-11.5
1983,Fre	200	15962	7767	74.0	23.0	10.9	43.2	-3.2
1983,Fra	208	16462	7880	50.3	23.2	10.0	26.4	-9.2

Table 25 (continued)

Year, location	Duration growing season[2] (d)	Dry matter production Total (kg/ha)	grain	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[3] (cm)
1984,B	235	18837	9116	53.1	23.3	8.1	29.7	-8.0
1984,T	240	20457	10200	56.5	22.3	9.1	32.3	-7.3
1984,S	225	18858	8948	39.7	28.0	9.6	12.1	-10.1
1984,K	219	18308	8671	55.3	24.8	9.2	25.9	-4.6
1984,Fre	215	17489	8232	49.9	26.0	10.8	22.2	-9.2
1984,Fra	228	17180	8009	42.5	24.7	8.7	20.7	-11.6
1985,B	234	20197	9436	45.8	26.3	9.1	10.4	-0.1
1985,T	243	20030	9624	51.3	26.2	10.0	15.7	-0.5
1985,S	216	19219	9871	35.8	28.0	8.8	9.3	-10.3
1985,K	212	19011	9737	46.9	26.1	8.8	17.5	-5.5
1985,Fre	207	17400	8811	51.6	25.3	9.3	23.5	-6.6
1985,Fra	223	18993	9240	33.0	27.8	7.9	6.5	-9.3
1986,B	233	20460	8321	38.5	30.0	8.5	18.1	-18.1
1986,T	237	21609	9678	42.4	31.1	8.7	17.8	-15.3
1986,S	215	14919	7449	41.6	23.2	12.2	15.9	-9.7
1986,K	211	14798	7020	46.8	22.2	11.0	22.4	-8.8
1986,Fre	209	14850	7105	70.7	23.0	12.2	38.1	-2.5
1986,Fra	216	17079	7944	33.9	25.6	9.1	13.7	-14.5
1987,B	238	20759	9147	64.0	26.3	8.5	28.4	+0.8
1987,T	245	21397	9145	56.3	26.8	7.1	22.6	-0.2
1987,S	225	17705	7896	53.8	24.7	8.3	21.0	-0.2
1987,K	219	18099	7750	55.6	25.3	9.1	21.8	-0.7
1987,Fre	214	17353	7182	63.5	26.5	10.0	30.6	-3.5
1987,Fra	230	19724	8599	50.5	26.9	7.3	17.3	-1.1
1988,B	218	16264	8047	59.6	22.1	10.5	31.1	-4.1
1988,T	223	15330	7714	49.0	20.2	10.2	23.1	-4.5
1988,S	204	16950	8767	36.0	22.7	10.2	11.1	-7.9
1988,K	201	16818	8809	55.3	22.7	11.0	29.5	-7.9
1988,Fre	197	15887	8756	56.6	21.1	13.3	23.1	-0.8
1988,Fra	209	16902	8399	38.5	23.6	9.6	19.4	-14.1
Average,B	228	19197	9022	46.8	25.9	9.0	20.3	-8.3
" ,T	233	18639	8819	45.7	25.2	9.1	19.4	-8.0
" ,S	214	17296	8320	37.4	25.2	9.0	11.3	-8.1
" ,K	210	17239	8250	47.6	23.9	8.8	21.0	-6.2
" ,Fre	207	17240	8252	56.9	25.5	9.9	24.9	-3.4
" ,Fra	218	17190	7990	38.6	24.6	8.3	15.3	-9.6
Standard deviation,B	7	1762	1015	9.8	2.2	1.3	7.6	5.9
" ,T	8	1734	885	7.9	3.3	1.5	5.9	6.0
" ,S	7	1672	1244	8.6	2.2	1.5	6.7	4.3
" ,K	6	1671	1082	10.6	2.2	1.3	8.0	4.8
" ,Fre	6	1482	971	11.0	2.8	1.6	9.3	4.1
" ,Fra	6	1858	1410	9.0	1.8	1.1	6.0	4.5

[1] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 21 cm water per m soil.

[2] Growing season is considered from January 1 till moment of crop maturing and components of water balance are calculated for this indicated season duration. In cold winters crop growth will actually start at a later date than January 1.

[3] Initial amount of available water at January 1 is set at the maximum amount per soil type.

Table 26 Water-limited production and water use of silage maize sown end of April in De Bilt (B) and Twente (T), the Netherlands, and half April in Strasbourg (S), France and in Karlsruhe (K), Freiburg (Fre) and Frankfurt (Fra), Germany on loamy[1] soils and leaching during the growing season over twenty years (1969-1988)

Year, location	Duration growing season[2] (d)	Dry matter production Total (kg/ha)	ear	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[3] (cm)
1969,B	140	20111	10629	34.7	26.9	7.4	2.1	-1.6
1969,T	140	17180	8499	26.8	28.7	8.5	1.3	-11.7
1969,S	122	20866	10488	26.7	28.0	6.6	0.9	-8.9
1969,K	115	20964	10793	33.6	27.4	5.9	2.2	-1.9
1969,Fre	113	21688	10655	44.3	30.8	6.1	4.7	+2.7
1969,Fra	124	20483	10631	27.7	26.3	7.2	1.2	-7.0
1970,B	140	22062	12000	33.2	27.2	4.5	0.1	+1.3
1970,T	140	19090	10419	30.6	29.1	6.6	0.0	-5.2
1970,S	121	21304	12309	25.3	25.3	6.0	1.0	-7.0
1970,K	115	20880	12121	33.0	26.0	5.8	6.6	-7.0
1970,Fre	113	20516	11799	42.6	27.2	6.8	13.2	-4.7
1970,Fra	126	19842	11406	25.6	23.9	6.3	0.0	-4.6
1971,B	140	20171	8502	26.8	27.2	5.9	5.7	-12.0
1971,T	140	18572	8089	24.2	24.3	5.0	1.6	-6.7
1971,S	113	22242	10543	22.3	30.2	4.6	0.0	-12.6
1971,K	106	21543	10407	19.5	28.3	4.8	0.0	-13.6
1971,Fre	107	22050	11189	33.9	30.4	4.7	4.9	-6.0
1971,Fra	118	22845	11682	25.0	30.2	4.4	2.5	-12.1
1972,B	140	16141	8807	31.8	17.5	10.5	2.9	+0.9
1972,T	140	14827	7319	43.1	15.1	9.6	15.7	+2.6
1972,S	141	21237	11749	30.3	26.2	7.2	2.9	-6.0
1972,K	126	20151	10848	30.6	25.1	6.8	3.8	-5.0
1972,Fre	125	20387	11332	36.3	26.4	6.6	8.0	-4.7
1972,Fra	147	19393	10562	32.2	25.1	7.2	5.6	-5.6
1973,B	137	21683	12163	28.6	26.5	6.3	1.5	-5.8
1973,T	140	19020	10652	21.0	24.4	6.5	0.0	-9.9
1973,S	114	20261	10901	20.6	28.1	5.4	0.0	-13.0
1973,K	111	20001	10758	29.8	26.6	5.4	0.0	-2.1
1973,Fre	108	20181	10543	33.3	27.8	6.3	5.9	-6.6
1973,Fra	118	18107	10019	16.7	25.1	5.7	0.0	-14.1
1974,B	140	19211	9337	42.2	21.1	7.7	10.1	+3.3
1974,T	140	15869	7739	33.4	17.7	9.9	2.8	+3.0
1974,S	122	21134	10664	22.4	30.3	5.0	0.0	-13.0
1974,K	121	20773	10719	26.5	28.0	5.1	0.0	-6.6
1974,Fre	118	21333	10478	40.4	31.3	6.1	4.2	-1.2
1974,Fra	134	19953	11123	23.4	25.1	7.1	0.0	-8.8
1975,B	133	20434	11541	19.4	25.5	5.8	0.0	-11.9
1975,T	140	20466	11643	19.5	25.1	6.3	0.0	-11.9
1975,S	119	18877	10586	28.0	24.7	6.4	3.1	-6.1
1975,K	113	18531	10719	40.4	24.0	6.2	11.2	-1.1
1975,Fre	115	19119	10803	51.1	26.1	6.3	15.8	+2.9
1975,Fra	118	15086	8999	27.6	19.3	8.6	2.4	-2.7
1976,B	132	19406	10522	18.9	25.4	6.4	0.0	-12.9
1976,T	140	19944	11580	18.3	25.8	7.2	0.0	-14.6
1976,S	108	14460	6017	13.5	24.7	4.9	0.0	-16.1
1976,K	102	16631	6841	14.8	25.5	4.4	0.0	-15.1
1976,Fre	103	19028	9485	23.5	29.3	6.2	0.8	-12.8
1976,Fra	110	12096	5136	8.5	20.0	4.8	0.0	-16.4

Table 26 (continued)

Year, location	Duration growing season[2] (d)	Dry matter production Total (kg/ha)	ear	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[3] (cm)
1977,B	140	18023	9096	23.4	20.8	6.0	0.0	-3.4
1977,T	140	14944	6900	26.5	16.6	7.7	1.0	+1.2
1977,S	126	19354	10931	31.7	24.1	6.7	2.6	-1.7
1977,K	119	19355	10691	23.0	24.2	5.5	0.0	-6.8
1977,Fre	119	21295	11956	40.6	27.1	5.3	6.2	+2.0
1977,Fra	132	17329	10038	23.8	21.0	6.3	0.0	-3.6
1978,B	140	19860	8615	25.5	24.5	3.8	0.9	-3.7
1978,T	140	18457	7951	30.3	21.6	5.4	1.6	+1.6
1978,S	138	22994	12756	38.6	28.7	5.6	6.7	-2.5
1978,K	133	22932	12257	50.8	27.4	5.4	19.7	-3.8
1978,Fre	130	22288	12390	52.1	28.1	6.6	18.2	-0.8
1978,Fra	142	21275	10955	26.3	27.7	5.6	6.0	-13.0
1979,B	140	19921	9045	28.0	24.2	6.9	4.6	-7.7
1979,T	140	18117	8232	24.3	21.9	6.4	0.0	-4.0
1979,S	123	20503	11534	22.8	25.6	7.4	0.9	-11.1
1979,K	116	19452	10577	18.2	24.2	5.3	0.0	-11.3
1979,Fre	114	21138	11772	34.0	28.3	6.6	0.0	-0.9
1979,Fra	123	20050	11207	21.9	25.3	6.8	0.0	-10.2
1980,B	140	19589	9983	35.6	22.3	5.6	8.8	-1.1
1980,T	140	14894	8248	35.5	14.6	9.6	12.0	-0.8
1980,S	135	18418	11091	31.5	22.6	7.5	0.7	+0.7
1980,K	129	18978	11028	40.4	23.6	6.7	10.8	-0.8
1980,Fre	126	18309	10660	45.9	24.6	8.2	13.9	-0.8
1980,Fra	138	18564	10401	37.1	22.2	7.0	10.0	-2.2
1981,B	140	21345	10931	30.9	23.7	6.0	3.0	-1.8
1981,T	140	20836	11285	31.0	23.3	7.0	4.3	-3.5
1981,S	119	20155	10571	29.2	26.4	5.2	1.4	-3.7
1981,K	117	20202	10284	27.7	26.1	5.2	3.1	-6.7
1981,Fre	115	19578	10458	41.7	26.4	6.0	9.3	+0.1
1981,Fra	126	20460	11184	43.0	26.1	5.3	13.5	-1.8
1982,B	125	22657	12308	19.2	29.0	4.7	0.0	-14.4
1982,T	129	22627	11582	17.2	28.1	4.2	0.0	-15.1
1982,S	110	18484	9868	32.0	23.9	6.5	1.0	+0.6
1982,K	104	18038	9546	31.0	23.2	5.9	1.2	+0.7
1982,Fre	103	17592	9319	36.9	24.1	6.2	4.9	+1.6
1982,Fra	111	16491	7222	14.3	23.7	5.2	0.0	-14.6
1983,B	130	19758	11275	27.1	24.5	6.9	1.0	-5.3
1983,T	140	17569	8551	21.6	25.6	7.7	1.4	-13.2
1983,S	110	17099	8831	27.9	24.6	7.6	10.8	-15.1
1983,K	106	16380	7667	19.6	22.7	6.2	6.3	-15.7
1983,Fre	105	17868	9995	39.9	25.1	8.0	16.8	-10.0
1983,Fra	112	18391	10170	22.2	25.3	6.7	4.3	-14.0
1984,B	140	17265	8413	36.4	20.2	7.1	5.4	+3.7
1984,T	140	21153	9915	35.8	22.2	7.7	4.4	+1.4
1984,S	135	20243	10425	34.4	27.2	7.1	4.8	-4.7
1984,K	129	19806	10736	36.9	25.4	7.7	6.3	-2.5
1984,Fre	120	19308	10868	32.6	26.1	7.2	5.5	-6.2
1984,Fra	139	19251	9715	32.6	26.1	7.4	5.4	-6.2

Table 26 (continued)

Year, location	Duration growing season[2] (d)	Drymatter production Total (kg/ha)	ear	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[3] (cm)
1985,B	140	20890	10112	33.6	24.8	5.2	1.4	+2.3
1985,T	140	17973	8426	34.9	22.3	6.9	3.3	+2.4
1985,S	121	23081	11545	26.9	32.1	5.3	1.5	-11.9
1985,K	115	22663	11637	28.1	30.0	5.2	3.8	-10.9
1985,Fre	109	20533	10804	29.3	29.1	6.1	2.8	-8.8
1985,Fra	130	22939	12094	26.3	31.2	5.2	0.1	-10.3
1986,B	140	18546	8772	22.8	24.9	6.7	0.0	-8.8
1986,T	140	17620	7395	22.0	25.6	6.2	0.0	-9.8
1986,S	116	20859	12166	30.2	28.8	6.7	1.1	-6.5
1986,K	106	20097	10865	29.4	28.0	5.6	2.3	-6.5
1986,Fre	104	20170	11374	40.2	27.9	7.0	5.7	-0.5
1986,Fra	119	18220	10058	19.8	25.5	6.4	0.0	-12.2
1987,B	140	15448	7880	46.0	16.8	9.4	17.2	+2.6
1987,T	140	13699	6099	41.8	14.4	10.8	14.0	+2.7
1987,S	128	14976	8982	41.3	16.9	10.9	12.8	+0.7
1987,K	124	17198	10294	40.1	19.9	11.0	8.4	+0.8
1987,Fre	119	17653	10519	45.4	22.4	10.7	13.2	-0.9
1987,Fra	134	17315	10152	37.7	19.6	10.0	6.5	+1.5
1988,B	140	19133	10642	34.2	22.0	5.4	3.8	+3.0
1988,T	140	18409	10062	30.5	21.4	6.0	1.0	+2.1
1988,S	115	21089	11574	24.8	27.2	6.0	0.0	-8.3
1988,K	110	21517	11485	23.5	29.1	4.3	0.0	-10.0
1988,Fre	107	21645	11607	33.2	29.4	6.0	3.1	-5.3
1988,Fra	118	19735	10311	15.9	26.6	4.0	0.0	-14.6
Average,B	138	19583	10029	29.9	23.8	6.4	3.4	-3.7
" ,T	139	18063	9029	28.4	22.4	7.3	3.2	-4.5
" ,S	122	19882	10676	28.0	26.3	6.4	2.6	-7.3
" ,K	116	19805	10514	29.8	25.7	5.9	4.3	-6.3
" ,Fre	114	20084	10900	38.8	27.4	6.6	7.9	-3.0
" ,Fra	126	18891	10153	25.4	24.8	6.4	2.9	-8.6
Standarddeviation,B	4	1844	1381	7.4	3.3	1.6	4.4	5.9
" ,T	2	2353	1716	7.5	4.6	1.7	4.9	6.6
" ,S	10	2313	1482	6.3	3.3	1.4	3.6	5.3
" ,K	9	1808	1283	8.9	2.5	1.4	5.2	5.1
" ,Fre	8	1477	795	7.1	2.3	1.2	5.4	4.4
" ,Fra	11	2512	1577	8.4	3.2	1.4	3.9	5.3

[1] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 21 cm water per m soil.

[2] Growing season is considered from crop emergence (May 8 for locations in France and Germany and May 15 for locations in the Netherlands) till date of crop maturing or date of harvest (set at October 2 when crop is not yet mature at that date) and components of water balance are calculated for this indicated season duration.

[3] Initial amount of available water at crop emergence is set at the maximum amount minus 3 cm water.

Table 27 Water-limited production and water use of mown permanent grassland in De Bilt (B) and Twente (T), the Netherlands, and in Strasbourg (S), France and in Karlsruhe (K), Freiburg (Fre) and Frankfurt (Fra), Germany on loamy[1] soils and leaching per year[2] over a period of twenty years (1969-1988)

Year, location	Dry matter production (kg/ha)	Rainfall (cm)	Transpiration (cm)	Evaporation (cm)	Leaching (cm)	Change amount soil water[3] (cm)
1969,B	16876	74.8	33.0	12.2	29.6	-0.1
1969,T	14386	67.0	29.8	13.7	23.4	+0.1
1969,S	17376	60.0	34.3	11.5	15.2	-1.0
1969,K	19963	79.1	34.8	12.4	32.0	+0.0
1969,Fre	21127	95.1	40.2	14.1	40.8	+0.0
1969,Fra	17022	58.1	30.8	11.3	16.0	-0.1
1970,B	16450	90.9	31.5	12.9	46.4	+0.0
1970,T	14472	83.3	29.2	12.6	41.4	+0.1
1970,S	18048	58.6	34.4	13.7	16.0	-5.5
1970,K	18158	85.5	33.8	14.1	37.2	+0.4
1970,Fre	18522	105.4	39.9	17.0	48.4	+0.1
1970,Fra	17146	66.8	32.2	13.0	21.1	+0.6
1971,B	17842	56.2	31.5	10.3	14.4	+0.0
1971,T	16560	52.8	28.7	10.2	13.9	+0.0
1971,S	15561	39.8	31.0	11.3	2.2	-4.7
1971,K	15603	46.2	29.8	11.1	5.4	+0.0
1971,Fre	20209	68.2	41.7	13.4	13.2	+0.0
1971,Fra	16145	45.0	32.9	9.6	4.2	-1.7
1972,B	18007	65.6	30.0	12.7	23.0	-0.1
1972,T	16879	74.6	27.4	11.2	36.2	-0.1
1972,S	18078	54.1	33.7	10.7	9.7	+0.0
1972,K	17977	66.0	32.5	11.4	22.1	+0.0
1972,Fre	20704	77.3	37.1	11.9	28.3	+0.0
1972,Fra	17360	56.0	31.9	9.4	14.7	-0.1
1973,B	15613	78.0	29.4	12.2	36.3	+0.0
1973,T	11710	71.6	24.9	13.5	33.2	+0.0
1973,S	14950	49.1	33.5	12.8	3.3	-0.4
1973,K	17938	75.6	37.3	13.3	25.0	+0.0
1973,Fre	18458	90.0	40.5	14.2	35.3	+0.0
1973,Fra	12714	46.7	27.2	11.4	8.1	+0.0
1974,B	20018	99.3	31.9	12.8	54.5	+0.1
1974,T	18715	83.6	32.0	12.7	38.8	+0.1
1974,S	16494	57.3	32.6	13.0	11.5	+0.2
1974,K	18290	76.1	33.8	13.4	28.4	+0.5
1974,Fre	20140	99.2	42.5	15.3	41.4	+0.0
1974,Fra	16712	64.9	30.6	11.2	22.5	+0.5
1975,B	15239	62.8	28.4	11.7	22.7	+0.0
1975,T	14349	58.7	27.2	11.4	20.2	-0.1
1975,S	17614	59.0	34.1	10.6	14.4	+0.0
1975,K	18331	82.0	35.2	12.2	34.3	+0.2
1975,Fre	18738	100.0	38.2	12.6	49.1	+0.1
1975,Fra	16817	63.5	33.4	11.0	18.9	+0.2
1976,B	9312	54.2	22.1	12.0	20.2	+0.0
1976,T	7434	50.0	19.5	13.2	17.3	+0.0
1976,S	7501	47.2	20.5	16.4	10.2	+0.0
1976,K	14234	64.8	28.8	12.7	23.3	+0.0
1976,Fre	16980	71.9	37.0	14.0	20.9	+0.0
1976,Fra	5222	36.7	16.0	12.2	8.6	+0.0

Table 27 (continued)

Year, location	Dry matter production (kg/ha)	Rainfall (cm)	Transpiration (cm)	Evaporation (cm)	Leaching (cm)	Change amount soil water[3] (cm)
1977,B	16394	81.3	28.6	11.5	40.9	+0.3
1977,T	17614	71.9	31.7	11.7	28.1	+0.4
1977,S	18518	68.4	38.7	13.2	16.6	+0.0
1977,K	18949	70.0	35.7	10.9	23.4	+0.0
1977,Fre	21164	96.9	39.6	14.6	42.8	+0.0
1977,Fra	14684	70.2	28.7	10.6	30.9	+0.0
1978,B	17595	64.5	30.5	9.9	23.9	+0.1
1978,T	17122	63.2	29.0	9.9	24.2	+0.1
1978,S	19333	67.7	38.0	14.0	15.1	+0.6
1978,K	19670	96.2	35.7	12.4	45.3	+2.8
1978,Fre	20139	104.0	38.1	15.3	50.1	+0.4
1978,Fra	15221	64.7	29.8	10.5	23.5	+0.9
1979,B	16957	87.3	30.4	12.5	43.2	+1.2
1979,T	16228	68.5	28.2	11.5	28.6	+0.1
1979,S	16703	63.4	32.9	13.9	16.5	+0.0
1979,K	16620	69.6	30.0	13.0	26.6	+0.0
1979,Fre	19094	102.3	38.2	15.4	48.5	+0.3
1979,Fra	17250	75.6	33.2	11.9	30.4	+0.1
1980,B	17168	86.3	29.5	11.2	45.5	+0.0
1980,T	17051	72.3	27.9	10.5	33.8	+0.0
1980,S	18385	57.9	36.1	12.6	9.2	+0.0
1980,K	19341	83.2	35.6	12.9	34.8	+0.0
1980,Fre	18977	94.9	39.3	14.2	41.5	+0.0
1980,Fra	17750	71.3	33.6	11.9	25.8	+0.0
1981,B	18528	99.2	29.7	11.6	57.2	+0.7
1981,T	17995	81.0	29.6	11.4	39.7	+0.3
1981,S	18607	68.3	36.5	12.8	19.0	+0.0
1981,K	18826	101.4	36.0	13.1	52.4	+0.0
1981,Fre	19080	111.2	39.9	16.1	55.2	+0.0
1981,Fra	18509	98.2	33.7	12.7	51.8	+0.0
1982,B	14031	63.5	27.5	12.7	23.3	+0.0
1982,T	13608	65.5	27.5	11.4	26.6	+0.0
1982,S	18243	76.5	38.4	14.0	24.1	+0.0
1982,K	18774	91.3	38.0	13.7	39.7	+0.0
1982,Fre	19752	113.0	42.5	14.3	56.2	+0.0
1982,Fra	8767	60.8	21.5	13.2	26.1	+0.0
1983,B	15342	89.1	27.3	11.9	50.0	+0.0
1983,T	11724	81.7	23.7	14.0	43.9	+0.0
1983,S	11801	67.1	25.1	16.9	28.4	-3.2
1983,K	11740	71.2	23.8	14.4	33.0	+0.0
1983,Fre	17550	104.7	39.0	15.5	50.3	+0.0
1983,Fra	14851	70.1	30.3	13.0	26.7	+0.0
1984,B	16707	89.0	29.9	10.2	49.0	+0.0
1984,T	17634	87.7	27.2	12.3	48.2	+0.0
1984,S	16840	65.1	35.6	13.1	16.5	+0.0
1984,K	17963	82.9	34.5	11.9	36.5	+0.0
1984,Fre	17844	97.8	38.4	13.9	45.5	+0.0
1984,Fra	14712	67.8	29.7	11.8	26.3	+0.0

Table 27 (continued)

Year, location	Dry matter production (kg/ha)	Rainfall (cm)	Transpiration (cm)	Evaporation (cm)	Leaching (cm)	Change amount soil water[3] (cm)
1985,B	17679	72.7	30.6	12.6	29.5	+0.0
1985,T	16925	73.5	30.3	13.2	30.0	+0.0
1985,S	17833	56.6	37.7	13.7	6.0	-0.8
1985,K	18444	69.6	36.2	12.7	20.6	+0.0
1985,Fre	18827	79.1	41.1	13.9	24.1	+0.0
1985,Fra	16699	46.7	33.8	12.0	5.0	-4.0
1986,B	15569	83.4	28.9	11.4	41.0	+2.0
1986,T	16418	77.7	29.9	11.2	34.6	+2.1
1986,S	17006	77.1	36.2	13.2	27.9	-0.2
1986,K	17020	90.3	34.9	13.1	41.6	+0.7
1986,Fre	18958	106.7	40.8	14.5	51.6	-0.1
1986,Fra	14565	63.7	28.4	12.6	22.5	+0.2
1987,B	18002	97.6	29.4	13.8	54.3	+0.2
1987,T	17717	89.3	27.4	12.7	49.1	+0.1
1987,S	17702	81.1	35.2	13.7	32.2	+0.0
1987,K	18509	81.0	35.3	14.8	31.0	+0.0
1987,Fre	19030	103.8	38.8	15.6	49.6	-0.1
1987,Fra	17981	73.7	32.5	13.3	27.9	+0.0
1988,B	17185	93.3	31.2	12.0	50.1	+0.0
1988,T	15737	78.9	28.9	10.8	39.2	+0.0
1988,S	17641	73.4	33.7	14.9	24.8	+0.0
1988,K	17905	93.5	35.5	14.6	43.5	+0.0
1988,Fre	20440	103.9	42.7	16.7	44.5	+0.0
1988,Fra	13421	65.6	26.5	12.3	26.9	+0.0
Average,B	16526	79.4	29.6	11.9	37.8	+0.2
" ,T	15514	72.6	28.0	12.0	32.5	+0.2
" ,S	16712	62.4	33.9	13.3	15.9	-0.8
" ,K	17713	78.8	33.9	12.9	31.8	+0.2
" ,Fre	19287	96.3	39.8	14.6	41.9	+0.0
" ,Fra	15178	63.3	29.8	11.7	21.9	-0.2
deviation,B	2165	14.4	2.3	1.0	13.3	0.5
" ,T	2742	10.9	2.8	1.2	9.8	0.5
" ,S	2718	10.6	4.4	1.6	8.3	1.7
" ,K	1942	12.9	3.4	1.1	10.5	0.6
" ,Fre	1155	12.7	1.7	1.3	11.8	0.1
" ,Fra	3249	13.3	4.5	1.1	10.9	1.0

[1] Soil with effective rooting depth of 50 cm and a maximum amount of available water of 10.5 cm water per m soil.
[2] Production and components of water balance are calculated for a period of one year, i.e. 365 days.
[3] Initial amount of available water at January 1 is set at the maximum amount per soil type.

Table 28 Average values and standard deviation of water-limited productions and components of the water balance during the growing season for winterwheat sown half November in De Bilt and Twente, the Netherlands, in Strasbourg, France and in Karlsruhe, Freiburg and Frankfurt, Germany on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviation have been established for historical weather data over a period of twenty years (1969-1988)

Location, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	Dry matter production grain (kg/ha)	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[6] (cm)
Average								
De Bilt,s	228	15387	6212	46.8	20.1	9.5	21.0	-3.8
„ ,sl	228	18383	8264	46.8	24.6	9.0	20.4	-7.1
„ ,l	228	19197	9022	46.8	25.9	9.0	20.3	-8.3
„ ,o	228	19324	9166	46.8	26.1	9.0	20.3	-8.5
Twente,s	233	15650	6461	45.7	20.4	9.5	19.8	-4.0
„ ,sl	233	18026	8215	45.7	24.0	9.1	19.4	-6.8
„ ,l	233	18639	8819	45.7	25.2	9.1	19.4	-8.0
„ ,o	233	18837	9007	45.7	25.7	9.1	19.4	-8.5
Strasbourg,s	214	15097	6375	37.4	21.3	9.2	11.5	-4.5
„ ,sl	214	17019	8003	37.4	24.6	9.0	11.3	-7.5
„ ,l	214	17296	8320	37.4	25.2	9.0	11.3	-8.1
„ ,o	214	17397	8431	37.4	25.5	9.0	11.3	-8.4
Karlsruhe,s	210	15639	6786	47.6	21.3	8.9	21.2	-3.8
„ ,sl	210	17066	8055	47.6	23.5	8.8	21.0	-5.8
„ ,l	210	17239	8250	47.6	23.9	8.8	21.0	-6.2
„ ,o	210	17268	8291	47.6	24.1	8.8	21.0	-6.3
Freiburg,s	207	16565	7647	56.9	24.1	10.0	25.1	-2.3
„ ,sl	207	17189	8195	56.9	25.3	9.9	24.9	-3.2
„ ,l	207	17240	8252	56.9	25.5	9.9	24.9	-3.4
„ ,o	207	17264	8289	56.9	25.7	9.9	24.9	-3.6
Frankfurt,s	218	14042	5392	38.6	19.6	8.6	15.4	-5.0
„ ,sl	218	16605	7360	38.6	23.5	8.3	15.3	-8.5
„ ,l	218	17190	7990	38.6	24.6	8.3	15.3	-9.6
„ ,o	218	17368	8188	38.6	25.0	8.3	15.3	-10.1
Standard deviation								
De Bilt,s	7	3545	2747	9.8	3.8	1.4	7.8	2.9
„ ,sl	7	2261	1885	9.8	2.0	1.3	7.6	4.8
„ ,l	7	1762	1015	9.8	2.2	1.3	7.6	5.9
„ ,o	7	1680	842	9.8	2.4	1.3	7.6	6.2
Twente,s	8	3366	2817	7.9	3.4	1.6	6.1	2.6
„ ,sl	8	2105	1582	7.9	2.3	1.5	5.9	4.6
„ ,l	8	1734	885	7.9	3.3	1.5	5.9	6.0
„ ,o	8	1708	736	7.9	4.1	1.5	5.9	6.7
Strasbourg,s	7	2172	1758	8.6	2.9	1.4	6.6	2.0
„ ,sl	7	1812	1433	8.6	2.3	1.5	6.7	3.5
„ ,l	7	1672	1244	8.6	2.2	1.5	6.7	4.3
„ ,o	7	1483	937	8.6	2.5	1.5	6.7	4.9
Karlsruhe,s	6	2613	2147	10.6	3.5	1.2	8.0	2.5
„ ,sl	6	1796	1352	10.6	2.3	1.3	8.0	4.0
„ ,l	6	1671	1082	10.6	2.2	1.3	8.0	4.8
„ ,o	6	1635	995	10.6	2.3	1.3	8.0	5.2
Freiburg,s	6	1712	1645	11.0	2.5	1.6	9.2	2.1
„ ,sl	6	1516	1112	11.0	2.7	1.6	9.3	3.6
„ ,l	6	1482	971	11.0	2.8	1.6	9.3	4.1
„ ,o	6	1475	896	11.0	3.1	1.6	9.3	4.6

Table 28 (continued)

Location, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[6] (cm)
Frankfurt,s	6	3618	2673	9.0	4.5	1.2	6.0	1.5
,, ,sl	6	2455	1992	9.0	2.8	1.1	6.0	3.4
,, ,l	6	1858	1410	9.0	1.8	1.1	6.0	4.5
,, ,o	6	1486	972	9.0	1.8	1.1	6.0	5.3

[1] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 7 cm water per m soil.
[2] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 14 cm water per m soil.
[3] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 21 cm water per m soil.
[4] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.
[5] Growing season is considered from January 1 till moment of crop maturing and components of water balance are calculated for this indicated season duration. In cold winters crop growth will actually start at a later date than January 1.
[6] Initial amount of available water at January 1 is set at the maximum amount per soil type.

Table 29 Average values and standard deviation of water-limited productions and components of the water balance during the growing season for silage maize sown end of April in De Bilt and Twente, the Netherlands, and half April in Strasbourg, France and in Karlsruhe, Freiburg and Frankfurt, Germany on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviation have been established for historical weather data over a period of twenty years (1969-1988)

Location, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	ear	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[6] (cm)
Average								
De Bilt,s	138	14015	6688	29.9	16.2	8.1	4.8	+0.8
" ,sl	138	18226	8854	29.9	22.1	6.6	3.5	-2.3
" ,l	138	19583	10029	29.9	23.8	6.4	3.4	-3.7
" ,o	138	19791	10226	29.9	24.0	6.4	3.4	-3.9
Twente,s	139	13371	5957	28.4	15.8	8.7	3.5	+0.4
" ,sl	139	16519	7610	28.4	20.4	7.5	3.2	-2.7
" ,l	139	18063	9029	28.4	22.4	7.3	3.2	-4.5
" ,o	139	18386	9344	28.4	22.9	7.2	3.2	-4.9
Strasbourg,s	122	14672	6693	28.0	19.0	7.6	2.7	-1.3
" ,sl	122	18206	9127	28.0	24.2	6.6	2.6	-5.4
" ,l	122	19882	10676	28.0	26.3	6.4	2.6	-7.3
" ,o	122	20498	11205	28.0	27.1	6.4	2.6	-8.1
Karlsruhe,s	116	14988	6844	29.8	19.3	6.9	4.7	-1.1
" ,sl	116	18614	9467	29.8	24.2	6.0	4.4	-4.9
" ,l	116	19805	10514	29.8	25.7	5.9	4.3	-6.3
" ,o	116	20246	10951	29.8	26.3	5.9	4.4	-6.9
Freiburg,s	114	17269	8818	38.8	23.3	7.4	8.6	-0.6
" ,sl	114	19753	10632	38.8	26.9	6.7	7.8	-2.5
" ,l	114	20084	10900	38.8	27.4	6.6	7.9	-3.0
" ,o	114	20194	10992	38.8	27.6	6.6	8.1	-3.4
Frankfurt,s	126	12514	5502	25.4	16.1	7.8	3.1	-1.7
" ,sl	126	16988	8439	25.4	22.4	6.5	2.9	-6.4
" ,l	126	18891	10153	25.4	24.8	6.4	2.9	-8.6
" ,o	126	19729	10923	25.4	25.9	6.3	2.9	-9.7
Standard deviation								
De Bilt,s	4	4029	2625	7.4	4.3	1.5	4.5	2.4
" ,sl	4	2318	1631	7.4	2.8	1.6	4.4	4.5
" ,l	4	1844	1381	7.4	3.3	1.6	4.4	5.9
" ,o	4	1989	1625	7.4	3.5	1.6	4.4	6.3
Twente,s	2	4178	2639	7.5	4.3	1.8	4.8	2.4
" ,sl	2	2404	1831	7.5	3.4	1.7	4.9	4.6
" ,l	2	2353	1716	7.5	4.6	1.7	4.9	6.6
" ,o	2	2504	1962	7.5	5.1	1.7	4.9	7.2
Strasbourg,s	10	3881	3209	6.3	4.4	1.3	3.6	2.0
" ,sl	10	2886	2362	6.3	3.2	1.3	3.6	3.6
" ,l	10	2313	1482	6.3	3.3	1.4	3.6	5.3
" ,o	10	1971	893	6.3	4.1	1.4	3.6	7.0
Karlsruhe,s	9	3959	3031	8.9	4.7	1.4	5.5	2.4
" ,sl	9	2826	2374	8.9	3.2	1.4	5.5	3.6
" ,l	9	1808	1283	8.9	2.5	1.4	5.2	5.1
" ,o	9	1491	664	8.9	2.7	1.5	5.2	6.1
Freiburg,s	8	3191	2160	7.1	4.3	1.6	5.5	2.4
" ,sl	8	1732	1013	7.1	2.4	1.2	5.5	3.9
" ,l	8	1477	795	7.1	2.3	1.2	5.4	4.4
" ,o	8	1476	726	7.1	2.6	1.2	5.3	5.0

Table 29 (continued)

Location, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	ear	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[6] (cm)
Frankfurt,s	11	4500	3176	8.4	5.4	1.3	3.9	2.1
„ ,sl	11	3398	2608	8.4	3.7	1.3	3.9	3.5
„ ,l	11	2512	1577	8.4	3.2	1.4	3.9	5.3
„ ,o	11	1896	944	8.4	3.5	1.5	3.9	7.0

[1] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 7 cm water per m soil.
[2] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 14 cm water per m soil.
[3] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 21 cm water per m soil.
[4] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.
[5] Growing season is considered from crop emergence (May 8 for locations in France and Germany and May 15 for locations in the Netherlands) till date of crop maturing or date of harvest (set at October 2 when crop is not yet mature at that date) and components of water balance are calculated for this indicated season duration.
[6] Initial amount of available water at crop emergence is set at the maximum amount per soil type minus 3 cm water.

Table 30 Average values and standard deviation of water-limited productions and components of the water balance per year for mown permanent grassland in De Bilt and Twente, the Netherlands, and in Strasbourg, France and in Karlsruhe, Freiburg and Frankfurt, Germany on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviation have been established for historical weather data over a period of twenty years (1969-1988)[5]

Location, soil	Dry matter production (kg/ha)	Rainfall (cm)	Transpiration (cm)	Evaporation (cm)	Leaching (cm)	Change amount soil water[6] (cm)
<u>Average</u>						
De Bilt,s	12775	79.4	22.8	13.1	43.4	+0.2
„ ,sl	15119	79.4	27.0	12.4	39.8	+0.2
„ ,l	16526	79.4	29.6	11.9	37.8	+0.2
„ ,o	18194	79.4	33.0	11.7	35.0	-0.3
Twente,s	12030	72.6	21.4	13.1	37.9	+0.2
„ ,sl	14343	72.6	25.8	12.2	34.5	+0.2
„ ,l	15514	72.6	28.0	12.0	32.5	+0.2
„ ,o	17538	72.6	32.2	11.4	29.8	-0.7
Strasbourg,s	13119	62.4	26.6	14.4	21.4	+0.0
„ ,sl	15638	62.4	31.6	13.5	17.6	-0.3
„ ,l	16712	62.4	33.9	13.3	15.9	-0.8
„ ,o	18628	62.4	38.4	12.6	14.4	-3.0
Karlsruhe,s	14268	78.8	27.1	13.9	37.6	+0.2
„ ,sl	16604	78.8	31.6	13.2	33.7	+0.2
„ ,l	17713	78.8	33.9	12.9	31.8	+0.2
„ ,o	19000	78.8	36.7	12.5	30.2	-0.6
Freiburg,s	16975	96.3	34.6	15.4	46.3	+0.0
„ ,sl	18753	96.3	38.5	14.9	42.9	+0.0
„ ,l	19287	96.3	39.8	14.6	41.9	+0.0
„ ,o	19660	96.3	40.7	14.5	41.0	+0.0
Frankfurt,s	11699	63.3	23.0	12.8	27.4	+0.1
„ ,sl	13621	63.3	26.7	12.4	24.1	+0.1
„ ,l	15178	63.3	29.8	11.7	21.9	-0.2
„ ,o	17872	63.3	35.6	11.2	18.6	-2.1
<u>Standard deviation</u>						
De Bilt,s	2903	14.4	3.8	1.2	13.0	0.5
„ ,sl	2743	14.4	3.2	1.1	12.9	0.5
„ ,l	2165	14.4	2.3	1.0	13.3	0.5
„ ,o	707	14.4	2.8	1.1	14.6	2.1
Twente,s	3709	10.9	4.9	1.8	9.7	0.5
„ ,sl	3231	10.9	3.4	1.4	9.7	0.5
„ ,l	2742	10.9	2.8	1.2	9.8	0.5
„ ,o	705	10.9	3.8	1.0	10.6	2.9
Strasbourg,s	3131	10.6	5.3	1.9	8.5	0.2
„ ,sl	2446	10.6	4.4	1.3	8.2	0.9
„ ,l	2718	10.6	4.4	1.6	8.3	1.7
„ ,o	721	10.6	2.6	1.2	8.8	5.0
Karlsruhe,s	2978	12.9	5.2	1.3	10.2	0.6
„ ,sl	2455	12.9	4.4	1.0	10.0	0.6
„ ,l	1942	12.9	3.4	1.1	10.5	0.6
„ ,o	667	12.9	2.0	1.2	11.2	2.6
Freiburg,s	1905	12.7	3.2	1.3	11.1	0.1
„ ,sl	1479	12.7	2.3	1.3	11.4	0.1
„ ,l	1155	12.7	1.7	1.3	11.8	0.1
„ ,o	889	12.7	2.0	1.3	12.5	0.1

Table 30 (continued)

Location, soil	Dry matter production (kg/ha)	Rainfall (cm)	Transpiration (cm)	Evaporation (cm)	Leaching (cm)	Change amount soil water[6] (cm)
Frankfurt,s	3635	13.3	5.7	1.2	10.5	0.3
„ ,sl	3590	13.3	5.3	1.2	10.8	0.3
„ ,l	3249	13.3	4.5	1.1	10.9	1.0
„ ,o	642	13.3	2.6	1.3	11.1	4.9

[1] Soil with effective rooting depth of 50 cm and a maximum amount of available water of 7 cm water per m soil.
[2] Soil with effective rooting depth of 50 cm and a maximum amount of available water of 14 cm water per m soil.
[3] Soil with effective rooting depth of 50 cm and a maximum amount of available water of 21 cm water per m soil.
[4] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.
[5] Production and components of water balance are calculated for a period of one year, i.e. 365 days.
[6] Initial amount of available water at January 1 is set at the maximum amount per soil type.

Table 31 Average values and standard deviation of water-limited productions and components of the water balance during the growing season for winterwheat sown half November in De Bilt, the Netherlands, and in Freiburg and Frankfurt, Germany on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviation have been established for historical weather data over a period of twenty years (1969-1988) that were changed on the basis of the Bultot scenario

Location, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[6] (cm)
Average								
De Bilt,s	195	21595	9238	42.9	18.0	7.3	21.3	-3.7
" ,sl	195	24515	11937	42.9	21.0	7.1	20.9	-6.2
" ,l	195	25231	12680	42.9	21.7	7.1	20.9	-6.9
" ,o	195	25276	12737	42.9	21.8	7.1	20.9	-7.0
Freiburg,s	181	19857	9475	51.7	18.7	9.0	25.6	-1.6
" ,sl	181	20417	10070	51.7	19.3	9.0	25.3	-2.0
" ,l	181	20432	10090	51.7	19.4	9.0	25.3	-2.1
" ,o	181	20432	10090	51.7	19.4	9.0	25.3	-2.1
Frankfurt,s	191	19648	7964	36.0	17.6	7.0	15.5	-4.2
" ,sl	191	22256	10563	36.0	20.3	6.9	15.5	-6.7
" ,l	191	22576	10917	36.0	20.7	6.9	15.5	-7.1
" ,o	191	22629	10990	36.0	20.9	6.9	15.5	-7.3
Standard deviation								
De Bilt,s	6	4011	3590	9.2	3.3	1.2	8.1	2.7
" ,sl	6	2666	2002	9.2	2.6	1.2	7.9	4.1
" ,l	6	2449	1231	9.2	2.9	1.2	7.9	4.5
" ,o	6	2440	1195	9.2	3.0	1.2	7.9	4.8
Freiburg,s	6	2649	1718	11.3	2.9	1.8	9.9	2.0
" ,sl	6	2901	1415	11.3	3.4	1.8	10.1	2.6
" ,l	6	2917	1414	11.3	3.5	1.8	10.1	2.8
" ,o	6	2917	1414	11.3	3.5	1.8	10.1	2.8
Frankfurt,s	6	3359	3117	9.3	3.3	1.5	6.8	2.5
" ,sl	6	2038	1555	9.3	2.3	1.6	6.8	4.3
" ,l	6	1945	1041	9.3	2.5	1.6	6.8	5.0
" ,o	6	1951	966	9.3	2.7	1.6	6.8	5.4

[1] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 7 cm water per m soil.
[2] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 14 cm water per m soil.
[3] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 21 cm water per m soil.
[4] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.
[5] Growing season is considered from January 1 till moment of crop maturing and components of water balance are calculated for this indicated season duration.In cold winters crop growth will actually start at a later date than January 1.
[6] Initial amount of available water at January 1 is set at the maximum amount per soil type.

Table 32 Average values and standard deviation of water-limited productions and components of the water balance during the growing season for silage maize sown begin April in De Bilt, the Netherlands, and end of March in Freiburg and Frankfurt, Germany on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviation have been established for historical weather data over a period of twenty years (1969-1988) that were changed on the basis of the Bultot scenario

Location, soil	Duration growing season[5] (d)	Drymatter production Total (kg/ha)	ear	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[6] (cm)
Average								
De Bilt,s	118	15176	7397	24.3	14.5	7.4	3.6	-1.2
„ ,sl	118	18416	9547	24.3	18.2	6.5	3.2	-3.6
„ ,l	118	19028	10167	24.3	18.9	6.5	3.2	-4.3
„ ,o	118	19075	10217	24.3	18.9	6.5	3.2	-4.3
Freiburg,s	104	15988	8845	35.0	16.8	7.8	10.2	+0.3
„ ,sl	104	16413	9171	35.0	17.4	7.6	10.2	-0.2
„ ,l	104	16495	9255	35.0	17.4	7.6	10.3	-0.4
„ ,o	104	16495	9256	35.0	17.4	7.6	10.6	-0.7
Frankfurt,s	110	13435	6777	22.0	13.4	7.2	3.2	-1.9
„ ,sl	110	15860	8596	22.0	16.2	6.8	3.1	-4.0
„ ,l	110	16162	8904	22.0	16.5	6.7	3.1	-4.4
„ ,o	110	16307	9050	22.0	16.7	6.7	3.1	-4.5
Standard deviation								
De Bilt,s	6	3805	3108	7.1	3.2	1.3	3.7	2.8
„ ,sl	6	1671	1494	7.1	1.8	1.3	3.8	4.6
„ ,l	6	1534	741	7.1	2.4	1.3	3.8	5.5
„ ,o	6	1553	750	7.1	2.5	1.3	3.8	5.6
Freiburg,s	5	2175	1658	8.1	2.3	1.5	5.9	1.6
„ ,sl	5	1884	1073	8.1	2.1	1.6	5.8	2.4
„ ,l	5	1848	951	8.1	2.2	1.6	5.8	2.7
„ ,o	5	1848	951	8.1	2.2	1.6	5.6	2.8
Frankfurt,s	6	3748	2678	6.9	3.7	1.3	3.9	1.6
„ ,sl	6	2723	1899	6.9	2.8	1.6	3.9	3.3
„ ,l	6	2312	1279	6.9	2.6	1.6	3.9	3.9
„ ,o	6	2166	981	6.9	2.7	1.6	3.9	4.2

[1] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 7 cm water per m soil.
[2] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 14 cm water per m soil.
[3] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 21 cm water per m soil.
[4] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.
[5] Growing season is considered from crop emergence (April 18 for locations in Germany and April 25 for locations in the Netherlands) till date of crop maturing or date of harvest (set at October 2 when crop is not yet mature at that date) and components of water balance are calculated for this indicated season duration.
[6] Initial amount of available water at crop emergence is set at the maximum amount per soil type minus 3 cm water.

Table 33 Average values and standard deviation of water-limited productions and components of the water balance per year for mown permanent grassland in De Bilt and Twente, the Netherlands, and in Strasbourg, France and in Karlsruhe, Freiburg and Frankfurt, Germany on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviation have been established for historical weather data over a period of twenty years (1969-1988)[5] that were changed on the basis of the Bultot scenario

Location, soil	Dry matter production (kg/ha)	Rainfall (cm)	Transpiration (cm)	Evaporation (cm)	Leaching (cm)	Change amount soil water[6] (cm)
Average						
De Bilt,s	20460	84.1	22.5	14.6	46.7	+0.2
" ,sl	23887	84.1	26.8	13.8	43.2	+0.2
" ,l	25829	84.1	29.4	13.2	41.2	+0.2
" ,o	27787	84.1	32.4	12.9	38.8	+0.0
Twente,s	19740	76.8	21.5	14.1	40.9	+0.2
" ,sl	22741	76.8	25.5	13.2	37.9	+0.2
" ,l	24343	76.8	27.8	12.9	35.9	+0.2
" ,o	26807	76.8	31.4	12.4	33.3	-0.4
Strasbourg,s	20452	64.9	26.4	15.8	22.7	+0.0
" ,sl	23697	64.9	31.1	15.0	19.1	-0.2
" ,l	25282	64.9	33.4	14.7	17.5	-0.7
" ,o	27766	64.9	37.6	14.0	16.1	-2.8
Karlsruhe,s	21936	82.8	26.7	15.2	40.7	+0.2
" ,sl	24835	82.8	30.8	14.6	37.2	+0.2
" ,l	26357	82.8	32.9	14.4	35.4	+0.2
" ,o	28059	82.8	35.7	13.9	33.6	-0.4
Freiburg,s	25199	100.7	33.9	17.1	49.6	+0.0
" ,sl	27545	100.7	37.6	16.7	46.3	+0.0
" ,l	28187	100.7	38.8	16.4	45.4	+0.0
" ,o	28591	100.7	39.6	16.3	44.7	+0.0
Frankfurt,s	18522	66.6	22.6	14.0	29.9	+0.1
" ,sl	21267	66.6	26.3	13.5	26.6	+0.1
" ,l	23629	66.6	29.7	12.7	24.3	-0.1
" ,o	26897	66.6	34.8	12.2	21.2	-1.7
Standard deviation						
De Bilt,s	4140	15.3	4.4	1.7	14.1	0.6
" ,sl	3123	15.3	3.2	1.3	14.2	0.6
" ,l	2497	15.3	2.3	1.2	14.6	0.6
" ,o	1071	15.3	2.4	1.3	15.7	1.3
Twente,s	4629	11.4	4.4	1.7	10.4	0.5
" ,sl	3739	11.4	2.9	1.6	10.4	0.5
" ,l	3476	11.4	2.7	1.4	10.5	0.5
" ,o	1233	11.4	3.8	1.2	11.0	2.2
Strasbourg,s	3986	11.0	5.2	1.8	8.9	0.2
" ,sl	3693	11.0	4.5	1.4	8.9	0.8
" ,l	3065	11.0	3.7	1.4	9.1	1.6
" ,o	1246	11.0	2.5	1.2	9.6	4.7
Karlsruhe,s	3882	13.6	5.0	1.3	11.1	0.7
" ,sl	3614	13.6	4.5	1.2	11.2	0.7
" ,l	2863	13.6	3.5	1.2	11.6	0.7
" ,o	857	13.6	2.0	1.2	12.2	2.3
Freiburg,s	2392	13.4	3.3	1.3	11.7	0.1
" ,sl	1741	13.4	2.2	1.4	12.0	0.1
" ,l	1325	13.4	1.7	1.4	12.4	0.1
" ,o	1025	13.4	1.9	1.4	12.9	0.1

Table 33 (continued)

Location, soil	Dry matter production (kg/ha)	Rainfall (cm)	Transpiration (cm)	Evaporation (cm)	Leaching (cm)	Change amount soil water[6] (cm)
Frankfurt,s	4408	14.1	5.3	1.2	11.7	0.3
" ,sl	4478	14.1	5.2	1.3	12.2	0.3
" ,l	3624	14.1	4.0	1.0	12.3	0.8
" ,o	901	14.1	2.3	1.1	12.4	4.2

[1] Soil with effective rooting depth of 50 cm and a maximum amount of available water of 7 cm water per m soil.
[2] Soil with effective rooting depth of 50 cm and a maximum amount of available water of 14 cm water per m soil.
[3] Soil with effective rooting depth of 50 cm and a maximum amount of available water of 21 cm water per m soil.
[4] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.
[5] Production and components of water balance have been calculated for a period of one year, i.e. 365 days.
[6] Initial amount of available water at January 1 is set at the maximum amount per soil type.

Table 34 Average values and standard deviation of water-limited productions and components of the water balance per year for mown permanent grassland in De Bilt, the Netherlands on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviation have been established for historical weather data (HIST) over a period of twenty years (1969-1988)[5] but with doubled CO_2 concentration and a daily average temperature increased by 1, 3 and 5 °C (T+1, T+3, T+5), for historical weather data of which also the rainfall data were changed on the basis of the Bultot scenario (BULT) and for historical weather data of which the rainfall data were changed two times as strongly as according to the Bultot scenario (2*BULT)

Rainfall temperature, soil	Dry matter production (kg/ha)	Rainfall (cm)	Transpiration (cm)	Evaporation (cm)	Leaching (cm)	Change amount soil water[6] (cm)
Average						
HIST,T+1,s	19690	79.4	21.5	13.7	44.0	+0.2
" ,sl	23051	79.4	25.6	12.7	40.9	+0.2
" ,l	24564	79.4	27.5	12.5	39.2	+0.2
" ,o	26104	79.4	29.7	12.4	37.4	+0.0
HIST,T+3,s	20617	79.4	22.7	14.5	42.1	+0.2
" ,sl	24032	79.4	27.0	13.7	38.5	+0.2
" ,l	25896	79.4	29.5	13.1	36.6	+0.2
" ,o	27787	79.4	32.4	12.8	34.4	-0.1
HIST,T+5,s	19708	79.4	22.6	16.1	40.5	+0.2
" ,sl	23425	79.4	27.6	15.0	36.6	+0.2
" ,l	25686	79.4	30.8	14.1	34.3	+0.2
" ,o	28342	79.4	35.0	13.5	31.3	-0.4
BULT,T+1,s	19582	84.1	21.3	13.9	48.6	+0.2
" ,sl	22966	84.1	25.5	12.8	45.5	+0.2
" ,l	24487	84.1	27.5	12.5	43.8	+0.2
" ,o	26104	84.1	29.7	12.4	41.8	+0.1
BULT,T+3,s	20460	84.1	22.5	14.6	46.7	+0.2
" ,sl	23887	84.1	26.8	13.8	43.2	+0.2
" ,l	25829	84.1	29.4	13.2	41.2	+0.2
" ,o	27787	84.1	32.4	12.9	38.8	+0.0
BULT,T+5,s	19559	84.1	22.4	16.2	45.2	+0.2
" ,sl	23154	84.1	27.4	15.1	41.3	+0.2
" ,l	25506	84.1	30.6	14.3	39.0	+0.2
" ,o	28342	84.1	35.0	13.6	35.6	-0.2
2*BULT,T+1,s	19366	88.7	21.1	14.0	53.3	+0.3
" ,sl	22808	88.7	25.3	13.0	50.1	+0.3
" ,l	24422	88.7	27.4	12.6	48.4	+0.3
" ,o	26104	88.7	29.7	12.5	46.3	+0.2
2*BULT,T+3,s	20327	88.7	22.3	14.7	51.4	+0.3
" ,sl	23754	88.7	26.7	13.9	47.9	+0.3
" ,l	25678	88.7	29.2	13.3	45.9	+0.3
" ,o	27787	88.7	32.4	12.9	43.3	+0.1
2*BULT,T+5,s	19524	88.7	22.4	16.1	49.9	+0.3
" ,sl	22976	88.7	27.1	15.3	46.0	+0.3
" ,l	25297	88.7	30.3	14.4	43.6	+0.3
" ,o	28341	88.7	35.0	13.7	40.0	-0.1
Standard deviation						
HIST,T+1,s	4023	14.4	3.8	1.3	13.0	0.5
" ,sl	2707	14.4	2.3	0.9	13.4	0.5
" ,l	1975	14.4	1.6	1.0	13.8	0.5
" ,o	957	14.4	2.4	1.0	14.9	1.1

Table 34 (continued)

Rainfall temperature, soil	Dry matter production (kg/ha)	Rainfall (cm)	Transpiration (cm)	Evaporation (cm)	Leaching (cm)	Change amount soil water[6] (cm)
HIST,T+3,s	3937	14.4	4.3	1.6	13.1	0.5
„ ,sl	3082	14.4	3.1	1.2	13.3	0.5
„ ,l	2403	14.4	2.2	1.2	13.6	0.5
„ ,o	1071	14.4	2.4	1.3	14.6	1.5
HIST,T+5,s	4632	14.4	5.8	2.0	12.8	0.5
„ ,sl	3656	14.4	4.2	1.5	12.7	0.5
„ ,l	2940	14.4	3.2	1.4	13.1	0.5
„ ,o	938	14.4	2.5	1.3	14.1	2.2
BULT,T+1,s	4154	15.3	3.9	1.4	13.9	0.6
„ ,sl	2799	15.3	2.4	0.9	14.3	0.6
„ ,l	2066	15.3	1.6	1.0	14.8	0.6
„ ,o	957	15.3	2.4	1.0	15.9	0.9
BULT,T+3,s	4140	15.3	4.4	1.7	14.1	0.6
„ ,sl	3123	15.3	3.2	1.3	14.2	0.6
„ ,l	2497	15.3	2.3	1.2	14.6	0.6
„ ,o	1071	15.3	2.4	1.3	15.7	1.3
BULT,T+5,s	4617	15.3	5.7	2.1	13.8	0.6
„ ,sl	3790	15.3	4.4	1.7	13.7	0.6
„ ,l	3102	15.3	3.4	1.5	14.0	0.6
„ ,o	938	15.3	2.5	1.4	15.3	1.9
2*BULT,T+1,s	4376	16.3	4.1	1.4	15.0	0.6
„ ,sl	2966	16.3	2.5	0.9	15.3	0.6
„ ,l	2124	16.3	1.7	1.0	15.7	0.6
„ ,o	957	16.3	2.4	1.0	17.0	0.7
2*BULT,T+3,s	4162	16.3	4.4	1.6	15.1	0.6
„ ,sl	3224	16.3	3.3	1.3	15.2	0.6
„ ,l	2601	16.3	2.5	1.2	15.5	0.6
„ ,o	1071	16.3	2.4	1.3	16.7	1.1
2*BULT,T+5,s	4425	16.3	5.6	2.1	14.7	0.6
„ ,sl	3880	16.3	4.5	1.7	14.7	0.6
„ ,l	3279	16.3	3.6	1.5	15.0	0.6
„ ,o	937	16.3	2.5	1.4	16.4	1.6

[1] Soil with effective rooting depth of 50 cm and a maximum amount of available water of 7 cm water per m soil.
[2] Soil with effective rooting depth of 50 cm and a maximum amount of available water of 14 cm water per m soil.
[3] Soil with effective rooting depth of 50 cm and a maximum amount of available water of 21 cm water per m soil.
[4] Soil with effective rooting depth of 100 cm and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.
[5] Production and components of water balance have been calculated for a period of one year, i.e. 365 days.
[6] Initial amount of available water at January 1 is set at the maximum amount per soil type.

Table 35 Sensitivity to changes in atmospheric CO_2 concentration of the average values and standard deviations of water-limited productions and components of the water balance during the growing season of winterwheat, silage maize and mown permanent grassland in De Bilt, the Netherlands on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviations have been established for historical weather data over a period of twenty years (1969-1988) but with the CO_2 concentration varying between actual (1.0*CO_2) and three times the actual concentration (3.0*CO_2)

CO_2, conc., soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain[6]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[7,8] (cm)
Winterwheat								
Averages								
1.0*CO_2,s	228	15387	6212	46.8	20.1	9.5	21.0	-3.8
„ ,sl	228	18383	8264	46.8	24.6	9.0	20.4	-7.1
„ ,l	228	19197	9022	46.8	25.9	9.0	20.3	-8.3
„ ,o	228	19324	9166	46.8	26.1	9.0	20.3	-8.5
1.5*CO_2,s	228	20877	8440	46.8	21.0	8.4	21.3	-3.8
„ ,sl	228	24539	10874	46.8	25.3	8.0	20.6	-7.0
„ ,l	228	25566	11841	46.8	26.5	8.0	20.5	-8.2
„ ,o	228	25715	12001	46.8	26.7	8.0	20.5	-8.4
2.0*CO_2,s	228	24517	10001	46.8	20.7	8.3	21.6	-3.7
„ ,sl	228	28446	12699	46.8	24.6	7.9	21.0	-6.7
„ ,l	228	29409	13621	46.8	25.6	7.9	20.9	-7.6
„ ,o	228	29524	13745	46.8	25.7	7.9	20.9	-7.7
2.5*CO_2,s	228	26761	11037	46.8	20.1	8.4	22.0	-3.7
„ ,sl	228	30703	13867	46.8	23.7	8.1	21.3	-6.3
„ ,l	228	31511	14658	46.8	24.4	8.1	21.3	-7.0
„ ,o	228	31590	14743	46.8	24.5	8.1	21.3	-7.1
3.0*CO_2,s	228	28673	11927	46.8	19.6	8.6	22.2	-3.6
„ ,sl	228	32652	14868	46.8	23.0	8.3	21.6	-6.0
„ ,l	228	33363	15571	46.8	23.6	8.3	21.6	-6.6
„ ,o	228	33422	15634	46.8	23.6	8.3	21.6	-6.6
Standard deviation								
1.0*CO_2,s	7	3545	2747	9.8	3.8	1.4	7.8	2.9
„ ,sl	7	2261	1885	9.8	2.0	1.3	7.6	4.8
„ ,l	7	1762	1015	9.8	2.2	1.3	7.6	5.9
„ ,o	7	1680	842	9.8	2.4	1.3	7.6	6.2
1.5*CO_2,s	7	4311	3452	9.8	3.6	1.4	7.9	2.9
„ ,sl	7	2524	2273	9.8	1.7	1.3	7.7	4.8
„ ,l	7	1813	1184	9.8	1.8	1.2	7.6	6.0
„ ,o	7	1632	963	9.8	2.0	1.2	7.6	6.3
2.0*CO_2,s	7	4707	3869	9.8	3.3	1.4	8.0	2.9
„ ,sl	7	2589	2336	9.8	1.6	1.3	7.7	4.8
„ ,l	7	1939	1251	9.8	1.8	1.3	7.7	5.8
„ ,o	7	1791	1104	9.8	1.9	1.3	7.7	6.0
2.5*CO_2,s	7	4865	4088	9.8	3.1	1.4	8.1	2.9
„ ,sl	7	2577	2229	9.8	1.6	1.3	7.7	4.8
„ ,l	7	2076	1281	9.8	1.9	1.3	7.7	5.6
„ ,o	7	1993	1209	9.8	1.9	1.3	7.7	5.7
3.0*CO_2,s	7	4970	4241	9.8	2.9	1.4	8.1	2.9
„ ,sl	7	2622	2153	9.8	1.6	1.3	7.8	4.8
„ ,l	7	2228	1340	9.8	1.9	1.3	7.8	5.4
„ ,o	7	2177	1306	9.8	1.9	1.3	7.8	5.5
Maize Averages								
1.0*CO_2,s	145	14056	6723	31.3	16.4	9.1	4.9	+0.9
„ ,sl	145	18517	9320	31.3	22.4	7.6	3.6	-2.2
„ ,l	145	19910	10528	31.3	24.1	7.4	3.4	-3.6
„ ,o	145	20202	10797	31.3	24.4	7.4	3.4	-3.9

Table 35 (continued)

CO_2 conc., soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain[6]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[7,8] (cm)
1.5*CO_2,s	145	15748	7706	31.3	15.7	8.6	5.9	+1.1
„ ,sl	145	19578	10256	31.3	20.1	7.4	4.9	-1.1
„ ,l	145	20115	10712	31.3	20.7	7.4	4.8	-1.6
„ ,o	145	20202	10797	31.3	20.7	7.4	4.8	-1.7
2.0*CO_2,s	145	17138	8629	31.3	15.0	8.1	6.7	+1.4
„ ,sl	145	19961	10578	31.3	17.9	7.4	6.1	-0.1
„ ,l	145	20196	10790	31.3	18.1	7.4	6.1	-0.2
„ ,o	145	20202	10797	31.3	18.1	7.4	6.1	-0.3
2.5*CO_2,s	145	18085	9320	31.3	14.4	7.9	7.4	+1.6
„ ,sl	145	20079	10679	31.3	16.3	7.4	7.0	+0.7
„ ,l	145	20202	10797	31.3	16.4	7.4	7.0	+0.6
„ ,o	145	20202	10797	31.3	16.4	7.4	7.0	+0.6
3.0*CO_2,s	145	18447	9589	31.3	14.0	7.8	7.7	+1.7
„ ,sl	145	20125	10723	31.3	15.6	7.4	7.3	+1.0
„ ,l	145	20202	10797	31.3	15.6	7.4	7.3	+0.9
„ ,o	145	20202	10797	31.3	15.6	7.4	7.3	+0.9
Standard deviation								
1.0*CO_2,s	7	4295	3009	7.7	4.6	1.9	4.9	2.3
„ ,sl	7	2851	2130	7.7	3.3	1.9	4.7	4.5
„ ,l	7	2275	1483	7.7	3.8	2.0	4.7	6.0
„ ,o	7	2295	1580	7.7	4.1	2.0	4.7	6.6
1.5*CO_2,s	7	3897	2695	7.7	3.7	1.9	5.4	2.3
„ ,sl	7	2446	1646	7.7	3.1	2.0	5.3	4.3
„ ,l	7	2226	1463	7.7	3.3	2.0	5.3	5.0
„ ,o	7	2295	1580	7.7	3.5	2.0	5.3	5.2
2.0*CO_2,s	7	3406	2214	7.7	2.9	1.9	5.9	2.1
„ ,sl	7	2259	1470	7.7	2.8	2.0	5.8	3.6
„ ,l	7	2288	1568	7.7	3.0	2.0	5.8	4.1
„ ,o	7	2295	1580	7.7	3.0	2.0	5.8	4.1
2.5*CO_2,s	7	3117	1917	7.7	2.5	1.9	6.3	2.0
„ ,sl	7	2217	1442	7.7	2.6	2.0	6.3	3.2
„ ,l	7	2295	1580	7.7	2.7	2.0	6.3	3.5
„ ,o	7	2295	1580	7.7	2.7	2.0	6.3	3.5
3.0*CO_2,s	7	2971	1797	7.7	2.4	1.9	6.4	2.0
„ ,sl	7	2231	1473	7.7	2.5	2.0	6.4	3.0
„ ,l	7	2295	1580	7.7	2.6	2.0	6.4	3.2
„ ,o	7	2295	1580	7.7	2.6	2.0	6.4	3.2
Grass Averages								
1.0*CO_2,s	365	12775		79.4	22.8	13.1	43.4	+0.2
„ ,sl	365	15119		79.4	27.0	12.4	39.8	+0.2
„ ,l	365	16526		79.4	29.6	11.9	37.8	+0.2
„ ,o	365	18194		79.4	33.0	11.7	35.0	-0.3
1.5*CO_2,s	365	16193		79.4	21.2	13.7	44.3	+0.2
„ ,sl	365	19327		79.4	25.4	12.7	41.1	+0.2
„ ,l	365	20608		79.4	27.3	12.6	39.3	+0.2
„ ,o	365	22070		79.4	29.7	12.3	37.4	+0.1

Table 35 (continued)

CO_2, conc., soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain[6]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[7,8] (cm)
$2.0*CO_2$,s	365	19071		79.4	21.0	13.4	44.8	+0.2
„ ,sl	365	22242		79.4	24.9	12.5	41.9	+0.2
„ ,l	365	23763		79.4	26.6	12.3	40.2	+0.2
„ ,o	365	24847		79.4	28.3	12.2	38.9	+0.1
$2.5*CO_2$,s	365	20296		79.4	20.1	13.7	45.4	+0.2
„ ,sl	365	23651		79.4	23.5	13.1	42.6	+0.2
„ ,l	365	25028		79.4	25.2	12.8	41.2	+0.2
„ ,o	365	26096		79.4	26.5	12.8	40.0	+0.2
$3.0*CO_2$,s	365	21410		79.4	19.5	14.0	45.8	+0.2
„ ,sl	365	24786		79.4	22.7	13.4	43.1	+0.2
„ ,l	365	26196		79.4	24.2	13.2	41.8	+0.2
„ ,o	365	27046		79.4	25.2	13.2	40.8	+0.2
Standard deviation								
$1.0*CO_2$,s	0	2903		14.4	3.8	1.2	13.0	0.5
„ ,sl	0	2743		14.4	3.2	1.1	12.9	0.5
„ ,l	0	2165		14.4	2.3	1.0	13.3	0.5
„ ,o	0	707		14.4	2.8	1.1	14.6	2.1
$1.5*CO_2$,s	0	3518		14.4	3.5	1.1	13.1	0.5
„ ,sl	0	2639		14.4	2.2	0.9	13.3	0.5
„ ,l	0	1974		14.4	1.6	0.9	13.8	0.5
„ ,o	0	787		14.4	2.4	1.1	14.9	0.8
$2.0*CO_2$,s	0	3715		14.4	3.0	1.1	13.1	0.5
„ ,sl	0	2708		14.4	1.9	1.0	13.5	0.5
„ ,l	0	1932		14.4	1.5	1.0	14.0	0.5
„ ,o	0	705		14.4	2.2	1.1	14.7	0.8
$2.5*CO_2$,s	0	3691		14.4	2.8	1.0	13.2	0.5
„ ,sl	0	2425		14.4	1.7	1.0	13.6	0.5
„ ,l	0	1582		14.4	1.4	0.9	14.1	0.5
„ ,o	0	1063		14.4	2.2	1.0	15.0	0.6
$3.0*CO_2$,s	0	3813		14.4	2.7	0.8	13.2	0.5
„ ,sl	0	2151		14.4	1.4	1.0	13.7	0.5
„ ,l	0	1446		14.4	1.5	1.0	14.2	0.5
„ ,o	0	948		14.4	2.1	1.1	15.0	0.5

1 Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 7 cm water per m soil.

2 Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 14 cm water per m soil.

3 Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 21 cm water per m soil.

4 Soil with effective rooting depth of 100 cm for permanent grassland, winterwheat and silage maize and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.

5 For winterwheat a growing season is considered from January 1 till moment of crop maturing. In cold winters wheat growth will actually start at a later date than January 1. For silage maize a growing season is considered from emergence at May 5 till moment of crop maturing or date of harvest (set at October 2 when crop is not yet mature at that date). Permanent grassland has a growing season of one year, i.e. 365 days. For the indicated season durations the components of the water balance are calculated.

6 For silage maize the total amount in the ears is given.

7 Initial amount of available water for winterwheat and permanent grassland is set at the maximum amount per soil type.

8 Initial amount of available water at emergence of silage maize is set at the maximum amount per soil type minus 3 cm water.

Table 36 Sensitivity to changes in average daily air temperature of the average values and standard deviations of water-limited productions and components of the water balance during the growing season of winterwheat, silage maize and mown permanent grassland in De Bilt, the Netherlands on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviations have been established for historical weather data over a period of twenty years (1969-1988) but with the average daily temperature varying between 1°C below (T-1) and 5°C above the actual temperature (T+5)[5]

Tempera-ture, soil	Duration growing season[6] (d)	Dry matter production Total (kg/ha)	grain[7]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[8,9] (cm)
Winterwheat								
Averages								
T-1,s	241	16312	6515	49.6	20.9	9.8	22.3	-3.4
T-1,sl	241	19245	8375	49.6	25.3	9.3	21.4	-6.5
T-1,l	241	20189	9258	49.6	26.7	9.3	21.3	-7.8
T-1,o	241	20331	9426	49.6	27.0	9.3	21.3	-8.1
T,s	228	15387	6212	46.8	20.1	9.5	21.0	-3.8
T,sl	228	18383	8264	46.8	24.6	9.0	20.4	-7.1
T,l	228	19197	9022	46.8	25.9	9.0	20.3	-8.3
T,o	228	19324	9166	46.8	26.1	9.0	20.3	-8.5
T+1,s	216	14758	5969	44.8	19.4	9.1	20.0	-3.6
T+1,sl	216	17508	7997	44.8	23.6	8.6	19.4	-6.9
T+1,l	216	18295	8779	44.8	24.9	8.6	19.3	-8.0
T+1,o	216	18416	8918	44.8	25.1	8.6	19.3	-8.3
T+2,s	205	14240	5860	42.4	18.6	8.6	19.1	-3.9
T+2,sl	205	16635	7801	42.4	22.4	8.2	18.6	-6.9
T+2,l	205	17352	8539	42.4	23.6	8.2	18.5	-7.9
T+2,o	205	17432	8635	42.4	23.8	8.2	18.5	-8.2
T+3,s	195	13388	5617	40.0	17.3	8.4	18.1	-3.7
T+3,sl	195	15333	7360	40.0	20.5	8.1	17.7	-6.3
T+3,l	195	15892	7934	40.0	21.4	8.1	17.6	-7.1
T+3,o	195	15950	8003	40.0	21.6	8.1	17.6	-7.3
T+4,s	186	12024	5256	37.3	15.4	8.6	17.2	-3.9
T+4,sl	186	13463	6649	37.3	17.9	8.5	17.2	-6.3
T+4,l	186	13806	7018	37.3	18.5	8.5	17.2	-6.9
T+4,o	186	13837	7056	37.3	18.6	8.5	17.2	-7.0
T+5,s	177	10440	4832	35.7	13.3	8.9	16.9	-3.4
T+5,sl	177	11306	5727	35.7	14.9	8.9	16.9	-5.0
T+5,l	177	11430	5874	35.7	15.2	8.9	16.9	-5.3
T+5,o	177	11437	5884	35.7	15.3	8.9	16.9	-5.3
Standard deviation								
T-1,s	8	3744	2764	9.6	4.1	1.5	8.0	2.8
T-1,sl	8	2403	1888	9.6	2.3	1.3	7.7	4.8
T-1,l	8	1810	821	9.6	2.4	1.3	7.7	5.7
T-1,o	8	1807	748	9.6	2.7	1.3	7.7	6.0
T,s	7	3545	2747	9.8	3.8	1.4	7.8	2.9
T,sl	7	2261	1885	9.8	2.0	1.3	7.6	4.8
T,l	7	1762	1015	9.8	2.2	1.3	7.6	5.9
T,o	7	1680	842	9.8	2.4	1.3	7.6	6.2
T+1,s	7	3376	2662	9.4	3.7	1.2	7.7	2.6
T+1,sl	7	2222	1846	9.4	2.2	1.2	7.4	4.0
T+1,l	7	1906	1164	9.4	2.4	1.3	7.3	5.0
T+1,o	7	1801	963	9.4	2.6	1.3	7.3	5.4
T+2,s	7	3146	2589	9.1	3.7	1.2	7.5	2.3
T+2,sl	7	2031	1700	9.1	2.4	1.3	7.1	3.8
T+2,l	7	1786	987	9.1	2.7	1.2	7.1	4.5
T+2,o	7	1755	869	9.1	2.9	1.2	7.1	5.0

Table 36 (continued)

Tempera-ture, soil	Duration growing season[6] (d)	Dry matter production Total (kg/ha)	grain[7]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[8,9] (cm)
T+3,s	6	2880	2435	8.5	3.6	1.1	7.1	2.7
T+3,sl	6	1997	1451	8.5	2.8	1.2	6.9	4.0
T+3,l	6	1847	891	8.5	3.1	1.2	6.9	4.6
T+3,o	6	1838	847	8.5	3.2	1.2	6.9	4.8
T+4,s	6	2690	2203	7.3	3.5	1.0	6.9	2.2
T+4,sl	6	2095	1264	7.3	3.1	1.0	6.8	2.9
T+4,l	6	2078	1016	7.3	3.4	1.0	6.8	3.5
T+4,o	6	2083	1016	7.3	3.5	1.0	6.8	3.7
T+5,s	6	2238	1704	7.5	3.2	1.2	6.8	1.8
T+5,sl	6	1972	996	7.5	3.1	1.2	6.8	2.7
T+5,l	6	2011	976	7.5	3.3	1.2	6.8	3.1
T+5,o	6	2017	981	7.5	3.4	1.2	6.8	3.2
Maize Averages								
T-1,s	150	13492	6001	32.0	15.5	9.5	5.8	+1.1
T-1,sl	150	17301	8312	32.0	20.4	8.4	4.7	-1.5
T-1,l	150	18126	9059	32.0	21.4	8.2	4.7	-2.3
T-1,o	150	18230	9161	32.0	21.5	8.2	4.7	-2.4
T,s	145	14056	6723	31.3	16.4	9.1	4.9	+0.9
T,sl	145	18517	9320	31.3	22.4	7.6	3.6	-2.2
T,l	145	19910	10528	31.3	24.1	7.4	3.4	-3.6
T,o	145	20202	10797	31.3	24.4	7.4	3.4	-3.9
T+1,s	134	13737	6612	28.6	16.5	8.6	3.7	-0.1
T+1,sl	134	18516	9319	28.6	23.2	6.8	2.6	-4.0
T+1,l	134	20236	10728	28.6	25.4	6.6	2.5	-5.9
T+1,o	134	20843	11286	28.6	26.2	6.5	2.5	-6.6
T+2,s	122	12733	5990	26.2	15.8	8.3	2.7	-0.6
T+2,sl	122	17629	8646	26.2	23.0	6.3	1.7	-4.8
T+2,l	122	19425	10047	26.2	25.4	6.0	1.7	-7.0
T+2,o	122	20281	10814	26.2	26.6	5.9	1.7	-8.1
T+3,s	112	11559	5354	23.7	14.8	8.0	2.2	-1.4
T+3,sl	112	16540	7909	23.7	22.3	5.8	1.4	-5.9
T+3,l	112	18306	9227	23.7	24.9	5.6	1.4	-8.2
T+3,o	112	19267	10105	23.7	26.2	5.5	1.4	-9.5
T+4,s	104	10560	4790	22.2	14.0	8.0	1.9	-1.6
T+4,sl	104	15476	7307	22.2	21.4	5.8	1.2	-6.2
T+4,l	104	17230	8617	22.2	24.1	5.5	1.2	-8.5
T+4,o	104	18163	9529	22.2	25.5	5.4	1.5	-10.2
T+5,s	98	9604	4315	21.3	13.0	8.0	1.9	-1.6
T+5,sl	98	14354	6755	21.3	20.3	5.8	1.4	-6.2
T+5,l	98	16036	8028	21.3	22.9	5.6	1.5	-8.7
T+5,o	98	16944	8929	21.3	24.2	5.5	2.1	-10.6
Standard deviation								
T-1,s	1	3570	2234	7.1	4.0	2.1	5.3	2.2
T-1,sl	1	2761	1703	7.1	4.0	2.2	5.3	4.3
T-1,l	1	2907	2005	7.1	4.5	2.3	5.3	5.4
T-1,o	1	2985	2157	7.1	4.6	2.3	5.3	5.6
T,s	7	4295	3009	7.7	4.6	1.9	4.9	2.3
T,sl	7	2851	2130	7.7	3.3	1.9	4.7	4.5
T,l	7	2275	1483	7.7	3.8	2.0	4.7	6.0
T,o	7	2295	1580	7.7	4.1	2.0	4.7	6.6

Table 36 (continued)

Temperature, soil	Duration growing season[6] (d)	Dry matter production Total (kg/ha)	grain[7]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[8,9] (cm)
T+1,s	11	4792	3340	8.6	5.3	1.7	4.1	2.8
T+1,sl	11	3267	2738	8.6	3.0	1.5	3.9	4.8
T+1,l	11	2052	1445	8.6	2.9	1.6	3.9	6.5
T+1,o	11	1815	956	8.6	3.6	1.6	3.9	7.7
T+2,s	8	5155	3338	7.3	6.1	1.8	3.4	2.5
T+2,sl	8	3398	2971	7.3	3.0	1.3	3.1	4.3
T+2,l	8	1995	1668	7.3	2.4	1.3	3.0	5.8
T+2,o	8	1704	870	7.3	3.4	1.4	3.0	7.2
T+3,s	7	5063	3191	7.1	6.2	1.9	3.2	2.5
T+3,sl	7	3226	3058	7.1	2.9	1.1	2.8	4.0
T+3,l	7	1908	1870	7.1	2.1	1.2	2.7	5.8
T+3,o	7	1542	866	7.1	3.3	1.2	2.7	7.5
T+4,s	6	4772	2856	6.7	6.1	1.9	2.9	2.6
T+4,sl	6	2864	2844	6.7	2.5	0.9	2.2	4.0
T+4,l	6	1600	1734	6.7	1.9	1.0	2.1	5.8
T+4,o	6	1316	694	6.7	3.3	1.1	2.1	7.6
T+5,s	5	4358	2510	6.4	5.7	1.7	2.8	2.0
T+5,sl	5	2625	2656	6.4	2.3	0.9	2.0	3.7
T+5,l	5	1432	1596	6.4	1.9	1.0	2.0	5.6
T+5,o	5	1187	598	6.4	3.3	1.1	2.2	7.3
Grass Averages								
T-1,s	365	12106		79.4	22.0	12.8	44.4	+0.2
T-1,sl	365	14366		79.4	26.1	12.3	40.8	+0.2
T-1,l	365	15761		79.4	28.5	11.9	38.7	+0.2
T-1,o	365	17262		79.4	31.5	11.7	36.3	-0.1
T,s	365	12775		79.4	22.8	13.1	43.4	+0.2
T,sl	365	15119		79.4	27.0	12.4	39.8	+0.2
T,l	365	16526		79.4	29.6	11.9	37.8	+0.2
T,o	365	18194		79.4	33.0	11.7	35.0	-0.3
T+1,s	365	13079		79.4	23.0	13.7	42.5	+0.2
T+1,sl	365	15537		79.4	27.7	12.9	38.7	+0.2
T+1,l	365	17050		79.4	30.3	12.4	36.5	+0.2
T+1,o	365	19116		79.4	34.6	11.8	33.3	-0.3
T+2,s	365	13036		79.4	22.9	14.5	41.8	+0.2
T+2,sl	365	15810		79.4	28.1	13.2	37.9	+0.2
T+2,l	365	17372		79.4	31.0	12.6	35.6	+0.2
T+2,o	365	19752		79.4	36.1	11.8	32.0	-0.4
T+3,s	365	13230		79.4	23.3	14.9	41.0	+0.2
T+3,sl	365	15893		79.4	28.5	13.8	36.9	+0.2
T+3,l	365	17619		79.4	31.9	12.9	34.4	+0.2
T+3,o	365	20193		79.4	37.6	12.1	30.6	-0.8
T+4,s	365	12710		79.4	23.0	15.9	40.4	+0.2
T+4,sl	365	15693		79.4	28.7	14.4	36.1	+0.2
T+4,l	365	17275		79.4	32.1	13.8	33.4	+0.2
T+4,o	365	20424		79.4	39.2	12.5	28.9	-1.1
T+5,s	365	12270		79.4	22.7	16.9	39.7	+0.2
T+5,sl	365	15067		79.4	28.6	15.3	35.3	+0.2
T+5,l	365	16641		79.4	32.3	14.5	32.5	+0.2
T+5,o	365	20319		79.4	40.7	12.8	27.2	-1.3

Table 36 (continued)

Temperature, soil	Duration growing season[6] (d)	Dry matter production Total (kg/ha)	grain[7]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[8,9] (cm)
Standard deviation								
T-1,s	0	3030		14.4	3.9	1.2	13.0	0.5
T-1,sl	0	2457		14.4	2.8	0.8	13.2	0.5
T-1,l	0	1951		14.4	2.1	0.9	13.7	0.5
T-1,o	0	588		14.4	2.5	0.9	14.8	1.6
T,s	0	2903		14.4	3.8	1.2	13.0	0.5
T,sl	0	2743		14.4	3.2	1.1	12.9	0.5
T,l	0	2165		14.4	2.3	1.0	13.3	0.5
T,o	0	707		14.4	2.8	1.1	14.6	2.1
T+1,s	0	3178		14.4	4.5	1.2	13.0	0.5
T+1,sl	0	2931		14.4	3.9	1.2	12.9	0.5
T+1,l	0	2334		14.4	2.9	1.1	13.3	0.5
T+1,o	0	644		14.4	2.6	1.1	14.3	1.9
T+2,s	0	3682		14.4	5.7	1.7	12.9	0.5
T+2,sl	0	3162		14.4	4.5	1.4	12.8	0.5
T+2,l	0	2664		14.4	3.5	1.0	13.2	0.5
T+2,o	0	745		14.4	2.8	1.0	14.4	2.3
T+3,s	0	3572		14.4	5.8	1.8	12.8	0.5
T+3,sl	0	3233		14.4	4.9	1.6	12.7	0.5
T+3,l	0	2760		14.4	3.9	1.2	13.0	0.5
T+3,o	0	818		14.4	3.0	1.0	14.1	2.9
T+4,s	0	3666		14.4	6.4	2.2	12.7	0.5
T+4,sl	0	3385		14.4	5.5	1.8	12.5	0.5
T+4,l	0	3070		14.4	4.7	1.3	12.7	0.5
T+4,o	0	814		14.4	3.2	1.0	13.9	3.5
T+5,s	0	3472		14.4	6.6	2.2	12.5	0.5
T+5,sl	0	3446		14.4	6.1	2.0	12.4	0.5
T+5,l	0	3324		14.4	5.5	1.6	12.5	0.5
T+5,o	0	734		14.4	3.0	1.1	13.4	4.0

[1] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 7 cm water per m soil.
[2] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 14 cm water per m soil.
[3] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 21 cm water per m soil.
[4] Soil with effective rooting depth of 100 cm for permanent grassland, winterwheat and silage maize and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.
[5] Relative humidity is kept constant by correcting the vapour pressure for the change in temperature.
[6] For winterwheat a growing season is considered from January 1 till moment of crop maturing. In cold winters wheat growth will actually start at a later date than January 1. For silage maize a growing season is considered from emergence at May 5 till moment of crop maturing or date of harvest (set at October 2 when crop is not yet mature at that date). Permanent grassland has a growing season of one year, i.e. 365 days. For the indicated season durations the components of the water balance are calculated.
[7] For silage maize the total amount in the ears is given.
[8] Initial amount of available water for winterwheat and permanent grassland is set at the maximum amount per soil type.
[9] Initial amount of available water at emergence of silage maize is set at the maximum amount per soil type minus 3 cm water.

Table 37 Sensitivity to changes in the amount of rainfall of the average values and standard deviations of water-limited productions and components of the water balance during the growing season of winterwheat, silage maize and mown permanent grassland in De Bilt, the Netherlands on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviations have been established for historical weather data over a period of twenty years (1969-1988) but with the daily rainfall varying between 0.7 times (0.7*R) and 1.3 times the actual rainfall data (1.3*R)

Rainfall, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain[6]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[7,8] (cm)
Winterwheat								
Averages								
0.70*R,s	228	13312	4559	32.8	17.2	8.9	11.9	-5.3
0.70*R,sl	228	17568	7446	32.8	23.4	8.2	11.8	-10.6
0.70*R,l	228	19009	8812	32.8	25.5	8.2	11.8	-12.7
0.70*R,o	228	19324	9166	32.8	26.1	8.2	11.8	-13.3
0.85*R,s	228	14526	5546	39.8	18.9	9.3	16.1	-4.5
0.85*R,sl	228	18082	7961	39.8	24.1	8.7	15.9	-8.8
0.85*R,l	228	19124	8940	39.8	25.7	8.6	15.9	-10.4
0.85*R,o	228	19324	9166	39.8	26.1	8.6	15.9	-10.8
1.00*R,s	228	15387	6212	46.8	20.1	9.5	21.0	-3.8
1.00*R,sl	228	18383	8264	46.8	24.6	9.0	20.4	-7.1
1.00*R,l	228	19197	9022	46.8	25.9	9.0	20.3	-8.3
1.00*R,o	228	19324	9166	46.8	26.1	9.0	20.3	-8.5
1.15*R,s	228	16039	6689	53.9	21.0	9.7	26.5	-3.4
1.15*R,sl	228	18602	8480	53.9	25.0	9.3	25.5	-5.9
1.15*R,l	228	19253	9087	53.9	26.0	9.3	25.5	-6.9
1.15*R,o	228	19324	9166	53.9	26.1	9.3	25.5	-7.0
1.30*R,s	228	16514	7028	60.9	21.8	9.9	32.2	-3.0
1.30*R,sl	228	18758	8635	60.9	25.2	9.5	31.3	-5.2
1.30*R,l	228	19290	9129	60.9	26.0	9.5	31.1	-5.8
1.30*R,o	228	19324	9166	60.9	26.1	9.5	31.1	-5.9
Standard deviation								
0.70*R,s	7	3206	2350	6.9	3.5	1.2	4.5	2.1
0.70*R,sl	7	2620	2245	6.9	2.4	1.2	4.5	3.3
0.70*R,l	7	1872	1290	6.9	2.0	1.2	4.5	4.6
0.70*R,o	7	1680	842	6.9	2.4	1.2	4.5	5.4
0.85*R,s	7	3515	2705	8.3	3.8	1.3	6.1	2.6
0.85*R,sl	7	2477	2124	8.3	2.2	1.2	6.0	4.0
0.85*R,l	7	1804	1130	8.3	2.1	1.2	6.0	5.3
0.85*R,o	7	1680	842	8.3	2.4	1.2	6.0	5.8
1.00*R,s	7	3545	2747	9.8	3.8	1.4	7.8	2.9
1.00*R,sl	7	2261	1885	9.8	2.0	1.3	7.6	4.8
1.00*R,l	7	1762	1015	9.8	2.2	1.3	7.6	5.9
1.00*R,o	7	1680	842	9.8	2.4	1.3	7.6	6.2
1.15*R,s	7	3418	2665	11.3	3.6	1.5	9.5	2.9
1.15*R,sl	7	2092	1660	11.3	2.0	1.4	9.0	4.9
1.15*R,l	7	1744	942	11.3	2.3	1.4	9.0	5.8
1.15*R,o	7	1680	842	11.3	2.4	1.4	9.0	6.0
1.30*R,s	7	3213	2530	12.8	3.3	1.5	11.1	2.9
1.30*R,sl	7	1964	1451	12.8	2.0	1.4	10.6	4.6
1.30*R,l	7	1731	905	12.8	2.3	1.4	10.5	5.4
1.30*R,o	7	1680	842	12.8	2.4	1.4	10.5	5.5

Table 37 (continued)

Rainfall, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain[6]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[7,8] (cm)
Maize								
Averages								
0.70*R,s	145	10879	4741	21.9	12.6	9.2	0.7	-0.6
0.70*R,sl	145	16812	7768	21.9	20.4	7.1	0.4	-6.1
0.70*R,l	145	19383	10020	21.9	23.5	6.8	0.4	-8.7
0.70*R,o	145	20202	10797	21.9	24.4	6.7	0.4	-9.6
0.85*R,s	145	12707	5887	26.6	14.7	9.2	2.3	+0.4
0.85*R,sl	145	17861	8729	26.6	21.6	7.4	1.5	-4.0
0.85*R,l	145	19724	10354	26.6	23.8	7.2	1.5	-5.9
0.85*R,o	145	20202	10797	26.6	24.4	7.1	1.5	-6.4
1.00*R,s	145	14056	6723	31.3	16.4	9.1	4.9	+0.9
1.00*R,sl	145	18517	9320	31.3	22.4	7.6	3.6	-2.2
1.00*R,l	145	19910	10528	31.3	24.1	7.4	3.4	-3.6
1.00*R,o	145	20202	10797	31.3	24.4	7.4	3.4	-3.9
1.15*R,s	145	14949	7288	35.9	17.5	9.1	8.1	+1.3
1.15*R,sl	145	19041	9788	35.9	23.0	7.7	6.5	-1.3
1.15*R,l	145	20012	10620	35.9	24.2	7.6	6.3	-2.1
1.15*R,o	145	20202	10797	35.9	24.4	7.6	6.3	-2.4
1.30*R,s	145	15650	7751	40.6	18.4	9.2	11.4	+1.7
1.30*R,sl	145	19376	10096	40.6	23.3	7.9	9.8	-0.4
1.30*R,l	145	20083	10683	40.6	24.3	7.8	9.7	-1.1
1.30*R,o	145	20202	10797	40.6	24.4	7.8	9.6	-1.2
Standard deviation								
0.70*R,s	7	4408	3198	5.4	4.6	1.6	1.4	2.3
0.70*R,sl	7	3614	3051	5.4	3.5	1.7	1.1	3.7
0.70*R,l	7	2423	1606	5.4	3.6	1.7	1.1	5.7
0.70*R,o	7	2295	1580	5.4	4.1	1.8	1.1	6.8
0.85*R,s	7	4541	3224	6.6	4.8	1.8	3.2	2.3
0.85*R,sl	7	3288	2575	6.6	3.5	1.8	2.9	4.2
0.85*R,l	7	2360	1541	6.6	3.7	1.9	2.9	6.0
0.85*R,o	7	2295	1580	6.6	4.1	1.9	2.9	6.8
1.00*R,s	7	4295	3009	7.7	4.6	1.9	4.9	2.3
1.00*R,sl	7	2851	2130	7.7	3.3	1.9	4.7	4.5
1.00*R,l	7	2275	1483	7.7	3.8	2.0	4.7	6.0
1.00*R,o	7	2295	1580	7.7	4.1	2.0	4.7	6.6
1.15*R,s	7	3954	2749	8.9	4.4	2.1	6.6	2.2
1.15*R,sl	7	2597	1835	8.9	3.4	2.0	6.3	4.3
1.15*R,l	7	2225	1439	8.9	3.8	2.0	6.4	5.4
1.15*R,o	7	2295	1580	8.9	4.1	2.0	6.4	5.9
1.30*R,s	7	3719	2553	10.0	4.2	2.2	8.3	2.1
1.30*R,sl	7	2400	1608	10.0	3.5	2.0	8.0	4.0
1.30*R,l	7	2217	1444	10.0	3.9	2.0	8.1	4.8
1.30*R,o	7	2295	1580	10.0	4.1	2.0	8.1	5.2
Grass								
Averages								
0.70*R,s	365	9851		55.6	17.9	13.4	24.2	+0.1
0.70*R,sl	365	12398		55.6	22.5	12.3	20.6	+0.1
0.70*R,l	365	14487		55.6	26.1	11.5	17.9	+0.0
0.70*R,o	365	18185		55.6	33.0	10.7	14.5	-2.6

Table 37 (continued)

Rainfall, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain[6]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[7,8] (cm)
0.85*R,s	365	11430		67.5	20.6	13.4	33.4	+0.2
0.85*R,sl	365	14122		67.5	25.3	12.4	29.7	+0.2
0.85*R,l	365	15779		67.5	28.3	11.7	27.4	+0.2
0.85*R,o	365	18190		67.5	33.0	11.3	24.4	-1.1
1.00*R,s	365	12775		79.4	22.8	13.1	43.4	+0.2
1.00*R,sl	365	15119		79.4	27.0	12.4	39.8	+0.2
1.00*R,l	365	16526		79.4	29.6	11.9	37.8	+0.2
1.00*R,o	365	18194		79.4	33.0	11.7	35.0	-0.3
1.15*R,s	365	13484		91.4	23.9	13.3	53.9	+0.2
1.15*R,sl	365	15730		91.4	28.1	12.7	50.4	+0.2
1.15*R,l	365	17019		91.4	30.5	12.1	48.6	+0.2
1.15*R,o	365	18198		91.4	33.0	12.1	46.2	+0.1
1.30*R,s	365	13939		103.3	24.8	13.4	64.7	+0.3
1.30*R,sl	365	16200		103.3	29.0	12.7	61.3	+0.3
1.30*R,l	365	17354		103.3	31.1	12.4	59.5	+0.3
1.30*R,o	365	18198		103.3	33.0	12.4	57.6	+0.3
Standard deviation								
0.70*R,s	0	3539		10.1	4.7	1.4	8.2	0.4
0.70*R,sl	0	3491		10.1	4.5	1.0	8.1	0.4
0.70*R,l	0	3229		10.1	3.9	1.1	8.0	0.7
0.70*R,o	0	712		10.1	2.8	1.0	7.6	5.4
0.85*R,s	0	3387		12.3	4.6	1.4	10.5	0.4
0.85*R,sl	0	3371		12.3	4.3	1.2	10.4	0.4
0.85*R,l	0	2887		12.3	3.3	1.1	10.7	0.5
0.85*R,o	0	709		12.3	2.8	1.0	11.4	3.6
1.00*R,s	0	2903		14.4	3.8	1.2	13.0	0.5
1.00*R,sl	0	2743		14.4	3.2	1.1	12.9	0.5
1.00*R,l	0	2165		14.4	2.3	1.0	13.3	0.5
1.00*R,o	0	707		14.4	2.8	1.1	14.6	2.1
1.15*R,s	0	2687		16.6	3.5	1.3	15.3	0.6
1.15*R,sl	0	2272		16.6	2.4	1.1	15.5	0.6
1.15*R,l	0	1763		16.6	1.7	1.1	15.9	0.6
1.15*R,o	0	706		16.6	2.8	1.2	17.2	1.0
1.30*R,s	0	2474		18.7	3.1	1.2	17.6	0.7
1.30*R,sl	0	2015		18.7	2.0	1.1	17.9	0.7
1.30*R,l	0	1467		18.7	1.8	1.2	18.4	0.7
1.30*R,o	0	706		18.7	2.8	1.2	19.7	0.7

[1] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 7 cm water per m soil.
[2] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 14 cm water per m soil.
[3] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 21 cm water per m soil.
[4] Soil with effective rooting depth of 100 cm for permanent grassland, winterwheat and silage maize and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.
[5] For winterwheat a growing season is considered from January 1 till moment of crop maturing. In cold winters wheat growth will actually start at a later date than January 1. For silage maize a growing season is considered from emergence at May 5 till moment of crop maturing or date of harvest (set at October 2 when crop is not yet mature at that date). Permanent grassland has a growing season of one year, i.e. 365 days. For the indicated season durations the components of the water balance are calculated.
[6] For silage maize the total amount in the ears is given.
[7] Initial amount of available water for winterwheat and permanent grassland is set at the maximum amount per soil type.
[8] Initial amount of available water at emergence of silage maize is set at the maximum amount per soil type minus 3 cm water.

Table 38 Sensitivity to changes in radiation of the average values and standard deviations of water-limited productions and components of the water balance during the growing season of winterwheat, silage maize and mown permanent grassland in De Bilt, the Netherlands on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviations have been established for historical weather data over a period of twenty years (1969-1988) but with the amount of radiation varying between 0.9 times (0.9*RAD) and 1.3 times the amount of radiation actually received (1.3*R)

Radiation, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain[6]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[7,8] (cm)
Winterwheat								
Averages								
0.90*RAD,s	228	14541	6020	46.8	19.2	9.7	21.6	-3.6
0.90*RAD,sl	228	16921	7761	46.8	22.8	9.3	21.0	-6.2
0.90*RAD,l	228	17409	8231	46.8	23.6	9.3	20.9	-7.0
0.90*RAD,o	228	17447	8275	46.8	23.6	9.3	20.9	-7.0
1.00*RAD,s	228	15387	6212	46.8	20.1	9.5	21.0	-3.8
1.00*RAD,sl	228	18383	8264	46.8	24.6	9.0	20.4	-7.1
1.00*RAD,l	228	19197	9022	46.8	25.9	9.0	20.3	-8.3
1.00*RAD,o	228	19324	9166	46.8	26.1	9.0	20.3	-8.5
1.10*RAD,s	228	15874	6276	46.8	20.8	9.5	20.5	-4.0
1.10*RAD,sl	228	19372	8491	46.8	26.1	8.8	19.9	-7.9
1.10*RAD,l	228	20581	9575	46.8	28.0	8.8	19.8	-9.7
1.10*RAD,o	228	20887	9900	46.8	28.5	8.8	19.8	-10.3
1.20*RAD,s	228	16074	6171	46.8	21.3	9.6	20.1	-4.2
1.20*RAD,sl	228	20029	8506	46.8	27.4	8.8	19.5	-8.8
1.20*RAD,l	228	21663	9907	46.8	29.9	8.6	19.4	-11.2
1.20*RAD,o	228	22286	10546	46.8	31.0	8.6	19.4	-12.3
1.30*RAD,s	227	16067	5951	46.8	21.6	9.8	19.7	-4.4
1.30*RAD,sl	228	20334	8310	46.8	28.3	8.8	19.1	-9.4
1.30*RAD,l	228	22480	10057	46.8	31.7	8.6	19.1	-12.6
1.30*RAD,o	228	23554	11125	46.8	33.6	8.6	19.1	-14.5
Standard deviation								
0.90*RAD,s	7	3095	2450	9.8	3.3	1.3	7.9	2.9
0.90*RAD,sl	7	1915	1416	9.8	2.0	1.3	7.6	4.7
0.90*RAD,l	7	1725	859	9.8	2.4	1.3	7.6	5.5
0.90*RAD,o	7	1693	813	9.8	2.4	1.3	7.6	5.6
1.00*RAD,s	7	3545	2747	9.8	3.8	1.4	7.8	2.9
1.00*RAD,sl	7	2261	1885	9.8	2.0	1.3	7.6	4.8
1.00*RAD,l	7	1762	1015	9.8	2.2	1.3	7.6	5.9
1.00*RAD,o	7	1680	842	9.8	2.4	1.3	7.6	6.2
1.10*RAD,s	7	3947	2977	9.8	4.3	1.5	7.7	2.8
1.10*RAD,sl	7	2736	2371	9.8	2.4	1.3	7.4	4.6
1.10*RAD,l	7	1918	1340	9.8	2.0	1.3	7.4	6.0
1.10*RAD,o	7	1665	876	9.8	2.3	1.3	7.4	6.7
1.20*RAD,s	7	4200	3044	9.8	4.7	1.6	7.5	2.7
1.20*RAD,sl	7	3238	2806	9.8	2.9	1.3	7.3	4.3
1.20*RAD,l	7	2206	1775	9.8	2.0	1.3	7.3	5.7
1.20*RAD,o	7	1637	906	9.8	2.4	1.3	7.3	7.0
1.30*RAD,s	7	4334	3002	9.8	4.9	1.6	7.4	2.7
1.30*RAD,sl	7	3607	3065	9.8	3.4	1.4	7.1	4.0
1.30*RAD,l	7	2599	2238	9.8	2.1	1.4	7.1	5.4
1.30*RAD,o	7	1616	949	9.8	2.4	1.4	7.1	7.4
Maize Averages								
0.90*RAD,s	145	13405	6462	31.3	16.0	8.7	5.5	+1.0
0.90*RAD,sl	145	17265	8974	31.3	21.1	7.5	4.4	-1.7

Table 38 (continued)

Radiation, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain[6]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[7,8] (cm)
0.90*RAD,l	145	18109	9704	31.3	22.2	7.4	4.3	-2.6
0.90*RAD,o	145	18261	9849	31.3	22.3	7.4	4.3	-2.8
1.00*RAD,s	145	14056	6723	31.3	16.4	9.1	4.9	+0.9
1.00*RAD,sl	145	18517	9320	31.3	22.4	7.6	3.6	-2.2
1.00*RAD,l	145	19910	10528	31.3	24.1	7.4	3.4	-3.6
1.00*RAD,o	145	20202	10797	31.3	24.4	7.4	3.4	-3.9
1.10*RAD,s	145	14277	6784	31.3	16.4	9.7	4.3	+0.8
1.10*RAD,sl	145	19408	9477	31.3	23.4	7.7	2.9	-2.7
1.10*RAD,l	145	21277	11061	31.3	25.7	7.5	2.7	-4.7
1.10*RAD,o	145	21855	11587	31.3	26.4	7.4	2.7	-5.3
1.20*RAD,s	145	14146	6669	31.3	16.2	10.5	3.8	+0.8
1.20*RAD,sl	145	20012	9495	31.3	24.3	8.0	2.4	-3.4
1.20*RAD,l	145	22247	11289	31.3	27.1	7.7	2.3	-5.8
1.20*RAD,o	145	23337	12277	31.3	28.5	7.6	2.3	-7.1
1.30*RAD,s	145	13847	6461	31.3	16.0	11.3	3.3	+0.7
1.30*RAD,sl	145	20330	9389	31.3	24.9	8.4	1.9	-4.0
1.30*RAD,l	145	22938	11329	31.3	28.4	7.9	1.8	-6.9
1.30*RAD,o	145	24693	12902	31.3	30.6	7.8	1.8	-9.0
Standard deviation								
0.90*RAD,s	7	3748	2686	7.7	4.1	1.8	5.2	2.3
0.90*RAD,sl	7	2450	1742	7.7	3.3	1.8	5.1	4.4
0.90*RAD,l	7	2167	1381	7.7	3.7	1.9	5.1	5.4
0.90*RAD,o	7	2243	1508	7.7	3.9	1.9	5.1	5.8
1.00*RAD,s	7	4295	3009	7.7	4.6	1.9	4.9	2.3
1.00*RAD,sl	7	2851	2130	7.7	3.3	1.9	4.7	4.5
1.00*RAD,l	7	2275	1483	7.7	3.8	2.0	4.7	6.0
1.00*RAD,o	7	2295	1580	7.7	4.1	2.0	4.7	6.6
1.10*RAD,s	7	4859	3301	7.7	5.3	2.1	4.6	2.3
1.10*RAD,sl	7	3425	2617	7.7	3.6	2.0	4.3	4.5
1.10*RAD,l	7	2464	1606	7.7	3.9	2.1	4.3	6.3
1.10*RAD,o	7	2337	1631	7.7	4.3	2.1	4.3	7.4
1.20*RAD,s	7	5598	3644	7.7	6.1	2.6	4.3	2.4
1.20*RAD,sl	7	4061	3163	7.7	4.0	2.1	3.8	4.3
1.20*RAD,l	7	2773	1800	7.7	3.9	2.1	3.8	6.2
1.20*RAD,o	7	2381	1675	7.7	4.6	2.2	3.8	8.0
1.30*RAD,s	7	6302	3968	7.7	7.0	2.9	4.1	2.4
1.30*RAD,sl	7	4682	3681	7.7	4.5	2.2	3.3	4.1
1.30*RAD,l	7	3232	2212	7.7	3.9	2.2	3.3	6.0
1.30*RAD,o	7	2416	1694	7.7	4.8	2.2	3.3	8.6
Grass								
Averages								
0.90*RAD,s	365	12400		79.4	22.9	12.7	43.7	+0.2
0.90*RAD,sl	365	14639		79.4	27.0	12.2	40.1	+0.2
0.90*RAD,l	365	15947		79.4	29.4	11.7	38.1	+0.2
0.90*RAD,o	365	17309		79.4	32.1	11.6	35.9	-0.1
1.00*RAD,s	365	12775		79.4	22.8	13.1	43.4	+0.2
1.00*RAD,sl	365	15119		79.4	27.0	12.4	39.8	+0.2
1.00*RAD,l	365	16526		79.4	29.6	11.9	37.8	+0.2
1.00*RAD,o	365	18194		79.4	33.0	11.7	35.0	-0.3

Table 38 (continued)

Radiation, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain[6]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[7,8] (cm)
1.10*RAD,s	365	12891		79.4	22.5	13.6	43.0	+0.2
1.10*RAD,sl	365	15261		79.4	26.9	13.0	39.3	+0.2
1.10*RAD,l	365	16846		79.4	29.7	12.4	37.1	+0.2
1.10*RAD,o	365	18988		79.4	34.2	12.0	33.7	-0.4
1.20*RAD,s	365	12616		79.4	21.9	14.7	42.6	+0.2
1.20*RAD,sl	365	15196		79.4	26.8	13.7	38.7	+0.2
1.20*RAD,l	365	16942		79.4	30.0	13.1	36.2	+0.2
1.20*RAD,o	365	19709		79.4	35.6	12.2	32.1	-0.5
1.30*RAD,s	365	12275		79.4	21.5	15.6	42.1	+0.2
1.30*RAD,sl	365	14884		79.4	26.4	14.6	38.1	+0.2
1.30*RAD,l	365	16809		79.4	30.0	13.8	35.4	+0.2
1.30*RAD,o	365	20284		79.4	37.2	12.8	30.3	-0.9
Standard deviation								
0.90*RAD,s	0	2744		14.4	3.6	1.4	13.0	0.5
0.90*RAD,sl	0	2406		14.4	2.8	0.8	13.3	0.5
0.90*RAD,l	0	1831		14.4	2.0	0.9	13.8	0.5
0.90*RAD,o	0	584		14.4	2.6	1.0	14.8	1.7
1.00*RAD,s	0	2903		14.4	3.8	1.2	13.0	0.5
1.00*RAD,sl	0	2743		14.4	3.2	1.1	12.9	0.5
1.00*RAD,l	0	2165		14.4	2.3	1.0	13.3	0.5
1.00*RAD,o	0	707		14.4	2.8	1.1	14.6	2.1
1.10*RAD,s	0	3216		14.4	4.4	1.2	12.9	0.5
1.10*RAD,sl	0	3181		14.4	3.9	1.2	12.8	0.5
1.10*RAD,l	0	2524		14.4	2.7	1.1	13.2	0.5
1.10*RAD,o	0	736		14.4	2.8	1.1	14.4	2.4
1.20*RAD,s	0	3494		14.4	4.8	1.5	12.8	0.5
1.20*RAD,sl	0	3621		14.4	4.6	1.4	12.8	0.5
1.20*RAD,l	0	3153		14.4	3.6	1.3	13.0	0.5
1.20*RAD,o	0	651		14.4	2.9	1.2	14.2	2.8
1.30*RAD,s	0	3717		14.4	5.1	1.8	12.7	0.5
1.30*RAD,sl	0	4076		14.4	5.4	1.9	12.8	0.5
1.30*RAD,l	0	3666		14.4	4.4	1.5	12.8	0.5
1.30*RAD,o	0	648		14.4	2.9	1.3	13.8	3.3

[1] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 7 cm water per m soil.
[2] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 14 cm water per m soil.
[3] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 21 cm water per m soil.
[4] Soil with effective rooting depth of 100 cm for permanent grassland, winterwheat and silage maize and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.
[5] For winterwheat a growing season is considered from January 1 till moment of crop maturing. In cold winters wheat growth will actually start at a later date than January 1. For silage maize a growing season is considered from emergence at May 5 till moment of crop maturing or date of harvest (set at October 2 when crop is not yet mature at that date). Permanent grassland has a growing season of one year, i.e. 365 days. For the indicated season durations the components of the water balance are calculated.
[6] For silage maize the total amount in the ears is given.
[7] Initial amount of available water for winterwheat and permanent grassland is set at the maximum amount per soil type.
[8] Initial amount of available water at emergence of silage maize is set at the maximum amount per soil type minus 3 cm water

Table 39 Sensitivity to changes in windspeed of the average values and standard deviations of water-limited productions and components of the water balance during the growing season of winterwheat, silage maize and mown permanent grassland in De Bilt, the Netherlands on sandy (s)[1], sandy loam (sl)[2], loamy (l)[3] and optimal (o)[4] soils; average values and standard deviations have been established for historical weather data over a period of twenty years (1969-1988) but with the windspeed varying between 0.5 times (0.5*WIND) and 2.0 times the actual values for the mean daily windspeed (2.0*WIND)

Windspeed, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain[6]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[7,8] (cm)
Winterwheat								
Averages								
0.5*WIND,s	228	16727	7054	46.8	19.4	7.8	23.2	-3.5
0.5*WIND,sl	228	18982	8816	46.8	22.5	7.6	22.6	-5.8
0.5*WIND,l	228	19319	9160	46.8	23.0	7.5	22.6	-6.2
0.5*WIND,o	228	19324	9166	46.8	23.0	7.5	22.6	-6.3
1.0*WIND,s	228	15387	6212	46.8	20.1	9.5	21.0	-3.8
1.0*WIND,sl	228	18383	8264	46.8	24.6	9.0	20.4	-7.1
1.0*WIND,l	228	19197	9022	46.8	25.9	9.0	20.3	-8.3
1.0*WIND,o	228	19324	9166	46.8	26.1	9.0	20.3	-8.5
2.0*WIND,s	227	12808	4719	46.8	20.5	13.1	17.5	-4.3
2.0*WIND,sl	228	16558	6796	46.8	27.2	12.0	17.0	-9.3
2.0*WIND,l	228	18370	8234	46.8	30.4	11.7	16.9	-12.3
2.0*WIND,o	228	19320	9161	46.8	32.4	11.7	16.9	-14.2
Standard deviation								
0.5*WIND,s	7	3080	2534	9.8	3.0	1.2	8.1	2.9
0.5*WIND,sl	7	1871	1281	9.8	1.8	1.1	7.8	4.7
0.5*WIND,l	7	1692	855	9.8	2.0	1.1	7.8	5.3
0.5*WIND,o	7	1680	842	9.8	2.0	1.1	7.8	5.3
1.0*WIND,s	7	3545	2747	9.8	3.8	1.4	7.8	2.9
1.0*WIND,sl	7	2261	1885	9.8	2.0	1.3	7.6	4.8
1.0*WIND,l	7	1762	1015	9.8	2.2	1.3	7.6	5.9
1.0*WIND,o	7	1680	842	9.8	2.4	1.3	7.6	6.2
2.0*WIND,s	7	3767	2516	9.8	4.9	1.8	7.1	2.8
2.0*WIND,sl	7	3144	2622	9.8	3.4	1.7	6.8	4.1
2.0*WIND,l	7	2283	1892	9.8	2.4	1.7	6.8	5.4
2.0*WIND,o	7	1689	853	9.8	3.2	1.7	6.8	7.4
Maize								
Averages								
0.5*WIND,s	145	15877	7697	31.3	16.7	7.6	6.0	+1.1
0.5*WIND,sl	145	19548	10208	31.3	20.9	6.7	5.0	-1.3
0.5*WIND,l	145	20118	10713	31.3	21.5	6.7	4.9	-1.8
0.5*WIND,o	145	20202	10797	31.3	21.6	6.7	4.9	-1.9
1.0*WIND,s	145	14056	6723	31.3	16.4	9.1	4.9	+0.9
1.0*WIND,sl	145	18517	9320	31.3	22.4	7.6	3.6	-2.2
1.0*WIND,l	145	19910	10528	31.3	24.1	7.4	3.4	-3.6
1.0*WIND,o	145	20202	10797	31.3	24.4	7.4	3.4	-3.9
2.0*WIND,s	145	10495	4809	31.3	14.6	12.6	3.4	+0.7
2.0*WIND,sl	145	16251	7581	31.3	23.9	9.5	1.9	-4.0
2.0*WIND,l	145	18570	9340	31.3	27.5	8.9	1.8	-7.0
2.0*WIND,o	145	20182	10778	31.3	30.0	8.7	1.8	-9.3
Standard deviation								
0.5*WIND,s	7	3735	2770	7.7	3.6	1.7	5.4	2.3
0.5*WIND,sl	7	2475	1675	7.7	3.1	1.8	5.3	4.4
0.5*WIND,l	7	2228	1464	7.7	3.3	1.8	5.3	5.1
0.5*WIND,o	7	2295	1580	7.7	3.4	1.8	5.3	5.3

Table 40 (continued)

Vapour pressure, soil	Duration growing season[5] (d)	Dry matter production Total (kg/ha)	grain[6]	Rainfall during season (cm)	Transpiration during season (cm)	Evaporation during season (cm)	Leaching during season (cm)	Change amount soil water during season[7,8] (cm)
1.0*VAP,s	7	4295	3009	7.7	4.6	1.9	4.9	2.3
1.0*VAP,sl	7	2851	2130	7.7	3.3	1.9	4.7	4.5
1.0*VAP,l	7	2275	1483	7.7	3.8	2.0	4.7	6.0
1.0*VAP,o	7	2295	1580	7.7	4.1	2.0	4.7	6.6
1.1*VAP,s	7	4023	2793	7.7	3.8	1.8	5.5	2.3
1.1*VAP,sl	7	2602	1770	7.7	3.2	1.8	5.4	4.4
1.1*VAP,l	7	2223	1438	7.7	3.6	1.8	5.4	5.4
1.1*VAP,o	7	2295	1580	7.7	3.9	1.8	5.4	5.8
Grass								
Averages								
0.9*VAP,s	365	11501		79.4	24.6	16.0	38.6	+0.2
0.9*VAP,sl	365	14183		79.4	29.9	14.9	34.4	+0.2
0.9*VAP,l	365	15777		79.4	33.1	14.2	31.9	+0.2
0.9*VAP,o	365	18186		79.4	38.1	13.8	28.5	-0.9
1.0*VAP,s	365	12775		79.4	22.8	13.1	43.4	+0.2
1.0*VAP,sl	365	15119		79.4	27.0	12.4	39.8	+0.2
1.0*VAP,l	365	16526		79.4	29.6	11.9	37.8	+0.2
1.0*VAP,o	365	18194		79.4	33.0	11.7	35.0	-0.3
1.1*VAP,s	365	13569		79.4	20.0	11.0	48.2	+0.2
1.1*VAP,sl	365	15854		79.4	23.9	10.3	45.0	+0.2
1.1*VAP,l	365	17143		79.4	26.0	9.9	43.3	+0.2
1.1*VAP,o	365	18198		79.4	28.2	9.8	41.4	+0.0
Standard deviation								
0.9*VAP,s	0	3318		14.4	5.1	1.5	12.4	0.5
0.9*VAP,sl	0	3123		14.4	4.4	1.2	12.4	0.5
0.9*VAP,l	0	2649		14.4	3.5	1.2	12.6	0.5
0.9*VAP,o	0	711		14.4	2.8	1.3	13.5	3.3
1.0*VAP,s	0	2903		14.4	3.8	1.2	13.0	0.5
1.0*VAP,sl	0	2743		14.4	3.2	1.1	12.9	0.5
1.0*VAP,l	0	2165		14.4	2.3	1.0	13.3	0.5
1.0*VAP,o	0	707		14.4	2.8	1.1	14.6	2.1
1.1*VAP,s	0	2838		14.4	3.2	1.0	13.4	0.5
1.1*VAP,sl	0	2406		14.4	2.3	1.0	13.6	0.5
1.1*VAP,l	0	1759		14.4	1.6	0.9	14.0	0.5
1.1*VAP,o	0	706		14.4	2.8	1.0	15.2	1.1

[1] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 7 cm water per m soil.

[2] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 14 cm water per m soil.

[3] Soil with effective rooting depth of 50 cm for permanent grassland and 100 cm for winterwheat and silage maize and a maximum amount of available water of 21 cm water per m soil.

[4] Soil with effective rooting depth of 100 cm for permanent grassland, winterwheat and silage maize and a maximum amount of available water of 50 cm water per m soil; on this fictive soil water shortage and crop stress wil not occur under any climatic condition.

[5] For winterwheat a growing season is considered from January 1 till moment of crop maturing. In cold winters wheat growth will actually start at a later date than January 1. For silage maize a growing season is considered from emergence at May 5 till moment of crop maturing or date of harvest (set at October 2 when crop is not yet mature at that date). Permanent grassland has a growing season of one year, i.e. 365 days. For the indicated season durations the components of the water balance are calculated.

[6] For silage maize the total amount in the ears is given.

[7] Initial amount of available water for winterwheat and permanent grassland is set at the maximum amount per soil type.

[8] Initial amount of available water at emergence of silage maize is set at the maximum amount per soil type minus 3 cm water.