Calculation of agricultural crop production and cost benefit on a regional level - model SIMCROP

E.P. Querner
R.A. Feddes

Report 13

The WINAND STARING CENTRE, Wageningen (The Netherlands), 1989

ABSTRACT

E.P. Querner and R.A. Feddes. 1989. Calculation of agricultural crop production and cost benefit on a regional level - model SIMCROP. Wageningen (The Netherlands). The Winand Staring Centre. Report 13.
21 p.; 7 figs.; 5 tables.

The crop production model SIMCROP has been developed to quantify regional water management aspects in terms of crop production and benefits. Effects of groundwater and open water level manipulation can be translated into production and benefits. In the model the production is based on the crop production of potatoes. For other crops the production is related to this by means of conversion factors.

Keywords: regional water management, crop production model, benefits, evapotranspiration, nutrient, growth rate

ISSN 0924-3062

This report has earlier been announced as Report 27 (1988) of the Institute for Land and Water Management Research (ICW), Wageningen, The Netherlands.

The WINAND STARING CENTRE for Integrated Land, Soil and Water Research, Postbus 125, 6700 AC Wageningen (The Netherlands). Phone: +31 8370 19100; fax: +31 8370 24812; telex 75230 VISI-NL

The WINAND STARING CENTRE is continuing the research of: the Institute for Land and Water Management Research (ICW), Institute for Pesticide Research, Environment Divison (IOB), Dorschkamp Research Institute for Forestry and Landscape Planning, Divison of Landscape Planning (LB), and Soil Survey Institute (STIBOKA).

Project 100.21 [REP/27]

CONTENTS

SUMMARY

Regional water management plays an important role in agriculture production. The crop production model SIMCROP has been developed to quantify regional water management aspects in terms of crop production and benefits. Effects of groundwater and open water level manipulation can be translated into production and benefits by means of the variable transpiration.

In the model SIMCROP the regional crop production is based on the crop production of potatoes. For other crops their potential production is related to this by means of conversion factors. The actual production is calculated by considering the relative evapotranspiration between emergence and harvest time. Having obtained these actual yields under optimal nutrient supply, one has to correct it for the actual nutrient supply.

To demonstrate the use of the crop production model some water management scenarios were calculated for a region of 35 ha in the Netherlands.

1. INTRODUCTION

Regional water management plays an important role in agricultural crop production. If certain changes in water management take place, then the question arises, what is the effect of these changes on agricultural crop production in a region; and in connection with this, what is the effect on the benefits. It is well known that under conditions of water shortage a crop will show a reduction in transpiration and hence in crop production. If one is able to determine the relationship between transpiration and crop production it will be possible to evaluate the effect of water use on crop production. Effects of groundwater and open water level manipulation can then be translated into effects on crop production, by means of the intermediate variable of transpiration.

To simulate agricultural crop production one needs to be informed about actual transpiration. Crop transpiration depends on the development stage and on meteorological and soil water conditions (FEDDES et al, 1978). For the calculation of transpiration a hydrological model is required on a regional scale. For certain situations such a model is required, because water level manipulations can have different effects within an area. In some parts of the area it can have a positive effect, and simultaneously in other parts a negative effect on crop production. For instance groundwater extraction decreases groundwater levels and lowers the soil water in the root zone. Drier soil water conditions results in less evapotranspiration and hence lower crop production. It is also possible that the occurrence of water logging can be decreased by the reduction in soil water resulting in higher transpiration rates and crop production. Therefore the calculation of crop production for a region should be based on results of a regional hydrological model.

An outline of the regional crop production model SIMCROP is given in Chapter 2. In Chapter 3 the general theory on crop production is presented and also yield reduction due to nitrogen supply. In Chapter 4 some applications of the model are given. This concerns examples on the effect of an increase in groundwater extraction and the effect of sprinkling on crop growth and cost benefit.

2. OUTLINE OF CROP PRODUCTION MODEL

A crop production model, CROPR, that quantifies the effects of water management on dry matter crop yield has been developed by FEDDES et al (1978). They have given a mathematical formulation of crop growth rate as a hyperbolic function of (normalized) transpiration. The production of a crop each day depends on a water use efficiency factor and the potential growth rate during that day, being mainly determined by solar radiation. Crop parameters have been derived mainly by taking measurements in the field over a number of years. Ideally such production models should be applied separately for each type of crop. Unfortunately the parameters have not been determined for all crop species so far. For potatoes long year experiments are available and the model has been verified extensively (FEDDES, WESSELING and WIEBING, 1984).

The regional crop production model SIMCROP (SIMulation of CROP production and calculation of benefits) is based on the same method as used in the CROPR model (Fig. 1). Therefore the yield for other crops is related to the production of potatoes. The potential yield of other crops is calculated by means of crop production factors. The actual yield is obtained by taking the relative evapotranspiration between emergence and harvest time into consideration. Subsequent the yield is corrected for differences in nutrient supply. Up till now the yields calculated are productions under optimal conditions. These yields are therefore multiplied by a factor, to obtain yields that are found in practice (Fig. 1).

From the agricultural yield the cost benefit is calculated. The benefit is based on a fixed market price per crop and all costs directly related to the production.

For the simulation of agricultural crop production actual transpiration data are required. The transpiration of a crop depends on the development stage of that crop, meteorological and soil water conditions. A hydrological model, in this case SIMGRO, is taken yielding evapotranspiration results. For a detailed description of this model see QUERNER and VAN BAKEL (1988). In principle, however, any other model that calculates transpiration or evapotranspiration rates can be taken. In the case of evapotranspiration values partitioning in transpiration and soil evaporation is required.

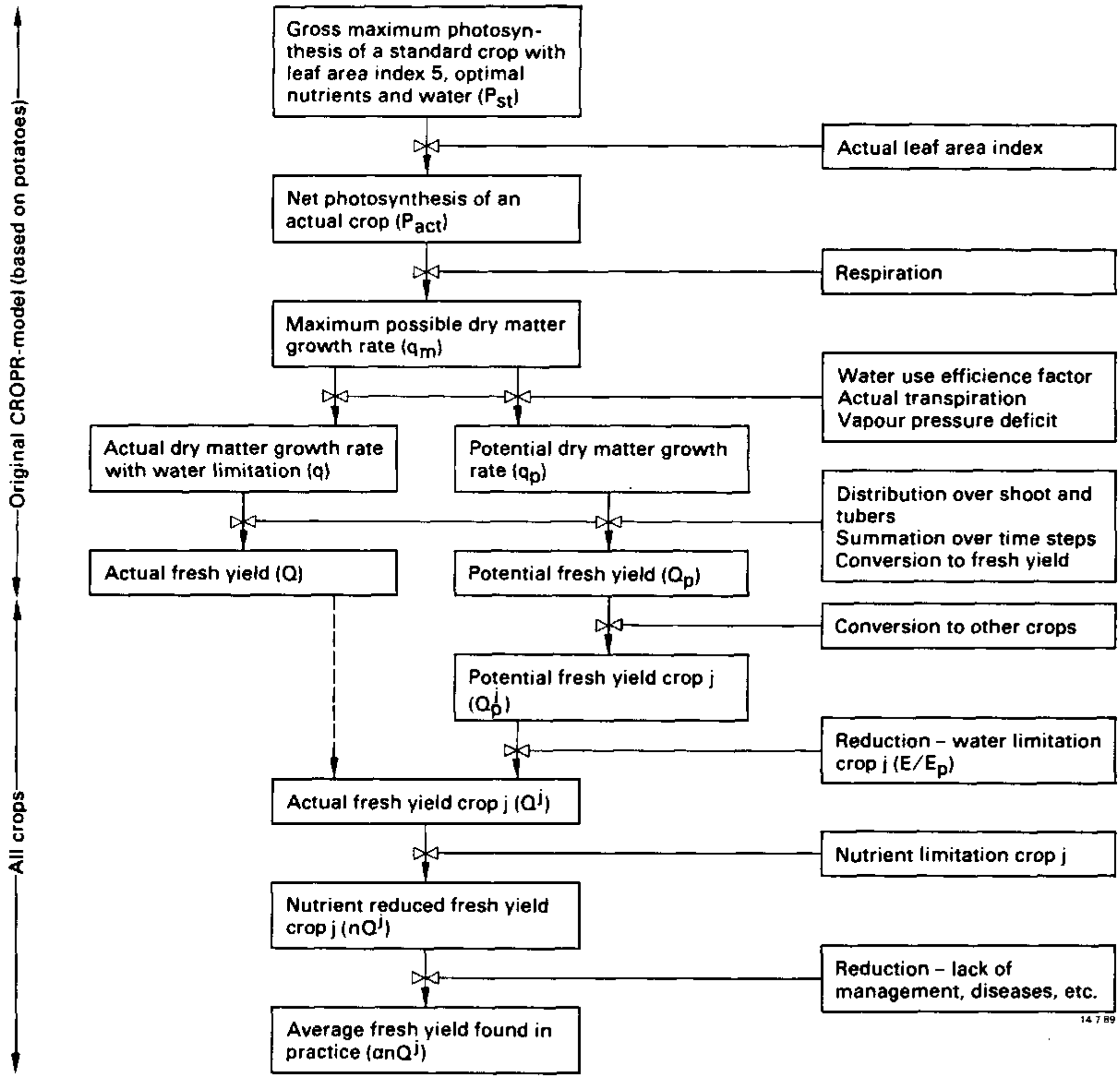

Fig. 1. Flow chart of calculation method to derive at crop productions per land use

The model SIMGRO computes the regional water movements in both the saturated and unsaturated zone. The model of the unsaturated zone has a relative simple approach to simulate the water behaviour. Two reservoirs are present, one for the root zone and one for the subsoil, being the part between the root zone and the groundwater level. Potential evapotranspiration is reduced according to the relative soil water content in the root zone. Actual evapotranspiration is the main link between the hydrological model SIMGRO and the crop production model SIMCROP. Evapotranspiration rate as calculated in the hydrological model is partitioned over transpiration and soil evaporation as a function of leaf area index.

3. CALCULATION OF CROP PRODUCTION

3.1. GENERAL THEORY

A crop production model that quantifies the effects of water management on dry matter crop yield has been developed by FEDDES et al. (1978). They have given a mathematical formulation of actual dry matter growth rate q_a as a hyperbolic function of the (normalized) transpiration E_t. The production of a crop each day depends on the water use efficiency factor A and the maximum growth rate q_m as:

$$\left(1 - \frac{q_a}{AE_t/\overline{\Delta e}}\right)\left(1 - \frac{q_a}{q_m}\right) = \xi \qquad (1)$$

where: $\overline{\Delta e}$ is the average vapour pressure deficit of the air and ξ is a mathematical parameter. The actual dry matter growth rate is considered as a production under ideal circumstances such as experimental fields. The maximum water use efficiency depends on the weather conditions over the year and different growing stages. This factor is determined from field experiments. The relationship given by equation (1) is depicted in Figure 2.
The maximum possible growth rate is derived from the gross maximum photosynthesis rate of a 'standard' canopy. A 'standard' canopy is defined as a canopy with a leaf area of index five (5 m^2 of leaves per square metre of soil surface) which is fully supplied with water and nutrients. Under actual field conditions these maximum growth rates will never be reached and corrections are made to derive the actual growth rate. The calculation of maximum possible, potential and actual crop production is given below.

Maximum possible growth rate

The gross maximum photosynthesis rate P_{st} of a 'standard' canopy with leaf area index I = 5 (ha leaves per ha soil area) that is fully supplied with water and nutrients can on any day and place at earth be found as:

$$P_{st} = \Lambda P_o + (1 - \Lambda)\, P_c \qquad (kg\ CH_2O.ha^{-1}.d^{-1}) \qquad (2)$$

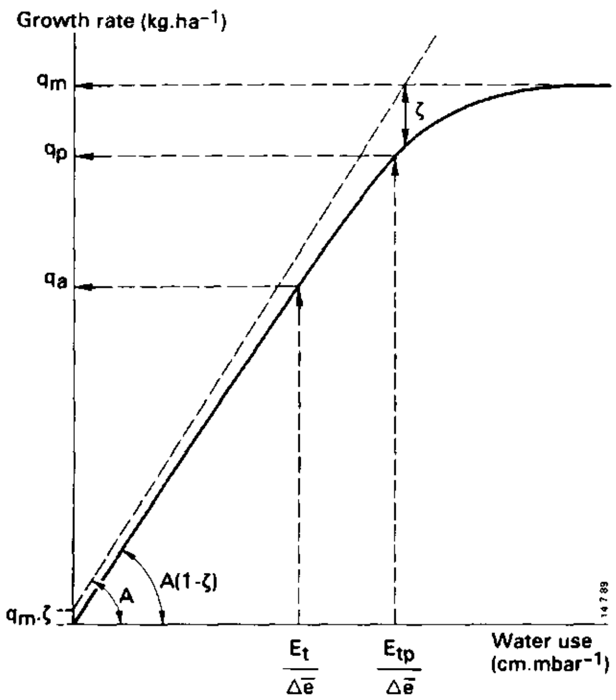

Fig. 2. Growth rate, q, in dependence on the growth factor water given as normalized transpiration. The resulting graph is a non-rectangular hyperbola. Nomenclature used: E_t = actual transpiration, E_{tp} = potential transpiration, q_a = actual growth rate, q_p = potential growth rate, q_m = maximum growth rate, ξ = mathematical parameter, $\overline{\Delta e}$ = average vapour pressure deficit

where: Λ is the fraction of time the sky under the actual conditions is overcast, P_o and P_c are the gross photosynthesis rate of a standard canopy on an overcast respectively a clear day. The value of Λ can be found from the expression:

$$\Lambda = \frac{R_c - 0.5\ R_s}{0.8\ R_c} \qquad (3)$$

where: R_c is the part of solar radiation flux that is involved in photosynthesis on clear days and R_s is the short wave global radiation flux. The daily totals for R_c P_o and P_c for various times of the year and at different latitudes have been calculated by GOUDRIAAN and VAN LAAR (1978). The annual variation at 52° north latitude (The Netherlands) is shown in Figure 3.

For an actual crop with leaf area index smaller than five an exponential extinction of photosynthetic radiation can be assumed, and the actual photosynthesis P_{act} can be expressed as:

$$P_{act} = P_{st}(1-e^{-\gamma I}) \qquad (\mathrm{kg\ CH_2O.ha^{-1}.d^{-1}}) \qquad (4)$$

where: I is the leaf area index and γ is the solar radiation extinction factor ranging from 0.6 to 0.8.

Part of the assimilated carbohydrates, CH_2O, will be utilized for maintenance respiration and growth respiration. Maintenance respiration X_m is

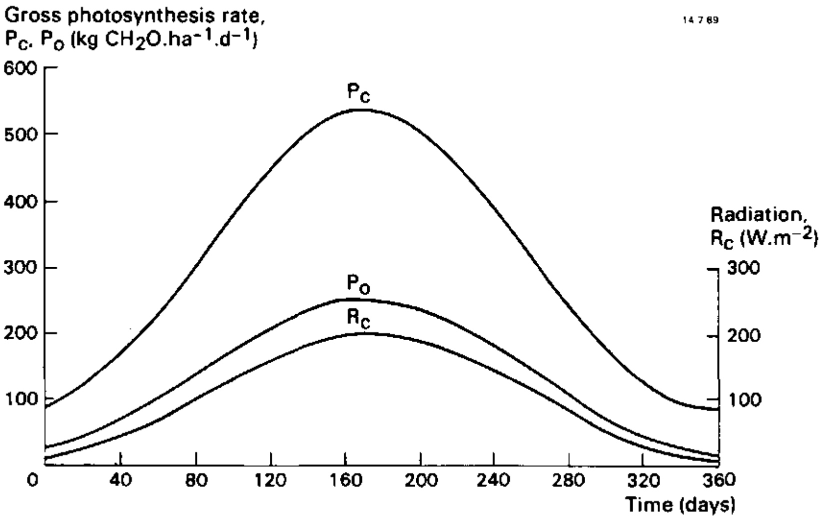

Fig. 3. Annual variation of gross photosynthesis for The Netherlands (standard canopy)

proportional to dry matter weight and strongly dependent on temperature, such that:

$$X_m = 0.01\ Q_t . 2^{\left(\frac{T-25}{10}\right)} \qquad (\mathrm{kg\ CH_2O.ha^{-1}.d^{-1}}) \qquad (5)$$

where: Q_t is the total yield of potatoes (shoot and tubers) and T is the air temperature. Growth respiration can be accounted for by a simple efficiency factor c to convert sugars into starch (c ≈ 0.7). The maximum possible dry matter growth rate can now be expressed as:

$$q_m = [P_{st}(1-e^{-\gamma I})-X_m]\ c \qquad (\mathrm{kg\ ha^{-1}.d^{-1}\ dry\ matter}) \qquad (6)$$

Potential and actual production

When solving Equation (1) explicitly for the actual dry matter growth rate q_a and actual transpiration rate E_t, one obtains:

$$q_a = 0.5\left[A\,\frac{E_t}{\Delta e} + q_m - \left\{\left(q_m + A\,\frac{E_t}{\Delta e}\right)^2 - 4\,q_m\,A\,\frac{E_t}{\Delta e}(1-\xi)\right\}^{0.5}\right]$$

$$(\mathrm{kg\ ha^{-1}.d^{-1}\ dry\ matter} \qquad (7)$$

In a similar way one can calculate potential growth rate q_p at potential transpiration rate E_{tp}.

The development of a crop with time varies from year to year, depending on environmental conditions such as temperature, day length, soil water content in the root zone, etc. Therefore a dimensionless development stage D_s of a crop has been introduced as:

$$D_s = \frac{t - t_e}{t_h - t_e} \qquad (8)$$

where t is the time considered, t_e is the emergence date and t_h is the harvest date. With known dates for the emergence and harvest of a crop the development stage can be computed for each value of t.

3.2. YIELD OF POTATOES

The maximum water use efficiency factor, A, required in Eq. (7) can be determined from field experiments. This factor has been found for potatoes in the range of approximately 2000 to 4300.

Analysis of long year field experiments of two different potato varieties showed that variation of soil cover S_c with the development stage is approximately constant over the years (Figure 4a). Also that their exists a fixed relationship between the leaf area index I (ha leaves per ha soil) and fraction of soil cover S_c as :

$$I = 2.6\ S_c + 1.5\ S_c^2 + 0.9\ S_c^3 \qquad (9)$$

In this way one can link soil cover to leaf area index at various crop development stages.

Depending on the development stage, the increase in total dry matter for each time step is distributed over the shoot and tubers (Figure 4b). Having calculated actual growth rate with eq (7), the total dry matter yield of potatoes is obtained by summation of the production per time step from emergence to harvest time. The length of the time step used depends on the output of evapotranspiration rates from the hydrological model.

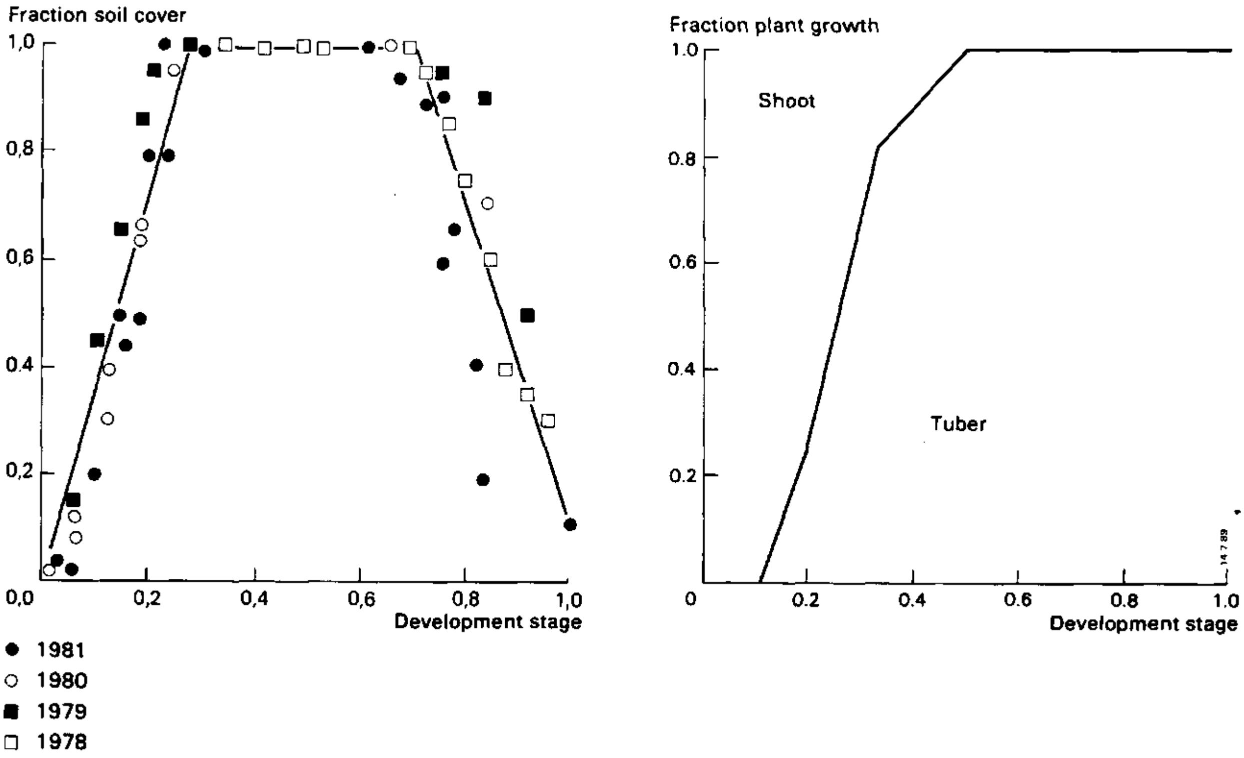

Fig. 4. Left: variation of soil cover, S_c, with development stage, D_s, for potatoes grown at different places over a number of years (1978-1981); right: distribution of increase in total dry matter production over shoot and tubers

3.3. YIELD OF OTHER CROPS

Potato dry matter yield is converted to total fresh yield by means of a factor, for which the value 4.7 is used (measured dry matter is 21% of total fresh yield). Having calculated this actual yield Q and potential yield Q_p yield of potatoes (yield of tubers and over growing season), the potential yield Q_p^j of other crops j is estimated as:

$$Q_p^j = F^j * Q_p \qquad (\mathrm{kg\ ha^{-1}.d^{-1}}) \qquad (10)$$

where F^j is the conversion factor to derive the potential production for the crop considered. As an example crop conversion factors F^j for various crops applicable for the Southern Peel region are given in Annex A. The actual fresh yield is corrected for the relative evapotranspiration and calculated as:

$$Q^j = \frac{E^j}{E_p^j} * Q_p^j \qquad (kg.ha^{-1}.d^{-1}) \qquad (11)$$

where the ratio actual to potential evapotranspiration is considered over the period from emergence to harvest time of the crop.

3.4. EVAPOTRANSPIRATION

The hydrological model SIMGRO calculates evaporation from plant and soil, i.e. evapotranspiration. Therefore partitioning of evapotranspiration in transpiration and soil evaporation as a function of leaf area index is required. FEDDES (1987) derived a relationship which is shown in Figure 5. It has been assumed that the soil surface is dry. The sum of evaporation from soil, transpiration from plant and evaporation of plant intercepted water is the total evapotranspiration. If one considers a dry surface most of the time and the crop well supplied with water, then the total water loss minus the evaporation of plant intercepted water is assumed to be equal to the potential evapotranspiration. Therefore one can write potential evapotranspiration as:

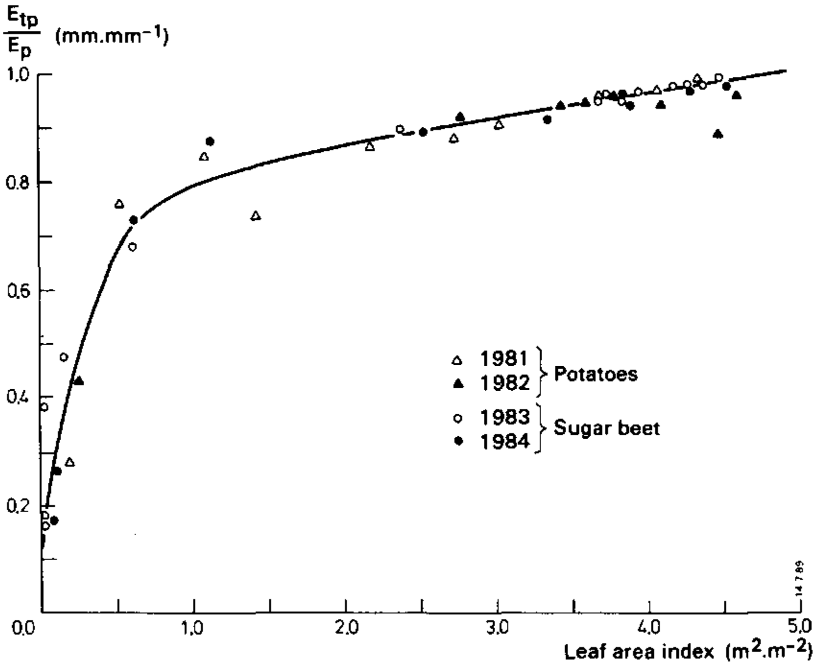

Fig. 5. Transpiration as a fraction of evapotranspiration depending on leaf area index for potatoes and sugarbeet, when the soil surface is dry most of the time (FEDDES, 1987)

$$E_p = E_{sp} + E_{tp} \qquad (12)$$

where E_p is the potential evapotranspiration, E_{sp} is potential soil evaporation and E_{tp} the potential transpiration.

3.5. NUTRIENT APPLICATION

Having obtained the yield under optimal nutrient supply, one has to correct for the actual nutrient supply, of which nitrogen is the most important. A reduction factor n dependent on the ratio actual to optimal nitrogen supply is introduced (FEDDES and RIJTEMA, 1983) as:

$$n = 1 - a\,(1 - N_a/N_o)^b \quad \text{for} \quad 0 <= N_a/N_o <= 1 \qquad (13)$$

$$n = 1 - c\,(N_a/N_o - 1)^d \quad \text{for} \quad N_a/N_o > 1 \qquad (14)$$

where N_a is the amount of nitrogen applied plus the amount available in the soil and N_o is the demand for optimal crop production. Equation (13) and (14) forms the mathematical formulation of the lines shown in Figure 6. The coefficients a to d necessary in these equations are given in Table 1.

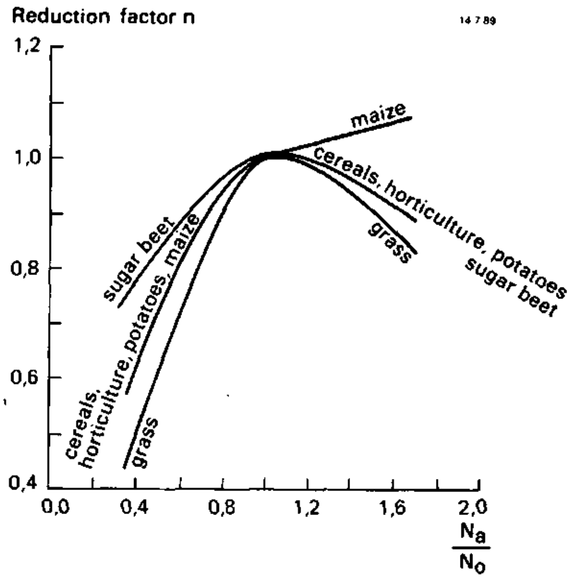

Fig. 6. Reduction in crop production dependent on ratio of the amount of nitrogen applied plus that available in the soil (N_a) and the amount of nitrogen for optimum fertilization (N_o)

Table 1. Values of the coefficients used in eqs (13) and (14) for different crops

Crop	Coefficients for Equation (13) and (14)			
	a	b	c	d
grass	1.147	1.618	0.168	1.576
cereals, row crops	0.859	1.683	0.302	1.688
maize	0.859	1.683	-0.060	0.333
horticulture	0.859	1.683	0.302	1.688

Up to now the calculated potential and actual yields should be considered as yields that theoretically can be obtained. One has to correct these yields for factors other then included in the model. These factors are for instance reduction due to lack of management, occurence of diseases, etc. Hence the actual yield has been multiplied by a 'lumped' factor 0.65 - 0.85 to reach fresh yields that are found in practice.

4. PRACTICAL APPLICATIONS

4.1. PRINCIPLES

In the hydrological model the processes are modelled as realistic as possible, but constraints are in general a lack of data and required computational effort, which can influence the results of certain processes to a certain degree. The hydrological schematization and the input parameters were verified by comparing the results with field measurements. A sensitivity analysis on the hydrogeological parameters has been done to determine their importance.

To demonstrate the use of the hydrological and crop production model some water management senarios where calculated for a region 35,000 ha with typical sandy soils in The Netherlands (Southern Peel region) as shown in Figure 7. The region is subdivided into 31 subregions characterized by homogeneous soil properties and hydrological conditions. First the hydrological model is run for a specific case.

Results in the form of evapotranspiration rates and sprinkling quantities are subsequent part of the input data for the agricultural crop production model.

The benefit from agricultural crop productions is determined with a simple relation:

$$Y^j = Q^j * M^j - C^j \qquad (15)$$

where M^j is the market price and C^j are all costs related to the production process. Production costs independent of the yield are replacements costs, planting material, fuel, weed control, plant protection, insurances, ect. Costs dependent on the yield are chemical fertiliser, waste application and sprinkling energy costs. The market prices for various crops are listed in Annex A. For the Southern Peel region production costs for various land use activities, denoted as technologies, were determined by REINDS (1985).

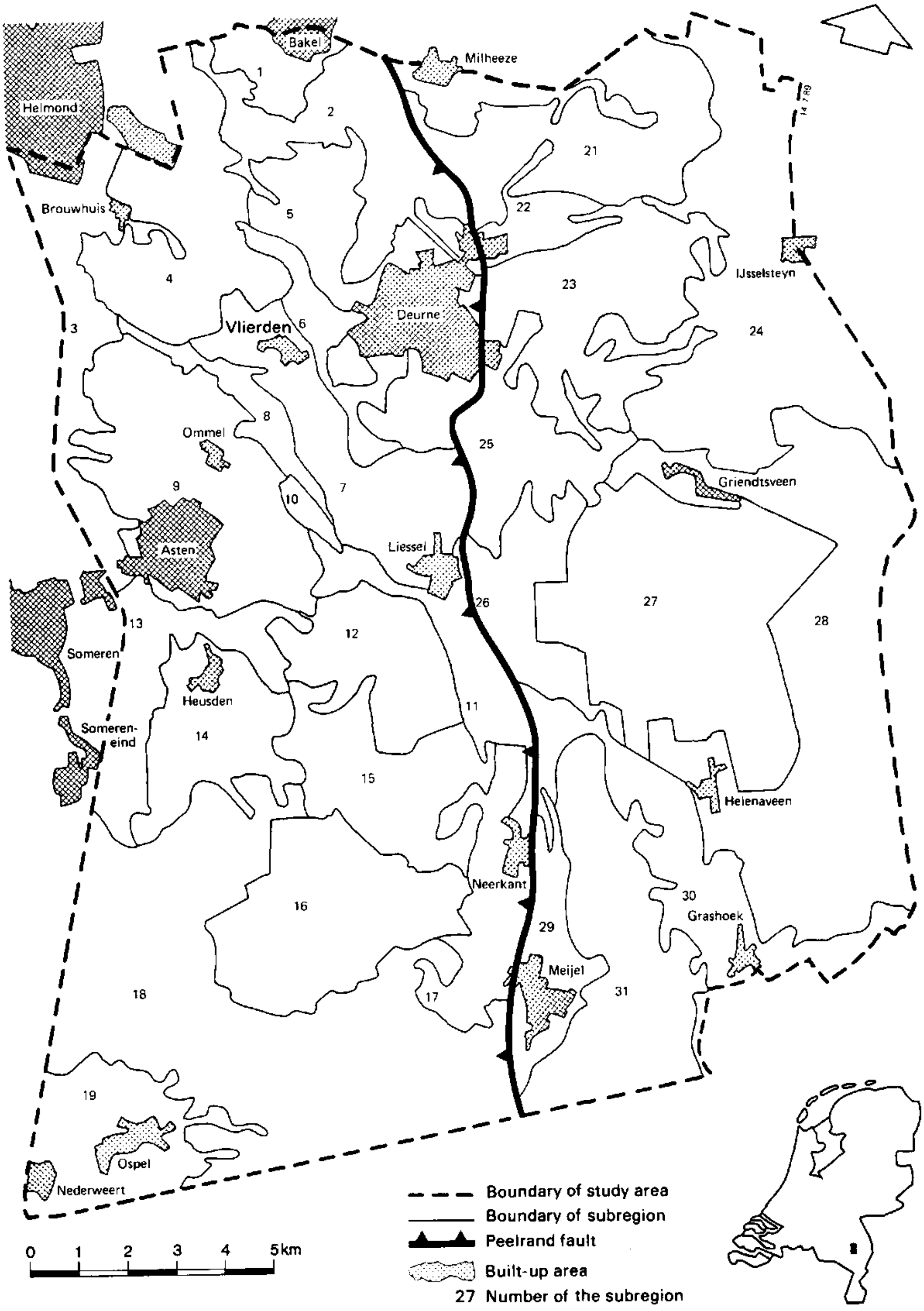

Fig. 7. Southern Peel region and the subdivision in subregions. The location of the study area in the Netherlands is indicated at the foot of the figure

4.2. GROUNDWATER EXTRACTION

In the Southern Peel region a pumping station for public water supply is located near the village of Vlierden (Figure 7). Its present capacity is approximately 10,000 $m^3.d^{-1}$. If the pumping rate is double the present capacity, then the benefits for the entire region reduces as shown in Table 2. For the very dry summer of 1976 the reduction in benefits becomes significantly. Consider the reduction in benefits over the increased extraction, then every cubic meter of additional extracted water costs Dfl 0.11 (price-level 1985). In these calculations it has been considered, fixed prices per crop, no variation of emergence and harvest time over these three years and an optimal nutrient supply.

Table 2. Benefits from Southern Peel region in case of two different groundwater extraction rates. Present situation is 10,000 $m^3.d^{-1}$ 20,000 $m^3.d^{-1}$ is a hypothetical situation

Year	Benefit (10^6 Dfl)		Weather conditions
	10,000 $m^3.d^{-1}$	20,000 $m^3.d^{-1}$	
1974	144.4	144.3	wet
1975	143.8	143.6	dry (10%)
1976	133.6	133.2	very dry (1%)

4.3. SPRINKLING

The efficiency of sprinkling on a regional scale can be judged from calculations with and without sprinkler irrigation. The results of the hydrological and crop production model are shown in Table 3. The market prices used for the calculations are given in Annex A. For the replacement cost of sprinkling equipment a figure of Dfl 610 per ha has been used and for energy a figure of Dfl 0.70 per mm water sprinkled. The amount of sprinkler installations used in the calculations is based on the estimated capacity present in the Southern Peel region in 1982. The results are based on hydrological calculations for a large area and only 31 subregions present. It is more to demonstrate the practical applicability of the crop production model.

Tables 3 and 4 give a good indication of the effect of sprinkling on a regional level. For the entire region only 1976 shows a positive benefit from sprinkling. However, within the region the other years (1974 and 1975) can have positive as well as negative benefits, but the negative benefits dominate. More interesting is to look at the difference in benefits for some of the technologies (Table 5).

Table 3. Results of calculations with SIMGRO with and without sprinkling. Nomenclature used: E, evapotranspiration; P_s, sprinkling from surface water and from groundwater

Year	No sprinkling	Sprinkling		$(E_2-E_1/P_s)100$
	E (mm)	E (mm)	P (mm)	(%)
1974	421	423	26	8
1975	396	408	38	32
1976	344	380	81	44

Table 4. Results of calculations with SIMCROP with and without sprinkling

Year	Benefits (10^6 Dfl)		Increase benefit (%)
	no sprinkling	sprinkling	
1974	147.9	145.1	-1.9
1975	143.7	142.8	-0.6
1976	127.0	133.9	5.4

Table 5. Effect of sprinkling on benefits for some lande use activities present in the Southern Peel region (I - no sprinkling; II - sprinkling)

Land use	Benefits ($Dfl.ha^{-1}$)					
	1974		1975		1976	
	I	II	I	II	I	II
Small scale horticulture	26,010	25,770	25,450	25,500	22,470	30,420
Large scale horticulture	2,310	1,710	1,570	1,920	310	2,370
Potatoes/sugarbeet	3,760	3,140	3,660	3,330	2,160	3,430
Maize	1,310	660	990	900	410	870

5. CONCLUSIONS

The use of subregions for the hydrological schematisation has the advantage of reducing required input data and computational time. This makes it easier to simulate a large number of alternatives. A crop production and cost benefit model as an integral part of the hydrological modelling process has the advantage of showing results in an independent way.

The crop production model can also be used in connection with a surface water and groundwater flow model (QUERNER, 1986). This model is useful for problems more related to the surface water system, such as water distribution and maintenance.

REFERENCES

FEDDES, R.A., 1987. Crop factors in relation to Makkink reference-crop evapotranspiration. Comm. Hydrol. Research TNO, The Hague. Proc. and Inf. No. 39. p. 33-44.

FEDDES, R.A., P.J. KOWALIK and H. ZARADNY, 1978. Simulation of field water use and crop yield. Simul. Mon., Pudoc, Wageningen, 189 pp.

FEDDES, R.A. and P.E. RIJTEMA, 1983. Calculation of actual evaporation and crop production for the Southern Peel area. ICW, Wageningen, The Netherlands, Nota 1421, 10 pp.

FEDDES, R.A., J.G. WESSELING and R. WIEBING, 1984. Simulation of transpiration and yield of potatoes with the SWACRO model. 9th Triennial Conference of the European Ass. for Potato Research (EAPR), Interlaken, Switzerland, 1 - 6 July, p. 346 - 348.

GOUDRIAAN, J. and H.H. VAN LAAR, 1978. Calculation of daily totals of the gross CO_2 assimilation of leaf canopies. Neth. J. Agric. Sci., vol 26, p. 373 - 382.

QUERNER, E.P., 1986. An integrated surface and groundwater flow model for the design and operation of drainage systems. Int Conf. on Hydraulic Design in Water Resources Engineering: Land Drainage, 16-18 April 1986, 101-108. Report 15. ICW, Wageningen, The Netherlands, 9 pp.

QUERNER, E.P. and P.J.T. VAN BAKEL, 1988. Description of the regional groundwater flow model SIMGRO. Report 7. The Winand Staring Centre, Wageningen, The Netherlands. 61 pp.

REINDS, G.H., 1985. The farm technology in the Southern Peel. ICW, Wageningen, The Netherlands, Nota 1653, 25 pp.

LIST OF SYMBOLS

A_j - maximum water use efficiency factor
C - costs related to production process of crop j
D_s - development stage
E - actual evapotranspiration
E_p - potential evapotranspiration
E_{sp} - potential soil evaporation
E_t - actual transpiration
E_{tp} - potential transpiration
F^j - conversion factor between production of potatoes and other crop species
I - leaf area index
M^j - market price for crop j
N_a - amount of nitrogen applied plus available in the soil
N_o - nitrogen demand for optimal crop production
P_{act} - actual photosynthesis rate
P_c - gross photosynthesis rate on clear day
P_o - gross photosynthesis rate on overcast day
P_{st} - gross maximum photosynthesis
q_a - actual dry matter growth rate (entire plant)
q_m - maximum possible dry matter growth rate (entire plant)
Q - actual fresh yield of potatoes (tubers, growing season)
Q_p - potential fresh yield (tubers, growing season)
Q^j - actual fresh yield of crop
Q_p^j - potential fresh yield of crop
Q_t - total potential yield of shoot and tubers
R_c - solar radiation flux
R_s - short wave global radiation flux
S_c - soil cover
t - time
t_e - emergence date
t_h - harvest date
T - temperature

X_m - maintenance respiration

Y^j - benefits

Δe - vapour pressure deficit of the air

Λ - fraction of time sky is overcast

ξ - mathematical parameter

Annex A

CROP PRODUCTION FACTORS AND MARKET PRICES

From yields found in practice the conversion factors F^j used to estimate crop yield from the yield of potatoes are based on information collected by PAGV (1984). Also the current market prices are from this source. The total (fresh) yield, the conversion factor to derive at productions per crop from production of potatoes and the market prices are listed in the table below. The figures are applicable for typical sandy soils in the Southern Peel region (south western part of The Netherlands).

Technology/crop	Total yield (kg)	Factor	Market price (Dfl.kg^{-1})
Potatoes	45,000	-	0.15
Sugarbeets	54,000	1.20	0.11
Maize	48,000	1.07	0.06
Cereals			
barley	7,700	0.17	0.35
winter rye	8,200	0.18	0.30
Small scale horticulture	42,650	0.94	0.83
Leek	40,000	0.89	0.84
Schozonera	17,000	0.38	0.48
Pole snap beans			
Strawberries	16,000	0.35	2.90
Ridge cucumbers	65,000	1.44	0.80
Carrots	65,000	1.44	0.19
Large scale horticulture	10,840	0.24	0.61
Garden peas	4,600	0.10	0.76
Broad beans	11,000	0.22	0.36
Brussels sprouts	20,000	0.44	0.90
Chicory	28,000	0.62	0.30
Grassland			
Dairy cattle	75,000	1.66	0.07
Rearing cattle	75,000	1.66	0.07

ANNEX A (continued)

It should be noted that for grassland used for rearing cattle the nutrient supply is in general lower then required for optimal grass production (e.g. amount of nitrogen applied plus available in the soil is 60 - 80 % of nitrogen demand required for optimal crop production).

Typical crop growing periods for various crops used for the calculations is given below:

Crop	Day no	
	emergence	harvest
Potatoes	121	258
Cereals	80	220
Maize	140	290
Small scale horticulture	106	305
Large scale horticulture	106	274
Grassland	60	305

Reference

PAGV, 1984. Quantitative information 1984-1985. Proefstation voor de Akkerbouw en de Groenteteelt in de Vollegrond, Lelystad, The Netherlands (in Dutch).