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A weather-based yield-forecasting model for sugar beet

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Abstract

A simple model to predict seasonal growth in sugar beet yield is presented. Time from sowing to the so called 'growth point date' (the date on which a plant contains 4 g sugar) is characterized by a temperature sum. The increase in sugar yield after this date is calculated from incoming solar radiation using an average radiation use efficiency. Temperature sums and radiation use efficiencies were estimated for each of the 11 Dutch sugar beet regions.

Keywords: sugar beet, yield-forecasting model, radiation use efficiency

Introduction

The Dutch sugar companies plan their harvest campaign on the basis of yield forecasts derived from periodic harvests during the growing season. This is done by comparing the results of these harvests to the seasonal yield trend of the previous years. This is a laborious and purely statistical procedure. This paper presents a model that (a) may partly replace the labour-intensive periodic harvests and (b) accounts for effects of weather conditions on yield, thus enabling some insight into the underlying causes of year-to-year variation.

Model description

Rates of plant emergence, and — as long as the plants are standing free — rates of leaf appearance and leaf area expansion relate almost linearly to temperature (e.g. Milford et al., 1985), so that time from sowing to full ground cover by the foliage can be characterized by a temperature sum. Once the foliage fully covers the ground, the crop growth rate is approximately proportional to incoming solar radiation (e.g. Milford et al., 1980). Start of full ground coverage is approximated by the 'growth point date' (g.p.d.), which is defined as the date on which a beet contains 4 g of sugar. This point also marks the start of secondary thickening of the tap root.

Hence, time from sowing to g.p.d. is described by a certain temperature sum (S_{gpd} in °C d). At g.p.d., the sugar yield (W in g m^{-2}) is set at a value of 4 g (the amount of sugar per beet) times the number of plants per m^2. The increase in sugar yield after g.p.d. is calculated as

$$\Delta W = RUE \times R$$

where ΔW is the daily rate of sugar accumulation (g $m^{-2}d^{-1}$), RUE the radiation use efficiency (g MJ^{-1}), and R the incoming solar radiation (MJ $m^{-2}d^{-1}$).

Parameterization

The model parameters (S_{gpd} and RUE) were estimated from the results of the periodic harvests over the years 1981-1986 (IRS 1981-1986). Each year, 10 successive harvests were carried out on each of 250 representative farmer fields, distributed over the Netherlands. The first three harvests around 1 July enabled an estimate of g.p.d. The later seven harvests gave the growth course; they started at the end of July and proceeded with fortnight intervals. The fields were grouped according to 11 regions (Fig. 1). For each year and for each region, S_{gpd} was calculated, and RUE was estimated for the fortnightly intervals using the temperature and solar irradiance data of the region (10 day-values).

Results and discussion

On average, g.p.d. was reached 75 days after sowing. The variation between years within a given region in the length of this period was considerably reduced when this period was expressed as a temperature sum (in °C d): the coefficient of variation (CV) reduced from 10.9 % for time expressed in days to 5.8 % and 4.8 % for time expressed as a temperature sum with a base of 3 °C and 0 °C, respectively. The temperature sum averaged 924 °C when a base of 0 °C was applied, or 701 °C when 3 °C was used as base temperature above which the daily mean temperatures were accumulated.

The various regions differed in their temperature requirements to reach g.p.d. (Table 1), with the higher yielding soil types or regions (region numbers 4 and 5) showing the lower requirements (clay compared to sand, the new polders compared to the old land). Probably the main reason is that the superior growth conditions on the clay soils overcompensate for the effect of the slow warming up of these soils compared to sand. The higher temperature requirements for the Loess region might be caused by less optimal soil structure in this region compared to the clay regions, in combination with a slower warming up compared to the sandy soils.

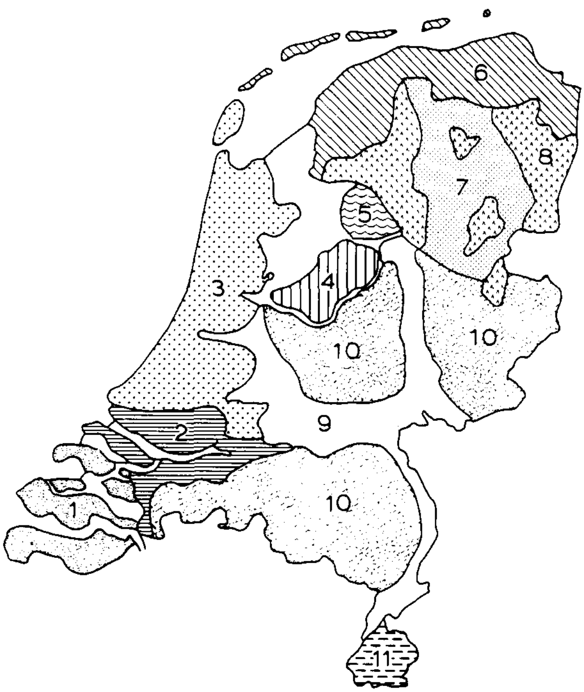

Fig. 1. Distinguished regions with different soil types. Region 1-6: marine clay; region 7 and 10: sandy soil; region 8: reclaimed peat subsoil; region 9: river clay; region 11: loess loam.

Table 1. Temperature sum from sowing to the growth point date and radiation use efficiency for the 11 different regions. The temperature sum is expressed by the difference with the national average ($\bar{S}_{gpd}$ = 924 °C d above a base of 0 °C). The amount of sugar produced per unit of incoming solar radiation is expressed relative to the national average trend (RUE in Fig. 2a).

Region	Soil type	$S_{gpd} - \bar{S}_{gpd}$	RUE / $\overline{RUE}$
1.	marine clay	−17	0.91
2.	marine clay	−18	1.03
3.	marine clay	− 8	1.04
4.	marine clay	−44	1.18
5.	marine clay	−29	1.16
6.	marine clay	−14	1.06
7.	sandy soil	+15	0.82
8.	reclaimed peat subsoil	+ 8	0.91
9.	river clay	− 5	0.98
10.	sandy soil	+27	0.94
11.	loess loam	+87	0.98

Growth after 'growth point date' (g.p.d.)

The time course of the efficiency of sugar accumulation per unit of incoming solar radiation is depicted in Fig. 2a. In August and September, this radiation use efficiency varies around a value of 0.9 g sugar per MJ of incident solar radiation. In July, the value is lower because then a substantial part of total dry matter growth is used for structural growth of tops and beets rather than for sugar accumulation. Towards the end of the season, the efficiency decreases, mainly as a result of a senescing foliage. Seasonal courses of RUE were more or less similar between regions, so that the RUE course of a certain region was expressed relative to the national average trend. The region specific multiplication factors are presented in Table 1. Sugar growth rates were highest in the new polders (regions 4 and 5), followed by the other clay regions, and lowest on loess and sandy soils. These differences are mainly caused by differences in soil conditions. Additionally, in dry years yields on sandy soils were somewhat reduced by drought. In contrast to the efficiency for su-

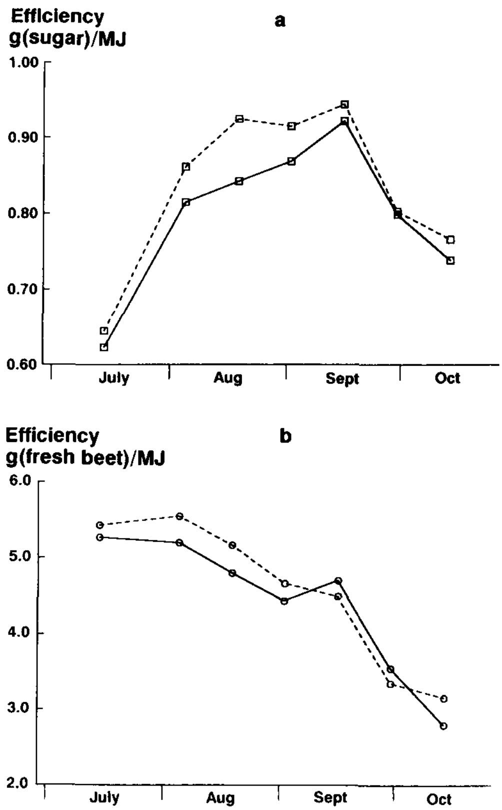

Fig. 2. Seasonal course of radiation use efficiency for (a) sugar accumulation and (b) increase in fresh beet weight, averaged over all 11 regions (solid lines) and the 7 clay regions only (dashed lines).

gar accumulation (Fig. 2a), the efficiency for the growth in beet fresh weight gradually declined in course of the season (Fig. 2b).

From the observed variation between years within regions, 70 % and 65 % were explained by the model for sugar yield and beet fresh yield, respectively. For the clay regions alone, making up 2/3 of the production area, these figures were 77 % and 73 %, respectively.

Yield forecasting

The presented model may be used as a tool in forecasting sugar beet yields. During the growing season, yields are simulated on the basis of the region specific parameters and the actual weather data for that region up to the present date. Predictions about the yield increase during the rest of the season are based on data of average weather for the region considered. Results of periodic harvests can be used to update current model predictions. The accuracy of the model is likely to be improved (a) when a simple water balance is attached to the model, especially for the sandy soils, and (b) when parameter estimates are based on a larger number of years and on daily weather data rather than on decade values.

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This synopsis is based on a student thesis entitled 'Een eenvoudig, voorspellend suikerbietenmodel' by B. Kiewiet, Department of Theoretical Production Ecology, Wageningen Agricultural University, Wageningen, 1989, 35 pp., 14 tables, 3 figs, 8 refs, 8 apps, in Dutch. Available as paper copy (order R107, free) at NARD, c/o Pudoc, P.O. Box 4, 6700 AA Wageningen (telex 45015 bluwgnl).
