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# Yield response of sugar beets to water stress under Western European conditions

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ABSTRACT

The average yield of sugar beet has almost doubled within the last 30 years. With the raise in average yields and the increase in sensitivity to water stress of sugar beets, the yield response factor (Ky) derived by Doorenbos and Kassam (1979) needs an update. In this article, the soil water balance model BUDGET (Raes et al., 2006) was calibrated and validated to obtain correct estimations of the evapotranspiration deficit (1 − ETa/ETc, where ETa = actual crop evapotranspiration and ETc = maximum crop evapotranspiration under standard conditions) of sugar beets in two locations in France. Datasets of observed soil water contents of several years and different irrigation treatments were used. The simulated evapotranspiration deficits and observed yields were used to derive a seasonal Ky. The obtained linear and polynomial yield response relation between observed yield decline and evapotranspiration deficit showed a high goodness-of-fit. The coefficient of determination ($R^2$) = 0.83, the Nash–Sutcliffe efficiency (EF) = 0.79, the relative root mean squared error (RRMSE) = 0.26 for linear; the coefficient of determination ($R^2$) = 0.85, the Nash–Sutcliffe efficiency (EF) = 0.79, the relative root mean squared error (RRMSE) = 0.25 for polynomial). The results suggested a more pronounced response of sugar beet to water stress in Europe as compared to the values previously reported by Doorenbos and Kassam (1979). The comparison between the observed and simulated yields (with the updated Ky) for another site in France confirmed the findings.



## 1. Introduction

The environment strongly affects sugar beet root yield and sugar quality across Europe (Hoffmann et al., 2009). An important factor is water stress. As a result of insufficient water the estimated yield loss for sugar beets in central Europe ranges between 15% and 30% in the period 1961–1995 and is greater for southern Russia and eastern Ukraine (Pidgeon et al., 2001). Climate change models predict that the annual variability of yield due to drought will increase in many regions of Europe (Jones et al., 2003). Given the relevance of water stress on the production of sugar beets, models estimating yield levels from simulated water stress are of great importance (Geerts and Raes, 2009).

Most of the crop physiological models simulating crop yield (e.g. Bouman et al., 1996; Brisson et al., 2003; Stöckle et al., 2003; Eitzinger et al., 2004) require a whole range of input data. Such data are often not available outside research stations. These models also demand a time consuming and site-specific calibration before they can be applied. For example SUCROS, which is often used for sugar beet yield prediction requires a considerable amount of remote sensing observations with regular frequency to reach an adequate accuracy of the yield prediction (Bouman, 1995). On the other hand, engineering type of models have been developed that are easy to use and require less input data. The Ky-approach of Doorenbos and Kassam (1979) is such a model and is often used for assessing yield response to water (Rao and Subramanian, 1989; Kipkorir et al., 2002; Raes et al., 2006; Popova et al., 2006; Lovelli et al., 2007; Harmsen et al., 2009). This empirical model, embedded in the BUDGET soil water balance model (Raes et al., 2006), describes the relation between water stress and the corresponding yield decline:

$$1 - \frac{\mathrm{Ya}}{\mathrm{Ym}} = \mathrm{Ky}\left(1 - \frac{\mathrm{ETa}}{\mathrm{ETc}}\right) \tag{1}$$

where Ya/Ym is the relative yield, (1 − Ya/Ym) the relative yield decline, ETa/ETc the relative evapotranspiration, and (1 − ETa/ETc) the water stress or relative evapotranspiration deficit. The response of crop yield to water stress is quantified through the

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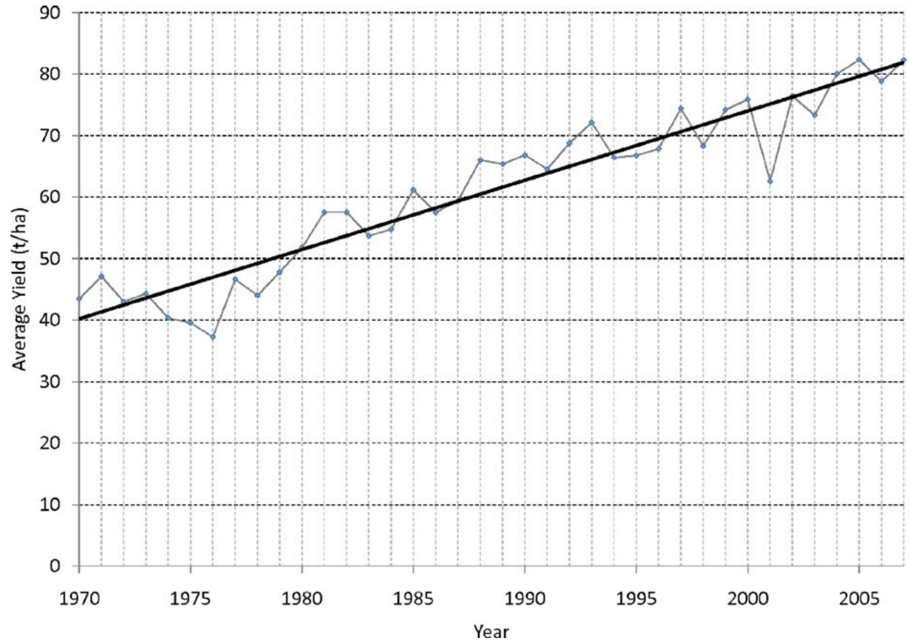


**Fig. 1.** Average sugar beet yield in ton per hectare in France from year 1970 to 2007 (FAOStat, 2009).

yield response factor Ky. Ky coefficients for the total growing period and individual growth stages for several crops are presented by Doorenbos and Kassam (1979). On the other hand, Ky factors have also been derived locally to get a more precise estimation of yield decline in response to water stress for a specific region (Kipkorir et al., 2002; Nautiyal et al., 2002; Moutonnet, 2002; Yilmaz et al., 2006; Lovelli et al., 2007). Further-on Ky factors might need to be updated if average reference evapotranspiration or crop yields increased substantially. The latter is the case for sugar beets where the average yield has almost doubled in France over the last 37 years (Fig. 1). Apart from improved genotypes, the increase might also be due to management practices and a slight increase of the irrigated area (Recensement Agricole, 2000).

In this article a seasonal Ky for sugar beets is derived from field data in France with the help of the soil water balance model BUDGET (Raes et al., 2006). A seasonal Ky, valid for the total growing period, is adequate for yield predictions of sugar beet, since the beetroot is a vegetative storage organ without a differentiated response to water stress at the various growth stages (Hoffmann et al., 2009).

## 2. Materials and methods

### 2.1. Data collection

In Baigneaux (48°2′N, 1°23′E) and Bazainville (48°11′N, 2°5′E), two locations in France, sugar beets were cultivated from 1999 to 2004. In the experimental fields various levels of irrigation water were applied in 10–40-day intervals and with doses ranging from 20 to 40 mm. The number of applications varied between 1 and 6 during the growing cycle. The root yields of sugar beets were measured in each location and for each year. The number of experimental fields in Baigneaux, Bazainville and Arcis-sur-Aube are listed in Table 1. The SWC measurements at soil depths of 0–30, 30–60 and 60–90 cm (3 replications) were taken 6–13 times throughout the season, with intervals ranging from 3 to 23 days. Additionally, yields of sugar beet under rainfed conditions were collected on-farm in Arcis-sur-Aube (48°32′N, 4°7′E) by Cristal Union$^{TM}$ between 1999 and 2006.

Daily rainfall was recorded in the field. The total rainfall within the season ranged from 256 to 752 mm across locations. Due to missing rainfall data for 2001 at Baigneaux and 1999 at Bazainville, these years are excluded from analysis (Table 1). Daily pan evaporation recorded in the experimental fields at Baigneaux and Bazainville were converted to reference evapotranspiration ($ET_o$) by means of a pan coefficient (Allen et al., 1998). For Arcis-sur-Aube, the $ET_o$ was calculated using the FAO-Penman Monteith method (Allen et al., 1998) using locally determined daily maximum and minimum temperature data, and common procedures to estimate missing climatic data presented by Allen et al. (1998). Mean daily ETo in Baigneaux and Bazainville ranged between 1.3 mm/day in March 2001 and 6.1 mm/day in August 2003 and in Arcis-sur-Aube between 1.5 mm/day in March 2006 and 5.8 mm/day in July 2005.

### 2.2. Simulation of the soil water balance

For each location, year and irrigation treatment, the relative evapotranspiration and water stress was simulated with BUDGET (Raes et al., 2006) by considering the observed daily rainfall, the estimated $ET_o$ and the crop and soil characteristics.

BUDGET requires the length and crop coefficient (Kc) for each of the 4 growth stages: initial, crop development, mid-season and late season stage. By considering the observed total length of the

**Table 1**
Available datasets for the 3 locations.

| Location | No. of years | Years (no. of experimental fields) | Total no. of datasets |
|---|---|---|---|
| Baingeaux | 5 | 1999 (2), 2000 (2), 2002 (3), 2004 (2) | 9 |
| Bazainville | 5 | 2000 (5), 2001 (2), 2002 (3), 2004 (2) | 12 |
| Arcis-sur-Aube | 6 | 1999–2006 (1) (excluded year 2001) | 7 |