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Effect of water deficiency on the development and technical quality of some sugar beet genotypes

Wpływ niedoboru wody na rozwój i jakość technologiczną wybranych genotypów buraka cukrowego

Field trials were conducted in 2003 at Heuchelheim in the southwestern part and Wörbzig in the eastern part of Germany. In the vegetation period yield and quality of four sugar beet varieties were assessed under reinfed conditions and in the irrigated plots. Drought caused the decrease both in yield and technical quality of beet roots, mainly due to the accumulation of melassogenic compounds: sodium, α-amino N, betaine and inverted sugar. The varieties responded in a similar way to changes in soil water content. There were no interactions between beet genotypes and irrigation in relation to yield or the analyzed constituents. Thus, no genotypic differences were found to exist in the response of sugar beet to water supply.

Key words: sugar beet, irrigation, yield, technical quality

W 2003 roku, w dwóch różnych miejscowościach, w Heuchelheim na południowym zachodzie i w Wörbzig na wschodzie Niemiec, badano dynamikę wzrostu, plon i jakość zróżnicowanych genotypów buraka cukrowego na obiektach z naturalnymi opadami w danym rejonie i z dodatkowym nawadnianiem. Niedobór wody spowodował spadek plonu i niepożądaną zmianę jakości przemysłowej korzeni buraka. Wystąpił wzrost zawartości sodu, azotu alfa-aminowego, betainy i sacharozy. W ciągu wegetacji odmiany buraka reagowały w podobny sposób na zmianę wilgotności gleby. Nie stwierdzono współdziałania między genotypem a nawadnianiem w odniesieniu do plonu jak i analizowanych składników w korzeniach buraka. Wyniki wskazują zatem, że nie było różnic genotypowych w reakcji buraka na poziom zaopatrzenia w wodę.

Słowa kluczowe: burak cukrowy, nawadnianie, plon, jakość przemysłowa

INTRODUCTION

The development of yield and quality in sugar beet results from the complex interrelationship of environment and variety. The environment is characterized by the site factor, comprising such variables as soil, climate and relief, and by the year factor, expressed in the changes of weather. Both factors are additionally modified by agronomic measures (Boguslawski, 1973).

Among these environmental factors, insufficient soil moisture during summer months is the major cause of sugar beet yield losses in many beet growing regions (Ober, 2001). Additionally, drought negatively affects beet quality for processing in the sugar factory (Kenter and Hoffmann, 2002).

The seasonal development of different sugar beet genotypes was investigated under irrigated and rainfed conditions in order to evaluate if there is genetic variability for the response to drought with regard to yield and quality parameters.

MATERIAL AND METHODS

Field trials were carried out in 2003 at Heuchelheim and Wörbzig, which are located in dry areas in Germany where irrigation is a standard measure in the sugar beet production system. The trials were established with and without irrigation at both locations. The trials were two-factorial with four genotypes and four harvest dates, carried out in block designs with four replications. Soil and climatic conditions of the trial sites are specified in Table 1. The investigated genotypes were supplied by different breeding companies. The selection comprised different variety types and was expected to represent a broad range with regard to the response to water deficiency. Genotype 1 can be categorized as a high sucrose variety, genotype 2 has been a successful variety over years in Italian sugar beet cultivation and is regarded as drought tolerant, whereas genotype 3 is the putative drought susceptible variety due to specific alterations in the root system. Genotype 4 is a high root yielding variety, also characterized as relatively drought tolerant. The field trials were sown on March 14th in Heuchelheim, and on April 3rd in Wörbzig. After field emergence the trials were manually thinned to a population density of 86,000 plants ha^{-1}. Fertilizer application (N up to a target value of 160 kg ha^{-1}), weed control, pest management and irrigation were carried out according to the local standard. Irrigation was applied five times with a total of 200 mm (Heuchelheim) and 150 mm (Wörbzig) of water. Irrigation measures commenced in the beginning of July at both trial sites.

Table 1

Characteristics of the trial sites
Charakterystyka warunków doświadczalnych

Location Lokalizacja	Altitude (m) Wysokość n.p.m.	Soil texture Struktura gleby	Soil type Typ gleby	Mean annual temperature (°C) Średnia temperatura roczna (°C)		Annual precipitation (mm) Roczna suma opadów (mm)	
				longterm mean średnia długoterminowa	deviation 2003 odchylenie	longterm mean średnia długoterminowa	deviation 2003 odchylenie
Heuchelheim	104	silty loam ił gliniasty	cambisol kambisol	10.3	+1.3	540	-132
Wörbzig	90	silty loam ił gliniasty	chernozem czarnoziem	8.5	+2.1	476	-165

From mid June until the beginning of October, four manual harvests were carried out at five-week intervals. The six-row-plots (21.6 or 24 m²) were core-harvested (10.8 and 12 m², respectively) to avoid neighbourhood effects (Büchse, 1999). The first harvest took place prior to the first irrigation. Up to this time the treatment of both "rainfed" and "irrigated" plots was identical. At harvest the plants were topped, the leaf weight including tops was determined in the field, the beets were washed and taproot yield was determined. Brei samples of the beet material were quick-frozen at -70°C and stored at –26°C until analysis. Soil samples were taken from 0–30, 30–60 and 60–90 cm depth from plots of genotype 1 only. The gravimetric soil water content was determined by drying for 24 h at 105°C.

Using an automated beet brei analyser (Venema, Groningen, NL) sucrose concentration was determined polarimetrically (ICUMSA, 1994), K and Na flame photometrically, and α-amino N fluorometrically (OPA method, Burba and Georgi, 1975/76) from aluminium sulphate clarified filtrates. Betaine and reducing sugars were measured colorimetrically (Storey und Wyn Jones, 1977; Nelson 1944; Somogyi, 1945). Each sample was analyzed in duplicate.

An analysis of variance was carried out with the program SAS version 8.1 (SAS Institute Inc., Cary, NC, USA) using the GLM procedure. Significant results are indicated with *, ** or *** for probabilities of error of $\alpha = 0.05$, 0.01 or 0.001, respectively, whereas n.s. identifies non-significant effects.

RESULTS AND DISCUSSION

Irrigation led to the differentiation in soil water contents. Under rainfed conditions at Wörbzig soil water contents were low during summer, particularly at the second harvest (Fig. 1).

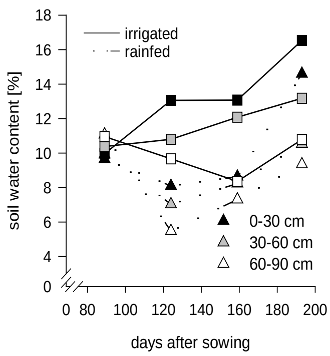

Fig. 1. The content of water in three layers of soil applied for sugar beet cultivation with or without irrigation (Wörbzig, 2003)
Rys. 1. Zawartość wody w trzech warstwach gleby wykorzystanej pod uprawę buraka cukrowego z nawadnianiem lub bez nawadniania (Wörbzig, 2003)

In the irrigated trial, in contrast, soil water content was kept on a relatively high level throughout the season, most notably in the upper soil layers 0–30 and 30–60 cm. Between the third and the final harvest, after rainfall, soil water contents markedly increased in both treatments. The increase in soil water content was clearly reflected by sugar beet growth and quality improvement. The growth of the storage root was reduced under drought, only between the third and the final harvest the increase in root yield was higher under rainfed than under irrigated conditions (Fig. 2 A). Leaf yields decreased under drought (Fig. 2 B) since at high temperatures and insufficient water supply leaf senescence is accelerated and the growth of new leaves restricted (Ehlers, 1996). Under irrigation, plants were able to maintain a closed canopy during summer, only at the end of the vegetation leaf yields decreased. Sucrose concentration constantly increased under irrigation, whereas in the rainfed treatment sucrose concentration was the highest at the second harvest and decreased from that time on (Fig. 2 C). This decrease was probably mainly due to the dilution following higher uptake of water with increasing soil water contents, but leaf regrowth in autumn led to the loss of sucrose in the storage root as well. Also α-amino N concentration in the beet was the highest when soil water content was at the lowest level (Fig. 2 D).

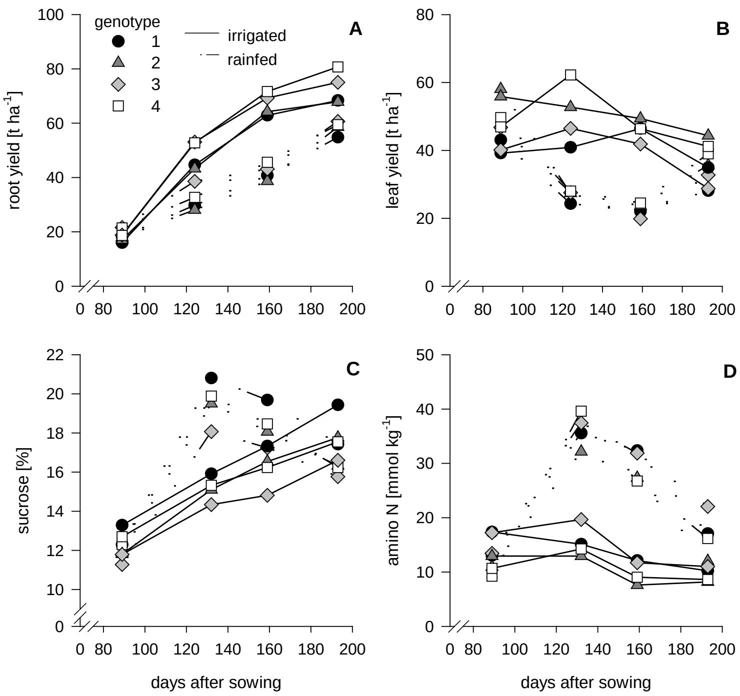

Fig. 2. Yield of roots (A) and leaves (B), and content of sucrose (C) and α-amino N (D) in four sugar beet varieties cultivated under irrigated and rainfed conditions (Wörbzig, 2003)
Rys. 2. Plon korzeni (A) i liści (B) oraz zawartość sacharozy (C) i azotu alfa-aminowego (D) w korzeniach czterech odmian buraka cukrowego, uprawianych z nawadnianiem lub bez nawadniania (Wörbzig, 2003)

High α-amino N concentrations are generally observed under water deficiency (van der Beek and Houtman, 1993) and are attributed to osmotic adjustment (Gzik, 1996) or disorders in the plant nitrogen metabolism (Kevrešan et al., 1997/98).

At the final harvest in autumn it was found that drought had affected almost all parameters under study. On an average for both locations, losses in root yield ranged from 24 to 33% in the different genotypes (Fig. 3).

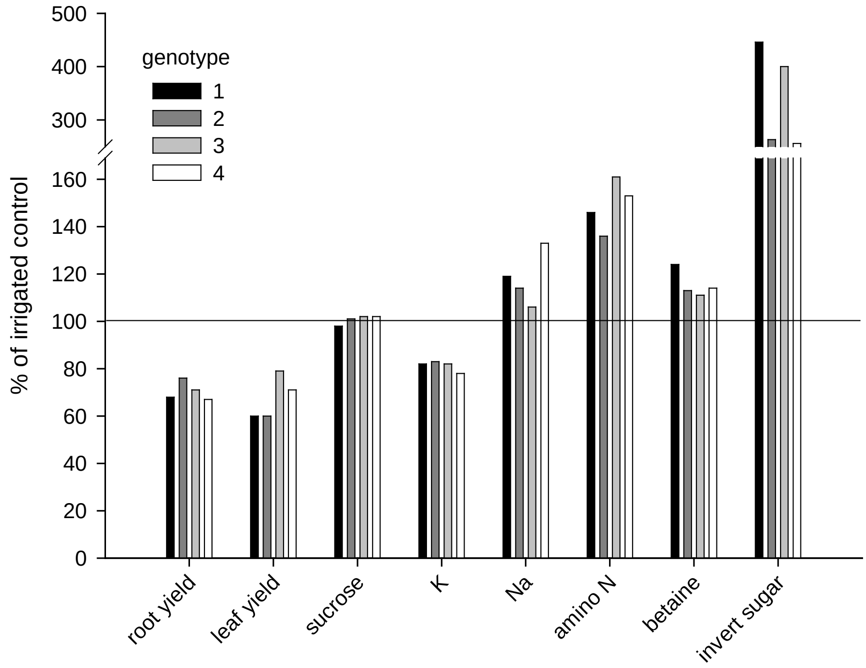

Fig. 3. Yield and quality of four sugar beet genotypes without irrigation as a percentage of the irrigated control (final harvest, mean for two locations in 2003)
Rys. 3. Wielkość i jakość plonu czterech odmian buraka cukrowego w uprawie bez nawadniania, w porównaniu z nawadnianym obiektem kontrolnym (zbiór końcowy, średnia dla dwóch miejscowości, rok 2003)

Similar reductions occurred in the leaf yield. Sucrose concentration was nearly the same under rainfed and irrigated conditions. Among the melassogenic compounds, K concentrations were lower under drought than under irrigation, whereas Na, α-amino N, betaine and invert sugar were accumulated under drought. For most parameters, changes due to drought were similar in different genotypes. Accordingly, analysis of variance of data from the final harvest showed clear effects of genotype and irrigation, but no interaction between these factors was found (Tab. 2).

The evaluation of technical quality in the German sugar factories is based on K, Na and α-amino N only (Buchholz et al., 1995). However, quality parameters, like betaine and inverted sugar, which are not analyzed in the routine process, are also affected by drought, which may lead to a misleading estimations of technical quality of sugar beet after a dry growing season.

Table 2

F-values of the impact of location (L), irrigation (I) and genotype (G) on yield and quality of sugar beet at the final harvest (two locations in 2003)

Wartości F charakteryzujące wpływ miejscowości (M), nawadniania (N) i genotypu (G) na plon i jakośc buraka cukrowego w zbiorze końcowym (dwie lokalizacje, rok 2003)

	Root yield Plon korzeni	Leaf yield Plon liści	Sucrose Sacharoza	K Potas	Na Sód	α-amino N Azot alfa-aminowy	Betaine Betaina	Inverted sugar Cukier inwertowany
Location (L)	2.19	0.5	20.87	0.56	3.21	121.63	0.65	40.6
Miejscowość (M)	n.s.	n.s	***	n.s	n.s	***	n.s	***
Irrigation (I)	36.04	169.24	48.99	11.56	1.1	121.76	47.14	50.54
Nawadnianie (N)	***	***	***	***		***	***	***
L × I	2.97	26.64	8.02	0.01	52.67	2.57	14.04	20.78
M × N	n.s.	***	*	n.s.	***	n.s.	***	***
Genotype	1.25	9.49	8.64	6.48	53.24	9.4	8.48	2.42
Genotyp (G)	n.s.	***	***	***	***	***	***	n.s.
L × G	0.06	0.58	0.01	0.11	2.2	1.11	1.12	2.42
M × G	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
I × G	0.07	2.08	0.04	0.01	0.68	0.06	0.67	1.66
N × G	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
L × I × G	0.02	0.55	0.02	0.14	1.47	0.12	0.59	2.23
M × N × G	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

n.s. — Not significant effect; Wpływ nieistotny

CONCLUSIONS

1. Drought stress during the vegetation period reduced sugar beet yield and increased the concentration of most melassogenic components.
2. During their seasonal development different genotypes responded very similarly to changing soil water contents. Accordingly, at the final harvest an interaction between genotype and irrigation did not occur for any of the parameters under study. Genotypic differences in drought tolerance did not exist.
3. Drought-induced changes in non-conventional quality parameters may result in incorrect evaluation of technical quality.

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