Water use efficiency in sugar beet, subjected to different sowing times and irrigation regimes in a Mediterranean environment

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Abstract

Southern Italy is an important area for sugar beet cultivation. The aim of this research is to measure the capability of sugar beet to convert water in dry matter and sucrose when subjected to two experimental factors: sowing date - autumn (October-December) and spring (March) - and irrigation regime - optimal and reduced (respectively with 100 and 60 % of actual evapotranspiration). Data sets from three experiments of spring sowing and three of autumn sowing were used to calculate water use efficiency of dry matter (WUE_{dm}, plant dry matter yield at harvest vs. seasonal water use ratio) and of sucrose (WUE_{suc}, sucrose yield vs. seasonal water use ratio).

The results indicated comparable WUE_{dm} values for sowing dates and irrigation regimes (on average, 3.08 g of dry matter per kg^{-1} of water used). A better WUE_{suc} was observed in the autumn sugar beet (1.23 vs. 0.88 g of sucrose per kg^{-1} of used water) for a root sugar content higher than in the spring sowing. WUE_{dm} and WUE_{suc} results related to the length of crop cycle expressed in growth degree days and mainly to the length of the period from full cover canopy to harvest, when root dry matter and sucrose accumulation is maximum. The results showed a certain stability of WUE_{dm} and a superiority of WUE_{suc} of autumnal sown beet.

Media summary

Autumn sowing time of sugar beet showed water use efficiency for sucrose yield higher than spring sowing. No difference between irrigation regimes emerged.

Key Words

Sugar beet, water use efficiency, sowing time, irrigation regime, crop cycle length.

Introduction

Sugar beet (*Beta vulgaris* L. *saccharifera*) is a crop cultivated for the production of sucrose. Radiation at higher latitudes (Scott and Jaggard, 1978), water at lower ones (Rizzo *et al*., 1983) restrict its productivity. In Northern Europe the sugar beet cropping areas is from 38? N to 60? N: it is usually sown in spring (March-April), while in the southern areas of Spain, Italy and Greece the beet is sown from October to March, using resistant lines to bolting, with a longer growing period, a lower irrigation requirements and a higher root sugar content.

An efficient water use could be a means of improving water utilisation in a water-limited environment.

In spring sown beet efficiency values for conversion to dry matter (WUE_{dm}) are reported to be between 4.6 and 5.6 g/kg^{-1} of used water (Brown *et al*., 1987). Dunham (1993) reviewed WUE_{dm} values ranging from 2.1 to 10.0 g/kg^{-1} in several environments; in experimental areas with seasonal water use close to Southern Italy conditions (600-900 mm rain), the values ranged from 2.3 to 5.8 g/kg^{-1}. Water use efficiency for sucrose production (WUE_{suc}) ranged from 0.7 to 1.6 g/kg^{-1} in spring sown beet (Cassel and Bauer, 1976), from 1.1 to 2.5 g/kg^{-1} in the locations with 600-900 mm of seasonal water use (Dunham, 1993). Ehlig and LeMert (1979) in autumnal sugar beet in USA reported WUE_{suc} values of 1.4-2.0 g/kg^{-1}.

The aim of this study is to evaluate, in a hot environment of Southern Italy, the effects of two sowing times - autumn and spring - and two levels of irrigation water application - optimal and reduced - on the efficiency of the sugar beet in using water in dry matter and sucrose transformation.

Methods

The experimental data used in this study were gathered at Foggia (lat. 41? 27" N; long. 15? 35" E, alt. 90 m a.s.l.) in Southern Italy, during the 1998-2002 period. The soil is a vertisol of alluvial origin (Typic Chromoxerert, fine, termic, according to the Soil Taxonomy-USDA), silty-clay (field capacity water content 0.396 m^3/m^{-3}; permanent wilting point water content 0.195 m^3/m^{-3}, available soil water 202 mm/m^{-1}). The climate is "accentuated thermomediterranean", with temperatures below 0 ?C in the winter and above 40 ?C in the summer. Annual rainfall (mean 550 mm) is mostly concentrated to the winter months.

Sugar beet was sown in the autumn (AU) and spring (SP) and submitted to two irrigation treatments, optimal (OPT) and reduced (RED). The OPT treatment was irrigated with 60 mm and the RED one with 36 mm, when the cumulated ETc (Penman-Monteith model by crop coefficients, Allen *et al.* 1998) reached 60 mm. To ensure uniform water distribution, a drip irrigation system was used.

A randomised block design with three replications was used; the usual crop management for sugar beet was adopted, with a plant population of 100,000 plants ha^{-1}, a nitrogen fertiliser application of 50-100 kg ha^{-1}, a pre-sowing application of mineral perphosphate with 61-88 kg/ha^{-1} of Phosphorus.

At harvest (end of July for AU and end of August for SP), the total plant dry matter was determined after drying at 80 ?C for 48 hours. Sucrose content (%) was measured with a polarimeter after extraction of sugar from the pulp with lead acetate. Sucrose yield (t ha^{-1}) was calculated by multiplying fresh root yield and sucrose content.

Seasonal water use (WU) was estimated according to the following water balance equation: WU = ?ΔU + R + I - D (1) where “ΔU” is the variation, between seeding and harvest date, of the volumetric soil water content in the 0-0.6 m depth layer, measured with the gravimetric method, “R” is the rainfall, “I” the irrigation during the beet crop cycle and “D” the water lost to deep percolation, all expressed in mm.

The water use efficiency (g kg^{-1}) was calculated as the ratio between the total plant dry matter at harvest (WUE_{dm}) or sucrose yield (WUE_{suc}) and seasonal water use (WU), estimated with equation (1).

Growth degree days (GDD) were calculate daily and cumulated from emergence to full canopy cover date (FCC) and from FCC to harvest, using a base temperature of + 3 ?C (Milford et al., 1985).

Results

Irrigation amount differed between the two sowing times and, obviously, between the two irrigation regimes (Table 1). The seasonal water use (WU) was shown to be higher in the OPT than in the RED regime (597 vs. 520 mm), mainly due to the higher seasonal irrigation application (404 vs. 281 mm). There was no significant difference in seasonal water use between sowing date treatments. The water lost as deep percolation (drainage) was greater in AU than in SP: it was mainly generated by rainfall following the irrigation applications (in spring and autumnal sown) and by winter rainfall.

The productivity in terms of total dry matter was similar for the two sowing times (Table 2). A significantly larger sucrose concentration (%) in the autumnal crop was observed (15.1 vs. 12.5 %), resulting in a larger production of sucrose (6.97 vs. 4.94 t/ha^{-1}).

There was equivalence between the two sowing times in terms WUE_{dm}, with an average value of 3.08 g/kg^{-1}. Considering, however, the reduced seasonal irrigation water of the AU crop, a better irrigation water use efficiency was evident in the AU crop. WUE_{dm} was not affected by irrigation regimes (3.15 vs. 3.03 g/kg^{-1}, on average for OPT and RED).

WUE_{suc} average values were in accordance with the values reported by Tariq and Aziz (1982), Ghariani (1981) and Howell *et al.* (1987) for sugar beet cropped in clay loam soils. A significant superiority of WUE_{suc} clearly emerged in the autumnal beet, while WUE_{suc} did not differ significantly between the two irrigation regimes (1.12 vs. 1.00 g of sucrose /kg^{-1}, for OPT and RED, respectively).

A significant correlation was observed between both WUE_{dm} and WUE_{suc} vs. crop cycle length expressed in GDD from emergence to harvest (r = 0.80; r = 0.89, respectively). In particular, the duration of period from FCC to harvest, showed a significant linear and positive relationship with WUE_{dm} and WUE_{suc}

(Figure 1).

Table 1. Water balance components in the six experiments on sugar beet (0-0.6 m soil depth).

Spring sowing time

	1999		**2000**		**2001**	
	Optimal	**Reduced**	**Optimal**	**Reduced**	**Optimal**	**Reduced**
Seasonal irrigation water applied	459	313	560	364	390	270
Rainfall	204	204	119	119	211	211
Soil moisture variation	47	39	88	86	-31	-29
Drainage	100	0	72	0	0	0
Seasonal water use	610	556	693	571	570	452
ETo (Penman-Monteith)	807	807	866	866	886	886

Autumnal sowing time

	1998		**2001**		**2002**	
	Optimal	**Reduced**	**Optimal**	**Reduced**	**Optimal**	**Reduced**
Seasonal irrigation water applied	303	249	360	248	346	232
Rainfall	276	276	342	342	442	442
Soil moisture variation	-5	18	36	35	-115	-103

Drainage	78	78	85	37	114	82
Seasonal water use	496	465	653	588	559	489
ETo (Penman-Monteith)	843	843	1062	1062	787	787

Table 2. Water use efficiency for total dry matter (WUE_{dm}) and sucrose production (WUE_{suc}) in sugar beet, subjected to two sowing times and two irrigation regimes (mean values of 3 years and 3 reps and ? 1 standard deviation).

Sowing time	Irrigation regime	Total plant dry matter (t/ha^{-1})	WUE_{dm} (g/kg^{-1})	Sucrose yield (t/ha^{-1})	WUE_{suc} (g/kg^{-1})
Spring	Optimal	18.65 ? 3.55	3.07 ? 0.64	5.54 ? 1.36	0.92 ? 0.28
	Reduced	16.03 ? 1.63	3.09 ? 0.15	4.34 ? 0.53	0.84 ? 0.07
	Avg.	*17.34 ? 3.00*	*3.08 ? 0.45*	*4.94 ? 1.17*	*0.88 ? 0.20*
Autumnal	Optimal	18.76 ? 4.92	3.23 ? 0.58	7.72 ? 3.10	1.31 ? 0.34
	Reduced	16.07 ? 3.50	2.96 ? 0.53	6.23 ? 1.20	1.15 ? 0.19
	Avg.	*17.42 ? 4.39*	*3.09 ? 0.56*	*6.97 ? 2.41*	*1.23 ? 0.31*

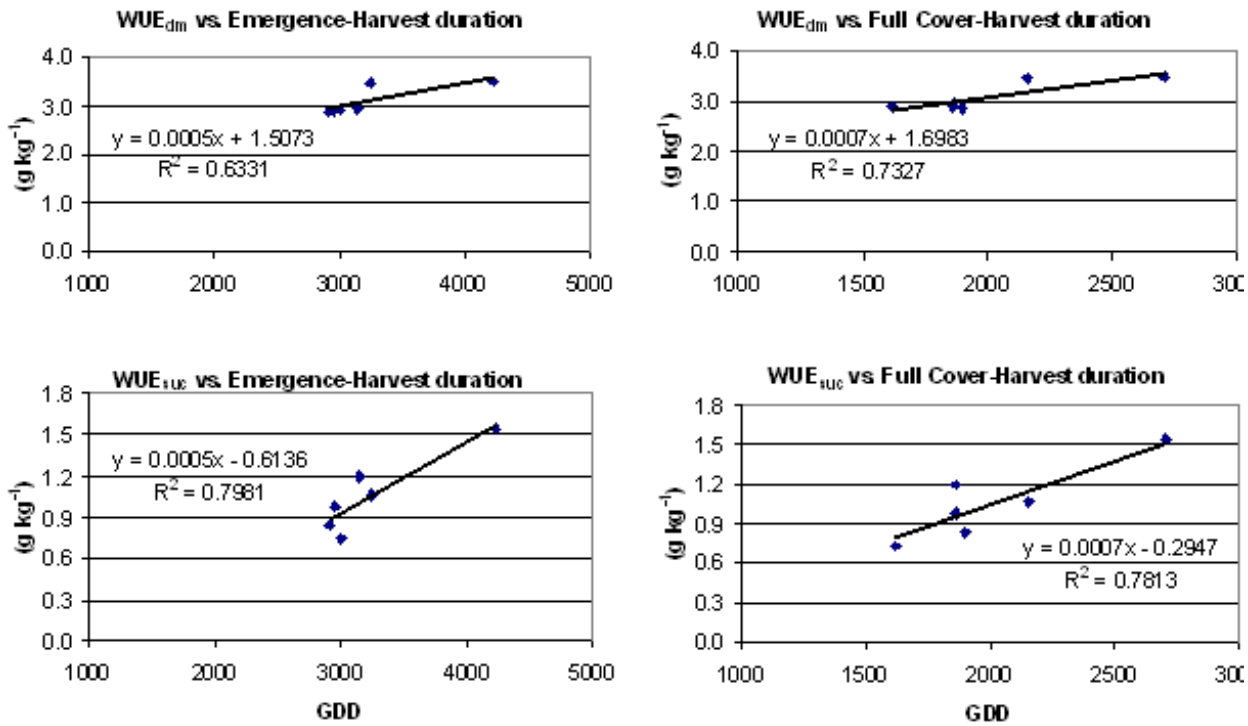

Figure 1. Relationships between water use efficiency for total dry matter (WUE_{dm}), water use efficiency for sucrose yield (WUE_{suc}) and length of emergence-full cover canopy and full cover canopy-harvest periods, expressed in GDD from emergence (T base = + 3 ?C).

Discussion

The autumn-sown (AU) beet yielded more than 50% of SP of sucrose and this can be attributed to the period from canopy closure to harvest, during which dry matter is translocated and accumulated in roots, longer in AU than in SP. Timing of full leaf cover with the occurrence of maximum radiation receipts is an important consideration in temperate climates: initially almost all the dry matter accumulated is located in the leaves, only in the following period the root storage organ becomes the main sink (Drycott and Webb, 1971).

On the other hand, is not possible to further delay the harvest date of SP beet because it is difficult, from an economic point of view, to ensure an adequate water supply to the crop during summer months. The high temperatures during July and August (up to 40-42 ?C), do not allow maintenance of leaf turgor especially in the midday hours, even in well-watered conditions. Another negative aspect of spring sugar beet in warm environments, is a greater transpiration rate after irrigation or rainfall, resulting in a reduction in sugar accumulation (Rinaldi *et al*., 2003).

The sucrose yield was greater in the OPT regime than in the RED treatment and this can mainly be attributed to the greater water availability.

Conclusion

The six data sets (3 for AU and 3 for SP sugar beet) showed a substantial parity among the sowing times for the WUE_{dm}. The sugar beet sown in autumn showed improved WUE_{suc}, because of its higher sugar content. WUE_{dm} and WUE_{suc} did not differ significantly between the two irrigation regimes.

The relationships found for water use efficiencies and crop cycle duration indicated the importance of autumnal sowing in environments with low-risk of winter frost and droughty springs and summer. This explains the efforts of researchers to select sugar beet lines with frost and bolting resistance characters.

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