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Potassium Efficiency of Wheat and Sugar Beet Evaluated Under Field Conditions

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Abstract: This study was conducted to investigate the potassium (K) efficiency of wheat and sugar beet under field conditions and to identify the varying mechanisms or factors behind their efficiency. Data were obtained from a long term fertilizer experiment, on a K "fixing" sandy clay loam in Bavaria, southern Germany, in which K fertilization rates varied from 0 to 1000 kg K ha^{-1} $year^{-1}$ with the last K application in 1986. In 2003, sugar beet and spring wheat were sown on March 13th and April 4th, respectively. At 4 and 5 harvests for wheat and sugar beet, respectively, random samples of shoots, roots and soil of each species from the unfertilized (-K) and the highest fertilizer level of 1000 kg K ha^{-1} (+K) treatments were analyzed. Sugar beet and wheat had similar K efficiency producing 76 % and 80 % beet and grain yield on unfertilized compared with fertilized treatments, respectively. As compared to wheat, sugar beet had a higher internal K requirement, two times higher shoot growth rate (GRs), 34% to 48 % of the wheat root length (RL), and consequently a larger GR/RL, that is higher demand for K uptake on the roots. However, sugar beet showed an exceptionally high uptake efficiency of the single roots or influx, which was 5 times higher in unfertilized treatments, as compared with wheat. Wheat K efficiency was attributed to a higher utilization efficiency or lower internal requirement, slow growing shoots and a large root system. Further investigations are necessary to study the mechanism by which sugar beet was able to achieve a higher influx than wheat.

Key words: Sugar beet; wheat; nutrient efficiency; potassium

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INTRODUCTION

Nutrient element efficient plant species are those which grow and yield well on soils of low fertility than inefficient species (Gouerly *et al.* 1994; Fageria *et al*. 2001). Plant species and even genotypes within a species differ in their K efficiency (Bhadoria *et al*. 2004). According to Sauerbeck and Helal (1990) nutrient efficiency is defined as plant yield per unit of nutrient supply i.e. it depends on two interrelated groups of plant factors. These are a) plant properties related to the uptake efficiency, which is nutrient uptake relative to its supply, and b) factors related to utilization efficiency, representing plant yield relative to nutrient uptake. Plant factors related to uptake efficiency are a) morphological root characteristics such as size of root system and root hairs. A large root system to satisfy shoot nutrient requirement is beneficial for nutrient efficiency, as it means less nutrient uptake effort per unit root and allows for exploitation of a larger soil volume for nutrients (Steingrobe and Claassen 2000). Higher root length-shoot weight ratios are reported under deficiency of different macro and micro nutrients (Cakmak *et al*. 1997; Jungk and Claassen 1997).

The other uptake efficiency component is root physiological activity such as different uptake kinetics, which result in different uptake rates or influx (Steingrobe and Claassen 2000), and ability to chemically change the rhizosphere to improve the availability of nutrients (Sattelmacher *et al*. 1994; Rengel *et al*. 1998). Wheat (*Triticum aestivum* L.) would be expected to be K efficient because of a large root system (Claassen 1994; Steingrobe and Claassen 2000) and low K internal requirement (2.9%-3.9 %) for maximum yield (Bergmann 1993). Sugar beet (*Beta vulgaris* L.), on the other hand, has a much smaller root system and higher (3.5%-6.0 %) internal K requirement (Bergmann 1993), nevertheless, in a pot experiment, sugar beet proved to have an extremely high uptake efficiency (El Dessougi *et al*. 2002).

The objectives of this study were (i) to investigate the K efficiency of wheat and sugar beet under field conditions on a low K supplying (K fixing) soil, and (ii) to identify mechanisms and factors responsible for differences in K efficiency of wheat and sugar beet.

MATERIALS AND METHODS

A field experiment was conducted in Bavaria in southern Germany, on a sandy clay loam with a high K fixing capacity having 33 % clay, 31 % silt, 3.8 % organic C and pH 7.2. It was conducted on the site of a long term fertilizer experiment which started in 1976 and ended in 1986; thereafter, all plots received no K fertilizer. The studied plants were from the unfertilized treatments (NH_4-OAc exchangeable K (K_{exch}) 782 µmol K kg^{-1} soil, soil solution concentration (C_{Li}) 4.2 µM), and from the highest fertilizer level of 1000 kg K ha^{-1} a^{-1} ($K_{exch.}$ 1047 µmol K kg^{-1} soil, C_{Li} 7.5 µM). The values of soil analysis given here were obtained 6 months before executing the experiment. In 2003, spring wheat cv. Star, and sugar beet cv. Kawetina were sown on 50 m^2 plots on March 13th and April 4th 2003, respectively. Before sowing, 80 kg N ha^{-1} were applied to the soil in the form of ammonium sulphate and ammonium nitrate (40 kg N from each fertilizer) and 43 kg P as super-phosphate. Harvests were carried out on 27th May, 24th June, 8th July and 5th August for both crops and on 7th October for sugar beet. At each harvest date, 3 sub-samples of plants, roots and soil were taken from random areas of each plot.

Shoots

Every sample for wheat was harvested from an area of 0.5 m^2 per treatment. The plants were separated into straw and ears after flowering. Samples from an area of 1.5 m^2 were harvested for sugar beet, and plant analysis was carried out on the leaves and the roots separately. After fresh weight determination, the dry weight was determined by drying representative samples at 105°C till constant weight. The samples were then finely ground and sub-samples were wet digested in a concentrated tri acid mixture ($HN0_3$, $HCLO_4$ and H_2SO_4 in a volumetric ratio of 8:2:1, respectively). Potassium concentration was determined by flame photometry.

Root sampling and samples preparation

Roots were sampled from the same plots as the shoot samples using a hand auger with 8 cm diameter (Boehm 1979). The sampling was carried out in the 0-15, 15-30, 30-60 cm soil layers. The 60-90 cm layer was sampled only at the final harvest, since it generally contains few roots and

K concentration of the soil solution was very low and as such did not contribute much to plants K nutrition. The samples consisted of a mixture of two soil cores, 1 in and 1 between the rows of wheat and 4 soil cores in and between the raw for sugar beet. The cores were soaked in water overnight and the roots washed out carefully over a 0.2 mm sieve. The water remaining on the roots was removed by a 10 minute centrifugation at 1200 rev. min^{-1}. After determining the root fresh weight, the root length was measured on representative sub-samples. The sub-samples of wheat were kept in a 20 % ethanol solution and those of sugar beet in a 20 % ethanol and 0.01 mM citric acid mixture at 4 ^{o}C. The root length was measured using a line intersection method (Tennant 1975).

Shoot growth rate (GR_s)

The shoot growth rate was calculated using the following equation:

$$GRs = \frac{SW2-SW1}{t2-t1} \qquad [1]$$

where:
SW = shoot dry weight (g), t = time (s), the indices 1 and 2 represent the first and second harvest.

Shoot growth rate in relation to root length (GRs/RL)

This ratio is related to the K acquisition load on roots imposed by the shoot growth. It is calculated by dividing the shoot growth rate (GR_s) by the average root length (RL).

$$\frac{GRs}{RL} = \frac{SW2-SW1}{t2-t1} \times \frac{2}{RL1+RL2} \qquad [2]$$

Influx (In)

The influx is the net amount of a nutrient element taken up per unit root length or root surface area and time. A direct measurement of the influx is not possible; therefore, only an average influx can be calculated for a given time period. For calculating the influx, at least two harvests are needed in which the nutrient content and root length of the plants are known. Assuming linear root growth by plants growing in the field, the influx was calculated as

$$\text{In} = \frac{U2 - U1}{t2 - t1} \times \frac{2}{RL1 + R2} \qquad [3]$$

where
U = nutrient element content in the shoot (mol), RL = root length (cm), time (s), the indices 1 and 2 represent the first and second harvest.

Soil Analysis
Soil solution: The soil solution was obtained by a modified displacement technique of Adams (1974), whereby a 250 ml cylinder with a filter paper covering an opening at the bottom, was filled with moist soil collected from the field. Using a peristaltic pump, water was allowed to drop slowly on the top, displacing the soil solution downwards, where it is collected in acid-washed glass beakers. The K concentrations were determined by flame photometry.

Exchangeable potassium, pH and water content: One gramme of field moist soil was weighed in a filter paper placed in a funnel. The soil was extracted 5 times with 10 ml 1 M NH40Ac solution (pH 7) at 15 minutes intervals. The K concentration in the extraction solution was determined by flame photometry. The pH was measured in 0.01 M $CaCl_2$ in a 1: 2.5 soil: solution ratio. Soil samples were dried at 105°C to constant weight, and the gravimetric water content was determined.

Statistical Analysis
The data were subjected to analysis of variance, and mean separation was conducted using the Tukey test.

RESULTS

Potassium concentration (C_{Li}) in soil solution and exchangeable K (K exch)
Generally, the K concentration of soil solution decreased with increasing soil depth. Under both crops, the K concentration of soil solution was relatively low and was lower under wheat than under sugar beet (Table 1). The mean values of exchangeable potassium, over the whole growth period and soil depths under sugar beet, were 973 and 670 umol kg^{-1} soil with and without fertilization, respectively. The respective values under wheat were 803 and 625 µmol kg^{-1} soil. The exchangeable K decreased with increasing soil depth under both crops (Table 2).

Table1. Potassium concentration in soil solution at different soil depths (0-90 cm) under sugar beet and wheat grown on a sandy clay loam in the field over the whole growth period

Crop	Month	Soil depth (cm)							
		0-15	15-30	30-60	60-90	0-15	15-30	30-60	60-90
		K concentration in soil solution µmol L^{-1}							
		-K (since 1976)				+K (1976-1986)			
Sugar beet	27/5	10.4a*	9.99a*	5.12a		23.3a	18.0b	7.03c	
		(1.2)	(1.5)	(0.8)		(0.6)	(0.7)	(0.9)	
	24/6	4.54a*	1.43b*	1.79b		4.3a	6.30b	1.98c	
		(0.2)	(0.2)	(0.5)		(0.8)	(0.5)	(0.2)	
	8/7	4.06a*	.02a*	2.54a		7.67a	5.13b	2.71c	
		(0.3)	(0.3)	(0.2)		(0.2)	(0.4)	(0.1)	
	5/8	3.56a*	2.90ab*	2.31ab*	1.44b	6.73a	5.80a	4.64	1.97
		(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(1.1)	(0.4)
	7/10	2.50a*	2.48a*	1.83a*		7.86a	4.54 b	3.13c	
		(0.3)	(0.3)	(0.01)		(0.7)	(0.3)	(0.01)	

Table 1. Cont.

Crop	Month	Soil depth (cm)							
		0-15	15-30	30-60	60-90	0-15	15-30	30-60	60-90
		K concentration in soil solution µmol L^{-1}							
		-K (since 1976)				+K (1976-1986)			
Wheat	27/5	6.45a	3.63b	1.12b*		7.05a	3.98b	3.27c	
		(0.6)	(0.1)	(0.1)		(0.2)	(0.4)	(0.3)	
	24/6	2.48a	2.19a	2.56a		4.12a	2.58a	2.39a	
		(0.2)	(0.2)	(0.1)		(0.4)	(0.1)	(0.4)	
	8/7	4.11a	3.44a	2.81ab	1.90 b	4.92a	3.62a	2.70ab	2.09 b
		(0.1)	(0.7)	(0.5)	(0.7)	(0.1)	(0.2)	(0.2)	(0.5)
	5/8	4.80a	2.43b*	2.79b*		6.25a	4.21a	3.85a	
		(0.2)	(0.1)	(0.1)		(0.6)	(0.1)	(0.5)	

Within treatments, specific dates and soil depths, values followed by different letters are significantly different, after Tukey ($P<0.05$).

*Significant differences ($P<0.05$) between treatments and within similar soil depths, after Tukey

Values between brackets represent the standard error of means.

Table 2: Exchangeable K at different soil depths (0-90 cm) under sugar beet and wheat grown on a sandy clay loam in the field over the whole growth period

Crop	Month	Soil depth (cm)							
		0-15	15-30	30-60	60-90	0-15	15-30	30-60	60-90
		Exchangeable K concentration µmol kg^{-1} soil							
		-K (since 1976)				+K (1976-1986)			
Sugar beet	27/5	351a*	1056b	999b		1609a	1477a	1053a	
		(26)	(27)	(47)		(52)	(142)	(140)	
	24/6	941a*	674b*	350c*		1396a	1216a	388a	
		(37)	(9)	(28)		(36)	(62)	(9)	
	8/7	574a*	505a*	166b		1027a	773a	191b	
		(9)	(29)	(29)		(73)	(29)	(0.1)	
	5/8	962a*	940ab	560b	440b	1258a	1253a	562b	498b
		(26)	(173)	(10)	(37)	(35)	(55)	(17)	(11)
	7/10	75a*	573a*	234b*		1243a	760ab	381b*	
		(25)	(17)	(16)		(218)	(8)	(21)	

Table 2. Cont.

Crop	Month	Soil depth (cm)							
		0-15	15-30	30-60	60-90	0-15	15-30	30-60	60-90
		Exchangeable K concentration µmol kg^{-1} soil							
		-K (since 1976)				+K (1976-1986)			
Wheat	27/5	1177a*	1031b*	730c		1601a	1160b	851b	
		(8)	(8)	(18)		(170)	(25)	(46)	
	24/6	600a*	579a	484 a*		832a	398b	264b	
		(27)	(9)	(18)		(18)	(44)	(27)	
	8/7	609a	402b*	175c*	147d*	745a	306b	208bc	177c
		(0.1)	(18)	(39)	(18)	(93)	(9)	(38)	(35)
	5/8	737a*	554ab*	427b		1204a	844b	461c	
		(53)	(64)	(29)		(81)	(25)	(29)	

Within treatments, specific dates and soil depths, values followed by different letters are significantly different after, Tukey test (P< 0.05).

*Significant differences (P< 0.05) between treatments and within similar soil depths, after Tukey test.

Values between brackets represent the standard error of means.

Relative and absolute dry matter yield

Figure 1 shows the dry matter yield of wheat leaves and straw and sugar beet leaves with and without fertilization at the different harvests. Except for May, fertilization increased the dry matter yield of wheat leaves or straw significantly (P< 0.05). On the other hand, no significant differences were detected for dry matter yield of grains between fertilized and unfertilized treatments (Fig. 1). Over the whole growth period, there were no significant differences between dry matter yield of sugar beet leaves on fertilized and unfertilized plots. However, in August and October leaf weight of the unfertilized treatments tended to be higher than that on the fertilized ones (Fig. 1). Beet dry matter yield, though, was significantly (P< 0.05) increased by K fertilization (Fig. 1). The dry matter yields of grains and beet of unfertilized relative to fertilized treatments did not differ greatly between species, (81 % for wheat and 76 % for sugar beet).

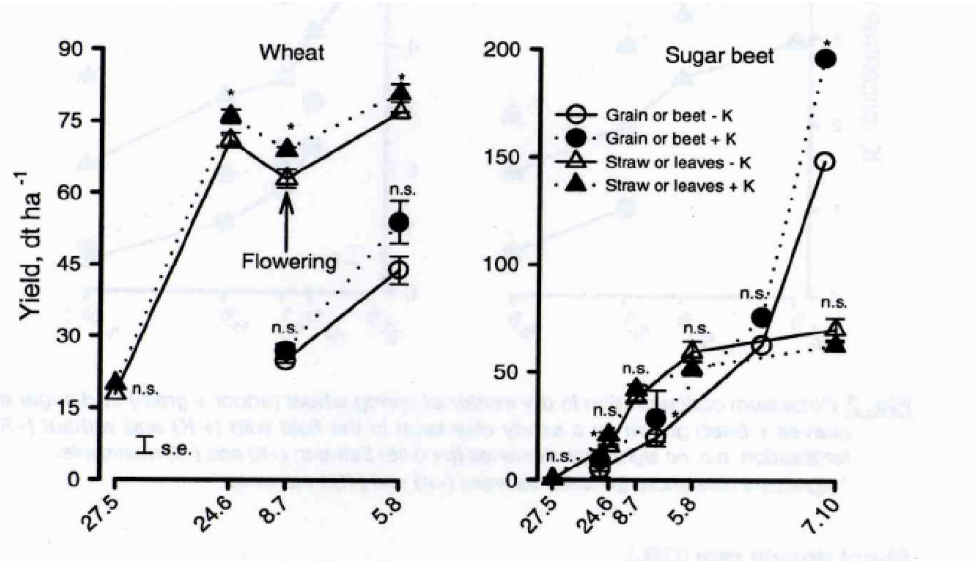

Fig. 1: Dry matter yield of spring wheat (leaves and straw + grains) and sugar beet (leaves + beet) grown on a sandy clay loam in the field with +K and without (-K) K fertilization. n.s. no significant difference (P<0.05) between +K and -K treatments. *Significant differences (P<0.05) between +K and -K treatments.

Potassium concentration in shoots

To assess the nutritional status of the plants, K concentration in dry matter was measured (Fig. 2). Potassium concentration in dry matter of wheat shoot ranged between 2.07 % and 3.79 % on fertilized and 1.42 % and 2.96 % on unfertilized treatments. The respective values for sugar beet leaves were 3.46 % and 6.55 % and 2.05 % and 5.28 %. Both crops had deficient K levels on unfertilized treatments. The effect of K fertilization was significant (P< 0.05) for both crops. The K concentration in grains started in July with 1 % and decreased to around 0.5 % at the final harvest. Differences between +K and -K were small, but at final harvest were significant with a tendency of the +K to show a lower K concentration. Potassium concentration of beets started in June with about 2.7% and decreased to about 0.5 % at final harvest. The +K plot always showed significantly higher K concentration (Fig. 2).

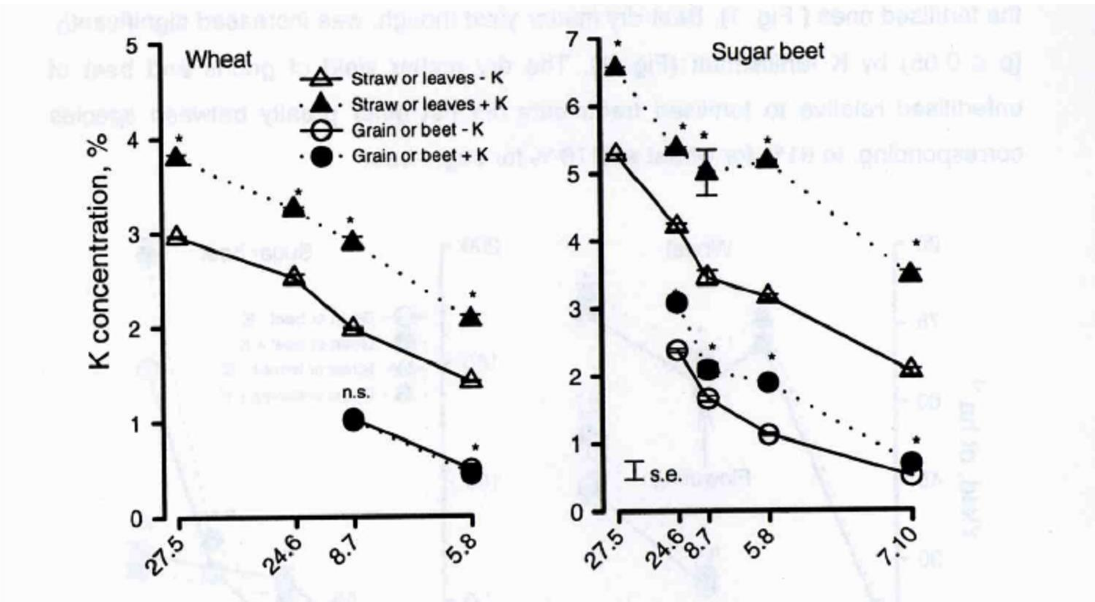

Fig. 2: Potassium concentration in dry matter of spring wheat (shoot + grain) and sugar beet (leaves + beet) grown on a sandy clay loam in the field with +K and without (-K) K fertilization. n.s. no significant difference (P<0.05) between +K and -K treatments. *Significant differences (P<0.05) between +K and -K treatments.

Shoot growth rate (GRs)

Figure 3 shows the GRs of wheat and sugar beet with +K and without -K fertilization over the different growth periods. Except for the growth period 27.5-24.6, sugar beet had 2 times higher shoot growth rate than wheat, in the growth periods 24.6-8.7 and 8.7-5.8. Wheat had generally lower, though statistically not significant, GRs on unfertilized as compared with fertilized treatments. The effect of K was largest on the GRs of sugar beet late in the season due to beet root growth.

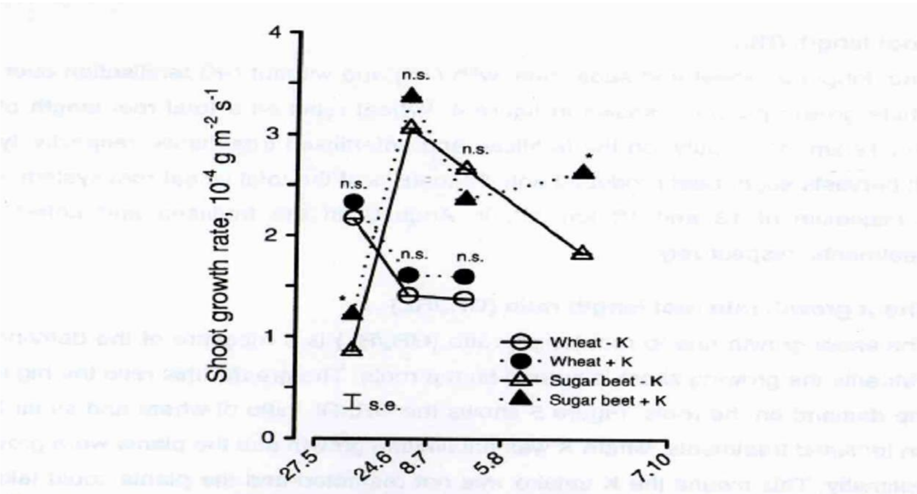

Fig. 3: Shoot growth rate of spring wheat (shoot + grains) and sugar beet (leaves + beet) at different growth stages on a sandy clay loam in the field with +K and without (-K) K fertilization. n.s. no significant difference ($P<0.05$) between +K and -K treatments. *Significant differences ($P<0.05$) between +K and -K treatments.

Root length (RL)

Figure 4 shows the root length of wheat and sugar beet with +K and without -K fertilization over the whole growth period. Wheat reached a total root length of 21 and 19 km m^{-2} in July in the fertilized and unfertilized treatments, respectively. At all harvests, sugar beet produced only 34% to 48 % of the total wheat root system, with a maximum of 13 and 10 km m^{-2} in August in the fertilized and unfertilized treatments, respectively.

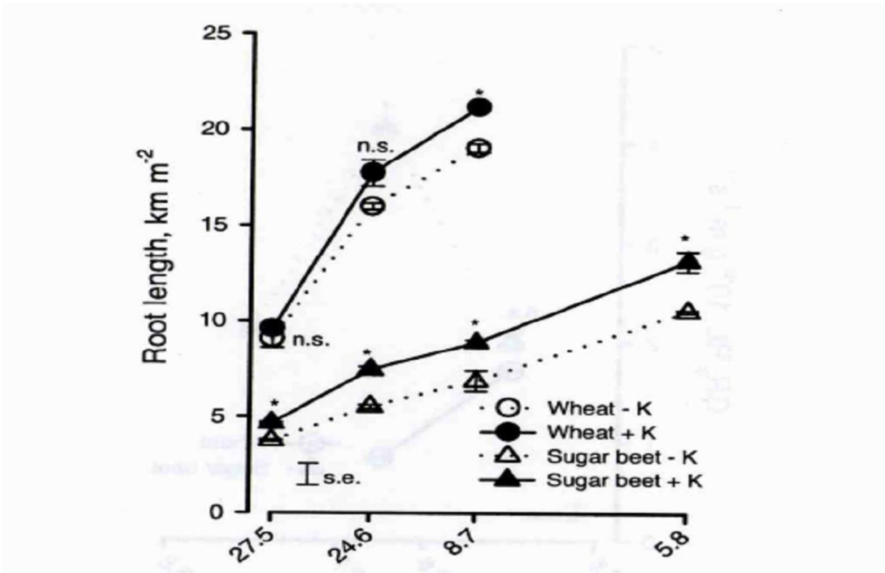

Fig. 4: Root length of spring wheat and sugar beet in a soil depth 0-90 cm grown on a sandy clay loam in the field with +K and without (-K) K fertilization. n.s.: no significant difference (P<0.05) between +K and -K treatments. *Significant differences (P<0.05) between +K and -K treatments.

Shoot growth rate: root length ratio (GRs/RL)

The shoot growth rate to root length ratio is a measure of the demand for nutrients the growing shoot is putting on the roots. The greater this ratio the higher is the demand on the roots. Figure 5 shows the GRs/RL ratio of wheat and sugar beet in fertilized treatments, where K was not limiting growth and the plants were growing optimally. This means that the K uptake was not restricted and the plants could take up enough K to meet their requirement, which represents the K demand to be met by the roots. A direct comparison between the crops for nutrient demand is difficult, since at the various growing periods the plants were at different growth stages. However, the highest value for sugar beet was more than twice that of wheat.

Total K uptake

Total K uptake in the dry matter is a measure of the ability of plants to acquire K from the soil and accumulate it in the shoots. It is the product of dry matter yield and K concentration in dry matter. Differences of K concentration in plants and of dry matter production resulted in two times higher total K uptake of sugar beet in comparison to wheat in both fertilized and unfertilized plots (Fig. 6). The K uptake followed a similar pattern for both crops; being low at the early growth stages and increasing with time reaching a maximum of 151 and 227 kg ha^{-1} in July with and without fertilization, respectively, for wheat; thereafter, no net uptake took place. Sugar beet with a maximum of 259 and 412 kg ha^{-1} in unfertilized and fertilized treatments in August had a 70%-80 % higher total K uptake than wheat. However, the highest value for sugar beet was more than twice that of wheat, which is to be expected because of its faster growing shoots (Fig. 3) and smaller root system (Fig. 4).

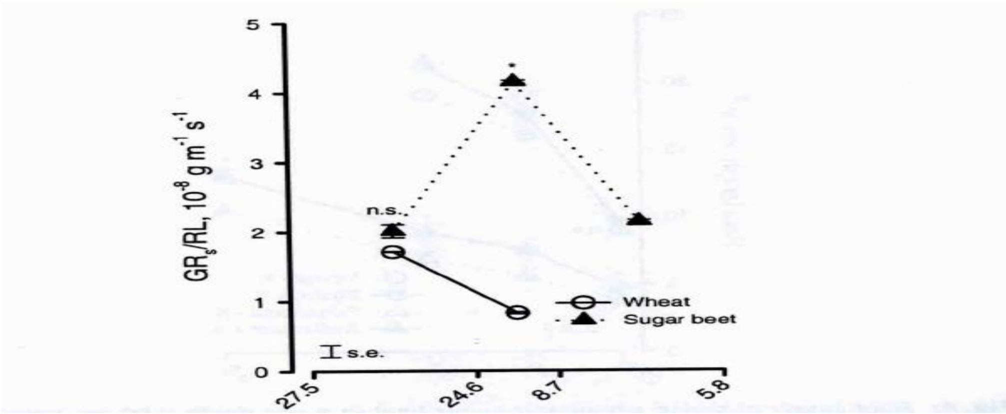

Fig. 5: Shoot growth rate (GRs) in relation to root length (RL) of spring wheat and sugar beet grown on a sandy clay loam at optimum K fertilization. n.s.: no significant difference (P<0.05) between plant species. *Significant differences (P<0.05) between plant species.

K influx

The influx is a measure of the physiological capacity of the roots to extract K from soil. The influx increased with plant age from 25 x 10^{-14} mol cm^{-1} s^{-1} and 34 x 10^{-14} mol cm^{-1} s^{-1}, in the growth period 27.5-24.6, to a maximum of 53 x 10^{-14} mol cm^{-1} s^{-1}, and 56 x 10^{-14} mol cm^{-1} s^{-1}, in 24.6-8.7, for sugar beet fertilized and unfertilized treatments, respectively, then decreased for both treatments (Fig. 7). As compared to wheat, these values are 2 folds higher influx in the growth period 27.5-24.6, in both treatments, and 10 and 8 times higher influx in the unfertilized and fertilized treatments, respectively, in the growth period 24.6-8.7, (Fig. 7). The highest influx for wheat was 13 x 10^{-14} mol cm^{-1} s^{-1} with fertilization and 17 x 10^{-14} mol cm^{-1} s^{-1} without fertilization.

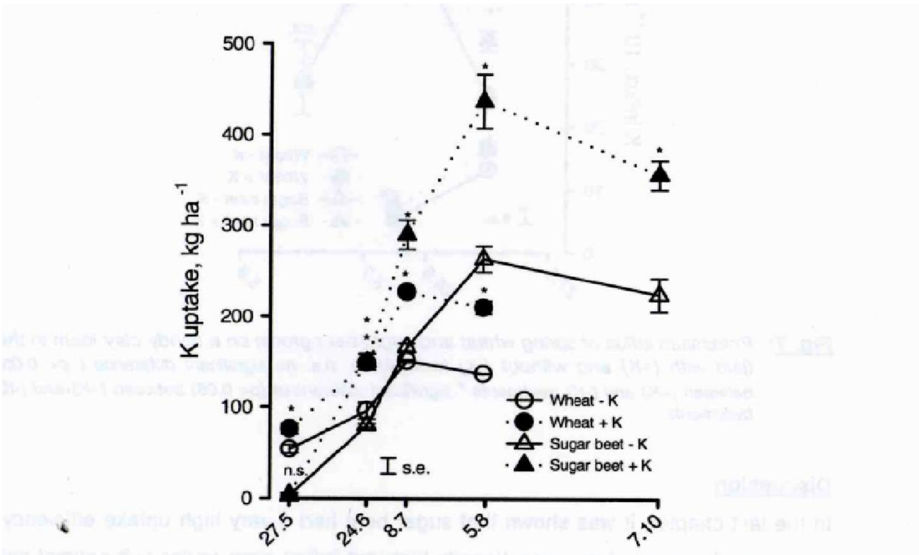

Fig. 6: Total K uptake of spring wheat and sugar beet grown on a sandy clay loam in the field with +K and without (-K) K fertilization. n.s.: no significant difference (P<0.05) between +K and -K treatments. *Significant differences (P<0.05) between +K and -K treatments.

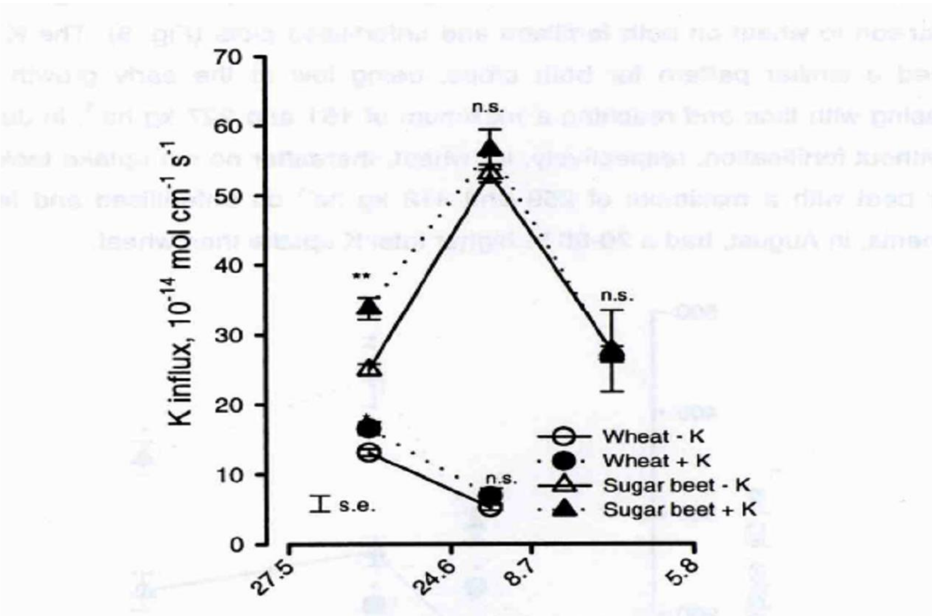

Fig. 7: Potassium influx of spring wheat and sugar beet grown on a sandy clay loam in the field with +K and without (-K) K fertilization. n.s.: no significant difference ($P<0.05$) between +K and -K treatments. *Significant differences ($P<0.05$) between +K and -K treatments.

DISCUSSION

Regarding the relative yield, sugar beet was as K efficient as wheat, producing up to 76 % of the beet yield without fertilization relative to fertilized yield. These findings contrast with those of Claassen (1994) who concluded from a field experiment, that sugar beet is less K efficient than wheat, since it obtained only 80 % relative yield, whereas wheat had 100 % relative yield. The results are in partial agreement with those of Kuhlmann (1983) who, regardless of the K content in soil or plant, did not detect any significant increase in grain yield of wheat due to varying fertilization levels, but beet yield was increased significantly. The fact that the dry matter yield of sugar beet leaves on unfertilized treatments, tended to be higher than that on fertilized ones could be explained by the role played by K in the rate of mass flow-driven solute transport in the sieve tubes. The transport rates of the photosynthates from source to sink are much lower in K-deficient, than in K-sufficient plants (Marschner 1995). Hence, the slower transport of the photosynthesis products leads to their accumulation in the leaves, and thus the observed increase in leaves yield in the K deficient plants.

On the other hand, the grain yield of wheat was not significantly lower in unfertilized than in fertilized treatments, but the former treatment had significantly higher K concentration in grains than the latter treatment. The thousand grain weight was significantly lower in -K than in +K plants (data not shown). This is also because of the disturbed transport rate of solutes in the phloem due to K deficiency.

Efficient plant species employ specific physiological mechanisms to increase the effectiveness of nutrient utilization (Sattelmacher *et al.* 1994); for example, they possess lower internal nutrient requirements or require less concentration of the nutrient in question in the plant tissues for dry matter production. In this experiment, the internal K requirement to produce 80% of maximum yield was between 3.5% and 5.0 % for sugar beet and 2.0% and 3.0 % for wheat. These values are lower than those of Kuhlmann (1983) who reported about 4.2 % K in wheat dry matter at the stage of shoot elongation, and between 4.5% and 6.0 % in sugar beet dry matter at full leaf expansion stage. These results agree with the values given by Bergmann (1993) for K concentration in dry matter required for optimum dry matter yield, which are 3.5%-6.0 % for sugar beet and 2.9%-3.9 % for wheat at comparable growth stages. However, the data showed that the K concentrations in dry matter, although within the range of the needed K concentration, were on the lower part of the range, indicating that the availability of K was low. These results and those cited from the literature show that wheat is more efficient in utilizing K for dry matter production as compared to sugar beet.

Nutrient amount and mobility in the soil as well as acquisition characters of the plant such as the root size, uptake kinetics and mobilizing ability of the root system control nutrient supply to the plants (Jungk and Claassen

1997). A large root system as well as alteration of root geometry could be considered as one of the strategies developed by plants for high uptake efficiency (Rengel 1999). In both treatments, wheat produced around 80% of the root system before flowering in June. During this time, the most active vegetative growth took place and the highest amount of K was needed. This could be the mechanism for wheat K efficiency. Claassen (1994) showed that not only the root size is important for wheat K efficiency, but also that the highest shoot growth in June and July coincided with a completely developed root system capable of acquiring the necessary K needed for growth by exploiting a larger soil volume for K. As could be seen from the above data, the efficiency of sugar beet could not be attributed to a larger root system, since it had only 34% to 48 % of the root length of wheat, over the whole growth period.

Plant growing tissues are sinks for photosynthetic products and mineral nutrients. Sauerbeck and Helal (1990) suggested that root development and physiological activity are controlled by the shoots, since nutrient uptake by the roots, translocation to the shoots and subsequent redistribution in the different plant organs is controlled by complex communications between shoots and roots.

Caradus and Snaydon (1986) reported that shoot systems can have large effects on nutrient uptake, if only by the demand for nutrients that they impose. Faster growing shoots require more nutrients as compared to slower growing ones. Sugar beet had a much higher shoot growth rate as compared to wheat. Steingrobe and Claassen (2000) reported that during a time interval, the nutrient content of already grown plant parts is nearly constant and thus causes no demand for nutrient uptake. At optimum nutritional status, the demand for nutrients imposed on the roots is caused mainly by the new shoot growth. As such changes in root growth pattern, in response to nutrient deficiency, are better described by the ratio of shoot growth rate to root length than by root length-shoot weight or shoot weight-root length ratios. As the GRs/RL ratio shows, sugar beet had much higher demand for nutrient acquisition, which means that the roots had to exert more effort for K acquisition to meet the shoot demand. The lower shoot growth rate and larger root system of wheat mean a lower nutrient uptake demand to be met by a unit of root. Nevertheless, sugar beet proved to be as K efficient as wheat.

Regarding the absolute dry matter yield, sugar beet produced much higher dry matter (150 and 70 t ha^{-1}) beet and leaves, respectively, than wheat (45 and 77 t ha^{-1}) grain and straw, respectively. As was shown in the results, sugar beet had higher K concentrations in dry matter because of its higher internal requirement. Consequently, sugar beet had double the total K uptake of wheat, since total K uptake is the product of dry matter and K concentration in dry matter. Hence, it is obvious that sugar beet had higher uptake efficiency than wheat. This can only be explained by the higher uptake efficiency of the single roots or acquisition rate per unit of root and time, i.e. the influx. The results of this study showed that to meet the demand for nutrient acquisition imposed by the fast growing shoots, sugar beet increased its uptake rates per unit root and time considerably. It had 2 and 10 times higher influx as compared to wheat, on the unfertilized treatments, in the growth periods 27.05-24.06 and 24.06-08.07, respectively. Especially at the growth period 24.06-08.07, with the highest demand for K acquisition on the roots, sugar beet had nearly twice higher influx as compared to the growth periods 27.05-24.06 and 08.07-05.08, respectively. Claassen (1994) showed that at similar K concentration in soil solution, sugar beet influx was thrice higher in July than in June, and that the higher shoot growth rate in July, representing a higher K demand on the roots, was covered by a higher influx. Caradus and Snaydon (1986) suggested that plants with small root systems had high uptake rates per unit root length because uptake per plant is determined by shoot factors.

The influx of sugar beet was relatively high for the very low measured soil solution concentrations and transport to the roots would probably limit K uptake (Jungk and Claassen 1997; Claassen and Steingrobe 1999). Hence, it remains to be investigated what enabled sugar beet to achieve a higher influx than wheat, even though the transport of K to the roots was limiting K uptake. A possible explanation of the higher influx of sugar beet could be that it might have caused chemical changes in the rhizosphere through root exudates, which released non-exchangeable K into the soil solution. Several workers reported the significance of chemical mobilization of mineral nutrients in the rhizosphere by plant roots, for example, of phosphate and micro-nutrients for plant nutrition (Gerke *et al*. 1994; Rengel *et al*. 1998). Little information exists about K mobilization by root exudates, for example, by organic acids (Meyer 1993).

CONCLUSIONS

1- Sugar beet is similarly K efficient as wheat.
2- Wheat efficiency could be attributed to a larger root system and a higher utilization efficiency or lower internal K requirement.
3- Sugar beet, even though it has a smaller root system, a higher shoot growth rate and a higher internal requirement, its K efficiency is similar to wheat because of a higher efficiency of the single root or influx.
4- It remains to be investigated why under limiting K supply; sugar beet was able to achieve a higher K influx than wheat.

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الكفاءة البوتاسية للقمح وبنجر السكر تحت ظروف الحقل

هنادى ابراهيم الدسوقى[1] و نوربرت كلاسن و شتاين قروبه

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المستخلص: أُجريت هذه الدراسة لبحث الكفاءة البوتاسية لمحصولى القمح وبنجر السكر تحت ظروف حقلية والتعرف على الاليات أو العوامل المسببة للكفاءة. جُمعت البيانات من تجربة تسميد طويلة الامد على تربة رملية طينية قريرية ذات قابلية عالية لتثبيت البوتاسيوم فى باڤاريا، جنوب المانيا. تراوحت معدلات التسميد بالبوتاسيوم من 0 الى 1000 كجم بوتاسيوم للهكتار فى العام وكان أخر تسميد فى عام 1986. فى عام 2003 زرع القمح وبنجر السكر فى 13 مارس و4 أبريل على التوالى. أخذت عينات عشوائية من الجذور والسوق والتربة اربع مرات للقمح وخمسة مرات لبنجر السكر من المعاملات غير المسمدة (K-) وأعلى معدل تسميد ($+K$ 1000 kg^{-1} soil) . كانت الكفاءة البوتاسية لبنجر السكر والقمح متساوية تقريبا حيث انتجا 76% و 80% من البنجر والحبوب فى المعاملات غير المسمدة مقارنة بالمعاملات المسمدة. مقارنة بالقمح كان لبنجر السكر حاجة داخلية اكبر للبوتاسيوم وضعف معدل نمو الساق و 48%- 34% من طول جذور القمح وبالتالى نسبة أكبر من معدل نمو الساق لطول الجذور مما يعنى ضغط أعلى على الجذور لإمتصاص البوتاسيوم. إلا أن بنجر السكر حقق كفاءة عالية جدا لمعدل الأمتصاص لوحدة الجذر والتى كانت أعلى بخمسة أضعاف فى المعاملات غير المسمدة مقارنة بالقمح. تُعزى كفاءة القمح الى كفاءة استخدام أعلى أو حاجة داخلية منخفضة، ومعدل نمو بطئ للمجموع الخضرى ومجموع جذرى كبير. هناك ضرورة لاجراء بحوث اكثر لدراسة الالية التى تحصل بها بنجر السكر على معدل امتصاص عالى لوحدة الجذر مقارنة بالقمح.

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