Der Tropenlandwirt, Beiträge zur tropischen Landwirtschaft und Veterinärmedizin,
96. Jahrgang, Oktober 95, S. 141 - 152

Salt Tolerance of Different Varieties of *Sorghum bicolor* and *Vicia faba*.

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1 Introduction

In regions of arid or semiarid climate, too much salt (often NaCl) in the soil or in the irrigation water frequently limits optimal growth of agricultural crops. In order to cultivate plants on salt-affected soils we have to look for plant species and varieties showing a high salt tolerance, and the question of our trials was: Are there any differences in the salt tolerance of *Vicia faba* and *Sorghum bicolor* and between cultivars of these species?

This question, which is very important for practical agriculture, requires an investigation into the causes of salt tolerance of plants. It has been suggested that resistance to salt is based on Na exclusion in some species or that Na is included, but without damaging the plant. Such processes in the plants are, for example, during the <u>short distance transport</u>:

a) Carrier proteins rather bind potassium instead of sodium at specific binding places (JESCHKE, 1972).

b) Hydrogen ions are pumped out of the cell and potassium ions are pumped into the cell by metabolic energy, and a second pump takes sodium out of the cell and hydrogen ions can return into the cell (JESCHKE and STELTER, 1976).

c) Potassium can be separated more easily than sodium from its hydration layer, therefore in the lipid phase potassium is much more soluble than sodium and can penetrate the cell membrane much more than sodium (SCOTT and SMITH, 1987).

Reasons for tolerance to sodium can also be based on different reactions of plants during the <u>long distance transport</u>:

a) In some plant species, sodium can be transported via the xylem to the very end of the vessels, and a salt excretion can take place on top of the leaf surface (ROZEMA et al., 1991), visible as a white layer on the leaves; this salt can be washed from the leaves by rain water or it can be blown away by wind.

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b) Na enters the xylem in the roots, but already in the roots it is taken off the xylem vessels in order to be accumulated in the xylem parenchyme tissue as well as in the lateral root primordia, so the sprout (being very sensitive) is protected against too much sodium (MARSCHNER and RICHTER, 1973, RICHTER and MARSCHNER, 1974).

c) A third possibility to avoid too much sodium in the plant is the transport downwards via phloem and excretion of sodium to the soil solution (LÜTTGE, 1983, MARSCHNER and OSSENBERG-NEUHAUS, 1976).

If we measure the yield of different varieties of a plant species after applying salt to its medium, and simultaneously measure the Na and K uptake of the roots and the shoots, we can see some reasons for a possible salt tolerance. If, for example, the high salt tolerance of a plant variety is combined with a high sodium accumulation in the roots and a low sodium translocation into the shoot we can conclude that the existing salt tolerance of this variety is based on the capability of the plant to protect its sprout against too much sodium by accumulation of this sodium in the root tissue (see also BEZERRA, 1985 and ASHRAF and KARIM, 1990).

2 Materials and methods

2.1 Plant species and varieties

21 varieties of *Sorghum bicolor*, kindly made available by Prof. Dr. Obilana from ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) in Bulawayo, Zimbabwe, and one German variety (Stamm 002, Südwestdeutsche Saatzucht) were examined.

We also tested 12 varieties of *Vicia faba* from ICARDA (International Center for Agricultural Research in the Dry Areas), Aleppo, Syria, kindly sent to us by Dr. Robertson. We included two German varieties (Alfred and Herz Freya). We examined these two species because of their importance as agricultural crops in semi-arid and arid regions where salt-affected soils are often to be found. We selected the above mentioned cultivars because according to ICRISAT and ICARDA these were the most important as to the aspect of salinity resistance.

2.2 Experimental soil

The soil utilised in our experiments was a loam developed from loess of a field in Hebenshausen, Hesse, Germany, with a pH (0.02 N $CaCl_2$) of 6.8, 0.5% calcium carbonate and 2% organic matter. The P supply (6.6 mg P(CAL) per 100 g of air-dried soil) as well as the K supply (15 mg K(CAL) per 100 g) were sufficient for optimal plant growth. The Mg supply was high (9 mg Mg($CaCl_2$) per 100 g) and the content of exchangeable Na was low (7.4 mg Na per 100 g). The content of the experimental soil in soluble salts was extremely low, its EC was 0.326 dS m^{-1} at 25°C.

Before the beginning of the experiments, the soil was mixed very well and filled into cylindrical (Mitscherlich) pots with a diameter of 20 cm and a height of 18 cm, containing 7 kg of air-dried soil.

2.3 Experimental set-up

On May 5th, 1992, 12 grains of each variety of *Vicia faba* and on May 12th, 1992, 20 grains of each variety of *Sorghum bicolor* were sown into the soil of each vessel. The pots were placed on tables outdoors in a wirehouse in order to protect the plants against damage caused by birds. The plants were irrigated by natural rain and, during dry weather, with rainwater collected beforehand from a neighbouring glasshouse roof. Any surplus of water with salts washed out of the soil and dissolved in it was collected in bowls underneath each pot and put on the soil when dryness began.

After 16 days, six *Sorghum* and five *Vicia* plants of similar height were left in their place in each vessel. At the age of 42 days the height of the plants was 35 cm and the salt was applied corresponding to 0, 4 and 8 (*Sorghum*) and 0,2,4 and 8 dS m^{-1} (*Vicia*) in the saturation extract. This treatment corresponds to the conditions of practical agriculture in semiarid regions, where the grains are sown in a soil still low in its salt content because of salt leaching during the rainy season. In rainfed agriculture, the salt concentration of the soil solution increases in time as a consequence of increasing dryness and evaporation. On irrigated fields, the salt concentration of the soil solution rises too, because of the usually high concentration of the irrigation water.

2.4 Determination of the amount of NaCl per application

The amount of NaCl to be applied corresponding to 2, 4 and 8 dS m^{-1} depends on the soil texture: The heavier the soil, the higher is the necessary amount of salt to reach a certain salt concentration of a soil saturated with water (RICHTER and VAN DER POL, 1975). Therefore we made a saturated soil paste of our experimental soil and determined the necessary humidity for a saturated paste (RICHARDS, 1969). The necessary quantity of salt to be added was calculated by the formula:

$$\text{g salt per 100g dry soil} = 0.064 \text{ dS m}^{-1} \frac{\text{water saturation (\%)}}{100\%}$$

For our experimental soil, we calculated the following amounts of salt application per vessel:

2 dS m^{-1}	corresponded to	4.32 g NaCl	per 7 kg	of soil
4	"	8.65	"	"
8	"	17.30	"	"

The NaCl was dissolved in 200 ml distilled water and put on the soil.

2.5 Growth, harvest and laboratory analysis

During the growth of the plants, the symptoms caused by the salt application were observed and described. *Sorghum* and *Vicia* were harvested after 57 and 65 days, respectively. The plants were separated into roots and shoots, and the soil was washed off from the roots as carefully as possible. The length of the shoots, the fresh weight and after drying the plants at 105°C , the dry weight were determined. After grinding, dry combustion at 550°C overnight and solution of the ash in concentrated hydrochloric acid K and Na were measured by flame photometry.

3 Results

3.1 Observations during the growth of the plants

During our experiments, the harmful NaCl influence on the soil structure became visible: in the salt-affected soils, water could hardly penetrate into the soil and rested upon the soil surface for several hours after rainfall or irrigation (Fig. 1).

One week after the salt treatment, clear symptoms on the *Sorghum* as well as on the *Vicia* plants were to be seen: They began as chloroses of the older leaves and turned into necroses of the leaf margins, finally all affected leaves died. The severity of the symptoms increased with the salt application (Fig. 2).

3.2 Results after the harvest of the plants

3.2.1 State of the roots

During the harvest, when the remaining soil was washed off the roots, the soil of the salt-treated plants was much easier to remove from the roots than the soil of the non-treated ones. The reason is probably a feeble development of small lateral roots and root hairs of the salt-affected plants, since with the salt treatment not only the leaves but also the roots were badly damaged (Fig. 3 and 4).

3.2.2 Yield and mineral content of Sorghum bicolor

The variety SDSH 398 showed the greatest reduction in yield as a result of salt application, as only 65% of the untreated plants could be harvested (Fig. 5). This lower yield was significantly different at the 5% level of probability. Differences between the other varieties existed, too, though not statistically significant. The influence of 4 dS m^{-1} was in between those of 0 and 8 dS m^{-1}. The yield shown in Fig. 5 corresponded in this same order with the fresh weight and the length of the plants.

Fig. 1: Sorghum bicolor, on the right 2 and on the left 0 dS m^{-1} NaCl in the soil saturation extract. In the salt-affected soils water cannot penetrate.

Fig. 2: Damage of the sprouts of Vicia faba after application of NaCl, corresponding to 8 dS m^{-1} in the saturation extract. Clearly to be seen are the necroses at the leaf margins, beginning on the older leaves, later on turning to the whole plant.

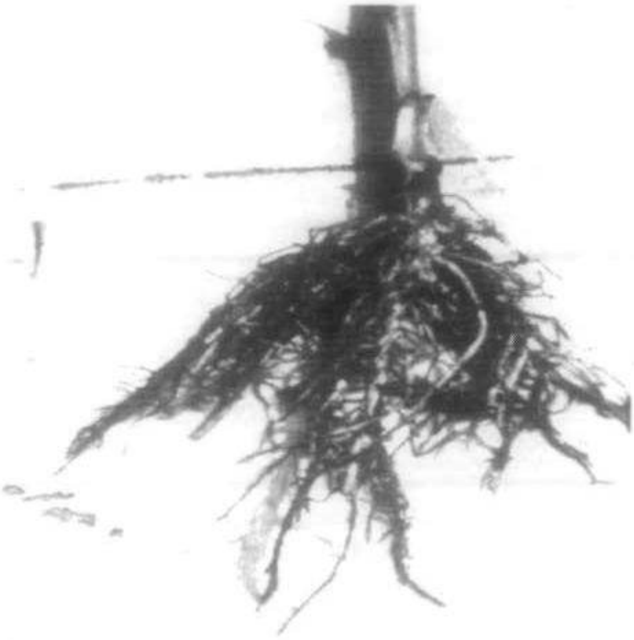

Fig. 3: Roots of *Vicia faba*, grown for 65d in a soil without salt application.

Fig. 4: Roots of *Vicia faba* after 42d without and the following 23d with NaCl application, corresponding to 8 dS m^{-1} in the saturation extract. The roots are of black colour, laterals and root hairs are hardly to be seen.

In Fig. 5, the yield of the 22 different varieties of *Sorghum bicolor* is shown, at 8 dS m^{-1} in comparison to no salt stress.

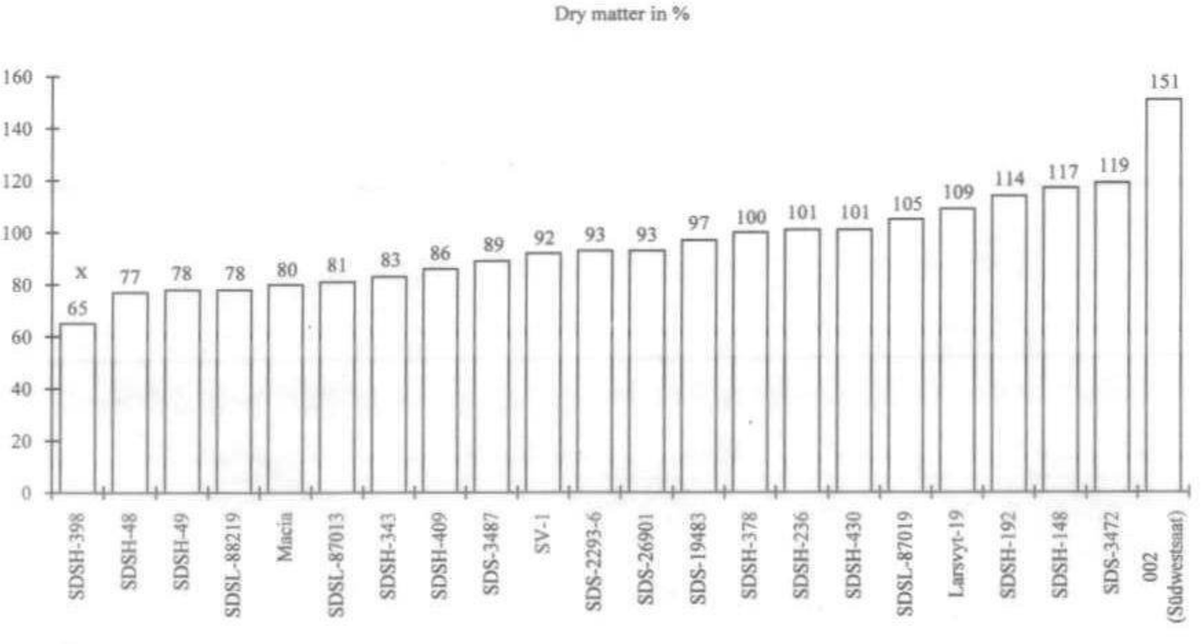

Fig. 5: Yield of different *Sorghum bicolor* varieties (dry matter of shoots) in %, influenced by 8 dS m^{-1} NaCl in the saturation extract. No salt application = 100%. x = significant difference to no salt application at 5% level of probability. Each figure is the mean of 5 replicates (plants).

In order to find out whether the observed salt influence on the yield was correlated with Na and K uptake and transport in the plants, we analysed Na and K in the roots and shoots of the harvested *Sorghum* (Table 1).

Table 1:Na and K content (mg/g dry weight) of 22 different varieties of *Sorghum bicolor* supplied with 0, 4 and 8 dS m^{-1} NaCl in the saturation extract as well as its correlation to the yield of 8 dS m^{-1} in comparison to no salt treatment. Each figure is the mean of 5 replicates (plants). r = correlation coefficient.

Application of NaCl ($dS\ m^{-1}$)	**Variation in Na (mg/g dry weight) between the different varieties**	**Correlation of Na content to the yield**	**Variation in K (mg/g dry weight) between the different varieties**	**Correlation of K content to the yield**
 Shoots				
0	0.07 - 0.21		18.8 - 37.7	
4	0.42 - 2.66		16.2 - 26.0	
8	0.81 - 6.45	$y = -0.05x + 8.6$ $r = -0.570$ (significant < 1%)	14.0 - 29.6	$y = -0.09x + 10.04$ $r = 0.596$ (significant < 1%)
 Roots				
0	0.26 - 0.52		5.49 - 9.66	
4	1.76 - 3.86		4.30 - 8.18	
8	3.63 - 7.13	$y = -0.00668x +$ 5.7 $r = -0.122$ (not significant)	3.77 - 6.99	$y = -0.002x + 5.7$ $r = -0.0416$ (not significant)

If the roots and shoots of all varieties are considered (Table 1), the Na content rises and the K content decreases with rising NaCl application. If the different *Sorghum* varieties of Table 1 are assigned separately to the yield order of Fig. 5, it is to be seen that the decrease of the yield by NaCl is not correlated with the Na or K accumulation in the roots, but very well with a transport of these ions into the shoots: the more tolerant a variety, the less Na and the more K is transported upwards from the roots into the shoots of *Sorghum*.

3.2.3 Yield and mineral content of Vicia faba

The influence of NaCl (8 dS m^{-1} in the saturation extract) on the yield of *Vicia faba* is shown in Fig. 6.

The effect of salt on the yield of the various *Vicia faba* varieties was different (Fig. 6), as was observed for *Sorghum bicolor* (Fig. 5). The yield of most of the varieties was significantly depressed by the salt (Fig. 6). Only variety 1813 showed a slight positive yield increase from the salt treatment, which however was not significant. The yields of the plants with the salt applications 2 and 4 were in between those of 0 and 8 dS m^{-1}.

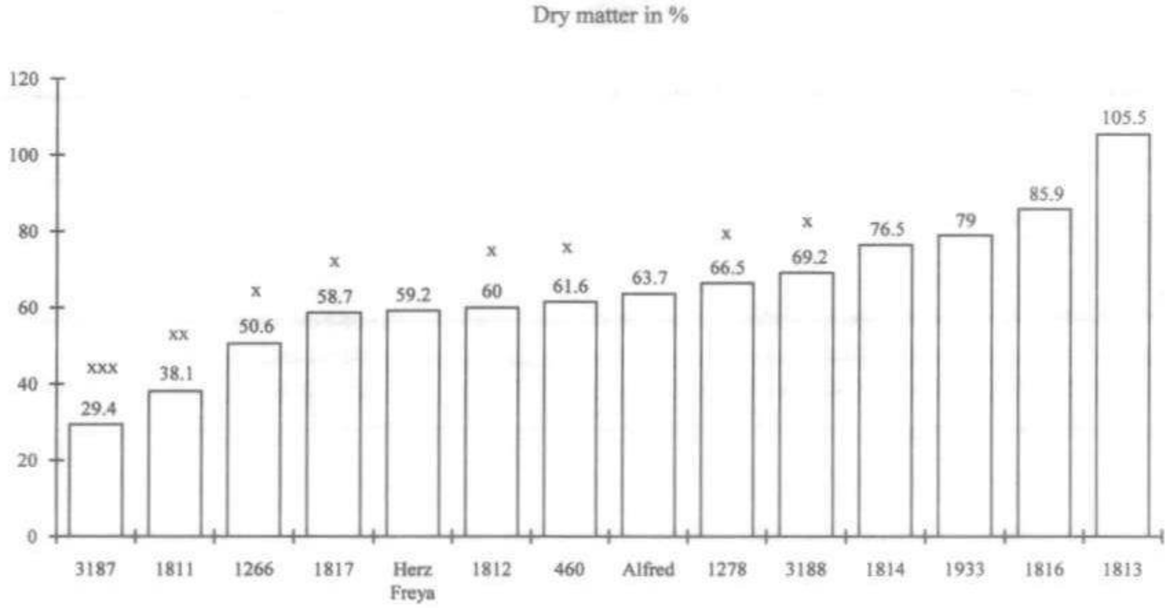

Fig. 6: Yield of different *Vicia faba* varieties (dry matter of shoots) in %, influenced by 8 dS m^{-1} NaCl in the saturation extract. No salt application = 100%. xxx = significant difference to no salt application at 0.1%, xx at 1.0% and x at 5% level of probability. Each figure is the mean of 5 replicates (plants).

The Na and K content of *Vicia faba* is shown in Table 2.

In *Vicia faba* as in *Sorghum bicolor* we measured a Na increase and a K decrease in the tissue with increasing salt stress. In comparison to *Sorghum* (Table 1) the high Na content in roots and shoots of *Vicia* is striking, as *Vicia* was grown on the same soil as *Sorghum*. Even in the *Vicia* plants without any salt application the Na content of the roots was 13 times higher and of the shoots 3.5 times higher than in *Sorghum*.

Furthermore, in *Vicia* faba roots a Na saturation of the root tissue could be observed from 2 dS m^{-1} onwards (Table 2), with an additional Na supply neither an additional Na nor a lower K accumulation in the roots takes place. The Na binding sites in the roots, though greater in number than in *Sorghum*, are already saturated with Na at 2 dS m^{-1}, all the Na which is taken up in addition is transported into the shoots.

If we regard the differences among the *Vicia faba* varieties, in contrast to *Sorghum*, we could neither observe any significant correlations between the order of the yield depression of the different varieties by salt (Fig. 6) and the Na or K content in the roots (Table 2), nor in the leaves. As our trials show, a high salt tolerance of a *Vicia faba* variety is not correlated with a low Na and a high K transport into the leaves. Therefore, for *Vicia* other mechanisms of adaptation than for *Sorghum* must be correlated with salt tolerance. In comparison to *Sorghum bicolor*, *Vicia faba* can be called more a Na includer plant.

Table 2: Na and K content (mg/g dry weight) in roots and shoots of different *Vicia faba* varieties after supply with 0, 2, 4 and 8 dS m^{-1} NaCl in the saturation extract. Each figure is the mean of 6 replicates (plants). For correlation statistics, see the text.

Application of NaCl ($dS\ m^{-1}$)	**Variation between the varieties (mg/g dry weight)**	
	Na	**K**
 Shoots		
0	0.29 - 0.95	13.7 - 21.9
2	3.32 - 5.61	12.4 - 24.7
4	5.62 - 11.20	11.9 - 20.7
8	17.30 - 25.90	9.86 - 20.5
 Roots		
0	3.92 - 5.38	12.3 - 21.3
2	6.93 - 13.20	8.64 -16.7
4	8.71 - 15.70	8.15 - 12.5
8	7.87 - 13.80	6.98 - 12.6

4 Discussion

4.1 Differences between the varieties

If the species itself, but not the varieties of a species are considered, Bernstein (1970) mentions a yield reduction of 75 % for *Sorghum* at 9 and for *Vicia faba* at 5.8 dS m^{-1} in the saturation extract, and EL KAROURI (1979) observed 50 % yield reduction of *Vicia faba* at 9 dS m^{-1} (above all dependent on Na) on soils in North Sudan. In our trials described above, according to the variety, we observed none, a low or a high yield depression. At 8 dS m^{-1}, of the most sensitive variety we harvested only 30 % of *Vicia* and 65 % of *Sorghum*, but other varieties were more tolerant, and others even were not damaged by the salt at all. For *Sorghum bicolor*, BEZERRA (1985) found clear differences in the salt tolerance between the varieties tested. The differences in the salt tolerance between the varieties are very important. Thus some *Vicia faba* varieties are able to grow well, even if the salt concentration is as high as 8 dS m^{-1} in the saturation extract, e.g. in the oasis Taghit of the Central Sahara in Algeria (RICHTER, unpublished data) and in many other semiarid and arid regions.

In addition, we observed for *Sorghum bicolor*, but not for *Vicia faba* that the more tolerant a variety (i.e. the less its yield was depressed after salt application), the less Na and the more K was transported from the roots into the leaves. These results correspond very well with those of BEZERRA (1985), who observed a low Na as well as a high K transport into the young, growing leaves of Na tolerant *Sorghum bicolor* varieties from India. It seems that a salt-tolerant *Sorghum* variety excluded Na from its shoot. This exclusion has also been shown for different varieties of *Glycine max* by LÄUCHLI and WIENEKE (1979) and WIENEKE and LÄUCHLI (1980), where the salt sensitive variety Jackson had a significantly higher Na content in the leaves than the tolerant variety Lee.

4.2 Differences between the species

Differences in salt tolerance exist not only between varieties but also between plant species, and even among different plant families, the *Chenopodiaceae*, for example, being very tolerant. Also Na uptake and transport mechanisms seem to be different between the species. In our trials, all varieties of *Vicia faba* (the salt-treated as well as the non-treated plants, Table 2) absorbed much more Na than all varieties of *Sorghum bicolor* (Table 1). As to the non-treated *Vicia* plants, we measured only 9% (0.34 mg Na) of the absolute Na quantity of each plant coming from its grain and 91% (3.82 mg Na per plant) being absorbed from the soil. Provided that the uptake mechanisms of *Sorghum* and *Vicia* would have been the same, the Na uptake of the two species would have been similar; however, it was much lower for *Sorghum* (e.g. 13 times lower in the roots and 3.5 times lower in the leaves of the non-treated plants, Table 1 and 2). With regard to Na, we conclude that *Vicia* can be called more an includer and *Sorghum* more an excluder plant.

4.3 Other influences

Certainly not only the cultivated species or variety is decisive for a possible yield reduction by Na-stress. Very important is also the kind of anion (Cl^- or SO_4^{2-}), and the presence of other cations (K^+, Ca^{2+}, Mg^{2+}) and other elements. So the salt tolerance of *Triticum aestivum* can be raised to a certain extent by fertilisation with Ca and K (SCHLEIFF and FINCK, 1976). Besides, a higher salt tolerance is obtained if the salts enter the cells slowly (UMIEL et al., 1980), so the cells can adapt their metabolism much better to the conditions of a high salt concentration. Such influences may be different in the various varieties of plant species, as well as our described observations.

5 Acknowledgement

The authors would like to thank Mrs. P. Pohlner for revising the English text.

6 Summary

Key words: Salt tolerance, Sorghum bicolor, Vicia faba

The influence of NaCl (0, 2, 4 and 8 dS m^{-1} in the saturation extract) on yield and Na and K content of roots and shoots was investigated in pot trials with 22 varieties of *Sorghum bicolor* and 14 varieties of *Vicia faba*. If the plants grew on the experimental soil without any additional salt application, the Na content of the plant tissue was much higher (roots: 13 times, shoots: 3.5 times) in *Vicia* than in *Sorghum*. *Vicia* can be called

more an includer and *Sorghum* more an excluder plant. With salt application, clear differences between the varieties were observed for *Sorghum bicolor* as well as for *Vicia faba*: As to the most sensitive varieties, we harvested only 65% (*Sorghum*) and 30% (*Vicia*) of the dry matter at 8 dS m^{-1} compared to no salt application. Some varieties showed more resistance, others were not damaged by the salt. Contrary to *Vicia*, the salt tolerance of *Sorghum bicolor* was correlated with high significance with a lower Na translocation (r = - 0.570) and also with a higher K translocation (r = 0.596) from the roots into the leaves. The reasons are discussed.

Salztoleranz verschiedener Sorten von *Sorghum bicolor* und *Vicia faba*

Zusammenfassung

In Gefäßversuchen wurde der Einfluß von 0, 2, 4 und 8 dS m^{-1} NaCl im Sättigungsextrakt auf den Ertrag sowie den Natrium- und Kaliumgehalt in den Wurzeln und Sprossen von 22 *Sorghum bicolor*- und 14 *Vicia faba*-Varietäten untersucht. Wuchsen die Pflanzen im Versuchsboden ohne Salzapplikation, war der Na-Gehalt in den Wurzeln von Vicia 13mal und in den Sprossen 3,5 mal höher als bei Sorghum. Vicia faba kann also mehr als eine Includer-Pflanze, Sorghum bicolor dagegen mehr als eine Excluder-Pflanze für Natrium angesehen werden. Bei Salzbehandlungen konnten deutliche Unterschiede in der Salztoleranz zwischen den Varietäten sowohl von *Sorghum bicolor* als auch von *Vicia faba* festgestellt werden: Bei den empfindlichsten Varietäten ernteten wir nur 65 % (*Sorghum*) und 30 % (*Vicia*) Trockensubstanz bei 8 dS m^{-1} im Vergleich zu keiner Salzbehandlung. Einige Varietäten waren toleranter, und andere wurden nicht durch das Salz geschädigt. Bei *Sorghum*, nicht bei *Vicia*, korrelierte eine hohe Salztoleranz mit einer geringeren Na-Translokation (r = -0,570) und einer höheren K-Translokation (r = 0,596) aus den Wurzeln in die Sprosse.

Tolérance aux sels de plusieurs variétés de *Sorghum bicolor* et *Vicia Fabia*

Résumé

Par culture en pot, l'influence de 0, 2, 4 et 8 dS m^{-1} NaCl dans l'extrait saturé sur le rendement et la teneur en Na et K était examinée dans les racines et les feuilles de 22 variétés de *Sorghum bicolor* et de 14 variétés de *Vicia faba*. Si les plantes poussaient dans le sol d'essai sans application de sel, *Vicia*, par rapport au *Sorghum*, contenait 13 fois plus de Na dans ses racines et 3.5 fois plus de Na dans ses feuilles. Comparé avec *Sorghum*, Vicia était beaucoup plus capable d'inclure le Na. Beaucoup de différences existaient entre les varietés de *Sorghum bicolor* et de *Vicia faba* concernant la tolérance contre la salinité: Pour les varietés les plus sensibles, avec application de 8 dS m^{-1} nous recoltions seulement 65% (*Sorghum*) et 30% (*Vicia*) de matière sèche comparé avec les plantes sans application de sels. Quelques varietés étaient plus tolérantes, des autres n'étaient pas détruites par le sel. Quand au *Sorghum*, la tolérance d'une varieté par rapport au sel NaCl était corrélée avec une faible translocation de Na (r=-0,570) et avec une forte translocation de K (r=0,596) hors des racines dans les feuilles des plantes.

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