

BRIEF COMMUNICATION

Transfer of cesium from the xylem to the phloem in the stem of wheat

U. FELLER*, T. RIESEN** and H.-J. ZEHNDER***

*Institute of Plant Physiology, University of Bern, Altenbergrain 21, CH-3013 Bern, Switzerland***Paul Scherrer Institute, CH-5232 Villigen, Switzerland****Swiss Federal Research Station for Fruit-Growing, Viticulture and Horticulture, CH-8820 Wädenswil, Switzerland******Abstract**

Steam-girdling experiments with detached wheat shoots showed that cesium was eliminated from the xylem sap and loaded into the phloem during acropetal transport. This transfer is important for the accumulation of cesium (especially also of the radiopollutants ^{134}Cs and ^{137}Cs) in maturing wheat grains.

Additional key words: grains, maturation, radioisotopes, transport, *Triticum aestivum*.

The mobility of macronutrients, micronutrients and pollutants in maturing wheat varies in a wide range (Martin 1982, Schenk and Feller 1990b, Marschner 1995, Zeller and Feller 1998). Potassium and rubidium are highly mobile in the phloem and are even transferred from the xylem to the phloem in the stem during acropetal translocation (Haeder and Beringer 1984, Feller 1989, Schenk and Feller 1990a, Kuppelwieser and Feller 1990). The xylem-to-phloem transfer is possible in the internodes indicating that the nodes are not a required (Kuppelwieser and Feller 1991). Since this process is stimulated by fusicoccin, it appears likely that the polarization of a membrane is important (Kuppelwieser and Feller 1990). The transport of Cs^+ (especially relevant after radioactive fallout) via xylem and phloem in maturing wheat was the focus of the work reported here.

Field-grown wheat (*Triticum aestivum* L., cv. Arina) plants were harvested 14 d after anthesis. The shoots were transported standing in deionized water to the laboratory, recut below the flag leaf node and then incubated for 6 d standing in a solution containing 1 mM LiCl , 1 mM NaCl , 1 mM RbCl , 0.1 mM CsCl and 1 mM SrCl_2 in a culture room with a 14-h photoperiod (irradiance at ear level of $120 \mu\text{mol m}^{-2} \text{s}^{-1}$ from four Philips TL 40W/33 and two

Osram Fluora fluorescent tubes), day/night temperatures of 24 - 26 / 21-23 °C and relative humidities of 40 - 50 / 70 - 80 %. Thus stable cesium was introduced together with rubidium and strontium via the cut xylem into one set of plants. Steam-girdling was applied to interrupt the phloem of some shoots (Martin 1982, Zeller and Feller 1998).

The radionuclide ^{134}Cs was introduced into another set of plants via flaps cut either into the stem below the flag leaf node or into the flag leaf lamina according to Schenk and Feller (1990a). In these experiments, wheat shoots were collected 9 d after anthesis in the field, transported standing in deionized water to the laboratory, recut below the second leaf node from the top and incubated for 8 d standing in nutrient medium (according to Hildebrand *et al.* 1994) in a culture room. ^{134}Cs (6.6 KBq in 0.8 cm^3 with 0.1 mM CsCl or without CsCl for controls) was applied. In some cases, the solution introduced via the flap contained additionally 0.1 mM CsCl to test whether excess of stable Cs interferes with the transport of ^{134}Cs .

Stable Cs, Rb and Sr were quantified by atomic absorption spectrophotometry (AA 1475, Varian Techtron Pty, Mulgrave, Australia) and ^{134}Cs by γ -spectrometry on a NaI counter (Wizard 1480, Wallac Oy, Turku, Finland).

Received 5 August 1999, accepted 7 December 1999.

Acknowledgements: We thank the LBBZ Rütli in Zollikofen for growing the wheat plants.

*To whom correspondence should be sent, fax: +41 31 332 20 59, e-mail: urs.feller@pfp.unibe.ch

Based on the steam-girdling experiments, it can be concluded that Cs was transferred from the xylem to the phloem similarly to Rb, while the transport of the phloem-immobile Sr was only slightly and most likely indirectly affected by a phloem interruption (Table 1). A high percentage of Cs and Rb was retained in the peduncle and in the leaf sheath during the experimental period, while only a minor portion reached the ear in control shoots (within the ear mainly the grains). The flux of Cs and Rb to the grains was markedly lowered in steam-girdled shoots indicating that these elements reached the grains in controls mainly via the phloem. The phloem-immobile Sr can serve as an indicator for the distribution of the xylem sap via the transpiration stream. This element was higher in the flag leaf lamina than in the sheath and accumulated

within the ear mainly in the glumes. Theoretical contents per shoot (total content) were computed from the transpiration rate and the concentration in the solution entering the shoot via the cut xylem. Theoretical and measured contents were similar for Sr, while for Cs and Rb the measured contents were far below the theoretical values. It appears likely that Sr was transported in the xylem with the transpiration stream and was therefore not released into the medium. Rb and Cs were presumably transferred from the xylem to the phloem in the basal part of the peduncle as reported previously for Rb (Kuppelwieser and Feller 1991) and were then released from the pressurized phloem into the medium. This hypothesis was confirmed in additional experiments (data not shown).

Table 1. Distribution of Cs, Rb, and Sr in different parts of detached wheat shoots after introducing these elements via the cut xylem. The phloem of some plants was interrupted below the ear by steam-girdling (steam-g). Means and SE of 4 replicates are shown. Theoretical contents were calculated from the transpiration rate and the concentrations in the solution applied.

Plant part	Contents in various shoot parts [$\mu\text{g plant}^{-1}$]					
	Cs		Rb		Sr	
	control	steam-g	control	steam-g	control	steam-g
Grains	14 $\pm$ 4	1 $\pm$ 1	61 $\pm$ 25	10 $\pm$ 6	137 $\pm$ 23	87 $\pm$ 11
Glumes	8 $\pm$ 4	2 $\pm$ 1	44 $\pm$ 21	16 $\pm$ 5	264 $\pm$ 41	247 $\pm$ 78
Rachis	11 $\pm$ 2	4 $\pm$ 1	127 $\pm$ 22	48 $\pm$ 11	222 $\pm$ 30	154 $\pm$ 22
Peduncle	76 $\pm$ 4	61 $\pm$ 8	817 $\pm$ 104	520 $\pm$ 26	1034 $\pm$ 66	783 $\pm$ 53
Lamina	17 $\pm$ 2	16 $\pm$ 6	99 $\pm$ 16	104 $\pm$ 34	705 $\pm$ 51	632 $\pm$ 195
Sheath	44 $\pm$ 3	34 $\pm$ 3	222 $\pm$ 13	207 $\pm$ 42	287 $\pm$ 14	222 $\pm$ 34
Shoot total (measured)	168 $\pm$ 9	119 $\pm$ 16	1368 $\pm$ 70	906 $\pm$ 92	2644 $\pm$ 79	2126 $\pm$ 294
Shoot total (theoretical)	432 $\pm$ 16	359 $\pm$ 49	2779 $\pm$ 103	2309 $\pm$ 316	2847 $\pm$ 105	2365 $\pm$ 324

Table 2. Influence of stable CsCl on the transport of ^{134}Cs in detached wheat shoots. ^{134}Cs with 0.1 mM CsCl or without CsCl for controls was applied via a flap cut either into the stem below the flag leaf node or into the flag leaf lamina. Means and SE of 4 replicates are shown. * 11.17 $\pm$ 5.13 in the stem flap; 8.75 $\pm$ 5.17 in the rest of this part of the stem, **18.91 $\pm$ 5.66 in the stem flap; 4.01 $\pm$ 3.18 in the rest of this part of the stem

Plant part	^{134}Cs content [relative units plant part $^{-1}$]			
	Flap in the stem below flag leaf node		Flap in flag leaf lamina	
	Control	+ 0.1 mM CsCl	Control	+ 0.1 mM CsCl
Grains	26.60 $\pm$ 2.24	26.32 $\pm$ 3.20	2.91 $\pm$ 0.66	2.86 $\pm$ 0.69
Glumes	19.79 $\pm$ 2.57	19.90 $\pm$ 4.05	2.37 $\pm$ 0.36	1.82 $\pm$ 0.10
Rachis	5.37 $\pm$ 1.03	6.80 $\pm$ 0.73	0.59 $\pm$ 0.34	0.48 $\pm$ 0.04
Peduncle	33.67 $\pm$ 5.13	35.44 $\pm$ 6.60	2.03 $\pm$ 0.53	2.03 $\pm$ 0.95
Flag leaf sheath	30.17 $\pm$ 0.87	29.57 $\pm$ 2.91	3.25 $\pm$ 1.18	4.17 $\pm$ 0.52
Flag leaf lamina	27.68 $\pm$ 6.84	21.85 $\pm$ 3.42	145.18 $\pm$ 21.60	165.79 $\pm$ 8.74
Stem leaf 2 to flag leaf	19.91 $\pm$ 2.37*	22.91 $\pm$ 4.19**	0.31 $\pm$ 0.37	0.36 $\pm$ 0.31
Sheath of leaf 2	0.03 $\pm$ 0.25	0.32 $\pm$ 0.41	0.29 $\pm$ 0.46	0.10 $\pm$ 0.20
Lamina of leaf 2	0.15 $\pm$ 0.31	0.39 $\pm$ 0.48	0.17 $\pm$ 0.26	0.07 $\pm$ 0.32

It must be borne in mind that the radiocesium concentration from radioactive fallout is extremely low.

Because this situation differs considerably from the conditions (0.1 mM CsCl in the medium) used in our

experiment (Table 1), ^{134}Cs was fed in a complementary experiment either alone or in combination with 0.1 mM CsCl via a flap directly into the plant. From these results (Table 2) it became evident that the the distribution of ^{134}Cs was not markedly affected by simultaneously applied stable Cs. This finding is important, since it allows the use of non-radioactive Cs in quantities easily detectable by atomic absorption spectrophotometry for

basic investigations in the field.

The experiments reported here clearly indicate that Cs can be transferred from the xylem to the phloem and may then accumulate in the maturing grains of wheat (major phloem sources after anthesis). The developmental stage of the plant, the plant parts being contaminated and the environmental conditions must be considered as important parameters in such experiments.

References

- Feller, U.: Transfer of rubidium from the xylem to the phloem in wheat internodes. - J. Plant Physiol. **133**: 764-767, 1989.
- Haeder, H.E., Beringer, H.: Long distance transport of potassium in cereals during grain filling in intact plants. - Physiol. Plant. **62**: 439-444, 1984.
- Hildebrand, M., Fischer, A., Feller, U.: Protein catabolism in bean leaf discs: accumulation of a soluble fragment of ribulose-1,5-bisphosphate carboxylase/oxygenase under oxygen deficiency. - J. exp. Bot. **45**: 1197-1204, 1994.
- Kuppelwieser, H., Feller, U.: Influence of fusicoccin and xylem wall adsorption on cation transport into maturing wheat (*Triticum aestivum*) ears. - In: Van Beusichem, M.L. (ed.): Plant Nutrition – Physiology and Applications. Pp. 117-120. Kluwer Academic Publishers, Dordrecht 1990.
- Kuppelwieser, H., Feller, U.: Transport of Rb and Sr to the ear in mature, excised shoots of wheat: effects of temperature and stem length on Rb removal from the xylem. - Plant Soil **132**: 281-288, 1991.
- Marschner, H.: Mineral Nutrition of Higher Plants. Second Edition. - Academic Press, London 1995.
- Martin, P.: Stem xylem as a possible pathway for mineral retranslocation from senescing leaves to the ear in wheat. - Aust. J. Plant Physiol. **9**: 197-207, 1982.
- Schenk, D., Feller, U.: Rubidium export from individual leaves of maturing wheat. - J. Plant Physiol. **137**: 175-179, 1990a.
- Schenk, D., Feller, U.: Effect of phloem interruption on leaf senescence and nutrient redistribution in wheat (*Triticum aestivum*). - In: Van Beusichem, M.L. (ed.): Plant Nutrition – Physiology and Applications. Pp. 121-125. Kluwer Academic Publishers, Dordrecht 1990b.
- Zeller, S., Feller, U.: Redistribution of cobalt and nickel in detached wheat shoots: effects of steam-girdling and of cobalt and nickel supply. - Biol. Plant. **41**: 427-434, 1998.