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Leaching of Potassium in a Lysimeter Experiment

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Summary

Leaching of potassium was studied in the lysimeter plant in Seibersdorf/ Austria (pannonian climate). Averaged over three years, gravitational water amounted to 15.7% of the sum of precipitation (mean 485 mm) and irrigation (mean 138 mm). Differences between the four soils with respect to drainage were explained by the specific percentage of the soil skeleton. The average yearly potassium leaching ranged from 3.64 kg K/ha·yr (Dystric Cambisol) to 22.7 kg K/ha·yr (drained Gleysol). Correlation between gravitational water volume and potassium leaching were only significant for one out of four soil types. No correlation was observed between extractable potassium in the soil profiles and potassium leaching.

Introduction

The total potassium contents of topsoils range from 0.2% to 3.3% (Scheffer and Schachtschabel, 1989). Only a small part, water soluble K, exchangeable K and a fraction of K bound in clay minerals is plant available. The CAL (calcium-acetate-lactate) extractable potassium is used as a measure for K plant availability in Austria. The respective mean value for topsoils in Lower Austria is 15 mg K_2O/100g soil (Bundesanstalt für Bodenwirtschaft, 1994), equivalent to 373 kg K/ha (0-20 cm).

This relatively small mobile fraction changes due to release of K from less available soil fractions, plant uptake, fixation processes in the soil and leaching. Concentrating on the losses, many data are available on crop uptake, fewer results on leaching of potassium. The present paper deals with potassium leaching under irrigation in the pannonian climate.

Materials and methods

The lysimeter plant consists of 12 soil monolithes (1 × 1 × 0.75 m; Gerzabek, 1990). Four soil types were sampled in the years 1989 and 1990 with three replicates. The results of the analyses of physical and chemical soil properties are shown in Table 1.

Soil I is classified as a slightly alkaline calcareous Cambisol with a low skeleton and high silt content and high productivity. Soil II is a Dystric Cambisol on fine colluvium with a medium skeleton content. The soil texture is a silty sand. The pH is low and the extractable potassium content is below the detection limit. Soil III, a Dystric Cambisol on silicate rock, is extremely high in soil skeleton and is characterized by a low pH and high extractable potassium contents. Soil IV is an already drained Gleysol with a medium to high fraction of soil skeleton. The soil is rich in organic matter and low in extractable potassium contents.

The water balance and the potassium leaching was determined for periods of six month duration (27.8.1990 - 11.3.1991; 12.3.1991 - 26.8.1991; 27.8.1991 - 2.3.1992; 3.3.1992 - 15.9.1992; 16.9.1992 - 4.3.1993; 5.3.1993 - 1.9.1993). During this period the following crops were grown in the lysimeters: endive (1990), corn (1991), winter wheat (1991/1992), mustard (1992), sugar beet (1993). Average yields of 13618 kg/ha (corn, grain), 3791 kg/ha winter wheat (grain), 26519 kg/ha (mustard, green material) and 50864 kg/ha (sugar beet) were recorded. The mean yearly precipitation was 485 mm. The mean irrigation amounted to 138 mm per year. During the whole investigation period the soils were equally treated with 548 kg K/ha (660 kg K_2O/ha).

Gravitational water was evaporated to a volume of app. 100 ml. An aliquot was transferred to a quartz tube. The ^{40}K activity was measured by means of γ-spectrometry. Taking into account the radioactive decay, the relative isotope abundance of ^{40}K, the Avogadro number and the molecular weight of potassium, the total amount of K leached was calculated as follows:

$$g\,K = Bq\,^{40}K \cdot 0.31791$$

Table 1. Selected soil properties of the experimental soils (0-20 cm/20-40 cm/40-75 cm).

Parameter	Soil I	Soil II	Soil III	Soil IV
pH ($CaCl_2$)	7.5 / 7.6 / 7.8	4.6 / 5.2 / 5.3	5.1 / 4.7 / 4.7	5.9 / 4.9 / 5.0
% fine gravel	0.7 / 0.4 / 0.2	11.9 / 12.1 / 11.2	11.2 / 15.8 / 13.0	17.5 / 17.2 / 31.1
% medium & coarse gravel	0.4 / 0.7 / 0.0	6.1 / 9.2 / 9.7	20.8 / 44.4 / 29.1	0.5 / 1.2 / 24.0
% sand	17 / 16 / 14	48 / 48 / 44	61 / 62 / 62	24 / 32 / 59
% silt	65 / 66 / 71	43 / 43 / 47	27 / 29 / 30	62 / 55 / 29
% clay	18 / 18 / 18	9 / 9 / 9	12 / 9 / 8	14 / 13 / 12
% humus	1.5 / 1.1 / 0.3	2.4 / 1.2 / 1.1	2.6 / 0.9 / 0.6	5.2 / 2.7 / 0.7
% $CaCO_3$	18.3 / 22.5 / 40.0	n.d. / n.d. / n.d.	n.d. / n.d. / n.d.	n.d. / n.d. / n.d.
mg K_2O/100 g (CAL/DL)	11.7 / 2.3 / <2.0	<2 / <2 / <2	34.9 / 24.5 / 11.8	5.2 / 7.3 / 12.5
mg P_2O_5/100 g (CAL/DL)	16.2 / 8.3 / <2	6.6 / 3.7 / 3.3	7.1 / <2 / <2	3.8 / <2 / <2

n.d.: not detectable.

Results and discussion

Leaving out the data of the first six month, the yearly average of gravitational water reached 90 mm, which implies evapo-transpiration of about 530 mm per year. The gravitational water in percent of the sum of precipitation and irrigation ranged from 3.9% (5.3.1993-1.9.1993) to 18.3% (3.3.1992-15.9.1992). Large differences were observed between the experimental soils. Soils I and II showed a three years average of 9.9% and 12.5%, soils III and IV (both on silicate rock) exhibited considerably higher proportions of gravitational water of 21.9% and 18.5%, respectively. These results cannot be explained readily from soil physical parameters like the K_f-value and the hydraulic conductivity of the unsaturated soil (Gerzabek *et al.*, 1991) or by variations of the transpiration due to differences in the dry matter yield. There was no correlation between dry matter production and evapo-transpiration. The most likely explanation of the phenomenon might be in the differences between profiles with respect to soil skeleton in the subsoil. Soil III exhibits the highest skeleton portion of 32% (0-20 cm), 60.2% (20-40 cm) and 42.1% (40-75 cm). The subsoil of profile IV has a content of 24% medium and coarse gravel.

The amounts of potassium leached per six month and hectar are shown in Table 2. There are considerable variations between periods and the standard deviations indicate distinct differences between monoliths of the same soil type. However, monoliths cannot be called real replicates, because of the spatial variability of soil parameters within even very small areas. The large variations observed for soil I in the 5th and 6th period are due to the fact that during this time in two out of three lysimeters no gravitational water appeared.

Table 2. Leached potassium in kg K per ha and six month (lysimeter plant Seibersdorf). n = 3

half-year	Soil I	Soil II	Soil III	Soil VI	Mean
1	2.36 ± 0.50	1.12 ± 0.08	4.86 ± 1.34	10.94 ± 2.78	4.82 ± 4.17
2	3.24 ± 0.31	1.69 ± 0.06	5.49 ± 1.19	25.53 ± 3.93	8.99 ± 10.23
3	0.53 ± 0.47	1.53 ± 1.43	5.99 ± 4.70	7.50 ± 0.24	3.89 ± 3.72
4	2.75 ± 0.74	2.21 ± 1.92	3.86 ± 0.93	9.87 ± 4.64	4.67 ± 3.88
5	1.72 ± 2.98	2.38 ± 0.59	5.84 ± 2.61	10.32 ± 3.01	5.07 ± 4.16
6	0.89 ± 1.54	1.96 ± 0.50	3.27 ± 1.27	3.94 ± 1.79	2.51 ± 1.69
Mean	1.92 ± 1.57	1.82 ± 0.97	4.89 ± 2.29	11.35 ± 7.42	4.99

The variations between half-year periods can be explained partly by the recorded drained water volume. The linear regression between water volume (x [mm / 6 month]) and K-leached (y [kg K / ha·6 month]) reads $y = 0.06375x + 2.1983$. However, the correlation is weak ($r = 0.609$) and not significant. Soil I exhibits a significant correlation ($r = 0.863$; $y = 0.0349x + 0.8885$), the soils III and IV show a weak correlation, for soil II no correlation was observed. Johnston and Goulding (1992) suggest the following model equation based on lysimeter experiments in Rothamsted: $y = 0.012x + 0.089$ ($r^2 = 0.75$) which indicates a potassium loss of approximately 1 kg/ha per 100 mm gravitational water. In our lysimeter plant the amounts of K leached in a similar water volume were considerably higher (app. 8.7 kg/ha).

The variations between soils are even more significant than the differences of K-leaching between half-years. In all periods soil IV exhibited the highest leaching losses, the smallest values were observed for soils I and II. Multiplying the values of Table 2 with a factor of two gives yearly K-losses between 3.64 kg K/ha (soil II) and 22.70 kg K/ha (soil IV). Scheffer and Schachtschabel (1989) report K-losses of 20 - 50 kg K/ha·yr for sandy soils of northwest Germany. Other sources (Faustzahlen, 1985) give a range of 8 to 60 kg K/ha·yr. Thus, the K-leaching observed in the lysimeter plant in Seibersdorf under pannonian climatic conditions is quite low in comparison. However, recent publications confirm the extremely low K-leaching of less than 4 kg K/ha·yr of soils I and II. Kopec (1993) reported a yearly K-leaching of 1.5 - 2.0 kg K/ha for a Cambisol in Poland with a higher percentage of gravitational water than measured in Seibersdorf. Eder (1993) showed a range from 17.8 to 28.2 kg K/ha·yr for a site in Gumpenstein/ Styria/Austria with an average yearly precipitation of more than 1000 mm.

The differences between soils with respect to K-leaching can only partly be deduced from the amounts of extractable potassium present in the soil profile (0-75 cm). Soils II and I are lowest in extractable potassium (I: 396 kg K/ha, II: 130 kg K/ha) and exhibit the lowest leaching losses. The lack of a distinct difference between these two soils despite the three times higher mobile K-pool in soil I is probably due to the extremely low extractable K in both subsoils (Table 1). The more permeable soil profiles III and IV show extractable K-contents of 1150 kg K/ha and 473 kg K/ha (soil skeleton taken into account), respectively. It is obvious that especially the K-leaching of soil IV cannot be explained by the mobile K-fraction. These results are in line with observations of Eder (1993) and Johnston and Goulding (1992) with respect to correlations between potassium status and K-losses. The most important factors influencing K-leaching are suggested to be the amount of drained water (Johnston and Goulding, 1992) and the site specific Kretardation due to adsorption and fixation processes (Scheffer and Schachtschabel, 1989). Soil IV is the only one exhibiting increasing extractable K-contents with depth. This could be due to the history of this profile. At the original site the soil had a typical gley characteristic, which resulted probably in very low K-leaching and thus in K-accumulation in the subsoil. The draining of the profile after the transfer to the lysimeter could be the reason for preferential K-losses from the subsoil.

Conclusion

Under pannonian conditions, leaching losses of potassium from irrigated soils are relatively small; plant uptake of K is much more important in determining the overall K balance (Faustzahlen, 1985). K losses from highly permeable soils with a high proportion of skeletal material are influenced by differences in K adsorption and/or fixation between topsoil and subsoil. Soil III with K-leaching losses of approximately 10 kg K/ha·yr can be taken as more or less representative for highly permeable soils. Soils I and II (average K-losses 3.7 kg K/ha·yr) represent the less permeable profiles. However, these values should be considered as rough default values only, taking into consideration the large variations of the results of the lysimeter experiment.

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