Distribution of roots and microbial biomass in monolithic lysimeters in response to edge effects and surrounding vegetation

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Wurzelmasse und mikrobielle Aktivität in monolithischen Lysimetern in Abhängigkeit von Randeffekten und vom Umgebungsbewuchs

1. Introduction

Physical and chemical processes within a lysimeter may result in edge effects and retarded plant growth. One aspect is the possible influence of edge flow on water and solutes transport between the monolith and the lysimeter wall, described as sidewall flow, which could be effectively reduced by using larger lysimeters (KLAGHOFER, 1991). To enhance representativeness, a minimal size of 1.0 m^2 is suggested (OECD, 2000). Moreover, the shrinkage of clay soils can lead to cavities along the walls of the lysimeter and thus to rapid movement of water and chemicals directly to the bottom of lysimeters (OECD, 2000).

Surrounding objects like buildings or trees and also non evapotranspirating areas like streets may influence the lysimeter equilibrium, therefore lysimeters should be build in sufficient distance to artefacts (ABOUKHALED et al., 1982). In fact, various studies show the importance of surrounding vegetation (KRENN, 2002). BELFORD (1979) found no significant edge effects, when winter wheat plants

Zusammenfassung

Um mögliche Randeffekte innerhalb der Lysimeteranlage des ARC Seibersdorf research zu quantifizieren, wurde im Juni 2000 eine Auswahl an Lysimetern (vergleyter Kalktschernosem) mit gleichartigem (Winterweizen) bzw. abweichendem (Gras) Umgebungsbewuchs untersucht. In den Bodenproben wurden die Wurzelmasse, die mikrobielle Biomasse, die Phosphataseaktivität sowie wasserlösliche Anionen bestimmt. Sowohl der Wassergehalt als auch die Wurzelmasse zeigten zum Beprobungszeitpunkt einen deutlichen Abfall vom Zentrum zum Rand der Lysimeter, wobei die Lysimeter mit gleichartigem Umgebungsbewuchs im Allgemeinen höhere Werte aufwiesen. Die Diskriminanzanalyse aller Bodenparameter, einschließlich mikrobieller Biomasse und Aktivität und Pflanzennährstoffe, ergab eine Trennung zwischen Lysimetern mit gleichartigem bzw. andersartigem Umgebungsbewuchs. Die Studie zeigt, dass Randeffekte vor allem in kleineren Lysimetern nicht vernachlässigt werden sollten.

Schlagworte: Lysimeter, Wurzelmasse, mikrobielle Biomasse, Randeffekte, Umgebungsbewuchs.

Summary

In June 2000 the lysimeters of the lysimeter plant (ARC Seibersdorf research) were investigated to quantify possible edge effects within soil monoliths surrounded by wheat or grass. Lysimeters filled with Chernozem soil were cropped with winter wheat and surrounded by either winter wheat or by grass. Top soil samples were taken to quantify root mass as well as microbial biomass, phosphatase activity and water soluble anions. Water content and root biomass decreased from the centre to the border of the lysimeters, showing generally higher amounts in lysimeters surrounded by wheat. Discriminant analyses of all soil parameters including microbial biomass and activity and plant nutrients gave differences between lysimeters surrounded by wheat or grass. In general, edge effects were minimal using adequate ambient crop.

Keywords: Lysimeter, root mass, microbial biomass, edge effects, surrounding crop.

growing on the lysimeters were surrounded by similar guard crop. The yields were equivalent to those obtained in the field and plants grown adjacent to the lysimeter wall yielded the same weight of grain per unit soil area as those in the central area of the lysimeter.

The distribution of the root mass in soils is governed by general soil and plant physiological conditions. The physiological capacity of plant roots depends on its species specific water- and nutrient assimilation, the extend and activity of root surface and its spatial distribution in soil, concerning equal environmental factors. In general, roots are cut or digged out and washed to determine root weight, root number and root length (KÖHNLEIN and VETTER, 1953; SMIT et al., 2000).

Soil microorganisms play an important role in enzymatic decay, building and conversion of complex organic substances and in liberating nutrients and trace elements from mineral and organic soil components. In general, bacteria, fungi and often mycorrhiza fungi are predominant. Their quantity and activity is closely linked to the cropped plant species, the soil type and the micro- and macroclimate. Nevertheless, the microorganism quantity rarely exceeds more than 1 % of soil volume (GISI et al., 1997).

The objectives of this study were (i) to investigate possible edge effects within the monolithic lysimeters of the ARC Seibersdorf research on root biomass, microbial biomass and plant nutrients and (ii) to quantify differences between lysimeters surrounded by wheat or grass.

2. Material and methods

2.1 Monolithic lysimeters and soils

The monolithic lysimeters investigated in this study are located in the ARC Seibersdorf research, Lower Austria, Austria (KRENN, 2002). The site belongs to the pannonian climate, which is characterized by an annual mean temperature of 10.9 °C and a mean annual precipitation of 556 mm. The lysimeters are used for various scientific questions but specially for pesticides studies with radio tracers under field conditions. The installation consists of 18 pots (1 m^2, 1 m^3), which are layered to the level of the surrounding soil. The soil monoliths sampled in this experiment were collected in Fuchsenbigl, Lower Austria, Austria, in 1996. The soil is characterized by moderate storage capacity, porosity and dryness, not endangered by erosion and set as arable land with high quality and good working possibilities. Physical and chemical characteristics of the Vermic Calcic Chernozem (WRB) are given in Table 1.

2.2 Sampling

Soil samples were taken at 27th and 28th of June 2000, immediately after winter wheat was harvested. Three lysimeters located in a homogeneous winter wheat field and three lysimeters surrounded by grass were sampled from 0–5 cm and 5–10 cm soil depth within a distance of 0–5, 5–10, 10–17 cm from the lysimeter wall and in the centre of the lysimeter. Soil sampling was carried out with steel cores in triplicate. Two separate sets of samples were collected to analyse soil parameters and root mass, respectively. The soil samples were stored at –20 °C and allowed to thaw at 4 °C few days before analysis, this method of sample handling minimises the risk of microbial changes (STENBERG et al., 1998).

2.3 Soil analysis

Separation and quantification of root mass was done according to the method of MURER and SCHEIDL (1991). Briefly, soil samples were treated with water and compressed air until complete separation of roots and soil particles were achieved. Due to their low density rinsed roots were retained on a 63-µm-sieve without soil particles. Microbial N (N_{mic}) was determined by fumigating soil samples with chloroform for 24 h. Ninhydrin-reactive N was measured after extraction with a 2 M KCl solution using a colorimet-

Table 1: Physical and chemical characteristics of the sampled A_1-horizon of the Chernozem
Tabelle 1: Physikalische und chemische Charakteristika des untersuchten A_1-Horizontes des Kalktschernosems

Horizon	pH	C_{org}	N_{tot}	Carbonate	Texture [g kg^{-1}]		
					2000–63 µm	63–2 µm	< 2 µm
A_1 (0–25 cm)	7.4	24.6	1.9	195	240	520	240

ric procedure. N_{mic} was calculated from ninhydrin-reactive N by multiplication with a k_N-factor of 3.1 (AMATO and LADD, 1988). Soil phosphatase was measured after incubation of soil samples at soil pH with a 0.1 M phenylphosphate solution for 3 h at 37 °C. Released phenol was coloured with 2,6-dibromochinone-chlorimide and determined photometrically (HOFFMANN, 1968). Total C and N were determined by dry combustion in a CNS-analysator (Carlo Erba), inorganic C was measured volumetrically after destruction of carbonate using 10 M HCl. Water soluble anions (NO_3^-, PO_4^{3-}, SO_4^{2-}) were extracted after shaking soil samples with distilled water in a ratio of 1 : 10 head-over-head for 1 h. Samples were centrifuged at 10.000 x *g* and filtered through 0.45-µm-membran filters. Quantification of anions was done by ion chromatography. All measurements were done in duplicate and referred to oven-dry soil (105 °C).

2.4 Statistics

No significant differences could be determined between the 3 replicates of each variant (lysimeters surrounded by wheat or grass). Therefore, data of the 3 lysimeters were pooled (n = 9 for the areas near the lysimeter wall and n = 3 for the centre). The pooled data were used to calculate the influence of the three variables surrounding vegetation, wall area and sampling depth by one-way ANOVA, using the LSD-test for post-hoc comparison of means ($p \leq 0.05$). Discriminate analysis was applied to quantify separations between lysimeters surrounded by wheat or grass. Multivariate Wilks' λ was used for stepwise selection of variables with significance at the $p \leq 0.05$ level of probability. Standardised canonical discriminant function coefficients were used to calculate discriminatory potency of each parameter.

3. Results

3.1 Water content

At sampling time a small shrinkage slit of about 1 cm occurred between the lysimeter wall and the soil monolith restricted to the uppermost 7–10 cm and disappeared in lower soil layers. In general, the water content in the surface layer (0–5 cm) of all soils investigated showed a distinct decrease from the lysimeter centre towards the wall (Fig. 1). In the soil depth from 5–10 cm a slight decrease of the water content towards the lysimeter wall was only detectable in the lysimeters surrounded by grass. In general, the water content of the lysimeters located in the wheat field was about 16 % higher than in the lysimeters surrounded by grass (Fig. 1).

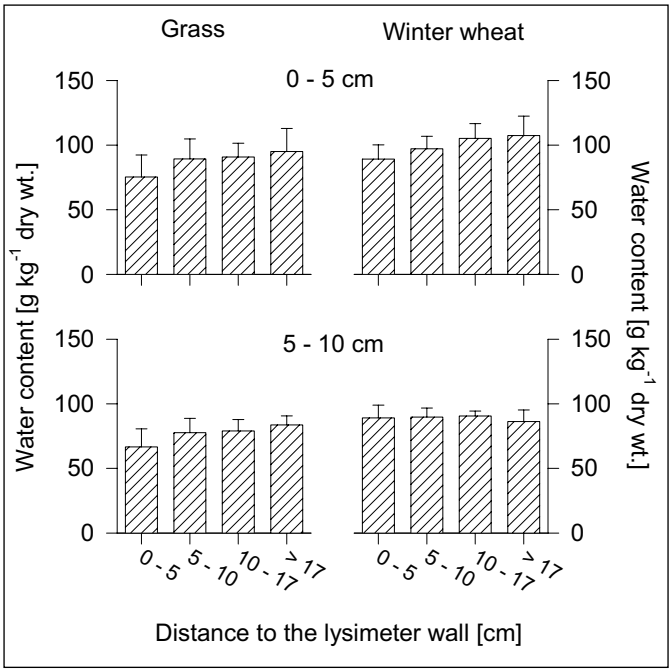

Figure 1: Gravimetrical water content of the lysimeter soils surrounded by wheat or grass in a distance of 0–5, 5–10, 10–17 and > 17 cm from the lysimeter wall at soil depths from 0–5 and 5–10 cm

Abbildung 1: Gravimetrischer Wassergehalt der beiden Lysimetervarianten mit gleich- und fremdartigem Umgebungsbewuchs im Abstand zum Lysimeterrand von 0–5, 5–10, 10–17 und > 17 cm in den beiden Beprobungstiefen 0–5 and 5–10 cm

3.2 Root mass

Figure 2 shows the distribution of root mass within the lysimeters. Despite the high data variability a distinct decrease from the lysimeter centre to the wall could be detected in the top soil layer without differences between lysimeters surrounded by wheat or grass. In general, root mass significantly decreased near the lysimeter wall from about 2.5 g kg^{-1} to 1.0 g kg^{-1}. In lower soil depths root mass was equally distributed without any differences according to surrounding vegetation or lysimeter wall area.

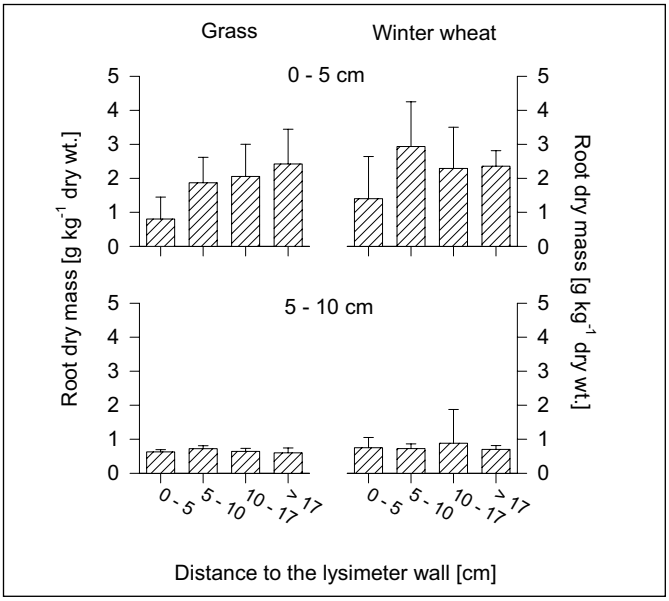

Figure 2: Root dry mass of the lysimeters surrounded by wheat or grass in a distance of 0–5, 5–10, 10–17 and > 17 cm from the lysimeter wall at soil depths from 0–5 and 5–10 cm

Abbildung 2: Wurzeltrockenmasse der beiden Lysimetervarianten mit und ohne gleichartigem Umgebungsbewuchs im Abstand zum Lysimeterrand von 0–5, 5–10, 10–17 und > 17 cm und in den beiden Beprobungstiefen 0–5 and 5–10 cm

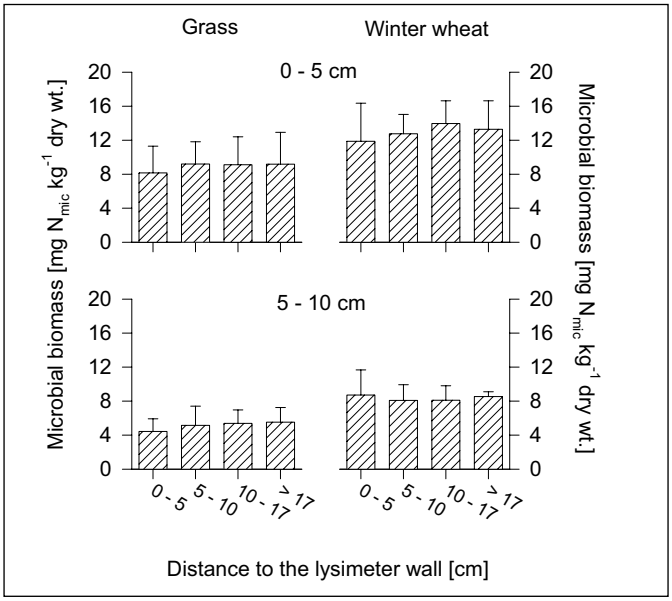

Figure 3: Microbial biomass (N_{mic}) of the lysimeters surrounded by wheat or grass in a distance of 0–5, 5–10, 10–17 and > 17 cm from the lysimeter wall at soil depths from 0–5 and 5–10 cm

Abbildung 3: Mikrobieller Biomasse-N der beiden Lysimetervarianten mit gleich- und fremdartigem Umgebungsbewuchs im Abstand zum Lysimeterrand von 0–5, 5–10, 10–17 und > 17 cm und in den beiden Beprobungstiefen 0–5 and 5–10 cm

3.3 Microbial biomass and soil phosphatase activity

In general, microbial biomass nitrogen (N_{mic}) showed a significant decline from the upper soil layer to the lower soil layer (Fig. 3), whereby N_{mic} was significantly higher in the lysimeters located in the wheat field (8.1–14.0 mg N_{mic} kg^{-1}) versus the lysimeters surrounded by grass (4.4–9.9 mg N_{mic} kg^{-1}). In general, microbial biomass was correlated with the soil water content and showed a slight decrease from the lysimeter centre to the wall in the upper soil depth, in the lower soil depth no tendency was detectable. Similar to microbial N soil phosphatase activity was slightly higher in the lysimeters with wheat as surrounding vegetation than with grass (Fig. 4). However, differences were not significant because of high data variability. No difference at all could be detected concerning soil depth and lysimeter edge effect.

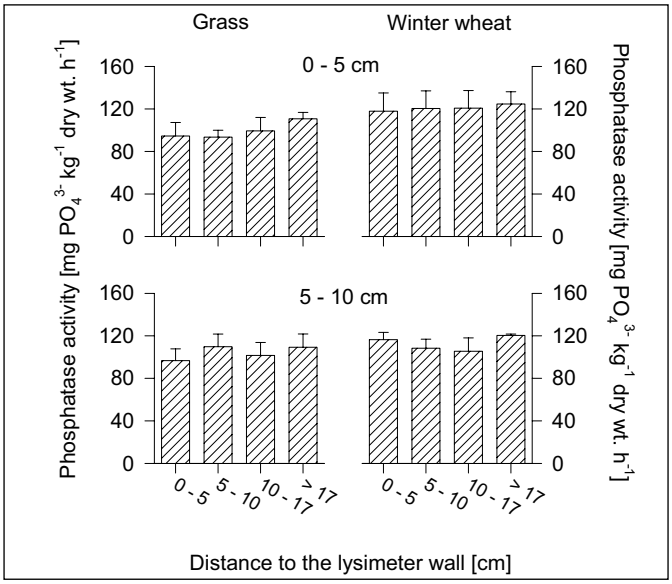

Figure 4: Soil phosphatase activity of the lysimeters surrounded by wheat or grass in a distance of 0–5, 5–10, 10–17 and > 17 cm from the lysimeter wall at soil depths from 0–5 and 5–10 cm

Abbildung 4: Boden-Phosphataseaktivität der beiden Lysimetervarianten mit gleich- und fremdartigem Umgebungsbewuchs im Abstand zum Lysimeterrand von 0–5, 5–10, 10–17 und > 17 cm und in den beiden Beprobungstiefen 0–5 and 5–10 cm

3.4 Water soluble anions (phosphate, nitrate, sulphate)

The variability of water soluble anions within the analysed soil samples was rather high (Table 2). Nevertheless, the easily available anions measured showed significant higher

concentrations in the upper layer 0–5 cm. The lysimeters located in the wheat field provided significant higher nitrate contents (23 %) whereas sulphate showed higher content in the lysimeters surrounded by grass with 8 % (Table 2).

4. Discussion

At sampling time the water content showed a distinct increase from the lysimeter wall to the centre of the lysimeter. In consequence, a shrinkage slit appeared in the uppermost 7–10 cm of soil depth, caused by the dryness during the last period before sampling. Side wall flows are usually limited to soils susceptible to shrinkage, i. e. clay soils and soils with high organic matter. Moreover, side wall flow effects become more accentuated with decreasing lysimeter size (BERGSTRÖM, 1990). Related to the relatively large size (1 m^2) of the investigated lysimeter and the little depth of the shrinkage slit (7–10 cm), rainfall would cause its disappearance and thus it could be neglected. Different studies describe such edge effects, reflecting they have no consequences on drainage measurements in large lysimeters (CRONAN, 1977; ROOIJ and STAGNITTI, 2000).

Considering the high humus content the microbial biomass was at a rather low level compared with other studies (STEMMER and KANDELER, 1995), probably caused by soil dryness and reduced biomass activity in midsummer. No significant differences could be measured between the centre and the lysimeter wall, although root biomass rapidly decreased towards the lysimeter wall. Nevertheless, the discriminant analysis, including microbial and nutrients parameters as well, gave a clear separation into the two sampling depths by discriminant function 1 (Fig. 5). As expected, distinct differences were measurable between the upper layer (0–5 cm) and the lower layer (5–10 cm) due to the high root mass and the high microbial activity in the upper soil layers. In general, microbial biomass was well correlated to root mass showing a decreasing tendency within soil depth (BURAUEL and BRIMHARD,1991). The lower level of water soluble sulphate in the lower depth might be caused by higher uptake due to the fine roots of the winter wheat. The remaining parameters showed insignificant differences, which is also reflected by the discrimination analyses (Tab. 3).

It is worth mentioning, that an additional separation between lysimeters surrounded by wheat or grass could be achieved by function 2 of the discriminant analysis (Fig. 5). Particularly, the sensitive microbial biomass indicated differences between the lysimeters surrounded by wheat or grass, which might be caused by microclimatic affects. Microbial parameters are well known to react in a sensitive way to slight environmental changes (PAUL and CLARK, 1996). In fact, KRENN (2002), who investigated the same lysimeter plant from 1998 to 2000, detected significant differences in harvest parameters between the lysimeters surrounded by wheat or grass. The different microclimate

Table 2: Means and standard deviations of water soluble phosphate, nitrate and sulphate of the lysimeters surrounded by wheat or grass within the wall areas from 0–5, 5–10, 10–17 and > 17 cm at soil depths from 0–5 and 5–10 cm (Data are given in mg kg^{-1} dry wt.)

Tabelle 2: Mittelwerte und Standardabweichungen von wasserlöslichem Phosphat, Nitrat und Sulfat der Lysimeter mit Weizen bzw. Gras als Umgebungsbewuchs im Abstand zum Lysimeterrand von 0–5, 5–10, 10–17 und > 17 cm in den Beprobungstiefen 0–5 und 5–10 cm (Die Daten sind in mg kg^{-1} Trockengewicht angegeben.)

	Distance from lysimeter wall [cm]	Winter wheat		Grass	
		Soil depth [cm]			
		0 – 5	5 – 10	0 – 5	5 – 10
Phosphate	0 – 5	1.5 ± 0.1	1.5 ± 0.4	1.6 ± 0.3	1.4 ± 0.3
	5 – 10	1.4 ± 0.4	1.5 ± 0.3	1.3 ± 0.2	1.3 ± 0.3
	5 – 17	1.3 ± 0.2	1.3 ± 0.5	1.3 ± 0.2	1.3 ± 0.3
	> 17	0.5 ± 0.0	1.0 ± 0.3	1.0 ± 0.3	1.2 ± 0.1
Nitrate	0 – 5	63 ± 35	52 ± 31	56 ± 26	66 ± 20
	5 – 10	59 ± 36	46 ± 18	47 ± 19	46 ± 14
	5 – 17	84 ± 25	32 ± 9	67 ± 32	46 ± 25
	> 17	nd	64 ± 41	113 ± 37	59 ± 15
Sulphate	0 – 5	34 ± 8	13 ± 6	29 ± 6	13 ± 5
	5 – 10	34 ± 5	8 ± 2	35 ± 8	10 ± 8
	5 – 17	37 ± 3	8 ± 3	33 ± 10	11 ± 11
	> 17	36 ± 6	9 ± 1	23 ± 14	11 ± 2

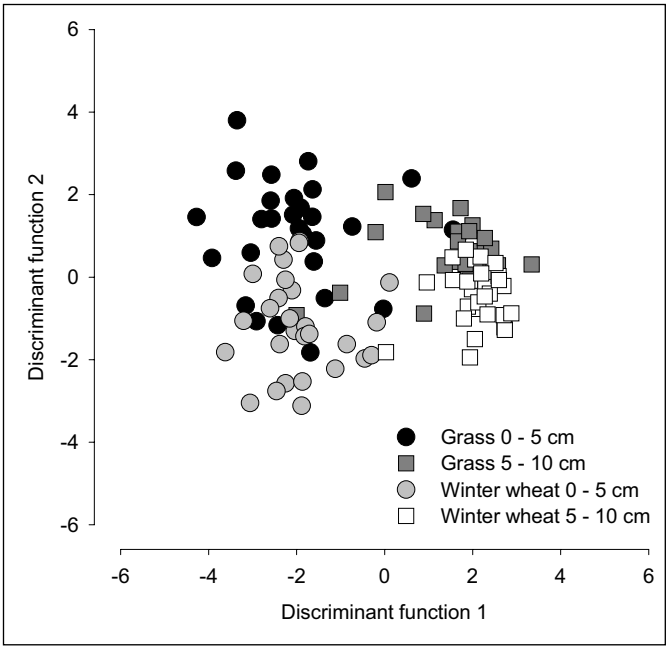

Figure 5: Plot of discriminant analysis of all measured parameters. Discriminant function 1 separates the soil depths (0–5 and 5–10 cm), discriminant function 2 separates lysimeters surrounded by wheat or grass.

Abbildung 5: Diskriminanzanalyse sämtlicher gemessener Daten. Diskriminanzfunktion 1 differenziert zwischen den Bodentiefen (0–5 und 5–10 cm), Diskriminanzfunktion 2 differenziert zwischen den beiden Lysimetervarianten mit gleich- und fremdartigem Umgebungsbewuchs.

Table 3: Discriminant analysis of the complete data set
Tabelle 3: Diskriminanzanalyse des gesamten Datensets

	Discriminant function 1	Discriminant function 2
Wilks' λ	0.109	0.526
χ^2	237	68
Degrees of freedom	30	18
Significance level	0.000	0.000
Percentage variance	82.1	15.8
Standardized coefficients of:		
Water content	-0.01	0.04
C_{org}	-0.15	0.11
N_{tot}	-0.05	-0.06
pH	-0.11	0.00
Rootmass	-0.36	0.04
N_{mic}	**-0.39**	**0.84**
Phosphatase activity	0.12	0.22
Phosphate	-0.09	-0.14
Sulphate	**-0.86**	**-0.44**
Nitrate	0.12	-0.24

between the lysimeter variants obviously caused differences in the water regime of the top soil, which was measurable at the sampling time. Surrounding crops act as microclimatic buffer zone and play an important role in reducing evapotranspiration. This fact is described as 'Oasiseffect' (KLAGHOFER, 1991). In order to obtain representative microclimatic conditions at the lysimeter surface of a planted lysimeter, guard crops should be grown in the surrounding area identical to that in the lysimeter (OECD, 2000). BELFORD (1979) stated, that lysimeters surrounded by similar guard crop gave yields equivalent to those obtained in the field. Edge effects were not significant, plants grown adjacent to the lysimeter wall yielded the same weight of grain per unit soil area as those in the central area of the monolith. Unsuited ambient growth or reduced buffer area may cause edge effects like headland effects in fields, due to long term changes of soil parameters (SPARKES et al., 1998). Using lysimeters not surrounded by an appropriate ambient growth may change chemical and biological properties and availability of nutrients, respectively. This might reduce representativeness and comparability to real field measurements and within lysimeter plants. Nevertheless, the verification and quantification of a possible impact of differences between lysimeters due to surrounding vegetation on the solute movement remains open for further investigations.

5. Conclusions

In conclusion, this study shows that edge effects should not be neglected in small lysimeters, especially in relation to surface dryness. Measurable edge effects in the wall area of lysimeters caused by temporal dryness could be apparently minimized by an appropriate surrounding crop. Micro climatic effects could cause inhomogeneous root distributions and differences in soil microbial biomass and activity. However, further microbial, chemical and physical investigations should be applied to support these findings and to prove their impact on crop yield and pesticide behaviour.

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